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9. ABSTRACT

A PROJECT: Recognizing that better water management could lead to increased agricultural production in a large portion of the developing countries, solutions to the water management problem were sought by a consortium of universities, solutions that could be transferable between countries with arid and sub-humid lands. Colorado State University studied water management principles in Pakistan and Vietnam, under the sponsorship of AID.
DURATION: April 1974 - March 1978.
DEVELOPMENTS: The Pakistan project is described in terms of its eight objectives and accomplishments over the past year, ranging from developing knowledge on conserving rainwater, on constructing conveyance and delivery systems, and on good land use related to water management, to improving soil and water properties through management practices. The bulk of the report contains an appendix detailing the project's 44 individual studies. The major results of the year's efforts described in the report are: 1) approval by the Government of Pakistan and USAID for an On-Farm Water Management Pilot Project; 2) training personnel from the host country for research and development activities; 3) the institutionalization of water management research activities; 4) assistance to WAPDA master planning, the University of Agriculture, Lyallpur, and other institutions of active research; 5) an increased focus on the role of women in farm water management programs; 6) focus on the need to improve water laws and codes, and the provision of incentives to farmers to organize to improve irrigation systems; 7) increased linkages with international organizations on farm irrigation, and 8) utilization of project personnel for surveys of irrigation projects in other low income nations.

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Annual Technical Report
WATER MANAGEMENT RESEARCH PROJECT
Nov. 1, 1975 to Oct. 31, 1976

Submitted to
The U.S. Agency for International Development
Contract AID/ta-c-1100

December 31, 1976

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, 1975 to October 31, 1976

Total Expenditures and Obligations Through Previous Contract Year:	567,019 April 1, 1975 to March 31, 1976
Total Expenditures and Obligations for Current Contract Year:	588,918 April 1, 1976 to March 31, 1977

Narrative Summary

A review panel was established by AID/Washington for an "Assessment and Field Review of Water Management Research by Colorado State University." This field review took place during January and February of 1976 in Pakistan. Essentially, the review panel recommended continuation of this project and provided recommendations that will result in a sharpening of focus and objectives. This field review has been instrumental in dramatically increasing the morale of both the CSU Field Party in Pakistan and on-campus personnel.

Throughout the year in keeping with program objectives, special efforts have been made which have resulted in wide dissemination and utilization of research results. As credibility with the Government of Pakistan has been increased as a result of a wide range of project activities, interest in Pakistan from farmers to government officials has accelerated. The major results of project efforts described in more detail below are: 1) official approval by the GOP and USAID for a comprehensive On-Farm Water Management Pilot Project; 2) the training of a large number of host country personnel for research and development activities; 3) the institutionalization of water management research activities at research stations and with other organizations; 4) assistance to WAPDA master planning, the University of Agriculture, Lyallpur and other institutions in action oriented research and development activities; 5) increased focus on the role of women in farm water management improvement programs; 6) focus on the need to improve water laws and codes and the provision of incentives for farmers to organize for improving their farm irrigation systems; 7) increased linkages with international organizations active in Pakistan and elsewhere with a concern and focus for on-farm irrigation problems; and 8) utilization of project personnel for reconnaissance surveys to irrigated projects in other low income nations.

Annual Technical 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. 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. 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.

D. Continued Relevance of the Objectives

Our research findings, surveys in Pakistan, and consultation with experienced water management personnel from USAID, FAO, the World Bank and several developing countries indicate that accomplishment of the original objectives will benefit the developing countries and contribute substantially to the fund of transferable water management technology. Survey of the resource positions of farmers in Pakistan 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 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.

The first field review of the CSU Water Management Research Project was conducted in Pakistan during January and February of 1976. The conclusions and recommendations from this field review are cited at the beginning of the next section. This field review will lend to a sharpening of the research focus, both in the field and on campus.

E. Accomplishments During the Reporting Year (Nov. 1, 1975 to Oct. 31, 1976)

1. General

A review panel was established by AID/Washington for an "Assessment and Field Review of Water Management Research by Colorado State University." The review panel consisting of Howard Haise, Team Leader, John Phelan, and Douglas Caton conducted an assignment of research content and design, progress from inception to date and prospective results of the CSU Water Management Research Project in Pakistan together with the supporting research being conducted on the CSU campus. Dr. Haise is a senior Agricultural Engineer-Agronomist, formerly with the Agricultural Research Service, USDA; Mr. Phelan is a senior Agricultural Engineer, formerly Director of Engineering of the Soil Conservation Service, USDA, and Dr. Caton is Senior Agricultural Economist, AID, Washington, D.C.

The panel assembled in Islamabad, Pakistan, Tuesday, January 27, 1976 and continued its review and report preparation through February 13, 1976, ending with a discussion of findings and reporting procedure with USAID Pakistan staff, CSU team members and Dr. D.L. Plucknett, Chief, Soil and Water Management Division, TA/AGR; and Mr. Charles Antholt, Asia/TD/DR, on February 12. The panel assessed program progress and relevance by reviewing the annual reports, the present work plan, project agreements, the status of the field projects, utilization of research results, and reactions from the Mission and host country officials.

The following conclusions were reached by the review panel:

1. The CSU research has been a process of evolution leading to an experimental pilot watercourse program:

    a. The work has now evolved to the point where it can begin to document costs and benefits, and indicate payoffs.

    b. The project has also reached the point where it can begin to help evolve a Pakistani institution(s) to take over the research and extension responsibility.

2. To gain these benefits, the CSU program should be continued, with the research feeding more and more into development:

a. To have research at this stage of identifying problems and ranking research priorities it has been necessary to build an experimental pilot watercourse and management program.

b. This process has also been necessary to be able to establish criteria to infuse and involve Pakistani institutions in this process.

3. For a number of sufficient reasons, the learning process has favorably affected the CSU personnel on the program, and more favorably affected on-campus attitudes and participation:

   a. The relevancy of what happens on the campus has increased as more people gained field experiences, on TDY, or through returnees to Fort Collins.

   b. Campus support activity is becoming less a residual, and more an integral of a total program.

   c. CSU is learning that some things, modelling and data analysis, can better be done on campus because of field time constraints and facilities.

4. As the GOP-USAID demonstration pilot program on water management of command areas develops they are going to want to have someone supply these inputs, for which CSU is the most qualified resource.

   a. Unless the GOP has an organization which has the training and the water management knowledge and can also reach the farmer with a broad water management, precision land leveling, and cropping system program the loan effort may fail.

   b. The experimental pilot watercourse from Tubewell 56 will be a valuable data resource. CSU can also help by their knowledge of the jobs that need to be done, and how the people in the jobs should be organized (and trained) and related to farmer's water management problems.

   c. Unless trained people are made available, and the total water management effort is institutionalized in Pakistan the long term potential food output and water savings benefits may not be realized.

   d. Saving 1 percent of the water for use in the root zone is equivalent to increasing water supplies at the barrage by 1 million acre feet.

5. The CSU research will be important to developing a better regional food system, and a national system from the pilot project results.

   a. This possibility will depend upon how well a way is found to feed the results into the loan program demonstration pilot project and to farmers.

   b. It will also depend upon how well and how soon a follow up program is developed to diffuse the demonstrations regionally and nationally.

   c. The extension follow up will need organization, specialists, incentives, credit, and so forth.

Based upon this review, the panel recommended continuation of the CSU program in Pakistan on the following components:

1. Techniques to reduce losses from watercourses

   a. Schedule to develop recommendations by March, 1977.

   b. To continue monitoring and evaluating watercourse rehabilitation in the USAID Loan Pilot Project.

   c. Recommend alternative uses of underground pipeline distribution systems.

2. Experimental Pilot Watercourse Program at Tubewell 56

   a. Covers water management, precision land leveling practices, cropping practices, and irrigation advisory service (scheduling).

   b. To June, 1980.

3. Farmer maintenance and monitoring of precision land leveling

   a. To cover farmer utilization of land leveling by following farmer practices and maintenance.

   b. To June 30, 1980.

4. Land Shaping, Cultural and Agronomic Practices

   a. To cover cultural practices such as bedding, furrow, irrigation, cropping techniques, and fertilization to improve stands and yields.

   b. An opportunity exists to tie in with the IRRI farm machinery program to be located in Pakistan headed by Amir Khan.

   c. To June 30, 1980.

5. Demonstration Pilot Watercourse Loan Program

   a. Could be involved as part of evolution, institution building and forward planning (not the place to discuss details but must spell out in definite terms what can be expected from technical specialists employed).

   b. 2 man/years 1976 forward (indefinite).

6. Skimming Well Program

   a. Acceptable data is now being collected to complete modeling program at CSU.

   b. Planned second phase of program is to be bypassed with direct application of findings to wells that have failed in the Mona area.

   c. Training of individuals to analyze well salinity profiles and to recommend the modifications of old wells and design of new wells necessary to produce water of satisfactory quality.

   d. To June 1977.

7. Physical and Socio-Economic Survey of Watercourses

   a. This mission project has taken roughly 2 man/years of professional TA/AGR time, plus secretary time, and the time of 2 assistants

   b. To April 30, 1977.

8. Watercourse Maintenance

   a. How to demonstrate to farmers how to organize themselves and maintain watercourses.

   b. Should be integrated into the water management loan program.

   c. To June 30, 1980.

9. Training and Institution Building

   a. CSU can provide information, train water management specialists to help organize farmers to assist themselves.

   b. It would be reasonable to expect those trained and experienced on country problems to be called upon.

   c. CSU has developed the start of an experimental pilot water management program. Their research will show how to work it, and how to get the results out to farmers.

   d. To June 1980 (include on-campus report writing, TDY backstopping, and graduate assistantships at CSU, etc.).

10. One Year On-Campus Publication and Project coordination Assistance

   a. Returnees should be relieved of on-campus responsibilities for at least one year to prepare necessary technical and training documents to gain full benefit of the field work.

   b. These documents and training tools are needed now in Pakistan and elsewhere in the arid and sub-humid areas of the LDC's.

   c. Some of this time could well be spent on data coordination with Utah and Arizona.

   d. To be paid for from project funds to June 30, 1980.

2. Pakistan

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project (MREP); (2) participation with the U.S.AID Mission to Pakistan in completing the loan paper for the On-Farm Water Management Pilot Project; (3) continuation of watercourse surveys, including physical and socio-eonomic aspects; (4) initiation of cooperative efforts with the Department of Agriculture in the three provinces of Punjab, Sind and North West Frontier in order to implement the On-Farm Water Management Pilot Project; (5) development of proposal for field studies in cooperation with the University of Agriculture, Lyallpur (UAL) regarding alternatives for organizing farmers in order to improve on-farm water management; and (6) development of training materials, initial training of trainers, and training watercourse engineers. Significant progress has been made towards problem identification, development and demonstration of technological alternatives, and identifying processes for implementing such technological solutions.

The following five 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. Alan C. Early (Agricultural Engineering), Dr. John O. Reuss (Agronomy), Dr. Sam H. Johnson III (Economics), and Dr. Sidney A. Bowers (Agronomy). Dr. C.J. deMooy (Agronomy) was a member of the CSU Field Party until mid-February, 1976 when he returned to campus. Two Ph.D. students were located in Pakistan during this report year; namely, Mr. Larry Nelson (Agronomy) in June, 1976 and Mr. Tom Trout (Agricultural Engineering) in September, 1976. At the end of the report year, the CSU Field Party consisted of seven personnel.

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

Developing the Loan Paper In 1975 Eckert, Dimick and Clyma analyzed the benefits and costs of various types of watercourse improvement in a report based on CSU watercourse improvement studies. This was one of the primary documents justifying a watercourse improvement component in the proposed loan program between U.S.AID and the Government of Pakistan to be titled "On-Farm Water Management Pilot Project." The official title used by each of the three provinces (Punjab,

Sind and North West Frontier) is "On-Farm Water Management Development Project." A report titled "Helping farmers identify and achieve their potential for watercourse improvement" by the CSU and Mona Reclamation Experimental Project (MREP) staff outlined the first full scale pilot watercourse improvement program, which demonstrated farmer acceptance of and participation in the type of earthen improvements proposed, and showed a 50 percent increase in supplies of water to the farmers fields. The preliminary reports of the Lowdermilk-Early surveys indicated that watercourse losses of 50 percent, found earlier in the Northern and Central Punjab by Clyma, were common throughout the rest of the Indus basin.

The services of Eckert and Lowdermilk were requested, on TDY's, to help write the economic, sociologic, training and extension components of the proposal. Field Party members drafted most of the section dealing with the procedures to be followed in motivating farmers to participate in watercourse improvement programs and the section on how to achieve the improvements.

As the pilot watercourse improvement program was further tested, a steady stream of at least 1000 visitors from the provincial and federal government, USAID, FAO, the World Bank and several other countries have visited the projects, talked to the farmers and seen the improvements. These visitors included the General Manager of Master Planning, WAPDA, the Special Assistant to the Prime Minister for Agriculture and representatives from the Sind, Punjab and NWF provinces and the Federal Government involved in planning. This on-site inspection has been reported as a major factor helping bring about the acceptance of the water management program by these various components of the Government of Pakistan.

Training of watercourse improvement Trainers. The SCS, CSU, MREP and the Governments of the respective provinces decided jointly that the experience gained in these pilot watercourse improvement projects should be transmitted to the persons in the Sind, Punjab and North West Frontier Provinces (NWFP) who would be training personnel to help farmers carry out essentially this type of program in the loan financed development projects in their own provinces.

Mr. Mushtaq Gill and Sadiq Shafiq who had also completed a successful watercourse improvement project under the Integrated Rural Development Program (IRDP) water management improvement project near Lahore were requested to help in this training activity. The Mona personnel plus Mr. Shafiq and Mr. Mushtaq met with CSU advisers to plan the training and make assignments. Mona staff were asked to draft sections for this training as follows:

(a) How to Measure Water Supply - M. Akram

(b) Effect of High Water in Watercourse Supply - M. Iqbal

(c) How to Measure Water Losses in Watercourses and Fields - M. Afzal & M. Yasin

(d) Agreements with farmers at the time of selecting the watercourse (before the work starts) - M. Azeem

(e) Topographic Survey and Mapping - M. Azeem

(f) Alignment of watercourse - M. Akram and M. Azeem

(g) Watercourse design - M. Iqbal

(h) Aids for watercourse design - CSU team

(i) Watercourse construction - M. Akram and M. Azeem

(j) Evaluation following improvement - M. Yasin

(k) Cleaning and maintenance of watercourses - Javaied Iqbal and M. Afzal

(l) Irrigation advisory service - S.M. Saeed

(m) Pakka structures for improved watercourses, their design, construction and use - M. Akram, W.D. Kemper, Iqbal Hussain, W.E. Hart, Bashir Ahmad, S.A.Bowers, J. Iqbal, Moh'd Azeem

(n) Motivating farmers - Mohsin Wahla, S.A. Bowers and W.D. Kemper

These drafts were extensively "reviewed" by the CSU advisers, but the first drafts were prepared largely by our Pakistani cooperators as part of their "training for report writing."

The SCS team helped the governments of the respective provinces select their men to come to a watercourse improvement training session which was held from Sept. 1 to Sept. 21, 1976. The trainees from the different provinces included: North West Frontier Province - Javed Mirza, Abdul Hamid Shah, and Mohammad Yousaf; Sind Province - Khan Ashraf Saeed, S. Irfan Ahmed Naqvi, Agha Umer Daraz, and Azfar Hussain; Punjab Province - Riaz Ahmed, Gulzar Muhammed Choudhry, Rab Nawaz and M. Hanif.

The SCS advisers for each province each came to the sessions for one week and also contributed in many ways to the training.

Intense rain during the first four days prevented field activity and the sessions were primarily lectures by the respective authors on the subjects of the training materials after these written materials were handed out. These sessions and the response were not completely satisfactory. An evaluation by the SCS, Mona and CSU staffs indicated that some of the problems were:

(1) The young Mona Engineers had essentially no teaching experience, gave brief discussions of the subjects, and assumed the trainees would read the written materials and ask questions.

(2) The trainees expected more extensive and sophisticated lectures and most of them did not understand that it was their responsibility to read and understand the written materials and ask questions.

(3) The CSU advisers had some emergencies, were able to attend only part of the time and during their absence, the discussions were not properly "catalyzed."

Consequently,

(1) The trainees were informed that they would be given a test on the written materials and should take the opportunity of asking questions of the various "trainers" on anything they didn't agree with or didn't completely understand.

(2) The trainers were asked to encourage more questions and expand their presentations in more detail.

(3) The schedule was made flexible so the activities could go to the field whenever it was not raining and a new watercourse, reachable by paved road near the project headquarters, was chosen for improvement as the core of the field training.

(4) Arrangements were made for CSU personnel to be there all the time and SCS personnel were invited to play a more active part in making comments, suggestions and generating discussion.

The rains diminished, the trainees were taken to the field where they participated in the measurements and surveys prerequisite to design, they helped design the new watercourse and participated in sessions with farmers where the farmers requests and the design criteria were mutually adjusted to provide a satisfactory design.

The report on the improvement of the watercourse at Tubewell 56R gives more of the details of the improvement.

Three of the trainees were fasting during the daylight hours in observance of Ramazan and the weather was hot and humid which curtailed the field activities somewhat. However, the trainees developed more interest as the training progressed (and the examination approached) and worked with Mr. Akram, Mr. Iqbal, and Mr. Azeem of the Mona staff until after midnight in informal sessions to learn more of the details of design.

Mr. Sadiq Shafiq and Mr. Mushtaq Gill, who had taken a year of training at Colorado State University during the previous year and had conducted a watercourse improvement program at Shadab as part of the studies leading to their M.Sc theses, also participated in these sessions (including the late evening sessions). They played a major role in training and in checking the design aspects.

Before the trainees left they were asked to give their suggestions for improvement of the training and these centered primarily on improving the housing facilities. If training is to become a regular part of the Mona program additional housing for the trainees is definitely needed.

The SCS will now work with these watercourse trainers to develop the training needed in the provinces. They will use the material written up by the Mona Engineers, SCS experience and guidelines, the findings of Mr. Shafiq and Mr. Mushtaq and continuing information from the Mona research studies to develop the written guidelines for the watercourse improvement engineers. CSU will assist as requested.

Training Water Management Advisors. Saving water in watercourses is not productive unless the water is used effectively to increase crop production. CSU has been asked to work with the University of Agriculture at Lyallpur in developing a training program which will prepare one Water Management Advisor for each water management development team under the On-Farm Water Management Pilot Project. His responsibility will be to help farmers improve their production through better management of his expanded water supply, leveled land and other essential inputs (seed, fertilizer and weed and pest control). Dr. Early, Dr. Lowdermilk and Dr. Johnson developed an outline for this training which has served as the basis for a training agreement between the Punjab Government and the University of Agriculture at Lyallpur.

Hopefully, the Sind and NWF Provincial governments will develop similar agreements with the University of Agriculture at Lyallpur. CSU will help develop training materials that can be used by all three provinces, and will assist to the extent of available personnel and as requested by the respective provincial governments.

In the Punjab, a cooperative research and training program between the Department of Agriculture Water Management Development Project and the University of Agriculture at Lyallpur will be encouraged which will include: (1) improvement of several watercourses in the Lyallpur area as part of the development program, but with some innovations as deemed advisable for research purposes and with university faculty cooperating in the improvement; (2) careful evaluation of the costs and benefits of these improvement programs and the use made of the increased water supply; and (3) the development of sufficient credibility with farmers on these watercourses that they will become cooperators, willing to test the new and improved methods of water management and crop production suggested by the research-cum trainers and their trainees.

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

At the request of USAID/Islamabad, Colorado State University agreed to develop a research project to test and identify the organizations that might help farmers more efficiently use their water. Dr. Sam Johnson was put in charge of coordinating this project and Dr. Dave Freeman was invited to come to Pakistan for six weeks to organize the study.

Dave Freeman, working with Ashfaq Mirza and Ali Moh'd. Chaudhry at the University of Agriculture, Lyallpur (UAL), developed a concrete project proposal and also prepared the survey instruments and statistical measuring techniques. In

order to reduce the red tape, it was suggested that this study be submitted directly to the Agricultural Research Council (ARC) in the central (federal) Government of Pakistan and they in turn subcontract with UAL for the study. A meeting was also held with Chaudhry Sultan Ali, Special Assistant in Agriculture to the Prime Minister, in which an agreement in substance was reached for the ARC to support the project.

The proposal has now passed through the University review process and the ARC review process. However, the deputy director at ARC felt the project needed provincial clearance and diverted it to the Agricultural Research Review Committee for approval. Dr. Naseem, the Secretary of Agriculture, Punjab, felt that the study was quite relevant to the work of the new Department of Agriculture Water Management Cell and decided to integrate this study with the Water Management Cell.

This process will delay this project but it should be funded during early 1977 and be ready to go by April. It is planned that Drs. Radosevich, Lowdermilk and Freeman will come to Pakistan on TDY assignments to advise Mr. Ashfaq Mirza (faculty member at UAL, who received two years training at CSU under the Water Management Research Project) on this study.

Farmer involvement in improving watercourses. One of the most exciting developments in Pakistan is the cooperative efforts undertaken by farmers to improve their own watercourses. The first example of this cooperative effort is very well told by Mr. Khan Mohamad Chandawana, one of the participating farmers, in the Sept., 1976 issue of War on Hunger (the cover photo shows a Pakistani engineer measuring irrigation water with a Cutthroat flume, which was developed by CSU). This story is very descriptive in illustrating the process for obtaining farmer cooperation.

About half of the water supplied to farm watercourses in Pakistan is lost before it reaches the fields. This loss was found to be primarily through the upper porous portions of the banks and in the vicinity of junctions where banks are thin. Concrete and brick linings and steel slide gate control structures reduced the loss to as low as 10 percent, but are too expensive for general use. Earthen improvements such as making new compacted banks and compacting cores in old banks were found to reduce water losses to less than 25 percent of their value in old watercourses.

Farmers were motivated to organize themselves to build their own earthen improved watercourse (28,000 ft.) according to design specifications drawn up by young Pakistani engineers. Low cost concrete diversion structures were developed and installed at junctions to eliminate continued borrowing of

soil. The improvements reduced losses to about one-half their previous values and provided the farmers with about 1 cusec of extra water. The cost was about Rs. 2/foot of watercourse improved, including farmers' labor.

The benefits to be gained within the first year equal the cost. Maintaining the benefits will require the investment of about 10 man-hours of labor per acre-foot of water saved. This is some of the least expensive water available in Pakistan. This type of improvement appears to be an ideal component for a development program which will increase crop production in other countries where rural labor has a low value during certain seasons. However, farmers require further information on how to use this water and other inputs to optimize crop production if they are to obtain full benefits from this extra water.

In another case, farmers were willing to support a labor intensive watercourse improvement program during the month of Ramazan. The laborers ate and drank during the working day, apparently on the assumption that the inherent virtue of the improvement project justified breaking their fast. The farmers primary reason for wanting the improvement program was to provide a masonry section through the village where the occasional losses were an obvious nuisance and the intensity of auxiliary use (for washing clothes, washing vegetables, bathing, animal watering, etc.) was extremely high. The farmers realized the high cost of building such a masonry section and were willing to pay the complete costs of their control structures and provide all the labor for the earthen improvements as "part of the bargain" to obtain the masonry section through their village. When the government is paying for the check structures, farmers demand many more than are essential, which results in conflicts with the engineers. On this project, where farmers were paying for their own, they were very reasonable and worked in close cooperation with the engineers to reduce the number of check structures to a minimum. The manufacturer of the concrete control structures was willing to decrease his price by about 25 percent to farmers who paid an advance and completed payment on delivery; as compared to his price to government agencies where payment often requires months and extensive paper work. Involvement of project personnel in socio-legal decision-making and disputes between farmers can be minimized by clearly defining their role as technical advisors and supporting the water users Executive Committee as the decision-making body in these matters.

3. 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. Evaluation of Errors in Gravimetric Determination of Soil Water

Soil water content is measured through sampling and gravimetric analysis. A set of soil moisture data collected from an irrigation-fertility experiment at Punjab Agricultural Research Institute was analyzed. The confidence interval was then determined as a function of number of cores. It was found that 5 cores taken before irrigation would estimate the mean profile of 9.5 inches within ± 4 percent of the mean. After irrigation, 5 cores would estimate a mean profile water content of 12 inches to ± 5 percent. However, the difference of 2.5 inches, which represents the use or storage between two sampling dates, is only estimated to a precision of ± 28 percent. This lack of sensitivity must be considered when defining operational or research programs in the field that depend on moisture sampling and gravimetric analysis for evaluating water use by crops.

b. Effect of Flooding and Drying on the Loss of Nitrogen from Soil

Basin irrigation is the usual irrigation practice in Pakistan. Irrigation water is usually added to a basin until even the high spots are covered. Because so much water is applied, the soil may remain saturated for 2 to 3 days which results in the redox potential of the soil to drop to a level which encourages the gaseous loss of nitrate-nitrogen by denitrification. Urea, the nitrogen fertilizer generally used in Pakistan, is a reduced form that is stable in a flooded soil, but is oxidized rapidly in a well aerated soil by a process called nitrification. Nitrogen is also lost by volatization of ammonia when alkaline soils containing ammonium-nitrogen salts are dried. Since the basin irrigations of Pakistan result in a reducing environment in the soil which is followed by periods favorable for nitrification, loss of nitrogen in these two ways may be factors in the low efficiency of fertilizer nitrogen use in Pakistan. Experiments were performed to evaluate the effect of cyclic flooding and drying, simulating field conditions on the growth and recovery of nitrogen fertilizer by sorghum. Two surface soils from cultivated fields, a silty clay loam, and a sandy loam, were treated in six different soil treatments of urea nitrogen, phosphorous, and potassium. These six treatments were then given 5 moisture-incubation treatments with three replications each, which gave a total of 30 treatments per soil.

The results of the study indicate that current basin irrigation practices in Pakistan may cause considerable gaseous loss of nitrogen from the soil. Although it was not possible to differentiate between the loss of nitrogen by denitrification or by ammonia volatilization, it is believed that denitrification was the primary contributing factor. Investigations are needed to evaluate nitrogen losses under field conditions and irrigation practices must be developed that minimize these losses.

c. Effects of Excessive Magnesium in Irrigation Waters on Wheat and Corn Growth

In the literature it has been generalized that when Mg exceeds Ca in nutrient and soil solutions, plant growth depression takes place. The cause of this growth depression is currently presumed to be the result of a Mg-induced Ca-deficiency (nutritional imbalance) in the plant. Experimentally, it is relatively easy to demonstrate a nutritional imbalance by the addition of a single Mg-salt to an adequate base nutrient solution with almost any plant species. Mixed salts, as in most irrigation waters, pose a more difficult problem because most plants vary in ability to absorb cations. Cation uptake is related to total cation concentration, also. The effects of high Mg contents in irrigation waters have not been studied and evaluated to any extent. It is necessary to deal with management practices, as well as ion types, ion ratios, and total concentrations.

This report constitutes the results of three separate experiments in which wheat and corn were irrigated with waters that simulate neutral (non-carbonate) compositions predominately of sulfate type in which Mg and Ca ratios were varied. The objectives were to determine Mg concentration levels or Mg:Ca ratios at which growth depression takes place.

4. 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. Soil Cement Blocks for Watercourse Construction and Sediment Utilization

Inexpensive building materials are needed in the rural areas of Pakistan. One type of material used for this purpose has been a block in which soil is mixed with cement, moistened with water, and compressed to about 70 percent of its loose volume in a press. Sediment cleaned from watercourses is commonly piled on valuable farm land. The strength of soil-cement blocks made from watercourse sediments and cement was greater than the blocks made from soil and cement. There is less labor involved in preparing the watercourse

sediment than the soil when making soil-cement blocks. These points indicate that watercourse sediment is a superior material for making soil-cement blocks. Sediment traps built on a watercourse at stretches which are accessible to roads can provide several thousand cubic feet of sediment per year. The farmers owning land adjacent to the watercourse are generally pleased to see this sediment removal from their farm land.

The soil cement blocks are resistant to erosion at normal watercourse flow velocities. Plaster on the surfaces of soil-cement blocks reduce leakage from 0.068 to 0.003 cusecs/1000 ft, but if the holes were plugges when the blocks were laid it appears plastering would not be necessary. Soil- or sediment-cement blocks can be used for lining watercourses or for watercourse structures where they will be subjected to frequent wetting and drying.

b. Water Loss Measurements on Watercourse 50440L (TW 51)

To evaluate the effect of renovation of Watercourse 50440L(TW-51), water conveyance loss measurements were made both before and after improvement. In most instances, "before" and "after" measurements were made over identical distances. Where possible predictive loss equations, as a function of initial flow rate, were developed and solved for particular flow rates. In other instances, "before" and "after" comparisons were made for losses over fixed distances where initial flow rates were similar. For comparison of the entire watercourse, the weighted average initial flow rate, loss, and conveyance distances were compared.

Although the watercourse proved a relatively efficient water conveyor before improvement, loss in all sections was decreased through renovation. In the main channel, solved predictive equations showed that losses decreased from 75 percent for a 1 cusec initial flow rate to 43.4 percent for a 6 cusec initial flow rate. On Branch B, losses were reduced 40 percent. On Branch C, losses were reduced at least 12 percent. Similarly on Branch D and the main channel including Branch D, losses were reduced 39.1 percent and 27.2 percent, respectively. Based on weighted averages, the loss reduction for the entire watercourse was 20.5 percent.

c. Watercourse Improvement: Methods, Costs and Loss Rates at Tubewell 78 Watercourse

The test watercourse sections at Tubewell 78 have provided data essential to the Pilot Watercourse studies in the Mona project area and the Watercourse Improvement Component of the Punjab Agriculture Department's On-Farm Water Management Development Project.

These data have led to the following conclusions: (1) a determination that pakka lined watercourses (costing over Rs 25/acre-foot) cannot generally be justified on a benefit/cost basis for branch channels, but may be justified for some main channels (Eckert, Dimick and Clyma, 1975); (2) that Pakistani masonry and concrete is porous and requires a good coat of plaster to achieve the desired reductions in water loss; (3) that losses from watercourses in a sandy loam soil can be reduced to 20 to 35 percent of their present value by a thorough job of bank reconstruction and compaction, or core compaction; (4) that farmers can reduce their water losses by 50 percent by reconstructing and doing a medium to poor job of packing the new banks by expending less than 0.5 man hours per foot of watercourse and that the water saved has a lower cost than other sources of water in Pakistan; (5) that farmer participation in planning and constructing the improvements is helpful to gaining their support of a continued maintenance and cleaning program; and (6) the warabundi system of orderly scheduling of water does avoid appreciable operational loss and should not be discarded as long as the irrigation systems are susceptible to these operational losses.

d. Water Losses from Watercourse 62394L (Tubewell MN 56)

Water conveyance loss measurements were used to evaluate the improvement due to watercourse renovation. Direct "before" and "after" comparisons were difficult to impossible because of differences in initial and final conveyance distances. Where feasible, loss-distance and loss-flow rate predictive equations were derived for comparison purposes.

The Main Channel, which was an efficient water conveyor, showed no decrease in conveyance loss after improvement. This lack of improvement may be related to the almost continuous flow in this channel. The Main Channel + Branch A renovation resulted in a decrease of conveyance loss of at least 46 percent. For the Main Channel + Branch C renovation, conveyance loss decreased 36 percent. For the other branches, the data were insufficient for valid improvement estimates. Based on arithmetic averages, the delivery efficiency and the percent loss/1000 ft for the entire watercourse "before" improvement were 47.5 percent and 6.52 percent respectively. The "after" values were, respectively, 69.7 percent and 4.15 percent

e. Aids for Watercourse Design and Improvement

The numerous possible shapes of watercourses often leave the beginning designer with a feeling that watercourse design is a difficult undertaking to be solved only by time consuming iteration using Mannings equation.

To simplify the watercourse design procedure, Ch. M. Hayat Khan developed a series of graphs using Mannings equation for watercourses with side slopes which are vertical, 1:2, 1:1, or 2:1. These slopes cover most of the needs for lined and earthen channels. Use by new designers in planning watercourses has shown that these graphs decrease the time required to design watercourses and allow quick checking of watercourse design. Many requests for earlier drafts of our "Aids for Watercourse Design" prompted us to present this revised procedure developed by Hayat, which has several advantages over our previous procedures.

Since Pakistan officially converted to the metric system on July 1, 1976, metric units are used throughout. However, to help those converting from the English to the metric units, lines representing volume units are given in multiples of 0.03 cubic meter since $0.03m^3$ is close to 1 cubic foot.

f. Pakka Structures for Improved Watercourses: Their Design, Construction and Use

Evaluation of existing watercourses has shown that an average of 50 percent of the water entering watercourses is lost before it reaches the fields. This degree of loss points out a great potential for increasing water supplied to the fields through watercourse improvement. Almost half of this loss was found to occur in the vicinity of junctions in the watercourse where banks have been weakened by weekly borrowing of soil from the banks and adjacent fields to construct earthen dams at the junctions (Kemper and Akram 1975).

To determine the best methods for saving this water and increasing delivery to the fields, several types of watercourse improvements have been made on watercourses in the Mona Reclamation Experimental Project (MREP) area. These included: (1) watercourses with rectangular cross sections with 13-1/2" thick, 9" and 4-1/2" thick brick walls and with 6" thick soil-cement brick walls; (2) trapezoidal sections using brick or concrete of 3 mixes; and (3) earthen improved sections including (a) completely rebuilt banks and (b) simple agumentations of the banks by adding earth to them.

As an integral part of these watercourses, several types of water control structures have been developed and installed. The costs of these improvements have been determined and their benefits are being evaluated. At present, it appears that earthen improved sections with concrete control structures have the highest benefits-to-cost ratio. The cost of saved water using this type of improvement ranges from 10 to 30 man-hours of work per acre-foot of water, which is considerably less expensive than other sources of water in Pakistan. However, the continued savings of

water by such improvements is dependent on continued maintenance and cleaning. How to assure this continued maintenance and cleaning is a pressing problem which needs an early solution. An attempt has been made to improve the maintenance of an improved watercourse serving Tubewell MN 56L by hiring a Khal Chowkidar who works daily to improve water delivery to the fields. He also helps the farmers plan and schedule their cooperative cleaning and maintenance efforts.

g. Design Data and Equipment Development for Watercourses

The work reported here has as its overall objective the improved design and operation of watercourses delivering water to individual farm plots. These investigations can be contributions to a design handbook for watercourses. Such a handbook would be of assistance to field engineers and planning offices in LDC's.

There have been three phases to the current work.

(1) Development of flow rating charts for rectangular and trapezoidal channels.

(2) Development of a form for rectangular concrete gates suitable for construction in LDC's.

(3) Model studies on rectangular and circular-opening gates to determine their head loss characteristics when fully open.

The first item is included in this report. Drawings for the second item, which has been constructed and sent to the CSU Field Party in Pakistan (Water Management Research Project) are included as a part of this report. A partial reporting of the third item is also included.

h. Measurement and Calibration of Mogha Outlet Discharge Using Staff Gauges

Common mogha outlets in Pakistan are masonry orifices, pipe outlets and wooden chutes. They are usually placed at the bed level of a distributary or minor canal. They may be circular, rectangular or trapezoidal in cross section and may operate under submerged flow (outlet under water on the downstream side) conditions, or free fall conditions.

Staff gauges are installed vertically according to the condition of flow (free fall or submerged). A Cutthroat flume is placed at a downstream point in the watercourse. Staff gauge readings and flume readings are taken 2-3 times daily for a week. The discharge calculated from the staff gauge readings ($Q = C_d A \sqrt{2gh}$) and corrected to the

flume readings is plotted against the working head calculated from the staff gauge readings.

i. Estimation of Water Losses in Watercourses

Most of the water loss studies to date have been conducted under conditions where steady state flow could be assumed. Summation delivery efficiencies of water through watercourses are considerably less than those measured under steady state conditions. Losses such as dead storage, infiltration, rodent holes and nakka leaks are involved before the water enters the field. The losses involved in filling dead storage, and infiltration during the early period of watercourse filling, can be estimated as a function of mogha discharge and time required to fill dead storage. Submission delivery efficiencies, E_s, can be calculated by dividing water delivered to the field by the volume of mogha flow.

j. Procedure for Permanent Raingage Installation

Long term watercourse studies require the measurement of water inputs to crop production from rainfall. The primary concerns in raingage installation is for security of the equipment and location of the raingage with respect to obstacles.

To take care of security of the raingage, a concrete pedestal and security chain are installed. The raingage should be located twice the distance from the nearest obstacle as that obstacle is tall.

k. Procedure for Permanent Flume Installation

Watercourse studies of long term duration, for an entire cropping season or longer, require frequent measurement of mogha discharge. Intensive studies over time require continuous measurement of mogha outlet discharge. For these purposes, the permanent installation of a Cutthroat flume is recommended with concrete used as a foundation, approach floor and walls.

The critical elements of permanent flume installation include the elevation of the flume with respect to the elevations of fields on the watercourse and the elevation of the flume with respect to the discharge relationships of the mogha.

The degree of mogha submergence is affected by the height of flume and distance from the mogha. A primary objective in measuring irrigation water of farmers is to cause the minimum possible disturbance of the natural conditions.

The procedure requires one week's monitoring of flume measurements and submergence levels with respect to specified field elevations encountered, and a reconnaissance topographic survey of a sample of field elevations with respect to mogha crest elevation.

1. Procedure for Observation Well Installation

To assess the possible contribution of the water table in meeting the crop needs for water, a record of water table fluctuations over time is required.

The procedure provides instructions to the field engineer for the installation of observation wells for watercourse surveys. One important requirement for the successful operation of observation wells to indicate water table depth is the provision of a pea gravel shroud around the pipe. This is essential for water table level to be accurately reflected in the measurements.

5. 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. 1976 Skimming Well Report: Field Studies

An interceptor well placed below a main well was pumped at rates up to 36 percent of the rate of the main well, but was not effective in keeping down the saline cone or keeping the salinity of the water within limits acceptable for irrigation.

The water table drawdown, saline-fresh water interface coning, and elementary hydraulic considerations show that most of the water pumped from the fresh water layer in regions where saline water lies within 100 feet of the surface is replaced by saline water moving up from below rather than by lateral transmission of fresh water or by air (water table drawdown).

Consequently, in using existing or new shallow fresh water layers, recharge will need to be localized, within a few furlongs of the point where the water is to be pumped out of the aquifer. Lateral transfer of fresh water in a thin layer overlying a thick layer of saline water in response to pumping of wells is accompanied by the lateral transfer of much larger amounts of saline water and a rise in the saline-fresh water interface.

b. Saline Water Pumpage and the "Monsoon Flush" as a Means for Building Fresh Water Storage and Reducing Salinity, Water Logging and Flooding in the Centers of the Punjab Doabs

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

Recharge to the aquifer from the rivers has pushed salt water to the centers of the doabs and the layers of fresh water in the centers of these doabs are often so thin that pumping for irrigation use is not feasible. This is a self aggravating problem because lack of pumping in these areas leaves the water table high, so when monsoon rains come, there is no room in the aquifer for this good fresh rain water. It accumulates on the surface, causing flood conditions and runs off slowly through the available drains. The net effect is loss of this good water to the sea, retention of saline water in the aquifer and negligible increase in thickness of the layer of fresh water.

This discussion outlines the data needed to evaluate the potential of pumping salt water out of the doabs during the monsoon season, which would allow the creation of fresh water storage in saline portions of the doabs in the Punjab.

c. Private Tubewells in SCARP-II: Water Costs and Utilization

In Pakistan there has been a constant debate on the merits of public tubewells versus private tubewells. The debate has often taken the position that the country must have one or the other, but not both. However, in reality, even in the areas of extensive public tubewell development, there are usually found a large number of private tubewells. The objective of this study is to explore the costs and utilization of private tubewells in a small unit of SCARP II.

The selected study site is the area in and around the Mona Reclamation Experimental Project (MREP). This experimental scheme includes about 110,000 acres out of the larger SCARP II scheme. The main objective of the MREP is to derive information from operational research that will assist in the identification and application of methods to achieve maximum effective use of the water and land resources in SCARP areas.

Recent research under the direct supervision of Mohammad Ashraf, Project Director, and in collaboration with the Water

Management Research Project Team from Colorado State University has focused on water management problems at the on-farm level. An integral part of this research is the integration of the use of surface water and groundwater supplies. Current research in this area includes development of freshwater skimming wells, improvement of SCARP watercourses, agronomic research using poor quality groundwater, and development of drainage and reclamation techniques. This report is a preliminary study to explore how farmers receiving both public and private tubewell water operate their private tubewells. The importance of this research is reflected in the fact that over 110,000 private tubewells have been installed in Pakistan, yet very little effort has been made to integrate them into the overall irrigation water system.

6. 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. Effect of Within Field Elevation Differences on Cotton Stands and Yields

Leveling of irrigated fields is a well accepted practice in many areas of the world. This practice is presently being promoted in Pakistan as a method of improving yields and conserving irrigation water. Farmers and agricultural advisors alike generally accept the practice as beneficial, but reliable data quantifying the effect of elevation differences within fields on yields and water use are rare. In order to better understand the effect of poorly leveled fields on crop productivity, stands and yields of cotton in 15 fields in the Mona project area, Sargodha District, were investigated.

b. Consumptive Use of Irrigation Water by Major Crops in Pakistan

Periodic gravimetric determinations of soil moisture profiles to a depth of 60 inches indicated consumptive use of water by wheat, berseem, cotton and wheat crops of 22.6, 29.0, 33.9 and 18.5 inches, respectively. Daily rates of actual and potential evapotranspiration are discussed.

Reliable measurements of the consumptive use of water of field crops produced under good management conditions are much needed for sound planning of irrigation water use. Experimental fields at PARI, Lyallpur, have provided such information for wheat, berseem and cotton.

c. Consumptive Use of Water Under Optimum Management Conditions for Major Crops in Pakistan

Although Pakistan possesses excellent soils, ideal climate, and the world's largest irrigation system, its yields for many irrigated crops are among the world's lowest. This project was organized through the efforts of Dr. C.J. deMooy for the purpose of determining the consumptive use of water by the major Pakistani crops under optimum management conditions. A secondary objective was to train Pakistani scientists in consumptive use measurements and optimum management techniques.

Seven experimental sites were located throughout Pakistan. The project is administered through Pakistan's Agricultural Research Council with Colorado State University remaining as a technical advisor. Crops selected for each site depend on local conditions and crops adaptability; however, procedures at all sites remained very similar.

Experiments contained three moisture treatments and two fertilizer treatments. Actual seasonal consumptive use was determined by a strict accounting of all soil moisture additions and depletions. Soil moisture contents were determined gravimetrically. Potential evapotranspiration is estimated using the Jensen-Haise equation.

The results will be published in Pakistan and utilized in irrigation scheduling and other watermanagement research. The lack of expertise and organizational problems have been the major constraints in the project. Some sites have not received the necessary measuring and recording instruments yet. Inspections at each site in 1976 show continuous improvement in the quality of work at most sites.

d. Estimation of Consumptive Use of Water for Wheat under Optimum Management Conditions

Pakistan is predominately an agricultural country. In spite of favorable conditions of soils, irrigation water and climate, agriculture in the country suffers from under production both in terms of yield per acre and production per farm worker. The country is heavily dependent on agriculture for food and fibre requirements of the ever increasing population. In order to cope with these requirements, it is essential to increase food and fibre production, not only to attain self sufficiency, but also to the extent of exportable surplus for earning foreign exchange.

Agriculture in the country mainly depends on irrigation. Unfortunately, present irrigation supplies in the country are inadequate. Conserving the existing irrigation supplies affords an opportunity of adopting quick measures to increase the irrigation supplies by reducing the loss of existing

irrigation supplies. In order to conserve the irrigation supplies and to increase crop yields, it is essential to know the actual consumptive use water requirements of crops grown in the country. This will also help the planners to fix more realistic and reliable targets of crop acreages and production.

Wheat is one of the most important food crops in Pakistan. It occupies by far the largest area under crops. The Government of Pakistan is doing everything within her means to increase wheat production to attain self-sufficiency in food. Little field work has been done to determine the consumptive use of wheat in Pakistan. Although estimation of water requirements of wheat have been made by certain workers, their estimations are either based on hypothetical calculations made by using climatological data, or on lysimeter studies. Reliable information about actual water requirements of crops based on carefully conducted field studies is lacking. Consequently, this study was carried out to estimate the consumptive use water requirement of wheat under optimum conditions of management, mineral nutrition, and water supply on demand indicated by soil moisture tension.

e. Toward Optimum Management Practices for Production of Maize in Irrigated Areas of the Punjab

Traditional practices of maize production are the major cause of the extremely low per-acre yields occurring in many areas. It was found that average maize yields can be doubled, and often much more than that, by application of a package of improved practices. These practices included good seedbed preparation and precision land leveling, the use of good quality seed of High Yielding Varieties, row planting, increased use of fertilizers, improved irrigation practices, and good weed and pest control measures. There were indications that bedding with the accompanying furrow irrigation, and also the use of farmyard manure, could raise the yield of maize to higher levels.

f. Improved Soil and Water Management Practices for Oilseed Production

The annual domestic consumption of oilseed in Pakistan is approximately 400,000 (4-lakh) tons and is increasing with the growing population of the country.

The annual production of vegetable oil of about 220,000 tons is short of the requirements by 180,000 tons. Pakistan is investing about 150 million rupees of foreign exchange per annum to cope with the situation. Importantion of vegetable oils seriously affects the developing economy of the country.

Various scientific, technological, and extension programs aiming at self-sufficiency in edible oils are in progress.

Several brassica species including mustard are important oilseed crops in Pakistan. The growing period of these crops synchronizes with wheat. The possibilities for increasing the acrea under rabi oilseeds are limited in view of the national interest in boosting wheat production. There is also considerable emphasis on irrigation and other farm resources for cereal production. The obvious solution to the problem is to increase the per-acre yields of oilseeds by making optimum use of the limited irrigation and other farm resources which are available. The present study is an attempt in this direction and focuses on consumptive use of water, fertilization, good crop protection measures and other optimum crop management practices.

7. 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. The Fertilizer Ratio Concept

The concept of plant nutrient ratios has long been utilized by agronomists and appears to be particularly prevalent in Pakistan. Production experts often express concern that the nutrient ratios utilized by the farmers are not optimum for a particular crop. These concerns are reflected in the press and are considered by those charged with planning production and imports. Agronomists interested in plant nutrients may thus find themselves designing experiments to determine the optimum ratios of plant nutrients for different crops grown under different conditions.

This paper discusses the two nutrients, nitrogen and phosphorous, and the resulting N/P ratios. These fertilizer elements are the most widely used in Pakistan and crops often respond to their use. However, combinations involving other nutrients or crop inputs are subject to the same principles.

The concept of an optimum ratio does not simply refer to a single rate of N and P_2O_5. First, an optimum ratio requires that a generalized N-P response surface exists that is reasonably valid for the fields concerned. Secondly, the economic optimum ratio will depend on the relative price of the two inputs. Finally, the concept of an optimum ratio would place severe constraints on the geometry of the response surface.

This paper illustrates some of the technical and economic limitations of the ratio concept. Raising an alarm over the Pakistan farmers' improper fertilizer ratio not only serves

no useful purpose, but also illustrates a lack of knowledge of the technical-economic relationships involved. There is no sound basis for assuming that ratios should be the same for different doses.

b. Fertility-Water Interaction Experiment on Rice

This is a revised version of the trials conducted the previous three years. The design provides for the application of irrigation variables based on potential evapotranspiration minus rainfall. This procedure will compensate for moderate rainfall and still allow irrigation variables to be imposed, but record monsoon rainfall prevented development of stress prior to the final three weeks before maturity. Significant yield differences did develop. A maximum yield of 72.6 mds/acre was attained by applying irrigation equivalent to 1.6 times (ET_p-Rain) in combination with 150 lbs N/acre. However, a very acceptable yield of 67.8 mds/acre was attained with only 50 lbs N and irrigation application of 1.0 times (ET_p-Rain).

c. Fertility-Water Interaction Experiments on Rice at Kala Shah Kaku

This paper shows the response surfaces obtained from three years of experimentation on high yielding rice (IR 6-945) at Kala Shah Kaku, and examines least cost alternatives for the use of nitrogen and water. Irrigation intervals of ten days or less generally gave maximum yields, but yields in excess of 60 mds/acre were obtained from 15 day intervals in two of the three years. Nitrogen levels for maximum yields varied from 100 to 200 lbs N/acre, but yield increases from application of more than 100 lbs/acre were generally small. Least cost alternative for 60 mds/acre valuing an irrigation at Rs. 30 and N at Rs. 1.5/lb were seven irrigations and 85 lbs N in 1975, 14 irrigations and 172 lbs N in 1974, and six irrigations and 25 lbs N in 1973. If water supplies were short, 60 mds/acre may have been an unrealistic goal in 1974 as 50 mds/acre required only eight irrigations and 114 lbs N.

d. Directions for Application of Controlled Amounts of Water with Siphon Tubes

Field measurements have been taken which enabled the calibration of 4.5 ft, 5.5 ft., and 6.5 ft. siphon tubes. Water application can be calculated under three different cases; 1) when the water level in the plot is below the outlet during the complete delivery; 2) when the plot does not initially contain water, but would fill above the end of the siphon outlet during the filling; and 3) when the plot contains water at the start of the application. Graphs needed for the calculation are developed for the three different cases.

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

a. Helping Farmers Identify and Achieve Their Potential for Watercourse Improvement

About half of the water supplied to farm watercourses in Pakistan is lost before it reaches the fields. This loss was found to be primarily through the upper porous portions of the banks and in the vicinity of junctions where banks are thin. Concrete and brick linings and steel slide gate control structures reduced the loss to as low as 10 percent, but are too expensive for general use.

Earthen improvements such as making new compacted banks and compacting cores in old banks were found to reduce water losses to less than 25 percent of their value in old watercourses.

Farmers were motivated to organize themselves to build their own earthen improved watercourse (28,000 ft.) according to design specifications drawn up by young Pakistani engineers. Low-cost concrete diversion structures were developed and installed at junctions to eliminate continued borrowing of soil. The improvements reduced losses to about one-half their previous values and provided the farmers with about 1 cusec of extra water. The cost was about Rs. 2/foot of watercourse improved, including farmers' labor.

The benefits to be gained within the first year equal the cost. Maintaining the benefits will require the investment of about 10 man-hours of labor per acre-foot of water saved. This is some of the least expensive water available in Pakistan and other countries where rural labor has a low value during many seasons.

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

b. Watercourse Improvement: Tubewell 56R During Ramazan

Farmers were willing to support a labor intensive watercourse improvement program during the month of Ramazan. The laborers ate and drank during the working day, apparently on the assumption that the inherent virtue of the improvement project justified breaking their fast.

The farmers primary reason for wanting the improvement program was to provide a masonry section through the village where the occasional losses were an obvious nuisance and the intensity of auxiliary use (for washing clothes, washing vegetables, bathing, animal watering, etc.) was extremely high. The farmers realized the high cost of building such a masonry section and were willing to pay the complete costs of their control structures and provide all the labor for the earthen improvements as "part of the bargain" to obtain the masonry section through their village.

The cost of the improvement of 11,400 feet of improved earthen channel with concrete control structures was about Rs. 1.8/foot, including the labor of engineers, field assistants, masons, farmers and their servants, and materials for installing the control structures. The observable benefits were an increase in water delivery to farmers fields of about 50 percent due partly to increasing the supply by 30 percent and partly to increasing the delivery efficiency of the channels by another 5 to 10 percent.

When the government is paying for the check structures, farmers demand many more than are essential, which results in conflicts with the engineers. On this project where farmers were paying for their own, they were very reasonable and worked in close cooperation with the engineers to reduce the number of check structures to a minimum.

The manufacturer of the concrete control structures was willing to decrease his price by about 25 percent to farmers who paid an advance and completed payment on delivery; as compared to his price to government agencies where payment often requires months and extensive paper work.

Involvement of project personnel in socio-legal decision-making and disputes between farmers can be minimized by clearly defining their role as technical advisers and supporting the water users Executive Committee as the decision-making body in these matters.

c. Irrigation Advisory Assistance

On-farm water management involves many components. Improved delivery systems can increase the supply of water, but this increased supply will only result in increased production if it is effectively utilized. The farmer is faced with the dual problem of deciding on a crop mix that will meet his economic and subsistence needs within the limitations of the available water supply, and the apportioning of his water supply among his crops within the limitations of the warabundi or weekly turn system.

The program presently being undertaken has three major components: 1) matching the cropping pattern on the

individual farms to the probably available supply; 2) helping the farmer to decide on the best use of his available water at each weekly turn to minimize both over-irrigation and crop stress; and 3) assembling a suitable data base for 1 and 2 above.

The pilot program is being conducted at the Mona Reclamation Experimental Project (MREP) near Balwhal in Sargodha district. Five farms were selected in July and projections developed for the remainder of the kharif season. However, near record rainfall tended to maintain soils at near saturation during monsoons so that irrigation advising was unnecessary. The program was restarted for rabi season with a goal of 10 participating farms, seven of which had been selected and records started prior to 25 Nov. 1976.

d. Water Problems in the Indus Food Machine

Irrigation water management for increased agricultural output is currently a very high priority development area. The major international donor agencies have realized that it is not sufficient to build massive dams and extensive irrigation schemes. It is also necessary to provide funding to improve the water delivery efficiency and to increase the degree of sophistication of on-farm water management. However, these agercies may well discover that improving on-farm water management is a more complicated task than building dams or providing capital intensive facilities. The socio-economic climate at the farm level does not readily lend itself to rapid change.

The purpose of this paper is to analyze some of the practical, field level water management problems that restrict the output of agricultural products in many developing countries. The examples provided in the paper use the Indus Basin as the sample area. Since this area has been irrigated under an extensive water delivery system for over 80 years, the problems currently existing provide a representative sample of problems that must be overcome before an irrigation scheme can be successfully implemented.

This paper examines, both in technical and socio-economic terms, factors that prevent the rapid expansion of food production. A case is made, presenting data from a number of studies and surveys, that it is not enough to simply provide more water, more seeds or increased availability of fertilizers. The underlying institutional factors go deeper than a lack of inputs and require extensive philosophical and institutional changes.

e. Improved Soil, Water and Crop Management for Increased Farm Production in Pakistan

Plant nutrients, HYV technology and crop management practices have been widely used as tools to increase farm yields. However, the concept of proper water management is new in Pakistan and little work has been done to include this aspect in the struggle to raise crop production.

The main source of water in Pakistan is the monsoon rains and, with the completion of the Mangla and Tarbela reservoirs and follow-up projects, 16 MAF of water can be stored for continuous supply during peak demand seasons. Now, this resource must be utilized to best advantage. The water requirements of the various crops grown under high standards of management are being measured experimentally in another CSU-supported program operating throughout Pakistan. In addition, it is necessary to find a practical combination of desirable irrigation practices with sound fertilizer and crop management. The new procedures must be made acceptable to the farmers under local conditions. Extravagant and other undesirable use of scarce water must be avoided. The present study is an attempt in this direction and focuses the attention on the potential contribution of irrigation water in interaction with fertilization, crop protection and cultural management of wheat, maize, fodder, sorghum, and cotton crops.

f. Case Study on Improved Farm Water Management in Pakistan

One of the major constraints limiting crop production in Pakistan has been the limited water supply available to the farmer. After taking efficiency measurements it was found only about 20 percent of water entering the watercourse is in the root zone available to crops. Average wheat production was increased 2-1/2 times by applying water as needed and using optimum fertilizers.

Almost half of the water lost from a watercourse occurs within 30 feet of the junctions. A permanent concrete control structure was developed which often increased the supply of water to the farmers fields by 50 percent for a cost between Rs. 50 and Rs. 90 (10 Rupees = approx. $1 U.S.). Efficiency measurements also identified that a large portion of the losses were due to the high permeability of the earthen watercourses. A program of compacting the soil banks of the watercourse was found to reduce seepage by 25 percent.

A third type of water loss could be eliminated by careful alignment of the bottoms of the watercourse. Because of the high cost of concrete or masonry ($3-$7/ft) it was generally not economically feasible to line a watercourse unless the water is carried more than 2 to 3 days per week.

On watercourses that are filled only one day a week, earthen improvements with concrete control structures are the most feasible. When these improvements were made on 1800 acres with 60,000 ft of watercourses, the supply of water to the farmers' fields has been almost doubled. The physical and socio-economic data observations taken on these pilot projects form part of the basis for proposed rational programs in Pakistan.

Unlevel land and over-irrigation are the major constraints to high application efficiencies. Technicians are being trained in a program of precision land leveling. Improvement of the watercourses to increase the flows and give the farmer better control of his work must be accompanied by the farmers knowledge of how much water the plants need. Seed drilling into a dry field, scheduling crops, and furrow irrigation are some of the possible solutions being investigated. Studies show land leveling is very economically beneficial. Cropping patterns and irrigation scheduling are being studied as to these benefits.

9. 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. Criteria for Irrigation Water Quality

Irrigation waters are classed as fit, marginal or unfit for irrigation based on their potential to create conditions hazardous for plant growth. The parameters mainly considered for evaluation of questionable quality waters are total soluble salts (TDS in ppm), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC in me/L). Their effect on soil and crops is interrelated. For example, a high value of one with a low value of other present in irrigation water is considered as safe for use of that particular water compared to the high values of all the parameters. Information in this area is limited under Pakistan conditions and needs further investigation. Therefore, an experiment is being carried out in Lysimeters at MREP using 29 water combinations to study the combined effect of TDS, SAR and RSC on soil properties and plant growth.

b. Crop Yields and Rate of Salinization of Soil as Affected by Irrigation Water Quality over a Period of Three Years

A field experiment with four water qualities and three leaching fractions in factorial combination was conducted for three years to relate crop yields to soil chemical conditions. It was found that the poorest water quality being used

converted the soil into a saline/alkali soil to a depth of approximately 12 inches. Noticeable increases in salt concentrations occurred to fully 5 feet depth and some rise in alkali to a depth of 2 feet. Under these conditions, yield losses of berseem and other fodder crops amounted to 25 to 29 percent. The salinity and sodium adsorption ratio of the soil were roughly linearly related to the quality of the irrigation water used and lend themselves to quantitative interpretation. Neither yield losses nor chemical deterioration showed a progressive trend despite continual input of salts with the irrigation water. This suggested that the environment exerted a balancing effect at least temporarily and under the conditions of the experiment.

Irrigation with saline tubewell waters has caused great problems to farmers, yet it is unavoidable in many instances. No damaging effects may be found at first, but slowly the soil becomes hard, the chemical conditions change and crop yields are reduced. Standards of quality for irrigation water and accompanying recommendations for agricultural practices on how to manage marginal soil and water conditions are very much needed in Pakistan. These standards must be derived for local climatic and other factors and compared with those defined in the U.S.A. (U.S. Salinity Laboratory, 1955) and elsewhere.

c. Use of Gypsum Stones to Lower the Sodium Adsorption Ratio of Irrigation Water

Much of the groundwater of the Indus basin has a sufficiently high Na^{+}/Ca^{+} ratio to be harmful to soils and crops. When the salt contents of the tubewell waters are reasonably low, the primary method of lowering this ratio is to apply extra Ca^{++} on the fields or in the water. Gypsum is generally the most reasonably priced source of Ca^{++}.

Gypsum stones 5 to 20 kilograms in size are a useable source of the Ca^{++} needed to bring down the SAR in sodic tubewell waters. The dissolution rate of the gypsum stones was proportional to the square root of the velocity of flow through the bed. Consequently, the increase in concentration of Ca^{++} is inversely proportional to the square root of the velocity of flow, and the size of the stones in the bed. Equations were developed to make the necessary estimations to design channels of the proper cross-section and length to supply the needed amounts of Ca^{++} to the water when the average size of the stones, the flow rate of the water, and the initial ionic concentration of the water are known.

10. 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. Farm Irrigation Constraints and Farmers Responses: Comprehensive Field Survey of Forty Watercourse Systems in Pakistan

1. Pakistan's Agricultural Potential

The agricultural sector of Pakistan possesses extraordinary resources for use in the production of food and fiber. Among these resources are deep alluvial soils, a favorable climate for year-round cropping and a large rural labor force to carry on these agricultural pursuits. Of major importance along with the above resources, is the Indus Basin Irrigation System. This 32 million acre system has tremendous production potential, much of which is unrealized. If efficient management techniques and policies could be developed to exploit the potential of the human and natural resources, this could easily become the most productive agricultural system in the world.

The purpose of this study is to answer the major question, "What are the significant farm level constraints confronting farmers in their irrigation systems which are presently responsible for low crop yields and crop production?" As a problem identification field survey, the goal is to describe how farmers respond to selected constraints as they manage irrigation water for their crop production systems.

2. General and Specific Objectives of the Study

The general and specific objectives of the study are as follows:

a) To identify and describe the major physical, economic, social, and legal factors which explain the present irrigation behavior and cultural practices of farmers.

(1) To evaluate and compare watercourse delivery efficiencies, farmers' irrigation application efficiencies, and practices between:

(i) Major agro-climatic regions of Sind and Punjab Provinces.

(ii) Private tubewell, public tubewell and non-supplemented watercourses.

(iii) Perennial, nonperennial and uncommanded watercourses.

(iv) Regulated and nonregulated watercourses.

(v) Farm locations on the watercourse reach and between various types of farms

(2) To evaluate farmers' cropping intensities, cropping patterns, and crop yields in relationship to selected physical, economic, and social factors.

(3) To examine farmers' responses to selected institutional and legal constraints related to the distribution and use of irrigation water.

b) To provide data on selected physical, economic and sociological factors for utilization by the present On-Farm Water Management Pilot Project in Pakistan:

(1) To identify the extent, types, and magnitude of watercourse losses of a sample of watercourses from the major irrigated regions of Pakistan.

(2) To estimate the need for precision land leveling and improved farm layout systems.

(3) To examine the extent of both over- and under-irrigation by farmers in relationship to selected physical, social and economic constraints.

(4) To provide criteria to be utilized for objective selection of those farm and watercourse improvement activities that will have the greatest likelihood of success and payoff to farmer clients.

(5) To provide information about farm level problems which can be utilized in training extension personnel for on-farm irrigation advisory services to farmer clients.

(6) To provide sociological and economic data about the propensity of farmers to collectively organize to promote their common interests in water delivery, control, and application leading to improved means of farmer organizations for the On-Farm Water Management Pilot Project.

(7) To provide data and methodologies which will be useful in designing evaluative procedures for the On-Farm Water Management Pilot Project.

c) To compare data on selected sample watercourses with a 1966 watercourse study where the same watercourses were included in both studies.

(1) To compare differences in cropping intensities, cropping patterns, crop yields, and adoption behavior.

(2) To estimate differences resulting from the high yielding varieties (HYV) program and Private tubewell installations which took place after 1966.

d) To provide empirical field data for policy formulation related to the extent, types, and magnitudes of farm irrigation and crop management problems.

(1) To provide micro data about farmers' responses resulting from legal and institutional constraints which can be utilized for suggesting policy alternatives to provide more efficient distribution and use of public canal water.

(2) To provide data on information and knowledge constraints which limit risk taking in cropping decisions and adoption of improved management practices.

(3) To identify major farm level problems which may require intensive adaptive and applied research to find appropriate solutions.

e) To provide information and guidelines for use in future watercourse investigations.

(1) To suggest hypotheses which can be tested in future studies.

(2) To suggest guidelines for selection, training, and evaluation of field investigators.

(3) To suggest guidelines for field supervision and procedures for data collection, data management, and analyses.

b. Socio-Economic Bench-Mark Survey Tubewell MN 56

The main objective of the Mona Reclamation Experimental Project (MREP) is to derive information from operational research that will make it possible to identify and apply methods to achieve effective use of water and land resources in SCARP areas. Active research has been carried on for over five years from the Project Headquarters located near Bhawal. Recent research, under the direct supervision of Mien Ashraf, and in collaboration with the Water Management Research Project Team from Colorado State University, has focused on the water management practices of the farmers.

This research has proven that losses of the magnitude of 40-60 percent of the flow at the mogha occur before the water reaches the farmer's fields. In order to reduce these losses, a series of pilot watercourse projects have been developed. The first pilot watercourses explored different techniques for brick and concrete lining of watercourse channels, but present research is now concentrating on developing techniques for rebuilding earthen improved watercourses.

The first earthen improved watercourse was started near Village 10ML in November, 1975 and completed in March, 1976. This watercourse was a cooperative effort between the farmers and the Mona staff. The farmers provided over 12,000 hours of volunteer labor and the Mona staff provided over 3,000 hours of technical expertise and supervision.

The object of this report is to document conditions related to the situation on the study watercourse prior to the improvement project. Future reports will document conditions after completion. This benchmark study was carried out by the Economics Section of the Mona Reclamation Project under the direction of Mohammad Hussain, Senior Research Officer, with direct field supervision from Barkat Ali, Junior Research Officer. Technical advice, data analysis, and report editing was provided by Dr. Sam H. Johnson III, Agricultural Economist, Colorado State University Water Management Research Team.

c. Community and Irrigation in the Pakistan Punjab--Physical and Sociological Dimensions of the Water Management Problem

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

The central thesis of this paper, therefore, is that programs to improve the management of irrigation water must center on the design and improvement of farmer irrigation organizations.

d. Legal Considerations and Alternatives to Organizing Water Users

This paper is a synthesis of information and experience based upon research and consulting in numerous countries on the subject of water law and water user associations and enlightenment on various water law systems by Prof. George Radosevich as a result of organizing with several colleagues at Colorado State University, Utah State University and in Spain and directing the International Conference on Global Water Law Systems, Valencia, Spain, held in September 1975.

The success of any agricultural development program with the objectives of enhancing the quality of rural life and meeting national food production requirements depends on a strong water policy to increase delivery and application efficiencies, to encourage conjunctive use of surface and groundwaters, and to integrate water quantity and quality control. These objectives can best be achieved through the active and well structured collaboration of local water users among themselves and with officials charged with administration, control and distribution of water.

The realization of these objectives also requires an awareness on the part of government officials and policy-makers of the conditions and constraints to change which water users face within their localities. 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 problems of local farmers and in providing the water users with timely information on water availabilities.

Formation of local water user associations can provide the infrastructure for improving irrigation efficiency and increasing agricultural production by:

(1) Getting farmers directly involved in the local decision-making process;

(2) Managing the water distribution system, thus improving the delivery, application, and removal of water throughout the system.

(3) Resolving disputes between water users as individuals, and problems arising between water users collectively and the central government;

(4) Serving as a communications link and forum for disseminating information and assistance on improved water use, agricultural practices and technologies, and methods for improving the quality of rural life;

(5) Channeling the needs and desires of farmers and rural communities to those government agencies best equipped to meet them through that level of the association hierarchy which has access to the appropriate level of government organization;

(6) Promoting the collective action of individual farmers by pooling their individual resources in actions which benefit the individual and the group;

(7) Establishing a formal management mechanism for administering government aid with a higher level of accountability and permanence; and

(8) Taking advantage of the economies of scale in committing scarce financial and technological resources to programs which are better integrated with national or regional goals and which will benefit greater numbers of individuals.

The recommended pattern for organizing water user associations is to examine both endogenous and exogenous entities and then structure and tailor the new entity to coincide with the religious, social, political, economic, and legal system for the country in question. Also, the water user association should commence with a simple, non-sophisticated organizational arrangement which is flexible enough to allow for institutional maturation as intra-water course demands and developments take place. It is also important to distinguish between improving an existing system and developing an entirely new program.

Other issues to be considered are: (1) the purposes of the organization, i.e., single purpose (irrigation) or multiple purpose (irrigation, conservation, drainage, reclamation, etc.); (2) jurisdictional or territorial limitations of operation; (3) financial operations, including assessments, public borrowing and membership dues; (4) internal decision making, including voting and selection of officers; (5) the interrelationship of the association with similar groups and with agencies of the central government; (6) possible incentives for individual participation; (7) how the water user association will function in relation to broader government policies for water and agricultural development; and (8) the method for resolving disputes which arise.

These issues must be viewed against the background of various influencing factors such as the trade-offs between the scarcity or abundance of labor and capital, the physical abundance of water resources and the environmental quality of that resource, and how the resource use is influenced by the seasonal aspects of surface runoff or aquifer recharge.

e. Organizing Farmers to Improve Irrigation Water Delivery--The Problem and Prospects for Solutions in Pakistan

Water losses of major magnitude are occurring due to poorly constructed watercourses. These losses can be reduced in major ways at great savings to the national economy. To accomplish the objective of improving any particular watercourse, farmers must be organized to collectively provide themselves with a well-designed, well constructed watercourse which will reduce seepage damage and will increase needed water supplies. Recent research indicates farmers will be responsive to an opportunity to improve their watercourses.

At present, three organizational alternatives are available for establishing the necessary water users' associations--the informal, the authority of the Companies Act, and the authority of the Cooperatives Act. Farmers may elect to organize in any of the three ways.

Improved seeds and fertilizers which constituted much of the "green revolution" are dependent on adequate supplies of irrigation water. At the present time the farmer will apply fertilizer at low levels to insure that his marginal costs do not exceed his marginal returns--a most rational response, but one which sacrifices productivity. If the farmer is given adequate supplies of irrigation water, he must decide how much he is willing to invest for seeds and fertilizers, which are very costly, to increase his crop production.

One of the most important ways to increase water supplies, as well as to reduce waterlogging and salinity, is to reconstruct poor watercourses which account for over 50 percent of the losses between the mogha and the field outlet. Farmers must be organized to reconstruct watercourses and to maintain the improvements.

f. Motivating and Organizing Farmers to Improve Their Watercourses

To supply the Pakistani farmer's basic need for water, a canal system diverts almost 100 million acre-feet of water from the rivers each year and another 30 million acre-feet per year is pumped from the ground water. However, of the water delivered to heads of the watercourses, about half is

lost during conveyance to farmers fields. With some exceptions, this condition is common throughout the 80,000 Pakistani watercourses.

The key to the economical reduction of this huge water loss is the spade, and the force able to turn the key is the Pakistani farmer. When convinced of the magnitude of this loss and shown how to decrease it, these farmers can reduce the losses and improve the welfare of their villages. With this objective in mind, meetings were held with the farmers in several villages to convince them of the need, and their ability, to reduce their water losses.

In choosing the watercourse on which to initiate the first pilot program on reduction of water losses, a priority list of required characteristics was developed as follows:

1. Farmer cooperation

2. Potential for improvements

3. Size of holdings

4. Accessibility

Based on the above, the watercourse serving Tubewell 56L (Village 10ML) was selected as the first watercourse to be improved in the pilot watercourse project.

g. The Need for a Water Management Extension Service in Pakistan

The purpose of this paper is to present a sample of survey data and engineering field measurements that documents the magnitude of losses in Pakistan's watercourses and the low level of scientific irrigation knowledge of most of Pakistan's farmers. The second section examines the factors relating to these problems, especially in terms of the quality of available extension advice relating to farm-water management. The final section presents a proposal for developing a dedicated corps of water management extension advisors and details how such a group could be organized and trained.

F. Dissemination and Utilization of Research Results

Throughout the year in keeping with program objectives, special efforts have been made which have resulted in wide dissemination and utilization of research results. As credibility with the Government of Pakistan has been increased as a result of a wide range of project activities, interest in Pakistan from farmers to government officials has accelerated. The major results of project efforts described in more detail below are: 1) official approval by the GOP

and USAID for a comprehensive On-Farm Water Management Pilot Project; 2) the training of a large number of host country personnel for research and development activities; 3) the institutionalization of water management research activities at research stations and with other organizations; 4) assistance to WAPDA master planning, the University of Agriculture, Lyallpur and other institutions in action oriented research and development activities; 5) increased focus on the role of women in farm water management improvement programs; 6) focus on the need to improve water laws and codes and the provision of incentives for farmers to organize for improving their farm irrigation systems; 7) increased linkages with international organizations active in Pakistan and elsewhere with a concern and focus for on-farm irrigation problems; and 8) utilization of project personnel for reconnaissance surveys to irrigated projects in other low income nations.

In May of 1976 USAID Washington approved an AID Mission to Pakistan proposal for a loan of over $10 million to help Pakistan launch a comprehensive On-Farm Water Management Pilot Project. This five year project will cover 1500 watercourse command areas totaling about 600,000 acres of land and involving about 60,000 farmers. The major components of this Pilot Project (costing an estimated $40 million) include watercourse rehabilitation, precision land leveling, and water management advisory services. The research data of the CSU program, and the particular vehicles by which these were tranfserred to farmer and official audiences, have convinced both the GOP and the USAID mission that such a pilot project is both needed and feasible.

Early in 1975 Eckert, Dimick and Clyma conducted a cost-benefit analysis of various alternatives for watercourse improvements to show the economic feasibility of the project. CSU and Mona Reclamation Experimental Project staff, using both applied and adaptive research methods, demonstrated the technical as well as the social and economic feasibility of the program by improving watercourses with farmers. In the summer of 1975, Early and Lowdermilk began a problem identification watercourse survey in the Punjab to document the magnitude of watercourse losses and farmers constraints. These studies which finally covered 40 farm irrigation systems from the northern Punjab to the southern Sind, also provided data along with other CSU research for the design of the Pilot Project. Eckert and Lowdermilk provided two man-months in providing assistance to the USAID Mission in writing the economic analysis, social soundness analysis, extension, and training components of the proposal. All CSU Field Party members participated in certain phases of technical aspects of program design. The CSU field team and campus staff have been requested to conduct further watercourse improvements to refine technologies and procedures and further document costs and benefits which will provide input into the five

year Pilot Project. Also, CSU will be involved in the training of personnel, and the research and evaluation of various phases of the program.

The undergirding philosophy of the CSU Water Management Research Project from its inception has been the clear objective of building up host country capabilities in the water management related fields. All research and other program activities involve host country personnel--ranging from extension workers, engineers, agronomists, social scientists, as well as officials in applied field training. The problem identification surveys in the Punjab and Sind Provinces alone resulted in field training of a group of about 30 individuals from disciplines including agronomy, economics, extension, and engineering. This state of the art study was done in cooperation with the WAPDA master planning group and all trained personnel have been employed by WAPDA for an intensive survey of 60 command areas which will require about $10 million (UNDP and World Bank funding) and two years for completion.

CSU, in cooperation with the SCS team in Pakistan and the newly formed water management cells in the Department of Agriculture of the Sind, Punjab, and NWFP provinces, have conducted a special training program for the trainers of engineers who will participate in the On-Farm Water Management Pilot Project. A training manual was designed for this field training and thus far 11 individuals have received training, who in turn will train the engineers required for the Pilot Project. These trainers were also carefully evaluated to ascertain if they had acquired the skills taught under actual farm conditions.

Another method of dissemination of research results was the special training program conducted by Dr. Bowers for agricultural research station personnel concerning the design and methodologies of conducting consumptive use studies.

Formal graduate training at the CSU campus was provided for Mr. Sadiq Shafiq, Mr. Nur Din, Mr. Mushtaq Gill, Mr. Ghulam Hussain, and Mr. Khalid Gill. An important innovation in this formal training is the requirement that after successful completion of course work, the candidate for a degree will return to Pakistan and conduct his thesis research on a relevant problem area in his respective field. The field research, data analysis, writing of the thesis, and final examination are all completed in-country under the guidance of CSU staff who compose the Field Party team.

Mr. Shafiq has successfully completed his M.Sc in agricultural engineering and is presently active in training programs. Mr. Mushtaq Gill is near completion of his masters thesis also in agricultural engineering. The research of

both these gentlemen was conducted on actual watercourse commands and result in findings which will advance technical and organizational procedures for water management improvement activities of farmers. Mr. Nur Din, who is a senior official of the Land and Water Reclamation Laboratory in Lahore has completed his M.Sc in agronomy and course work for a Ph.D. Both Mr. Ghulam Hussain and Mr. Khalid Gill have completed course work at the Ph.D. level in agronomy and respectively will return to important research positions at the WAPDA-Mona Reclamation Experimental Project (MREP) and at the Punjab Agricultural Research Institute. They will complete the requirements for the Ph.D. degrees in soils at their respective institutes under CSU staff guidance.

Realizing the world-wide demand for expertise in on-farm irrigation related fields, the project has provided an opportunity for two state-side graduates to conduct field research in Pakistan. Mr. Tom Trout is a Ph.D. candidate in agricultural engineering and his research will result in a comprehensive technical design manual for improvement of farm water conveyance systems. Mr. Larry Nelson is conducting his research at the Mona Station related to the problem of Kharif Season (summer) high soil temperatures and the germination and emergence of maize and cotton. Both candidates received much orientation at CSU prior to their research tour in Pakistan. They are expected to complete their work in 1978.

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

Another training program which has evolved in relationship to both the Pilot Project and the concern of provincial agricultural departments is that for farm level extension personnel. It has been realized that saving water through reducing conveyance losses is only half the job; the farmer must also receive hlep to utilize his water more effectively for increased crop production possibilities. Lowdermilk, Early, and Johnson developed a proposal documenting training needs and outlining the methodologies and types of practical training required. The Punjab Agriculture Department and the University of Agriculture at Lyallpur have developed a cooperative agreement for this training program which will begin in March, 1977. CSU staff will assist in developing training materials based on research and experience in Pakistan and will help establish the program and assist their trainers. Evaluative research methods will be used to improve both materials and training methodologies and to ascertain the success of the program. Finally, the

Agricultural University at Lyallpur in cooperation with the Punjab Department of Agriculture is planning to conduct a research-development program including research comprehensive improvements on several watercourses. This effort if successful will move the university more into the application of knowledge to real farm problems.

All these training efforts have evolved with time from the objective to build-up host country capabilities and the philosophy that training, whether formal or informal, must focus on the acquisition of skills to solve real world problems at the farm level.

In the past year, the staff of the CSU Water Management Research Project has been in considerable demand by several international organizations and universities in various aspects of research and development problems. It has been and is our stated policy to provide assistance and develop improved linkages with these agencies and organizations to share research findings, experience, and expertise. The major formal contacts, linkages, and activities have been the following:

1. The CSU Field Party is almost continuously involved with meetings and presentations with not only Pakistani organizations, but also many international organizations such as the World Bank, FAO, UNDP, Ford Foundation, etc.

2. Jerry Eckert and Max K. Lowdermilk participated with the USAID Mission in Pakistan in developing the proposal for the Water Management Improvement Project in January and February.

3. David Freeman and Max K. Lowdermilk presented a paper on Farmer Organization for Improvement of Irrigation Systems at the annual meeting of the Asian Society in Toronto, Canada in March of 1976.

4. In April, Wayne Clyma of the CSU Field Party and Willard Schmehl from campus participated in a review of on-farm irrigation problems at the invitation of the USAID Mission in Egypt and the Government of Egypt.

5. Max K. Lowdermilk was requested to assist the World Bank, Harza Engineers International and WAPDA in the design of a comprehensive watercourse survey, the evaluation of planning efforts, and the training of field workers.

6. Alan Early, Max Lowdermilk and David Freeman were invited to present a paper and participate in a workshop on Irrigation Systems with colleagues from other universities, sponsored by Cornell University in July of 1976.

7. George Radosevich, Max Lowdermilk, David Freeman, Jerry Eckert and Alan Early consulted with Utah State University in an exchange of research approaches and experiences in overseas research and development in July.

8. George Radosevich participated during August in the East-West Center Workshop on "Implementing Public Irrigation Projects."

G. Work Plan for the Coming Year

The present AID Contract (AID/ta-c-1100) terminates March 31, 1977. A work plan will be developed for the first year (April 1, 1977 to March 31, 1978) of the new contract during February, 1977 in Pakistan by the principal investigators, the CSU Field Party, Dr. Gilbert Corey AID/TAB/AGR/SWM who will be the AID Project Manager, and personnel of the AID Mission to Pakistan. Therefore, the work plan will be prepared as a separate document (copies will be available upon request.

Appendix 1

EVALUATION OF ERRORS IN GRAVIMETRIC DETERMINATION OF SOIL WATER

J.O. Reuss, S.A. Qureshi and Noor Mohd. Chaudry[1]

INTRODUCTION

Gravimetric determination of soil water is a technique commonly used in soil and water management research. In the process of designing an experiment involving fertility and water variables a question arose as to the number of samples that might be required to achieve a specified precision. Data were available from a previous experiment in which the method of gravimetric sampling of field plots had been utilize The error structure of this data set was examined in order to provide information on the expected precision. The results of this analysis are reported here along with a discussion of implications concerning the use of the technique in field experiments.

EXPERIMENTAL METHODS

Field Sampling

The data set analyzed here was from wheat experiments involving water and fertility variables conducted by the Cereal Botany Section of the Punjab Agricultural Research Institute at Lyallpur. In general each plot was sampled before and after irrigation. As the season progressed irrigation was discontinued on several treatments, thus decreasing the number of plots sampled.

Plots were laid out in a randomized block pattern utilizing three replications. Plot size was 12 x 33 ft. Most of the plots sampled received 100 lbs N per acre but one 50 lb N/acre and one 200 lb N/acre treatment were included. Each plot was split with one half receiving 150 lbs P_2O_5/acre while no phosphorus was applied to the other half. Samples were taken without regard to phosphorus application.

The following depths were sampled:

0 - 6 inches
6 - 12 "
12 - 24 "
24 - 36 "
36 - 48 "

[1]CSU Field Party Member,

Samples were taken from each plot utilizing a core sampler approximately 3/4 inch in diameter. They were immediately sealed in moisture cans, taken to the laboratory and weighed, dried at 105 degrees C. and reweighed. Separate bulk density measurements were taken by depth and the average bulk density was assumed in the calculation of volumetric soil water in all plots and at all dates.

Storage Calculations

Various methods can be used to calculate the moisture storage or loss between samplings. For instance, the mean soil water at each depth can be calculated for each sampling. These can be summed and the storage or loss computed as the difference between the two totals. Alternatively the difference in soil water at each depth may be calculated for each plot and the mean of this difference then computed. Still another approach is to calculate the total water for each core. This can be paired with the results from that plot from a different date, or the mean at each date taken and the difference in the means computed. Where a constant bulk density is used and no data are missing, it can easily be shown that the storage or loss calculated by any of these methods will be identical. However, the estimates of random errors and confidence intervals may not be the same, as different assumptions are involved.

RESULTS

Fertility Effects

A careful examination of the data including analysis of variance to test for differences in soil water content or water utilization failed to show any indication that fertility levels were affecting water use or storage at either location. Therefore, the data were pooled over fertility treatments, thus effectively increasing the number of replications available for error estimation.

In the non-paired analysis the total inches of water in each core was calculated. The means and variances of these totals for each sampling date were then computed (Table 1).

For the first three before irrigation samplings the mean total water was 9.70, 10.13, and 10.60 inches with error variances of .208, .147, and .169 respectively. For the first two sets of samples taken after irrigation the mean water content was 11.83 and 11.59 inches and the error variances were .392 and .558 respectively. It appears that variances are higher after irrigation than before. Therefore, pooled error variances were calculated for all samples before and after irrigation as follows:

before (76 df) $s^2 = .1717$
after (59 df) $s^2 = .4617$

Table 1. Mean water content, variance, and number of cores for 0 to 4 ft samplins before and after irrigation. Data set No. 1, PARI.

Date	Before or After Irrigation	Average Water (inches)	Number of Cores	Variance	Standard Error
15/11	B	9.70	27	.208	.088
21/11	A	11.83	26	.392	.123
2/1	B	10.13	20	.147	.086
11/1	A	11.59	20	.558	.167
1/2	B	10.60	18	.169	.097
8/2	A	Not Sampled			
20/2	B	10.75	9	.105	.108
27/2	A	11.71	9	.149	.129
8/3	B	11.48	5	.272	.233
14/3	A	12.56	6	1.084	.427
21/3	B	10.48	3	.025	.091
27/3	A	11.17	3	.112	.193
22/4	(Harvest)	6.73	18	.224	.112

These results indicate that the difference in variances for the before and after irrigation samplings are highly significant. We can now calculate the expected error variance for the difference between the mean of the total inches of water in a before and after irrigation sampling set. The variance of a difference of two independent sets of samples is estimated by the sum of the variance. Therefore, the variance of the difference is estimated by: .1717 + .4617 = .6334.

This expected variance would apply equally to a storage period where a set of samples before irrigation is followed by one after irrigation, or to a period of utilization where a set of samples after one irrigation is followed by a second set prior to the next irrigation.

In this experiment, as in many experiments involving moisture storage or loss, the possibility of reducing the error through pairing exists. In this case the same plots were sampled before and after irrigation. If individual plots tend to be either high or low at both samplings (positive cross correlation) the error of the difference between these individual differences (Δ's) will be lower than the above estimate from the sums of the variances at each sampling. Therefore, the differences between total water on each plot at the start and end of each storage or use period were computed along with the associated error variances. These are shown in Table 2 along with the variances calculated from the sum of the before and after variances for that sampling period. Although in some cases the variances are lower when paired there is no clear advantage to pairing.

Also note that differences in variances may not be directly reflected in standard errors. This arises becuase in some cases more plots were sampled at the start of a period than at the end. In using the paired data only those plots can be used which were sampled at both times while with the sum of the variance method all plots are used. With the paired data the standard error is given by:

$$s.e. = (s_1^2/N_p)^{\frac{1}{2}}$$

Where s_1^2 and s_2^2 are the variances of each sampling and N_1 and N_2 the respective number of observations.

From Table 3 we can also compute a pooled variance for all the paired data. This gives a value of .5835 as compared to .6334 given above for the sum of the variance. This may indicate a slight advantage to pairing but at this site the advantage is not significant at the .05 level. Pairing has the disadvantage of resulting in a greater loss from any missing data. Even so pairing is probably the safest

Table 2. Storage and evapotranspiration with estimates of variance and standard error for data set No. 1. The paired values are the variances of the difference in total water measured in each plot at the start and end of the period. The non-paired estimates are the sums of the variances at the two sampling dates.

Period	Storage or ET (inches)	Paired Cores			Non-Paired Cores	
		Variance	N	Standard Error	Variance	Standard Error
15-11 to 21-11	2.13	.699	26	.164	.600	.151
2-1 to 11-1	1.49	.393	19	.144	.705	.188
1-2 to 8-2	1.10					
20-2 to 27-2	1.32	.601	9	.258	.254	.168
8-3 to 14-13	1.39	1.124	5	.473	1.356	.425
21-3 to 27-3	.69	.035	3	.108	.137	.214
Evapotranspiration						
21-11 to 2-1	1.92	.434	19	.151	.539	.150
11-1 to 1-2	.94	.500	24	.162	.727	.193
8-2 to 20-2	.95					
27-2 to 8-3	.16	.496	5	.317	.421	.266
14-3 to 21-3	2.23	2.143	3	.845	1.109	.467

Table 3. Comparison of variances estimated by summing the variance of individual depths with variances estimated from the total water in the core. Data set No. 1.

Period	Non-Paired		Paired	
	Sum of depths	Core Total	Sum of depths	Core Total
15/11-21/11	.265	.600	.297	.699
21/11- 2/1	.284	.539	.309	.439
2/1 - 11/1	.513	.705	.314	.393
11/1 - 1/2	.493	.727	.301	.500

procedure if no previous information is available on the uniformity of the site.

Another possible method for estimating the sampling error would be to sum the error variances for each depth. The error variance of the difference in total water could be estimated by calculating the mean water content in each depth and the associated variances. The water contents by depth and the variances are summed. The difference in total water at two dates is then calculated and the errors summed. This method will be valid if there is no inter-correlation, i.e. high values at one depth in a particular core must not be consistently associated with either high or low values at other depths.

Variances of the difference between two samplings were calculated by this method for the first four periods at location No. 1. They were consistently lower than variances estimated using the core total as the comparable non-paired method (Table 3). This indicates positive inter-correlation with high moisture values at one depth in a core being associated with high values at other depths. As a result the sum of the variance of the parts is less than the variance of the total, causing this method to underestimate the error in total water. The comparable paired method involves taking the differences in soil water between two samplings for each depth in each plot. Means and variances of these differences are calculated for each depth and summed. This method also gave lower estimates of error than the comparable paired estimates using core totals(Table 3). Here again positive inter-correlation appears to cause low estimates of variance, so this method should not be used.

DISCUSSION

Using the estimates of error variances obtained above we can calculate the precision expected from any given number of samples, assuming these error values to be typical for this type of experiment. The confidence interval is given by:

$$CI = \bar{X} \pm t\ (s^2/n)^{\frac{1}{2}}$$

Where CI is the confidence interval, $\bar{X}$ is the observed mean, t is students t value for the degrees of freedom associated with s^2, the error variance, and n is the number of observations. With the number of degrees of freedom used in these variance estimates t .05 is approximately 2.0. We would expect that 95 percent of the time the true mean would lie within $\pm\ 2\ (s^2/n)^{\frac{1}{2}}$ of the observed mean.

A plot of $\pm\ 2\ (s^2/n)^{\frac{1}{2}}$ is convenient for evaluating potential error as shown in Figure 1 for the paired error variances. For changes in soil water to a depth of 4 ft

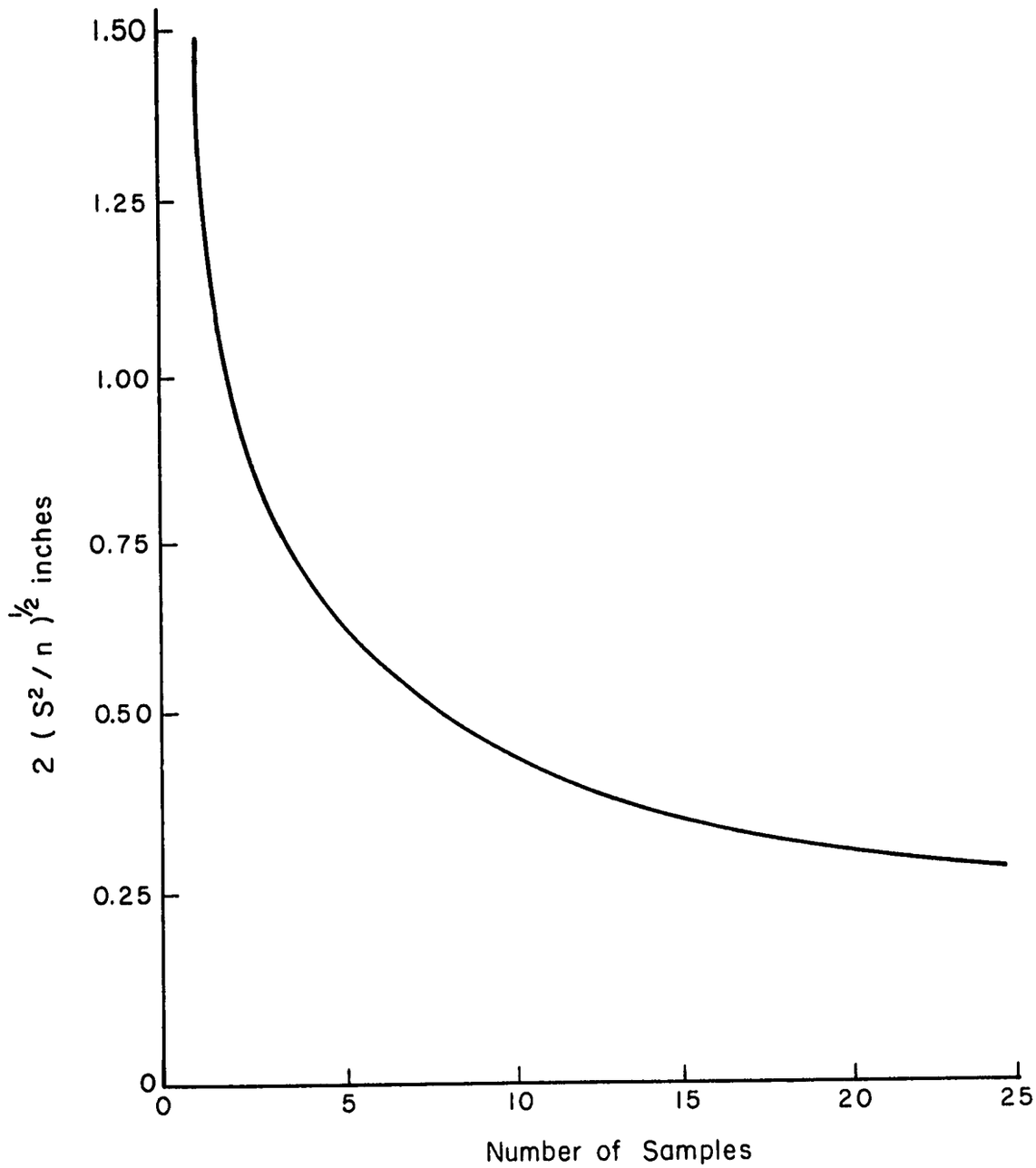

Figure 1. Expected precision for measuring changes in soil water by means of gravimetric sampling as estimated by data collected at Punjab Agricultural Research Institute. The probability of the true mean lying within plus or minus this amount of the mean of N observations is 0.95.

measured by gravimetric samples we would not expect the true mean to vary from the mean of n observations by more than the amount shown. The results are rather disturbing. The mean of three samples before and after a loss period will only estimate the true mean to $\pm$ .9 inches and it takes 10 samples to reduce this to 0.5 inches. The storage or evapotranspiration between any two sampling dates was seldom greater than 2.0 inches. With 10 samples and a difference of 2.0 inches our 95 percent confidence interval is $\pm$ 0.5 inches or 25 percent of the mean. The sampling of experiments presently under way is being conducted with great care in order to minimize human errors.

The possibility exists that these are particularly "noisy" data, and the errors can be substantially reduced by careful sampling and analysis. However, one must recognize the inherent difficulty involved in precise measurements of a small difference between two relatively large numbers. For instance, consider a profile containing 9.5 inches of water before irrigation which we estimate from 5 cores. We estimated the error variance prior to irrigation as .1717 so $\pm$ 2 $(s^2/n)^{\frac{1}{2}}$ for n = 5 is .370 inches or 3.9 percent of 9.5 inches. Similarly the error variance after irrigation is .4617 and $\pm$ 2 $(s^2/n)^{\frac{1}{2}}$ is .606 inches or 5.1 percent of the 12 inches present. These would generally be considered quite acceptable. The difference of 2.5 inches is only measured to a precision of $\pm$ .712 or 28.5 percent of the mean, an often unacceptable error.

The advantages to be gained from increasing the precision of the weighing equipment do not appear to be great. The balances used can achieve $\pm$ 0.1 g precision and if competently operated should be well within $\pm$ 0.2 g. Practically all samples are 40 g or larger so the ratio of precision to sample weight would be 0.005 or less. Errors in estimates of soil water content from this source should not be more than $\pm$0.2 percent (Gardner, 1965) which would be minor compared to the errors observed. It is not possible to evaluate the contribution of actual weighing or handling errors as compared to that of field sampling variability from these data.

A final point concerns the effect of these errors on estimates of seasonal evapotranspiration computed using gravimetric soil water measurements. One of the methods used involves summing the loss in soil water measured by sampling after one irrigation and before the next (Haider, Farooqi, and de Mooy 1975). Let us assume that 8 samples are taken before and after irrigation and that 5 sampling periods are summed for the final calculation. The expected error variance for each period is 0.5 and for the sum is 0.5 x 5 or 2.5. The 95 percent confidence interval for the sum is then given by:

$$\pm\ 2.0\ (2.5/8)^{\frac{1}{2}} = \pm\ 1.1 \text{ inches}$$

The error from this source in the seasonal measurement is thus of the order of 1.0 inches or perhaps a little more if the measured values are used to extrapolate to periods not covered. Where total ET is estimated in the range of 13 to 18 inches this measurement error may be acceptable. For comparisons based only on 4 samples at each date the expected 95 percent conficence interval would be 1.6 inches.

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Appendix 2

EFFECT OF FLOODING AND DRYING ON THE LOSS OF NITROGEN FROM SOIL

Khalid H. Gill and W. R. Schmehl[1/]

Basin irrigation is the usual irrigation practice in Pakistan. Irrigation water generally is added to a basin until all the soil, including the high spots, is covered. It is commonly assumed that 3 to 4 inches of water is applied per irrigation, but apparently larger quantities are common (Clyma et al., 1975). Where infiltration rates are of the order of 0.1 in. per hr. after the initial wetting of the dry surface soil, the time for the water to enter the soil may be 24 to 36 hr., and the soil may remain near saturation for another 24 to 36 hr. During the 2 to 3 days that the soil is saturated, the redox potential of the soil may drop to a level that will encourage the gaseous loss of nitrate-nitrogen by denitrification. Urea, the nitrogen fertilizer generally used in Pakistan, is a reduced form and is stable in a flooded soil, but it is oxidized rapidly in a well aerated soil by a process called nitrification to give the nitrate form. This may require only a few days or may take a few weeks, depending upon soil temperature and several other factors, but it occurs most rapidly in well aerated soils at moisture contents of about field capacity.

Nitrogen can also be lost by volatilization of ammonia when an alkaline soil containing ammonium-nitrogen salts is air dried. This can occur in the alkaline soils of Pakistan as the surface soil air dries between irrigations. Nitrate-nitrogen is not volatilized by air drying.

The low efficiency in the utilization of fertilizer nitrogen reported for Pakistan has been attributed, at least in part, to leaching of nitrate nitrogen (Kemper, et al., 1975). Since basin irrigation results in a reducing environment in the soil for periods of 36 hr. or more that alternate with periods favorable for nitrification, loss of gaseous nitrogen by denitrification and by ammonia volatilization may be factors involved in the low efficiency of fertilizer nitrogen. The greenhouse experiments reported here were conducted to evaluate the effect of cyclic flooding and drying to simulate field conditions on the growth and recovery of nitrogen fertilizer by sorghum.

1/Graduate Research Assistant and Agronomist, respectively, Colorado State University, Fort Collins, Colorado.

MATERIALS AND METHODS

Two calcareous surface soils from cultivated fields, a silty clay loam, and a sandy loam, were selected for the study. Both soils were low in soil organic matter and in mineral nitrogen at the time of sampling. The soils were air dried, ground to pass a 2-mm sieve, and each soil was mixed thoroughly to insure uniformity of subsamples.

There were six soil treatments - three rates of urea nitrogen (0, 100, and 300 ppm N) and two crop residue rates (0 and 5 metric tons per ha-15 cm). Wheat straw for the crop residue treatments contained 0.5% total N and was ground to pass a 2-mm sieve. Phosphorus and potassium were applied to all treatments at the rate of 50 ppm P and 63 ppm K from KH_2PO_4.

The urea and crop residues were mixed with the soil to give the six soil treatments, then 1 kg of soil for each treatment was placed in each of 15 plastic-lined, cardboard, quart containers. Five moisture-incubation treatments, with three replications each, were imposed on the soil treatments to give a total of 30 treatments per soil. The moisture-incubation treatments were:

D - Soil maintained at field capacity moisture throughout the incubation period (28 days).

$C_1^{\neq}$ - One cycle of flooding and drying, then incubation at field capacity for 21 days.

C_2 - Two cycles of flooding and drying, then incubation at field capacity for 14 days.

C_4 - Four cycles of flooding and drying.

F - Continuous flooding for 28 days.

After the moisture treatments listed above, the soil from all treatments was again removed from the containers, air-dried, ground to pass a 2-mm sieve, and replaced in the respective containers, with careful packing to give approximately uniform bulk densities.

Sorghum (*sorghum vulgare*), variety T.E Yieldmaker, was grown as a test crop. Six seeds were sown in each pot at a depth of one inch. After sowing, each soil was watered to its

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≠ C_1 refers to flooding the soil and maintaining about 1 cm water on the soil for 72 hours, drying for 24 hours, and then maintaining at field capacity for 72 hours. C_2 and C_4 refer to repeating this cycle two and four times, respectively.

field capacity. When germination was complete the plants were thinned to four plants per pot. The pots were weighed periodically and watered to bring the soil back to its field capacity. Insect pests, when observed, were sprayed with Malathion. The clay loam soil was planted on July 28, and the sandy loam on August 6, 1976, and designated as Experiments I and II, respectively. Plants in both experiments were grown for a period of eight weeks, then harvested and placed in weighed paper bags, dried in a forced-air oven at 65° to 70°C for 48 hrs, and weighed for dry matter yield. The dried plant material was ground with a stainless steel Wiley mill to pass a 20-mesh screen. The plant material will be analyzed for total nitrogen.

After harvesting, the roots were removed from the one replication for measurement of dry weight and total nitrogen.

RESULTS AND DISCUSSION

The effect of the moisture and nitrogen treatments on dry matter production of sorghum averaged over crop residues, is summarized in Tables 1 and 2 for the two experiments. There was a marked response to the application of nitrogen for all moisture treatments in both experiments. This would be expected because of the intensive cropping used for the study.

The moisture treatment prior to cropping had a highly significant effect on plant growth. Maximum yields were obtained when the soil was maintained at field capacity during the entire pre-growth period (Treatment D). Yields decreased progressively as the flood-dry cycles increased. With continuous flooding (Treatment F) the yield of sorghum was greater than either the C_2 or C_4 treatments and generally was equal to, or greater than, the C_1 treatment. With increasing number of flooding cycles (treatments D_1, C_1, C_2, C_4) foliar symptoms of nitrogen deficiency increased progressively and suggests that the primary cause for reduced growth was reduced available nitrogen. Nitrogen deficiency symptoms were less on F treatment than on D treatment at comparable levels of fertilizer nitrogen. In Experiment II with the sandy loam there were a few foliar symptoms of manganese toxicity when the soil was flooded continuously and notably at the highest rate of nitrogen, but since these plants also exhibited marked nitrogen deficiency, the principal cause of reduced growth probably was the lack of nitrogen. Plant analyses for total nitrogen are now in progress and the results will help to explain the results.

There was a significant nitrogen by moisture interaction for both experiments. It was caused primarily by relatively less response to 300 ppm N for the C_2 and C_4 treatments in the clay loam and for the C_4 moisture treatment in the sandy loam than for the other moisture treatments.

The incorporation of wheat straw residue caused a reduction in yield of sorghum for all nitrogen levels and for all moisture treatments. For each comparison increased nitrogen deficiency symptoms were noted. Presumably, the high rate of residue immobilized both soil and fertilizer nitrogen and enhanced the deficiency. The residue by nitrogen interaction was significant for sorghum grown in the clay loam but not in the sandy loam. The interaction effects are shown graphically in Figures 1 and 2.

CONCLUSIONS

The results of this study indicate that current basin irrigation practices in Pakistan may cause considerable gaseous loss of nitrogen from the soil. Although it was not possible to differentiate between the loss of nitrogen by denitrification or by ammonia volatilization, it is believed that denitrification was the primary contributing factor. Tharatabhand (1976) found that the same moisture treatments had similar effects in a slightly acid soil. Investigations are needed to evaluate the nitrogen losses under field-type conditions and to devise irrigation practices that will minimize these losses.

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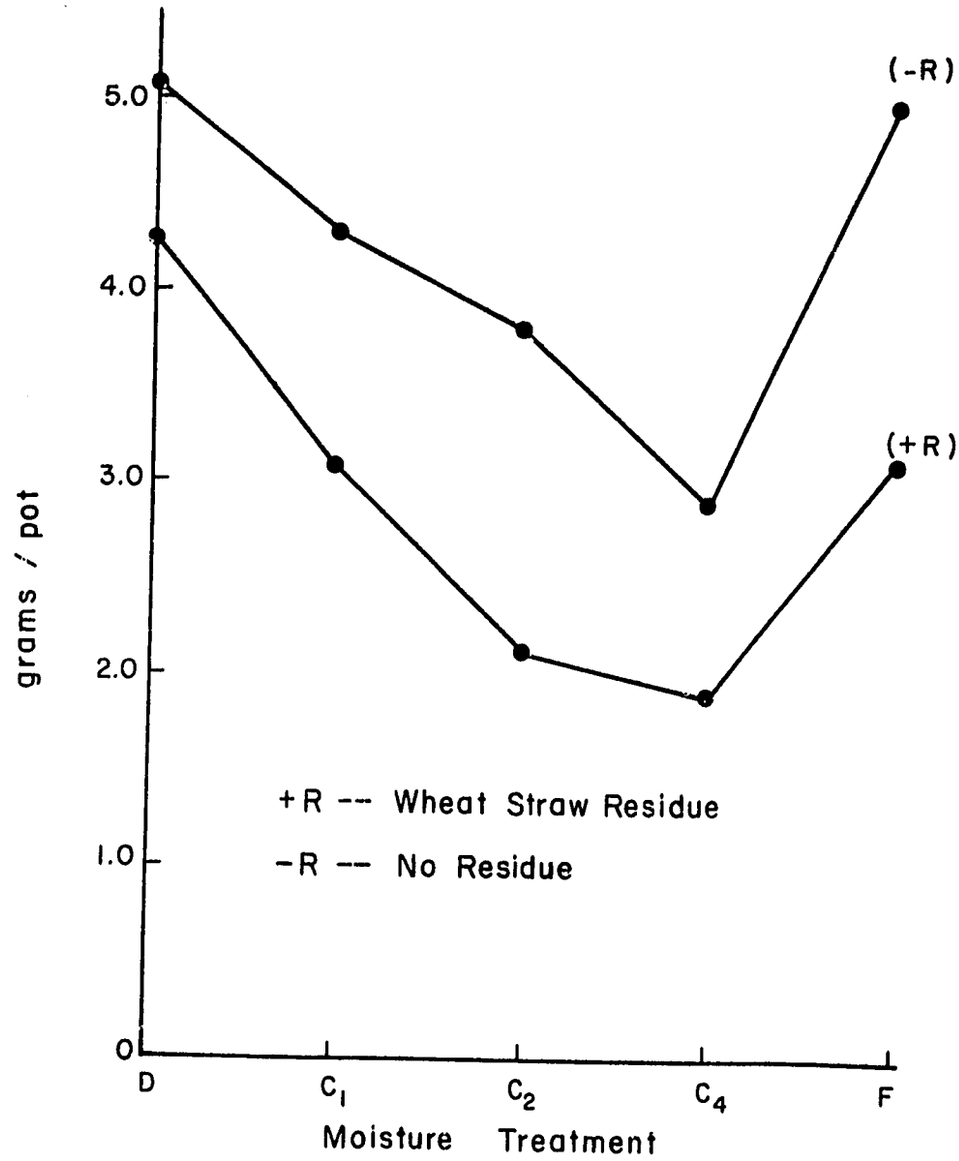

Figure 1. The yield of sorghum as affected by moisture treatment with and without the incorporation of wheat straw. Experiment I.

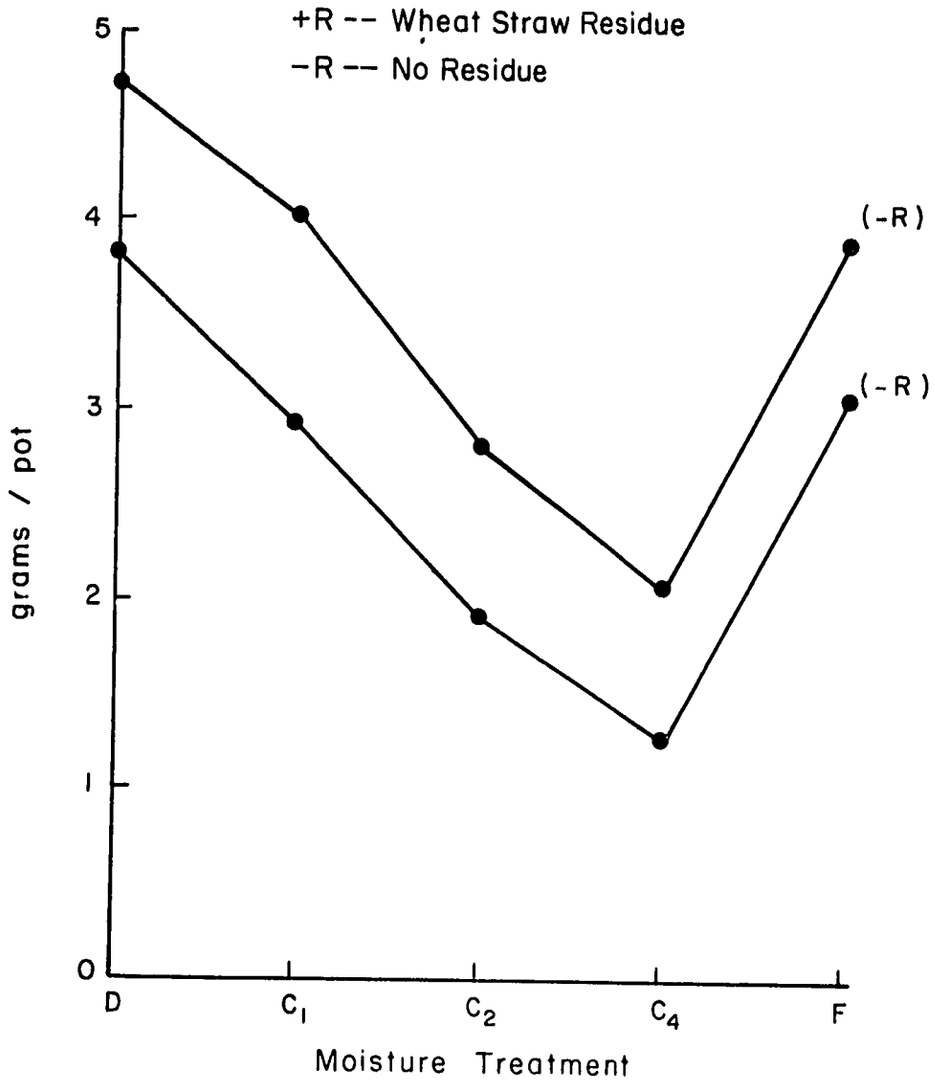

Figure 2. The yield of sorghum as affected by moisture treatment with and without the incorporation of wheat straw. Experiment II.

Appendix 3

EFFECTS OF EXCESSIVE MAGNESIUM IN IRRIGATION WATERS ON WHEAT AND CORN GROWTH

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

INTRODUCTION

In the literature it has been generalized that when Mg exceeds Ca in nutrient and soil solutions, plant growth depression takes place. The cause of this growth depression is currently presumed to be the result of a Mg-induced Ca-deficiency (nutritional imbalance) in the plant. Experimentally, it is relatively easy to demonstrate a nutritional imbalance by the addition of a single Mg-salt to an adequate base nutrient solution with almost any plant species. Mixed salts, as in most irrigation waters, pose a more difficult problem because most plants vary in ability to absorb cations. Cation uptake is related to total cation concentration, also. The effects of high Mg contents in irrigation waters have not been studied and evaluated to any extent. It is necessary to deal with management practices, as well as ion types, ion ratios, and total concentrations.

This report constitutes the results of three separate experiments in which wheat and corn were irrigated with waters that simulate neutral (non-carbonate) compositions predominately of sulfate type in which Mg and Ca ratios were varied. The objectives were to determine Mg concentration levels or Mg:Ca ratios at which growth depression takes place.

MATERIALS AND PROCEDURES

Three concurrent experiments were conducted in the greenhouse using 3 kg of a neutral (non-calcareous) clay loam soil placed in 3.78 l (1 gal) cans in which a copper tube was soldered into the bottom for drainage. The experiments were set up in a randomized block design replicated four times. Corn was grown from September 22 to December 3, 1975 (Experiment I), followed by wheat grown from February 13 to May 13, 1976 (Experiment II). Corn was grown again from July 1 to September 1, 1976 (Experiment III).

Water Compositions and Equilibrations with Soil

Plants were irrigated with waters varying in salinity as well as proportions of Mg. A "check" treatment consisted of

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irrigating with tapwater that had a conductivity of 80 micromhos/cm, an SAR of 0.1, and 20% Mg based on total Ca plus Mg in solution. A total of 18 waters were prepared using three levels of salinity (2, 4, and 6 mmhos/cm) and 6 proportions of Mg:Ca. The Mg:Ca proportions used for corn and wheat in Experiments I and II were: 30, 50, 70, 90, 95, and 100% Mg (percentage based on total me/l of Ca + Mg). The Mg:Ca proportions used to irrigate corn in Experiment III were changed to: 30, 50, 60, 70, 80, and 90%. The 18 waters were adjusted to an SAR of 5. The anions in the simulated waters were predominately SO_4 ions, making up two-thirds of the total anion content and the rest was composed of Cl ions.

Prior to the experiments the soil exchange complex was predominately saturated with Ca. First, concentrated solutions of $MgCl_2$ and NaCl were applied on the soil to replace calculated amounts of Ca that would bring the exchangeable cations into equilibrium with those in the water. Then, the soils were exhaustively leached to reduce the salt level of the effluent solutions as closely as possible to the level of those in the different waters.

Planting, Fertilization, and Irrigation

Six corn seeds were planted in each can for both corn experiments and later thinned to 3 plants per can. Twelve wheat seeds were planted in each can and later thinned to 6 plants. On a soil weight basis, 10 ppm of N (NH_4NO_3) were applied at each irrigation on the corn and wheat. Additional N was applied on the corn during the growth period. Single applications of 50 ppm P ($NH_4H_2PO_4$), 5 ppm Fe (Fe-EDDHA), and 3 ppm Zn (Zn-EDTA) were made on each crop.

The time of irrigation of all cans was based on the amount of depletion by the "tapwater" treatment. All cans were irrigated before 75% moisture was depleted in the "tapwater" cans. A 50% leaching fraction (excess irrigation equal to evapotranspiration) was applied on the corn in Experiment I. A 25% leaching fraction (excess equal to one-half evapotranspiration) was applied on Experiments II and III. Suction was applied at the drain tube, part of the time, to facilitate drainage. The drainage waters were saved for chemical analysis.

Harvesting and Chemical Analyses

The corn plants were harvested at initiation of tasselling. Leaves and stems were harvested and weighed separately from the stems and leaves. All corn leaves and part of the stems were ground after drying. The wheat straw was ground for analysis, also. Subsamples from each ground sample were digested in HNO_3-$HClO_4$ solution. Digested samples were analyzed for Ca, Mg, Na, and K.

The drainage effluents were analyzed for electrical conductivity, pH, Ca, Mg, and Na before planting and after each irrigation.

RESULTS AND DISCUSSION

Wheat Grain and Straw Yields

The grain yield results are shown in Fig. 1 as "relative yields" using the tapwater (check) treatment as 100%. Relative yield is plotted versus the "time-weighted" average of the soil solution conductivity (EC x 10^3) rather than water conductivity in order to more closely reflect the average of the root zone during the experiment. The average EC x 10^3 of the soil solution was calculated as a simple average of effluent conductivity at the end of equilibration before planting and the effluent conductivity after each irrigation, time-weighted to reflect different time intervals between irrigations. The numbers on the left of each series of data points represent the Mg/Ca+Mg percentage in the water and those to the right of each data point represent the weighted average Mg/Ca+Mg percentage calculated for the soil solution. When the Mg percentages in water are low, the soil solution Mg percentages generally are higher than those in the water. This is probably caused by solution concentration and precipitation of Ca as gypsum. When the Mg percentages in the water are highest, the soil solution Mg percentages are lower than those in the water. This is caused by slow release of Ca from exchange sites or from organic matter.

The tapwater (check) grain yields were significantly lower than those yields obtained with the 50% Mg/Ca+Mg treatment. The opposite was true for straw yields, however (Fig. 2). Thus, the differences in yields appear to be related to total growth, reflected in straw grain ratios. The 30% Mg treatment resulted in somewhat lower yields than the 50% Mg treatment, also.

It appears from the data in Fig. 1 that grain yield depression is initiated when Mg in the soil solution is greater than about 55-65% in relation to Ca+Mg. Total uptake of both Ca and Mg increased as the soil solution concentrations increased, but yield depression appears to be more closely related to Mg/Ca uptake proportions (Fig. 3). A significant interaction between Mg:Ca proportions and increased salinity appears to occur when soil solution Mg is about 90%. Severe grain yield depressions occurred when the Mg content was in this range. Strikingly visible Ca-deficiency symptoms on grain heads were visible on these treatments.

Relative grain and straw yields are compared in Fig. 2. Grain and straw yields did not respond in the same manner with respect to Mg and salinity treatments. The tapwater treatment

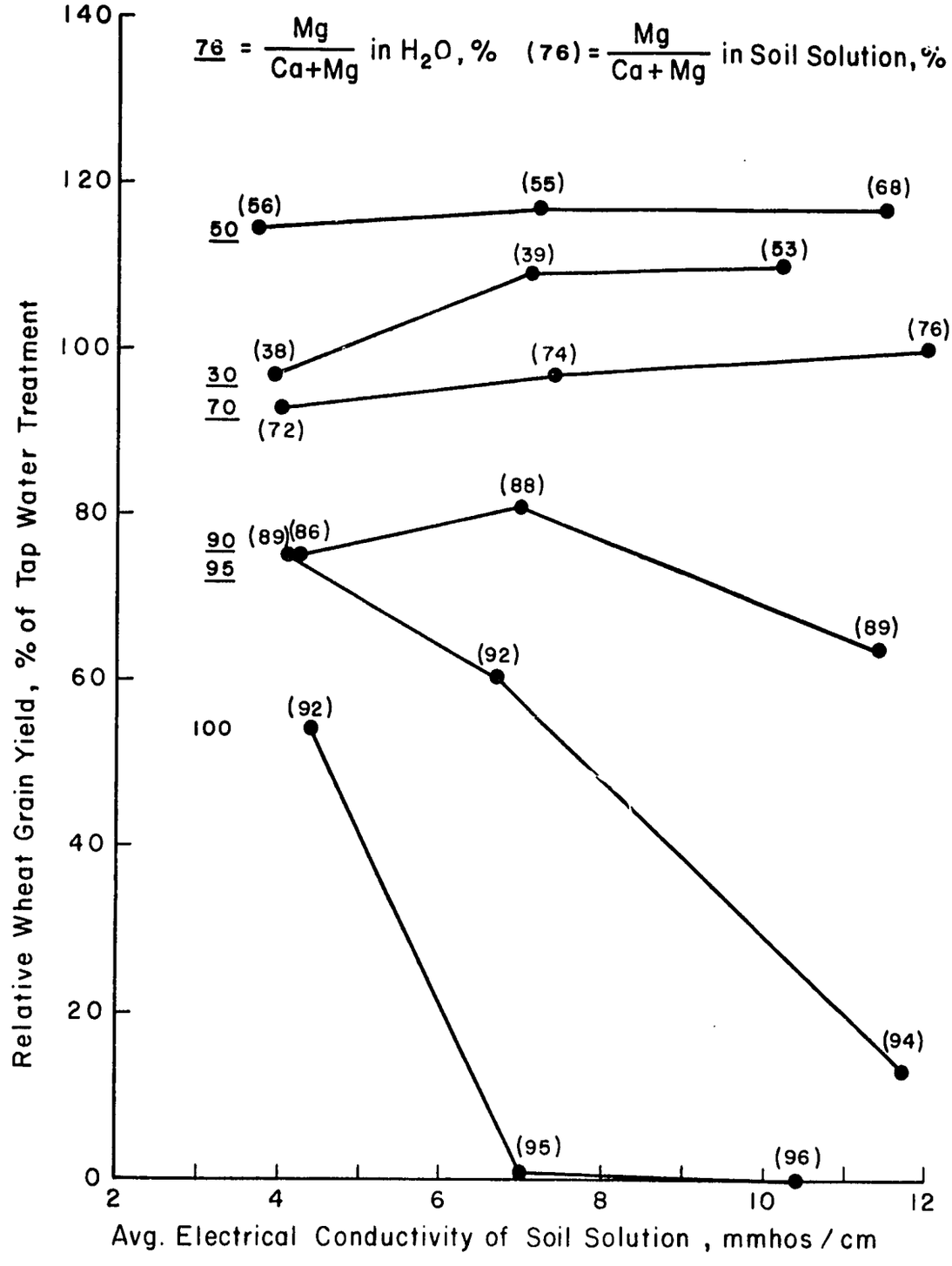

Figure 1. Relationships between relative grain yield, soil solution conductivity and Mg/Ca+Mg percentages.

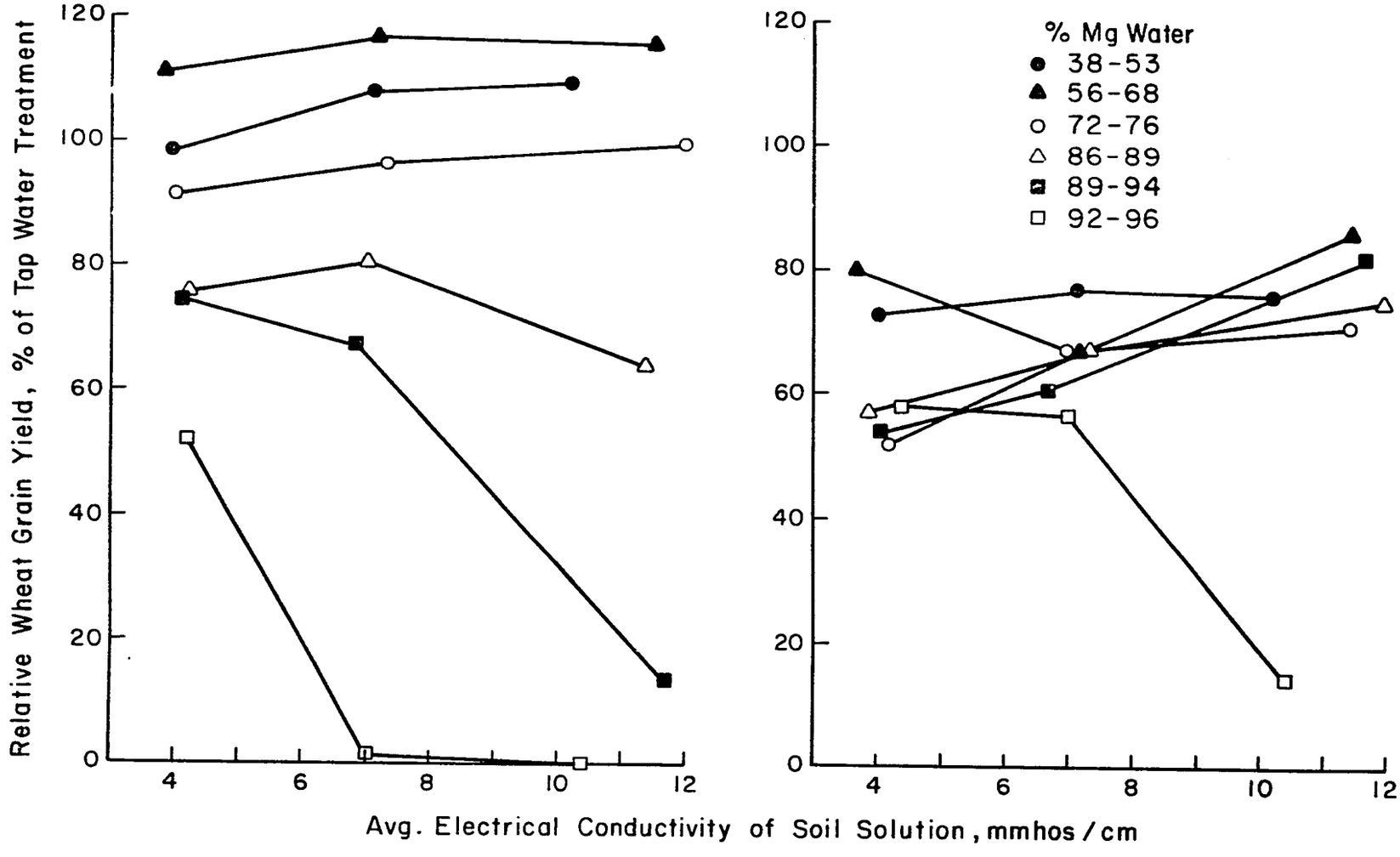

Figure 2. Relationships between relative wheat straw and grain yields.

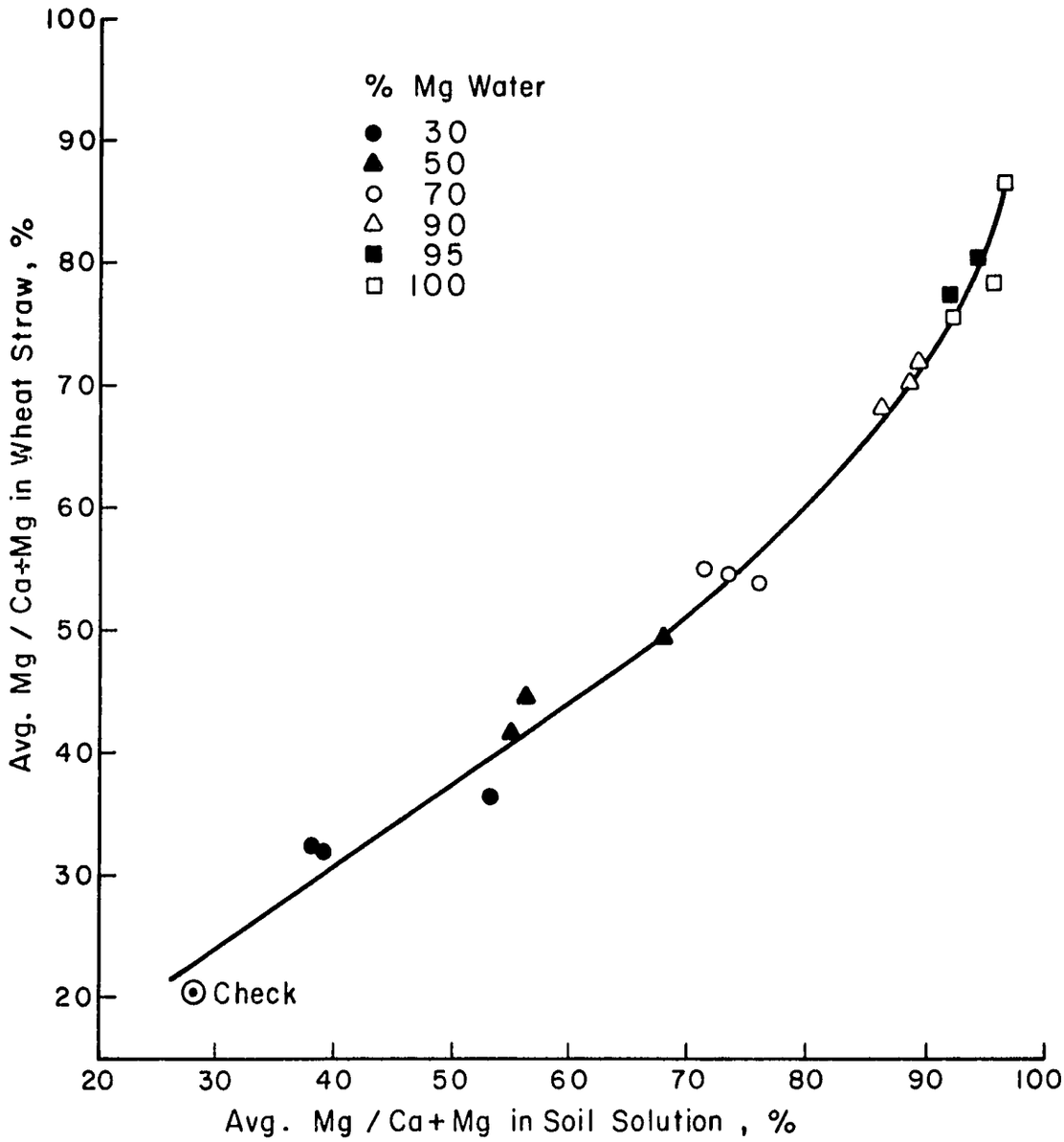

Figure 3. The relationship between Mg/Ca+Mg in the soil solution and in the wheat straw.

produced the largest average number of tillers and, consequently, the highest yield compared with average tillers produced for a given salinity level. High levels of Mg and increasing salinity levels stimulated tiller development. Thus, except for the 100% Mg treatment, straw yields were not decreased by increasing salinity. In most cases, straw yields increased as water salinity increased. Stimulation of tillering with increased salinity has been noted in other studies.

Corn Yields

The relative corn dry matter yields for Experiments I and III are shown for comparison in Fig. 4. Experiment I was conducted during the winter and III was conducted during the summer period. Except for the 100% Mg/Ca+Mg water at EC = 6 mmhos/cm, no significant effects of Mg or salinity levels were found. The yields, in g/can, were about one-third of those found in Experiment III.

In Experiment III all yields were significantly lower than the tapwater check treatment. Salinity at the EC = 6 mmhos/cm significantly reduced yields. It should be noted that the salinity levels in the soil solution were about twice those in Experiment I as a result of using a 25% leaching fraction instead of 50%. Also, the 90% Mg/Ca+Mg water at EC = 4 and 6 mmhos/cm significantly reduced corn yields.

Relationships between corn leaf and soil solution Mg/Ca+Mg percentages in both experiments are shown in Fig. 5. The results for both experiments appear to be fairly consistent. Mg absorption increases as the proportion in the soil solution increases. The relation in Experiment III is more curvilinear at higher values than in I. Total absorption of Ca and Mg differed between the experiments, however. In Experiment I the total Ca and Mg absorbed by the leaves did not change as the total salinity content of the water increased, whereas the reverse was true for Experiment III.

A significant Mg-salinity interaction for reduced corn TDM appears to occur at about an 85-95% Mg/Ca+Mg in the soil solution. This is similar to the 90% value found for initiation of severe growth depression for wheat grain. Also, it appears that very high Mg percentages and high salinity contents of the soil solution are necessary to reduce corn dry matter yields with neutral (non-bicarbonate) waters. It is possible that corn grain yields may undergo greater grain yield depression than dry matter, similar to wheat. However, it was not feasible to mature corn grain in the greenhouse. It is very probable that greater yield depressions of both dry matter and grain will be found with predominately bicarbonate waters.

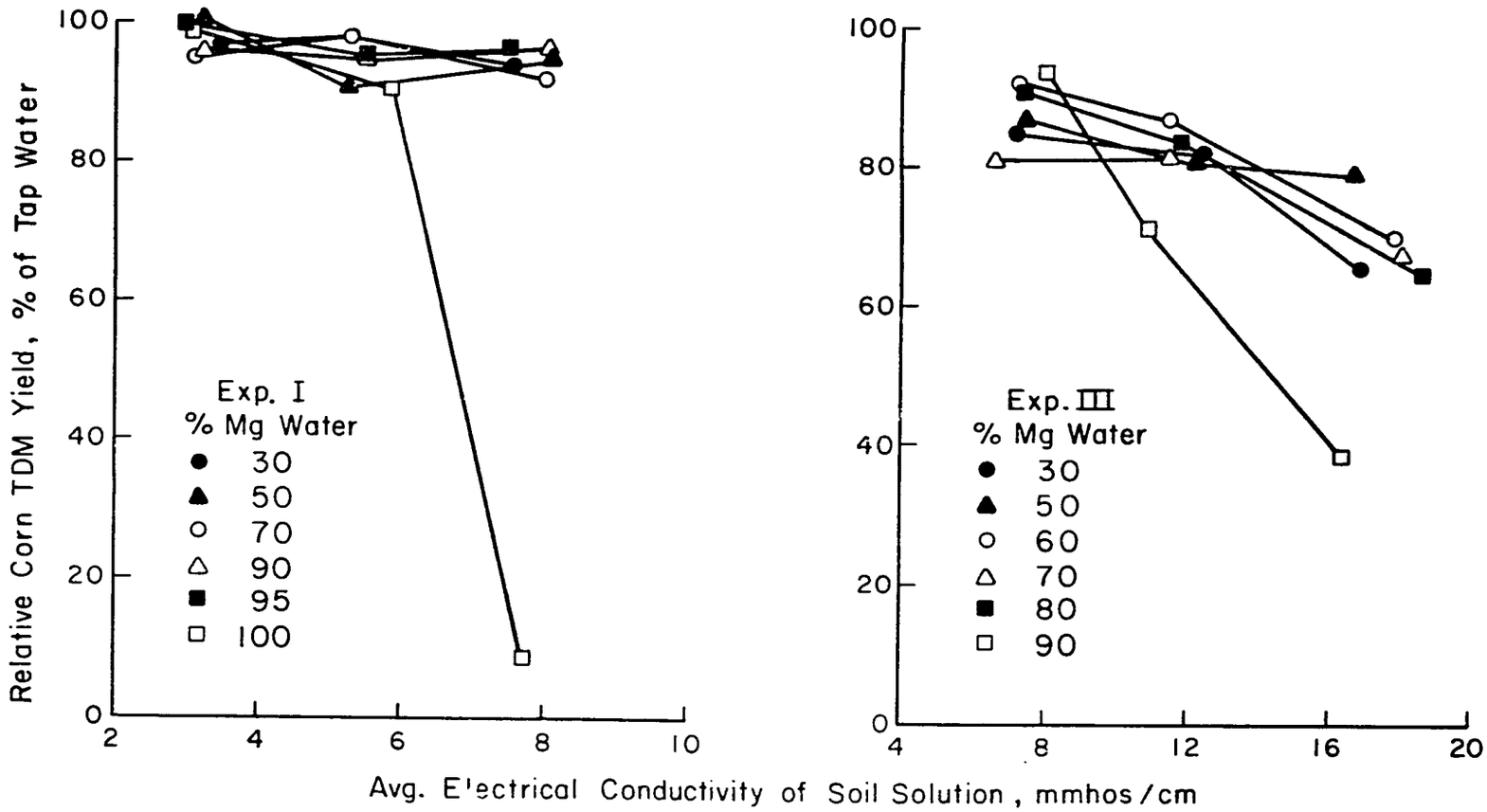

Figure 4. Relationships between soil solution conductivity, Mg/Ca+Mg in soil solutions and relative corn TDM yield for experiments I and III.

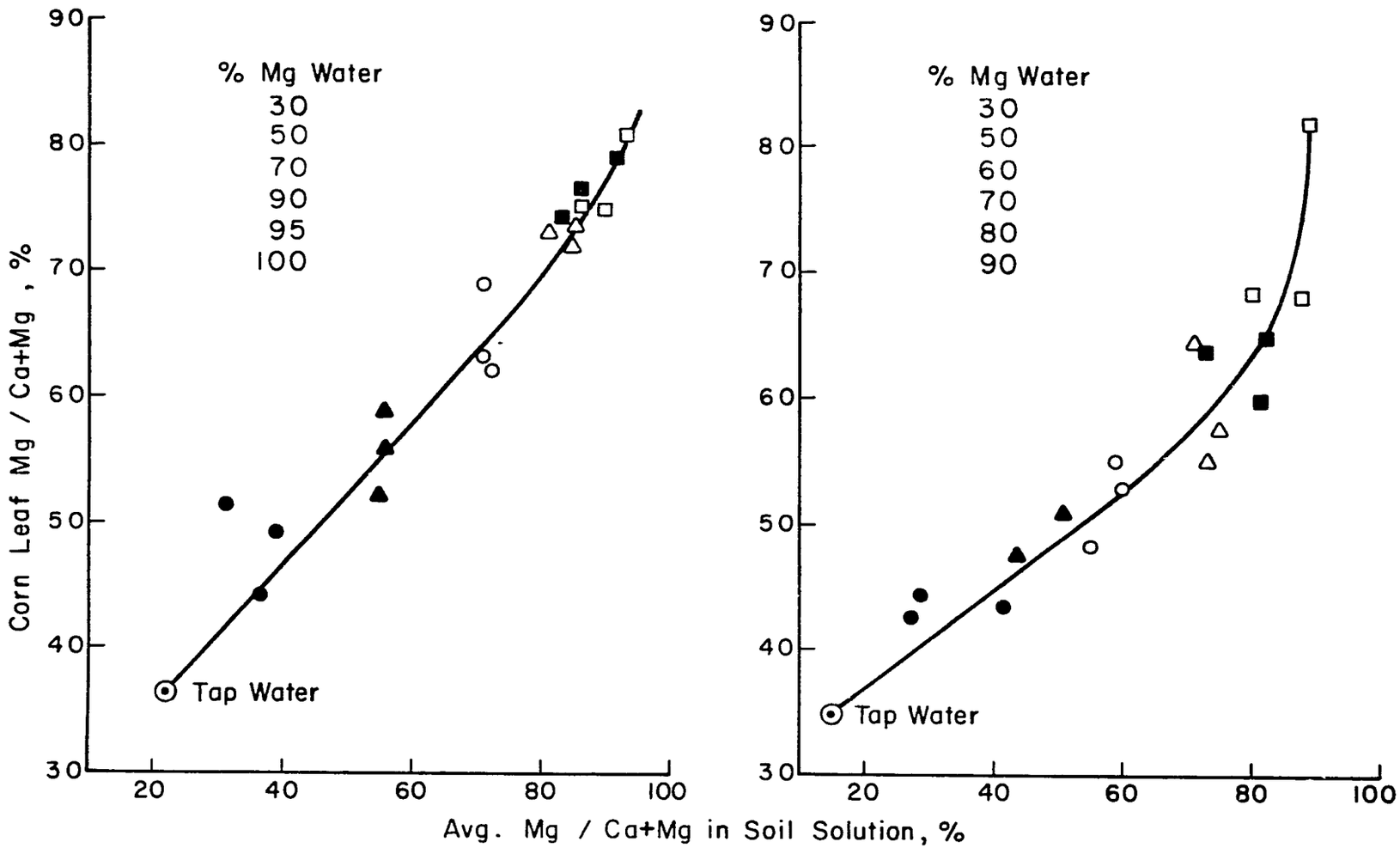

Figure 5. The relationship between Mg/Ca+Mg in soil solutions and leaf composition in experiments I and III.

Appendix 4

SOIL CEMENT BLOCKS FOR WATERCOURSE CONSTRUCTION AND SEDIMENT UTILIZATION[1]

W.D. Kemper and Moh'd Akram[2]

Purpose of Study

Sediment cleaned from watercourses is commonly piled beside the watercourse taking valuable land out of product on. Traps (wide and deepended sections of the watercourse) can be constructed which decrease the velocity of the water and allow most of the sediment to settle on the bottom of that section.

Inexpensive building materials are needed in the rural areas of Pakistan. One type of material used for this purpose has been soil cement brick in which cement is mixed with soil at ratios of about 1 to 8 or less. The mixture is moistened with water and compressed to about 70 percent of its loose volume in a press. The resulting blocks are then cured by watering every few hours for a few days. They are then used for construction purposes although, like most cement products, they do not reach their maximum strength until they have been aged for several months.

One of the most time consuming operations in the manufacture of these blocks is the screening of the soil and subsequent mixing of this soil with the cement to obtain a uniform mix. The sediment cleaned from watercourses is high in fine sands and silt and breaks easily into an almost monograin powder. It takes only about half as long to prepare this soil for use in soil cement blocks as to prepare finer textured soils which have stable aggregates. In general, farmers who are trying to maintain a watercourse would be glad to have this sediment removed. If the resulting blocks have a strength comparable to those made from the finer textured soils the possibility will exist for

[1]Research report from the Mona Reclamation Experimental Project, WAPDA and the Colorado State University Water Management Research Team. Portions of this work were supported by USAID/Pakistan, Agreement No. 204-75 and by USAID/Washington Research Contract No. AID/TA-c-1100. Appreciation is expressed to Mr. M.A. Niazi, JRO who determined the percent sand, silt and clay in the soil and sediment, and to CARE/Pakistan staff who furnished instruction and the presses for making the blocks.

[2]CSU Party Chief and MREP Jr. Agr. Engineer, respectively.

developing micro industries preparing soil cement blocks at sediment traps near the head of watercourses.

This study evaluates strength and other physical characteristics of block made from soil and watercourse sediment and the rate of water seepage from watercourses constructed from this type of block.

Procedures

Sediment was taken from the accumulated pile along the bank of a watercourse, was screened through an eight mesh screen, mixed 8 parts to 1 with cement, and was moistened with water until the mixture formed a firm ball when squeezeed in a person's hand. This loose material was then used to fill a con-va-ran compression machine which compresses this soil to about 60 percent of its loose volume. The resulting 12 inch by 6 inch by 4 inch blocks were then removed from the compressor, stacked and wetted about four times a day and the blocks were then allowed to dry for about a week. At the end of this time some of the blocks were placed in water and left there for a week. At the end of this time 3 of the wet and 3 of the dry blocks were selected at random for strength testing.

The test consisted of supporting the 12 inch long block on two 3/4 inch OD pipes held parallel to each other with centers 10 inches apart. Another 3/4 inch OD pipe was then laid across the middle of the top of the block and weight was loaded on a platform supported by this pipe until the test block on the pipe support block broke.

This same general procedure for constructing, curing and testing the block was used beginning with soil taken from an adjacent field where the soil has considerably more finer textured particles. This soil was in the texture range normally considered satisfactory for the construction of soil cement block.

The percent sand, silt and clay were determined using the hydrometer method.

After thorough drying, three blocks from each material were weighed, immersed in water and weighed again after 5 days of soaking. This data was used to determine the block densities and water sorption (or porosity).

Blocks were constructed in the manner described above of loam soil at Bonni village. These blocks were then used by local masons to construct a section of watercourse through this village. The section was rectangular in cross-section with inside dimensions 20" wide and 28" deep. Walls were 6" (one block) thick and the floors were 4" thick (depth of one block). Fine sections were treated as follows:

Section 1: 56 feet long made of blocks containing 1:6 cement:soil mixture

Section 2: 41 feet long, made of blocks with 1:8 mixture and all inside walls plastered with 1:3 cement: sand plaster (about 0.4" thick)

Section 3: 40 feet long, made of 1:8 blocks with no plaster

Section 4: 42 feet long, made of 1:8 blocks with 0.4" thick plaster on inside walls. Plaster was 1:3 cement to sand mix with _____cc of concentrated sodium silicate per 100 lbs of cement sand mix.

Section 5: 50 feet long made of 1:8 blocks with no plaster.

Seven months after these sections were constructed they were separated by compacted earth bunds, 2 feet thick, filled with water, and the rate at which the water surface receded was measured to determine their leakage rate.

Results

As anticipated, it took about twice as much labor to prepare the soil from the field for making the blocks as to prepare the soil that was taken from the pile of water-course sediment. When the blocks were taken out of the press, the blocks made from the sediment were obviously more fragile and had to be handled more carefully as they were lifted off the press and stacked. However, the transfer was still possible and less than 1 percent of the blocks broke in the process of transfer. At this stage of the block construction the cohesiveness of a block is the result of the natural cohesiveness of the soil material when it is in a moist condition. Blocks made of soil with a higher clay content are more cohesive at this stage.

However, as indicated in Table 1, when the blocks have been cured and dried, giving the cement time to bond the particles together, blocks made of the sediment had considerably more strength than the block made of the loam soil. This may be a result of a smaller number of surfaces between particles in the sediment blocks which generally have a larger particle size.

Table 1. Force (pounds) Required to Break 6" x 4" x 12" Blocks

	Loam Blocks		Sediment Blocks	
	Dry	Wet	Dry	Wet
Block 1	510	220	880	300
Number 2	420	140	560	220
Number 3	450	110	880	290
Average wt. to break (lbs.)	460	157	773	270

After the blocks had been soaked in water for a week the average strength of these wet blocks decreased to about 35 percent of the strength of dry blocks made from the same material. This is shown graphically in Figure 1 in which the modulus of rupture of the blocks in pounds per square inch is plotted for the dry and wet blocks made of each of the two test soil materials. A modulus of rupture (R) was calculated from the weight (W) applied to break the block from the equation

$$R = 3 \times W \times L/(2 \times B \times D^2),$$

where R is given in pounds per square inch when the weight is given in pounds, the length of a block (L) is given in inches, the breadth of the block (B) is given in inches and the depth (D) is given in inches. A strength criteria commonly used in building materials is that the material should have a modulus of rupture at least 50 pounds per square inch.

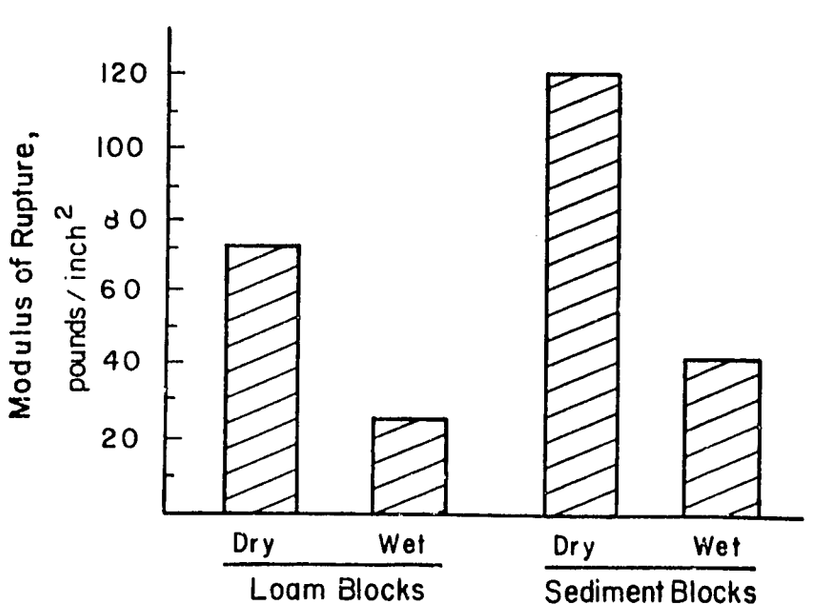

Figure 1. Modulus of Rupture of Soil Cement Blocks.

It is probable that the strength of these blocks would have been increased had they been cured for an extended length of time. It is also likely that the soaked wet blocks will regain their original strength when they dry again although this was not tested in this limited study.

The texture of the soil and sediment are given in Table 2, and the density and water sorption characteristics (percent volume) of these blocks are shown in Table 3.

The sediment has much less clay than the soil. This shortage of small particles to fit in between larger particles results in the sediment blocks having higher porosities and lower densities than the soil blocks.

Table 2. Textural Composition of Soil and Sediment

Material	Composition % Sand	% Silt	% Clay	Textural Classification
Soil	43	35	22	Loam
Sediment	51	43	6	Sandy Loam
Banni Village Soil	44	53	3	Silt Loam

Table 3. Cement Block Density and H_2O Sorption when made of Sediment and Soil

Block Composition	Density Gram/cc	Water Sorption in 5 days cc/cc
Cement:Soil	1.80*	.35
Cement:Sediment	1.75*	.39

*Volume of blocks = 4000cc

Since the sediment blocks are stronger than the soil blocks, it is apparent that strengths of bonds between surfaces are more important in determining block strength than is the density.

Examination of the soil cement blocks in the watercourse section seven months after construction indicates that erosion of the exposed blocks by the flowing water has been negligible. Water flows through this channel for about 9 hours, once a week at an average velocity of about one foot per second.

The losses from the five sections of this soil cement block watercourse are shown in Table 4.

There was only one replicated treatment which was the 1:8 cement to soil ratio with no plastering which was common to sections 3 and 5. The difference between 0.035 and 0.087 cusecs loss per 1000 feet is probably caused by difference in texture and packing of the surrounding soil in addition to the differences in the masonry.

Table 4. Loss rate from rectangular watercourse 20" wide and 30" deep made of soil cement blocks with the indicated cement:soil ratios and plaster.

Section Number	Blocks Cement: Soil Ratio	Plaster (Cement sand at 1:3 ratio)	Surface Recession Rate cm/50min ft/sec	Loss Rate Cusecs / 1000 ft.
1	1:6	None	49.2×10^6	0.082
2	1:8	0.4"	2.4 "	0.004
3	1:8	None	52.2 "	0.087
4	1:8	0.4"*	1.0 "	0.002
5	1:8	None	20.6 "	0.035

*Treated with sodium silicate

There was only one replicated treatment which was the 1:8 cement to soil ratio with no plastering which was common to sections 3 and 5. The difference between 0.035 and 0.087 cusecs loss per 1000 feet is probably caused by difference in texture and packing of the surrounding soil in addition to the differences in the masonry.

The sodium silicate was added to the plaster to reduce its water permeability, and comparing loss rates in sections 2 and 4 it appears that this treatment has reduced the rate of flow. However, the lack of replication prevents a positive statement in this respect. The significant difference in this test is the reduction from an average water loss rate of 0.068 to 0.003 cusecs/100 feet, caused by plastering the walls of the masonry.

This difference is a result of the porous joints common to most masonry construction in Pakistan. The Pakistani mason uses much drier mortar than masons in the U.S. and Canada. This drier mortar does not flow and fill in the whole space between bricks as a brick is pressed down on the mortar. Consequently, there are many small holes in the normal Pakistani brick walls, that are blocked only when the joints are "pointed", or when the walls are plastered. Holes in the bottom of these watercourses are soon filled with sediment and the water passing through them is fairly small. However, holes in the vertical sides of brick watercourses remain open and transmitting water rapidly. To obtain a comparison the rapidly of leakage through these holes, the leakage from the unplastered segments of this watercourse may be compared with the leakage from the newly constructed earthen portions of D Branch of TW 78 watercourse. The average water loss in successive sections of D Branch were 0.08, 0.07, 0.08, 0.06, 0.23, and 0.09 cusecs per thousand feet. Except for the leaky 5th section of D watercourse, the average loss was 0.076 cusecs per 1000 feet which is close to the 0.068 loss taking place through the unplastered segments of this cement block watercourse. In

other words, construction of a brick or cement block watercourse may not reduce water losses below those on an earthen improved watercourse unless the joints are pointed, or the insides of the walls are plastered.

The cost of mortar and labor for plastering is about Rs 10/cf of 1:3 mix and a watercourse with wells 2.5' high and an inside width of 2.0 feet will require 0.22 cubic feet of mortar per linear foot of watercourse to form a plaster layer 0.4 inches thick. The cost of the plaster layer will be about Rs 22 per linear foot or Rs 2,2000 per 1000 feet. If this plaster layer lasts for 10 years and saves 0.068-0.003 cusecs of water for 300 days each year, the savings will be 390 acre feet of water.

Thus, the cost of the water saved in a main channel watercourse (flowing 300 days/year will be 2200/390 + Rs 5.7/ acre foot.

If the watercourse carries water only about 10 hours per week (as this one does at Banni Village) the plastering will save about 27 acre feet of water in 10 years and the cost of the water saved will be 2200/27 = Rs 82 which is near the cost of tubewell water delivered to the field (Rs 100/acre foot).

Since the main cost of the plaster is the materials cost, and the soil cement blocks themselves are not eroding, another section should be constructed and tested for leakage where the masons do a careful job of "pointing" the joints. This may be able to prevent most of the leakage at a small fraction of the cost of plastering.

Conclusions

The strength of blocks made from watercourse sediments, composed predominately of fine sand and silt was not only equal to the strength of blocks made from soil with a larger amount of fine particle material but was greater. This plus the lower labor costs involved in preparing the sediment for the blocks indicate that watercourse sediment is a superior material for making soil cement blocks. Sediment traps built on a watercourse at stretches which are accessible to roads can provide several thousand cubic feet of sediment per year and the farmers owning land adjacent to the watercourse are generally pleased to see this sediment removed and thereby reduce its encroachment upon their lands.

The soil cement blocks are resistant to erosion at normal watercourse flow velocities. Plaster on the surfaces of soil cement block reduces leakage from 0.068 to 0.003 cusecs/1000 ft, but this appears to be a matter of plugging holes in the mortar between the blocks. It appears that

these soil or sediment-cement blocks can be used for lining watercourses, or for watercourse structures where they will be subjected to frequent wetting and drying.

Appendix 5

WATER LOSS MEASUREMENTS ON WATERCOURSE[1] 50440L (TUBEWELL 51)

M. Azeem Cheema, M. Akram, M. Yasin, and S.A. Bowers[2]

INTRODUCTION

The effectiveness of watercourse renovation is primarily based on water loss measurements both before and after improvement. As explained in an earlier paper (1) the evaluation procedure consists of measuring, with cutthroat flumes, the inflow and outflow in a particular channel section and defining the discharge difference as water loss.[3] In continuing the watercourse renovation study initiated in 1975 jointly by CSU and the Mona Reclamation Experimental Project the decision was made to renovate watercourse 50440L (TUBEWELL 51) (Figure 1) of the Scarp II area near Bhalwal, Pakistan. The below is a summary of the water loss measurements made on this watercourse.

PROCEDURE

Cutthroat flumes (12" x 3') were installed near the head of the watercourse and at various distances downstream. The upper flume was placed at a distance 1080 ft. from the mogha in order to prevent mogha submergence and a loss of irrigation water to the farmer. The difference in discharge between any two consecutive flumes was equated to the loss occurring in that enclosed section. Such losses were expressed as total cusecs lost, loss/1000 ft., percent loss/1000 ft., and the percent delivery efficiency (E_d).

Loss measurements were made both before and after renovation. Based on the experience of TW 56 (1) flumes were installed at the same locations. Since loss is a function of distance comparisons between measurement sets are simplified when conveyance distance is maintained constant.

When feasible predictive loss equations as a function of initial flow rate were computed over fixed conveyance distances. Equations were computed for both the "before" and "after" measurements and comparisons made by solving for

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[1]Cooperative study between Mona Reclamation Experimental Project, WAPDA and CSU Field Party.

[2]Assistant Agricultural Engineers, WAPDA, Assistant Agricultural Engineer, CSU, and CSU advisor respectively.

[3]Loss here is defined as both seepage and wastage.

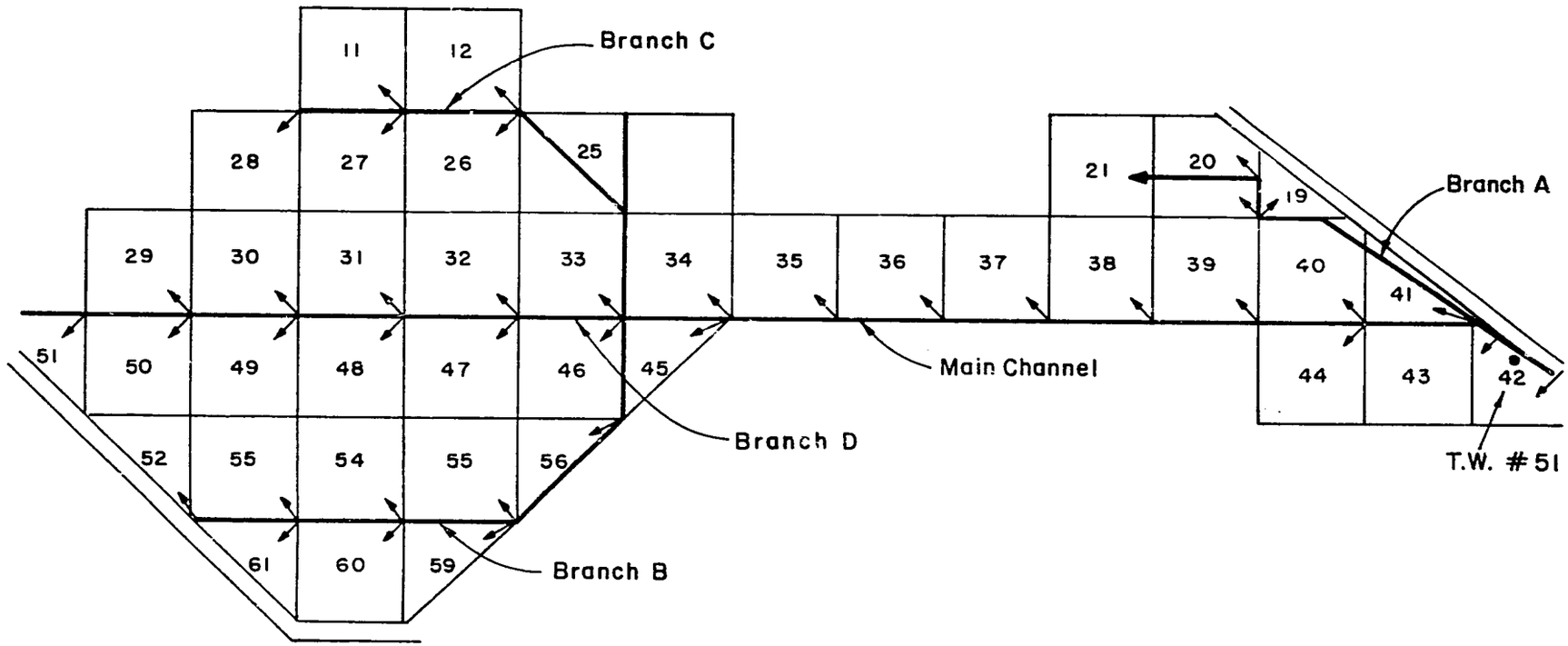


Figure 1. Watercourse 50440-L(TW-51).

common initial flow rates. Where data was insufficient to develop such equations loss comparisons were made, for fixed distances, between those "before" and "after" measurements whose initial flow rates were closest in magnitude. For the whole watercourse weighted averages of initial flow rate, loss, and conveyance distance was used to estimate the improvement due to renovation.

RESULTS AND DISCUSSION

Tables 1 and 2 respectively list the "before" and "after" loss measurements. The "before" data indicates that the main channel was a relatively efficient water conveyor. For a distance of 8433 ft. the average percent loss/1000 ft. was 3.06 percent, the average delivery efficiency was 74.2 percent, and the average initial flow rate was 4.07 cusecs. It had been observed on TW 56 (1) that the main channel was also efficient as a water conveyor. Such efficiency without improvement was attributed, but without verification, to the almost constant flow in these channels. It was assumed that constant flow and bank saturation retards development of plant, insect, and rodent populations which promote bank porosity and seepage losses. This argument probably holds true for this main channel on TW51 since it carries water 93 percent of the time.

From the "before" data of Table 1, the following loss equation for a fixed distance of 8433 ft. was developed.

$$\text{Loss(cusecs)} = 0.2206e^{0.3576Q_i} \qquad (1)$$

$$r^2 = 0.7827$$

where Q_i = initial flow rate in cusecs.

While a linear regression allows a slightly better fit of the curve to the data points previous analysis and experience indicates that the relationship of loss to initial flow rate is curvilinear.

The "after" loss measurements for the same 8433 ft of main channel show the following relationship between loss and initial flow rate

$$\text{Loss(cusecs)} = 0.04974e^{0.5116Q_i} \qquad (2)$$

$$r^2 = 0.9832$$

Figure 2 shows the plot of equations 1 and 2. By solving these before and after predictive equations for particular initial flow rates the loss decrease due to improvement can be calculated. The results are shown in Table 3. Although the data show the main channel was an efficient water conveyor before improvement renovation did decrease losses by 75 percent to 43.4 percent (Table 3).

Table 1. "Before" Loss Measurement (Cusecs) on Watercourse 50440-L (TW-51)

No.	Date	Inital Flow	Final Flow	Loss	Distance (ft)	Loss 1000 ft	% Loss 1000 ft	E_d %	Water Source
					MAIN				
1	5-6-76	2.05	1.35	0.70	8430	0.08	4.05	65.9	Canal
2	5-8-76	4.80	3.31	1.49	8430	0.18	3.68	69.0	TW+Canal
3	5-11-76	5.36	3.84	1.52	8430	0.18	3.36	71.6	TW+Canal
4	5-13-76	5.45	3.50	1.95	1320	1.48	27.1	64.2	TW+Canal
5	5-14-76	2.98	2.60	0.38	5270	0.07	2.42	87.2	Canal
6	5-15-76	3.06	2.45	0.61	8430	0.07	2.36	80.1	Canal
7	5-16-76	2.60	2.25	0.35	8430	0.04	1.60	86.5	Canal
8	5-10-76	5.60	3.95	1.65	8430	0.20	3.49	70.5	TW+Canal
9	5-23-76	5.00	3.80	1.20	8430	0.14	2.85	76.0	TW+Canal
					BRANCH A				
10	5-21-76	3.05	2.90	0.15	5000	0.03	0.89	95.1	Canal
					BRANCH B				
11	5-16-76	2.40	1.90	0.50	4227	0.12	4.93	79.2	Canal
12	5-23-76	3.80	3.50	0.30	2860	0.10	2.76	92.1	TW+Canal
					MAIN + BRANCH B				
13	5-23-76	5.00	3.50	1.50	12660	0.12	2.37	70.0	TW+Canal
					BRANCH C				
14	5-10-76	3.95	1.84	2.11	5060	0.42	10.56	46.6	TW+Canal
					MAIN + BRANCH C				
15	5-10-76	5.60	1.84	3.76	11760	0.32	5.71	32.9	TW+Canal
					BRANCH D				
16	5-11-76	3.84	3.15	0.69	2860	0.24	6.28	82.0	TW+Canal
17	5-26-76	4.30	3.20	1.10	4070	0.27	6.28	74.4	TW+Canal
					MAIN + BRANCH D				
18	5-11-76	5.36	3.15	2.21	12500	0.18	3.30	58.8	TW+Canal
19	5-26-76	4.60	3.20	1.40	12500	0.11	2.43	69.6	TW+Canal

Table 2. "After" Loss Measurements (Cusecs) on Watercourse 50440-L (TW-51).

No.	Date	Initial Flow	Final Flow	Loss	Distance (ft)	Loss 1000 ft	% Loss 1000 ft	E_d %	Water Source
				MAIN					
1	10-28-76	5.73	4.83	0.90	8430	0.11	1.86	84.3	Canal+TW
2	10-27-76	5.73	5.10	0.63	5270	0.12	2.09	89.0	Canal+TW
3	10-29-76	2.81	2.62	0.19	5270	0.04	1.28	93.2	Canal
4	10-29-76	2.81	2.60	0.21	8430	0.02	0.89	92.5	Canal
5	11-1-76	5.95	4.75	1.20	8430	0.14	2.39	79.8	Canal+TW
6	11-1-76	5.95	5.01	0.94	8430	0.11	1.87	84.2	Canal+TW
				BRANCH A					
7	11-2-76	5.70	3.15	2.55	2580	0.99	17.3	55.3	Canal+TW
				BRANCH B					
8	10-29-76	2.70	2.40	0.30	4230	0.07	2.63	88.9	Canal
				MAIN + BRANCH B					
9	10-29-76	3.05	2.40	0.65	12660	0.05	1.68	78.7	Canal
				MAIN + BRANCH C					
10	10-30-76	6.20	2.90	3.30	11760	0.28	4.53	46.8	Canal+TW
				BRANCH D					
11	11-1-76	5.01	4.34	0.67	4070	0.16	3.29	86.6	Canal+TW
				MAIN + BRANCH D					
12	11-1-76	5.95	4.34	1.61	12500	0.13	2.16	72.9	Canal+TW

Table 3. "Before" and "After" Losses in Main Channel (Cusecs) and Loss Decrease Due to Improvement

Initial Flow	"Before" Loss	"After" Loss	Loss Decrease	% Decrease
1	0.32	0.08	0.24	75.0
2	0.45	0.14	0.31	68.9
3	0.64	0.23	0.41	64.1
4	0.92	0.39	0.53	57.6
5	1.32	0.64	0.68	51.5
6	1.89	1.07	0.82	43.4

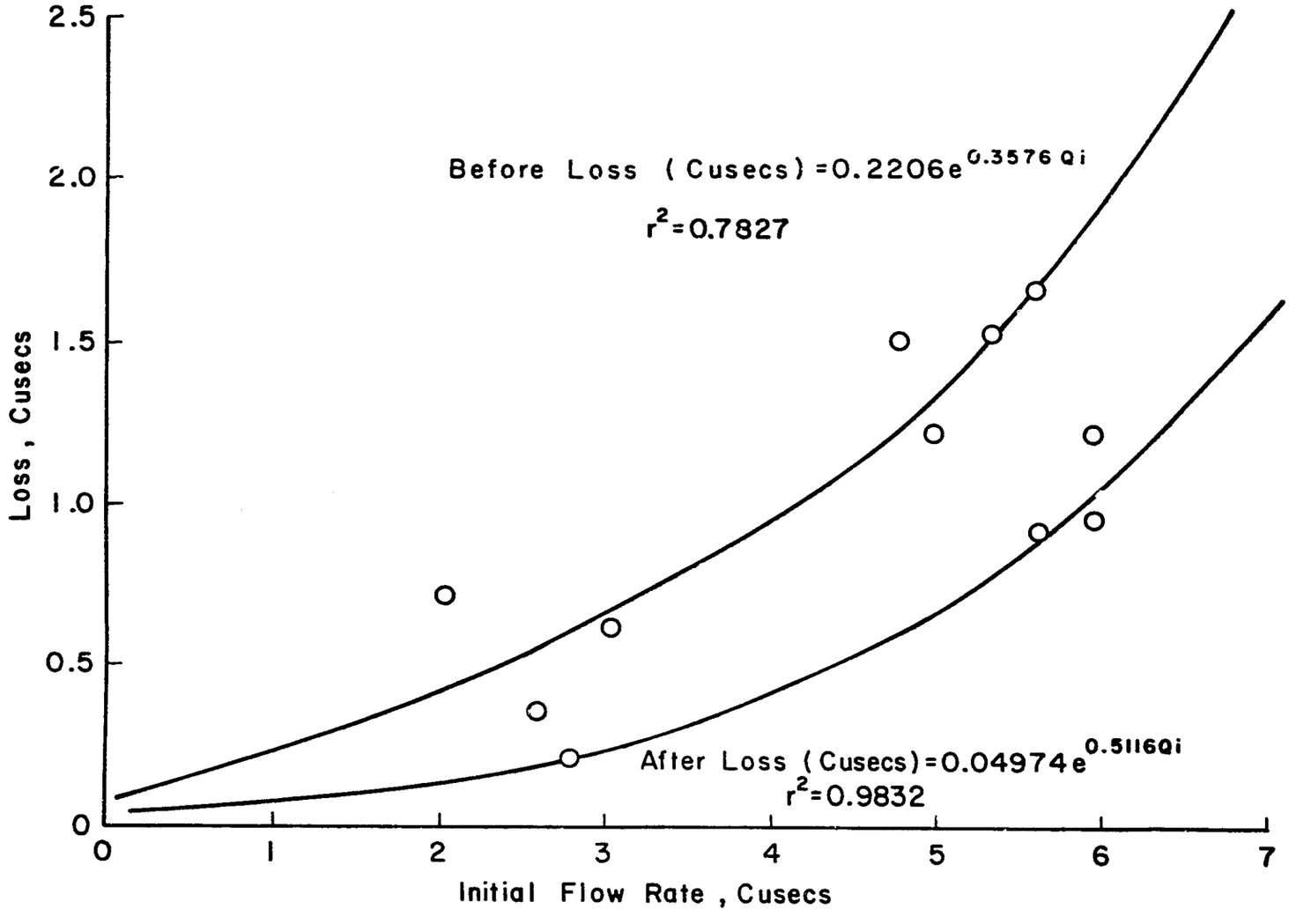


Figure 2. Main channel losses, TW 51.

During renovation branch A only was not improved. The "before" and "after" measurements on branch A show a degeneration in its water conveyance ability over the five month period between measurements.

Conveyance improvement due to renovation of the branches is more difficult to establish since data was insufficient to establish predictive loss equations and "before" and "after" flow rates were, in general, dissimilar. On Branch B the "before" loss over a distance of 4230 ft. was 0.50 cusecs for an initial flow rate of 2.40 cusecs (Table 1, no. 11). The "after" loss over the same distance was 0.30 cusecs for an initial flow rate of 2.70 cusecs (Table 2, no. 8). Thus improvement of Branch B reduced the loss by at least 0.20 cusecs or 40 percent. Actually, this reduction would probably be greater than 40 percent since had the "before" initial flow rate been 2.70 cusecs instead of 2.40 cusecs the losses, from the trends shown in Figure 2, would have exceeded 0.50 cusecs. Because of great differences in the "before" and "after" initial flow rates on Main + Branch B no valid calculation of loss reduction due to water course renovation is possible.

Calculation of loss reduction on Branch C individually is not possible since the "after" loss measurements were incomplete. However, loss data is available for the Main through Branch C. The "before" shows that 3.76 cusecs were lost over an 11,760 ft. distance for an initial flow rate of 5.60 cusecs (Table 1, no. 15). The "after" data shows that 3.30 cusecs were lost for an initial flow rate of 6.20 cusecs (Table 2, No. 10). Thus, watercourse improvement saved at least 0.46 cusecs resulting in a 12.2 percent loss reduction. Again the actual saving due to watercourse improvement would probably have been greater had the before initial flow rate been 6.20 cusecs instead of 5.76.

Similar arguments can be made for Branch D individually. The "before" loss over 4070 ft. was 1.10 cusecs for a 4.30 cusec initial flow rate (Table 1, No. 17). The "after" loss was 0.67 cusecs for a 5.01 initial flow rate (Table 2, No. 11). Thus, channel improvement saved at least 0.43 cusecs and reduced loss 39.1 percent. Again, this must be considered minimum savings since from the trend of Figure 2 had the "before" initial flow rate been 5.01 cusecs instead of 4.3 cusecs the loss would have exceeded 1.10 cusecs; consequently, the savings due to improvement would have been greater.

For the Main + Branch D the "before" loss was 2.21 cusecs with an initial flow rate of 5.36 cusecs (Table 1, No. 18). The "after" loss was 1.61 cusecs for an initial flow rate of 5.95 cusecs. Thus, watercourse improvement reduced the loss 0.60 cusecs or 27.2 percent. For reasons stated above this loss reduction must be considered a minimum.

Table 4. "Before" and "After" Weighted Average Loss Data (Cusecs) for the Main and Main Plus Various Branches.

	Initial Flow	Final Flow	Loss	Distance (ft)	E_d%
Before	5.01	3.30	1.71	9470	65.9
After	5.70	4.34	1.36	10512	76.1

Using weighting factors of loss (cusecs), initial flow rate (cusecs), and conveyance distance the "before" and "after" weighted averages of initial flow rate, loss, and conveyance distance for the whole watercourse were calculated (Table 1, Nos. 1-9, 13, 15, 18, 19 and Table 2, Nos. 1-6, 9-10, 12). The results are shown in Table 3. Thus for the whole watercourse channel improvement reduced loss on the average by 0.35 cusecs or 20.5 percent. Again because of reasons given earlier this is a conservative estimate of improvement since had the "before" average initial flow rate been 5.70 cusecs the initial loss would have exceeded 1.71 cusecs and thus the loss reduction would exceed 20.5 percent.

CONCLUSION

Despite the fact that Watercourse 50440L was relatively efficient in water conveyance renovation did decrease losses. For the entire watercourse, the weight average loss decrease after renovation was 20.5 percent.

For the main channel equations were derived to describe the loss-initial flow rate relationship both before and after improvement. The reduction in loss due to renovation varied from 75 percent for a 1 cusec initial flow to 43.4 percent for a 6 cusec initial flow. Loss was reduced in Branch A by 40 percent. On the Main through Branch C loss was reduced by at least 12.2 percent. For Branch D loss was reduced at least 39.1 percent; for the Main through Branch D the loss reduction was 27.2 percent.

REFERENCE

1. Bowers, S.A., Bashir Ahmed, Ch. M. Hyat Khan, M. Azeem Cheema. Water losses from watercourse 62394L(TW MN 56) Annual Report 1976. Water Management Research Project, Colorado State University, Fort Collins, Colorado.

Appendix 6

WATERCOURSE IMPROVEMENT: METHODS, COSTS AND LOSS RATES AT TUBEWELL 78 WATERCOURSE[1]

Mohammad Akram and W.D. Kemper[2]

Background and Layout

Beginning in 1973 a series of test sections were constructed on the watercourse serving Tubewell 78. The test sections were constructed primarily to evaluate methods for reducing the loss of water from these watercourses which was high, averaging up around to 10 to 15 percent of the water per 1000 feet.

The basic plan of the improvements designed by Mian Ashraf, Gilbert Corey and Wayne Clyma was to provide the best watercourse for the mainline channel and to improve branches and sections of branches with less costly lining which had more possibility of failing. A map of the watercourse command area, showing the main channel and branches A through U is shown in Figure 1. The types of improvement installed are shown in Figure 2, and the costs of the sections are shown in Table 1.

Measurements

Loss measurements were taken using the surface recession method. For most of these measurements the sections chosen were approximately 220' long and a compacted earthen bank was formed at each end of the test section. After the section had been filled with water to slightly above the normal operating level, a ruler was fixed vertically in each section and the rate at which the level of water in the watercourse receded was recorded. This recession rate is combined with the width of the watercourse surface at the measurement time to compute the rate of water loss.

Concrete and Masonry Improvements

The data (Table 2) show the losses of water through the walls and bottom of the portion of the main channel which had

[1]Based on studies conducted by the Mona Reclamation Experimental Project, the Colorado State University Water Management Research Team and Cooperating farmers. Studies were supported by USAID/Pakistan agreement No. 204-75 and by USAID/Washington Research Contract No. AID/ta-c1100.

[2]Junior Agricultural Engineer, MREP, and Field Party Chief, CSU WMR. See acknowledgements for other participants.

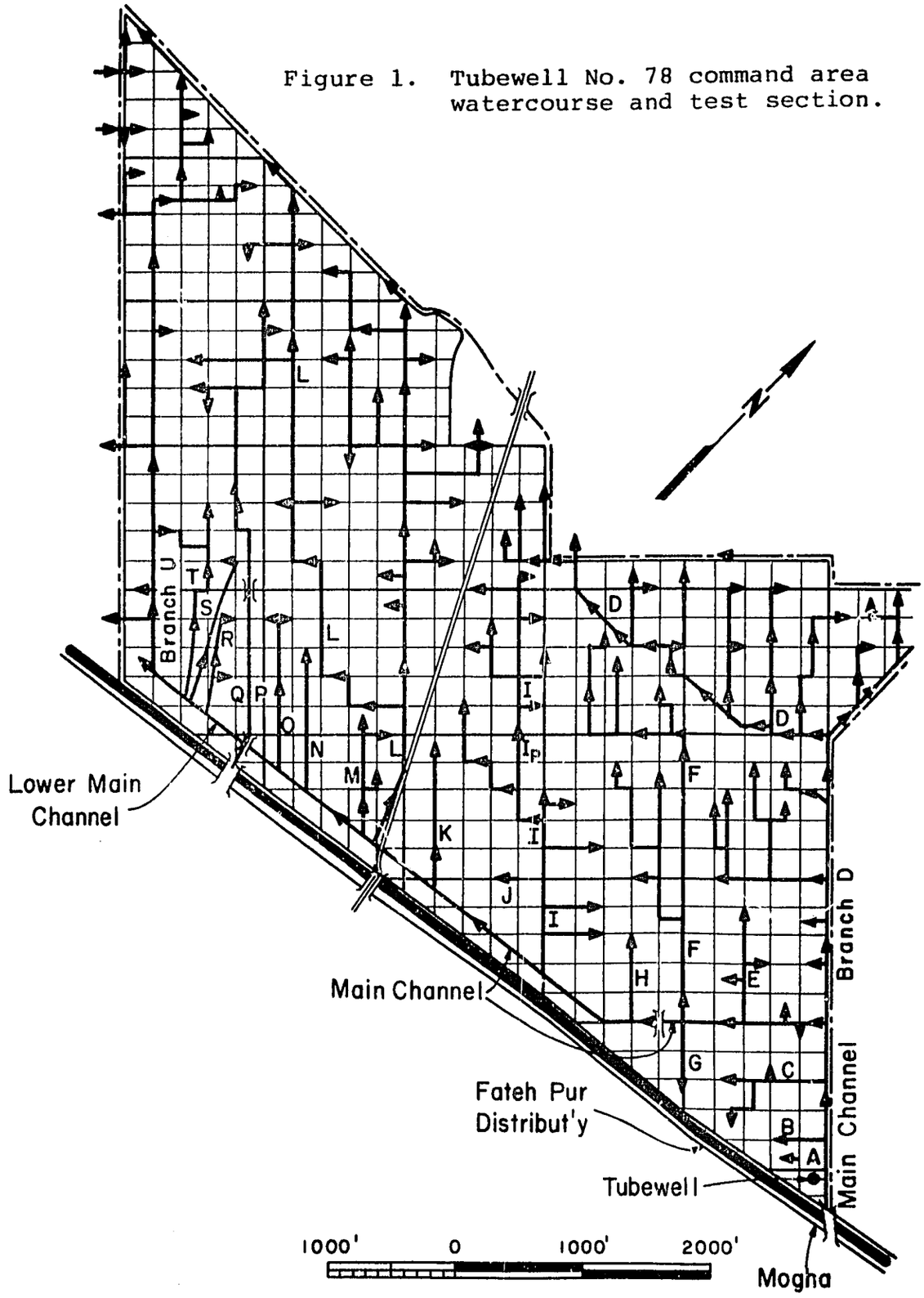
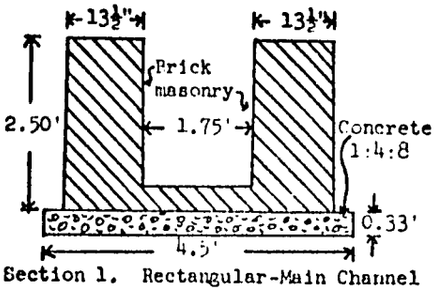
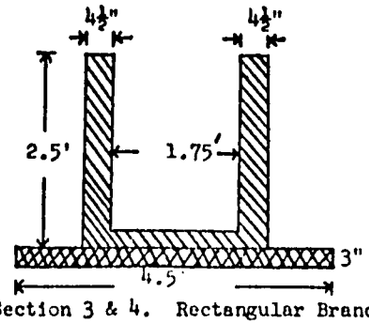


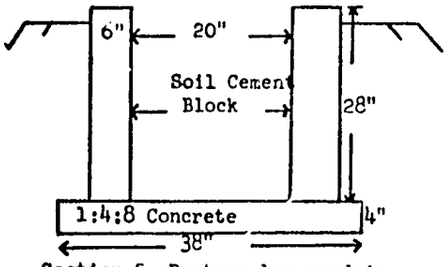
Figure 1. Tubewell No. 78 command area watercourse and test section.



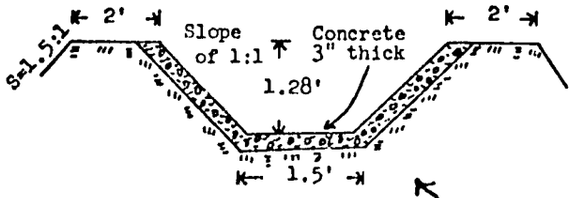
Section 1. Rectangular-Main Channel



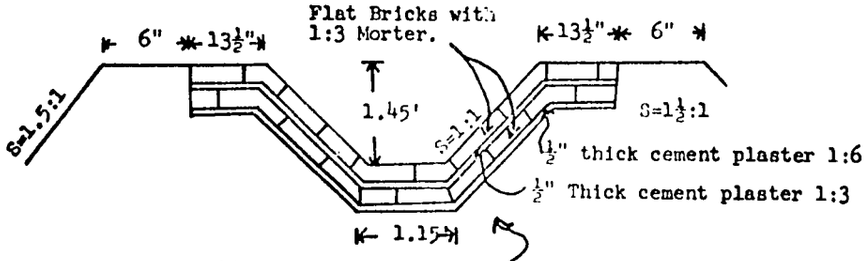
Section 3 & 4. Rectangular Branch U.



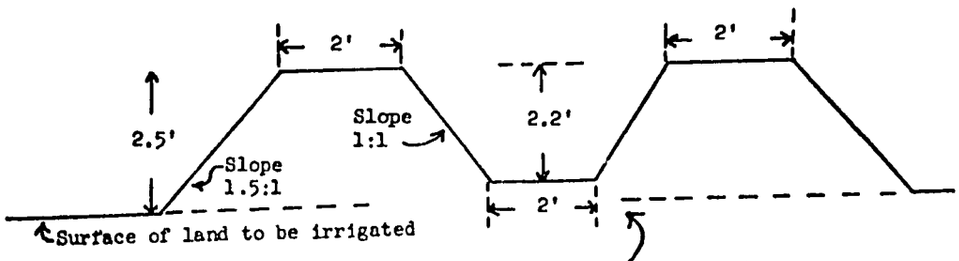
Section 5. Rectangular used in Banni Village



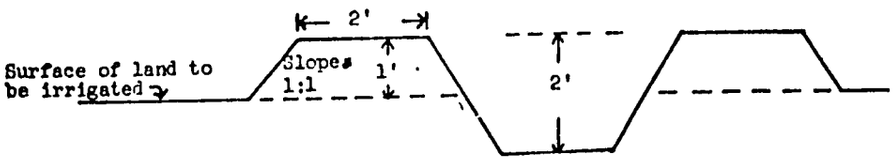
Sections 6, 7 & 8. Trapezoidal (Branches C, E & K)



Section 9. Trapezoidal Brick (Branch F)



Section 10. Trapezoidal Earthen Improved (Branch D) Built by contractors.



Section 11. Trapezoidal Earthen Improved, Renovated by farmers (branch I).

Figure 2.

Table 1. Cost and Details of Construction of Watercourse Serving TW No. MN-78.

Section	Description	Length	*Cost/1000 ft	Type/Design
1.	Main Channel	5280	41,480	Rectangular Section. Brick Masonry. 13-1/2" Thick wall.
2.	Main Channel Watercourse	2240	55,810	Rectangular Section. Brick Masonry. 9" Thick Wall.
3.	Branch "U"	1000	26,930	Rectangular Section. Brick Masonry. 4-1/2" Thick wall.
4.	Branch "U"	1000	26,930	Rectangular Section. Brick Masonry. 4-1/2" Thick wall. 3" Thick C.C. 1:4:8 Foundation.
5.	Banni Village	220	18,000 20,000 (Plastered)	Rectangular Section. Base of 1:4:8 concrete. Walls of 6x4x12" soil cement block.
6.	Branch "C"	769	35,150	Trapezoidal Section. Cement Concrete 3" Thick (1:3:6).
7.	Branch "E"	642	36,240	Trapezoidal Section. Cement Concrete 3" Thick (1:2:4).
8.	Branch "K"	908	36,260	Trapezoidal Section. Cement Concrete 3" Thick (1:4:8).
9.	Branch "F"	3248	55,210	Trapezoidal Section with 2 Brick Layers.
10.	Branch "D"	4600	10,920	Trapezoidal Section. Earthen Improved. Built by Contractors.
11.	Branch "I"	2200	2,000	Trapezoidal Earthen Improved. Built by Farmers.

*Cost includes construction of check structures and outlets.

Table 2. Rates of Loss from Pakka Sections at Tubewell 78 Watercourse

Description of Section	Replication	Rates of Loss in cusecs per 1000 ft. Before plastering or repair	After plastering or repair	Cost of repair or plastering (Rs./1000 ft.)
Rectangular section, plastered brick walls 12-1/2" thick (main channel)	1 2	0.009 0.007		
Trapezoidal section, concrete 1:3:6 walls 3" thick (Branch "C")	1 2	0.040 0.059		1290
Trapezoidal Section, concrete 1:2:4 walls 3" thick (Branch "E")	1 2	0.414 0.354	.014	1290
Trapezoidal Section, Concrete 1:4:8, walls 3" thick (Branch "K")	1 2	0.341 0.750	.022	1290
Trapezoidal Section, Double thick brick walls (Branch "F")	1 2	0.103 0.197	.012	1290
Rectangular section, plastered brick walls 9" thick (Lower main channel)	1 2	0.348 0.595	.005** .013	218
Rectangular section, plastered brick walls 4-1/2" thick (Branch "U")	1 2	0.057 0.104	.038**	50
Rectangular section, plastered soil cement block walls 6" thick ("I")	1 2*	0.004 0.002		
Rectangular section, unplastered soil cement block 6" thick ("I")	1 2	0.082 0.087	0.048+ 0.036+	160
Rectangular section, plastered brick walls 9" thick (Branch "F")	1	0.30	0.04***	286
Rectangular section brick walls 9" thick (Branch "F")	1 2	0.56 0.96	0.01	1800

* Plaster containing Pakka Kaum (Sodium silicate)

** Repair of old plastering job where poorly mixed plaster (sand) had eroded away.

*** Rain, beginning when this plaster repair had not had time to set caused some washout of the plaster at the repair points.

\+ "Pointing", or filling of obvious holes in joints between blocks 6 months after construction.

plastered walls 13-1/2" thick were less than 0.01 cusecs per 1000 feet. This is practically negligible loss. However, there were surprisingly large losses in many of the other pakka (concrete or masonry) lined test sections. Some of the largest rates of loss were found in the trapezoidal concrete sections. In the sections constructed of 1:2:4 mixtures of cement, sand and gravel and in the 1:4:8 sections the average rate of loss was over 0.40 cusecs per 1000 feet. This is near the average rate of loss encountered in unimproved unlined watercourses. Inspection of these sections indicated that when the sections were constructed the concrete was not completely tamped and the occasional holes occurring in the concrete frequently extended all the way through the three inches of concrete and passed water rapidly to the outside of the concrete section. The fact that this was a matter of quality control during the time of tamping rather than the amount of cement in the mix is shown by the rate of loss in branch "C" in which the mix was 1:3:6 and the rate of loss was only 1/10 as much as in the other concrete trapezoidal sections. Section "C" was one of the first constructed and there was closer supervision of the contractors employees which apparently resulted in the better quality of the concrete mixing and tamping.

The other test section showing the highest rate of loss was the rectangular cross section of the main watercourse where brick wall linings are 9" thick and plastered on the inside. This was surprising because this section should have had loss rates nearly as low as those with the 13-1/2" wall thickness. Inspection showed that a poor job of plastering had been done toward the bottom of the walls and that the plaster had either eroded or broken away from the walls in many places where the walls joined the floor and for 2 or 3" above that line. This indicated that there had been considerable sediment in the bottom of this watercourse at the time of plastering and that the masons had allowed this sediment to mix with their plaster. There was also a crack in the base of this watercourse in the first section measured which was near the end before it joins Branch U. This crack occurred in the section where fill in the channel of the original earthen watercourse was necessary to bring the bed up to grade and apparently this fill was not adequately compacted before the concrete bottom of this watercourse was installed.

Going from this section of 9" thick walls with loss rates averaging more than 0.4 cusecs per 1000 feet, to the immediately following section in Branch U which has walls 4-1/2" thick and a loss rate averaging only 0.08 cusecs per 1000 feet, it is again apparent that the loss rates are more highly dependent on quality control than on thickness of the brick wall.

Repair and Plastering

At the lower end of branch "F" there is a section which has rectangular cross-section and has walls 9" thick, built of brick, one section of which is not plastered and one section of which was plastered, but erosion of the plaster indicates that the plaster was poorly mixed. The rates of loss from these sections were measured and found to average about 0.8 cusecs per 1000 feet.

It seemed apparent that both the brick and cement sections should receive a coat of plaster to reduce their permeabilities to acceptable levels. The effectiveness of a good plaster job was further pointed out by comparison of the sections of watercourse constructed of soil cement blocks. When these were not plastered the rate of loss was slightly less than 0.1 cusecs per 1000 feet. The plastered section had a loss of 0.004 cusecs per 1000 feet where common plaster was used and where this plaster had been treated with sodium silicate (locally known as pakka-kaum) the loss was 0.002 cusecs per 1000 feet. Since plastering of sections can cost up to Rs. 2 per lineal foot of watercourse the question raised was whether a careful pointing of joints between the soil cement bricks could reduce the rate of loss since pointing could be done at lower cost. The data in Table 2 show that an improved pointing of the joints did reduce the rate of loss from an average of about 0.08 to about 0.04 cusecs per 1000 feet.

On the basis of these indications of the effectiveness of a good plaster job for reducing the loss rates the sections on which cost and loss data are shown in the last two columns of Table 2 were plastered, or the existing plastering job was repaired as indicated in the footnote to that table.

Since we have found in other studies that the bottoms of watercourses are sealed by sediment from the canal water, only the sides of these watercourses were plastered, or repaired.

The plastering of unplastered sections stopped an average of 94% of the leakage at costs of Rs 1.3 to Rs 1.9 per foot of watercourse (Table 2), saving an average of 0.34 cusecs of water per thousand feet of watercourse plastered.

If water flows in such a watercourse for 50 days a year, the savings would be 34 acre feet of water per year which is a good investment of 1300 to 1800 Rs and indicates that a good plaster job to seal the masonry or cement walls should always be a part of pakka watercourse construction.

Unimproved and Earthen Improved Branches

Branch D (Contractor constructed)

This branch was designed as indicated in Figure 2 so the bed of the watercourse was generally about at the ground surface and all the water could be drawn out of the watercourse at any point, thereby eliminating "dead storage" in the channel. The specifications called for compacted earth. However, soil sampling following construction showed there were many sections of this branch which 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 sections, despite their being 30" high, about 4 inches higher than the design operating level, 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. 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 3 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 percent. This is considerably lower than the average losses measured in the large unimproved earthen watercourses in this area, despite the fact that this newly constructed watercourse was poorly compacted.

After twenty months the rate of loss in this watercourse was measured again. One hour after filling the watercourse the rate of loss was 0.13 cusecs per 1000 feet in each of the first two sections. This indicated approximately 70 percent increase in the permeability of the banks during that twenty months.

Table 3. Characteristics of 6 sections of Branch D of the Watercourse Serving TW 78 at Mona*

Sections between drops #	Water Surface Fall Rate (Ft/sec) At Operating Level**	Cusecs Loss per 1000 feet	% of Flow Lost per 1000 feet
Start-1	$.014 \times 10^{-3}$	0.08	1.7
1-2***	.012 "	0.07	1.5
3-4	.015 "	0.08	1.8
4-5	.011 "	0.06	1.3
5-6	.041 "	0.23	5.0
6 to end	.017 "	0.09	2.0
Start-1	.022 "	0.13	2.8
1-2	.022 "	0.13	2.8

* 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.

Branch I (Unimproved and Earthen Improved)

Effects of Water Level in Watercourse on Loss Rates

Comparing the loss rates in the Old Sod Bank Section (Kemper et. al. (1975)) and in the straight channel sections and junction sections (which were also unimproved) Table 4, it is apparent that lowering the level of water in the watercourse sharply reduces the rate of loss. Reducing the water level by 0.2' resulted in an average reduction of loss to one-third of the loss occurring at full supply level. Close inspection of these banks showed many insect and rodent holes near the upper portion of the bank and when the water level in the watercourse was lowered below the openings of these holes on the inside banks of the watercourse, the rates of water loss were sharply reduced. Further reduction of level of water in the watercourse and a continued exponential decrease in loss rates indicate that practically negligible amounts of water are lost from the bottom sections of these watercourses. However, the upper portions of the banks commonly have permeabilities from 5 to 10 times the permeability of cropped soils in adjacent fields.

Loss Rates at Junctions Compared to Straight Sections

In this unimproved branch watercourse about 45 percent of the loss was occurring in the junction sections, (those obviously widened sections of watercourse with deteriorated banks which are within 20 to 30 feet of the point where sub branches leave the main branch)(Kemper and Akram, 1975, and Table 4 comparing the straight and junction sections). Estimates of losses on other watercourses also indicate that roughly half of the loss is in the vicinity of degraded junctions. At these junctions weekly borrowing of soil to build dams, and erosion of this soil downstream during the process of dam construction and dam removal lowers the level of the soil in adjacent fields, if the farmers owning those fields permit (or endure) the borrowing. When the farmers owning those fields strongly object to this borrowing of soil and destruction of their crops, the man building the dams takes soil from the inside of the watercourse, and from the banks themselves, resulting in a broadening of the watercourse and the banks become thinner. The banks also tend to become taller as borrowing from inside and outside the watercourse reduces the ground and bed levels. The result is thin, tall banks at most of these junctions, which are extremely leaky.

This condition can be improved by bringing soil from the fields into these junction areas, building the banks back to proper cross section and providing excess soil at these junctions for the weekly dam building. A solution to this problem requiring more initial expense, but having a high benefit/cost ratio is to install concrete control structures

Table 4. Losses measured in earthen test sections on Branch I

Treatment or condition	Loss Rates Cusecs/1000 ft
Unimproved old sod banks of full supply level	0.75
Same section as above with level 0.2' lower than FSL	0.25
Straight Channel sections at "Full Supply Level"**	0.06
" " " " " " "	0.56
" " " " " " "	0.40
" " " " " " "	0.25
Sections, level 0.2' lower than FSL	0.01
" " " " " "	0.28
" " " " " "	0.32
" " " " " "	0.08
Junction Sections* at full supply level	0.70
" " " " " "	2.15
" " " " " "	1.25
Junction Sections*, level 2.5" lower than FSL	0.05
" " " " " " "	0.74
" " " " " " "	0.68
Newly constructed by farmers without compaction	0.38
" " " " " "	0.44
Same as above, but banks carefully compacted	0.10
" " " " " " "	0.16
Leaky section (a) after first filling	0.61
" " (b) " " "	0.44
" " (c) " " "	0.66
Leaky section (a) after second filling+	0.11
" " (b) " " "	0.37
" " (c) " " "	0.50

+ Compacted cores were formed in the banks of section (a) between the first and second filling.

** That surface water level which occurs when full supply of water is running in the channel.

* Generally included the widened sections which were within 30 ft. of the junction point.

at each of these junctions which will eliminate the need for borrowing appreciable amounts of soil.

Role of Bank Compaction in Reducing Water Loss

When the banks are carefully compacted, as indicated in Table 4, rates of water loss were reduced to only 26 to 35 percent of those occurring in sections which were not compacted. The core compaction technique discussed by Kemper and Akram (1975) with results indicated at the bottom of Table 4, reduced the loss rate to only about 20 percent of that occurring before a compacted earthen core was formed in the bank. This core was compacted while water was flowing in the watercourse by trimming away the freeboard down to within one inch of the water level, compacting a 3" wide core in the center of the banks to a depth of about 8" below the water level (see Kemper and Akram 1975 for further details). The low loss persisted for about 11 months and then a sudden surge of rodent activity in that section increased the loss again. However, rodent activity generally appears to be lower in packed than in unpacked banks. Core compaction of this type requires about one hour to do ten feet.

Operational Losses in Branch I before Improvement

Measuring all the water entering the watercourse and all the water leaving the watercourse for the fields during the complete irrigation turn of Branch I it was found (Kemper et. al. 1975) that only 43 percent of the water entering this branch reached the field. This compared with steady state measurements at this and other times which indicated an average of 60 percent of the water entering this branch was reaching the field. The difference has been called "operational loss" and is that portion of the water which is used in rapid initial wetting of watercourse banks, filling of watercourses, occasional dam ruptures etc., during which times, steady state measurements are generally not taken. The drastic increase of operational losses which occurs when farmers in different branches of a watercourse trade water indicate that the warabundi system does help reduce these operational losses compared to what they would be if a "demand system" were installed and water was delivered randomly with time to farmers within the command area.

Effect of Farmer Reconstruction on Water Losses

On the basis of the lower loss rates measured in the newly constructed test sections with compacted banks, the farmers were asked to reconstruct and compact the banks of their watercourse. They did this (i.e. see Kemper, Clyma and Ashraf 1975, or Chandawana, 1976). The compaction of this whole branch was supervised by an extension field assistant and was not as complete as on the test sections. However, the farmers were able to reduce their loss rate to less than half of what it had been previously and to increase deliveries

to their fields by almost 50 percent. This was done at a labor cost of about one man hour per two feet of watercourse reconstructed. Concrete control structures were also installed in these sections and the total cost of the improvement averaged about Rs 2.2/foot. However, it will require at least 300 man hours of labor per year to clean and maintain this 2500 foot branch.

The benefit/cost ratio was greater than 3 and this cooperative study with the farmers provided the essential information used in planning the Pilot Watercourse improvement program initiated on the watercourse at Tubewell 56L.

Summary

The test watercourse sections at Tubewell 78 have provided data essential to the Pilot Watercourse studies in the Mona project area and the Watercourse Improvement Component of the Punjab Agriculture Departments Water Management Development Program.

These included (1) a determination that pakka lined watercourses (costing over Rs 25/acre foot) cannot generally be justified on a benefit/cost basis for branch channels, but may be justified for some main channels (Eckert, Dimick and Clyma, 1975); (2) that Pakistani masonry and concrete is porous and requires a good coat of plaster to achieve the desired reductions in water loss; (3) that losses from watercourses in a sandy loam soil can be reduced to 20 to 35 percent of their present value by a thorough job of bank reconstruction and compaction, or core compaction; (4) that farmers can reduce their water losses by 50 percent by reconstructing and doing a medium to poor job of packing the new banks by expending less than 0.5 man hours per foot of watercourse and that the water saved has a lower cost than other sources of water in Pakistan; (5) that farmer participation in planning and constructing the improvements is helpful to gaining their support of a continued maintenance and cleaning program; and (6) the waribundi system of orderly scheduling of water does avoid appreciable operational loss and should not be discarded as long as the irrigation systems are susceptible to these operational losses.

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The efforts of Mohsin Wahla in convincing the farmers they should cooperate by reconstructing Branch I and the leadership displayed by Moh'd Khan Chandawana in that reconstruction were vital to the introduction of the "farmer component" into this study.

Appendix 7

WATER LOSSES FROM WATERCOURSE 62394L (TUBEWELL MN 56)[1]

S.A. Bowers, Bashir Ahmed,
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INTRODUCTION

of importance in evaluating the need for and the improvement due to watercourse renovation is the measurement of water conveyance loss.[3] While several procedures for loss measurement are feasible the "inflow-outflow" method is perhaps the most convenient. Here, two flumes are installed in a channel separated by a distance of 1,000 feet or more; the difference in discharge between the two flumes is equal to the loss. Such loss can be expressed in several ways; i.e. delivery efficiency, total cusecs lost, cusec loss per 1,000 feet of channel, percent loss per 1,000 feet of channel, etc. The latter expression gives the loss in cusecs per cusec of initial flow per 1,000 feet of channel and recognizes the dependence of loss on both flow rate and distance.

Measurements taken before improvement provide the justification for watercourse renovation. Primarily, on the basis of such "before" loss measurements the watercourse at tubewell 56 was renovated. Complete reconstruction was ordered, this included channel alignment, establishment of proper slope, proper channel cross section, rebuilt compacted banks of proper elevation and width, and installation of relatively leak free concrete turnout and check structures. Some 28,000 feet of watercourse was improved. Loss measurements were made "after" improvement to evaluate the effectiveness of the renovation.

PROCEDURE

The inflow-outflow method using cutthroat flumes (3) was used for all loss measurements. All loss measurements were made at "steady-state" conditions and thus did not include operational losses. Since loss appeared to be a function of both flow rate and distance an attempt was made to compare "before" and "after" loss measurements of the

[1]Cooperative study by Colorado State University and the Mona Reclamation Experimental Project.

[2]CSU Advisor and Assistant Agricultural Engineers, respectively.

[3]Loss as herein used includes both seepage and wastage.

same initial flow rates over identical distances. In most instances the data did not permit such identical comparisons. Therefore, the second comparative approach was to develop, from the available data, predictive equation describing "before" and "after" loss rates and flow rates as a function of initial flow rate or measurement distance. Attempts were then made to solve the flow rate or loss rate-distance equations for a common distance and make the appropriate loss comparisons. Where there existed for a particular distance sufficient loss measurements of varying initial flow rates the derived equations were solved for a common initial flow rate and loss comparisons made. All equations were derived using regression techniques. Where data were insufficient for equation derivation comparisons were made on the basis of percent loss/1000 feet.

RESULTS AND DISCUSSION

The "before" loss measurements are shown in Table 1. All measurements except one were made under tubewell supplemented conditions. The variation in initial flow rate, although of limited extent, resulted from variation in the distributary operational level and variations in that fraction of tubewell water directed to an adjacent watercourse.

From the data of Table 1, the main channel (Figure 1) was obviously an efficient water conveyor. Delivery efficiencies were 88 to 89 percent and losses/1000 feet were 3.12 percent to 3.24 percent. Although the initial flow rates were moderately high, 4.4 and 4.8 cusecs, the delivery efficiencies and the percent loss/1000 feet were respectively the highest and lowest of all before measurements. The excellent performance of this main channel was probably due to an almost continuous flow of water which kept the channel both saturated and sealed and excessive freeboard near the watercourse head which resulted from periodic cleaning of the watercourse.

When approximately the same initial flow, 4.60 cusecs, was diverted into Branch A (which connects with the main channel 1100 feet below the distributary) delivery efficiencies decreased 20 to 36 percent and loss/1000 feet increased 7 to 15.5 percent even though two of the Main + A measurements were made over much shorter distances (Table 1). This again exemplifies the possible difference between relatively continuous flow and alternate flow channels. Alternate wetting and drying is more conducive to establishment of plant, insect, and rodent population which results in a more porous bank. The drying during the non-flow periods promote seepage loss by shrinking and cracking of both banks and silt films.

Table 1. Watercourse Losses for TW56 before Improvement

No.	Date	Initial (Cusecs)	Final (Cusecs)	Loss (Cusecs)	Distance (ft)	Loss (cusec/1000)	% Loss 1000 ft	Ed %
		Main						
1.	19 Nov 75	4.40	3.90	0.5	3,640	0.14	3.12	89
2.	20 Nov 75	4.80	4.20	0.6	3.860	0.16	3.24	88
		Main + A						
3.	18 Nov 75	4.60	2.45	2.15	2,440	0.88	19.16	53
4.	18 Nov 75	4.60	3.19	1.41	2,080	0.68	14.74	69
5.	18 Nov 75	4.60	2.50	2.10	4,270	0.49	10.69	54
		Main + C						
6.	15 Nov 75	4.48	2.24	2.24	9,340	0.24	5.35	50
7.	15 Nov 75	4.48	1.40	3.08	9,840	0.31	6.99	31
		Branch C						
8.	20 Nov 75	4.20	2.70	1.5	5,480	0.27	6.52	64
9.	20 Nov 75	4.20	2.97	1.23	3,680	0.33	7.96	71
10.	19 Nov 75	3.40	2.20	1.20	2,580	0.47	13.68	65
11.	19 Nov 75	3.40	2.60	0.80	1,340	0.60	17.56	75
12.	20 Nov 75	4.20	1.75	2.45	6,290	0.39	9.27	42
		Main + G						
13.	17 Nov 75	1.88	0.64	1.24	11,300	0.11	5.84	34
		Main + C + D + E + F						
14.	15 Nov 75	4.48	1.31	3.17	9,140	0.35	7.74	29
15.	15 Nov 75	4.48	2.65	1.83	9,140	0.20	4.47	59
16.	15 Nov 75	4.48	2.65	1.83	9,340	0.20	4.37	59
17.	15 Nov 75	4.48	2.30	2.18	9,840	0.22	4.95	51
18.	15 Nov 75	4.48	0.90	3.58	10,340	0.35	7.73	20

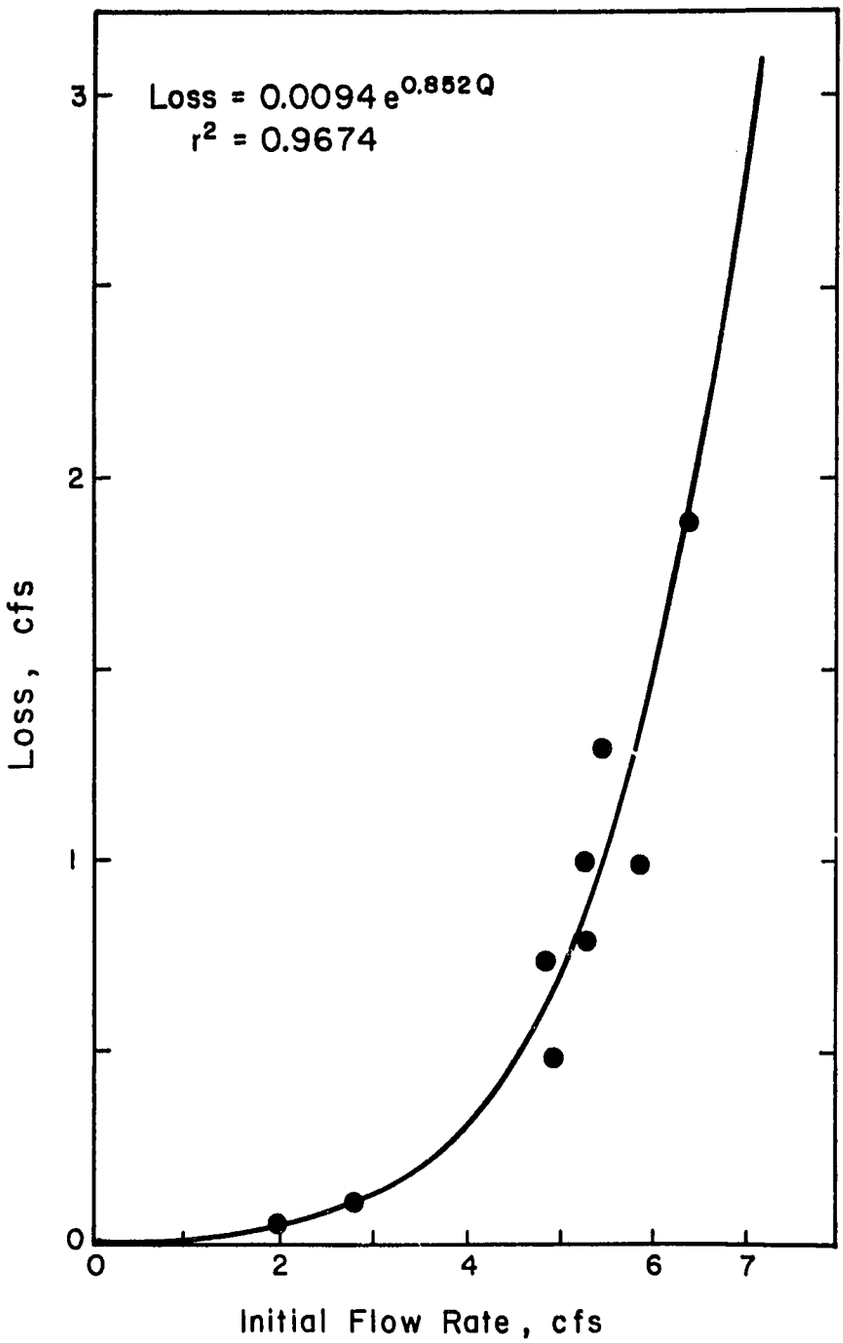

Figure 1. Curve depicting the "after" relation between loss (cusecs) and initial flow rate for a distance of 3980 ft in the main channel.

One general observation from the before data of Table 1 is that for a particular initial flow rate delivery efficiencies decrease while loss and percent loss/1000 feet increases when going from the main channel out through the various branches. The "before" data is not sufficiently extensive to establish exact relations between loss and initial flow rate or distance. However, from the Main through most branches the data it implies as a general relationship of the form $Y = a\ e^{bx}$ where b is positive or negative according to the dependent variable.

Of primary concern is the amount of water delivered to the end of the watercourse. Farmers at the tail do not receive their full allotment. At the end of Branch F, a distance of greater than 10,000 feet, only 20 percent of the 4.48 cusec initial flow was delivered. At the end of Branch C (No. 2 + 12, Table 1), a distance of 10,150 feet, only 36.5 percent of the initial 4.8 cusecs flow was received. Similarly at the end of Branch G for an initial flow of 1.88 cusecs and an 11,300 feet distance only 34 percent of the water was delivered.

After completion of the watercourse renovation conveyance losses were again measured to determine the improvement water delivery (Table 2). The "after" losses were measured under a greater range of initial flow rates due to a greater variation in distributary operating levels. In addition, measurements were made with and without supplemental tubewell water.

Figure 1 shows the "after" relationship between loss (cusecs) and discharge through the upper flume for a fixed distance of 3.980 feet in the main channel. The best fitting equation to these data points of Table 2 (Nos. 2,3,4,5,7,8, 9,10,11) is

$$\text{Loss (cusecs)} = 0.00946e^{0.852Q} \qquad (1)$$

Where Q = initial flow rate (cusecs)

$r^2 = 0.9674$

The curve described by equation 1 is similar in form to the loss flow rate relationship shown by Clyma et al (1).

Similarly from the same data the following equation was calculated

$$\%\ \text{Loss/1000 feet} = 0.185e^{0.587Q} \qquad (2)$$

$$r^2 = 0.9376$$

Obviously, for a given channel cross section the greater the initial flow rate the greater the water depth. Thus, at

Table 2. After Renovation Water Loss Measurements on T.W.56

No.	Date	Initial (Cusecs)	Final (Cusecs)	Loss (Cusecs)	Distance (ft)	Loss (cusec/1000)	% Loss 1000 ft	Ed %
		Main						
1	2-6-76	2.55	2.25	0.25	2200	0.11	5.36	88.2
2	2-18-76	6.20	4.30	1.90	3980	0.48	7.69	69.4
3	2-19-76	2.92	2.80	0.12	3980	0.03	1.03	95.9
4	2-21-76	5.45	4.15	1.30	3980	0.33	5.99	76.1
5	2-23-76	5.30	4.50	0.80	3980	0.20	3.79	84.9
6	2-26-76	2.60	2.55	0.05	1100	0.05	1.73	98.1
7	3-8-76	5.85	4.85	1.00	3980	0.25	4.30	82.9
8	3-10-76	5.30	4.28	1.02	3980	0.26	4.84	80.8
9	3-22-76	2.05	2.00	0.05	3980	0.01	0.60	97.6
10	3-24-76	5.00	4.50	0.50	3980	0.13	2.51	90.0
11	3-27-76	4.85	4.10	0.75	3980	0.19	3.89	84.5
		Main + A						
12	2-10-76	6.50	5.37	1.13	3300	0.34	5.27	82.6
13	2-24-76	5.70	4.60	1.10	3300	0.33	5.85	80.7
14	2-26-76	2.60	2.00	0.60	4400	0.14	5.25	76.9
		A						
15	2-26-76	2.55	2.00	0.55	3300	0.17	5.25	76.9
		Main + C						
16	2-4-76	2.97	1.95	1.02	6180	0.16	5.50	66.6
17	2-5-76	2.00	1.34	0.62	9480	0.07	3.27	67.0
18	2-20-76	5.73	4.95	0.78	6180	0.13	2.20	86.4
19	3-4-76	6.15	3.19	2.96	9480	0.31	5.07	51.9
20	3-8-76	5.85	3.15	2.70	9480	0.28	4.86	53.8
		C						
21	3-4-76	5.23	3.19	2.04	5500	0.37	7.09	61.0
22	3-8-76	4.85	3.15	1.70	-	-	-	64.9
23	3-18-76	4.76	4.09	0.66	-	-	-	86.1
		Main + C + D						
24	2-13-76	6.65	4.35	2.30	8380	0.27	4.13	65.4
25	2-20-76	5.73	4.10	1.63	6180	0.26	4.66	71.2
		C						
26	2-20-76	4.95	4.10	0.85	1100	0.77	15.6	82.8
		Main + C + D + E						
27	3-6-76	6.13	4.30	1.83	7480	0.24	4.00	70.1
		F						
28	3-6-76	4.30	3.25	1.05	-	-	-	75.6
		Main + G						
29	2-7-76	5.50	3.45	2.05	9480	0.22	3.93	62.7
30	2-16-76	6.60	4.15	2.45	9480	0.26	3.91	62.9
31	2-23-76	5.30	4.15	1.15	9480	0.12	2.29	78.3
		G						
32	2-23-76	4.50	4.15	0.35	2200	0.16	3.55	92.2

greater initial flow rates the operating levels should be at the upper portion of the bank which are more porous due to their greater insect, rodent, and plant populations. Logically, one could expect greater percent loss/1000 feet from the larger flow rates. Because of this relationship between loss and initial flow rate "before" and "after" loss comparison should be made at the same discharge through the upper flume.

The "after" measurement taken on March 27, 1976 (No. 11, Table 2) is the most logical single choice for main channel improvement evaluation. Both the initial flow rate and the distance approximate the "before" values. The conclusion is that for initial flow rates up to 4.80 cusecs renovation did not improve water conveyance in the main channel. However, improvement may have eliminated possible overtopping at higher flow rates on the lower reaches of the main channel.

For Main + Branch A there was no direct comparison of "before" and "after" measurements since both their initial flow rates and measurement distances greatly differed. Nevertheless, the greater initial flow rates after renovation resulted in less water loss over greater conveyance distances. According to Figure 1, losses for a particular distance should increase with greater initial flow rates. For an average "after" flow rate 6.10 cusecs (No. 12, 13, Table 2) the average loss over 3300 feet was 1.12 cusecs, the delivery efficiency was 81.6 percent and the percent loss/1000 feet was 5.56 percent. Compare this with the "before" weighted averages (Nos. 3,4,5, Table 1) where the initial flow rate was 4.60 cusecs, the weighted average loss was 1.95 cusecs at weighted average distance of 3030 feet, the delivery efficiency was 57.6 percent, and the percent loss/1000 feet was 14.0 percent.

Another potential method for comparing "before" and "after" losses can be derived from the limited data taken "before" improvement. There is indication that the decrease in flow rate with distance is roughly proportional to the flow rate, i.e.

$$\frac{dQ}{dD} = KG \qquad (3)$$

Fitting this linear equation to the weighted average (Nos. 3,4,5, Table 1) the following particular equation can be derived for flow prior to improvement

$$Q = 4.60e^{-0.000182\ (D)} \qquad (4)$$

Where Q = flow rate in cusecs
D = distance in feet

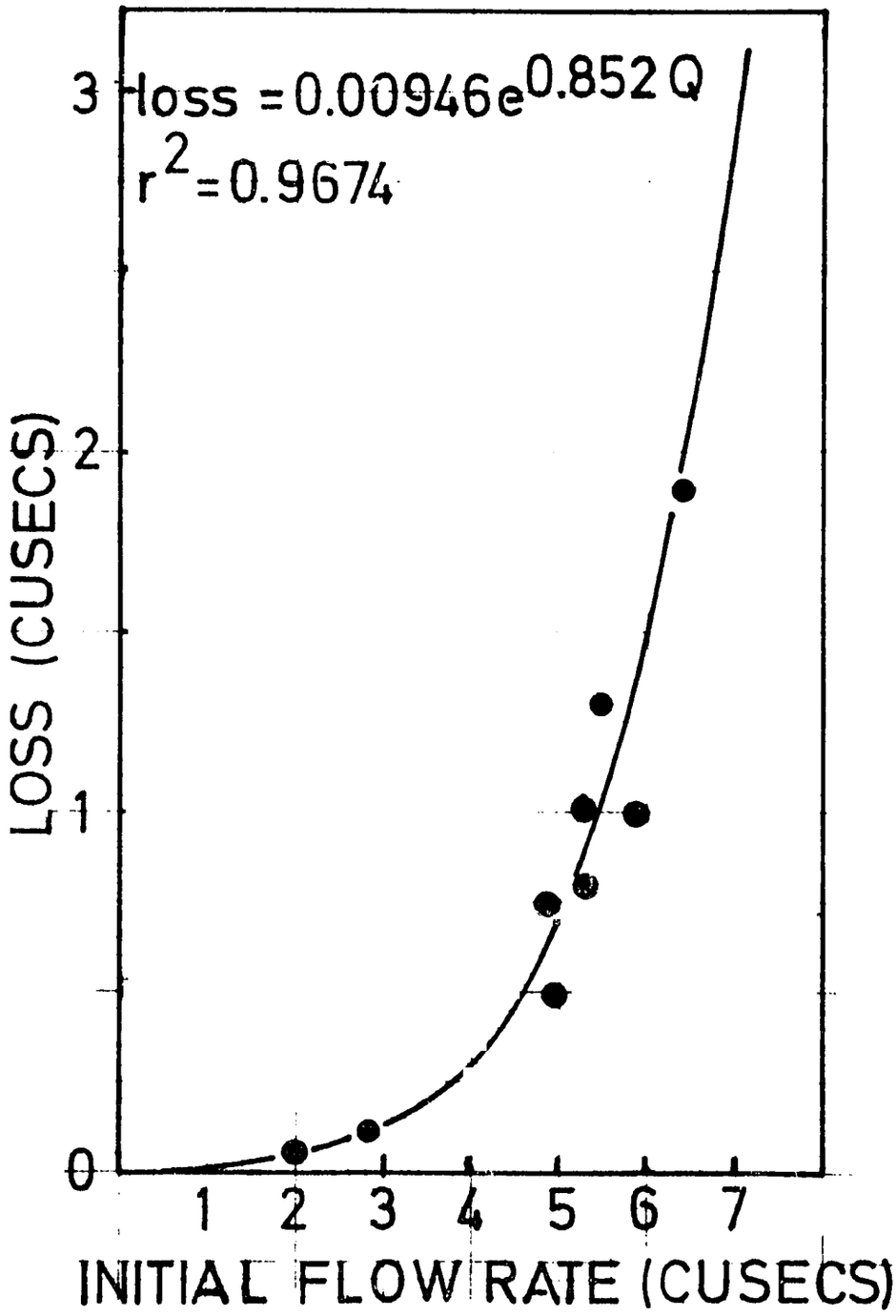

Fig. 1 Curve depicting the "after" relation between loss (cusecs) and initial flow rate for a distance of 3980 ft in the main channel.

When solved for a distance of 3300 feet the "before" flow rate is 2.52 cusecs resulting in a 2.08 cusec loss. Thus comparing the extrapolated "before" loss at 3300 feet with the "after" measured loss at 3300 feet the minimum improvement in conveyance loss from the Main through Branch A could have been as follows:

$$\% \text{ improvement} = (1 - \frac{1.12}{2.08}) \quad 100 = 46.2\%$$

Minimum is here emphasized, since from Figure 1 had the "after" flow rate been only 4.6 cusecs (the same as the "before" rate) the expected loss would have been less than 1.12 cusecs. Consequently, 46.2 percent must be considered as a conservative estimate of the improvement (decrease) in conveyance loss. The correctness of the above answer, the validity of the linearity assumption in equation 3 and general observations of the loss data presented in this paper appear to support this assumption.

"Before" and "after" measurements on Main + Branch C were also difficult to directly compare since their flow rates and loss distances differ. Therefore, a loss equation was derived for the "before" condition. Using regression techniques on the measurements (Nos. 1,2,6,7, 2+9, 2+12, Table 1) the following equation was derived:

$$\text{Loss (cusecs)} = 0.204e^{0.000270 \text{ (D)}} \qquad (5)$$

$$r^2 = 0.9834$$

In the above measurements flow rates varied from 4.4 to 4.8 cusecs with a mean of 4.65, these differences were ignored and considered part of the errors involved. Obviously, the equation overestimates loss in the vicinity of the upper flume but is reasonably correct at other distances.

From equation 5, a "before" loss of 2.64 cusecs was calculated for a distance of 9480 feet. From Table 2 "after" measurements No. 17, 19, and 20 give the cusecs lost over a distance of 9400 feet for initial flow rates of 2.0, 6.15, and 5.85 cusecs. Again using regression techniques the following equation relating flow rate and loss at a distance of 9480 feet was derived:

$$\text{Loss (cusecs)} = 0.290e^{0.379Q} \qquad (6)$$

$$r^2 = 0.9998$$

Equation 6 was solved for loss at a flow rate of 4.65 cusecs, the mean of the "before" flow rates used in deriving equation 5. The calculated "after" loss 1.69 cusecs at 9480 feet. Thus, the improvement in conveyance loss due to watercourse renovation was

$$\% \text{ improvement} = (1 - \frac{1.69}{2.64}) \quad 100 = 36 \text{ percent}$$

Again, because of noncomparable flow rates, distances, and insufficient data, water conveyance improvement could not be directly determined for Main + C + D + E + F branches. From measurements Nos. 1, 2, 14, 15, 16, 17 and 18 of Table 1 the following "before" loss - distance equation was derived:

$$\text{Loss (cusecs)} = 0.207e^{0.000257\ (D)} \qquad (7)$$

$$r^2 = 0.9165$$

As previously, the flow rates which varied from 4.4 - 4.8 cusecs (mean 4.51) were considered of the same value. Equation 7, which was solved for a distance of 7400 feet, showed a 1.42 cusec loss. The percent loss/1000 feet was 4.21 percent.

The one "after" measurement (#27, Table 2) was for a distance of 7480 feet and showed a loss of 1.83 cusecs for an initial flow rate of 6.13 cusecs. The percent loss/1000 feet was 3.99 percent. The site of this measurement was along the path for which equation 7 was derived.

The improvement on Main + Branch G was equally hard to establish. Again the "before" and "after" differed greatly in their initial flow rates and moderately with distance. In addition, the data were insufficient to establish loss-distance equations. On the basis of percent loss/1000 feet, the single "before" measurement was 5.84 percent (No. 13, Table 1) for a 1.88 cusec initial flow over a distance of 11,300 feet. The "after" measurements (Nos. 29, 30, 31, Table 2) showed an average 3.38 percent loss/1000 feet for an average initial flow rate of 5.80 cusecs and a 9,480 feet distance. The "after" for G only, for 2200 feet, was 2.55 percent/1000 feet with a delivery efficiency of 92.2 percent (No. 32, Table 2).

The data does not permit a valid comparison of "before" and "after" conditions for the entire watercourse. However, an arithmetic average, with recognition of its deficiency, of the "before" (Nos. 3-7, 2+9, 2+12, 13-18; Table 1) and "after" (Nos. 12-14, 16-20, 24-25, 27, 29-31; Table 2) are presented in Table 3 as an <u>indication only</u> of possible improvement. These averages show the "before" delivery efficiency at 8058 feet was 47.5 percent, the "after" delivery efficiency at 7300 feet was 70.6 percent.

CONCLUSIONS

Improvement due to watercourse renovation, evaluated on the basis of differences between "before" and "after" comparisons were difficult to impossible because of differences in initial flow rates and length of channel conveyance. Where feasible, loss-distance and loss-flow rate predictive equations were derived for comparison purposes. For initial

Table 3. Average Supply to the Watercourse, Delivery to the Field, and Delivery Efficiency Before and After Improvement at TW 56.

	Supply to WC (cusecs)	Delivery to Fields (cusecs)	% Loss / 1000	Ed %	Ave. Flow Measurement Distance
Before	4.36	2.07	6.52	47.5	8058
After	5.24	3.65	4.15	70.6	7300

flow rates up to 4.8 cusecs the data showed no improvement in the Main channel due to renovation. This is possibly due to the almost continuous flow which helped maintain a better channel seal. Subject to additional verification, future design of new watercourses may consider, where topography permits, maximizing the length of continucus flow main channels where loss is low and minimizing the length of alternate flow branch channels where losses are relatively high.

Evaluation of improvement on Main + Branch A, based on an assumed flow distance relationship, shows a 46 percent minimum decrease in conveyance loss due to renovation.

For the Main through Branch C, by establishing from the data points the best fit loss-distance and loss-flow rate equation, a decrease in water conveyance loss of 36 percent was determined.

On the Main through Branch E, because of dissimilar flow rates and insufficient measurements, it was impossible to establish the improvement in water conveyance over a given distance. The only comparison possible was percent loss/1000 feet; before renovation it was 4.21 percent/1000 feet while after renovation it was 3.99 percent/1000 feet. Because these loss rates were established for different initial flow rates the similarity of the percentages does not necessarily imply little improvement. Similarly for Main + Branch G the only convenient improvement comparison was percent loss/1000 feet; the "before" value was 5.84 percent and the "after" value was 3.38 percent. For the entire watercourse, based on arithmatic averages, the "before" percent loss/1000 feet and delivery efficiency were, respectively, 6.52 percent and 47.5 percent; the respective "after" values were 4.15 percent and 69.7 percent.

Based on the experience of the watercourse, future "before" and "after" loss measurements should be made the same range of initial flow rates and conveyance distances. Sufficient data should be gathered to establish predictive loss equations.

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Appendix 8

AIDS FOR WATERCOURSE DESIGN AND IMPROVEMENT[1]

W.D. Kemper, Ch. M. Hayat Khan, Wayne Clyma, W.E. Hart, Shahaid Ahmad, Javaied Iqbal[2], Moh'd Iqbal, Moh'd Akram, Moh'd Azeem, Bashir Ahmad,[3] M. Siddique Shafique and Mushtaq Gill[4]

A. Introduction

The numerous possible shapes of watercourse often leave the beginning designer with a feeling that watercourse design is a difficult undertaking to be solved only by time consuming iteration using Mannings equation.

To simplify the watercourse design procedure Ch. M. Hayat Khan drew up the attached series of graphs using Mannings equation for watercourses with side slopes which are vertical, 1:2, 1:1, or 2:1. These slopes cover most of the needs for lined and earthen channels. Use by new designers in planning watercourses has shown that these graphs decrease the time required to design watercourses and allow quick checking of watercourse design. Many requests for earlier drafts of our Aids for Watercourse Design prompted us to present this revised procedure developed by Hayat, which has several advantages over our previous procedures.

Since Pakistan officially converted to the metric system on July 1, 1976, metric units are used throughout. However, to help those converting from the English to the metric units, lines representing volume units are given in multiples of 0.03 cubic meter since $0.03M^3$ is close to 1 cubic foot.

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[1]Prepared by the CSU Water Management Research Team based on experience at the Mona Reclamation Experimental Project Watercourse Improvement Program and the Punjab Water Management Research Project. Portions of this work were supported by USAID/Pakistan Agreement Nos. 204-75, and 39-17-110-390, 73-4 and by USAID Research Contract No. AID/ta-c-110.

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AA. Head Loss Through Rectangular Nakkas and Circular Submerged Nakkas

1. Why Concrete Control Structures are Needed.

The concrete control structures are needed to:

a. Provide effective water control systems, and

b. To reduce water losses and reduce borrowing of soil from fields and banks near junctions which weakens banks.

2. Reason for Head Loss

When the water passes through the nakkas, which have a smaller cross section for flow than the earthen channel, the velocity energy (kinetic energy) increases according to the formula:

$$K.E. = 1/2\ m\ v^2$$

Where K.E. = Kinetic energy
m = Mass of the moving body
v = Velocity of the body

This increased kinetic energy comes from head loss and is the main cause of head loss. Its value depends upon the following:

a. Entrance loss

It is primarily dependent on the change in flow cross sections from the channel to the orifice, but is somewhat dependent on the shape of the entrance.

b. Friction loss

It depends upon the material of the nakka, the length of the opening or pipe, and ratio of the wetted perimeter to the cross sectional area of flow.

c. Elbow loss

It depends upon the angle of intersection of the two cylinder, (i.e., the pipe bend, 45 degrees, 60 degrees, 30 degrees ...) whatever the case may be.

d. Exit loss

Account for the fact that when water gets out of the nakka it dissipates all the velocity energy of the existing water in turbulence and is not available for useful work -- thus, exit loss coefficient = 1. Hence, the increased kinetic energy which comes from the conversion to K.E. of a portion of the elevation head, is dissipated in turbulence.

3. Magnitude of Head Loss

The magnitude of head loss depends upon the discharge and the type and size and entrance conditions of the nakka. Figures 1, 2 and 3 were constructed to allow quick estimates of head loss in common types of nakkas. Figure 1 shows the relationship between the head loss and discharge at different diameters of submerged nakkas with circular openings. This figure is also reasonably accurate for round culverts less than 4 meters in length. Figures 2 and 3 show the relationship between the head loss and discharge at different heads through rectangular nakkas which are 0.508 and 0.61 meters wide respectively.

Use of Figure 1

Suppose we are designing a watercourse and at one junction on this watercourse we will have 60 lisecs (cubic liters per second) discharge. We can tolerate a head loss of 2.5 cm or less at this junction and we have reinforced concrete panels available to us with orifices of the sizes indicated in Figure 1. In Figure 1 discharge and head loss readings for circular submerged orifices are given on the left and the bottom of the figure respectively. The graph lines for orifice diameters ranging from 25.3 to 76.3 cm are plotted in the figure. Take the 60 lisecs reading on the discharge scale and move to the right where this line will intersect the vertical line representing a head loss of 2.5 cm. This intersection is just below the line relating head loss to discharge for a 38.1 cm diameter orifice. If we use an orifice 38.1 cm in diameter the head loss at 60 lisecs of flow will be about 2.2 cm. The actual head loss may be slightly different than this theoretical head loss depending on the approach conditions to the check structure and the angle to the horizontal at which the panel is involved. Normally, the actual head loss is close enough to those indicated in Figure 1 for design purposes.

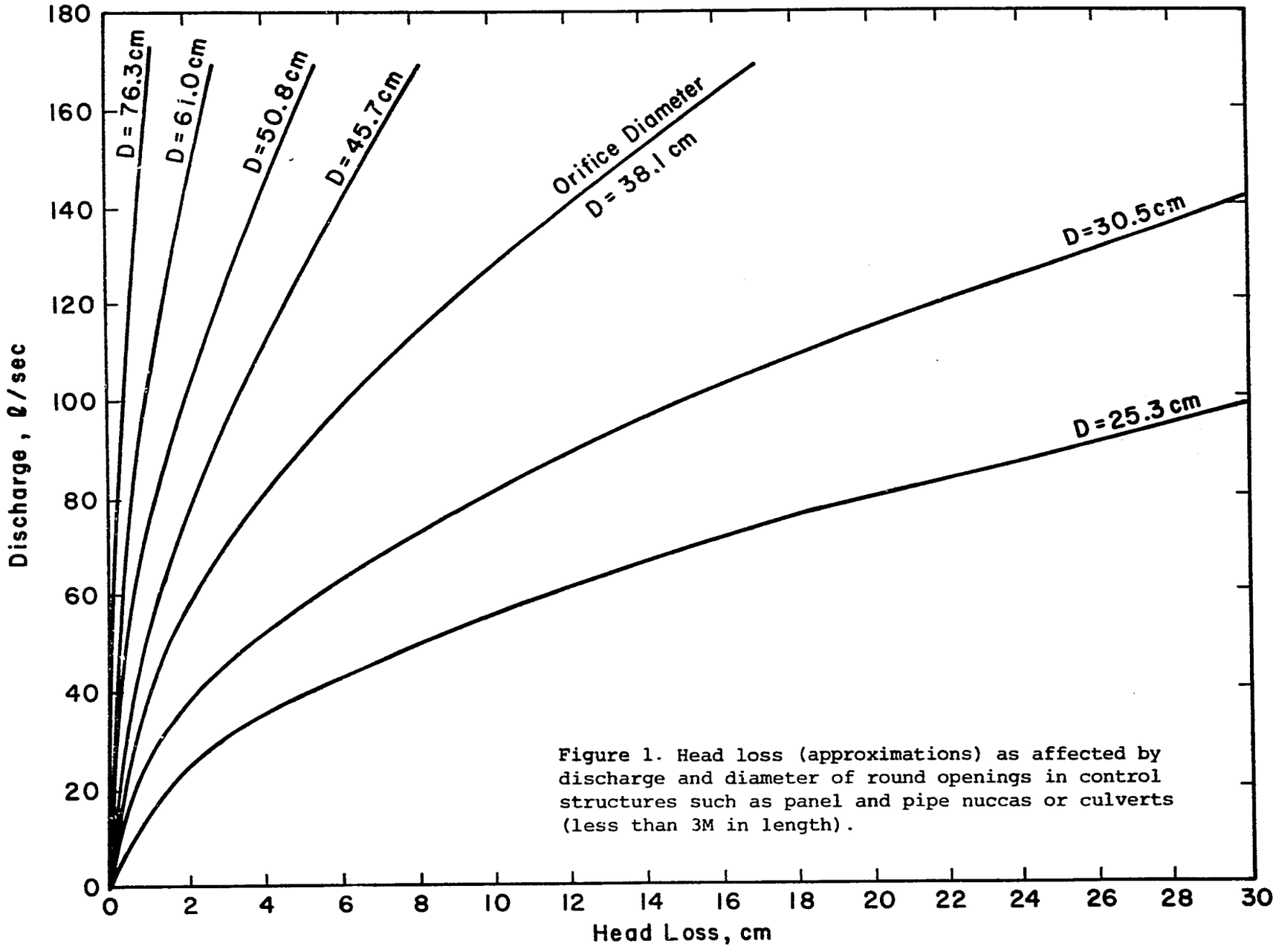


Figure 1. Head loss (approximations) as affected by discharge and diameter of round openings in control structures such as panel and pipe nuccas or culverts (less than 3M in length).

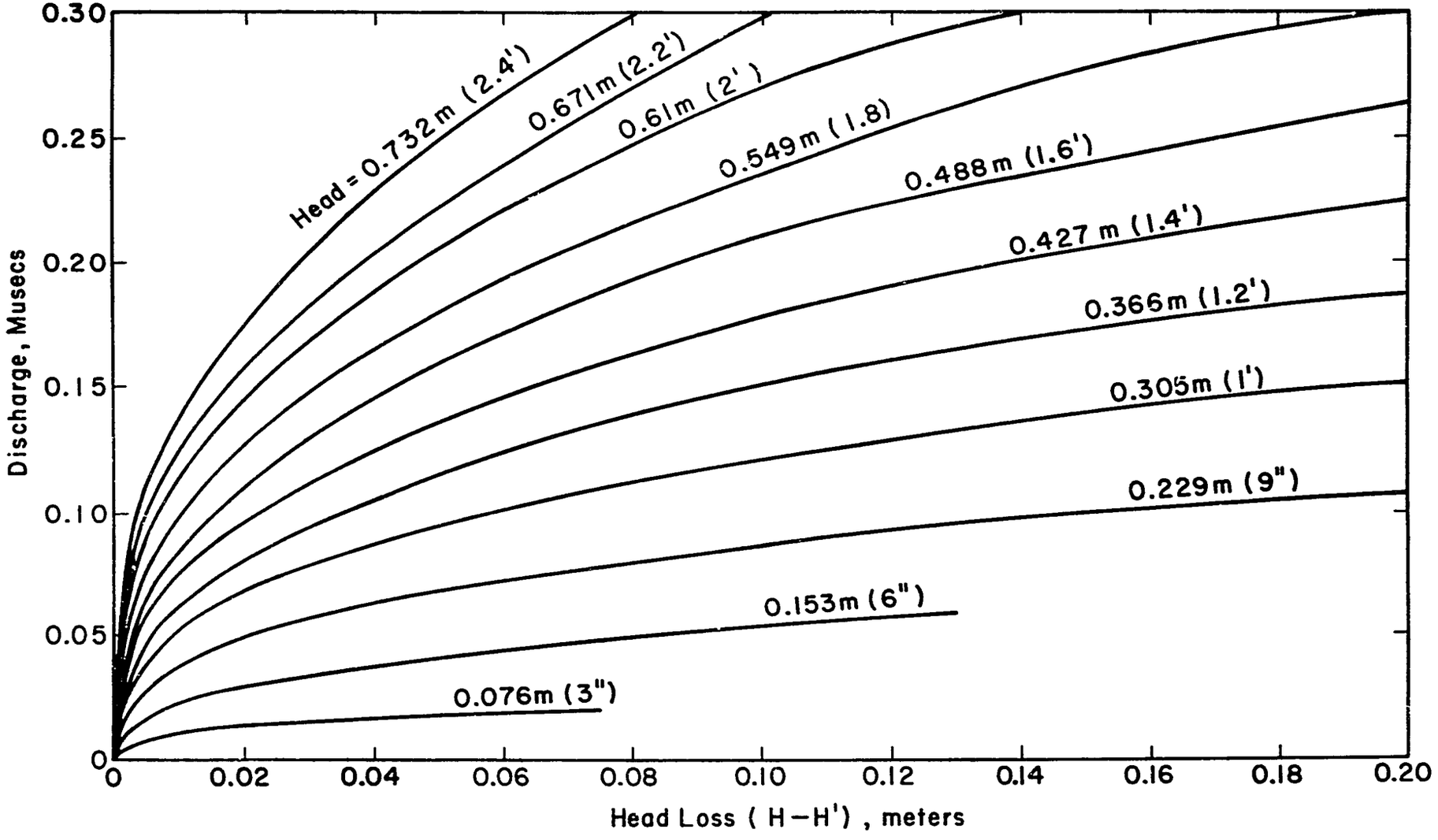


Figure 2. Shows the relationship between head loss and discharge at different heads with 0.508 meter width (rectangular panel nakka).

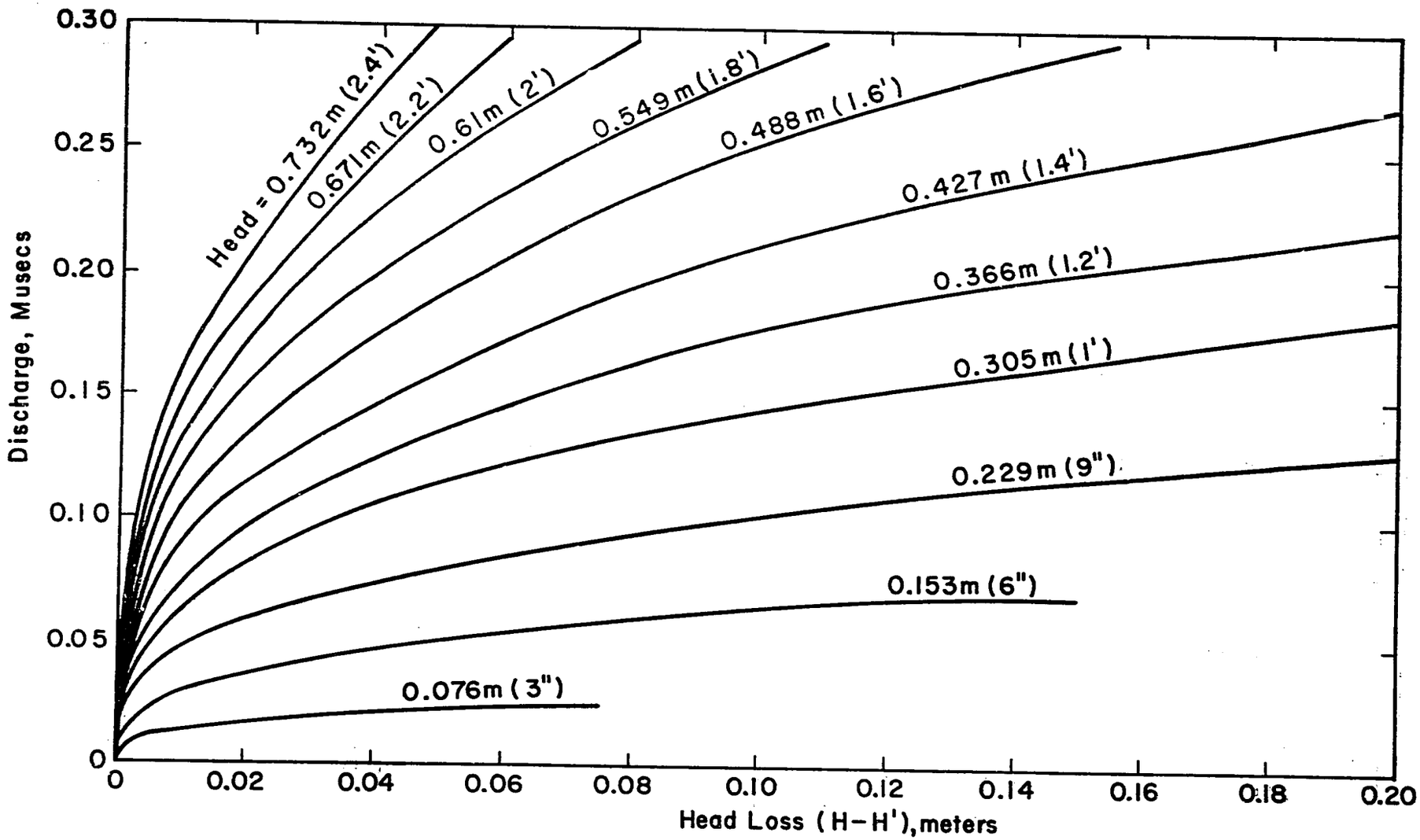


Figure 3. Shows the relationship between head loss and discharge at different heads with 0.61 meter width (rectangular panel nakka).

Use of Figure 2

Suppose we have a rectangular nakka of 0.508 meter width, and 0.1 musecs[1] (cubic meters per second) discharge is passing through it with 0.427 meter head (upstream). We can calculate the head loss through this sturcture as follows:

Consider Figure 2 where discharge and head loss readings are given on the left and the bottom of the figure respectively. The graph lines at different heads ranging from 0.076 to 0.732 meters are plotted in the figure.

Take 0.1 musecs reading on the discharge scale and move straight way towards right and where this line will intersect the graph line of 0.427 meter head, read out the value of head loss just below that point, and here in this case it is .022 meter.

Use of Figure 3

It is similar to the Figure 2, except the width of the rectangular orifice is 0.61 meters. Suppose we have a rectangular nakka of 0.61 meter width, with 0.2 musecs passing through it with water 0.549 meter above the floor of this nakka head immediately upstream from the nakka. We wish to know the head loss. Use Figure 3 where discharge and head loss readings are given on the left and the bottom of the figure respectively, and the graph lines at different heads ranging from 0.076 to .732 meter are plotted in the figure.

Take 0.2 musecs reading on the discharge scale and move straight way towards right and where this line will intersect the graph line of 0.549 meter head, read out the value of head loss just below that point, and here in this case it is .04 meter, or 4 centimeters.

B. Mannings Formula and Roughness Coefficient

The slope of the watercourse bed (and the equal slope of the operating water level), S, is related to the average velocity, V, of the water by Mannings equation,

$$V = R^{2/3} S^{1/2}/N,$$

when V is given in meters/second and R, the hydraulic radius, is calculated in square meters per meter. Note that the

[1] 0.1 musecs = 100 lisecs.

constant 1.49 that precedes the right hand side of this equation when "feet" are used to define V and R becomes unity when meters are used. The hydraulic radius, R, is equal to the cross sectional area of flow divided by the wetted perimeter.

The Mannings coefficient, or roughness coefficient "N" can be as low as 0.03 for smooth newly cleaned earth watercourses. However if grass is allowed to grow in such a watercourse, values of N may increase to as high as 0.30 (Schwab et al 1966, p. 233). Trout and Akram measured N values in sections of Branch D of the watercourse serving tubewell MN-78, and found values of N varying from 0.04 to 0.08 depending on whether or not grass had been cleaned from the channel. The grass was about 15 to 38 cm high in the sections where N was 0.08 and considerable overtopping occurred during the irrigation turn prior to when the farmers began cleaning the sections. Flow in this channel was about 0.12 musecs (i.e. cubic meters per second) its slope is about 0.0005 and it had a bed width of 60 cm and 1:1 side slopes. In the case of the roughness coefficient changing from 0.03 to 0.07 for this channel and flow rate, figures 4 and 5 can be used to show depth of water in the channel would increase from 0.42 to 0.62 meters. It is apparent that channels designed assuming a roughness coefficient of 0.03 will overtop if they have only 0.15 meters of free board and vegetation pushes the roughness coefficient up around 0.06 or higher. Regular cleaning to prevent development of such roughness coefficients is essential to prevent overtopping. Well defined marks on concrete control structures showing the designed operating level can help farmers evaluate the need for, and schedule, cleaning of their watercourse.

The Warabundi system which keeps water in each branch for only about one day of each week provides conditions favoring growth of weeds and grass in those branches. Sections of the main channel which are continuously filled with water may develop some water plants, but generally have lower N values because normal grasses and weeds do not grow under these conditions.

In designing a watercourse, a regular cleaning program must be agreed upon which will maintain N reasonably near the value used in the design, or sufficient freeboard must be allowed to take care of the increases in operating level that will occur when N increases appreciably.

Long term fluctuations of operating levels in a watercourse encourage the invasion into lower portions of watercourse banks when the operating levels are low, of insects and rodents which are always present in the upper portions of the banks. Then when the operating levels increase again the holes left behind by these invaders are below the water

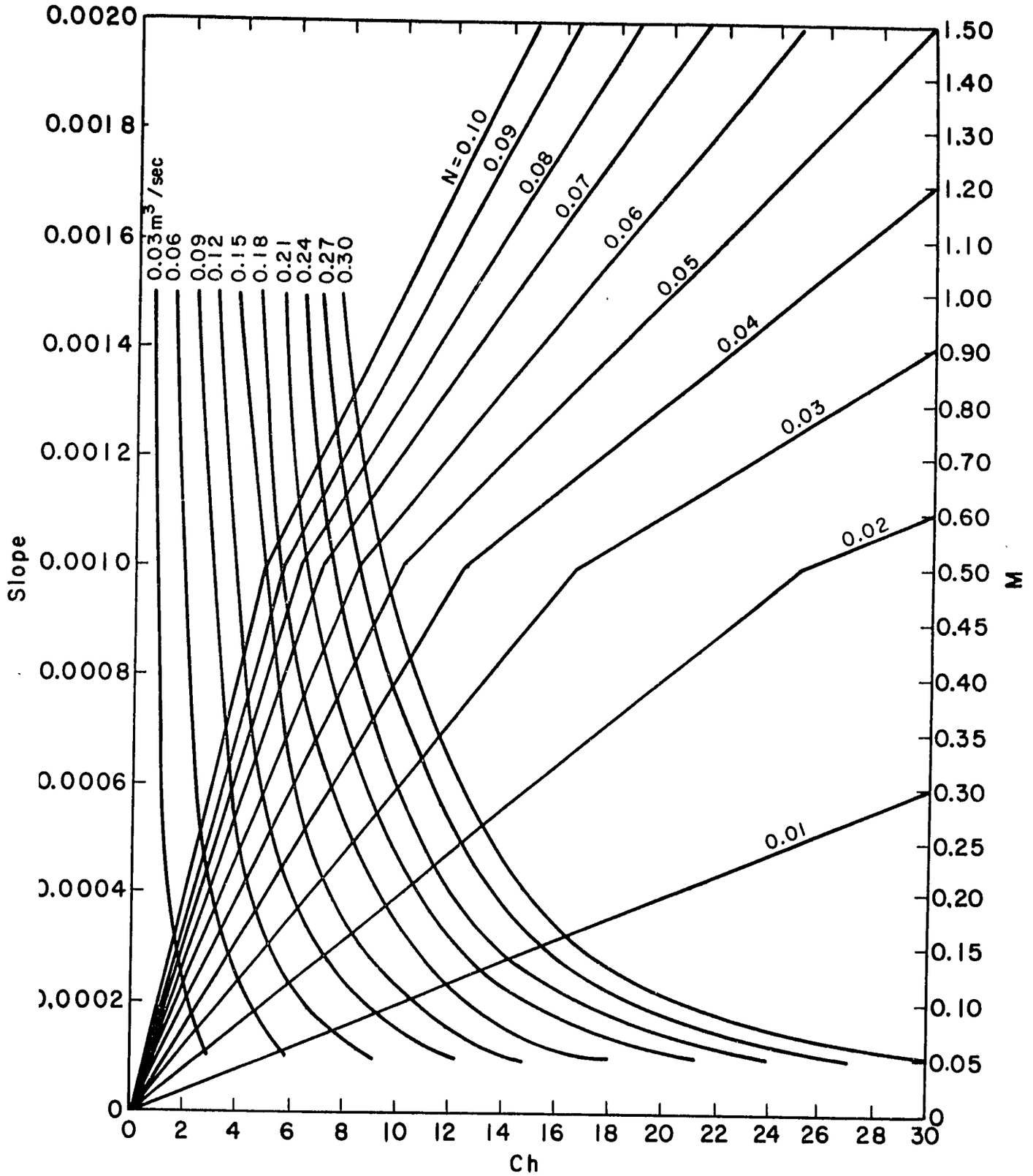


Figure 4. Relationship between discharge 'Q', slope 'S', constant 'Ch', roughness coefficient 'N', and constant 'N', to design watercourse by Hayat's method.

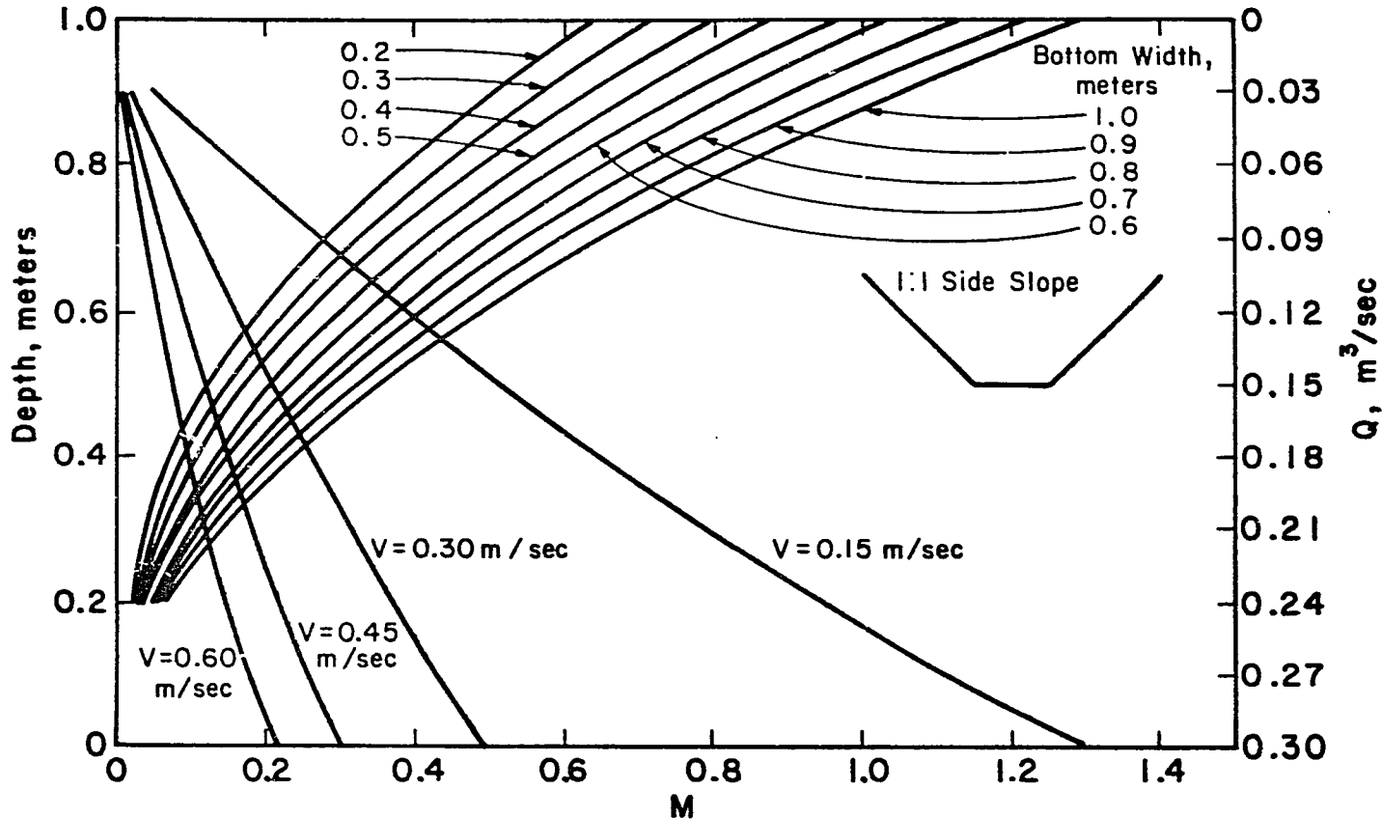


Figure 5. Graph for determining bottom width and depth with side slope 1:1 by Hayat's method.

surface and cause increased water loss. Consequently, the best plan, technically, is to obtain agreement with the farmers on a regular cleaning program which will maintain N values down around 0.84. If farmers are not cooperative and it appears likely that regular cleaning will not occur, more freeboard may be added to help save them from the consequences of their own folly. However, increasing free board amounts to providing more dwelling space above the water level for rodents and insects, and encourages increases in their population--all within a few inches of the life lines of Pakistan's agriculture--its watercourses. This fact and the need for regular cleaning and maintenance should be strongly presented to the farmers to gain their commitment to regular cleaning programs at the time of watercourse building or reconstruction.

C. Relations Between Slope, Discharge, Roughness Coefficient and Channel Size Based on Mannings Equation

While Mannings equation is relatively simple, the presence of fractional exponents often prevents the beginner, who may have no access to a slide rule or calculator, from using it freely.

To assist beginning designers, Hayat drew Figures 4 through 10 which can be used as outlined in Figure 6 to calculate the depth and width of a watercourse required to carry a given flow in one of the 4 types of cross sections (side slopes at 2:1, 1:1, 1:2 and vertical).

Following Figure 6, to design a proper cross section for a length of a watercourse, the rate of flow (or discharge) to be handled, and the slope of the watercourse (assumed as parallel to the full supply level) must be known. Using the line at the top left of Figure 4 with the appropriate flow rate and following this line down to where it intersects the appropriate slope, the appropriate coefficient Ch is directly below this intersection. This constant Ch is proportionately related to another constant, M, and this proportionality is a function of the roughness coefficient as shown in Figure 4. The value of M in Figure 4 can be determined for a given value of Ch, by moving along the constant Ch line to where it intersects the appropriate roughness coefficient of N line, and then going horizontally to the right hand ordinate to find the value of M.

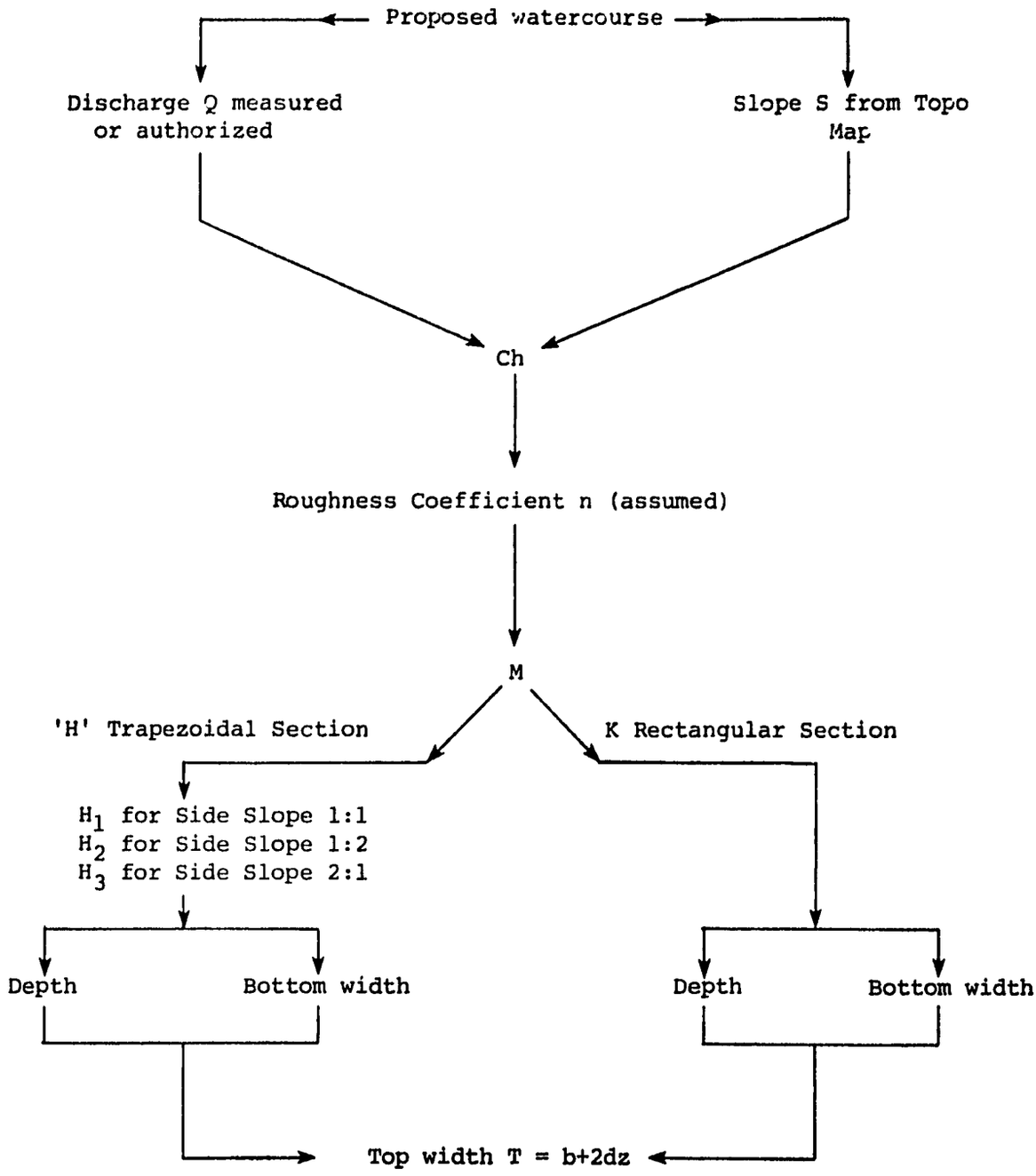
This value of M is then carried to Figure 5, 8, 9 or 10 depending on whether the side slope of the channel is 1:1, 2:1, 1:2, or 0 (vertical) respectively.

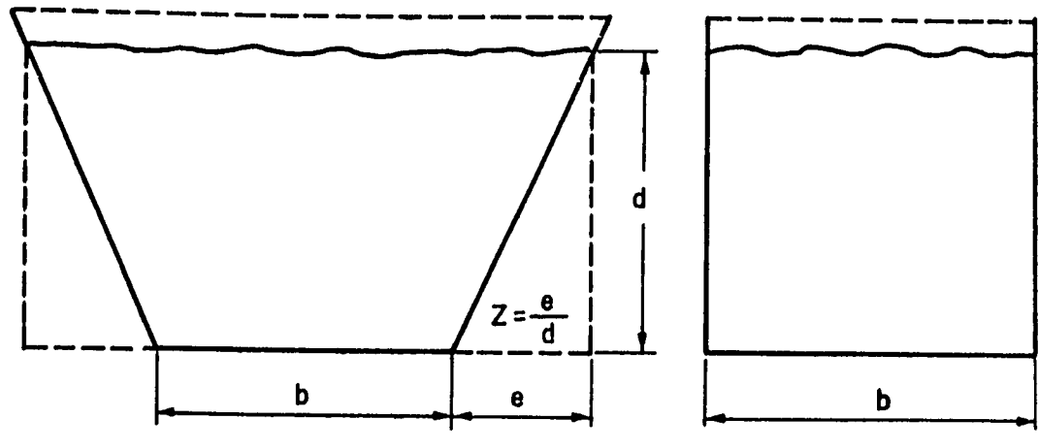
Locating the value of M at the bottom of the appropriate figure one follows this line upward until it crosses the line representing the bottom width desired, and that determines the depth of the full operating level.

Figure 6

DESIGN OF WATERCOURSE BY HAYAT'S METHOD

The easiest way to move for design by this method to remember Ch. M.H.K. and then move respectively.





TRAPEZOIDAL SECTION

Crossectional area	A
$bd + Zd^2$	
Wetted Perimeter	P
$b + 2d\sqrt{Z^2 + 1}$	
Hydraulic Radius	R
$(bd + Zd^2)/(b + 2d\sqrt{Z^2 + 1})$	
Top Width	T
$b + 2dZ$	

RECTANGULAR SECTION

Put Z=0 for above

Figure 7. Channel shape and hydraulic area. Radii wetted perimeter and top width for watercourse design.

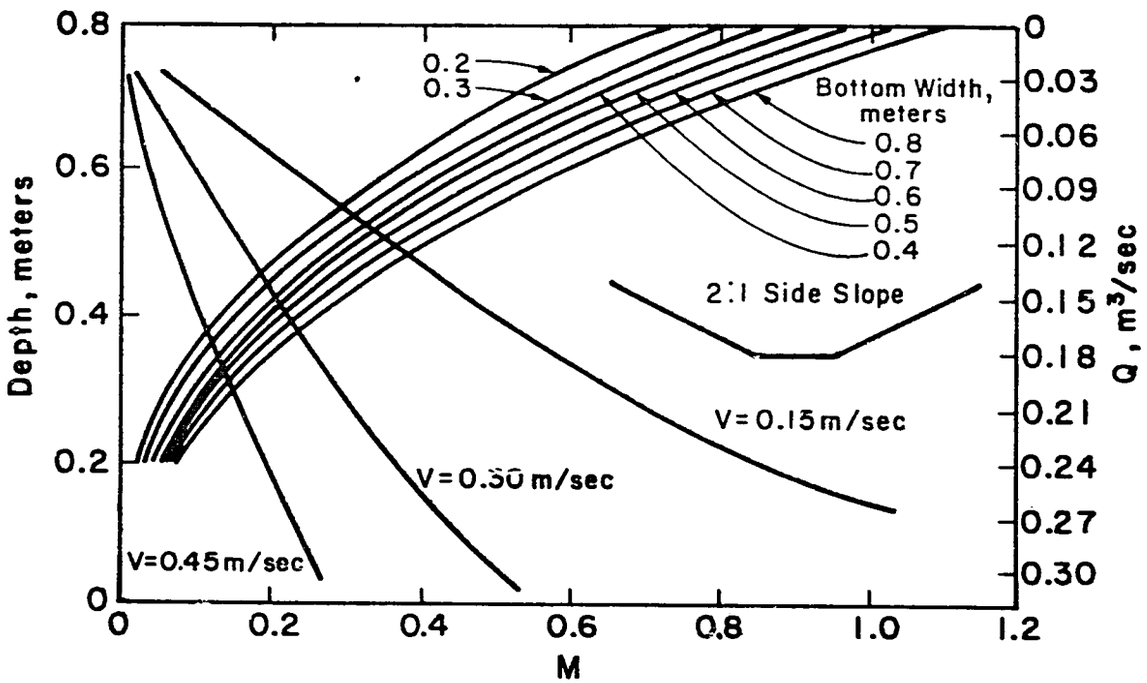


Figure 8. H_3 graph for determining bottom width and depth, width side slope 2:1 by Hayat's method.

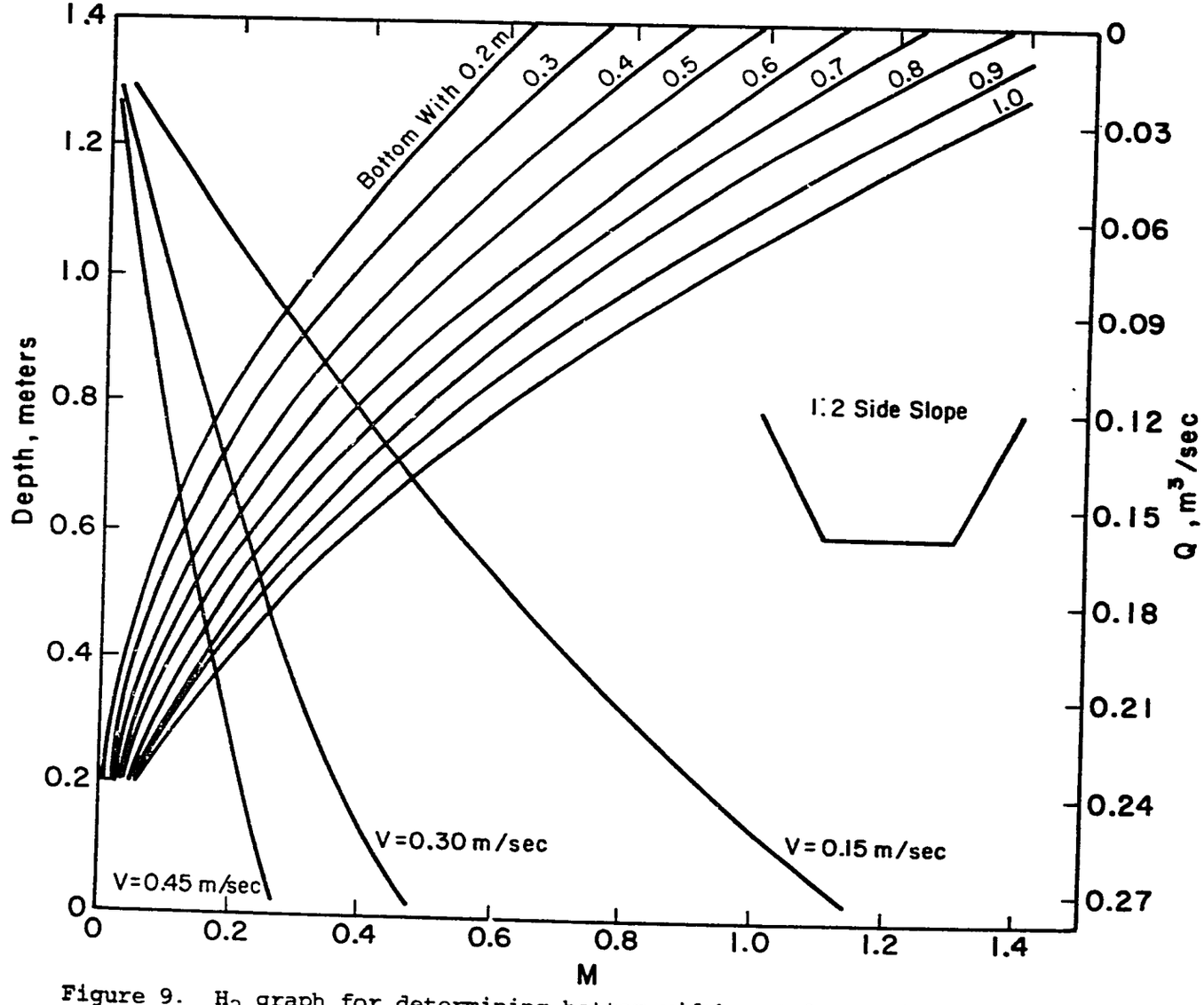


Figure 9. H_2 graph for determining bottom width and depth width side slope 1:2 by Hayat's method.

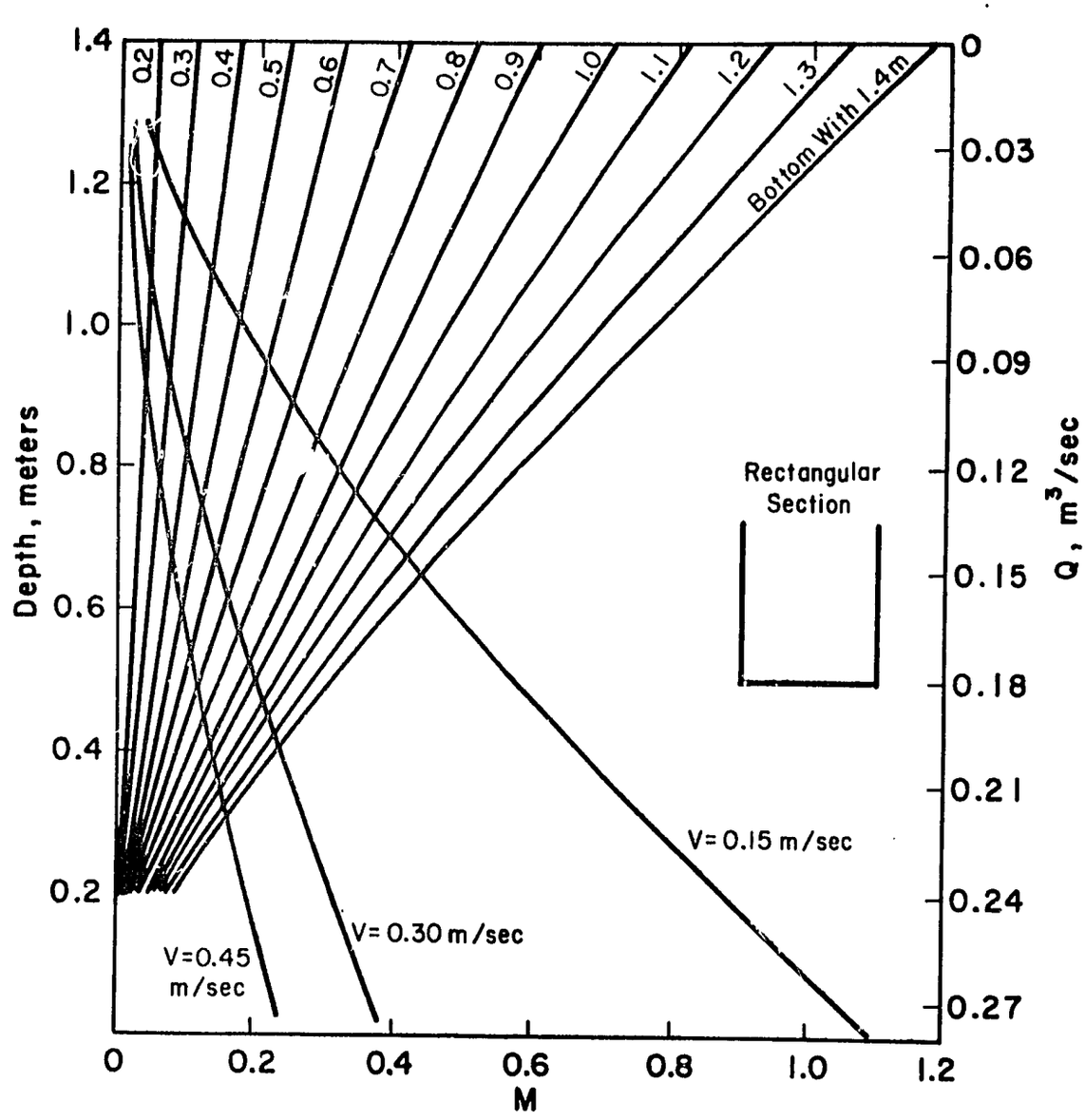


Figure 10. K graph for determining bottom width and depth when Z = 0 (rectangular section) by Hayat's method.

Alternatively, if one desires to keep the depth constant, he proceeds up the M line until he reaches the desired depth and then interpolates between the set of "bottom width" lines nearest the intersection of the appropriate slope and M lines. The lines (in Figures 5,8,9 and 10 labelled 0.15, 0.30, 0.45 and 0.60 meters per second are the lines representing the combinations of flow rate and M values that can be used to obtain the respective average velocities. This allows one to estimate quickly whether the flow-rate in the designed watercourse is near that desired by noting the relative position of the intersection of the respective M and Q lines relative to the V lines.

D. How to Use Figures 4,5,7,8,9 and 10 to Facilitate Watercourse Design and Improvement

1. Basic Information Needed to Design Watercourses

a. Flow rate to be handled

This can be measured using any of several measuring instruments. Calibrated flumes of the cutthroat variety are one of the least expensive devices, and are manufactured in Pakistan. The delivered flow rates should be checked against authorized flow rates to determine whether you are helping the farmers obtain their fair share of the water, or more.

b. Elevation of land to be served

If only the main watercourse is to be reshaped and realigned, fully supply operating levels of water in all of the branches where they leave the main channel is adequate elevation information unless the farmers are having difficulties irrigating some of their fields with the existing system. If a field is so high that overtopping of watercourse banks occurs when that field is being irrigated, design calculations should start at the elevation of that field and work back to the mogha. If the whole watercourse system is to be renovated a topographic map should be made with elevations determined for each bunded area.

c. Elevation of the Water Supply

The elevations of the operating water surface in the canal and the water surface just below the mogha, when the authorized flow rate is occurring through the mogha, are necessary. A common problem, particularly in watercourses

supplemented by tubewells, is that the water level in the watercourse rises so high that it "submerges the mogha" reducing the flow of water through the mogha from the canal. Consequently, it is also essential to know the difference between the canal and watercourse water levels needed to obtain the full authorized flow through that mogha.

d. The elevation of the land along the watercourse channel

These elevation profiles should be fairly detailed if the land surface has considerable irregularity. On most watercourses in the Indus Basin an elevation every 30 to 33 meters will be sufficient and can be matched to the acre lines.

e. Elevations of Existing Watercourses

If the design will involve modification of existing channels, the bed and bank levels of those channels should be determined at 30 to 33 meter intervals, particularly at all junctions.

2. Watercourse Design (An Example)

a. Given:

i) A bunded area map of a watercourse command area showing the elevation of each bunded area and location and length of existing watercourse channels and location of traffic routes and existing culverts.

ii) Full supply level of the canal at the mogha (elevation = 9.84 meters) with respect to a benchmark taken as 10.00 meters on the mogha top.

iii) Authorized and measured supply of water from the mogha of 0.142 cubic meters per sec (Musecs).

iv) Measurements showing average losses from the watercourse are 0.038 Musecs/1000 meters when full supply is furnished at the mogha, and previous experience which shows that by alignment and reasonable earthen improvement and installation of pakka control structures this loss can be reduced to 0.019 musecs/1000 meters.

v) A committee representing the water users has asked you to design their new watercourse giving them the full supply level necessary to provide water to all bunded areas at a full supply level at least 0.15 meters above the surface of that field, with the main watercourse to have a freeboard of 0.24 meters and the branch watercourses to have a freeboard of 0.15 meters. They have also agreed to a general design for their watercourse of trapezoidal channels with a bed width of 0.61 meters, 1:1 side slopes, and banks at least 0.45 meters wide at the top. They are willing to continue handling the sediment by cleaning the watercourse and there is no convenient location for a sediment removal trap, so you do not consider sediment in your design.

vi) Concrete control structures are available which have round orifices of 0.381, 0.458 or 0.508 meters diameter and concrete pipe culverts are available with internal diameter of the same size.

vii) Roughness coefficients for operating earthen channels in this area have been measured at about 0.04.

b. Procedure:

i) Inspection of the elevation map shows that the least average slope from the mogha to any bunded area in this watercourse command is to a field (elevation 8.960 meters at the end of a 183 meter private sub branch which leaves branch C at 671 meters from the junction of branch C with the main channel which is 671 meters from the mogha. The authorized main channel ends at 1342 meters from the mogha and there is 134 meters of private watercourse from that point to the last field served by the watercourse. This field has an elevation of 8.743 meters.

ii) First a design work sheet such as shown in Table 1 is prepared for the least average slope section which begins at the end of the 183 meter sub branch taking off from branch C and ends at the high field. Beginning with the field elevation of 8.960 meters the recommended working head of 0.153 meters is added to obtain the full supply

Table 1. Design Worksheet (for branch watercourse).

Station (meters from main watercourse)	Description	Depth	Q Flow Rate (musecs)	Head Loss & F.S.L.
854	Elevation of field most difficult to serve			8.96m
	Recommended working head			.15
	Design full supply level in watercourse at field		0.114	9.11
	183m sub branch channel @ 0.0002	0.60		
671	Elevation below double 0.508m check structure			0.01
				9.15
	Head loss through double 0.508m nakka			0.01
	Elevation above double structure			9.14
	335m branch channel @ 0.00025 slope	0.60		0.08
336	Elevation below combined c.s. + c		0.117	9.24
	Head loss through 0.508 m combined c.s. + c			0.03
	Elevation above structure			9.27
	336m branch channel @ 0.00025 slope	0.61		0.08
000	Elevation below double check structure		0.123	9.35
	Head loss through double structure			0.01
	Elevation above double check structure		0.129	9.36

level in the sub branch of 9.112 m at 183 m from branch C. Since this branch is the most difficult to serve, the head loss along the channel should be kept at a minimum to avoid raising the main channel up out of the ground any further than necessary. Consequently, a minimum slope of 0.0002 meters/meter is assigned to the 183 m sub branch back to where it joins channel C. Using Figure 4 for S = -.0002 at a flow rate of 0.113 musecs, a Ch value of 8.2 is found. This Ch value intercepts the N = 0.04 line at M = 0.33 and it is found that a depth from operating level to bed level of 0.60 meters is needed to accommodate this flow. The head loss through a 0.508 m diameter orifice check structure from the main branch to the sub branch (where the flow will be about 0.116 musecs assuming 0.142 musecs at the mogha and 0.019 musec/1000 meters loss) will, according to Figure 1, be about 2.6 cm (i.e. 0.026m). This is more head loss than desired at this point. Check structures of larger diameter could be constructed, however the 0.508m diameter size is about as large as a "small farmer" can manage physically. Other designs should be developed. However, given the availability of these 0.508m diameter structures and a desire to reduce this head loss, another alternative is to place two of these orifices side by side in the channel. Since the head loss is a function of the square of the flow rate through the structure, this use of a double orifice reduces the head loss from 0.027 meter to about 0.006 meter across the check structure at this juncture of the sub branch with branch C.

Keeping the head loss low in the section of C from 671 meter to 335.5 meter at 0.00025 slope of the full supply level of water in the watercourse requires a depth of about 0.595 meter and results in a head loss of 0.082 meter through this section in which the estimated flow is 0.121 musecs. Assume that a check structure is needed at 336 meters and that a culvert is also needed in this vicinity. As discussed in detail at another point, proper coupling of a round culvert and check structure together can allow a single head loss practically equal to the head loss of either one singly, so they should be coupled when minimum head loss is desired. A structure using two culverts (and two control structures) could

further reduce the head loss, but is not recommended because it would be expensive. The coupled culvert and check structure would cause about 0.03 meter of head loss (at a full supply flow rate of 0.121 musecs) bringing the operating level above this structure to 9.27 meter.

Maintaining the same slope in the first 335.5 meter of branch C as in the 336 to 671 m section, requires a slightly greater depth of channel because the average flow in this section is estimated to be 0.006 musecs higher at 0.121 musecs rather than 0.115 musecs. The head loss in this section will be 0.085 meters.

At the junction of branch C with the main watercourse a double 0.508 meter orifice structure is recommended again to keep the head loss at a minimal 0.006 meters, and consequently the full supply level in the main watercourse at this junction can be kept down to 9.36 meters.

Calculations used to the section from this junction back to the mogha on the main channel are shown in the design worksheet in Table 1. At the mogha allow 0.076 meter for head loss to maintain free flow in the mogha and another 0.076 meter to allow for head increase in the channel due to silting and plant growth between cleanings.

The average slope of watercourse in this section may be calculated by taking the canal supply level minus the desired working head at the field, 8.89, (= 9.84 - 8.89 = 0.95) subtracting the head losses at all the structures, and dividing the remainder by 671 meter distance.

Assuming the structures indicated in Table 2 at 152.5, 335.5 and 503.25 meter along the main channel and flow rates of 0.139 musecs, 0.136 musecs and 0.133 musecs at these points respectively (due to decrease in flow of 0.019 musecs/1000 m and diameters of 0.58 m, 0.509m and 0.509m of the control structures at these respective points, head losses of 0.058m, 0.037m and 0.034m would be encountered for a total head loss of 0.129m leaving an allowable head

Table 2. Design Worksheet (for branch watercourse).

Station (meters from main watercourse)	Description	Depth	Q Flow Rate (musecs)	Head Loss & F.S.L.
1476	Elevation of the field to be served		.112	8.74m
	Recommended working head			.15
	Designed full supply level in branch channel			8.89m
	134 m branch channel @ 0.00045 slope	1.60		.06
1342	Elevation below 0.5083m check structure		.115	8.95m
	Head loss through 0.5083m check structure			.03
	Elevation above check structure			8.98
	336 m Main channel @ 0.0004 slope	1.71		0.13
1006	Elevation below check structure		.122	9.12
	Head loss 0.5083 m check structure			0.03
	Elevation above check structure			9.14
	167 m Main channel @ 0.00042 slope	1.73		.07
839	Elevation below 0.4575 m culvert		.125	9.21
	Head loss through 0.4575 m culvert			.05
	Elevation above culvert			9.26
	168 m Main channel @ 0.00038 slope	1.81		.06
671	Elevation below check structure		.129	9.28
	Head loss through 0.5083 m check structure			.03
	Elevation above check structure			9.36
	168 m Main channel @ 0.0003	1.90		.05
503	Elevation below check structure		.132	9.41
	Head loss through 0.5083 m check structure			.03
	Elevation above check structure			9.44
	168 m Main channel @ 0.0003 slope	1.92		.05
335	Elevation below combined 0.5083 m c.s. + c.		.135	9.49
	Head loss through combined structure			.04
	Elevation above combined structure			9.53
	183 m Main channel @ 0.0003 slope	1.95		.05
152	Elevation below 0.4575 m culvert		.139	9.59
	Head loss through 0.4575 m culvert			.06
	Elevation above culvert			9.65
	152 m Main channel @ 0.0003 slope	2.00		.046
000	Elevation at mogha		0.142	9.69

loss for 671 meter of channel of 0.204 meter and a slope of 0.0003.

Below the junction with branch C, the land slopes off more rapidly and the slope of the main channel is increased to keep the channel down as low as possible and still give adequate head at junctions with other branches. The slope is increased gradually rather than abruptly to avoid having the channel become shallower abruptly and thereby cause dead storage in the section above the steeper channel.

When these design work sheets for these and the other branches are properly matched at all junctions and otherwise completed, they should be graphed as indicated in Figures 11 and 12 for the main channel and branch C respectively. From these figures the the check and alignment sheets shown in Tables 3 and 4 may be constructed. These check and alignment sheets should be in a form which may be taken to the field on a clip board or in a field book, and they are used for:

(a) setting elevations bed and bank levels and width from shoulder to shoulder of the watercourse.

(b) setting elevations for concrete control structures and culverts,

(c) checking all elevations with established bench marks.

3. <u>Problems and Their Solutions</u>

a. When the tubewell is on, the water level in the watercourse is almost as high as that in the canal and authorized canal flow is not drawn into the watercourse from the canal. The solution is to lower the level of the water at the head of the watercourse. This can be done by increasing the depth and/or width of the channel, and by decreasing the roughness coefficient through removal of grass, weeds, etc., from the channel. The question to be answered is how much enlargement or cleaning is necessary.

i) First assume that the head of this main channel is fairly free of grass and weeds so the roughness coefficient is about 0.04 and cannot be appreciably reduced. Further assume that the land most difficult to get water on because of its elevation and distance down the watercourse is a field 1,220 meter from the mogha with an elevation 0.915 meter lower than the operating surface of water in the canal. Also, assume that the watercourse should be carrying 0.099 musecs of water, composed of 0.037 musecs canal water and 0.062 musecs of tubewell water.

A difference in head of 0.076 meter across an open flume mogha is generally sufficient to achieve free flow. However, sedimentation, weeds, etc., will reduce the carrying capacity of the watercourse channel with time and increase the water level at the head of the watercourse. Consequently, to avoid mogha submergence before the next cleaning operation another 0.076 meter of head drop should be arranged at the mogha, for a total designed head loss from canal to head of watercourse of 0.152 meter.[1]

To push the water out onto the land at the point 1220 meter down the watercourse, the operating surface of water in the watercourse should be at least 0.15m above the land surface. Consequently, the total elevation drop between the operating surface at the head of the watercourse and at 1220 meter is 0.61 meter and the average slope is 0.61/1220 = 0.0005.

Using Figures 4 and 5 with a flow of 0.099 musecs at a slope of 0.0005, we can calculate that the water in this channel (trapezoidal 1:1 side slopes and 0.61m bottom width) should be about 0.43 meter deep and the average velocity of the water will be about 0.21 meter/second.

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[1]Other types of moghas such as pipe nakkas, or flumes with head blocks will require more head loss for authorized flow. To determine the effect of water level in the watercourse, install a flume within 10 to 20 feet of the mogha, turn off the tubewell and measure the flow through the flume and the water level between the mogha and the flume as it drops.

However, if 6 check structures and two culverts should be installed on this watercourse they will cause some head loss. If each of these have round 0.508m diameter openings, according to Figure 1, the head loss on each will be about 0.018m and the total head loss due to six check structures and two culverts will be 0.144 meters. This leaves a total head difference to push water through the 1220 meter channel of 0.61-0.144 = 0.466 or an average slope of 0.466/1220 = 0.00038. Using the flow rate of 0.99 musecs and the slope of 0.00038 in Figure 4, a Ch of 4.3 and an M of 0.17 are found and using this value of M in Figure 5 with a bottom width of 0.61 meters we find that the depth of the channel should be 0.47 meters when these structures are in place.

Check structures can be constructed which cause less head loss. However, they will generally cost more and leak more. These "costs" should be compared to the labor required to dig the trapezoidal channel deeper (0.04m deeper in this case), and the value of the extra land used by the larger (wider) channel.

ii) As an alternate set of assumptions assume that there is considerable vegetation in the channel, that the channel has 0.76m of head loss in 1220m and is trapezoidal in shape with 0.61m bottom width and an operating depth averaging about 0.55m.

The mogha is completely submerged and no water is entering the watercourse from the canal, but 0.071 musecs of water is flowing from the tubewell.

We wish to estimate the roughness coefficient of the channel and determine how much the water surface can be dropped just below the mogha by cleaning the watercourse to reduce the roughness coefficient to 0.04.

First, the slope is 0.76m in 1220m or 0.00063, the depth of the water in the trapezoidal channel is 0.55m and the flow is 0.071 musecs. To estimate the roughness coefficient use Figure 5 with depth = 0.55 and bottom width = 0.61 to locate M = 0.28. Locate this value of M on Figure 4 and follow it

from the interpolating between the 0.06 and 0.09 musec lines, one finds the roughness coefficient of about 0.10.

The effect of cleaning the watercourse and reducing N to 0.04 on decreasing the level of water just below the mogha can be estimated by using Figure 4 and the same slope (0.00063) and the same flow rate (0.071 musecs) to obtain a Ch value of 2.8 and a roughness coefficient N = 0.04 an M value of 0.12. Taking this M value to Figure 5 at a bed width of 0.61 meters, the depth after cleaning will be 0.37 meters.

If the authorized supply from the canal for this mogha is 0.037 musecs the total flow at the head of the watercourse should be 0.037 + 0.071 = 0.108 musecs. This flow rate would raise the water level in the channel to a depth of 0.43 meters, which is only 0.55 - 0.43 = 0.12 meters lower than it was before cleaning.

A drop of 0.12 meters in many moghas is not sufficient to deliver the authorized rate of flow.

To obtain their authorized supply they will have to reduce the full supply level at the head of the watercourse which will require deepening their watercourse and reducing its slope. Assume you've checked the flow rate from the canal at reduced level of the watercourse as discussed in the footnote on page 148 and have found that 0.20 cm of head loss at the mogha provides authorized discharge. Reducing the elevation, allowing the farmers an extra 0.10 cm of head to take care of roughness developing between cleanings, the full supply level below the mogha should be 0.30m below the canal leaving a total head difference over the 1220m distance of 0.46m and a slope of 0.46/1220 = 0.00038. At this slope and flow rate (0.108 musecs), from Figure 4, Ch = 5.5 and M = 0.225. Taking this M value to Figure 5, at a bottom width of 0.61m, the depth of watercourse required will be 0.50 meters below the full supply level.

Since the full supply level at the head of the watercourse is to be dropped by 0.30

meters from the canal level, the new bed at the head of this watercourse should be at least 0.50 + 0.30 = 0.80 meters below the canal supply level and should have a slope of 0.00038 as it goes toward the tail of the watercourse.

Consequently, our recommendation to the farmers would be that if they want to obtain their fair share of the canal water they should:

(1) Clean the weeds and vegetation from the channel.

(2) Excavate and maintain the bottom of the channel at the head of the watercourse to a depth of 0.80m below the canal water level with a bottom width 0.61m wide and side slopes 1:1).

(3) Watch the level of water below the mogha and whenever it gets up near 0.20m of the canal level, arrange for cleaning and maintenance of the watercourse channel.

To help motivate them to clean and maintain the channels at designed cross sections we can tell them that losing their canal supply by complete submergence would cost them about 0.8 acre meter of water per day and that the value of this water in crop production has been estimated by experts (Eckert et al 1975) as over Rs 900/ acre meter. Or in other words, when they allow the channel to degrade and submerge their mogha they are allowing themselves to lose up to Rs 720 per day. If their tubewell water is slightly saline, the need for canal water to dilute that salinity to acceptable levels is another motivating factor that most farmers will understand.

b. <u>Less than 30% of the watercourse supply is reaching the farmers at the lower end of the watercourse</u>.

This problem is common. In some cases it may be due to highly permeable sandy soils. However, the most frequent cause of this problem is poorly maintained, leaky watercourses.

i) Assume that you have walked along this watercourse when it was in use and have observed much vegetation in the channel, occasional overtopping and frequent leaks through the upper portions of the banks.

You wish to predict how much the operating water level in the channel can be lowered by cleaning the watercourse and reducing the roughness coefficient to 0.04. Assume that you've found that the flow rate is .057 musecs, the slope is 0.0006 and that the channel bottom width is about 0.30 meter with 1:1 side slopes and the present operating depth is 0.54 meter. Figure 5 for 1:1 side slope shows that for a bed width of b=0.3m and depth of 0.46 meters, the appropriate M value is 0.12. Taking this value to Figure 4 where it crosses the 0.06 cusecs flow rate line, we obtain a value of Ch=3.9. Following up this value of Ch to where it meets the slope = 0.0006 line, we find the intersection is almost on the N = 0.08 line.

From Figure 4, for Q = 0.057 musecs, S = 0.0006 and N = 0.04, Ch = 2.2 and M = .11. Using this value in Figure 5 for a bottom width of 0.30M the necessary operating depth is 0.45m. In other words, cleaning the channel and reducing the roughness coefficient from 0.08 to 0.04 will reduce the operating depth from 0.54 to 0.45 meters.

In most watercourses, such a reduction in operating level will not only prevent overtopping, but will help bring the water level below most of the rodent and insect holes which are primary causes of loss. The result will commonly be more than 50 percent reduction in water loss in that section of the watercourse.

ii) Most of the watercourse banks appear to be in good condition. The farmers asked you to increase their delivery and have promised to reconstruct, clean and maintain the channel to your specifications.

You have walked along the watercourse and have observed that six junctions on the main watercourse are primary sources of leakage. There are also 8 points on the main watercourse where animals crossing the watercourse have caused deterioration and leakage. Your

estimates (or preferably measurements) indicate that 50 percent of the water loss occurs at these junctions and crossings. Other than these primary points of leakage, the banks of the watercourse appear to be in good condition. This main channel is 1525m long and the junction points are 295m, 569m, 823m 1098m, 1281m and 1525m from the mogha. The mogha is not submerged when the tubewell is operating and the operating water level below the mogha is 0.275m below a well defined pakka reference point on the mogha structure which can be used as a 0.00 bench elevation mark.

You have measured the effect of water level below the mogha on flow rate through the mogha and the levels of water in the canal, and in the watercourse with the tubewell on and off (generally as recommended in the footnote on page 149). You have obtained the data shown in Figure 11. The farmers told you on the day that you took this data, that they planned to clean this watercourse the following week. So it appears that they are judging their delivery system correctly and cleaning the watercourse just before the increasing level at the head begins to reduce their delivery.

However, it is apparent that they cannot raise the operating water level at the head of the watercourse appreciably without reducing their supply. The present operating levels at the junctions with respect to the bench mark are -0.386, -0.500, -0,636, -0.759, -0.890 and -0.920 respectively.

You've decided to install pakka control structures at the six main junctions, and 3 concrete culverts, 4 of which could be immediately adjacent to junctions 1, 3,5 and 6, and the other 4 are needed midway between junctions 4 and 5 and midway between junctions 5 and 6. The combined canal and tubewell supply is 0.108 musecs.

You wish to calculate the size of the channels necessary between the various junctions to carry the flow rate, assuming that after improvement the loss will be reduced from 0.04 musecs per 1000 meters to 0.02 musecs per 1000 meters and that the flow in the reaches between the mogha and junction 1, junctions 1 and 2, 2 and 3, 3 and 4, 4 and 5, 5 and 6 will average 0.099, 0.094, and 0.088, 0.082, 0.976 and 0.071 musecs respectively.

To keep the operating head at about the same elevation, when you cause a headloss by installation of a structure, you must compensate by increasing

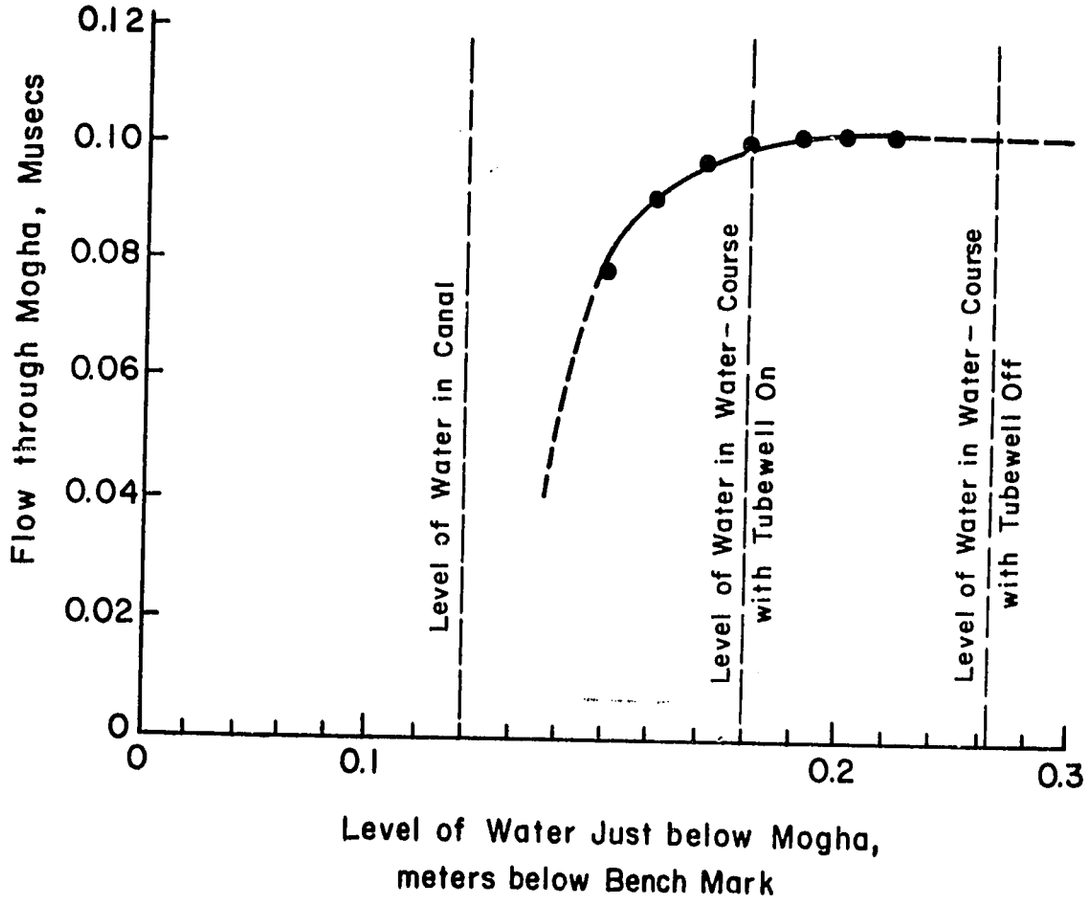

Figure 11. Data for deciding design level at head of the watercourse.

the cross section of the channel between structures to decrease the head loss in the channel.

This balance can be achieved by installing structures so large that they cause practically no head loss, consequently the channel can remain essentially the same size as the original. However such large structures are expensive and the least expensive balance is generally achieved by using a medium sized structure with moderate increase in channel size.

In section 1 (mogha to first junction) the flow rate averages 0.099 musecs. One culvert is necessary, the designed operating level at the top will remain at -0.275m and the operating level at the first junction should remain -0.386m so your total head loss in this first section can be 0.11m in 274m. This head loss is to be divided between that occurring in the channel and that at the culvert. Assume that cost and transport of 0.458m diameter concrete culverts are Rs. 140 as compared to Rs. 180 for 0.508m diameter culverts. At 0.099 musecs discharge the 0.458 diameter and 0.508 diameter culverts, according to Figure 1, will cause 0.032 and 0.018m of head loss respectively. The head loss remaining to push water through the channel would thus be 0.079m or 0.098m in 274m for the 0.458m and 0.508m diameter culverts, for average slopes of 0.00029 and 0.00034 respectively. Going to Figure 4 for a channel with a slope of 0.00029, a flow rate of 0.099 musecs (interpolated between 0.09 and 0.12)n^3/sec lines a Ch value of 5.9 is found, which coupled with a roughness coefficient of N = 0.04 yields an M value of 0.234. Using M = 0.234 in Figure 5 with a channel 0.61m wide shows that the depth should be 0.51m. Using the bigger (0.508m dia.) culvert the slope of the channel was 0.00034 and the channel depth should be 0.48m. It would require about 16.8m^3, (= 0.03 x 2.04 x 274) of extra excavation for the 274m section to go from the 0.48m to the 0.51m depth. Farmers have been observed to excavate earth at an average rate of about 0.5 cubic meter per hour, and at that rate could accomplish the extra excavation in about 33 man hours. In addition to being deeper, the channel will be 0.08m wider (1:1 side slope) and in 274m will occupy 22 square meter more land. Since land is valued at about Rs. 2.5/square meter, the farmers lose about Rs. 55 in land value by going from the 0.508m to the 0.458m culverts. If they are paying for the culverts, the land and doing the excavation they will prefer to pay the extra Rs. 40 for the larger culvert rather than spend 33 man hours

and Rs. 55 of land in making the channel larger. They will therefore prefer the 0.508m rather than the 01458m culverts.

At the start of section 2 the 0.508m diameter orifice check structure can be combined with the 0.508m diameter culvert and a head loss of 0.018 (0.094 musecs) at that combined structure[1] will leave the operating water level below that structure at an elevation of -0.404m. The total difference between -0.404 and -0.500m may be used to push the water through this 274m section so the slope can be 0.096/274 = 0.00035. According to Figure 4, at this slope and at an average flow of 0.094 musecs and a roughness coefficient of 0.04, M = 0.26 and from Figure 5, we find that the depth (from operational level to channel bottom) should be about 0.47 meters.

Section 3 begins at junction #2, including that check structure and extends 274 feet, including the culvert midway between those structures. The large 0.508 orifice check structure and culvert will again be the best bargain for the farmer. However, they cannot be joined together and consequently each will have its own head loss. At an average flow rate of about 0.088 musecs the head losses at these structures will be 0.015 meters each, for a total of 0.030. The total head loss allowable between junctions 2 and 3 is 0.636 - 0.500 = 0.136, and the head difference available to push water through this 274 foot long channel will be 0.00039 and following the previous procedure (assuming N = 0.04) the depth in this channel should be 0.44m.

This type of calculation can then be continued for the 4th, 5th and 6th sections.

[1]Head loss in these culverts and orifice check structures is primarily a result of energy needed to increase the velocity (Kinetic energy) of the water to the speed necessary for the flow rate to go through the restricted cross section. Only a small portion of the head loss is caused by side friction in short sections such as culverts which are only 2.44 or 3.05 meters long. Consequently, coupling together for a culvert and a check structure of equal diameter, so there is no opportunity for the average velocity to decrease due to eddy turbulence, will generally result in a head loss approximately equal to that occurring at a single culvert or a single check structure.

Other Preparations

Before starting the design, the Irrigation Department should be contacted to determine the designed full supply level in the canal (or distributary or minor). They can often furnish characteristics of the mogha which will let you know how much head loss between canal and watercourse is necessary to achieve the authorized discharge through the mogha of interest.

A copy of the new watercourse plan should also be provided to the farmers so they can send it to the irrigation department for approval and adjustments of warabundis to account for new positions of turnouts, etc.

Most farmers will want a check structure at every turnout. On watercourses with little slope, a large number of check structures on the main channel causes an intolerable head loss. Consequently, on these watercourses the number of check structures should be kept to the minimum required to control the water without overtopping. Farmers who have to fill up lengths of watercourse beyond their turnout should be compensated by time added to their watercourse.

A Final Word

Remember--you can help the farmers. You know more about designing watercourses than they do. However, it is their watercourse and they must accept your design or it will not last long after you leave.

Avoid arguments with individual farmers. As a farmer asks you for structures and culverts that would not be to the advantage of the whole group, explain the reasons why you think he should not have it. If he continues to insist, tell him to come to a future meeting of the watercourse users association where you explain the problem to the whole assembled group, make your recommendation and then ask the group if they want to accept your recommendation.

You will have to work hard and be a teacher and a diplomat to successfully help these farmers improve their watercourse. However, you will have much lasting satisfaction if you do a good job. They will remember you for the rest of their lives.

Appendix 9

PAKKA STRUCTURES FOR IMPROVED WATERCOURSES THEIR DESIGN, CONSTRUCTION AND USE[1]

M. Akram, W.D. Kemper, Iqbal Hussain, William E. Hart, Bashir Ahmed, Sidney Bowers, Javaied Iqbal and Mohammad Azeem[2]

BACKGROUND

Evaluation of existing watercourses has shown that an average of 50 percent of the water entering watercourses is lost before it reaches the fields. This degree of loss points out a great potential for increasing water supplied to the fields through watercourse improvement. Almost half of this loss was found to occur in the vicinity of junctions in the watercourse where banks have been weakened by weekly borrowing of soil from the banks and adjacent fields to construct earthen dams at the junctions (Kemper and Akram 1975).

To determine the best methods for saving this water and increasing delivery to the fields, several types of watercourse improvements have been made on watercourses in Mona Project areas. These included:

(1) Watercourses with rectangular cross sections with 13 1/2" thick, 9" and 4 1/2" thick brick walls and with 6" thick soil cement brick walls.

(2) Trapezoidal sections using brick or concrete of 3 mixes.

(3) Earthen improved sections including (a) completely rebuilt banks and (b) simple augmentations of the banks by adding earth to them.

As an integral part of these watercourses, several types of water control structures have been developed and installed. The costs of these improvements have been determined and their benefits are being evaluated. At present it appears that

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[1]Studies conducted by the Mona Reclamation Experimental Project and the Colorado State University water management research project personnel.

[2]Junior Agricultural Engineer, MREP, WAPDA; Chief-of-Party, CSU Field Party; Sub Engineer, MREP, WAPDA; Agricultural Engineer, Colorado State University, Fort Collins; Junior Agricultural Engineer, MREP, WAPDA; Agronomist, CSU Field Party; Junior Agricultural Engineer, CSU Field Party; and, Junior Agricultural Engineer, MREP, WAPDA, respectively.

earthen improved sections with concrete control structures have the highest benefits to cost ratio. The cost of saved water using this type of improvement ranges from 10 to 30 man hours of work per acre foot of water which is considerably less expensive than other sources of water in Pakistan. However, the continued savings of water by such improvements is dependent on continued maintenance and cleaning. How to assure this continued maintenance and cleaning is a pressing problem which needs an early solution. An attempt has been made to improve the maintenance of an improved watercourse serving Tubewell MN 56L by hiring a Khal Chowkidar who works daily to improve water delivery to the fields. He also helps the farmers plan and schedule their cooperative cleaning and maintenance efforts.

PANEL NACCAS

Naccas have been a constant problem for water management. The farmer generally cuts a hole in the bank of the watercourse to let water into his field. This katcha nacca is closed by placing wet soil in the hole. When this soil dries, cracks often develop and subsequent flow of water in this branch will result in leakage of water through the cracks and occasional washouts. Millions of acre feet of water are wasted through such leaky naccas of the traditional watercourses of the Punjab each year.

Pakka Naccas are required in pakka lined watercourses, and are highly desirable in improved compacted earth watercourses to prevent deterioration at outlets and junctions. Basic design criteria for pakka naccas are:

1. That they stop the water flow with reasonable effort by the irrigator; and

2. That their cost be low and their life be long.

Katcha naccas, dug in a bank to let the water into adjacent fields often result in continued erosion of the watercourse banks as the water flows rapidly through these openings. Considerable soil is also carried away during opening and closing of the nacca if the water level in the watercourse is much higher than that in the field. This erosion and generally inadequate refilling of the breach are major factors deteriorating watercourses and leading to spillage loss.

In the lined watercourses serving Tubewell MN 78, steel gates were used. Some of the steel gates worked well. However, some of them were extremely hard to open and close and most of them had considerable leakage. In some cases it was possible to check this leakage by putting mud in front of these naccas. However, since the panels were vertical

and mud will only maintain a slope of about 45 degrees, a large amount of mud is required. The handles of many of these steel naccas were broken as a result of pounding by farmers who were trying to open or close those gates which were sticking.

These steel gates were manufactured locally and their quality was not consistent. During installation the steel frames were sometimes warped or the channels holding the slides were placed too close together, causing the sliding panel to bind and stick in these channels. Rust forming following their installation also increased the force necessary to move the steel slide.

FACTORS CONSIDERED IN SELECTION OF MATERIALS AND DESIGNS

Since Pakistan must import its steel, the cost of these gates exceeded Rs. 500 each. This plus their installation costs makes them economically unfeasible for use by Pakistani farmers. Low cost control structures were needed.

Cement is manufactured in Pakistan. Concrete control structures made of cement were designed in various forms, built and tested. These included concrete pipes with a 45 degree angle and collar and a lid flush with a bank with 1:1 side slope as shown in the bottom segment of Figure 1. Because of difficulty in getting good compaction around these pipes, cut off walls of concrete on the inside of the watercourse bank, (as shown in Figure 1) were often a practical necessity to prevent washouts alongside these structures. The cost of pipe naccas 12" ID and 6' long with a 45 degree angle, plus a lid essentially as shown in Figure 1, are currently about Rs. 100 each. They require about 7" of head loss to move 4 cusecs of water through them. If soil is carefully compacted around such pipe naccas, washouts around them will generally not occur and the total cost of purchase and installation is only about Rs. 120 each. When cutoff walls were installed their cost ranged from Rs. 10 to Rs. 50, depending upon the size of the cutoff wall. Consequently the total costs of purchase and installation of these pipe naccas ranged from Rs. 110 to Rs. 150.

Wooden forms were being used in construction of the lids and these warped slightly when wet, the result being the lids did not fit the collars properly. The manufacturer was invited to the site to see the problem. He then had steel forms machined and since that time has been doing a reasonable job of maintaining the quality and precision necessary to produce satisfactory concrete control structures. These control structures are built with a special groove designed to be filled with mud. If this mud seal is made properly there is no leakage. However, the farmers frequently

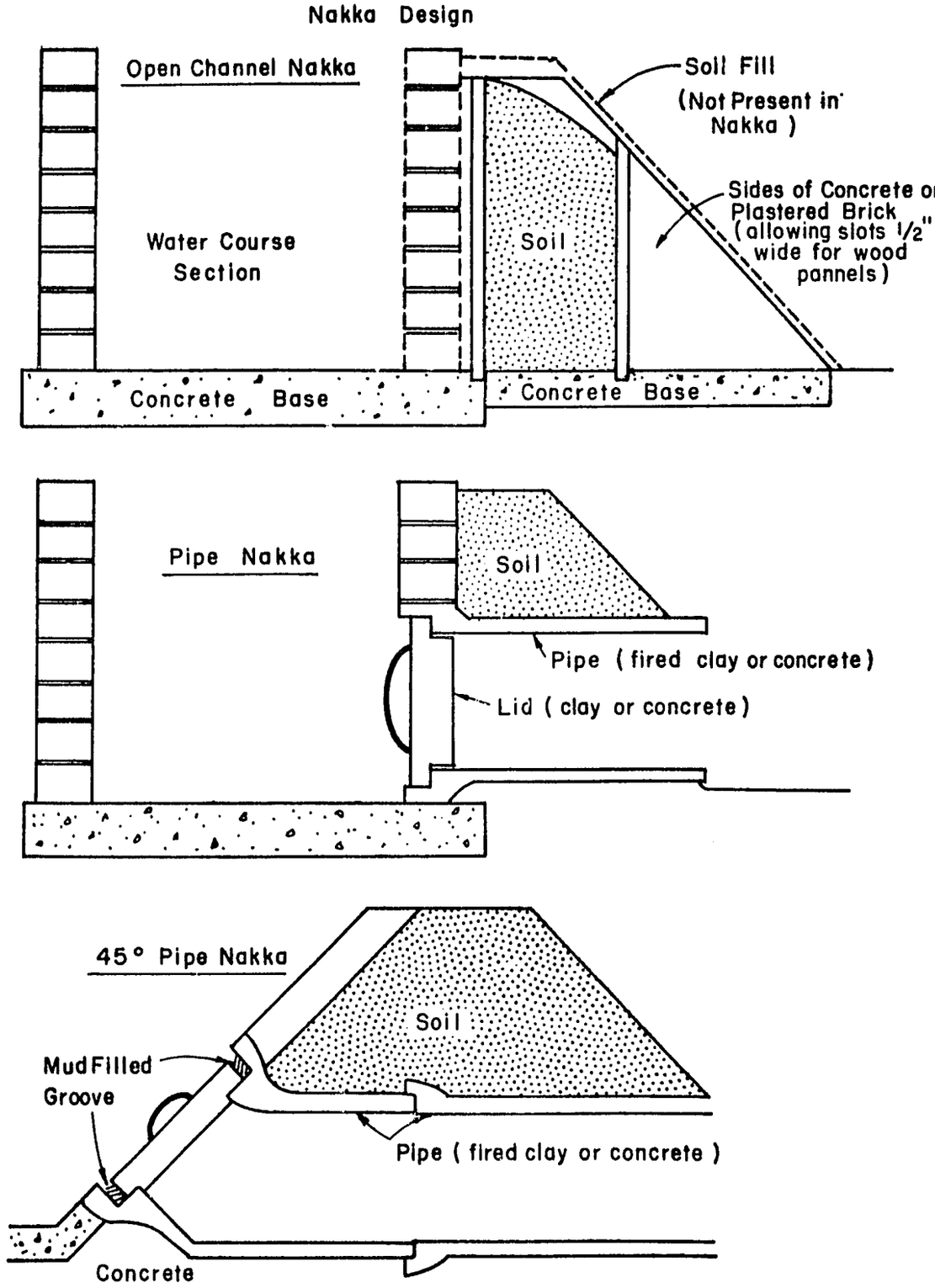


Figure 1. Design of low cost structures to control release of water from watercourses.

do not take the time to make this seal. The result is a small amount of leakage, generally less than 0.01 of a cusec.

The variant of these concrete control structures currently most popular for use at diversions involves panels such as shown in Figure 2 with circular orifices into which round lids fit. The present cost of the panel and lid is Rs. 50 for a 21" x 21" x 3" panel with a 15" diameter orifice and Rs. 60 for a 26" x 26" x 3" panel with a 20" diameter orifice.

Even when the farmers fail to properly fill the mud groove the loss of water through these panels is sufficiently small that it is generally less than the losses which the farmers had in the past when they had parallel water courses whose purpose was to reduce the number of offtakes from the main channel. These concrete control structures also reduce the time which a farmer spends in turning a 4 cusec stream of water from an average of about 20 minutes to less than 5 minutes.

LOSSES MEASURED THROUGH CONCRETE NACCAS

Leakage measured through these panel naccas installed on D branch of TW 78 watercourse are given in Table 1 below (Data of Trout and Akram, 1975).

Table 1. Losses through pakka naccas from "D" branch watercourse.

Nacca No.	Type of Nacca	Losses Gallons/ Minute	Losses Cu.ft/ Second
2	12" ID pipe with 45 angle	3.58	.008
3	" " " " " "	0.00	.000
4	" " " " " "	2.31	.000
5	" " " " " "	0.00	.000
6	" " " " " "	0.07	.000
7	20" panel with mud seal	17.02	.038
8	" " " " "	0.00	.000
9	" " " " "	0.00	.000
10	20" panel with rubber gasket	0.00	.000
11	" " " " "	0.00	.000
12	" " " " "	0.00	.000
	TOTAL	22.98	.054

The leakage through only one nacca, a panel nacca with mud seal, exceeded .005 cfs. It was improperly sealed, and later the leakage was stopped by a passing farmer. There was essentially no leakage from the panel naccas with rubber gaskets. These sponge rubber gaskets cost about Rs. 5 and last for about one year. However, in some locations these gaskets were torn loose from the lids and stolen. For this reason they may not be practical.

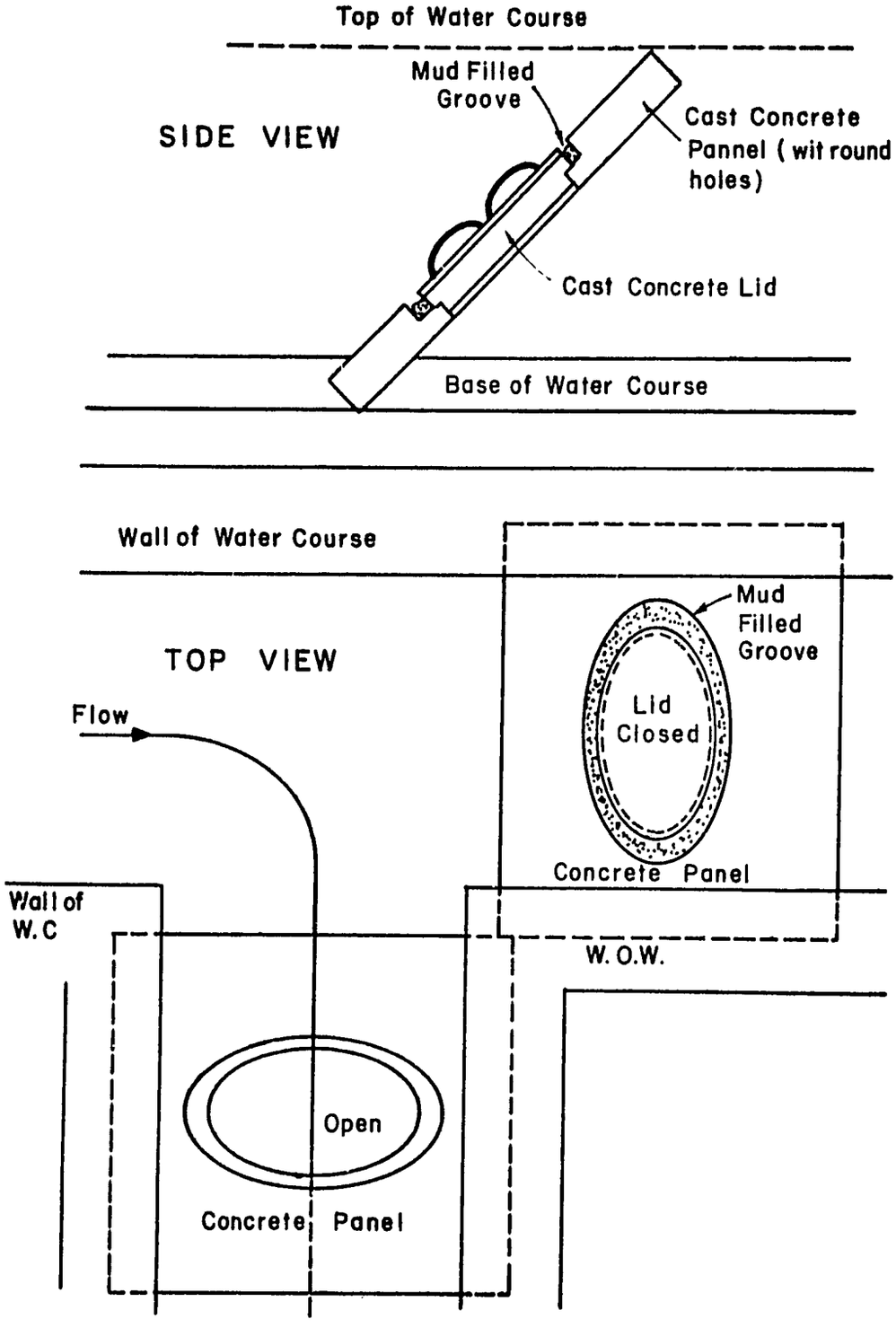


Figure 2. Diversion Structure.

Total losses from 11 naccas of the 4900 foot watercourse were .054 cfs or 1 percent of the total flow of 5.5 cfs. Seventy percent of these losses were from one nacca.

HEAD LOSS THROUGH PANEL NACCAS

Head loss is the difference in elevation of the water surface in front of and behind an open check structure. At some places we want head loss whereas at other places we wish to minimize head loss. Where the land surface has so much slope that water flowing in a channel of equal slope will cause erosion, we can reduce the slope between structures by increasing head loss at the structures or we can install more check structures and thereby use up a larger portion of the head so the channel slope can be smaller. In cases where slope is minimal we should decrease the head loss at structures by decreasing the number of structures or using structures with larger cross-section for flow. Since the head loss is a squared function of the rate of flow through an opening, placing two openings side by side in a channel reduces the head loss to 1/4 of the head loss occurring through a single opening of the same size.

To estimate the head loss through structures with submerged circular openings of different diameters with different flow rates, Figure 3 is attached. This graph has been derived from theory and the assumption that the total head loss energy (mgsh) is converted to kinetic energy ($1/2\ MV^2$) as the velocity of the water is increased from practically zero to a much higher value as it passes through the orifice. Actual head losses through the panel naccas are generally somewhat smaller than these simplified estimates because the water already has a finite velocity when it approaches the orifice. Structures similar to those in Figure 2 have been installed at different angles to the horizontal, standardizing the entrance and exit. Most of the panels have been installed at 45 degree angle or 65 degree angle. Head losses through these structures are being measured. The structures installed at 65 degree angle gives less head loss.

DESIGN AND PANEL INSTALLATION

Two sizes of concrete panel naccas were commonly installed at the Pilot Watercourses where flow varies from about 2 to 6 cusecs. One is 26" x 26" x 3" and has an orifice 20" diameter and the other is 21" x 21" x 3" and has an orifice 15" diameter costing Rs. 60 and Rs. 50 each respectively. The reinforcement and other specifications are shown in Figures 4 and 5. These panels were installed at angles from 45 degrees to 65 degrees from horizontal depending on the elevations needed at the top and bottom of the panels and whether minimum head loss was needed. Installation at 65 degrees results in lower head loss than when the

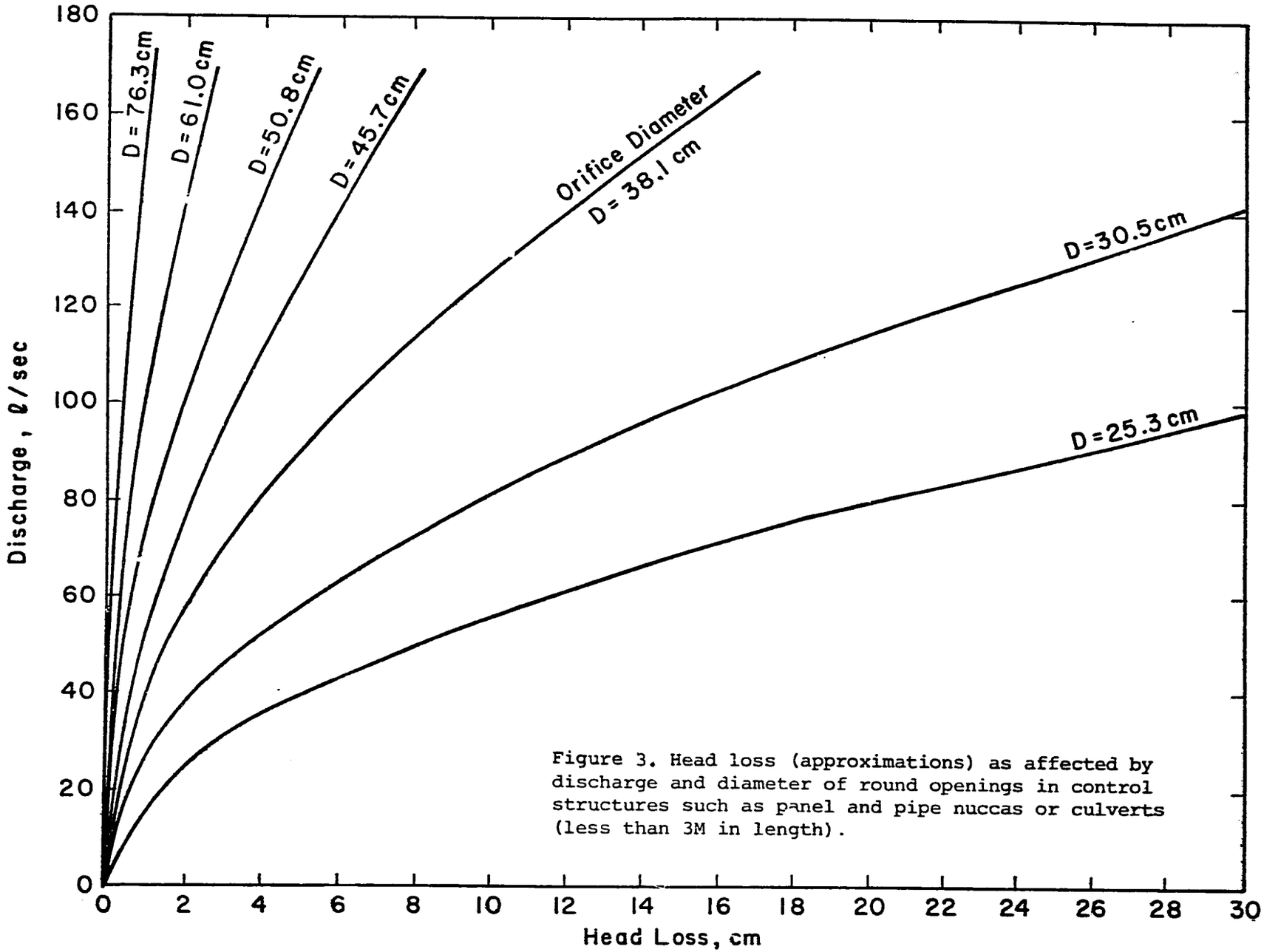


Figure 3. Head loss (approximations) as affected by discharge and diameter of round openings in control structures such as panel and pipe nuccas or culverts (less than 3M in length).

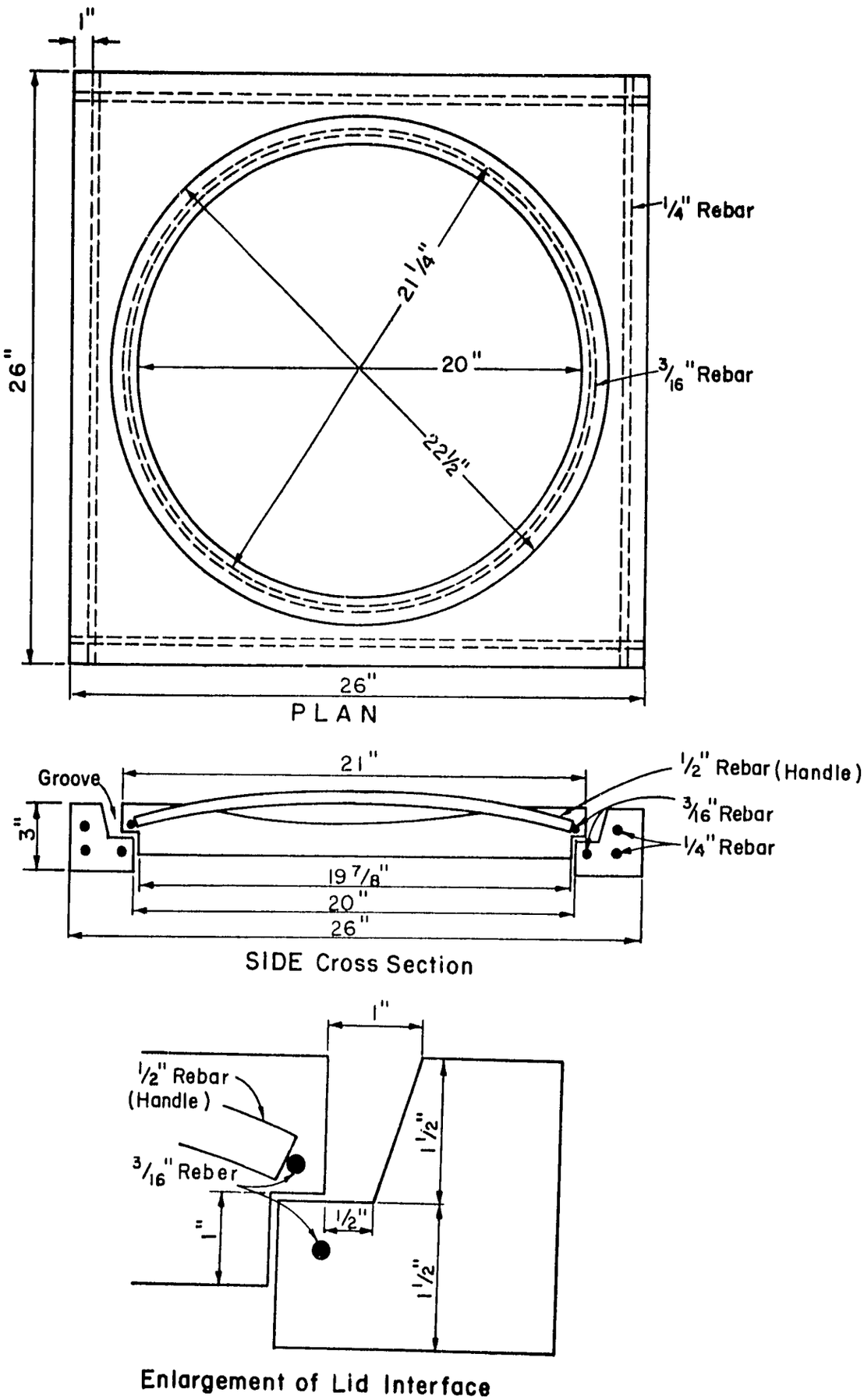


Figure 4. Details of the 20" orifice pannel and lid showing reinforcement.

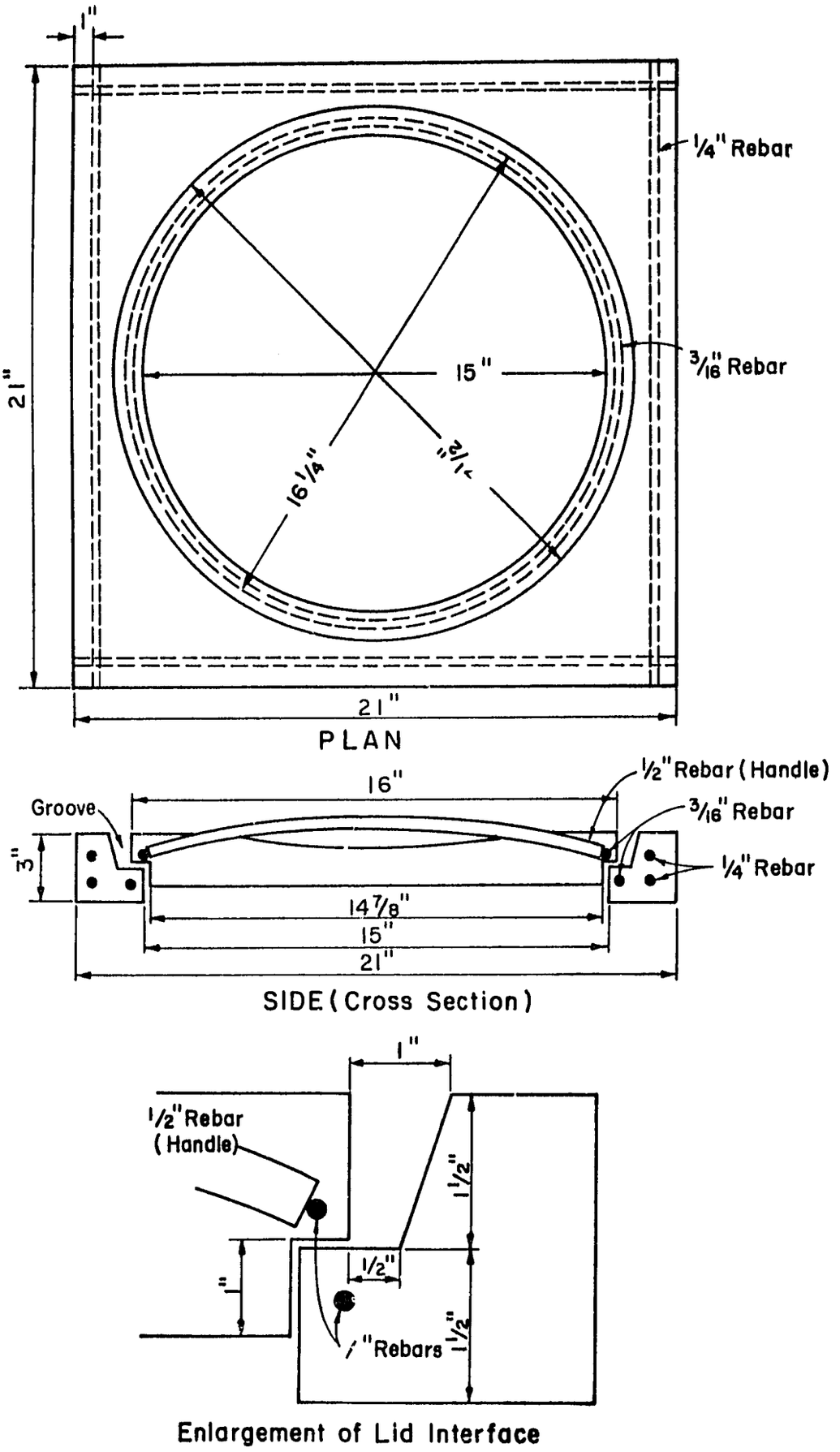


Figure 5. Details of 15" diameter orifice pannel and lid, showing reinforcement.

panels are installed at 45 degrees. In all cases the lids are still held in place effectively by gravity.

Several types of installation, including various shapes and sizes of wingwalls and abutments were tried at TW 78 and 56 for check and outlet structures. Diagrams and installation costs of these are given in Figures 6 through 15 along with comments on their merits and demerits. Recommendations for design and installation based on the experience and testing carried out to date are made at the end of this section.

BUFFALO BATHS

Animals are a constant problem in watercourses. The Holy Quran makes it clear that the priority of use of water is for man, then animals and then crops. Consequently, animals must be allowed to drink at agricultural watercourses. Observations of the watercourses indicated that many of the badly degraded sections had reached their deplorable state as a result of buffalo entering, wallowing in and coming out of the watercourses at that point.

To concentrate this animal activity and limit its damaging effect it was decided to build permanent watering and bathing stations for livestock at locations designated by the farmers. Farmers agreed to limit watering and bathing of their cattle to these locations.

Four buffalo baths were constructed at the Tubewell 56 Pilot Watercourse Project. These consisted of 9" thick brick walls around an enlarged section of the watercourse with ramps which could be traversed by buffalo leading down into the section. Since no criteria for design was available, designs were developed by the engineers in consultation with the farmers. Four different shape and sizes were designed. The drawing and details of cost and construction are given in Figures 16A, 16B, 17 and Tables and The structural defect of these baths was in the ramps. The floors of these were generally two layers of bricks thick. However, when the soil below them was wet and buffaloes weighing up to 1600 lbs stepped on these, the bricks commonly broke loose from each other and the floor disintegrated. It was decided that a base of at least 9" of gravel or broken brick should be placed under the masonry or concrete used in these ramps.

On future pilot watercourse studies some katcha watering and bathing stations will be constructed and evaluated as means for keeping the cost of construction down. Water losses will be measured at each of these buffalo baths to determine their total cost to the water users.

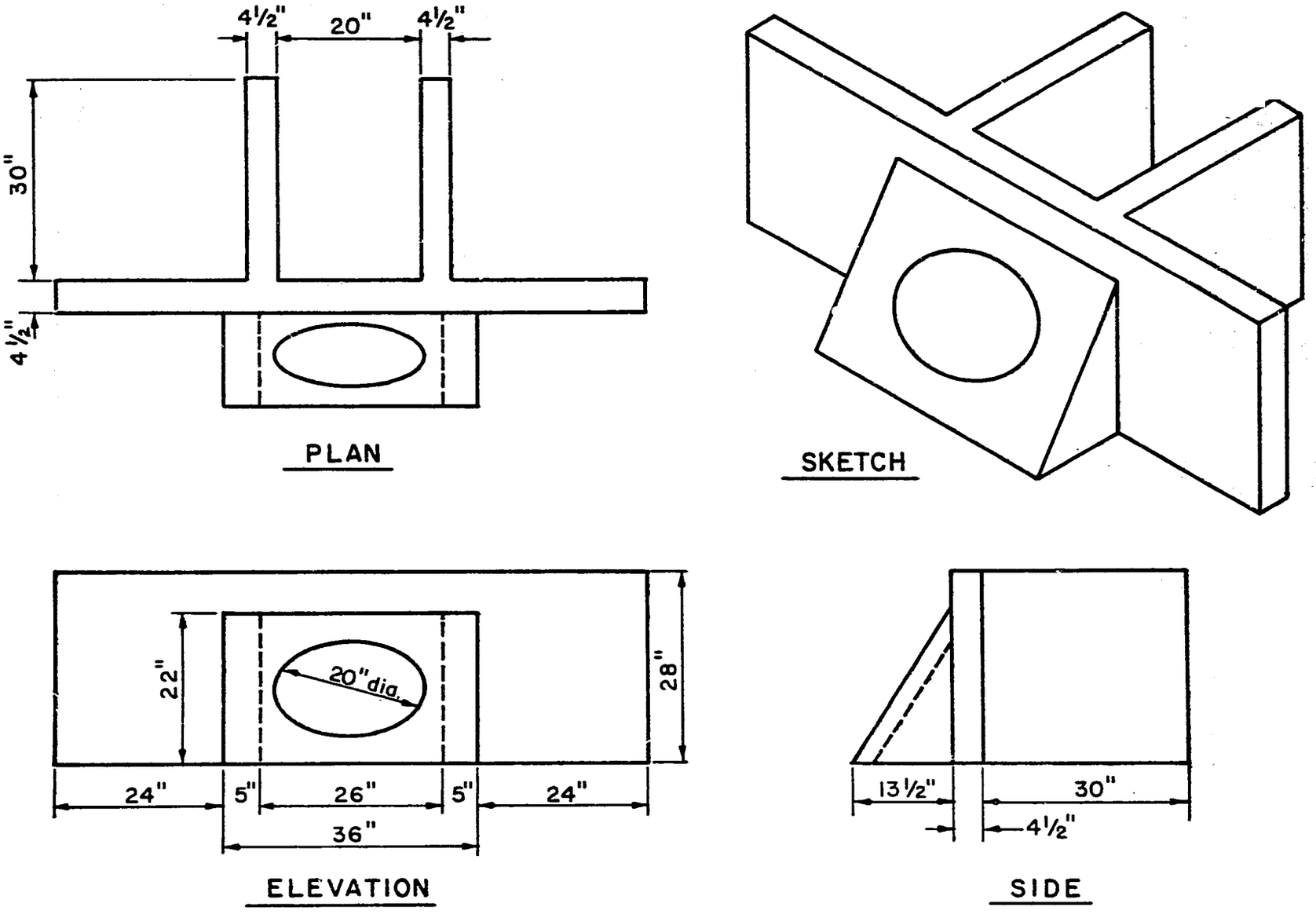


Figure 6. Type 1 panel nacca with masonry.

Table 2. Installation Cost of Panel Cacca Type I

	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu.Ft.
i	Abutment	2	2.88	.38	2.33	5.10
ii	Wingwall	2	2.00	.375	2.33	3.50
iii	Layer at top of Nacca	1	3.00	.375	0.50	2.25
iv	Inclined brick work ($v = bxlxh/_2$)	2	1.13	.38	1.83	.79
v	Bed					3.20
					TOTAL	14.84

(i) BRICK COST

No. of brick in 1 cft = 14.2
No. of brick in 14.84 cft = 211

(ii) MORTAR COST

Mortar required for masonry average 0.35 cubic feet mortar/cubic feet masonry. Consequently mortar required = 0.35 x 14.8 = 5.2 cubic feet. The cement sand ratio used in the mortar was 1:3. The density of the mortar is about 110 lbs/cu. ft. Therefore the amount of cement required is 5.2 x 110 x 1/4 = 143 lbs (approx. 1.28 bag) and the amount of sand required is 5.2 x 110 x 3/4 = 430 lbs. = 4.3 cu. ft.

COST OF MATERIAL

(i)	Bricks, 211 Bricks @ Rs. 0.225/brick	=	Rs. 47.50
(ii)	Cement, 1.28 bag @ Rs. 21/bag	=	26.90
(iii)	Sand, 4.3 cft. @ Rs. 0.75/cft	=	3.22
(iv)	26" x 26" panel nacca @ Rs. 60	=	60.00
			137.62
Labor Cost			12.00
	TOTAL COST		Rs.149.62

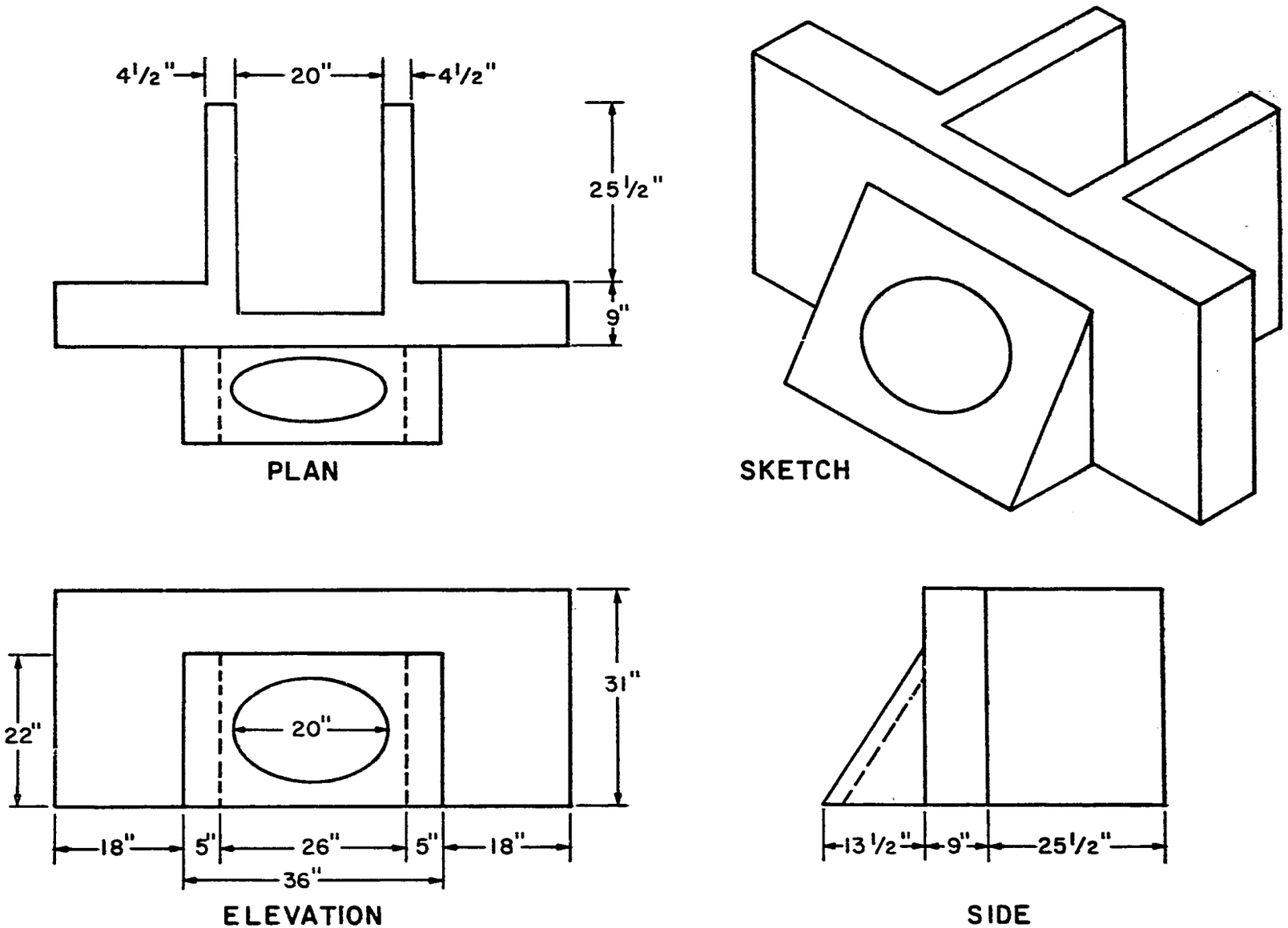


Figure 7. Installation of Type #2 nacca.

Table 3. Installation Cost of Panel Nacca Type 2

	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu. Ft.
i	Abutment	2	2.88	0.38	2.58	5.65
ii	Wingwall	2	1.75	0.75	2.58	6.78
iii	Layer at top of Nacca	1	1.67	0.38	0.75	0.48
iv	Inclined brick work	2	1.12	0.38	1.83	.78
v	Bed					3.20
					TOTAL	16.89

No. of bricks per cft = 14.2
No. of bricks per 16.89 cft = 240

Since masonry requires about 0.35 cft mortar/cft masonry, the mortar required is 0.35 x 17 = 6 cft. Using a cement/sand ratio of 1:3 and assuming dry mortar weight of 110 lbs/cft the weight of cement needed is 165 lbs = 1.5 bags. The amount of sand required would be about 5 cft or about 500 lbs.

COST OF MATERIAL

(i) Bricks, Rs. 0.225/brick. Therefore 240 bricks costs Rs. 54
(ii) Cement, Rate of one bag=Rs. 21, cost of 1.5 bags = Rs. 31.5
(iii) Wand, Rate of one cft about = .75. Cost of 5 cft = Rs. 3.75
(iv) Nacca. Cost of nacca with lid = 60.00 + Rs. for delivery

Total materials cost = Rs. 149
Labor cost 11
TOTAL COST Rs. 160

COMMENTS

In this type of installation 9 1/2" thick and 1 1/2' long wing walls were evaluated. But the abutment is 4 1/2 thick and 2'2" long. The wing walls proved ok but the abutment structure was not that good. Particularly the length of the abutments were often not as long, as the width of the bank, there was some erosion problem on the downstream side of the panel. This type of installation costs about Rs. 160.

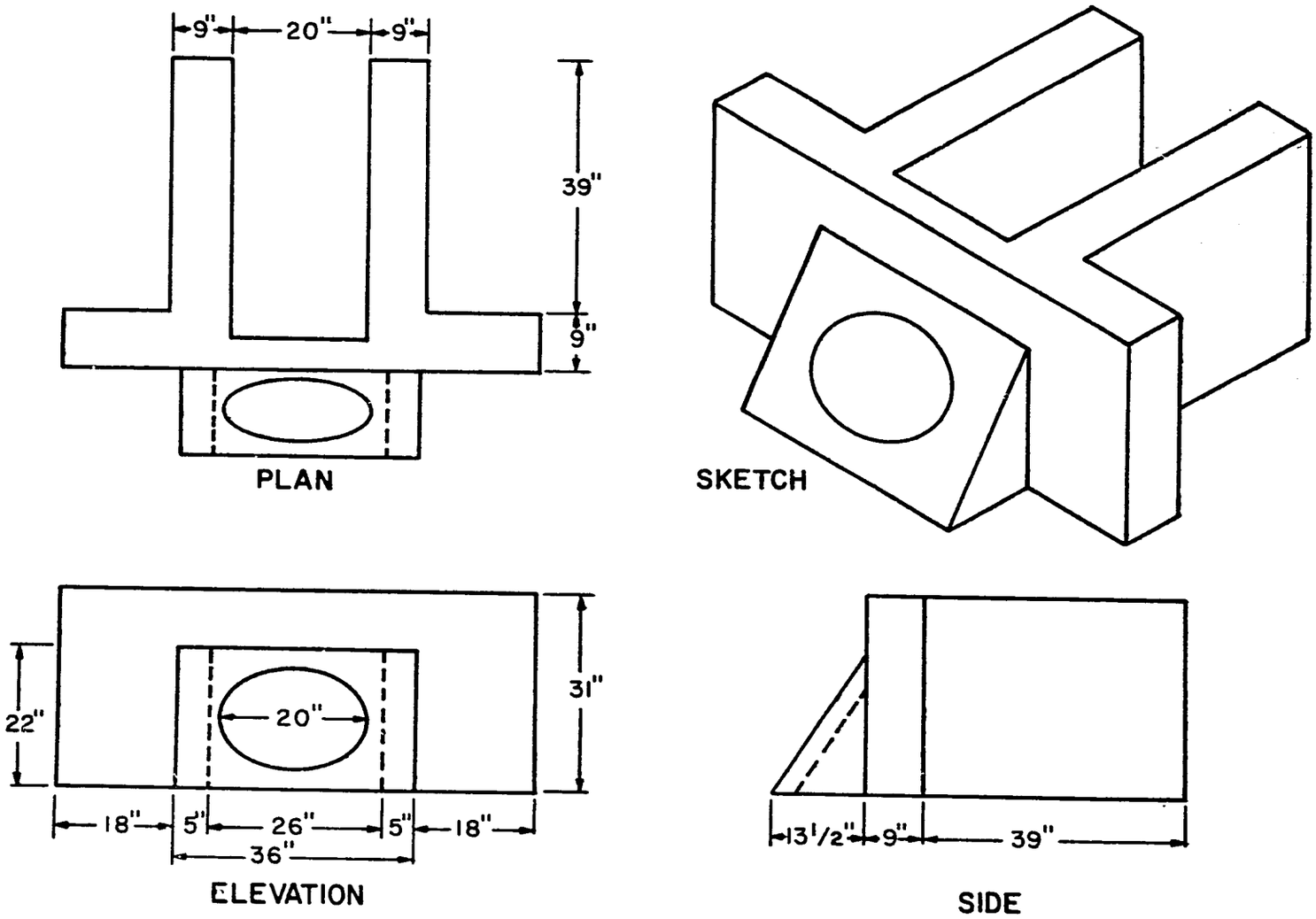


Figure 8. Installation of Type #3 nacca.

Table 4. Installation Cost of Panel Nacca Type 3

	Description of Itmes	No.	L in feet	B in feet	H in feet	Volume Masonry Cu. Ft.
i	Abutment	2	4.00	0.75	2.58	15.50
ii	Wingwall	2	1.50	0.75	2.58	5.80
iii	Layer at top of Nacca	1	1.67	0.38	0.75	0.48
iv	Inclined brick work		1.12	0.38	1.84	0.78
v	Bed					3.20
				TOTAL		25.7

No. of bricks in 25.76 cft = 366
Behind Nacca = 10
TOTOL 345 bricks, or about 25.8 cft of masonry which required about 9.7 cft of mortar.

Using cement/sand ratio 1:3, this requires 2 bags of cement and 7.4 cft of sand.

COST OF MATERIAL

i	Bricks	Rs. 82.50	(i.e. 366 @ Rs. 0.225/brick)
ii	Cement	42.00	(2 bags @ Rs. 21/bag)
iii	Sand	5.60	(7.4 cft. @ Rs. .75/cft)
iv	Cost of Nacca	60.00	
	TOTAL COST (Mat.)	190.10	
	LABOR	19.40	
	TOTAL COST	Rs.208.50	

COMMENTS:

This is an installation of a side nacca. The wing walls are 1.5' long and 0.75' thick. In this installation abutments are 0.75' thick and 3.25' long. This is a good installation of the side nacca but the cost of installation is relatively high. This type of installation costs Rs. 204.60. Erosion was less at the lower end of the installed nacca as the length of the abutment was longer. However, the vertical end of these abutments cannot be matched to a 1:1 slope, and the steeper slopes used always resulted in some sloughing and erosion. Jack Phelan of the SCS, who reviewed this project, pointed out that if the abutments were stair stepped down, as shown in Type 4, the soil bank with a 1:1 slope could be curved around to meet these abutments.

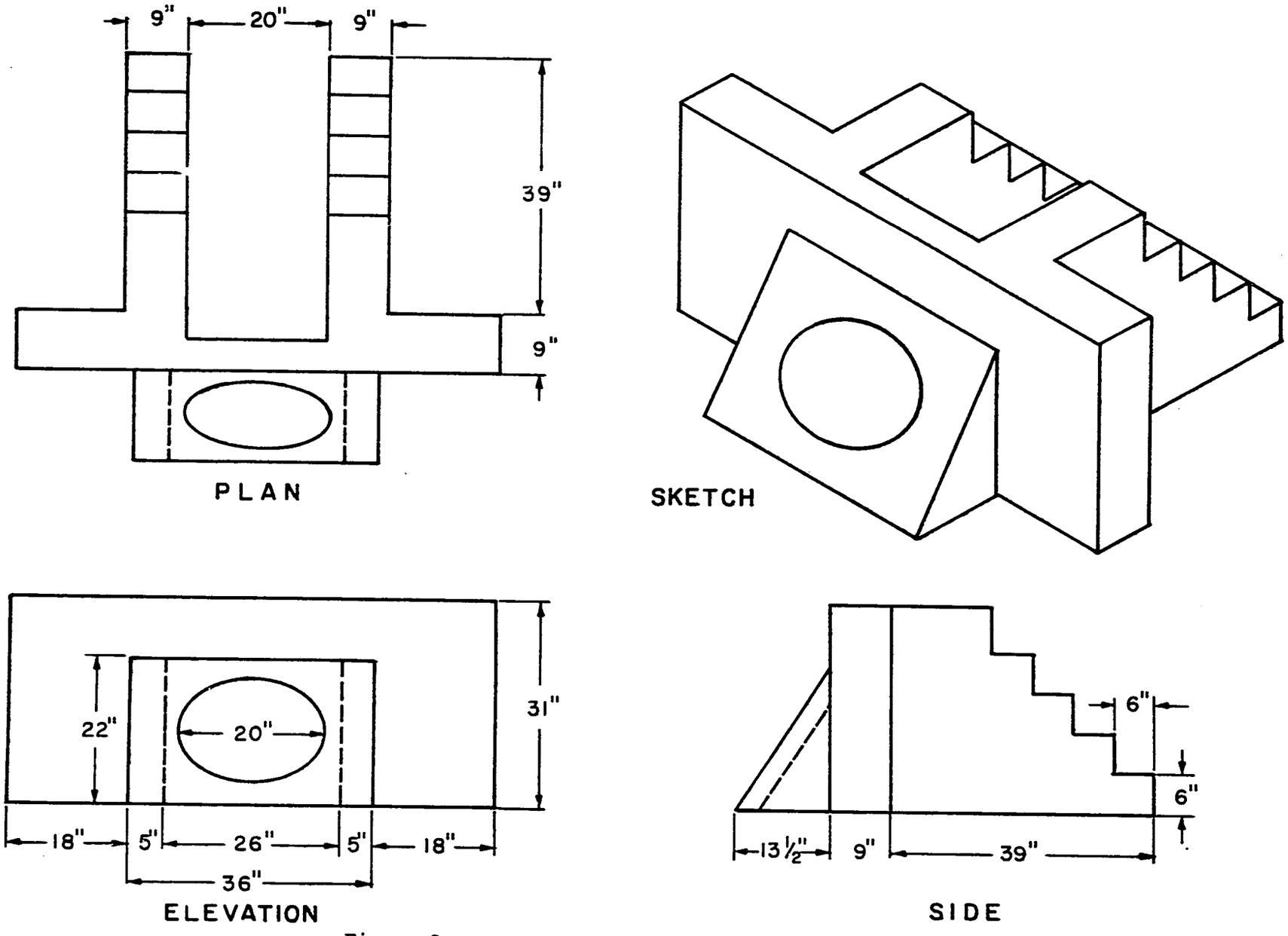


Figure 9. Installation of type #4 nacca structure.

Table 5. Installation Cost of Panel Nacca Type 4

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu. Ft.
1	Abutment in 1st step	2	4.00	0.75	0.50	3.00
2	2nd step	2	3.50	0.75	0.50	2.62
3	3rd step	2	3.00	0.75	0.50	2.25
4	4th step	2	2.50	0.75	0.50	1.87
5	5th step	2	2.00	0.75	0.58	1.75
6	Wing wall	2	1.42	0.75	2.58	5.50
7	Layer at the top of nacca	1	1.67	0.38	0.75	0.47
8	Inclined brick work		1.12	0.38	1.83	0.78
9	Bed					3.20
					TOTAL	21.44

No. of bricks = 305
Total bricks in cft = 21.44 cft.
Mortar = 8 cft.
Cement sand ratio = 1:3
Cement 1 3/4 bag
Sand, 6.6 cft.

COST OF MATERIAL
Bricks = 68.70
Cement = 36.75
Sand = 5.00
Cost of Nacca 60.00
Total Materials cost 172.45
Labor pay 19.40
Total cost = Rs. 191.85

COMMENTS

Type four is an installation of the side nacca. In this type of installation wingwalls were 1.5 ft. long and 0.75 ft. thick. The abutment in this case is made by steps as recommended by Mr. Phelan. This helped check the erosion at the downstream of the nacca because the 1:1 slope of the soil banks could be curved around to meet this stair step arrangement. An even better fit to the soil banks would result if the stair steps were 3" long and down. The top of the structure would match the bank better if the top of the abutment was about 6".

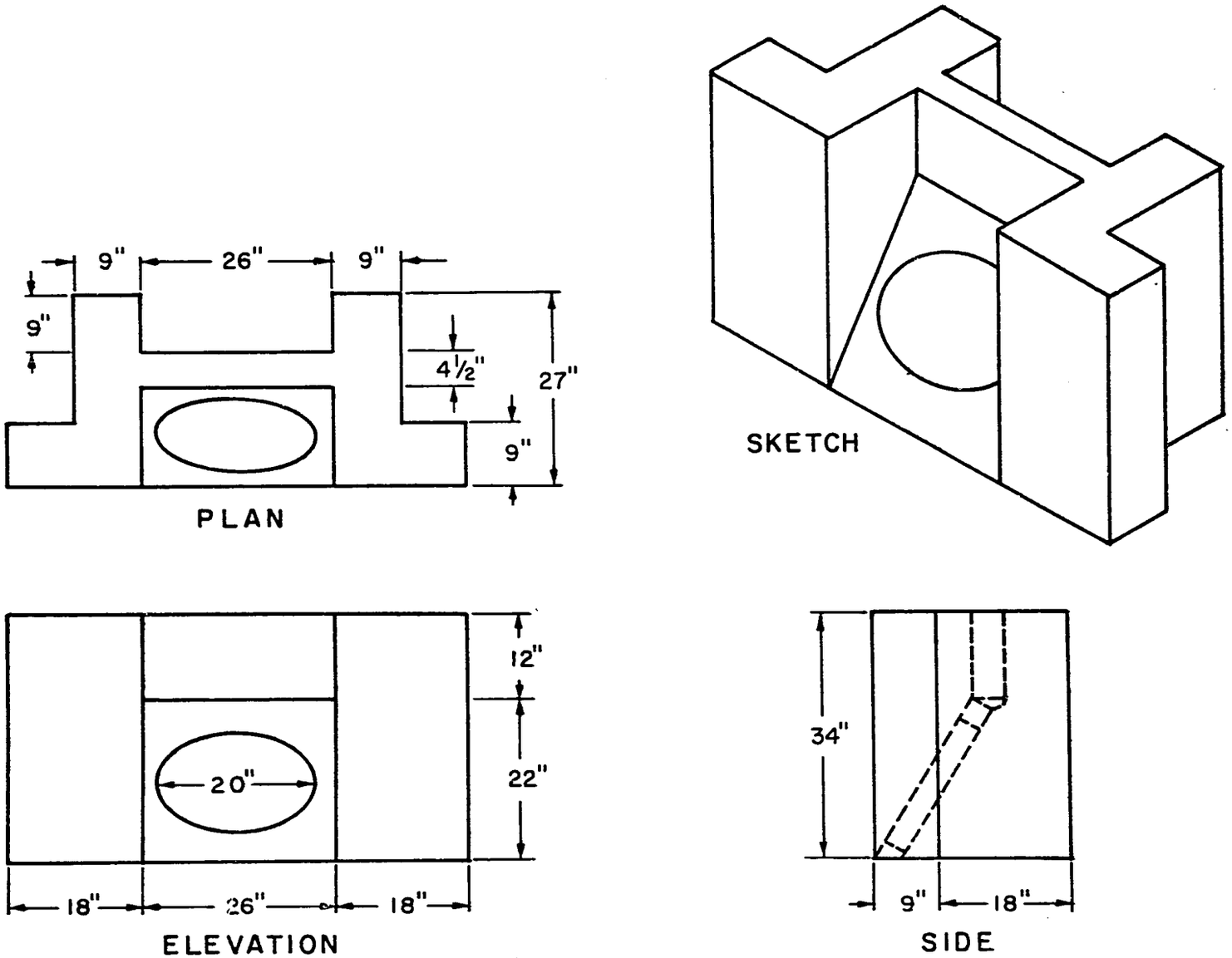


Figure 10. Installation of Type #5 nacca structure.

Table 6. Installation Cost of Panel - Nacca Type #5

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu. Ft.
1	Abutment	2	2-1/4	3/4	2-5/6	9.56
2	Wing wall	2	3/4	3/4	2-5/6	3.19
3	Layers at the top of	1	2-1/6	3/8	1	.80
				TOTAL		13.55

Number of bricks:

In main structure -	133
In bed	35
Behind panel	10
TOTAL	228

Bricks, 228 @ Rs. 0.225 = Rs. 51.30
Mortar 6 cft with cement/sand of 1/3
Cement: 1.32 bag @ Rs. 21/bag = Rs. 27.80
Sand: 5 cu ft @ Rs. 0.75/cu ft = Rs. 3.75

Nacca - 20" dia. orifice 26"x26"x3" =	Rs. 60
Materials cost	142.85
Labor cost	11.00
TOTAL COST	153.88

COMMENTS

Type 5 is the installation of check structure. In this case the wingwalls are 1.50 ft. long and 9" thick whereas the abutment is 1 5/6 ft. long and 9" thick. This is a very durable and strong installation, therefore consumes more construction material. But erosion problems at the downstream is faced. As the watercourse is trapezoidal shaped whereas the abutment of this nacca is rectangular. This increases the velocity of water hence the banks of the watercouse are eroding. The whole structure is unplastered. The cost of this installation is Rs. 154.47.

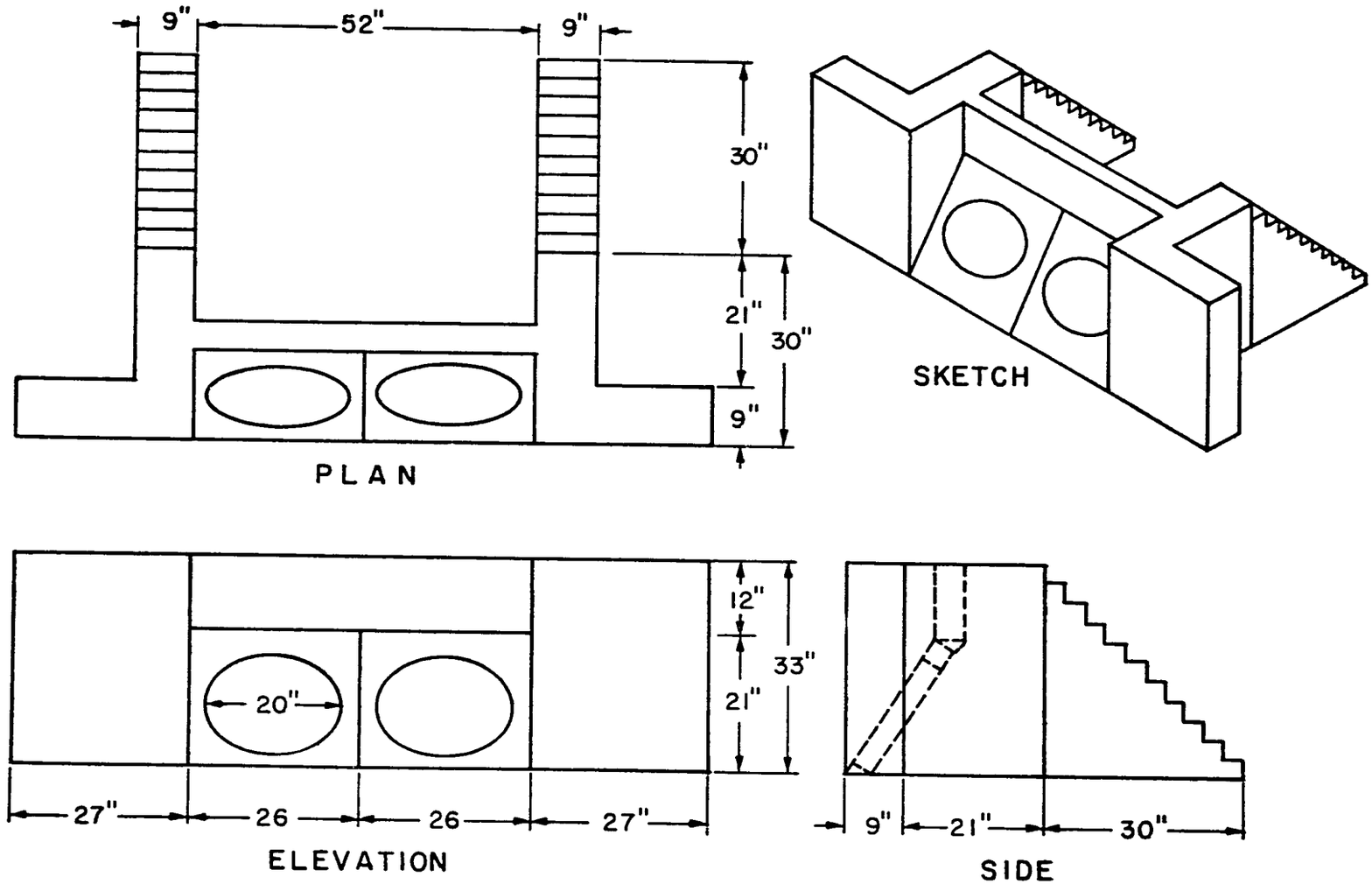


Figure 11. Installation of Type #6 double orifice nacca structure.

Table 7. Installation Cost of Double Orifice Panel Nacca

Description of Items	No. needed	Dimensions in feet Length	Width	Height	Feet^3 Volume
Abutment	2	3.75	.75	2.75	15.44
Wing wall	2	2.25	.75	2.75	9.24
Layer at top of panel	1	4.33	.38	1.00	1.65
Behind the panel	2	1.5	.25	2.75	2.06
Masonry between two panels	1	1.25	.38	1.75	0.83
Floor					4.23
		Total Masonry			33.45

No. of Brick = 33.45 x 14.2 = 475 = Rs. 107
Mortar required = .35 x 33.45 = 11.72 cft.
Sand Rs. .75/cu. ft.
Naccas Rs. 60 ea.
Mortar ratio of 1:3 requires:
Three bags cement = Rs. 63
Ten cu. ft. sand = Rs. 8
Two naccas @ Rs. 60 = Rs. 120
Materials Cost Rs. 298
Labor Cost 14
TOTAL COST Rs. 312

COMMENTS

This type of check structure keeps headloss to 1/4 of its value of when a single orifice of equal size is used. For instance at 5 cusecs flow (142 liters/sec) headloss through a single orifice with 20" diameter (50.8 cm) will be 4 cm (0.13 ft) but through a double orifice (both 20" in diameter) the headloss will be only 1 cm (0.03 ft.).

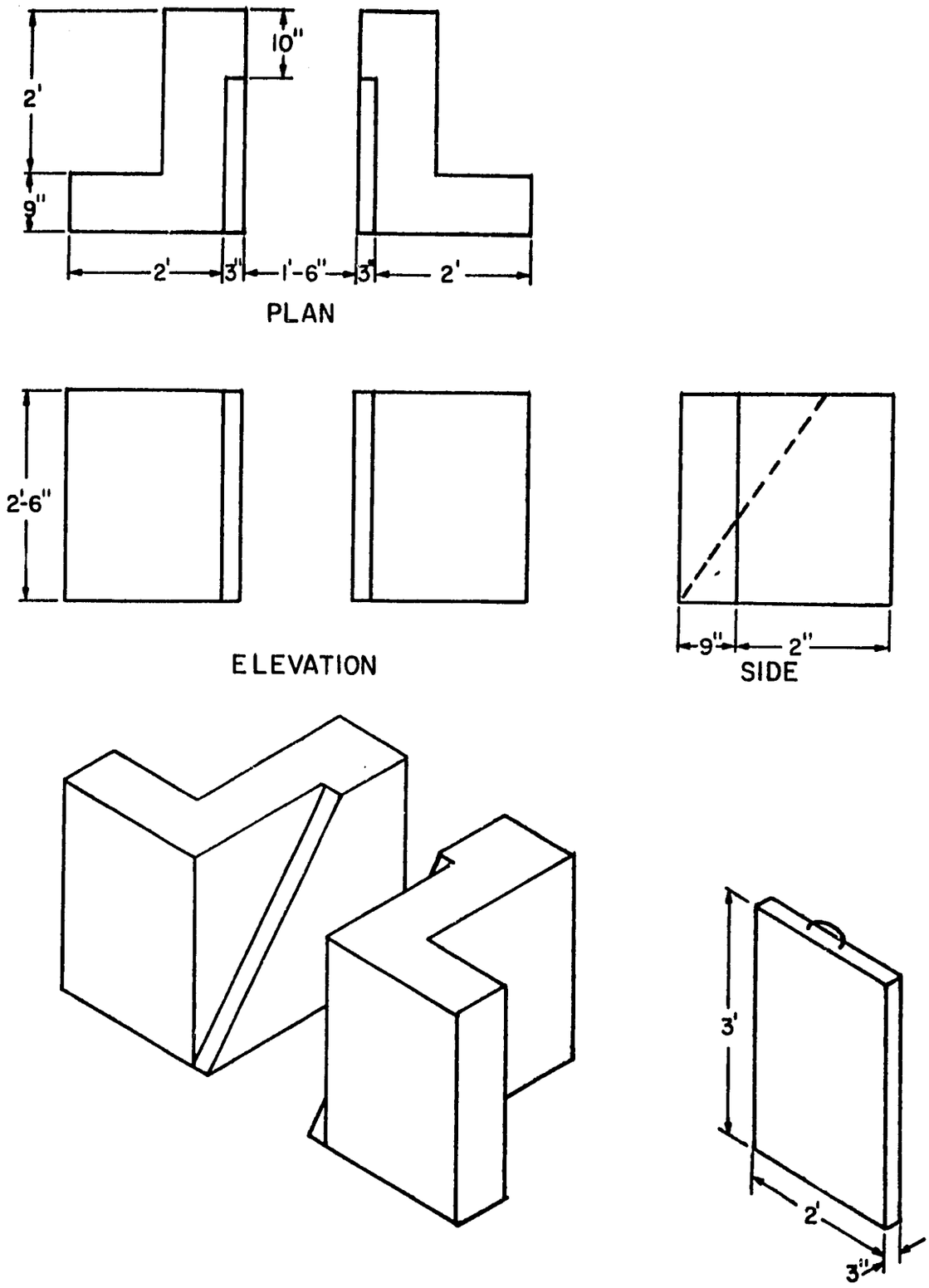


Figure 12. Installation of slide nacca Type #7.

Table 8. Installation Cost of Slab Nacca Type #7

S.No.	Description of items	No.	L in feet	B in feet	H in feet	Volume Cu. Ft.
1	Wing Wall	2	2	0.75	2.5	7.5
2	Column	2	2	0.75	2.5	7.5
3	Bricks for support slab 2' x 9" x 10" / 2	2	1.87	0.25	2.5	2.35
4	Bed	1	6	3	0.25	4.50
				TOTAL		21.85
5	Plastered at the top	12 sq. ft.				

No. of bricks = 297
Cement = 1.65 bag
Sand = 6 cft.

COST OF MATERIALS

Bricks, 297 @ Rs. 0.225/brick	= 44.30
Cement, 1.65 bag @ Rs. 21/bag	= 34.60
Sand, 6 cu. ft @ Rs. 0.75/cft	= 4.50
Cost of slab (2' x 3' x 3")	= 40.00
Total 146.65	Rs.123.40

Labor
Mason 1/2 day and 2 helpers for 1/2 day = Rs. 19.70

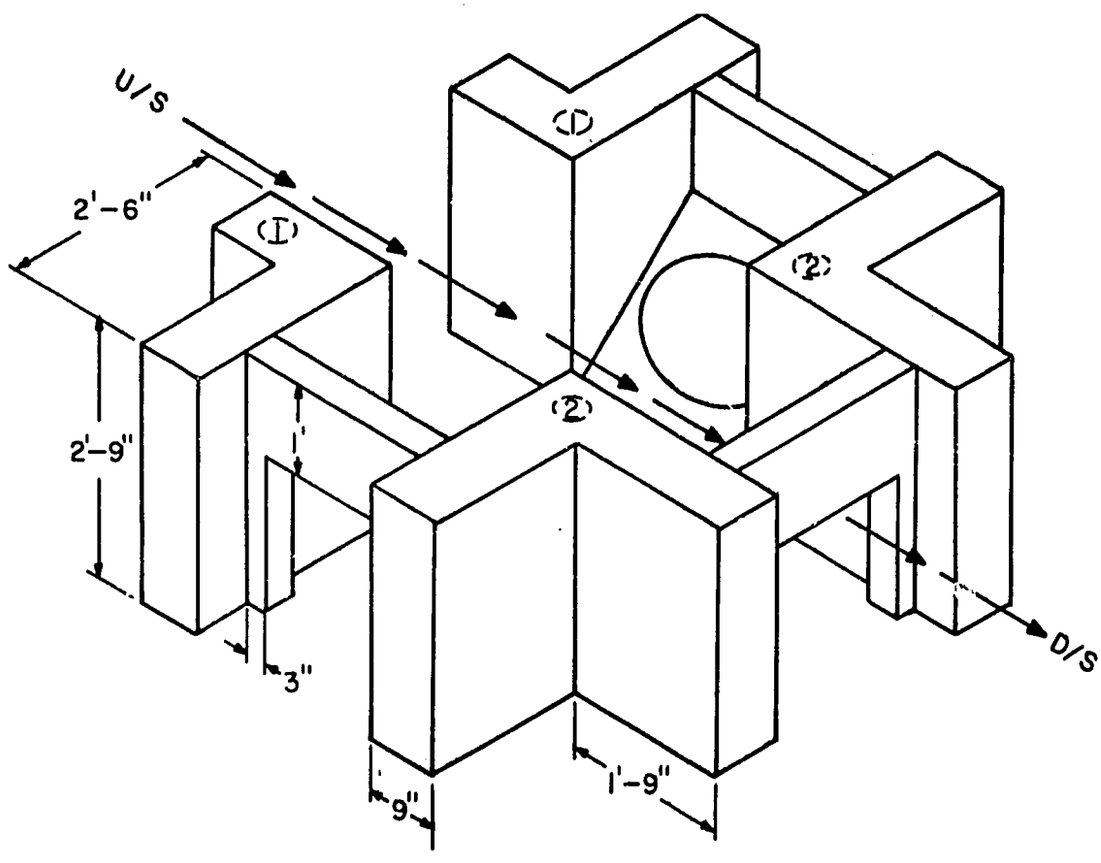
TOTAL COST Rs. 143.10

COMMENTS

This is the installation of the slab nacca. This is installed as a check structure particularly at the places where we cannot afford head loss. The length of the wing wall is 2 ft. which is 3/4' thick whereas the the column are 2 ft. long and 3/4' thick. This type of installation costs about Rs. 153.10.

The main problem is the weight of the slab which is about 160 lbs. Its weight can be reduced to about 110 lbs. by decreasing its thickness to 2" and increasing the amount of reinforcing steel therein to a grid of 3/16" bars at about 6" spacing.

We tried to put in even more steel, reducing the thickness to one inch and using asbestas powder instead of sand. However this thin slab cracked.



SKETCH

Figure 13. Drawing of panel nacca combined structure Type 8.

Table 9. Installation Cost of Panel Nacca Type #8
Combined Structure

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Cu. Ft.
1	"L" wall (1) long wall	2	2.5	0.75	2.75	10.32
	" " (1) short wall	2	0.75	0.75	2.75	3.10
2	"L" wall (2) long wall	2	2.5	0.75	2.75	10.32
	" " (2) short wall	2	1.75	1.75	2.75	7.20
3	Bricks at the top of nacca	3	2.17	0.37	1.0	2.44
4	Brick behind the nacca	6	1.0	0.37	1.75	4.00
5	Bed	1	8	6	1/4	12.00
			GROSS TOTAL			49.48
	Deduction for bed under wall (2)	2	2	2	0.25	-2.00
	(1)	2	2	0.75	0.25	-0.75
			Adjusted Total			46.73

No. of Bricks, 635 @ Rs. 0.225/brick = Rs. 144
Cement, 4 bags @ Rs. 21/bag 84
Sand 10.25 cft. @ Rs. 0.75/cu. ft 8
Nacca panels (26" x 26" x 3" with 20" orifice) @ Rs. 60 = Rs. 180

Cost of material Rs. 416

Labor

Masons 1 day @ Rs. 12.60
Labor 2 days @ Rs. 6.70 = 13.40
Rs. 26.00
TOTAL COST = Rs. 442

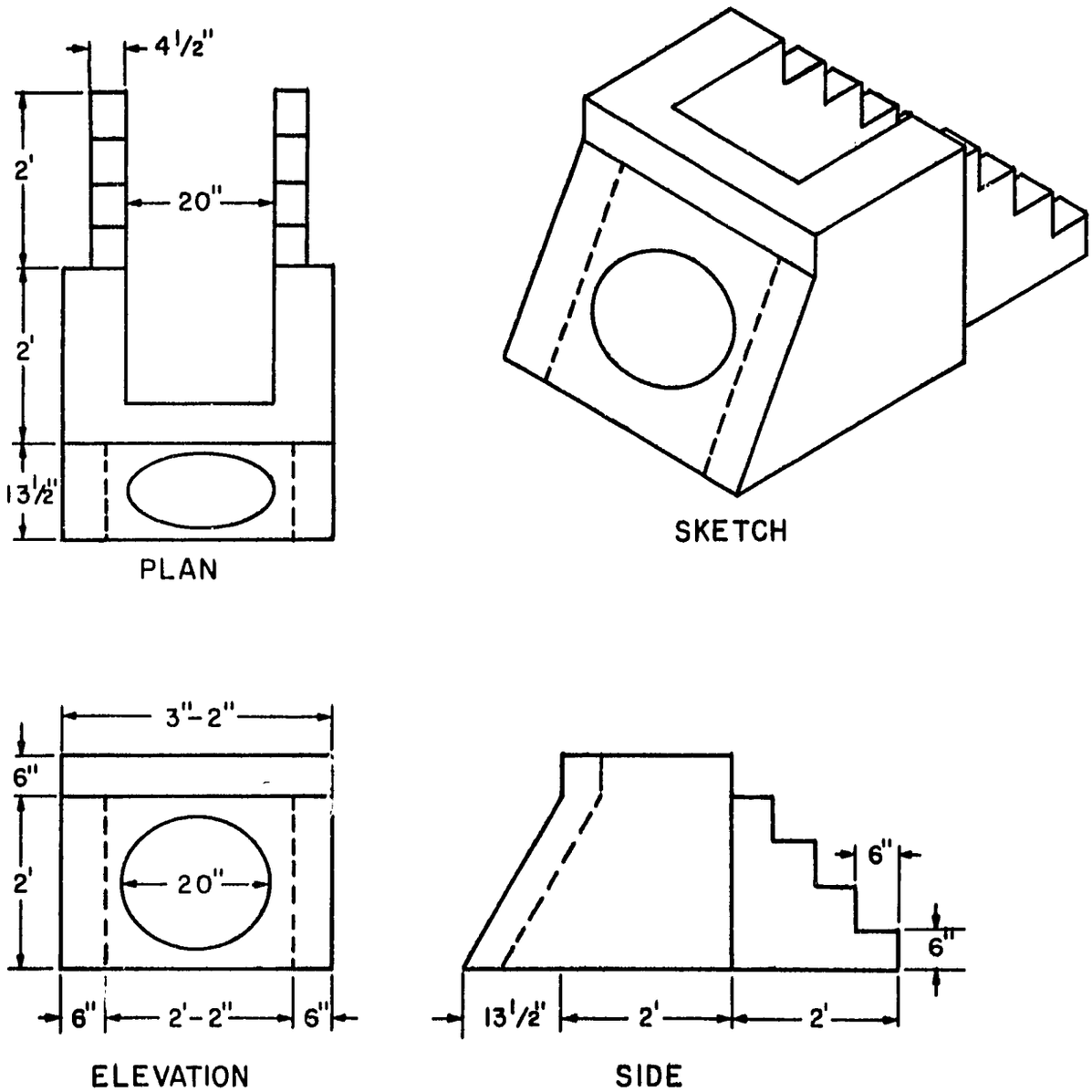


Figure 14. Structural details of Type 9 panel nacca installation.

Table 10. Cost of Panel Nacca Type #9 (Side Nacca)

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Cu.Ft.
1	Abutment	2	2.0	0.75	2.5	7.50
	Behind 1st step	2	2.0	0.38	0.5	
	2nd step	2	1.5	0.38	0.5	0.56
	3rd step	2	1.0	0.38	0.5	0.37
	4th step	2	0.5	0.38	0.5	0.19
2	At the top	1	1.67	0.38	0.5	0.19
				TOTAL		9.69
3	Inclined bricks, bed of naccas about	130 bricks				
		95				
	Total	225 Nos.				

Materials

Bricks, 225 - Rs. 0.225 ea. =	Rs. 51.00
Cement, 1.25 bag @ Rs. 21/bag	26.20
Sand, 5 cu. ft. @ Rs. 0.75/cu. ft.	3.70
One nacca @ Rs. 60	60.00
Materials Cost	140.90
Labor cost	12.00
Total Cost	152.90

COMMENTS

This style does not have wing walls and it tends to leak unless the soil is carefully compacted along the sides of the structure. However, if moist soil free from organic matter is compacted by foot along each side of this structure, leaks do not develop and it has been one of the least expensive structures.

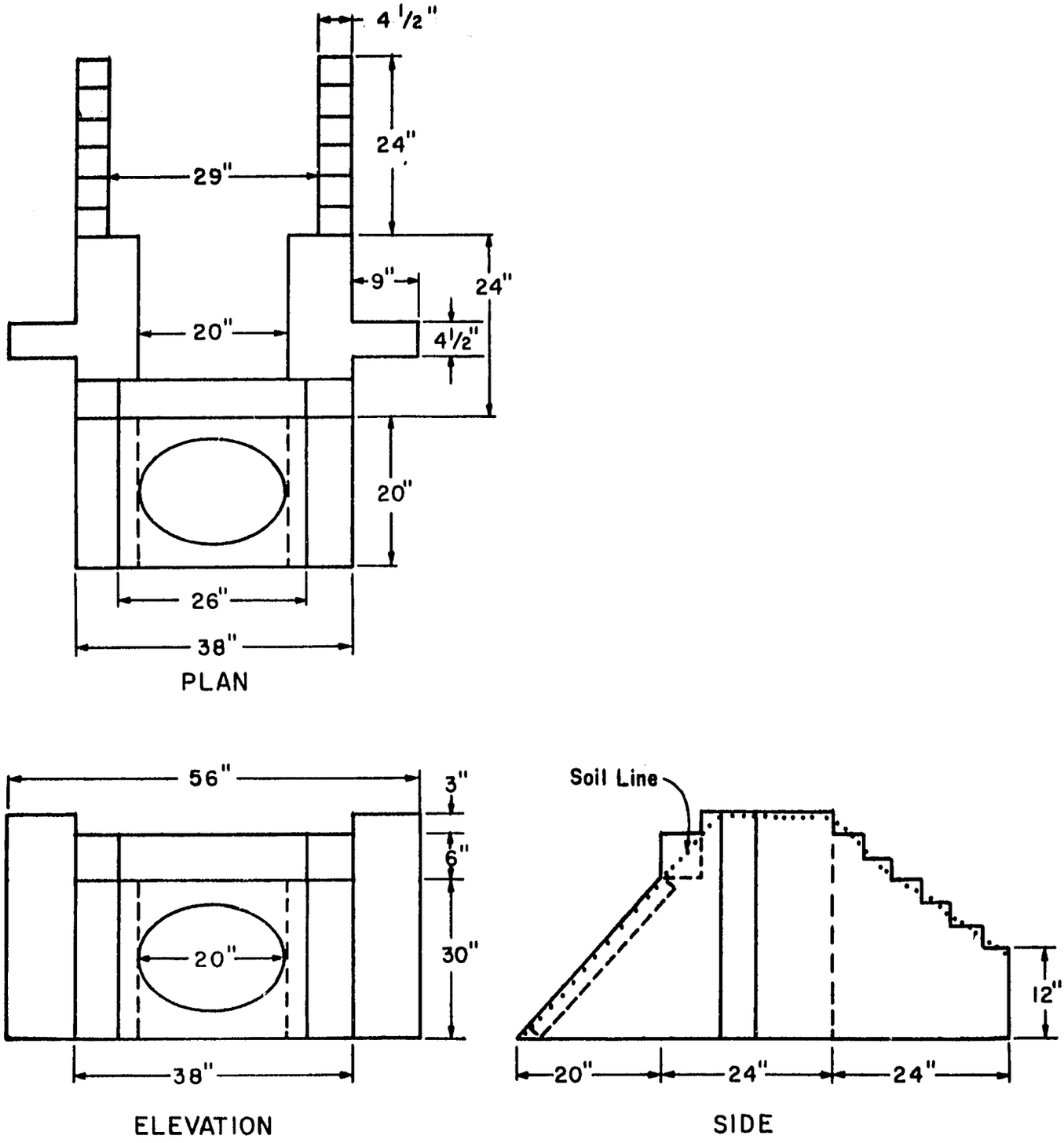


Figure 15. Pannel nacca, type 10 installation.

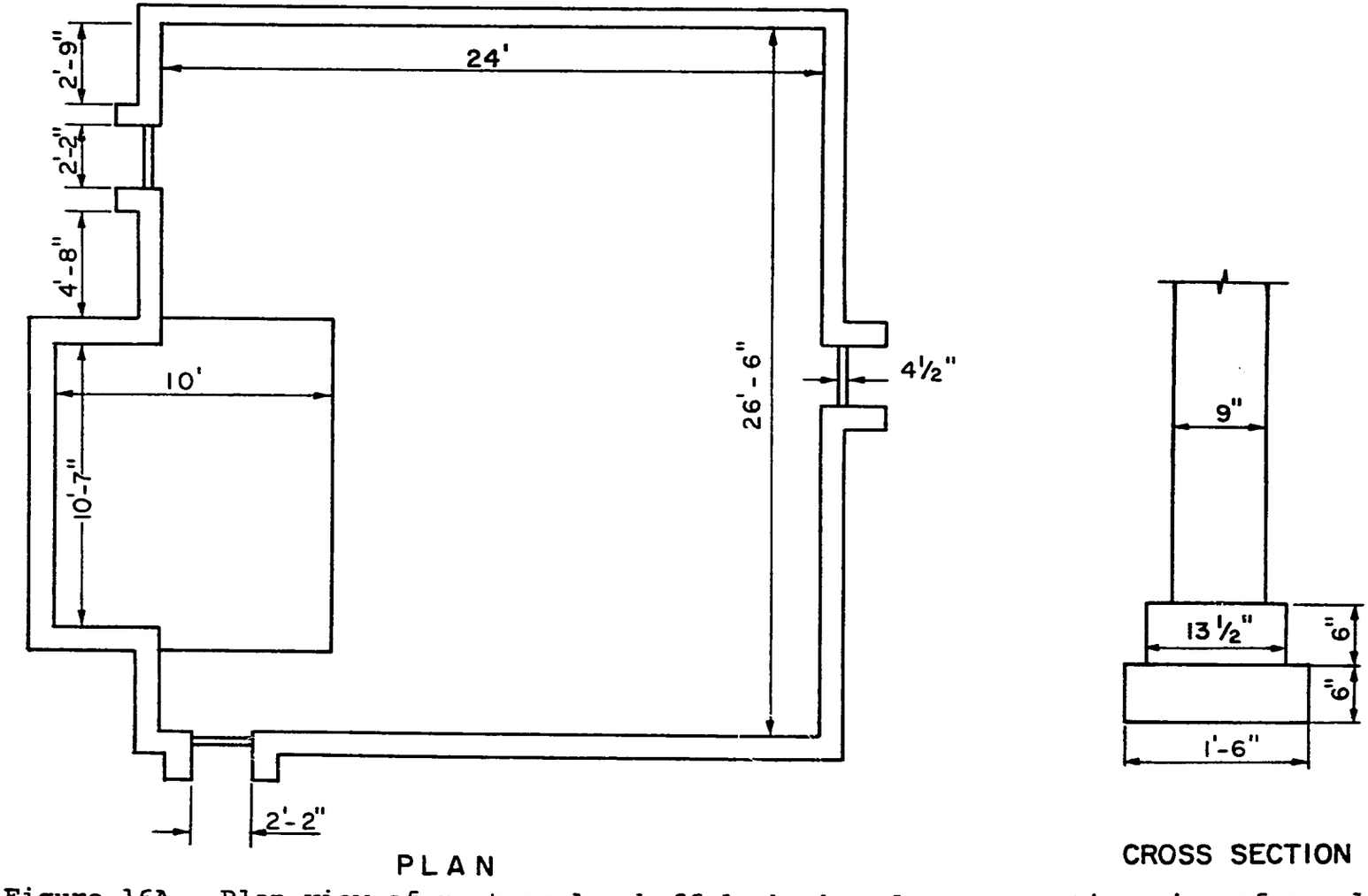


Figure 16A. Plan view of rectangular buffalo bath and cross section view of a wall.

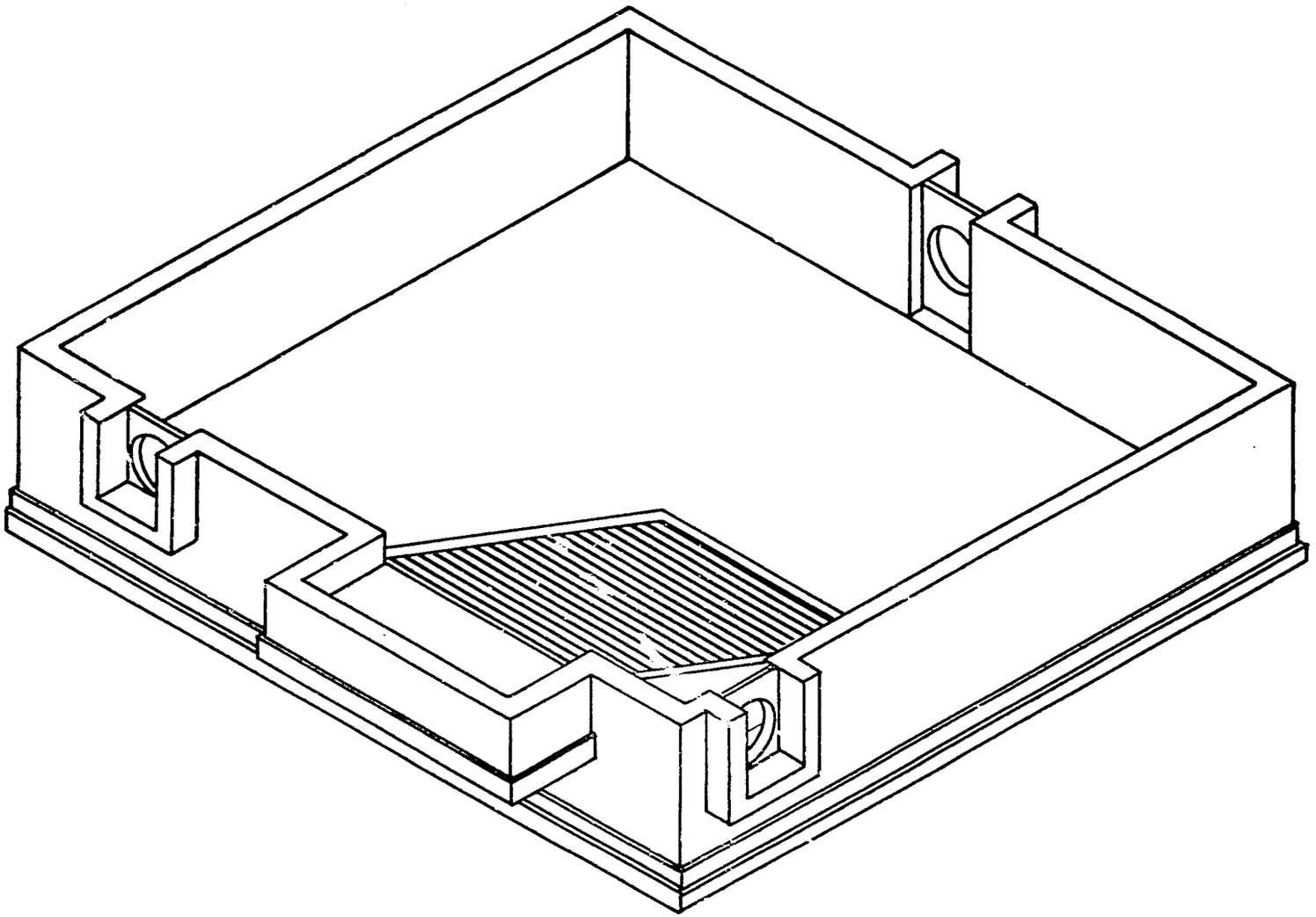


Figure 16B. Sketch view of rectangular buffalo bath.

Table 11. Cost Calculation - Rectangular Buffalo Bath

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Cu. Ft.
I	Long wall foundation					
	(i) 1st step	2	26.25	1.50	.50	39.37
	(ii) 2nd step	2	25.88	1.13	.50	29.10
	Short wall					
	(i) 1st step	2	25.50	1.50	.50	38.25
	(ii) 2nd step	2	25.88	1.50	.50	38.81
	Underground 3/4" thick wall long wall	2	26.25	.75	1	39.37
	Underground 3/4" thick wall short wall	2	25.50	.75	1	38.25
	Super structure					
	Wall "A"	1	25.50	.75	3	57.37
	Wall "B"	1	26.50	.75	3	59.61
	Wall "C"	1	27.33	.75	3	61.50
	Wall "D"	1	16.75	.75	3	37.70
	Ladders Foundation long wall	1	12.50	1.13	.50	28.12
	short wall	2	4	1.13	.50	4.50
	Super structure					
	long wall	1	10.63	.75	1	8.00
	short wall	2	4	.75	1	6.00
	Ladder slope wall short wall	1	6	.75	3	13.50
	Front long wall	1	12	.75	.50	4.50
	Slope pouring on edge	1	10.63	7	.38	27.90
	Plate pouring on edge	1	10.63	4	.38	16.00
	Panel Nacca	3	2.17	.38	1	2.43
				TOTAL		550.28

MATERIAL	COST
Bricks, 7425 @ Rs. 0.225/brick	Rs. 1671
Cement, 44 bags @ Rs. 21/bag	924
Sand, 168 cft. @ Rs. 0.75/cft	126
Panels, 3 @ Rs. 60/panel	180
TOTAL	Rs. 2901
Labor Cost	266
TOTAL COST	Rs. 3167

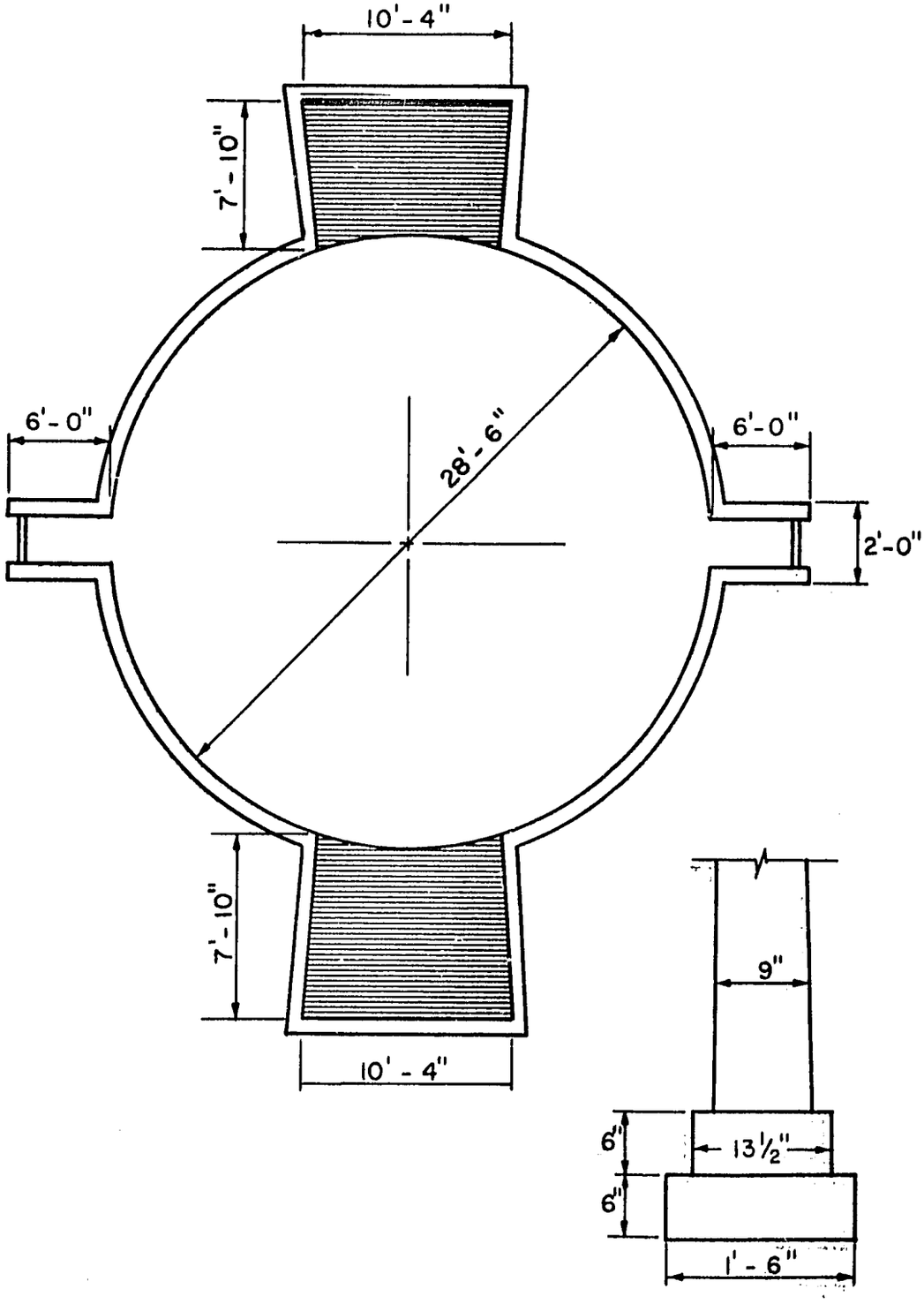


Figure 17. Round buffalo bath with two access ramps and an entrance and an exit for water.

Table 12. Cost Calculation - Circular Buffalo Bath

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Cu.ft.
I	Foundation					
	(i) 1st step	1	90	1.5	0.5	67.50
	(ii) 2nd step	1	90	1.13	0.5	50.61
	(iii) 3rd step	1	90	0.75	1	67.50
	(iv) super structure	1	67.67	0.75	3	152.25
	Panel Nacca Straight wall					
	(i) 1st step	4	5	1.50	0.5	15.00
	(ii) 2nd step	4	4.87	1.12	0.5	11.00
	(iii) 3rd step	4	4.25	0.75	4	51.00
	Layer on the top of nacca	2	2.17	0.38	1	1.62
	Ladders long wall					
	(i) 1st step	2	10.33	1.13	0.5	11.62
	(ii) 2nd step	2	10.33	0.75	1	15.50
	Short wall					
	(i) 1st step	4	7.87	1.13	0.5	17.70
	(ii) 2nd step	4	7.87	0.75	3.5	82.70
	Slope Pouring	2	7.63	9.6	0.38	55.30
				TOTAL		599.30

MATERIALS		COST
Bricks, 8100 @ Rs. 0.225/brick	Rs.	1820
Cement, 46 bags @ Rs. 21/bag		966
Sand, 175 cu.ft. @ Rs. 0.75/cu.ft.		131
Panels, 2 @ Rs. 60/panel		120
Cost of Materials	Rs.	3037
Cost of Labor		260
Total Cost	Rs.	3297

CULVERTS

Two types of culverts were tried on the pilot watercourses:

1) Precast R.C.C. pipe culverts (with and without retaining walls at the ends).

2) Brick masonry culverts (with arched tops and with flat reinforced tops). Precast R.C.C. culverts 20" in diameter and 8' long were installed at a cost of approximately Rs. 200 each. However, erosion occurred at the entrance and exit of these culverts. Wingwalls and/or riprap and sod were used to reduce the erosion immediately upstream and downstream from the culvert. Riprap or sod to protect the banks from erosion was needed for about 7' below and 3' above the structures. When the culverts were to carry tractor trolley traffic and the approaches are not straight the length of the culverts should be extended to 10 or 12 feet. Designs of these culverts are given in Figures 18, 19 and 20, and their costs and advantages are indicated in the respective tables and text accompanying those figures.

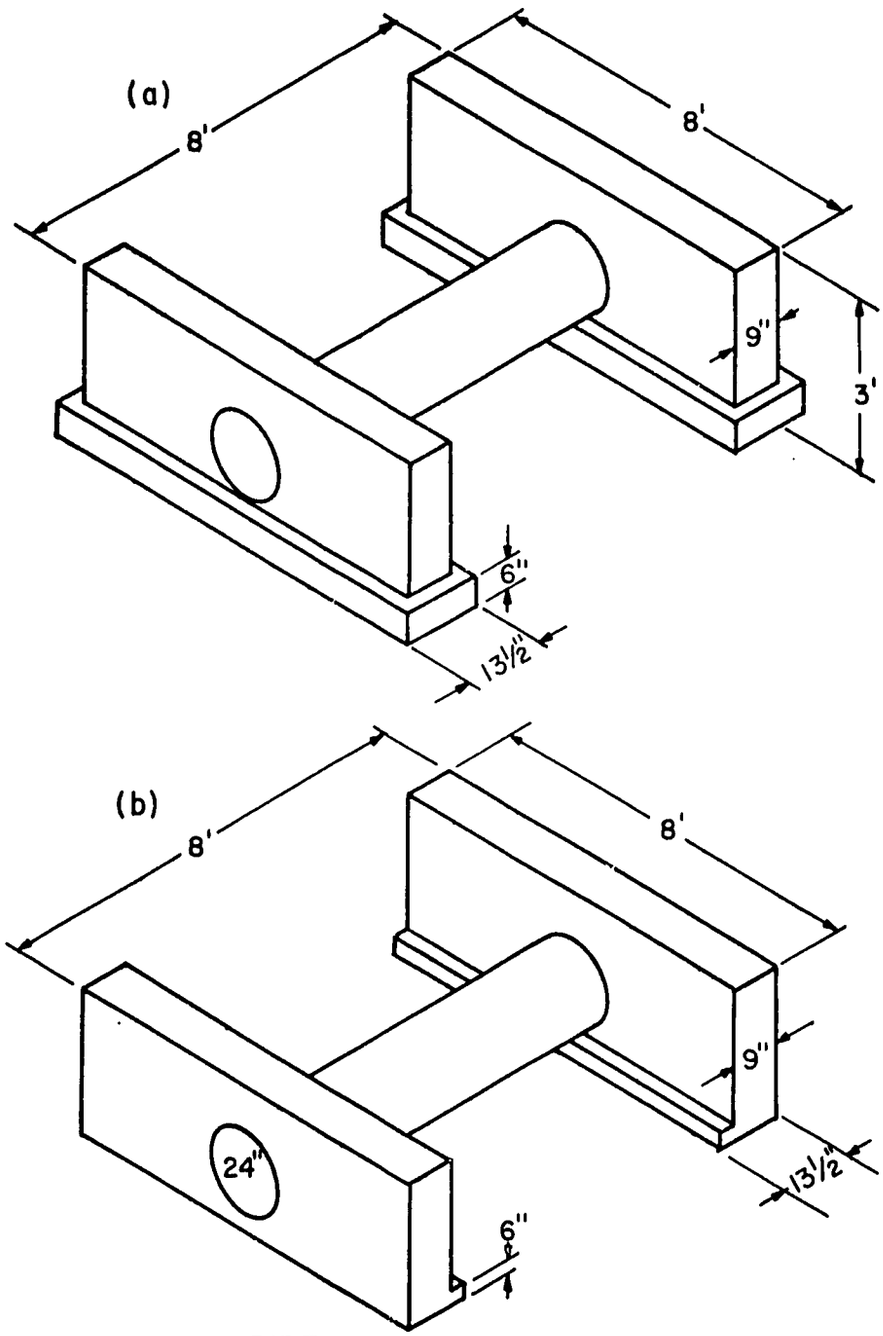
RECOMMENDATIONS

The short period of time (less than 1 year) for which these structures have been tested requires that these recommendations be classified as tentative.

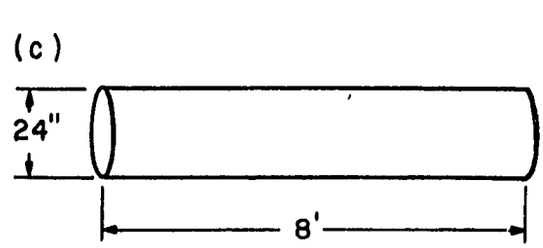
CONTROL STRUCTURES

1) For single take outs or check structures where head loss must be less than 0.20 feet. The type 10 panel nacca shown in Figure 15 is recommended. It requires reasonably good packing of the soil alongside the structure which allows use of the short cutoff walls and results in a low cost installation (about Rs. 160). The cutoff wall is designed to sit in the middle of the earthen bank.

2) For single take outs or check structures where head loss can be up to 0.5 feet. The pipe nacca shown at the bottom of Figure 1 is recommended. The cutoff wall shown in that figure will cost about Rs. 40, and a 1 foot diameter pipe 6' long with 45 degree angle and lid will cost about Rs. 90, for a total installation cost of about Rs. 130. The installation cost can be reduced by reducing the size of the cutoff wall, or by replacing it with a bank of mortar around the pipe in the middle of



PIPE CULVERT WITH WING WALLS



PIPE CULVERT WITHOUT WING WALLS

Figure 18. Installations of pipe culverts.

Table 13. Cost Calculation - Installation Cost of Pipe Culvert with Wing wall

Type (1)

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu.Ft.
I	1st step Brick work	2	8.38	1.12	0.5	9.40
	2nd step Brick work	2	8	0.75	2.5	30.00
	Reduction	2	r^2B			-4.71
					TOTAL	34.69

MATERIALS	COST
Bricks, 475 @ Rs. 0.225	Rs. 107.00
Cement, 2.5 bags @ Rs. 21/bag	52.50
Sand, 7 cu. ft. @ Rs. 0.75/Cu.Ft.	5.25
Pipe, 24" dia., 8' long	200.00
Material Cost	Rs. 364.75
Labor Cost	19.40
Total Cost	Rs. 384.15

Type (2)

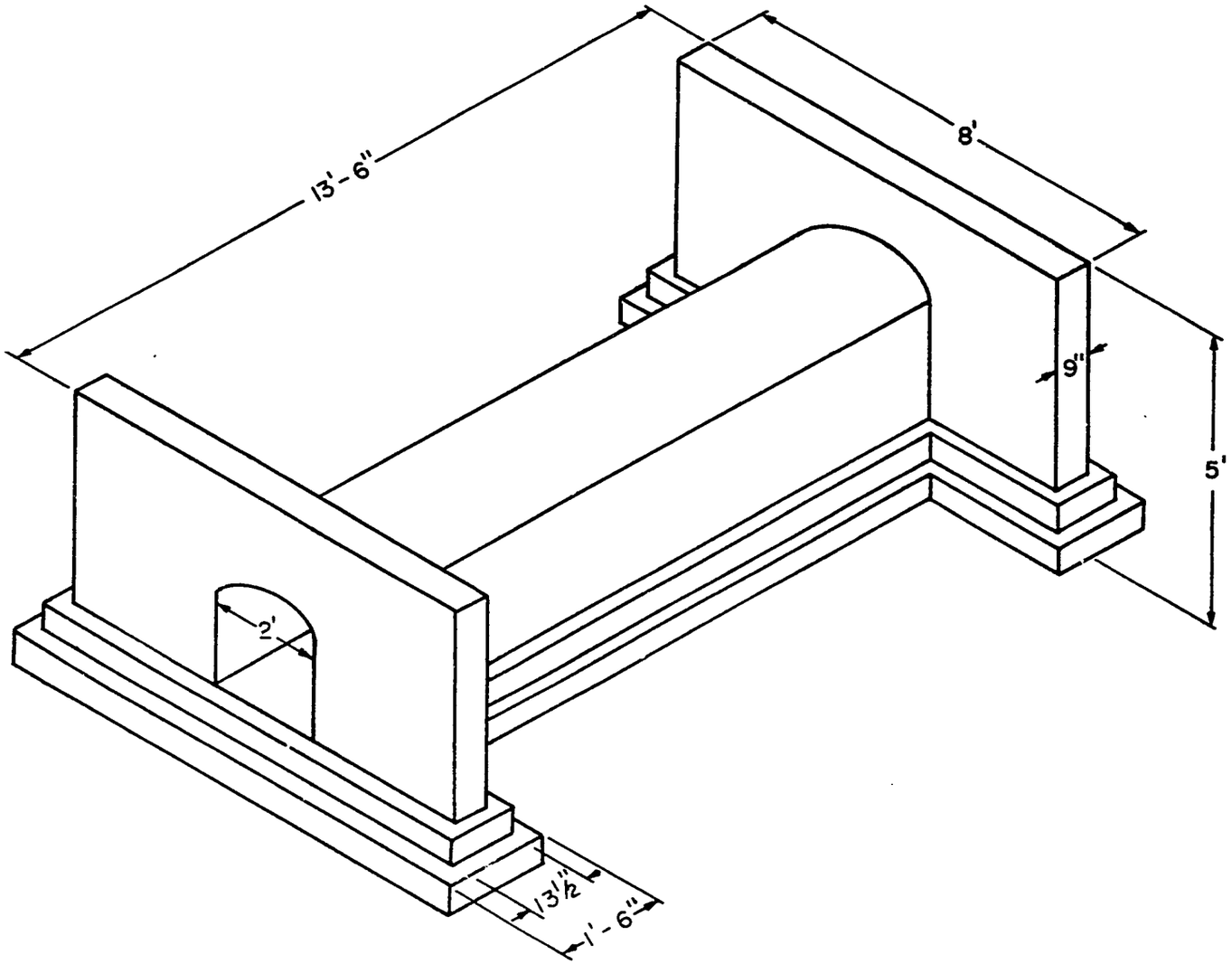
S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu.Ft.
I	1st step Brick work	2	8	1.13	.50	9.00
	2nd step Brick work	2	8	.75	2	24.00
	Reduction	2	r^2B			-4.71
					TOTAL	28.29

MATERIALS	COST
Bricks, 385	Rs. 87
Cement, 2.10 bag	44
Sand, Soft	6
Pipe (24" dia., 3' long)	200
Material Cost	Rs. 337
Labor Cost	16.25
Total Cost	Rs. 353.25

Type (3)

Cost of pipe 24" dia., 1 rft = 25.00
8 rft = 25 x 8 = 200
Rs. 200

Note: No labor cost.



ARCH CULVERT

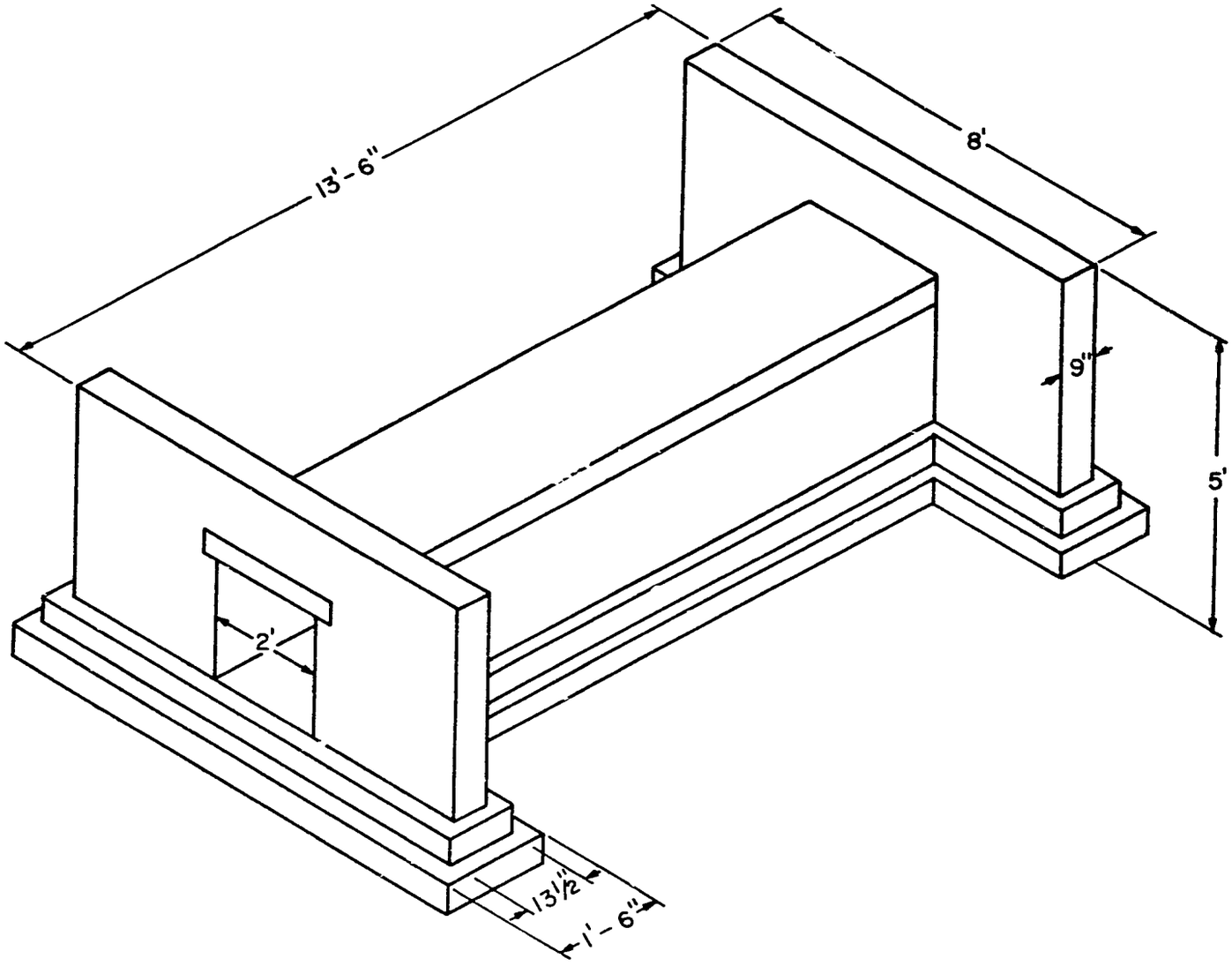
Figure 19. Design of arch culvert made of brick and mortar.

Table 14. Cost Calculation - Arch Culvert

S.No.	Description of Items	No.	L in feet	B in feet	H in feet	Volume Masonry Cu. Ft.
1	Wing walls					
	1st step	2	8.75	1.50	.50	13.12
	2nd step	2	8.38	8.13	.50	9.50
	3rd step	2	8	.75	4	48.00
2	Abutment					
	1st step	2	11.25	1.50	.50	16.87
	2nd step	2	11.63	1.13	.50	13.10
	3rd step	2	12	.75	2.75	49.50
3	Floor, brick paving flat	1	12	1.63	.38	6.50
4	Arch or roof	1	13.50	2.50	.38	12.70
					TOTAL	169.29
	Deduction open surface	2	2	.75	2.75	8.25
						161.04
5	Brick Ballast					
	1st step	1	11.25	1.25	.50	7
	2nd step	1	11.63	1.63	.25	8
					TOTAL	15

MATERIALS

	COST
Bricks, 2175 @ Rs. 0.225	Rs. 489
Brick Ballast	12
Cement, 12.5 bag @ Rs. 21/bag	262
Sand, 48 cft @ Rs. 0.75 cft	36
Cost of Materials	799
Labor Cost	84.40
Total Cost	Rs. 883.40



SLAB CULVERT

Figure 20. Design of slab culvert made of brick and mortar and a steel reinforced concrete slab.

Table 15. Cost Calculation - Slab Culvert

S.No.	Description of Items	NO.	L in feet	B in feet	H in feet	Volume Masonry Cu. Ft.
1	Wing wall					
	1st step	2	8.75	1.50	.50	13.12
	2nd step	2	8.38	1.13	.50	9.50
	3rd step	2	8	.75	4	48.00
2	Abutment					
	1st step	2	11.25	1.50	.50	16.87
	2nd step	2	11.63	1.13	.50	12.10
	3rd step	2	12	.75	2.75	49.50
3	Floor, brick paving flat bricks	1	12	1.63	.33	6.50
				TOTAL		156.59
	Duduction	2	2	.75	2.75	8.25
						148.34
4	Brick Ballast					
	1st step	1	11.25	1.25	.50	7
	2nd step	1	11.63	1.63	.25	8
5	R.C.C. Slab	1	13.50	2.50	.25	8.5
	Steel = .085 cft.					
	Concrete = 3.41 cft.					

Bricks: 2025 Nos. @ Rs. 0.225/brick	Rs. 456
Cement: 13.5 bag @ Rs. 21/bag	284
Sand: 49.5 cft. @ Rs. 0.75/cft	38
Brick Ballast: 15 cft. @ Rs. 0.8/cft	12
Steel: 0.52 maunds @ Rs. 150/maund	78
Aggregate: 7.75 cft. @ Rs. 1.0/cft	8
Materials cost	Rs. 876
Labor Cost	81
TOTAL COST	Rs. 957

COST OF MATERIAL:

Bricks	455.60
Cement	283.50
Sand	37.50
Brick Ballast	12.00
Aggregate	7.50
Steel	78.00
TOTAL COST	874.10

NOTE: Digging with help of farmer labor pay - 81.40

NET TOTAL: Rs. 955.50

he bank. These procedures reduce the cost of this structure to as low as Rs. 100, but are in the initial stages of testing.

3) For single take outs or check structures where head loss must be less than 0.10 ft. A structure similar to that shown in Figure 12 (type 7) is recommended for check structures where a reasonable amount of leakage (up to 0.03 cusecs) can be tolerated. The head losses for different rates of flow can be estimated from Figures 21 and 22 for these structures. To prevent erosion and allow better matching of the 1:1 slope bank to the structure a step down tail section similar to that shown in the type 10 structure in Figure 15 should be added. The total cost will be about Rs. 180.

A more expensive alternative which will further reduce the headloss is the double orifice type 6 structures shown in Figure 11. As Figure 3 indicates, at a flow rate of 5 cusecs (142 liters/sec) the headloss is reduced to about 0.03 ft. (about 1 cm.). The cost of this structure is high (Rs. 312). This can be reduced to slightly under Rs. 300 by making the step down tail section only one brick thick.

4) For combined takeouts and check structures. Combining structures as shown in Figure 13 increases the strength of the structures and allows sharing of headwalls and reduction in the unit cost. Consequently combined structures are recommended where feasible. The structure shown in Figure 13 should have step down tail sections added to each outlet (which will cost about Rs. 21 per outlet for single brick width walls plus the added floor. This will add to the cost of the structure so the total cost of the type of structure with step down tail walls will be Rs. 505.

BUFFALO WATERING AND BATHING STATIONS

1) The round or rectangular stock watering and bathing stations have been satisfactory, except for failure on some of the ramps. Consequently, to avoid this problem all ramps should have a layer of gravel or broken brick at least 8" thick below the masonry or concrete layer that is to support the weight of the animals on the ramp.

The relatively high cost of these structures raises the question as to whether tanks with compacted earth banks at 1/4 or 1/3 slopes may be the best means for providing animal access to the water.

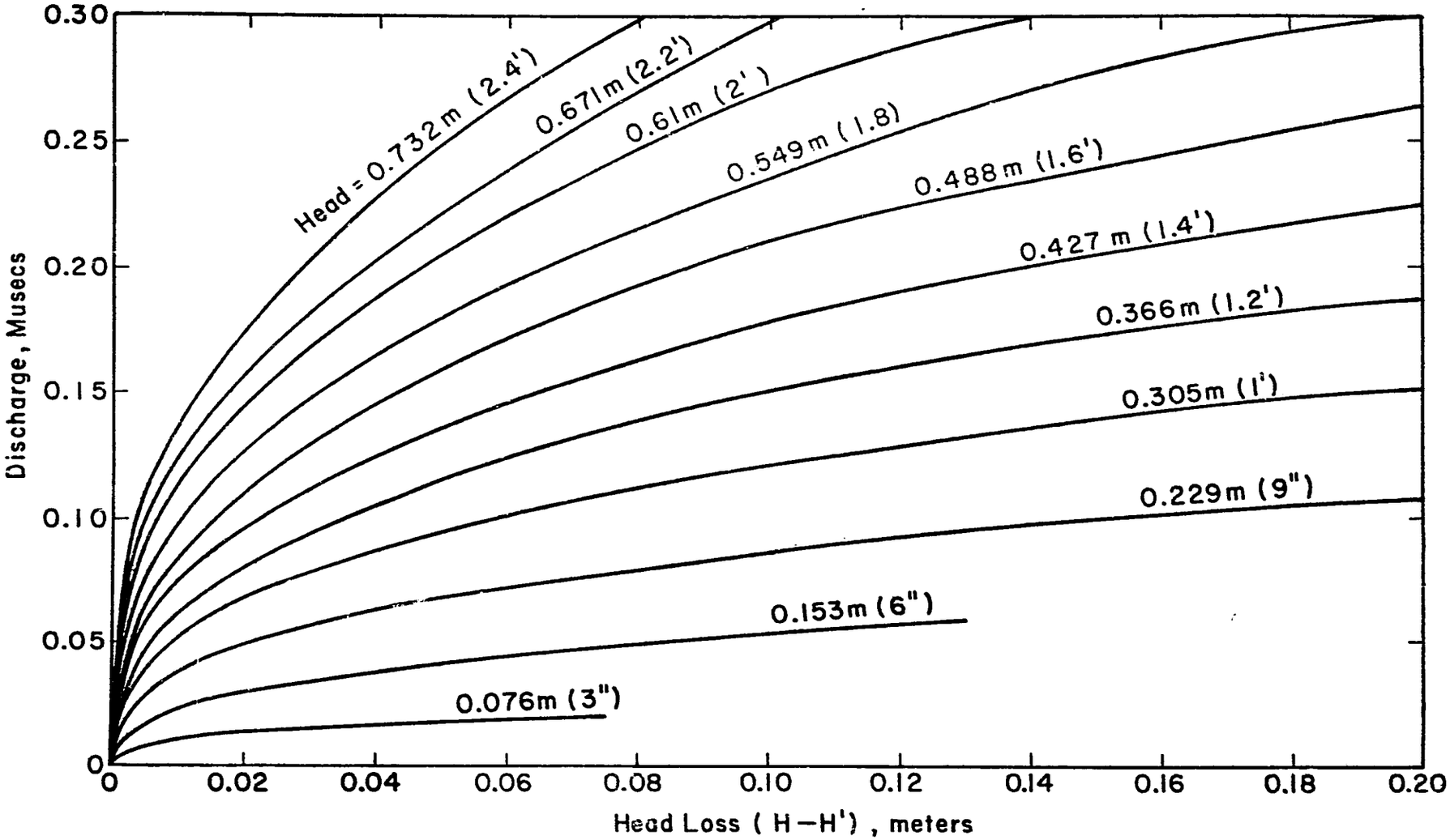


Figure 21. Shows the relationship between head loss and discharge at different heads with 0.508 meter width (rectangular panel nakka).

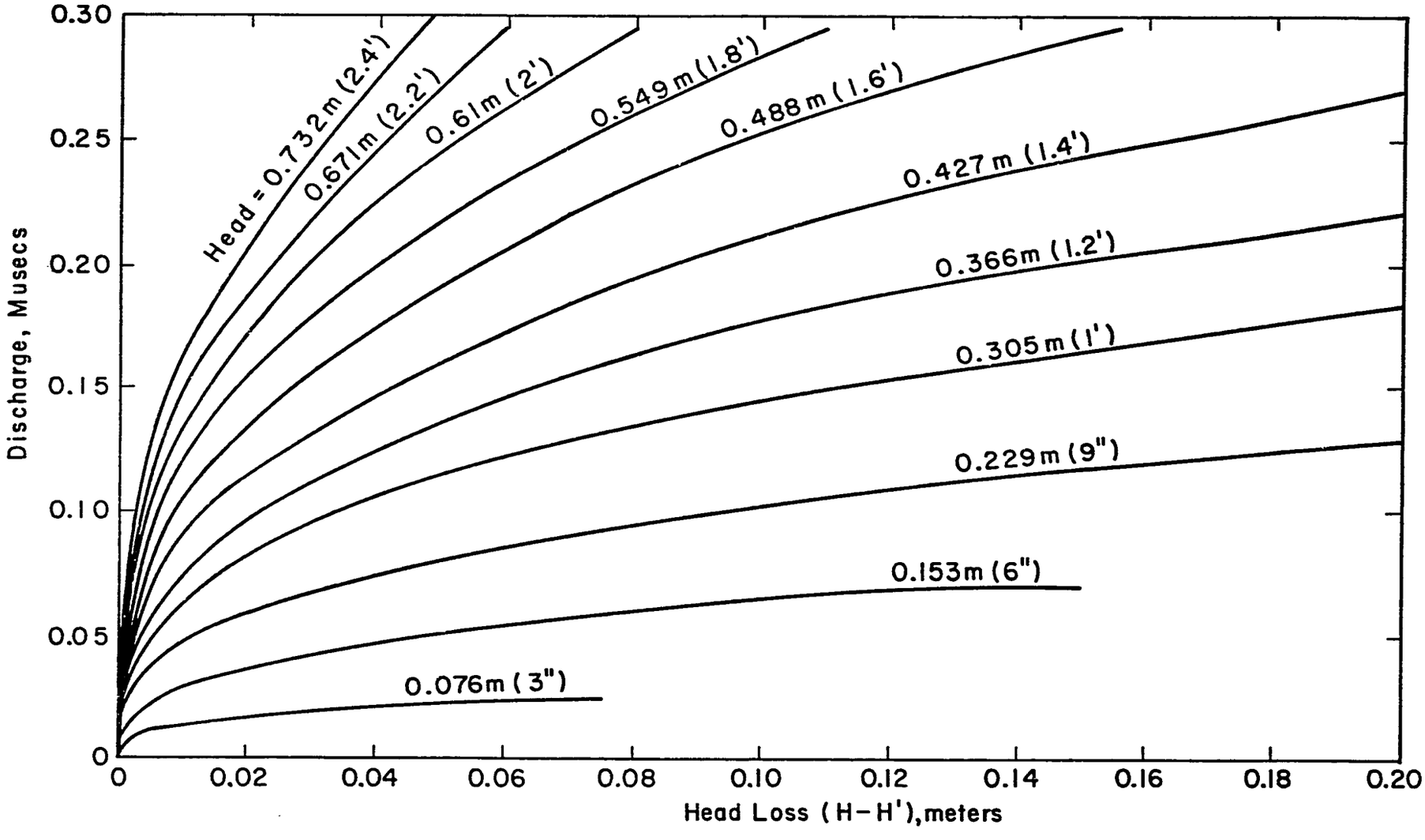


Figure 22. Shows the relationship between head loss and discharge at different heads with 0.61 meter width (rectangular panel nakka).

It is actually illegal to build a place for buffalo to bath on the sarkari khal (authorized watercourse). Consequently, they should be built on private watercourses or built at the side and connected to the watercourse by a pipe or short watercourse section.

CULVERTS

The least expensive culvert is generally a concrete pipe. End walls as shown in Figures 18a and 18b cost about as much as an additional 4 ft. section and the riprap which would be necessary to prevent erosion at the two ends of the structure.

1) Where the traffic is primarily men, bullock and bullock carts, concrete pipe culverts 8 ft. long are recommended, with riprap at each end to prevent erosion. Generally at least 6" of soil should cover the pipe to cushion it against impact from animal hooves and bullock cart wheels.

2) Where traffic includes tractors and trolleys, concrete pipe culverts 12 ft. long are recommended with riprap at each end to prevent erosion. At least 6" of soil should cover the pipe to spread the weight more evenly over the pipe.

3) When watercourses are extremely flat and head losses greater than 0.03' cannot be tolerated, brick and mortar arched culverts with cross sections for flow greater than 4 sq. feet should be used.

The head losses encountered at these culverts may be estimated from the graphs in Figures 3, 21 and 22.

Permanent Elevation Markers for Watercourse Levels

Sedimentation, vegetative growth and cleaning operations can drastically modify the shape and size of the watercourse cross section over a period of years. The watercourse then becomes too small to carry the water, or uses more land than is necessary.

To help maintain the watercourse at the proper size permanent markers are suggested.

These may be installed at regular intervals on the watercourse (i.e. every 500 feet), or they may be more conveniently attached to check structures.

They may have many forms. One of the simplest and least expensive is a single row of bricks mortared to the cutoff

wall of the check structure showing the bed and side levels. The floor of the check structure should be level with the bed of the watercourse behind the structure.

Measurement Structures

Concrete flumes and staff gauges to help farmers recognize their losses and monitor their losses and elevation of water in their water courses, are being evaluated as aids to watercourse cleaning and maintenance programs.

However, testing of these structures has not progressed to where recommendations can be made.

Appendix 10

DESIGN DATA AND EQUIPMENT DEVELOPMENT FOR WATERCOURSES

William E. Hart [1]

ABSTRACT

The work reported here has as its overall objective the improved design and operation of watercourses delivering water to individual farm plots. These investigations can be contributions to a design handbook for watercourses. Such a handbook would be of assistance to field engineers and planning offices in LDC's.

There have been three phases to the current work.

(1) Development of low rating charts for rectangular and trapezoidal channels.

(2) Development of a form for rectangular concrete gates suitable for construction in LDC's.

(3) Model studies on rectangular and circular-opening gates to determine their headloss characteristics when fully open.

The first item is included in this report. Drawings for the second item, which has been constructed and sent to the field party in Pakistan (Water Management Research Project) are included as a part of this report. A partial reporting of the third item is also included.

RATING CURVES FOR OPEN CHANNELS

Trapezoidal channels have greater hydraulic radii for a given wetted perimeter than do rectangular ones. They are thus the preferred choice when construction materials are at a premium. However, because of the ease of constructing rectangular channels by hand methods, they are often preferred in LDC's. In addition, the latter are less subject to damage by draft animals which frequent areas adjacent to watercourses. The design charts herein presented thus include both rectangular channels ($z = 0$) and 45-degree side slope trapezoidal channels ($z = 1$). The prediction equation used is that of Manning.

$$Q = \frac{1}{n} S_o^{1/2} R^{2/3} A, \qquad (1)$$

[1]Assoc. Professor, Department of Agricultural Engineering, Colorado State University, Fort Collins, Colorado.

Where n is the Manning roughness coefficient, Q is the flow rate ($m^3 sec^{-1}$), S_o is the invert slope ($m\ m^{-1}$), R is the hydraulic radius (m) and A is the cross-sectional area of flow (m^2).

When constructed by hand methods, channels are frequently unlined earth, of bare brick, or of mortar-covered brick. The flow charts included in Appendix A reflect the full range of roughnesses expected with these surfaces. The appropriate Manning n to be used for each surface, as recommended by Chow (1959) are given in Table 1. Flows for channels with roughnesses different from those given can be determined from the following equation.

$$Q = Q_1 \frac{n_1}{n} \qquad (2)$$

Where Q is the flow in a channel of roughness n and Q_1 is the flow in a channel of roughness n_1, both channels of identical geometry and flowing at equal depths.

RECTANGULAR CONCRETE GATE

The Colorado State University (CSU) WMR project has initiated the construction of improved watercourses in an attempt to eliminate or reduce leakages and unauthorized withdrawals. The channels may be improved earthen ones, or lined with brick, concrete, etc. However, they all require the use of gates to control the flow of water within them and into branches, etc. Ideally, such gates should have the following characteristics.

1. Leak proof
2. Low head loss when fully open
3. Some capacity for adjustment of flow
4. Easily operable
5. Inexpensive to construct
6. Easily constructed by local labor
7. Utilize materials readily available locally.

W.D.Kemper, Chief of the CSU WMR field party conceived of and developed (Hart, 1975) a concrete gate having a circular opening (Figure 1). This unit is easily constructed by manufacturers of concrete pipe. The gate frame is cast as part of a concrete slab, which is installed in the channel at a 45-degree angle, tilted downstream. The unit incorporates all the desirable characteristics mentioned above, with the possible exception of low head loss (item 2). By

Table 1. Values of Manning's n to be used in estimating flow rates in open channels (After Chow, 1959).

Channel Description	n
Concrete, trowelled finish	0.013
Brick in cement mortar	0.015
Earth, straight and uniform, clean, recently completed	0.018
Concrete bottom float finished with sides of cement rubble masonry, plastered	0.020
Earth, winding and sluggish, no vegetation	0.025
Earth, winding and sluggish, with grass and some weeds	0.030
Rock cuts, smooth and uniform	0.035

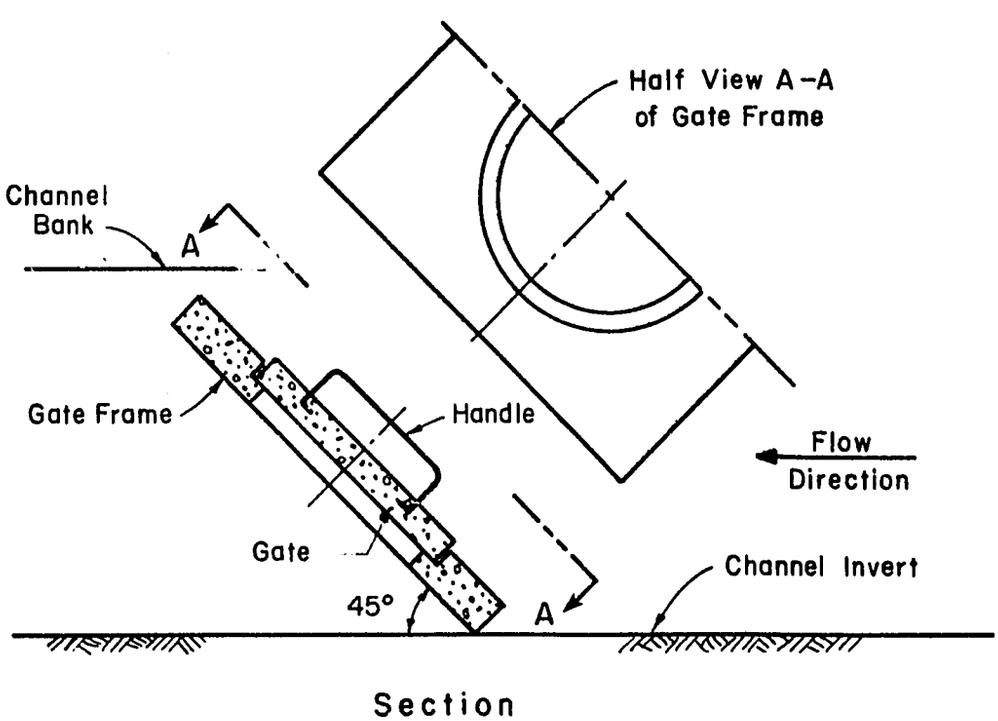


Figure 1. Circular gate. Opening is 12 to 18 in.

its very geometry, the gate opening causes a significant restriction to flow in an open channel. Thus, when flow rates are high, so are the head losses. (See later section of this report entitled "Headlosses in Circular and Rectangular Concrete Gates.") In an effort to overcome these head loss restrictions a rectangular gate (Figure 2) was designed, aluminum forms were constructed for its manufacture, two gates were built, and the forms were shipped to the WMR field party in Pakistan for field trials. The dimensions of the gate forms are given in Appendix B of this paper. The particular gate described is designed especially for use in a 20-inch wide rectangular channel. However, it is also adaptable to wider channels, to trapezoidal channels with a minimum bottom width of 20 inches, and to channels of other shapes (Hart 1975). A similar design, with different dimensions, is adaptable to any size channel. A relatively minor change in the forms would make them adjustable so that gates of appropriate width could be made to match channels of various sizes. Although the gate is normally fully open or fully closed, it can be set at a partial opening. In this case it acts as a sluice.

The material of construction is concrete and steel reinforcing bars. The sealing material is cellular rubber rod. All these materials are available in many LDC's.

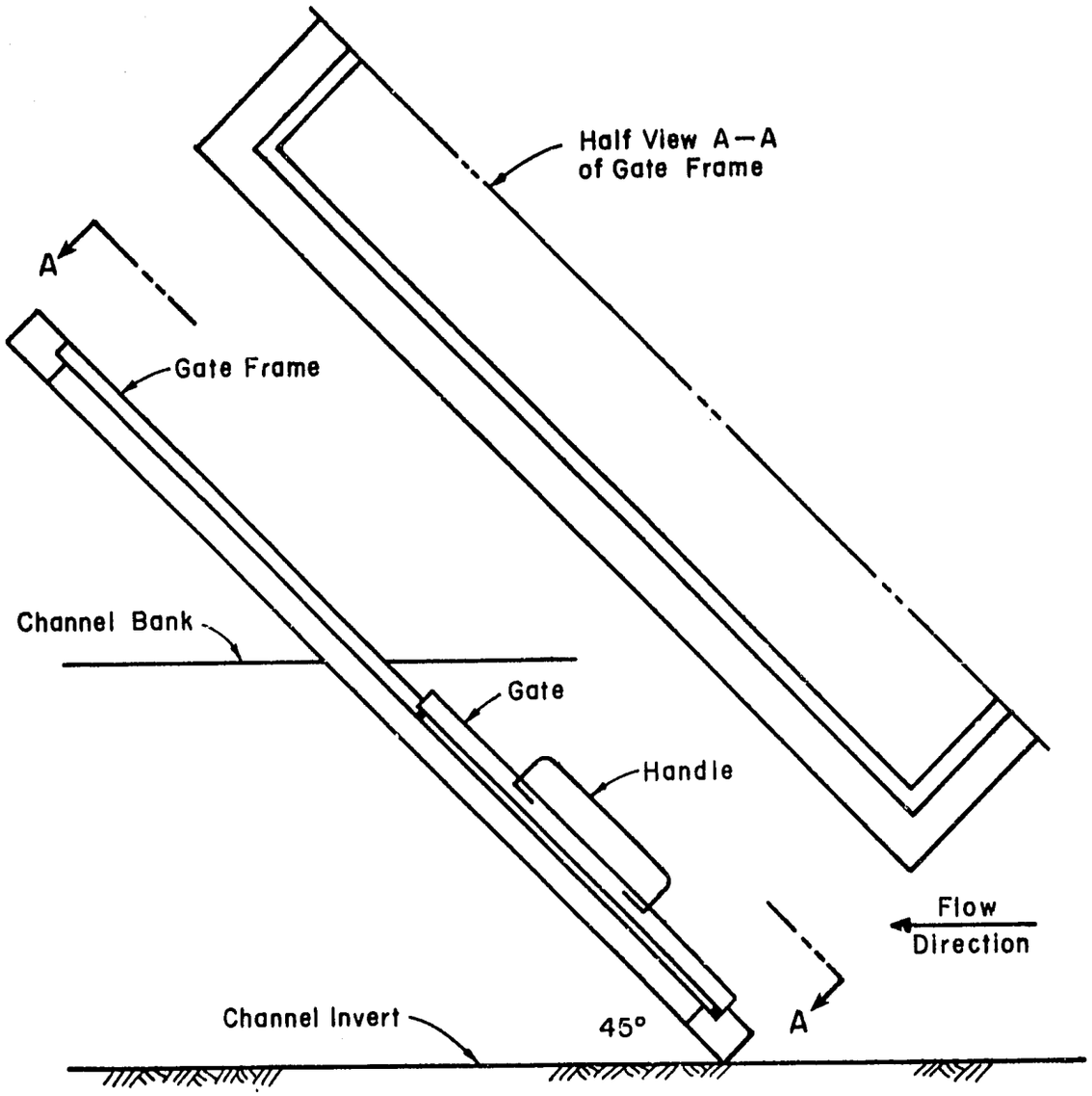
HEAD LOSSES IN RECTANGULAR AND CIRCULAR CONCRETE GATES

Model studies were performed to determine the head losses in rectangular and circular concrete gates of the type described in the previous section. The studies were run in a 0.6-meter (2-ft) wide rectangular open channel because of the availability of this for model studies. The particular set of model geometries investigated are given in Figure 3 and 4. These gates were all tested when placed at a 45-degree slope to the flow direction (Figures 1 and 2).

A commonly used channel width in the WMR investigations is 0.5 meter (20 inches), and these studies can be used to estimate losses of geometrically similar gates in such channels. Because of the nature of the flow regime (fluid weight is the predominate force acting), the appropriate modeling criterion is the Foude number, F_r.

$$F_r = V/(gL)^{\frac{1}{2}}, \qquad (3)$$

where V is the average velocity in the flow cross section, L is some characteristic length, and g is the acceleration due to gravity. The results of these studies can thus be adjusted for the 0.5-meter channel by applying the ratios given in Table 3.



Section

Figure 2. Rectangular gate. Opening is 14 in.

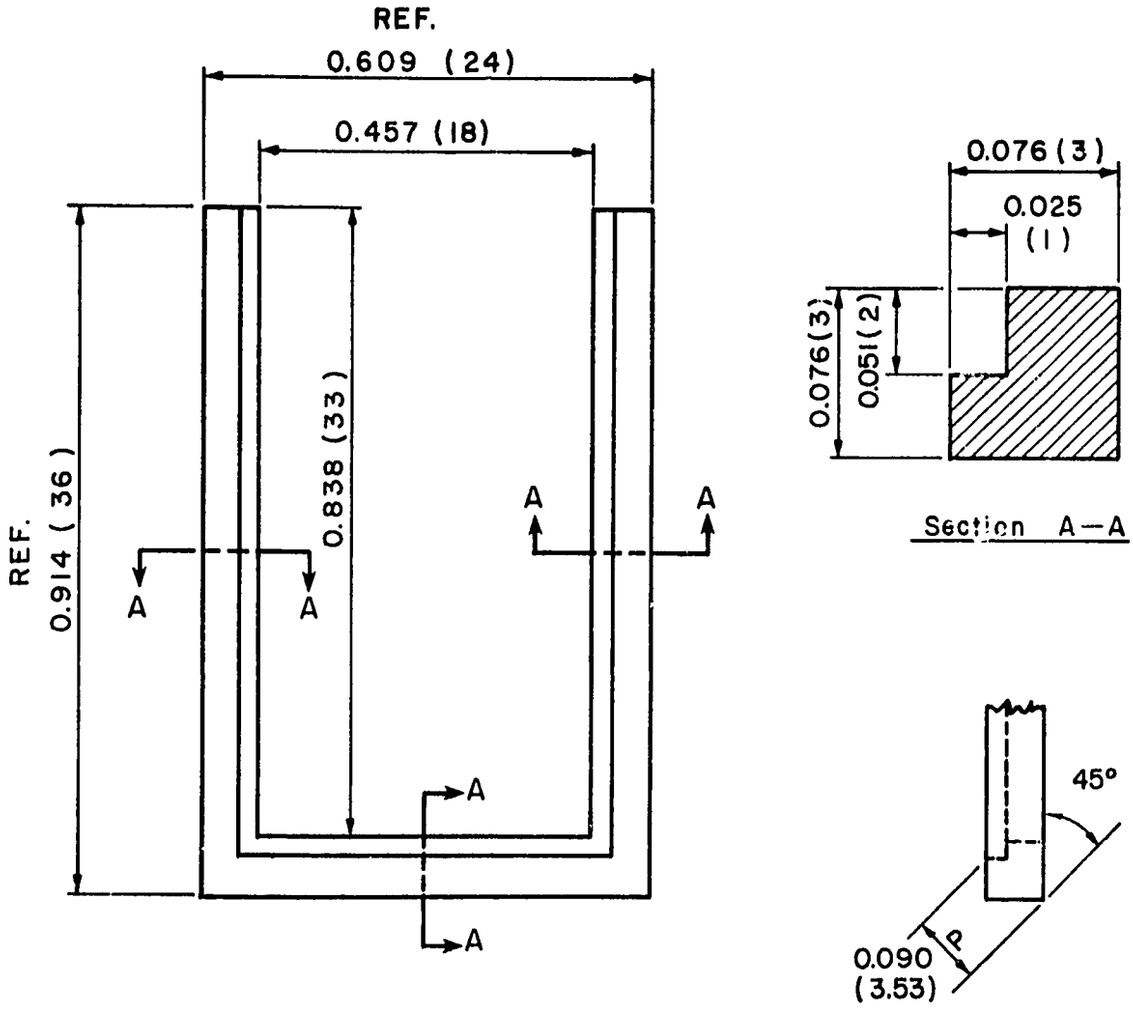
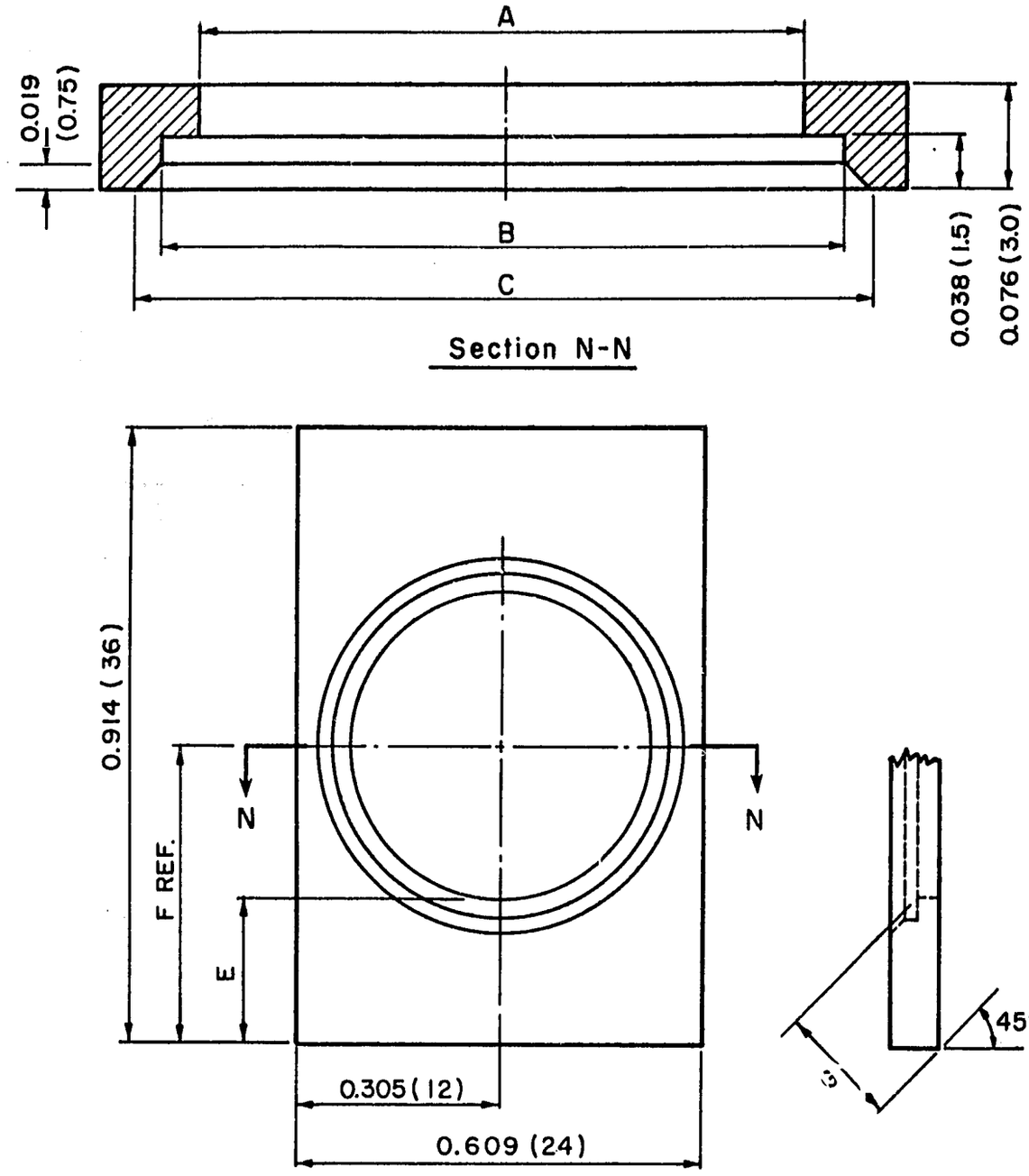


Figure 3. Rectangular gate. Dimensions in meters and (in.).



A	0.457 (18)	0.381 (15)	0.381 (15)
B	0.513 (20.2)	0.432 (17)	0.432 (17)
C	0.559 (22)	0.483 (19)	0.483 (19)
D	0.028 (1.1)	0.025 (1.0)	0.025 (1.0)
E	0.213 (8.4)	0.229 (9)	0.229 (9)
F	0.442 (17.4)	0.419 (16.5)	0.419 (16.5)
G	0.178 (7.0)	0.188 (7.4)	0.135 (5.3)

Figure 4. Circular gate. Dimensions in meters and (in.).

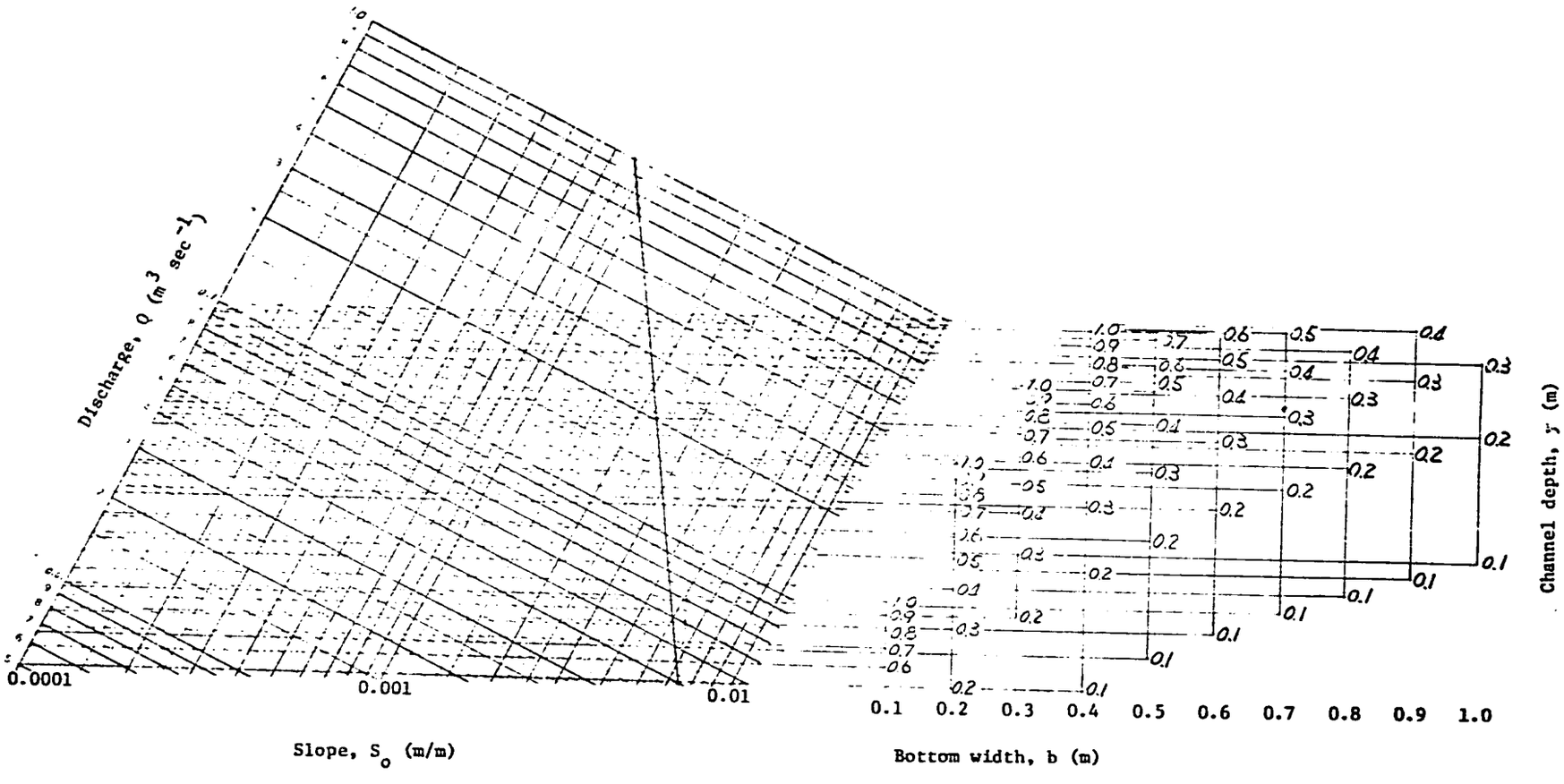


Figure A-1. Flow in rectangular open channel, n = 0.013 (concrete, trowelled finish), by Manning's equation.

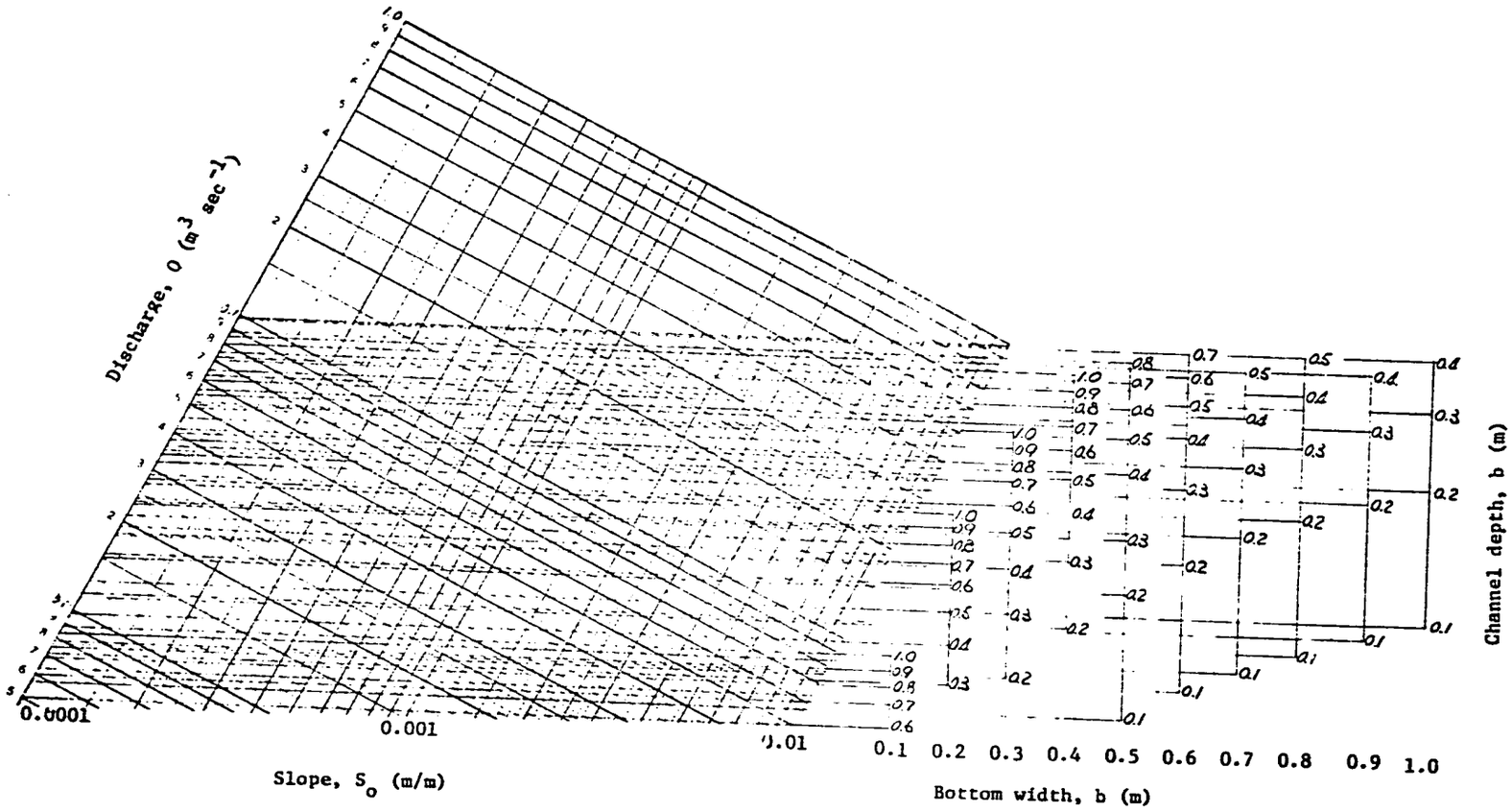


Figure A-2. Flow in rectangular open channel, n = 0.015 (brick in cement mortar), by Manning's equation.

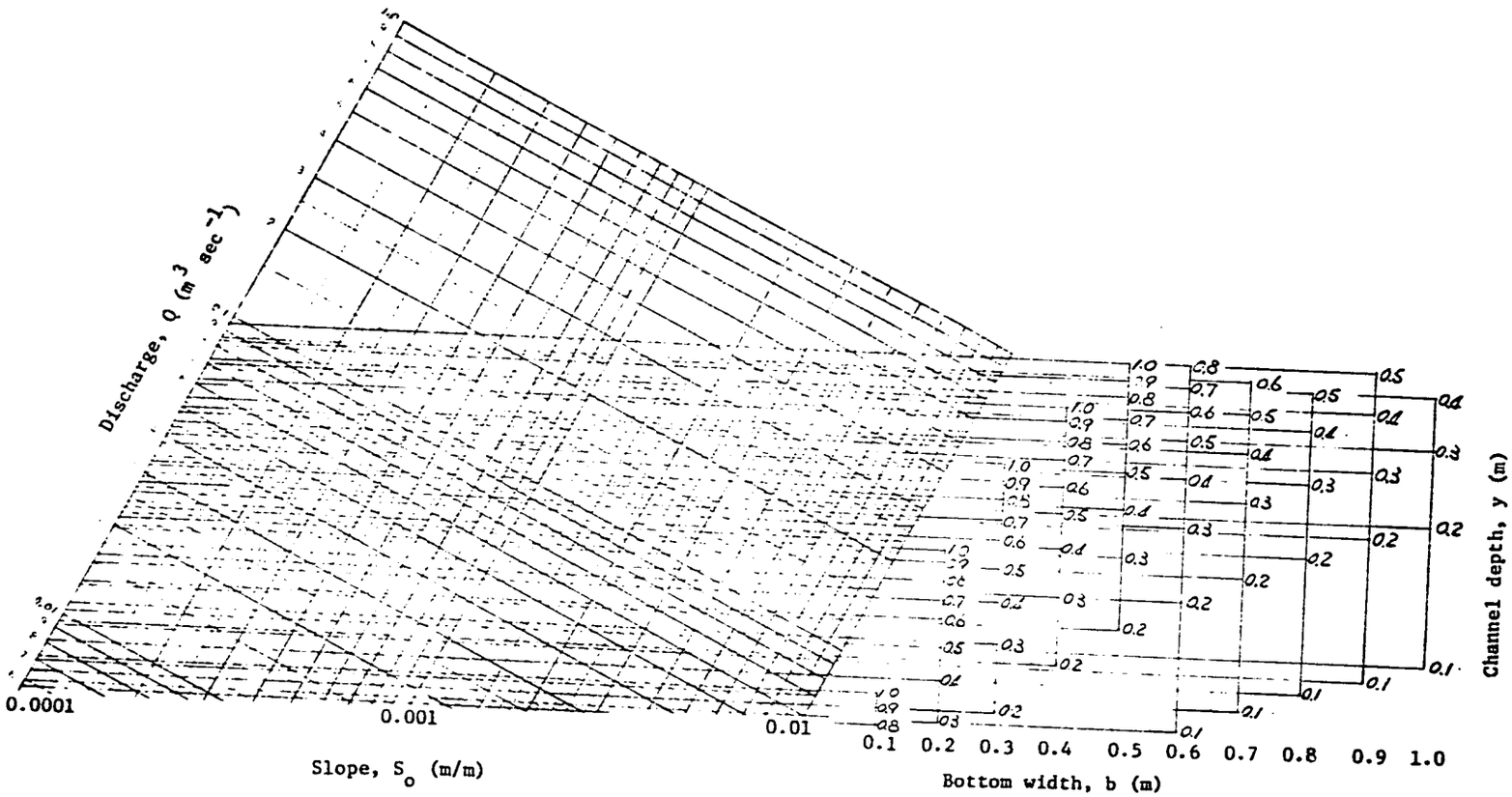


Figure A-3. Flow in rectangular open channel, n = 0.018 (earth, straight and uniform, clean, recently completed), by Manning's equation.

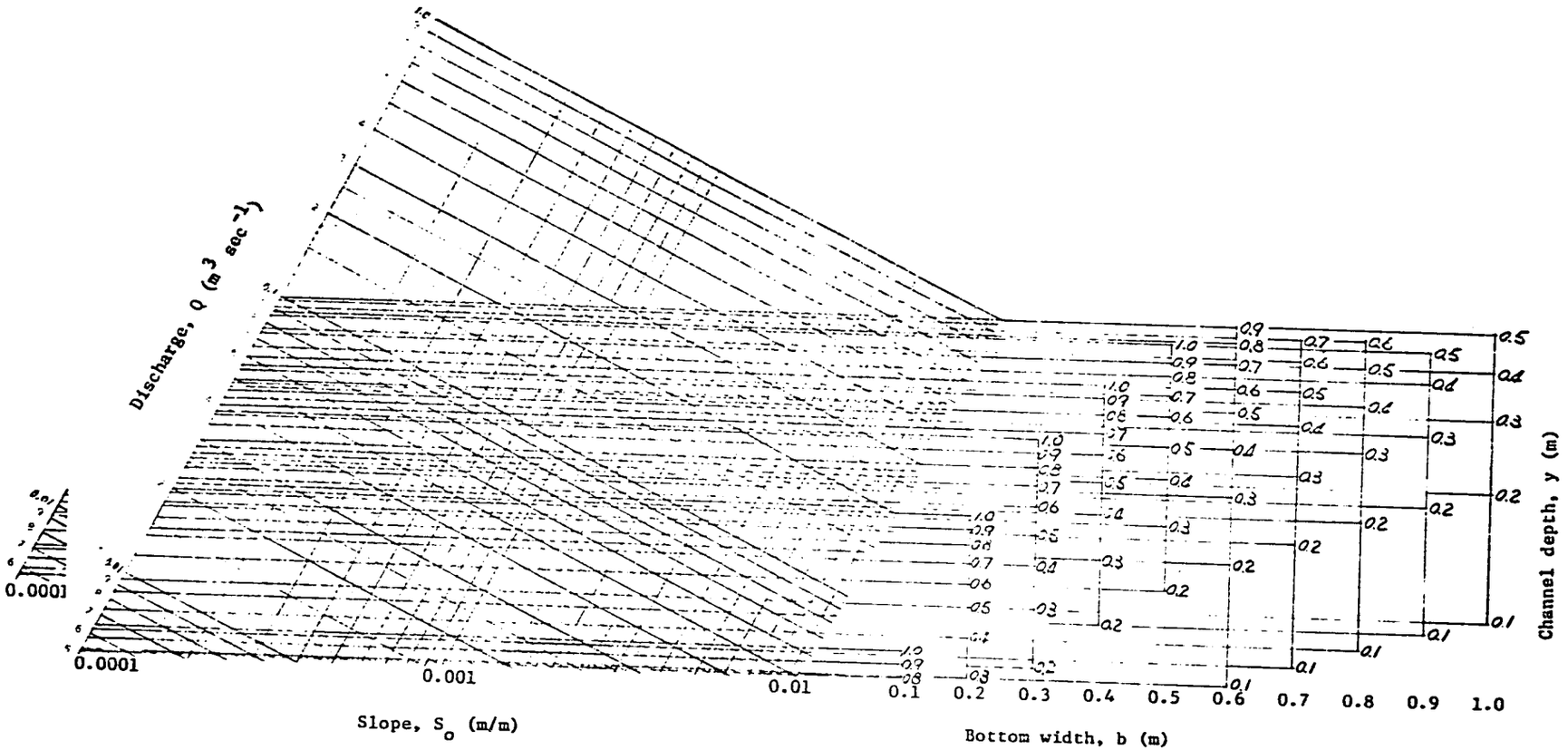


Figure A-4. Flow in <u>rectangular</u> open channel, <u>n = 0.020</u> (concrete bottom float finished with sides of rubber masonry, float finished) by Manning's equation.

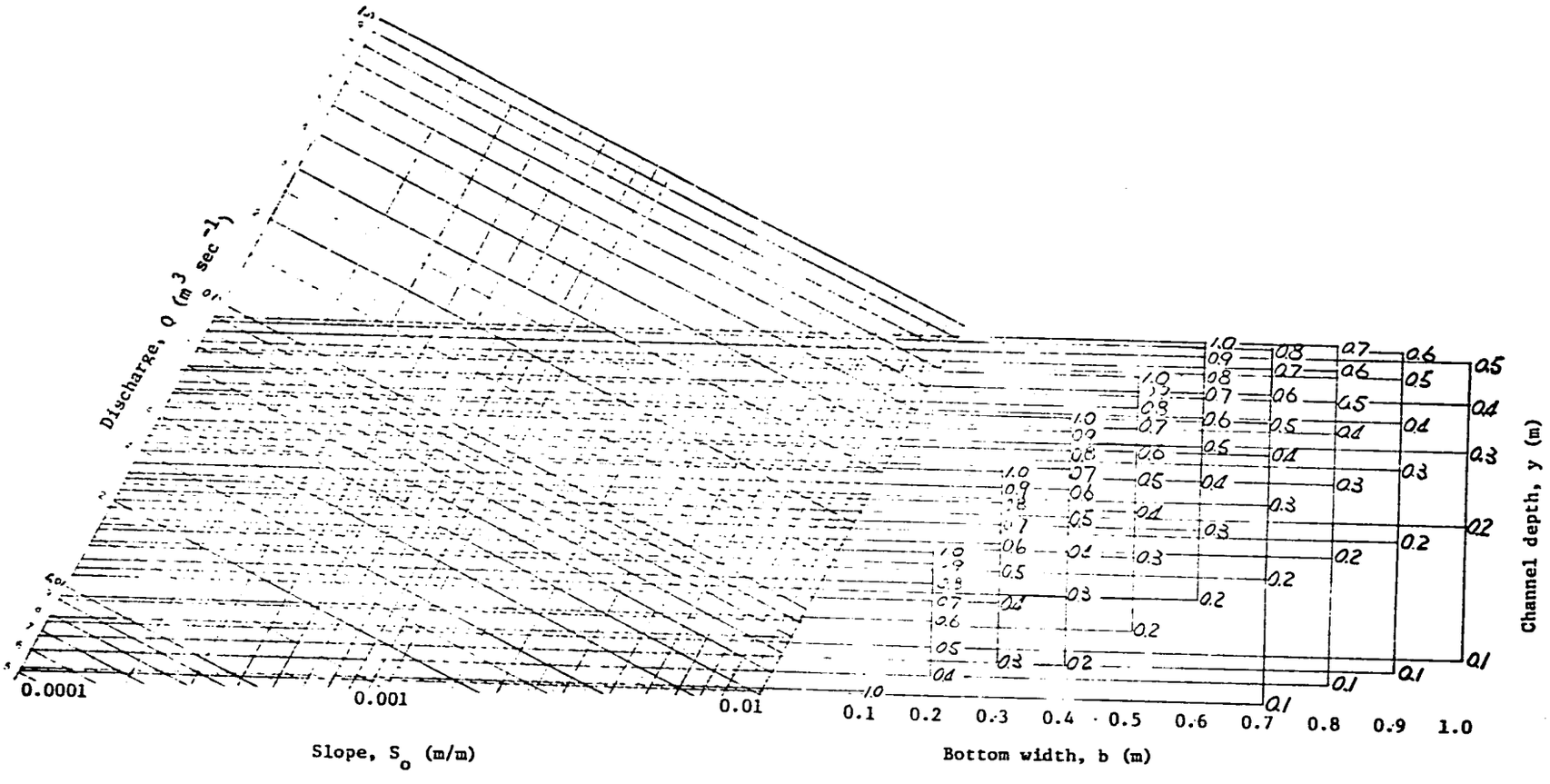


Figure A-5. Flow in <u>rectangular</u> open channel, <u>n = 0.025</u> (earth, winding and sluggish, no vegetation), by Manning's equation.

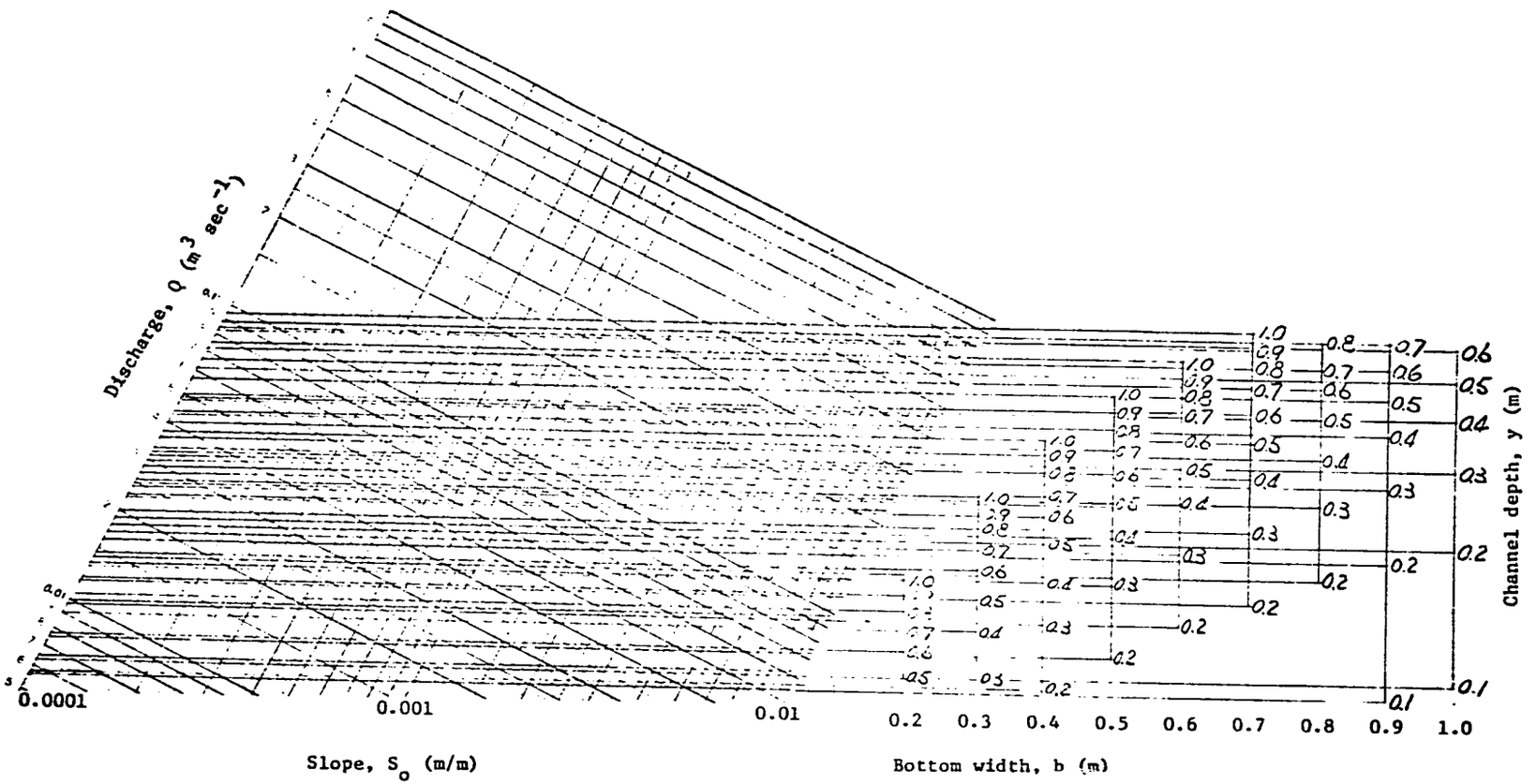


Figure A-6. Flow in rectangular open channel, n = 0.030 (earth, winding and sluggish, with grass and some weeds), by Manning's equation.

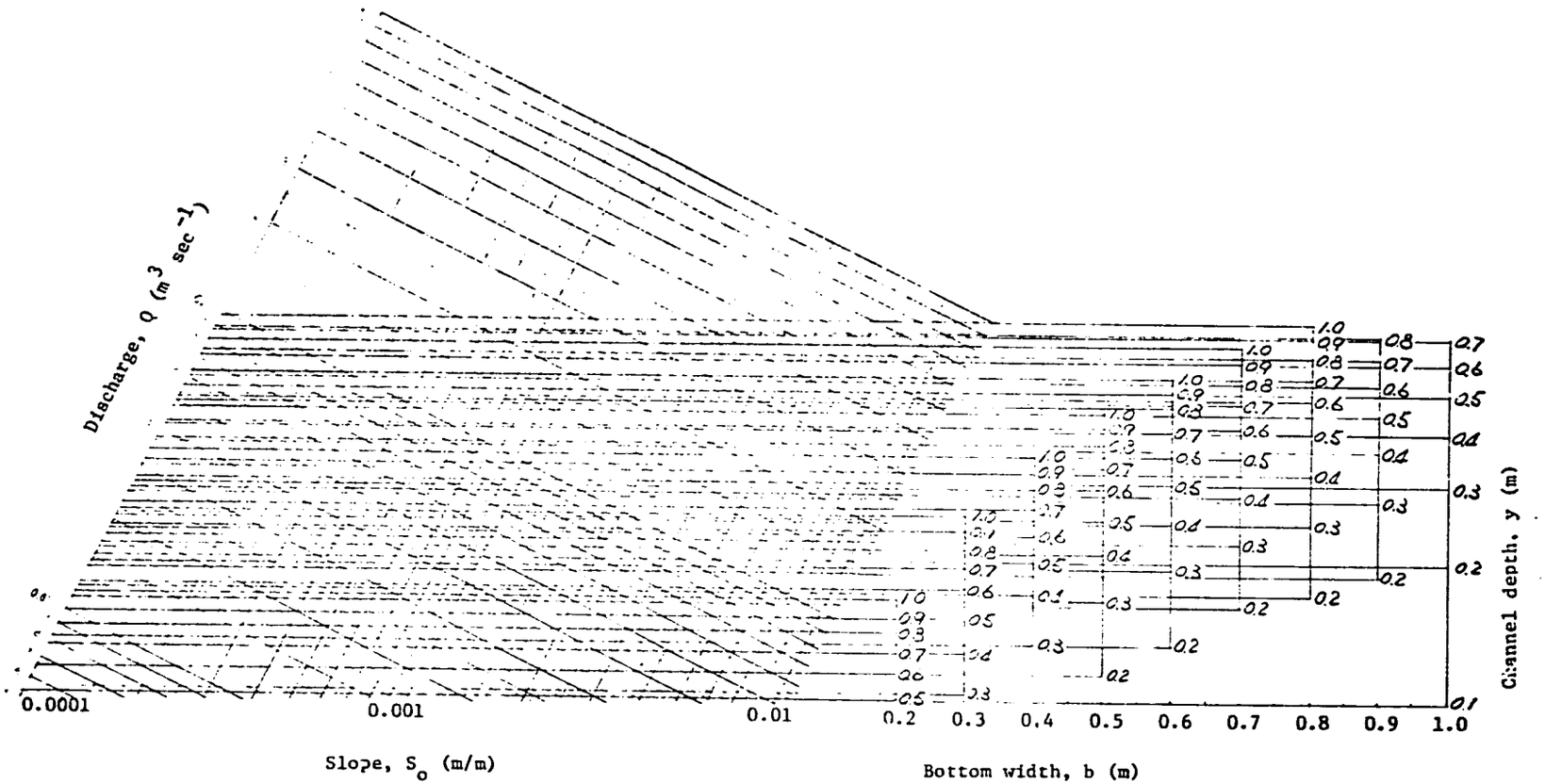


Figure A-7. Flow in rectangular open channel, n = 0.035 (rock cuts, smooth and uniform), by Manning's equation.

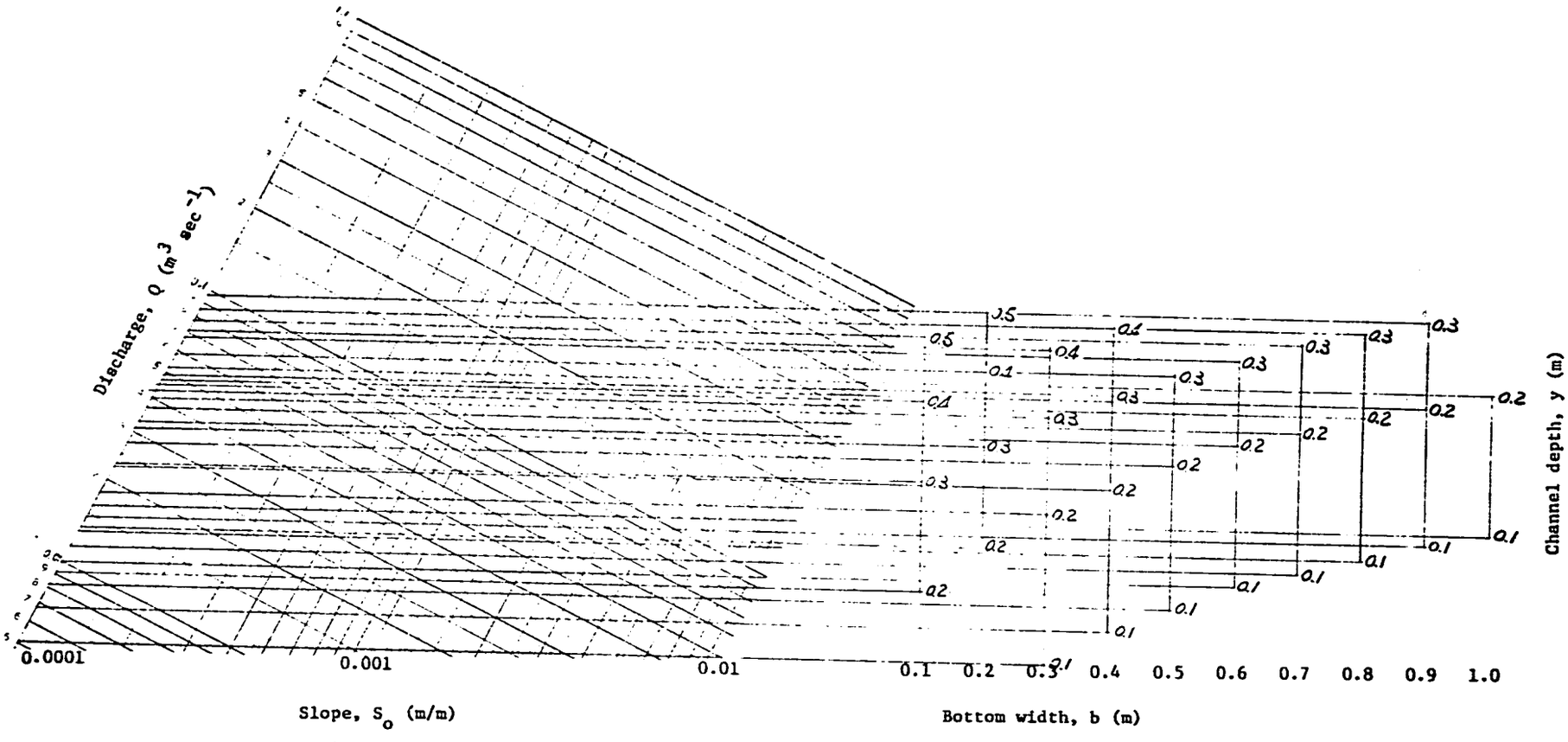


Figure A-8. Flow in 45-degree side slope trapezoidal open channel, n = 0.013 (concrete, trowelled finish), by Manning's equation.

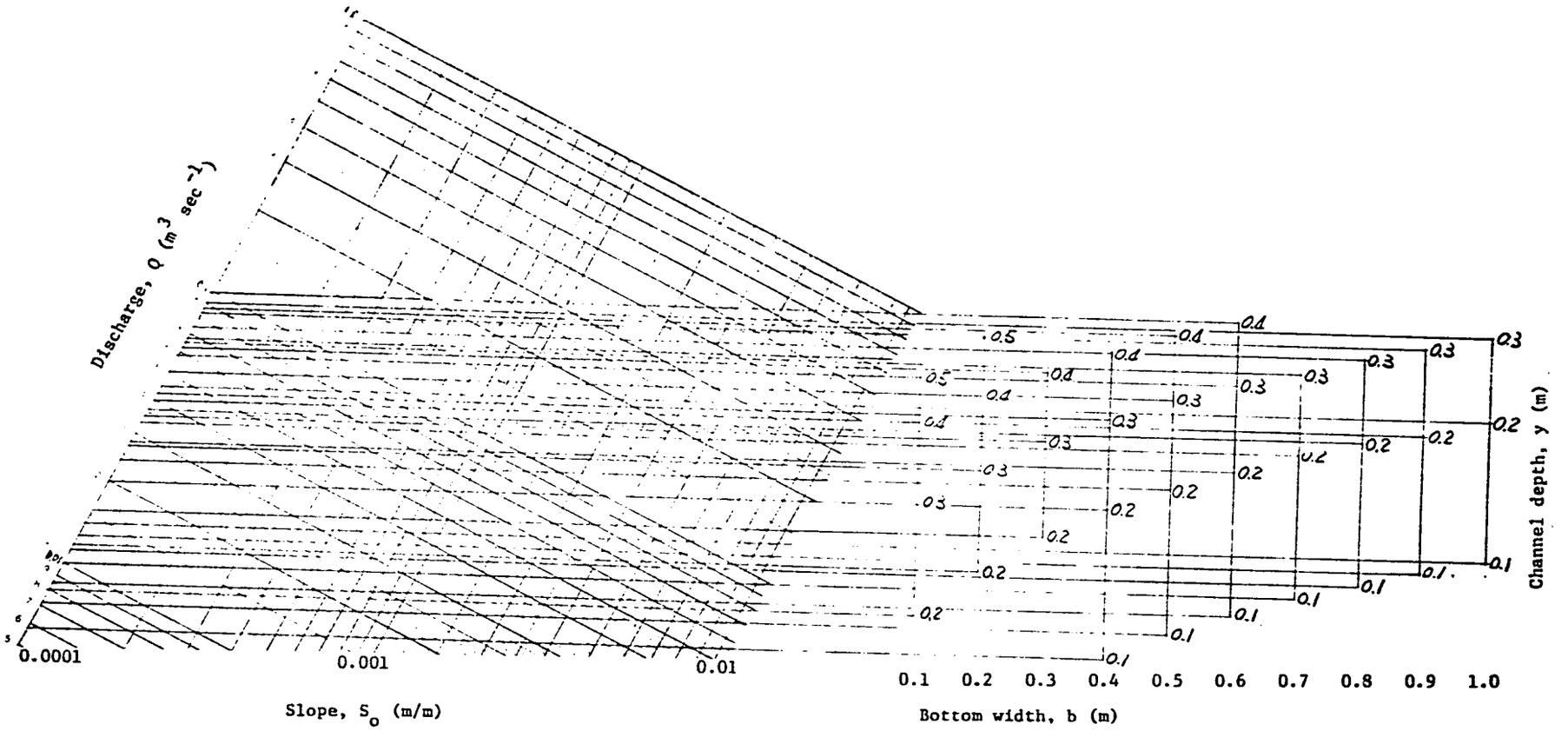


Figure A-9. Flow in 45-degree side slope trapezoidal open channel, n = 0.015 (brick in cement mortar), by Manning's equation.

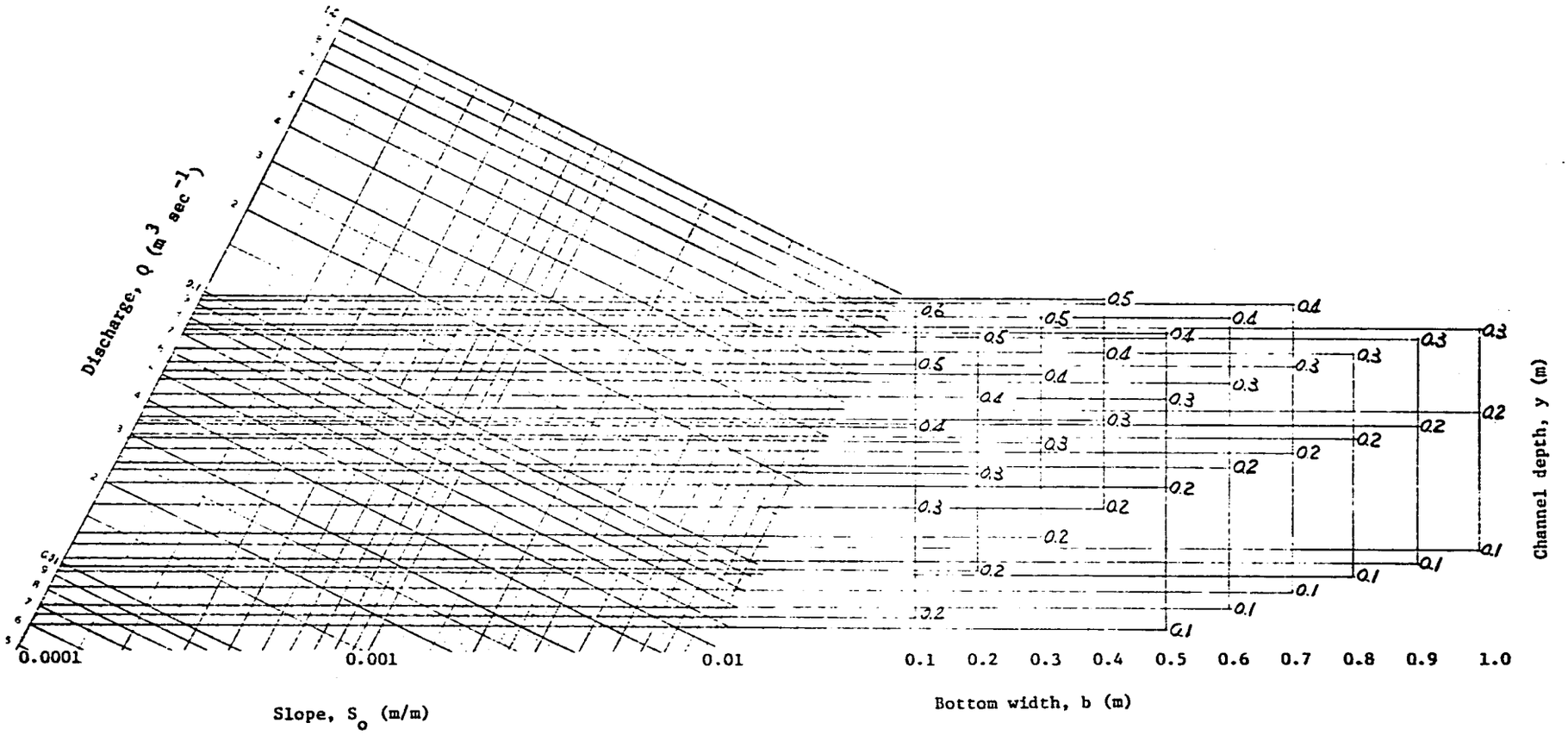


Figure A-10. Flow in 45-degree side slope <u>trapezoidal</u> open channel, <u>n = 0.018</u> (earth, straight and uniform, clean, recently completed), by Manning's equation.

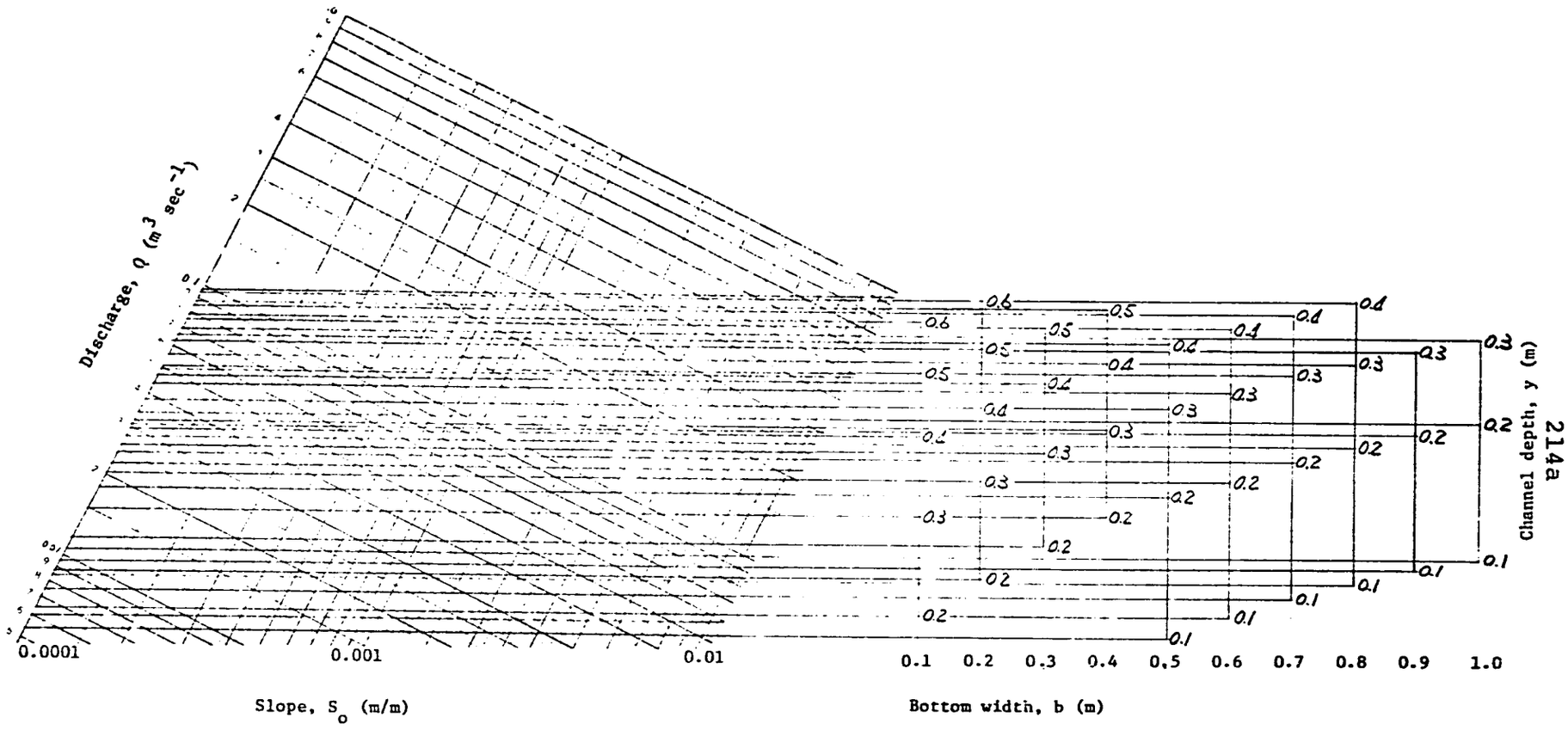


Figure A-11. Flow in 45-degree side slope trapezoidal open channel, n = 0.020 (concrete bottom float finished with sides of cement rubble masonry, plastered), by Manning's equation.

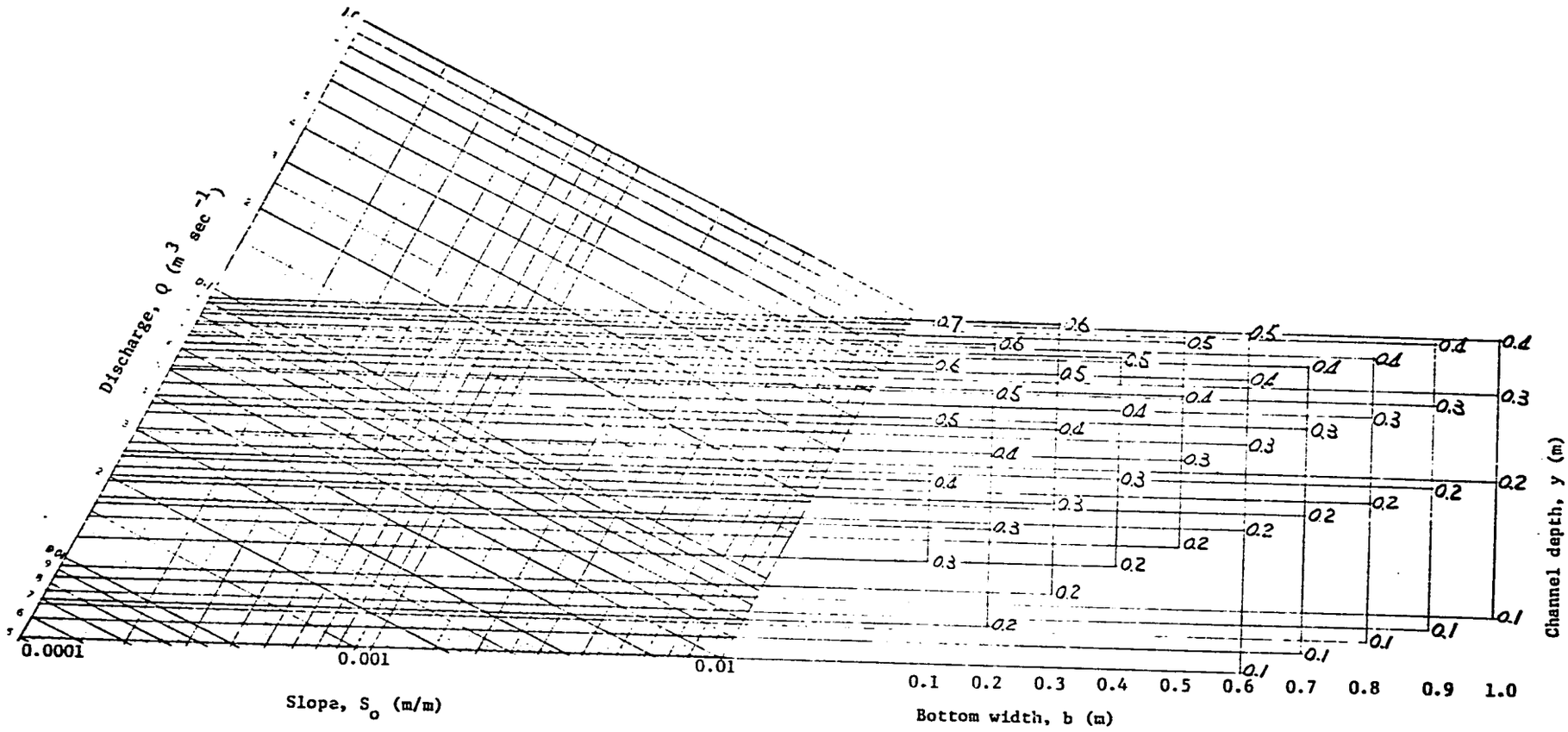


Figure A-12. Flow in 45-degree side slope trapezoidal open channel, n = 0.025 (concrete bottom float with sides of cement rubble masonry, plastered), by Manning's equation.

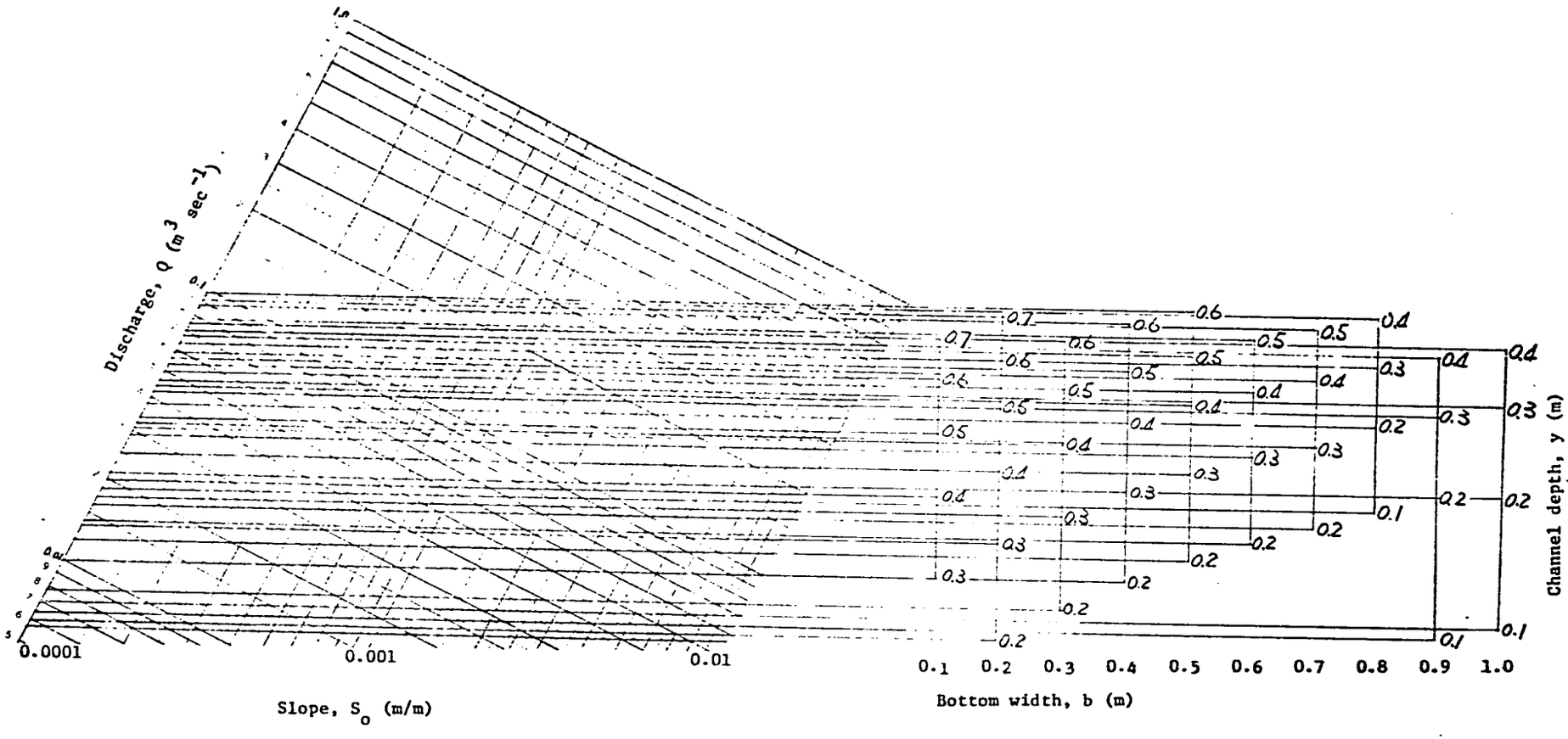


Figure A-13. Flow in 45-degree side slope trapezoidal open channel, n = 0.030 (earth, winding and sluggish, with grass and some weeds), by Manning's equation.

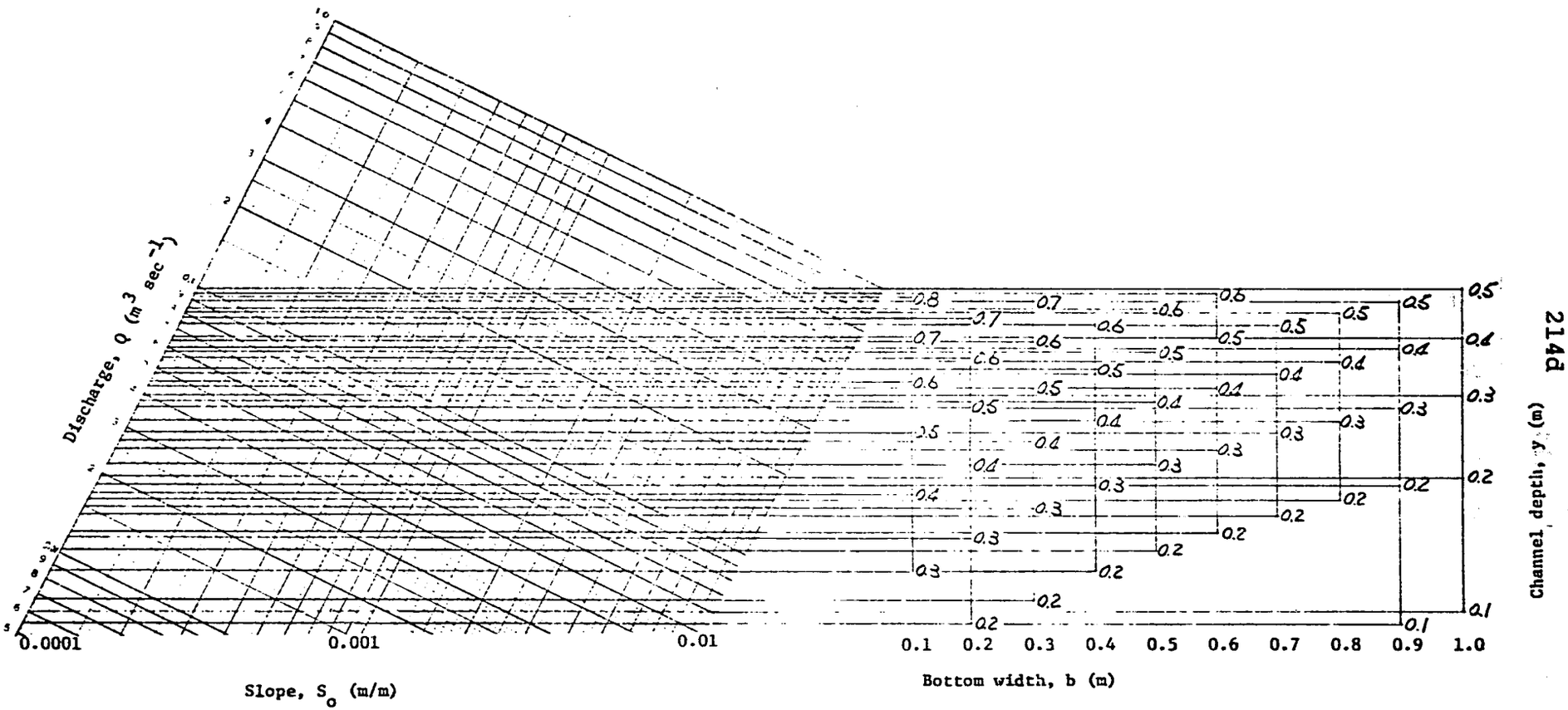


Figure A-14. Flow in 45-degree side slope trapezoidal open channel, n = 0.035 (rock cuts, smooth and uniform), by Manning's equation.

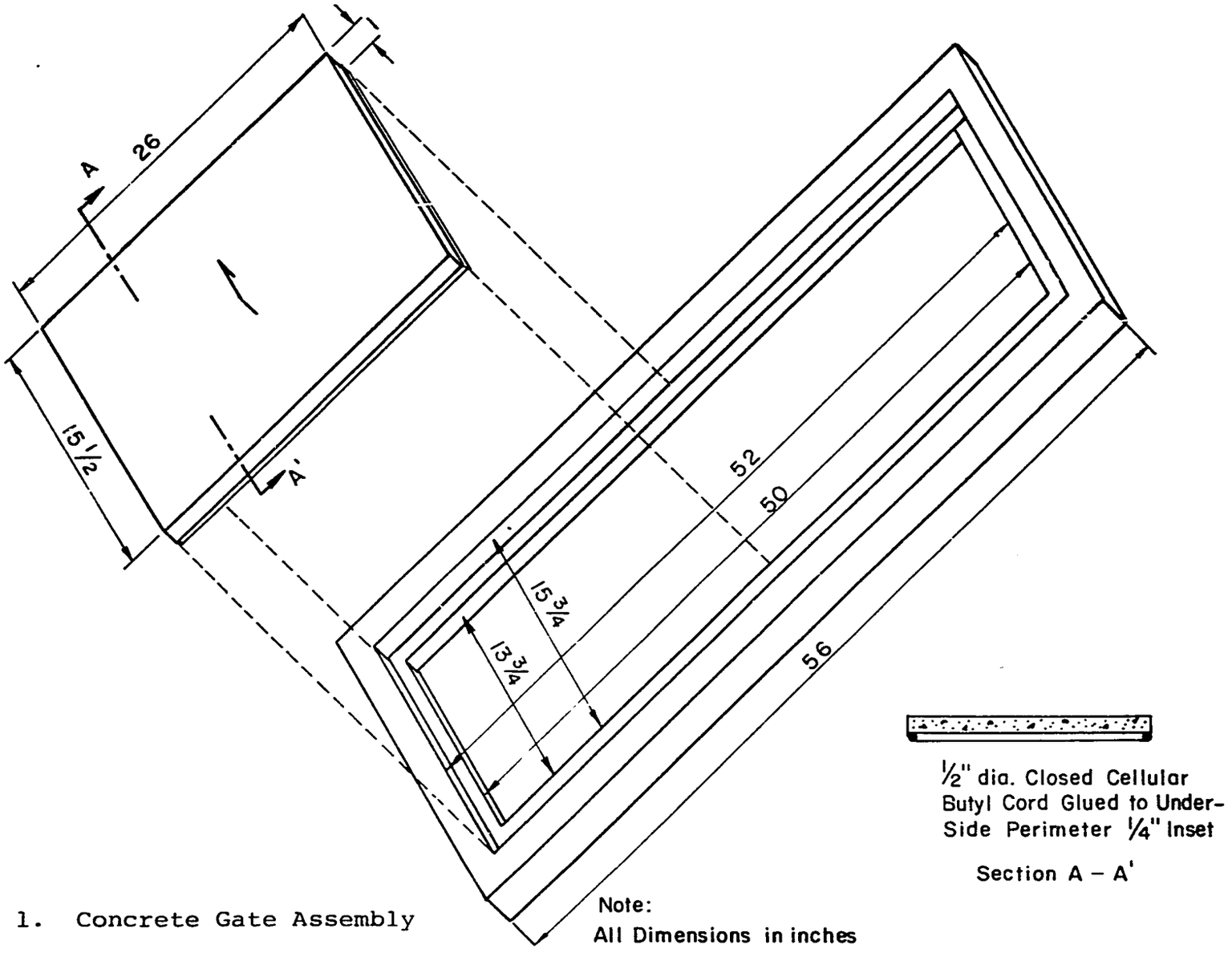


Plate 1. Concrete Gate Assembly

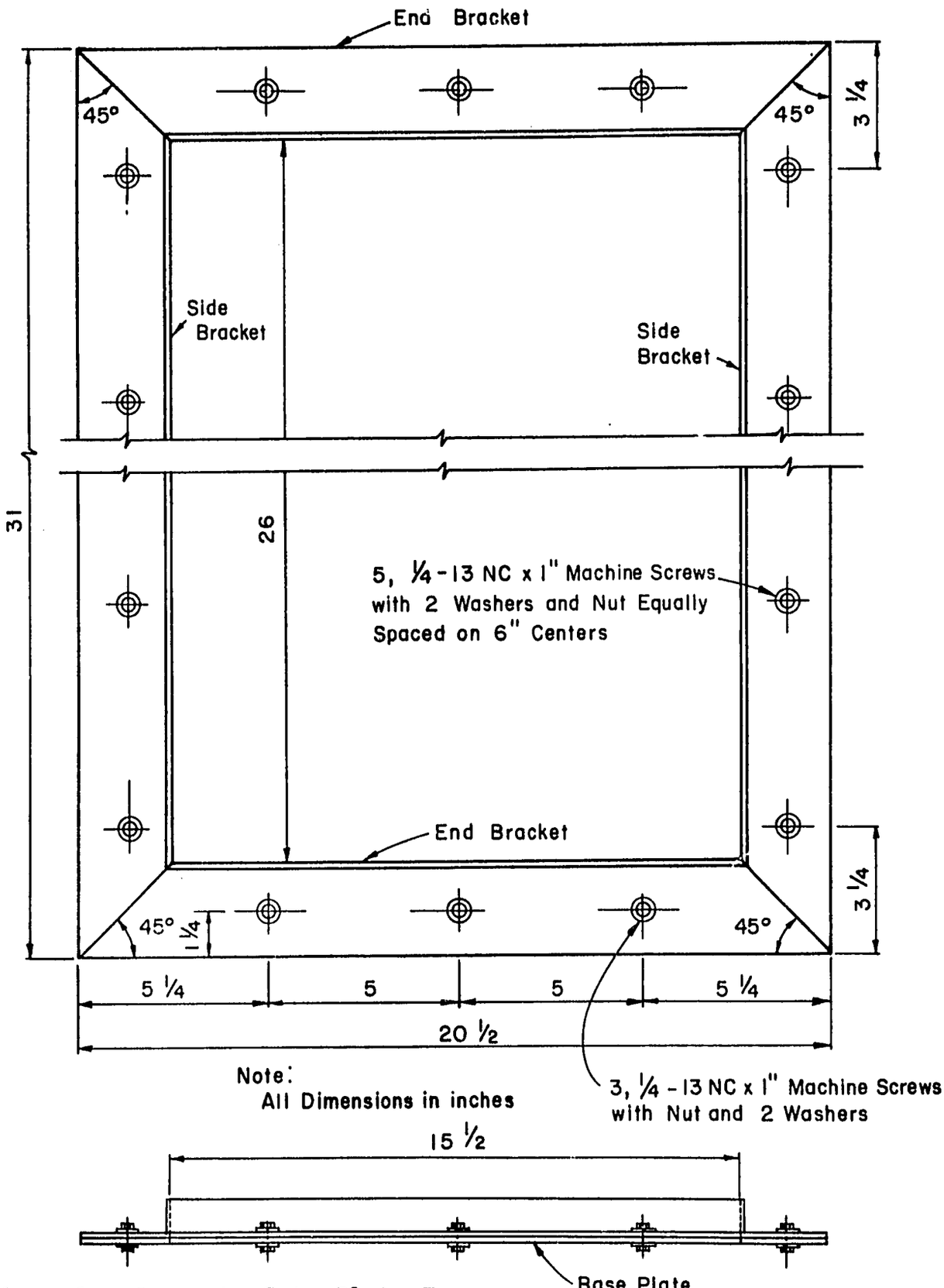
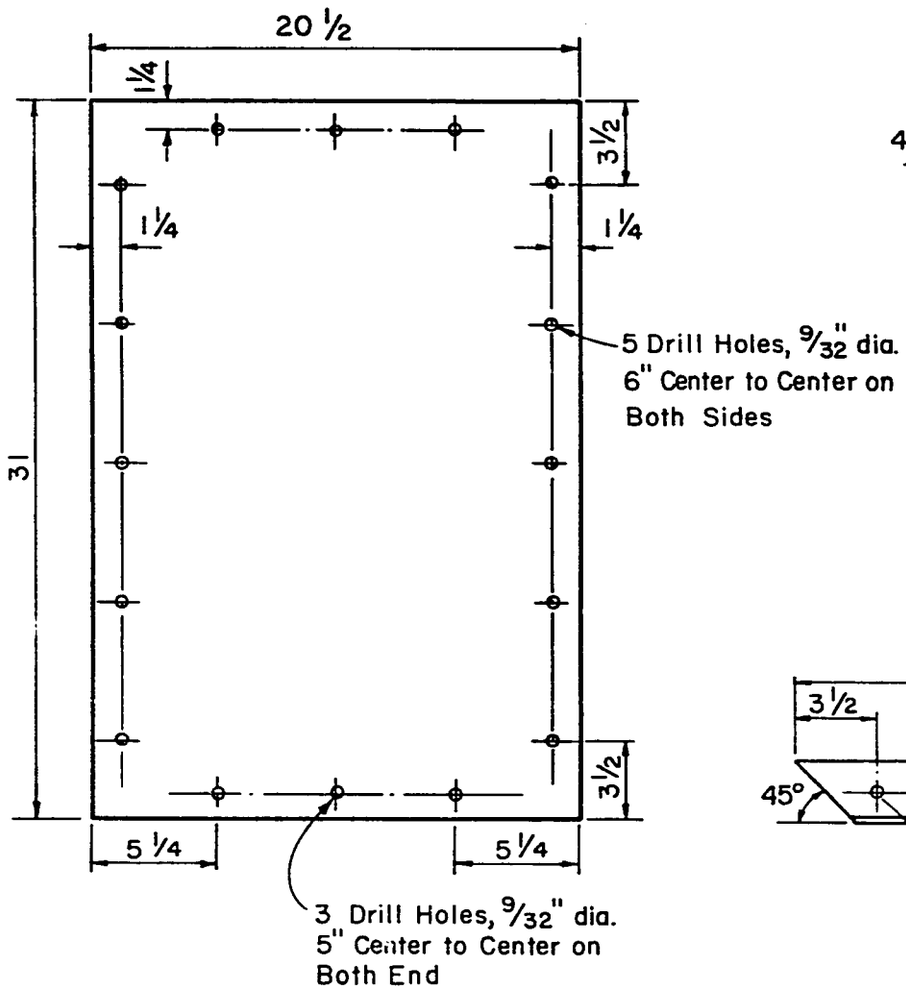
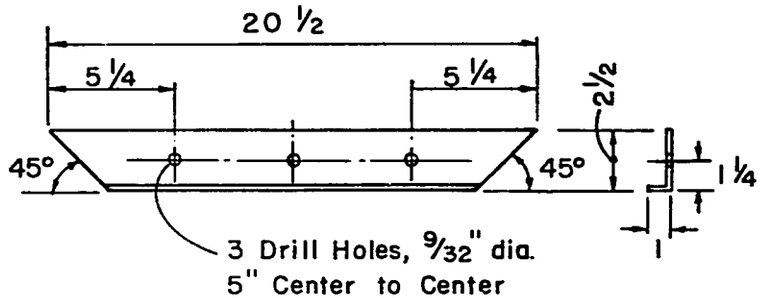
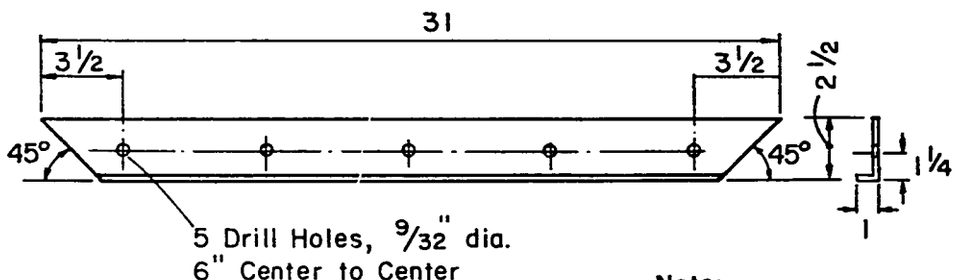


Plate 2. Concrete Gate Plate Form Assembly





End Brackets



Note:
All dimensions in inches

Side Brackets

Req'd	Materials
1	31 x 20 1/2 x 1/4, 6061-T6 Alminum Plate
2	2 1/2 x 2 x 3/16, 6061-T6 Alminum Angle
2	2 1/2 x 2 x 3/16, 6061-T6 Alminum Angle

Plate 3. Concrete Gate Plate Form Parts

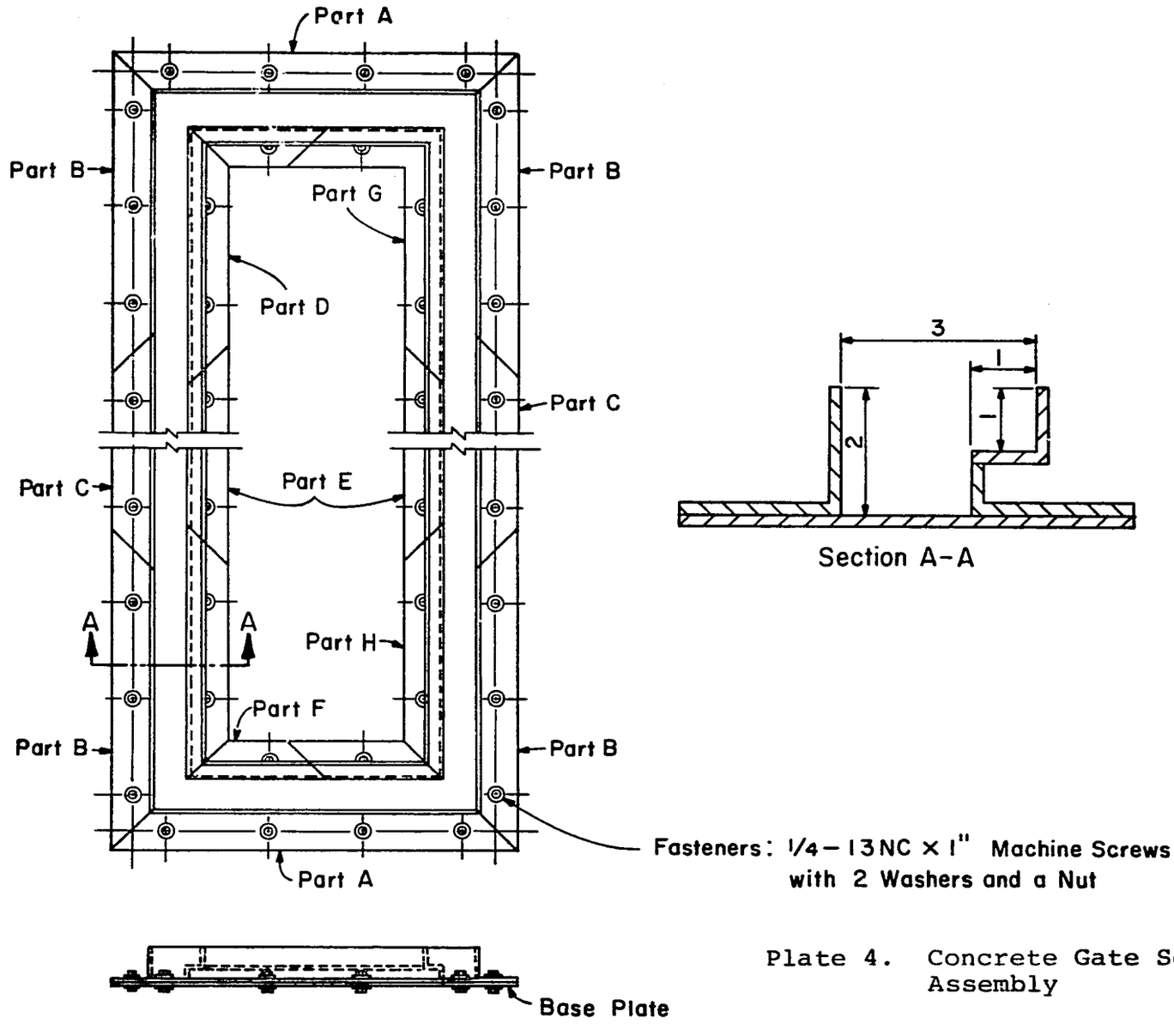
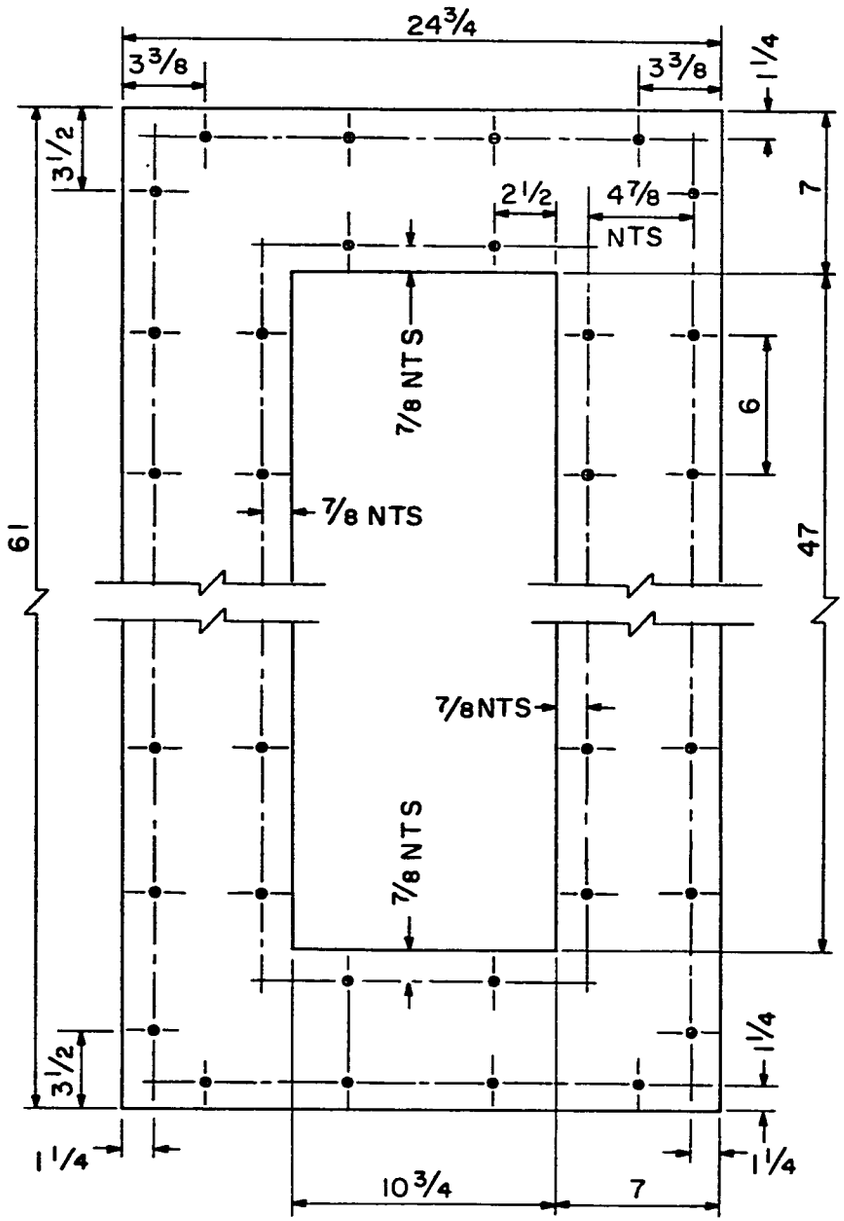
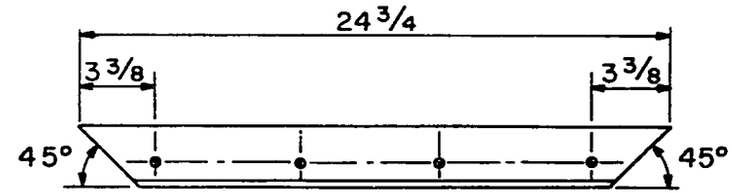


Plate 4. Concrete Gate Seat Form Assembly

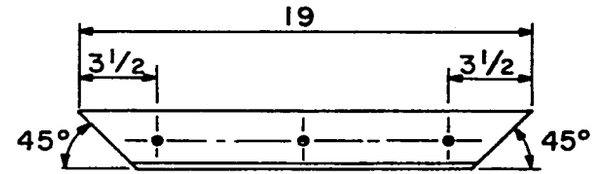


Base Plate

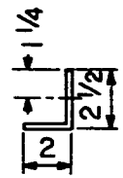
Mat'l: 6061-T6 Aluminum Plate



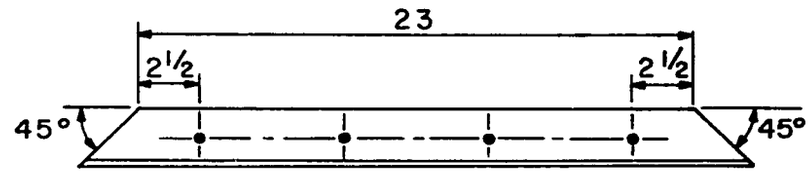
Part A



Part B



End View of A, B, & C



Part C

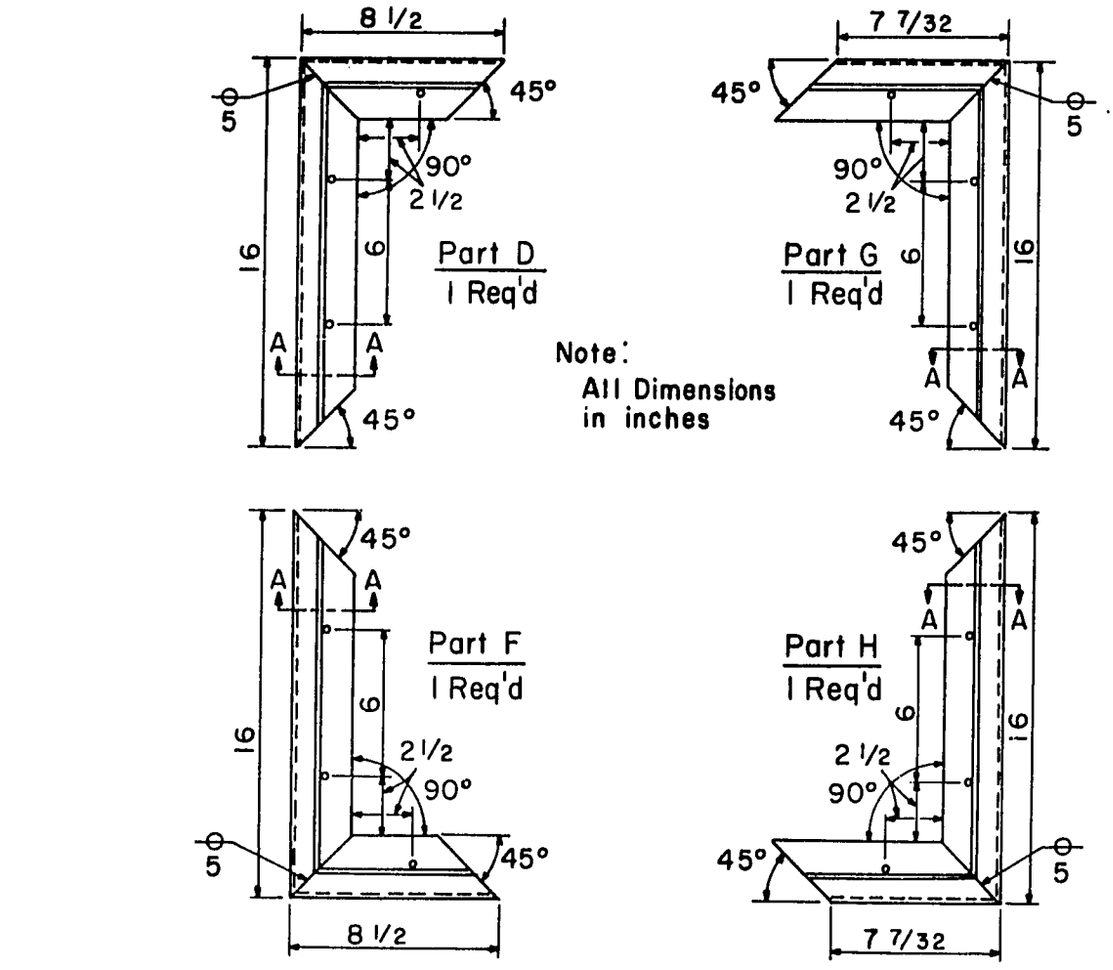
Note:

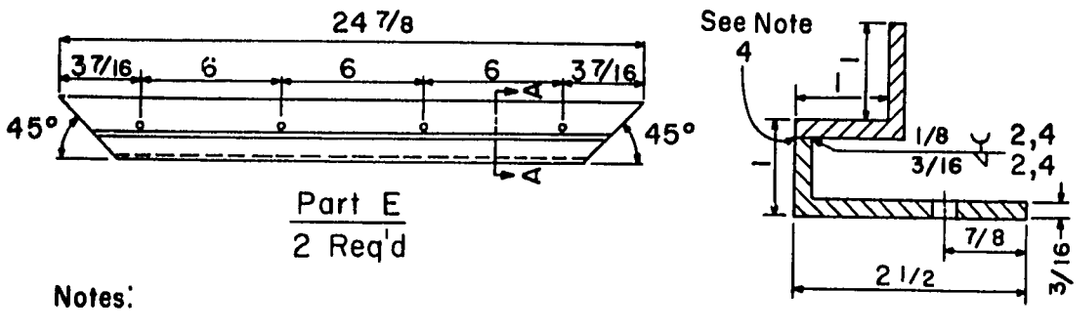
1. All Holes 9/32 Drill 6" Center to Center
2. All Dimensions in inches

Mat'l for Parts A, B, & C:

2 × 2 1/2 × 3/16 6061-T6 Aluminum Angle

Plate 5. Concrete Gate Seat Form Parts





Notes:

1. Spot Weld Corner at 90°. No Significant Stresses will be Encountered in Use.
2. All Holes 9/32 Drill
3. Welds are Opposite each Other.
4. Grind this Side Flush after Welding

Mat'l:
All Angles are
6061-T6 Aluminum, 3/16 Thick

Plate 6. Concrete Gate Seat Form Parts

Appendix 11

MEASUREMENT AND CALIBRATION OF MOGHA OUTLET DISCHARGE USING STAFF GAUGES[1]

Methodology Series Number Fourteen

M.F.K. Niazi, Nazir Ahmad and A.C. Early[2]

Common mogha outlets in Pakistan are masonry orifices, pipe outlets and wooden chutes. They are usually placed at the bed level of a distributary or minor. They may be circular, rectangular or trapezoidal in cross section and may have submerged (outlet under water on the downstream side) condition, or free fall condition.

For the submerged mogha outlet as shown in Fig. 1, the discharge formula is

$$Q = KA\sqrt{h}$$

where Q is discharge in cusecs, A is cross sectional area in square feet of the orifice/pipe, h is the working head in feet i.e. difference between the water levels of distributary or minor and of the watercourse, and K is a constant which is equal to $C_d\sqrt{2g}$. It is equal to approximately 5 in the case of masonry orifices and 6 is the case of iron or wooden orifices.

There is usually provided a face wall on the distributary side and a drop wall at the end of the bank as shown in Fig. 1. On the face wall and drop wall staff gauges are fixed[3] for reading the water levels in the distributary and watercourse for determining h.

For a free fall mogha (outlet) condition, the discharge formula is

$$Q = C_d A\sqrt{2gh}$$

where C_d is equal to 0.6 (coefficient of discharge), A is the cross sectional area of pipe or orifice in sq. ft., and h is the

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1/Adapted to Pakistan conditions for use in irrigation evaluations in watercourse chak farming surveys.

2/Junior Agricultural Engineers, Watercourse Studies, Master Planning and Review Division, WAPDA and Agricultural Engineer, Colorado State University, Water Management Research Program in Pakistan respectively. 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.

3/The base of staff gauge of both face wall and drop wall must be at the same level i.e. bed level of the distributary.

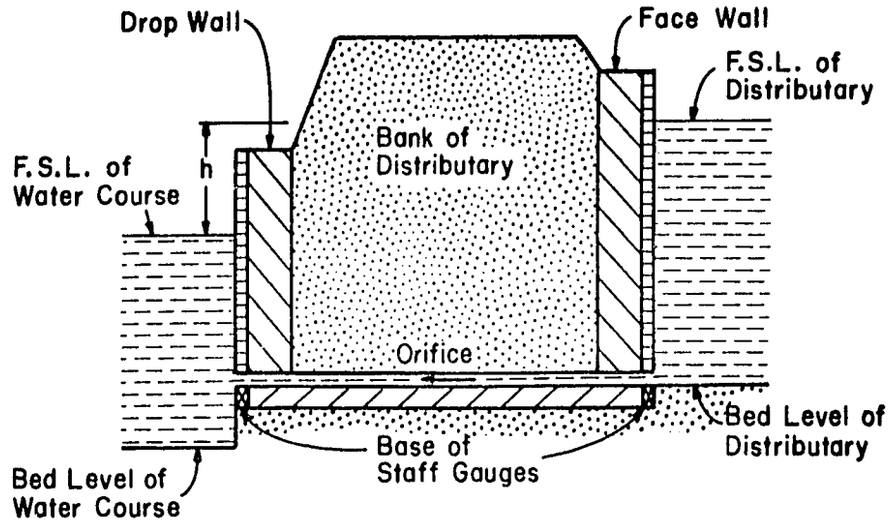

Figure 1. Submerged mogha cross section.

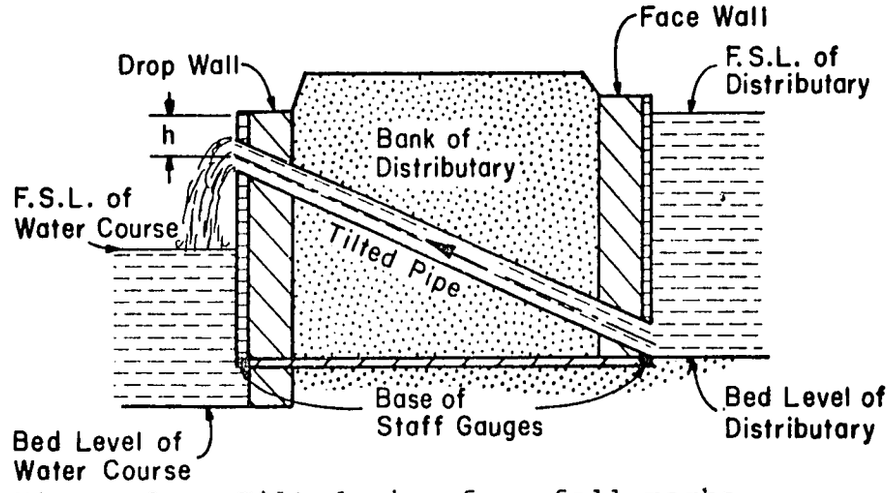

Figure 2a. Tilted pipe free fall mogha.

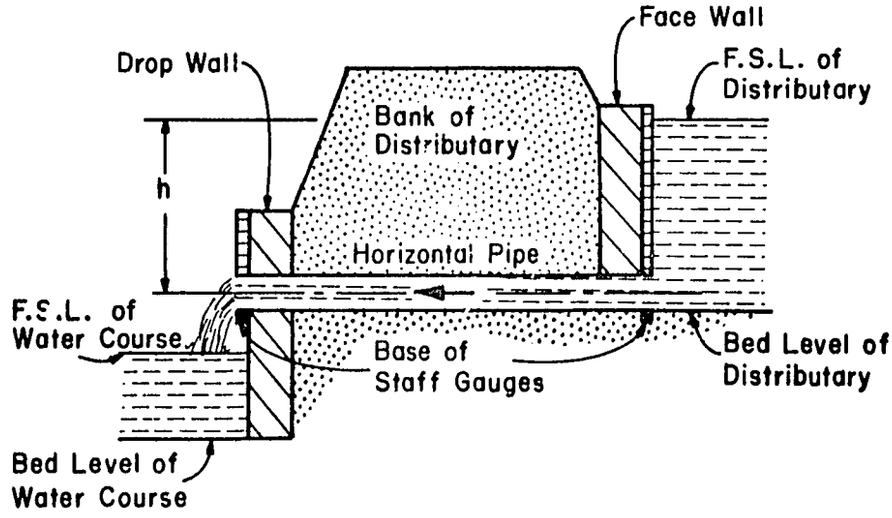

Figure 2b. Horizontal pipe free fall mogha.

head from full supply level in distributary to the center of the orifice or pipe at the outfall, and g is the acceleration due to gravity, 32.2 ft/sec/sec. The pipe may be tilted or horizontal as shown in Fig. 2a and 2b.

Examples:

1. A submerged mogha is made of concrete pipe of 6" diameter. The face wall staff gauge in the distributary is giving F.S.L. at 3.55 and the drop wall staff gauge is giving F.S.L. of watercourse at 2.55. Calculate discharge of mogha.

   Solution: $Q = K A \sqrt{h}$

   $K = 5$ for concrete or masonry moghas

   $A = \frac{d^2}{4}$ where d = 6" or .5'

   So $A = \frac{3.14 \times .25}{4}$ sq. ft.

   $h = 3.55 - 2.55 = 1'$

   $Q = \frac{5 \times 3.14 \times .25 \times 1}{4} = 0.98$ cusecs.

2. A free fall mogha of 5½" dia. iron pipe has F.S.L. of distributary at 4.60 gauge reading on the face wall. The centre of orifice is at 3.50 gauge reading of the drop wall. Calculate the mogha discharge.

   Solution: $Q = C_d A \sqrt{2gh}$ C_d is 0.6 i.e. coefficient of discharge.

   $g = 32.2$ (standard)

   $A = \frac{d^2}{4} = 3.14/4 \frac{(11)^2}{(24)}$

   $h = 4.6 - 3.5 = 1.1'$

   $Q = .6 \times \frac{3.14}{4} \frac{(11)^2}{(24)} \sqrt{2 \times 32.2 \times 1.1} = .83$CFS

For some orifice type outlets which have additional advantage of adjustability and proportionality, i.e. A.P.M. (Adjustable Proportional Module) outlets, the discharge formula is

$$Q = Kby \sqrt{h}$$

where Q is discharge in cusecs
b is width in ft.
y is height of opening
h is working head i.e. depth on crest (H) - y

K is the constant which is taken as 7.3 by the Irrigation Department in Pakistan according to material used in the outlets.

The adjustability of the outlet is arranged by providing bolts passing through a cast iron roof block and a check plate.

Example: An A.P.M. outlet has depth on crest (H) = 4.5'

Its wideth is 3" and height of opening 6", calculate discharge of outlet.

$Q = K$ by $\sqrt{h}$

$b = .25'$

$y = .5'$

$h = 4'$

$Q = 7.3 \times .25 \times .5 \times 2 = 1.825$ cusecs.

CALIBRATION OF STAFF GAUGE FOR MOGHA DISCHARGE

The two conditions of mogha flow: free and submerged flow require specific treatment for calibration of mogha discharge.

1. Free Flow Condition

When the outlet is above the water surface on the down stream side, the mogha is said to be at free flow condition. Noise of free fall is another indication. In this case working head is measured from full supply level in distributary to the center of the outlet.

When the mogha remains at the free flow condition, one staff gauge is needed to be installed about two feet into the distributary near the mogha.

2. Submerged Flow Condition

When the outlet is under water on down stream side, the mogha is said to be submerged. In this case the working head is equal to the difference between the water surface level in distributary and the water level in the watercourse. Discharge of this type of mogha varies considerably. It increases when watercourse is cleaned and decreases with siltation. In other words working head may change even if water surface level in the distributary remains constant. Therefore, two staff gauges are needed to be installed at the same level, one in the distributary and the other in the watercourse, both close to the mogha.

CALIBRATION PROCEDURE

1. Install the gauges vertically according to the condition of flow (free flow or submerged).

2. Install a Cutthroat flume at a downstream point in the watercourse (See Cutthroat flume installation discussion in Master Planning Watercourse Studies Handbook.)

3. Take staff gauge readings along with flume readings for 7-day period when rotating staff are on the watercourse or 2 to 3 times daily if stationary Cutthroat flume is in use.

4. Compute the discharge of mogha with corresponding flume readings.

5. Calculate the working head from staff gauge readings.

6. Plot a calibration curve by taking mogha discharge on horizontal scale and working head of distributary staff gauge on vertical scale.

Appendix 12

ESTIMATION OF WATER LOSSES IN WATERCOURSES[1]

Methodology Series Number Fifteen

Nazir Ahmad and Alan Early[2]

Most of the water loss studies to date have been conducted under conditions where steady state flow could be assumed. Summation delivery efficiencies of water through watercourses are considerably less than those measured under steady state conditions.

When water is diverted into the watercourse, the following losses are involved before it enters the field.

1. Dead Storage: It is due to:

   (a) Watercourses are usually deeper than the fields. Especially near the village "Abadi", people remove mud from watercourses for construction purposes.

   (b) Buffalo wallows: These are formed by the animals when they walk and cool themselves in a muddy watercourse.

   (c) Wide shallow sections of watercourse created by animals, tractors, and bullock carts crossing the watercourse.

   (d) Negative gradient of the watercourse due to a lack of surveying when watercourse is cleaned.

2. Infiltration: The rate of infiltration into the banks is at its highest in early periods of flow. This rate of infiltration exceeds that of field soils for the area by a factor of about 5 due to regular capillaries.

3. Rodent Holes: Inspection and excavation of the banks reveals many holes created by insects, rodents, and roots. The highly porous nature of these banks is one reason for the high rates of infiltration. Most

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1/Adapted to Pakistan conditions for use in irrigation evaluations in watercourse chak farming surveys.

2/Junior Agricultural Engineer, Watercourse Studies, Master Planning and Review Division, WAPDA, and Agricultural Engineer, Colorado State University, Water Management Research Program in Pakistan, respectively. 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.

of these holes originate in the sides of the channels and rather than going through the banks they go down into the subsoil which is sometimes of coarse texture.

4. Nakka Leaks: Most of the water is wasted through katcha nakkas due to less compaction of soil. Water is absorbed in the watercourse bunds, as well as wasted through leakage of nakkas. Every irrigation evaluator is supposed to estimate this kind of losses before doing steady state flow measurements.

The losses involved in filling dead storage and infiltration during the early period of watercourse filling, can be estimated as a function of mogha discharge and time required to fill the dead storage.

For measurement of discharge, mogha C.T.F. readings during this period should be taken, time should be noted when water is diverted into the watercourse and when water reaches the field. But this time also includes the time that would have been required even if a good cross section of watercourse was maintained through head and tail. Therefore, we must also estimate this necessary time and subtract from the time noted in the field. This can be estimated as follows:

1. Select a very good section of watercourse. There should be no dead storage, no over topping and no erosion in that section. This can usually be found near the mogha.

2. Measure the area of cross section with the help of staff gauge. Use the average depth of flow and average width of the cross section evaluated.

3. Calculate the time required in case the ideal cross section was maintained throughout the watercourse length. Use the formula below:

$$Tn = \frac{A \times L}{Q \times 60 \times 60}$$

where Tn = Time necessarily required (hours).
A = Area of ideal cross section (ft^2).
L = Length of watercourse, filled (ft).
Q = Average mogha discharge ft^3/sec.

Suppose total time taken by the water to reach the field is T. Then time required to fill the dead storage = T - Tn.

Hence, the volume of water in acre-inches wasted through dead storage and infiltration = Q (T - Tn).

SUBMISSION DELIVERY EFFICIENCY: (Es)

$$Es = \frac{\text{Total volume of water delivered to the fields}}{\text{Total volume from mogha flow}}$$

The summation delivery efficiency can be calculated from time discharge curves which can be plotted by taking mogha discharge (cfs) and nakka discharge (cfs) on vertical scale and time (day hours) on horizontal scale. (See Fig. 1)

Area under mogha discharge curve will give the total mogha flow volume, and area under nakka discharge curves will sum up the total volume of water delivered to the fields, where appropriate conversion factors are applied.

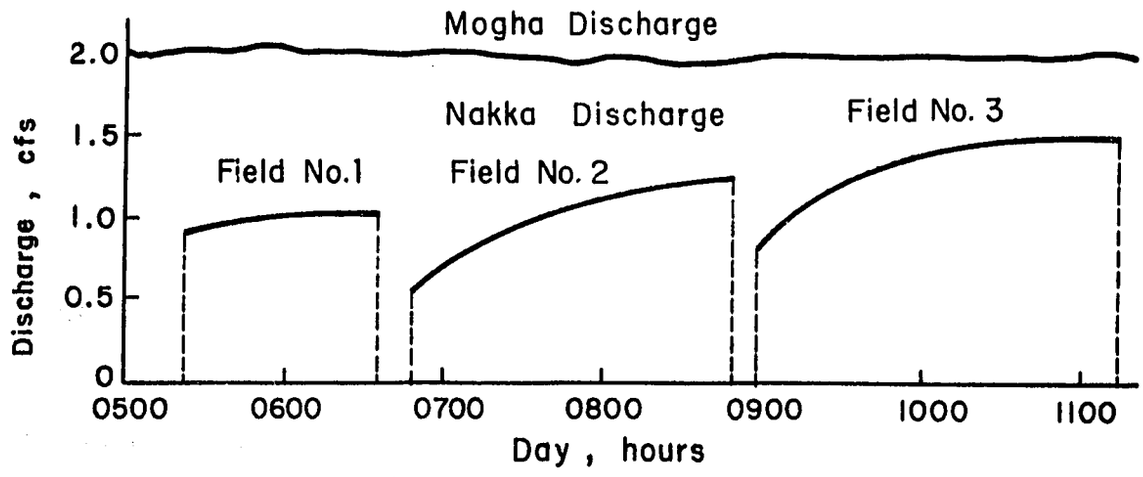
Reference:

"Where water goes in a watercourse" by W. D. Kemper and others, Colorado State University, mimeograph, 1975, Islamabad.

The following form is provided in the Irrigation Evaluation Field Book to record the data.

DEAD STORAGE IN WATERCOURSE

Date	Q Mogha	Time Water Diverted into Watercourse	Time water reached the Field	Hours (T)	Cross Sectional area of good section A	Length of W/C (L)	Actual time required Tn = $\frac{AL}{Q}$	Time for dead storage (T-Tn)	Volume wasted Q(T-Tn) Ac. In.	Remarks



Appendix 13

PROCEDURE FOR PERMANENT RAINGAGE INSTALLATION[1]

Methodology Series Number Eleven
Alan Early and Waryam Ali Mohsin[2]

Long term watercourse studies require the measurement of water inputs to crop production from rainfall. The primary concerns in raingage installation is for security of the equipment and location of the raingage with respect to obstacles.

To take care of security of the raingage, the following procedure for preparation of a concrete pedestal and security chain and selection of a site near a settlement is suggested. To prevent the taking of abnormal readings, the raingage should be twice the distance from the nearest obstacle as that obstacle is tall. Also attached is a form for recording meteorological observations.

PROCEDURE FOR PUCCA RAINGAGE INSTALLATION

1. Conduct a reconnaissance of watercourse command area noting shape, length, and width of watercourse command area.

2. Note the position of major obstructions on the watercourse.

3. Choose a position near the center of the watercourse that is free of obstructions such as walls, trees and houses, yet which is relatively secure. Often the roof top of a house away from trees and higher houses near the center of the watercourse area will be the most secure place for the raingage. If not on a roof top, it must be near someone's dhera.

4. Arrange for sand, aggregate cement and a mason.

5. Prepare a concrete form 6" deep x 12" wide x 12" long. The end of an empty kerosene tin makes an ideal form which is also reusable.

1/Adapted to Pakistan conditions for use in irrigation evaluations in watercourse chak farming surveys.

2/Agricultural Engineer, Colorado State University Water Management Research Program in Pakistan and Senior Agricultural Engineer, Watercourse Studies, Master Planning and Review Division, WAPDA, respectively. 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.

6. Place 2" of mortar in bottom of the form, insert raingage in the center of the form and fill form with mortar around the raingage.

7. Place the end of the security chain in the concrete (buried by at least 2 inches and buried over at least one foot of length).

8. Remove the raingage before concrete hardens. Rotate raingage in and out of the concrete several times to make certain for ease of access in future.

9. When concrete has fully hardened, remove the form and place the concrete block and raingage at its intended position, locking the lid and gage in place with the security chain.

10. Train agricultural assistant on making measurements by putting water in the raingage repeatedly and having him remove lid and gage and measure water with graduated cylinder provided with the raingage.

METEOROLOGICAL OBSERVATIONS

LOCATION_____ WATERCOURSE_____

OBSERVER_____ MONTH_____YEAR_____

TIME OF DAILY OBSERVATION_____

DATE	RAINFALL		REMARKS	
	Vol. of water	In. of water	Cloudiness	Duration of rain
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				

Appendix 14

PROCEDURE FOR PERMANENT FLUME INSTALLATION[1]

Methodology Series Number Twelve
Alan Early and Waryam Ali Mohsin[2]

Watercourse studies of long term duration, for an entire cropping season or longer, require frequent measurement of mogha discharge. Intensive studies over time require continuous measurement of mogha outlet discharge. For these purposes, the permanent installation of a Cutthroat Flume is recommended with concrete used as a foundation, approach floor and walls.

The critical elements of permanent flume installation include the elevation of the flume with respect to the elevations of fields on the watercourse and the elevation of the flume with respect to the discharge relationships of the mogha. The field elevations to be served by the watercourse will determine the percentage of submergence of the flume as different elevations are encountered.

The degree of mogha submergence is affected by the height of flume and distance from the mogha. A primary objective in measuring irrigation water of farmers is to cause the minimum possible disturbance of the natural conditions.

A flume that is installed too low will encounter a high percentage of submergence, or total submergence for some high elevation fields to be served and all measurements will be lost. A flume that is installed too close to, or too high, with respect to the crest elevation of the mogha will increase mogha submergence and cause farmers to lose available water. A flume that is installed too high may cause excessive upstream losses so that the farmer loses available water. All of these conditions are to be avoided.

The following procedure requires one week's monitoring of flume measurements and submergence levels with respect to specified field elevations encountered, and a reconnaissance topographic survey of a sample of field elevations with respect to mogha crest elevation.

1/Adapted to Pakistan conditions for use in irrigation evaluations in watercourse chak farming surveys.

2/Agricultural Engineer, Colorado State University Water Management Research Program in Pakistan and Senior Agricultural Engineer, Watercourse Studies, Master Planning and Review Division, WAPDA, respectively. 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.

If a permanent flume can be installed on a watercourse to avoid the excessive losses described, this type of procedure is required to identify the correct flume floor elevation for installation.

PROCEDURE FOR PUCCA FLUME INSTALLATION

1. Install flume in kacha manner using upstream canvas blanket and compacted soil.

2. Instruct Agricultural Assistant on reading flume and checking levelness of flume.

3. Have Ag Assistant make flume readings eight times per day (one reading every three hours) for one week--noting location of field being irrigated at time of each reading.

4. Return to site and scrutinize the record, especially noting the submergence, H_bH_a, with respect to the fields irrigated.

5. Run a quick topographic circuit, closing the level survey on the mogha, but including two shots on each field irrigated during the period.

6. Arrange delivery of sand aggregate bricks and cement.

7. Arrange for local mason to work for one or two days.

8. Make an estimate of the elevation of the flume floor which would keep the submergence above 50% and less than 90% throughout the warabundi.

9. Install a staff gauge in the watercourse upstream from flume and record water surface level before flume installation.

10. Select site for flume installation keeping in mind the existing amount of mogha submergence and divert the flow of water around the chosen flume location for pucca installation.

11. Excavate soil 12 inches below chosen elevation for footing and base of flume.

12. Pour concrete to the desired elevation, setting the flume level in place in the wet concrete and suspending it rigidly using stakes and boards from upstream and downstream sides to keep it from gravitating into concrete.

13. Next day pour concrete and place brick extensions from both walls next to flume.

14. Allow concrete to cure for several days, keeping concrete moistened frequently every 2-3 hours during the day.

15. Reshape the watercourse and redivert flow through the flume.

16. Record water surface level on staff gauge after pucca flume installation and note the change of mogha submergence, if any.

17. Repeat steps 9 through 16 iteratively if mogha is excessively submerged by flume, or if flume submergence over an entire warabundi falls outside the allowable ranges of 50 to 90% submergence.

PUCCA FLUME INSTALLATION TABULATION SHEET

Elevation Crest of Mogha _____ ft. Watercourse #_____

Elevation Flume Floor _____ ft. JAE _____

Water Surface Level Before _____ ft. Date _____

Water Surface Level After _____ ft. AA _____

Date	Time	H_a	H_b	Q	H_b/H_a	Field location square-acre	Field elevation

Appendix 15

PROCEDURE FOR OBSERVATION WELL INSTALLATION[1]

Methodology Series Number Thirteen

Alan Early and Waryam Ali Mohsin[2]

To assess the possible contribution of the water table in meeting the crop needs for water, a record of water table fluctuations over time is required.

The following procedural note provides instructions to the field engineer for the installation of observation wells for watercourse surveys. One important requirement for the successful operation of observation wells to indicate water table depth is the provision of a pea gravel shroud around the pipe. This is essential for water table level to be accurately reflected in the measurements.

PROCEDURE FOR OBSERVATION WELL INSTALLATION

1. Make a quick reconnaissance of hand pumps, open wells, ponds, etc., on the entire watercourse area noting the depth to the water table of each on attached form. If the indicated depth trend is greater than 20 feet, observation wells need not be installed on that watercourse.

2. Select representative positions at the head, middle and tail of the watercourse that are at least two acres but not more than five acres distance from the main watercourse. These positions should be acre corners in kila bundi or bund intersections in Kishtiwar system.

3. Arrange for two cubic feet of pea gravel, plus sand, aggregate and cement at the site.

4. Arrange for the local mason to work for one day.

1/Adapted to Pakistan conditions for use in irrigation evaluations in watercourse chak farming surveys.

2/Agricultural Engineer, Colorado State University Water Management Research Program in Pakistan and Senior Agricultural Engineer, Watercourse Studies, Master Planning and Review Division, WAPDA, respectively. 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.

5. Auger a hole (using regular open ended auger for clay and silt soils and closed ended auger for sandy soil) incrementally to the full depth of auger handle possible, or to one handle extension length below the depth at which water appears, whichever happens first.

6. Leave the hole for several hours in a sandy area to overnight in a clayey area.

7. Later, upon returning, lower the weighted end of 25 foot calibrated plastic tubing until the water table is detected by the sound of bubbling when blowing air through the tubing.

8. Withdraw the tubing, noting the depth of water table from the ground surface and determine the combination of well point, 5 foot, 3 foot, 2 foot and one foot lengths of one inch pipe needed to put the tip of the well point approximately to three feet below the water table level.

9. Attach the various lengths of pipe required firmly above ground using pipe wrenches: insert the pipe into hole and suspend it with the top four inches above the ground surface.

10. Slowly add the pea sized gravel around the entire circumference of the observation well pipe using a long stick or rod for compacting the gravel tight against the pipe. Make certain that the hole is full of gravel around the pipe and that no air space is present.

11. When the hole is filled to within six inches of the surface excavate a collar-shaped area of one foot diameter around the pipe.

12. Pour concrete in the collar shaped volume and smooth off level with ground surface.

13. Place cap on the pipe, screwing tightly in place with desi wrench.

14. Instruct Agricultural Assistant on making fortnightly readings.

15. Test the Agricultural Assistant by having him remove the cap on the pipe and measuring the water table depth in your presence. Instruct him to always leave the cap on the observation well tightly so that the cap will not be stolen and children should not fill the pipe with sticks and stones.

16. Leave calibrated plastic tubing, small desi wrench, and data tabulation form with Agricultural Assistant.

WATERCOURSE

DATE	TYPE OF OBSERVATION	DEPTH OF WT	LOCATION	HMT

Appendix 16

1976 SKIMMING WELL REPORT: FIELD STUDIES[1]

D.B. McWhorter, W.D. Kemper and M. Jehangir[2]

Shallow Multiple Wells

The installation shown in Figure 1 was constructed. Tubewell #1 was constructed first to a depth of 60', with screen from 10 to 60 feet. It was run from January 5 to January 20. The water table heights before, during and after pumping are shown in Figure 2. The salinity of the water at 10' depth intervals down to about 110' depth was measured at about 3 day intervals and salinity (electrical conductivity) is plotted as a function of depth for observation wells T_{1-1}, T_{1-3} and T_{1-5} in Figures 3, 4 and 5.

The isoconcentration line equal to 5 mmhos of electrical conductivity was chosen to indicate the "saline-fresh water interface" and it is plotted in Figure 6 to indicate the rise of the saline-fresh water interface during pumping, and in Figure 7 to show the fall of the s-fw interface after the pump was stopped.

The concentration of the pumped water was determined daily during pumping and is shown as the top curve in Figure 9.

Wells #2 and #3, each 30' deep, were constructed at the locations and with the dimensions and connections indicated in Figure 1, during April and May of 1976. After disturbances due to the drilling operations had largely dissipated, pumping was begun from wells #2 and #3 on July 2. The flow from the two wells was "balanced" by opening the valves in the lines connecting these wells to the pump, and measuring the draw down inside each well casing. The valve to the well with the greatest drawdown was then turned down in successive

---

[1]Contribution from the Mona Reclamation Experimental Project, WAPDA and Colorado State University. This study was begun with a grant from USAID through CARE. The major installations were completed by June 1976. Since that time, the MREP, WAPDA has assumed responsibility for the operation of this study.

[2]Professor of Agr. Engineering, CSU; CSU Chief-of-Party, Pakistan; and sub-engineer, Mona Reclamation Experimental Project, respectively. The assistance of Mr. Sadiq Cheema, new Jr. Agr. Engr. with MREP during the last month of the year has been appreciated.

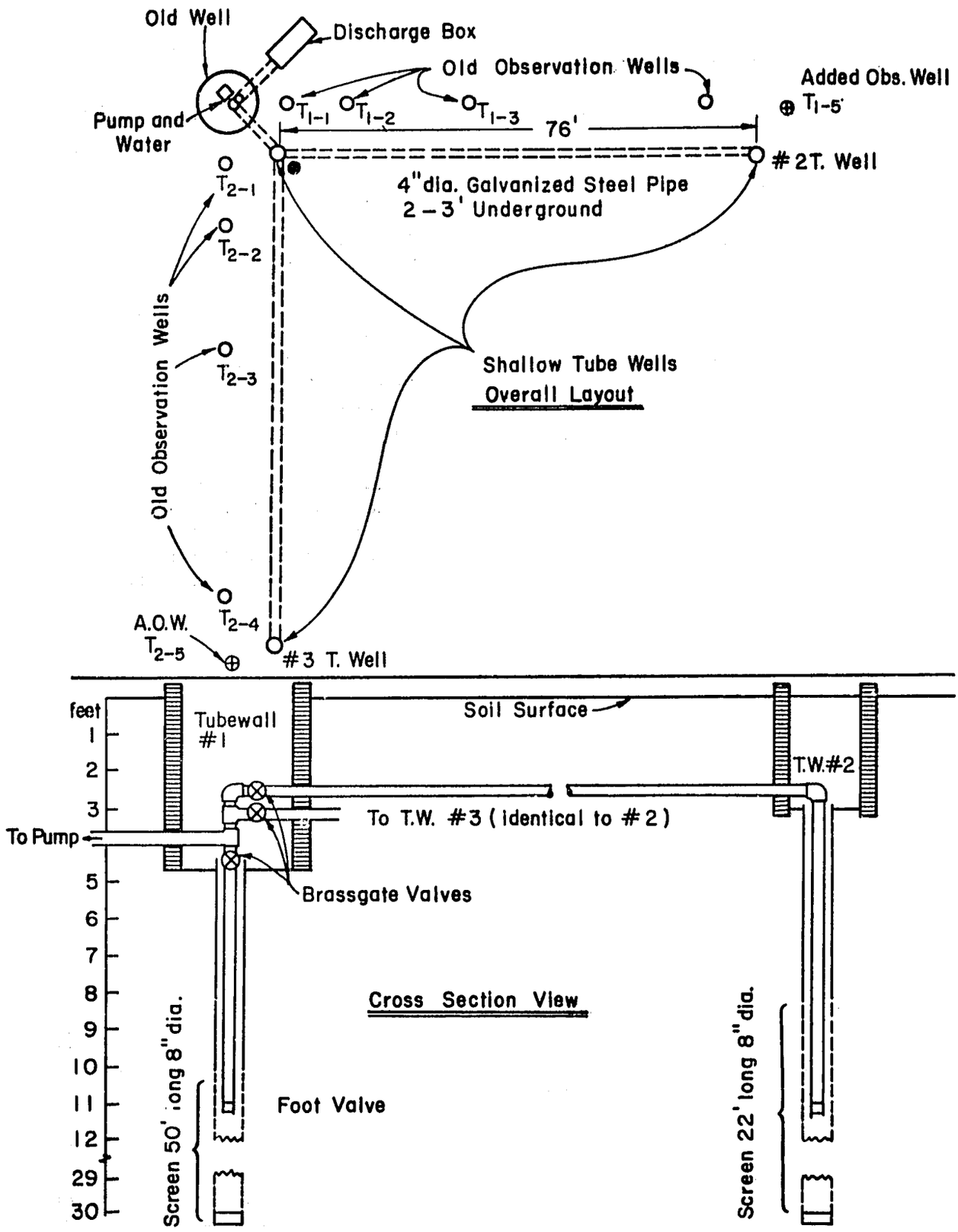


Figure 1. Multiple well testing installation.

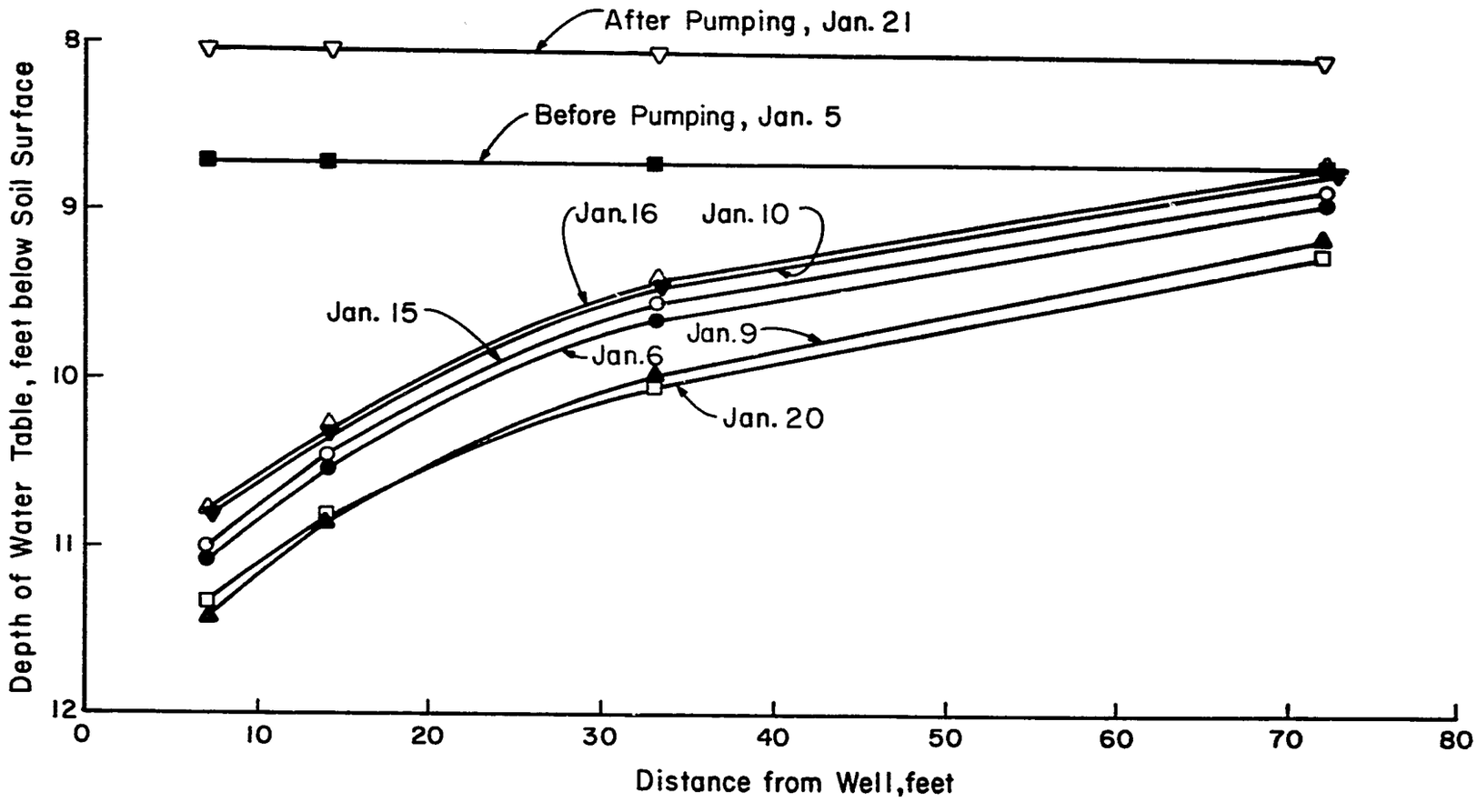


Figure 2. Water table before, after and during pumping.

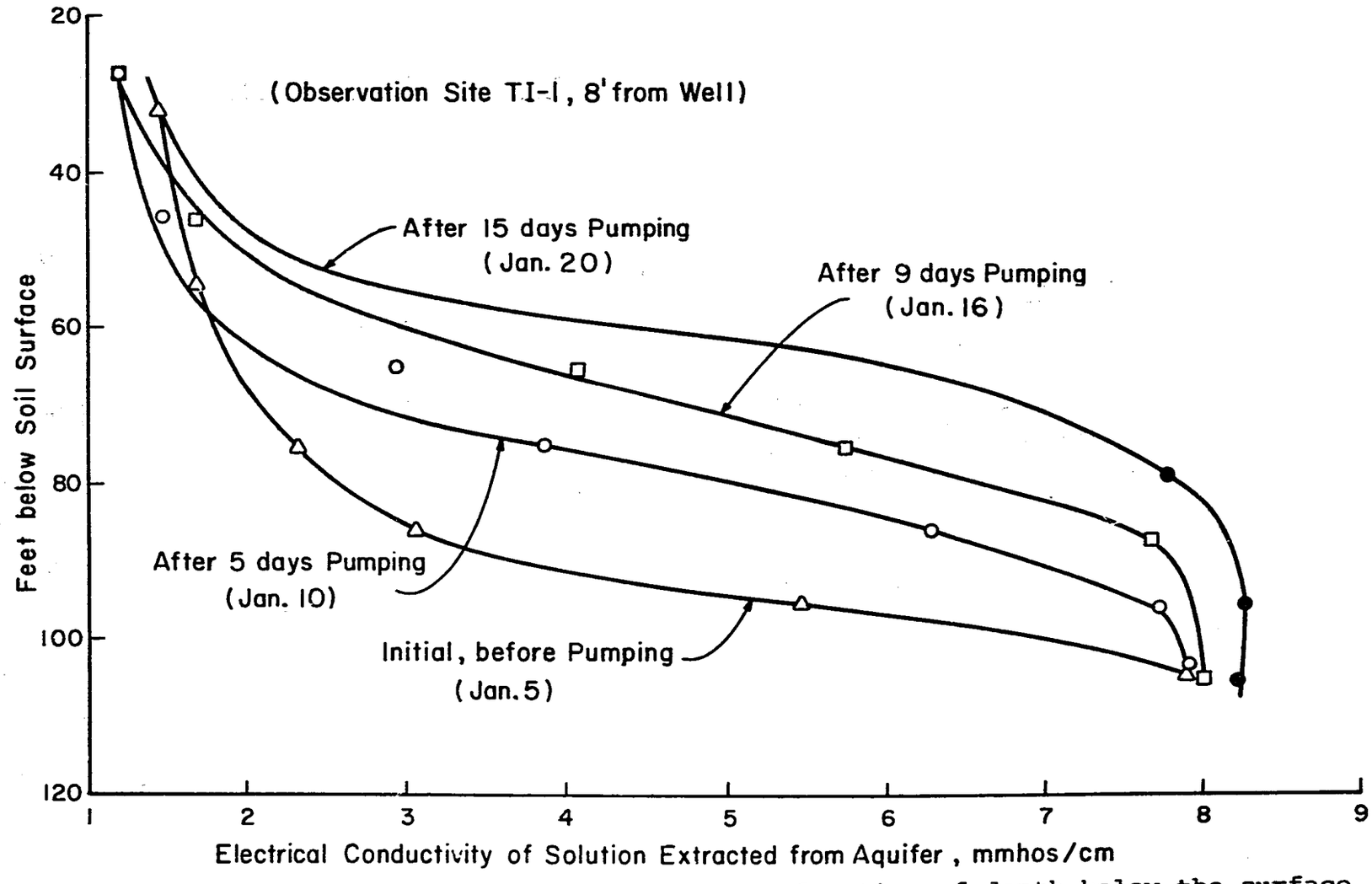


Figure 3. Salinity of water in the aquifer as a function of depth below the surface before and during pumping.

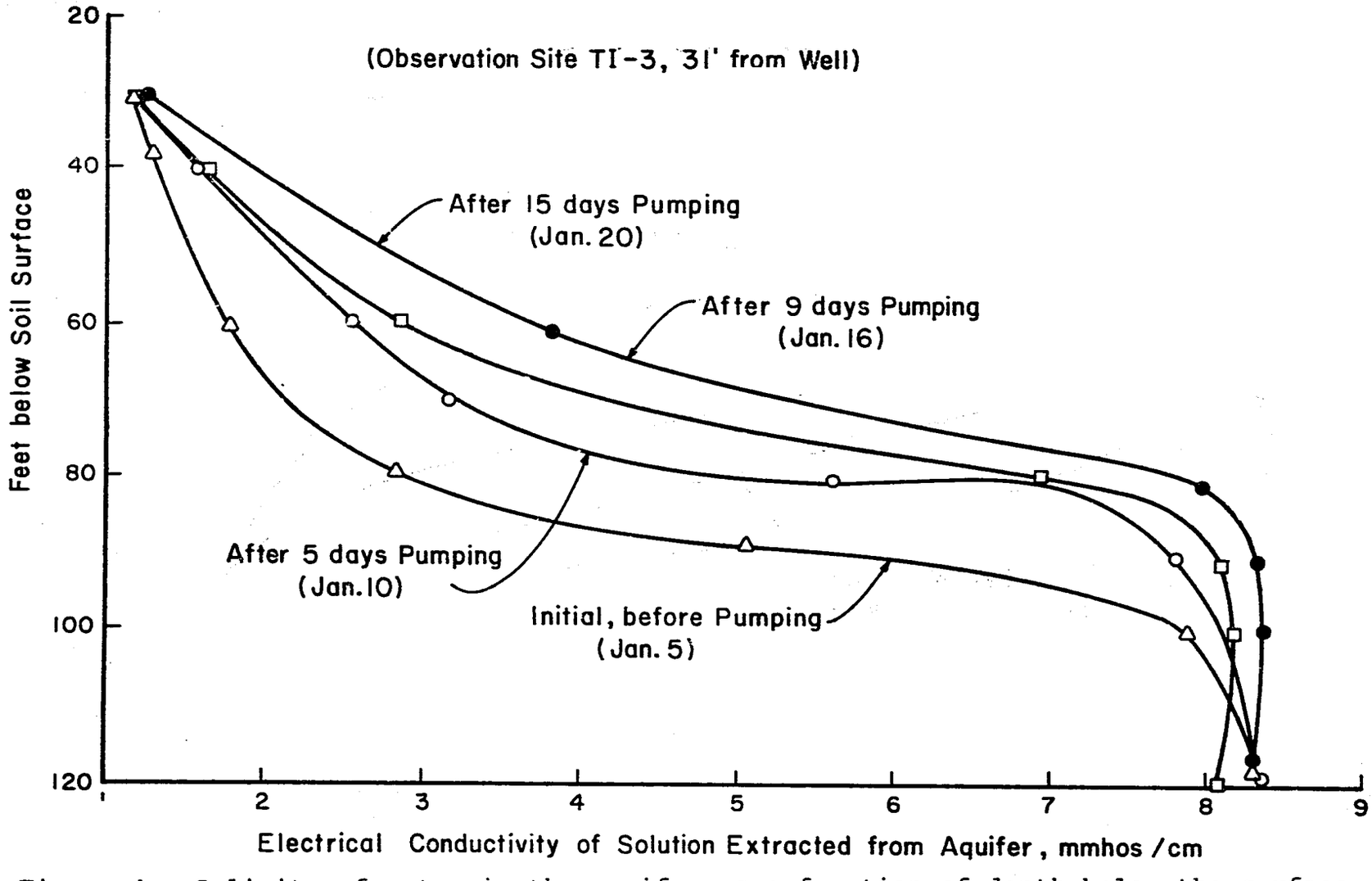


Figure 4. Salinity of water in the aquifer as a function of depth below the surface and before and during pumping.

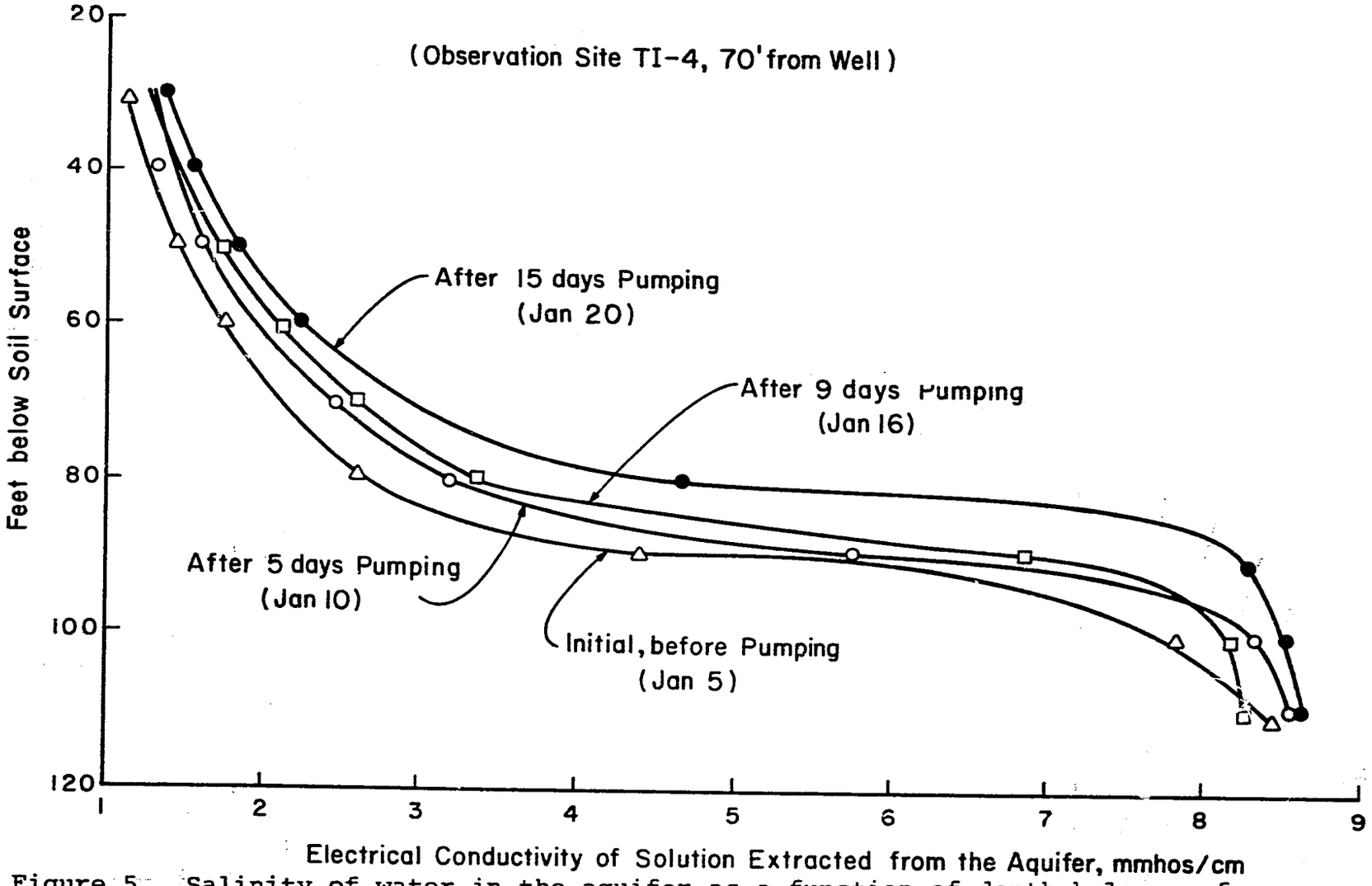


Figure 5. Salinity of water in the aquifer as a function of depth below surface before and during pumping.

Figure 6. Rise of saline-fresh water interface as indicated by successive positions of the 5mm ho/cm LSO concentration line during pumping.

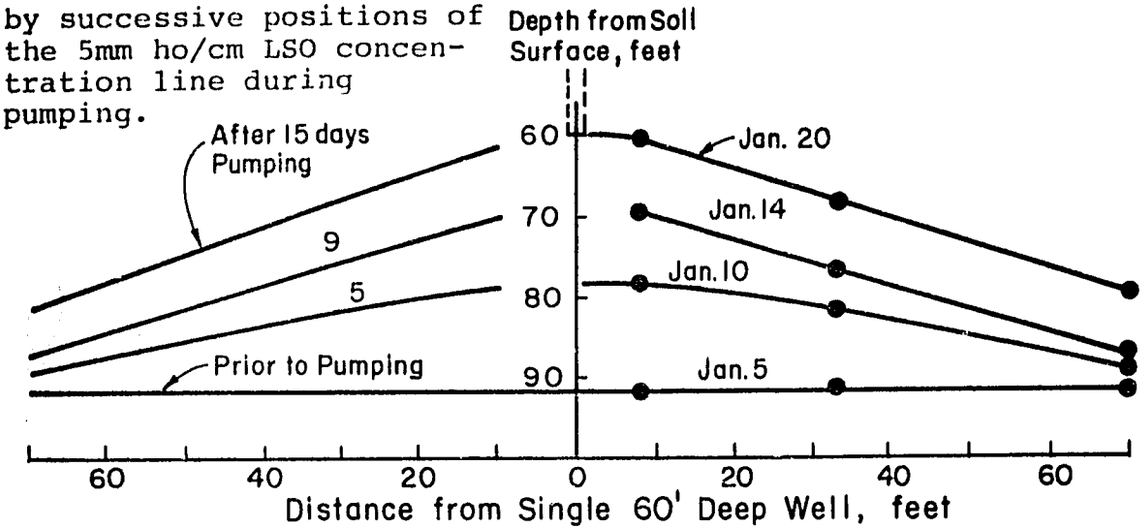


Figure 7. Fall of saline-fresh water interface.

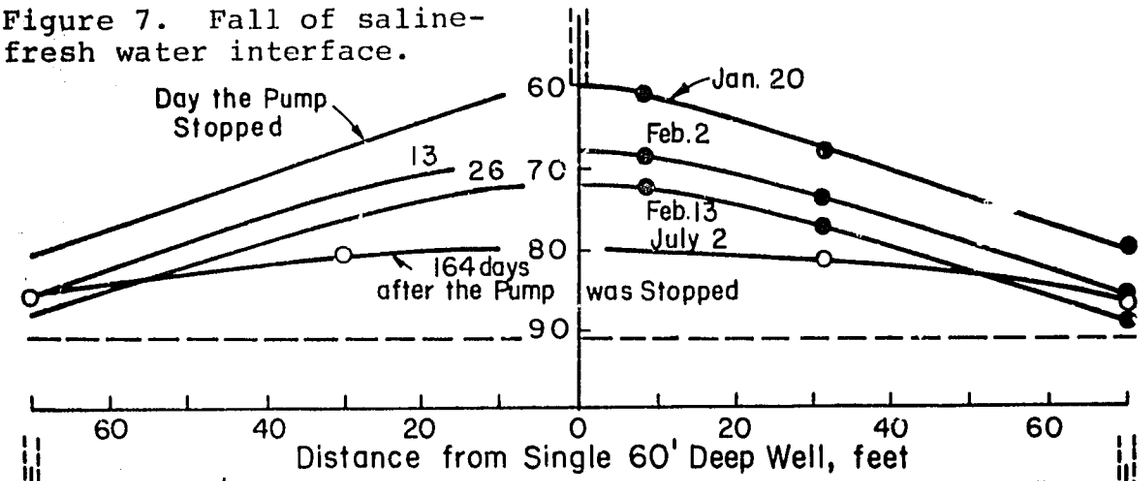
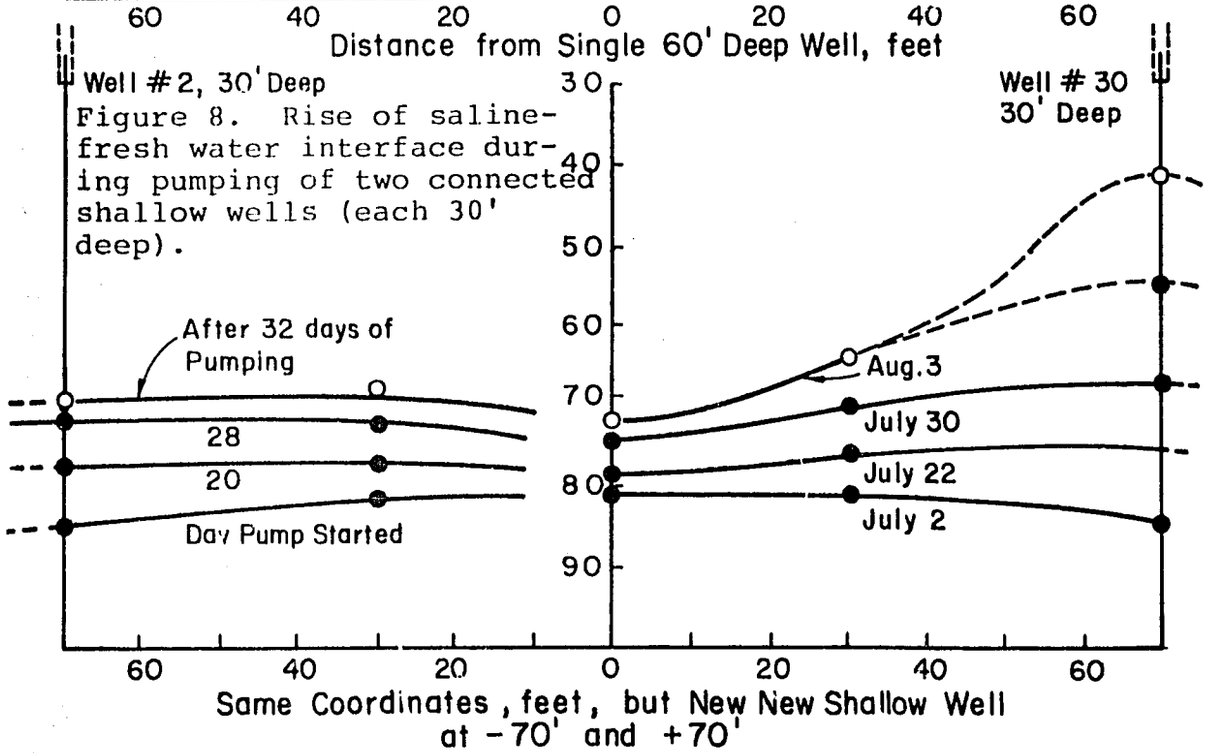


Figure 8. Rise of saline-fresh water interface during pumping of two connected shallow wells (each 30' deep).



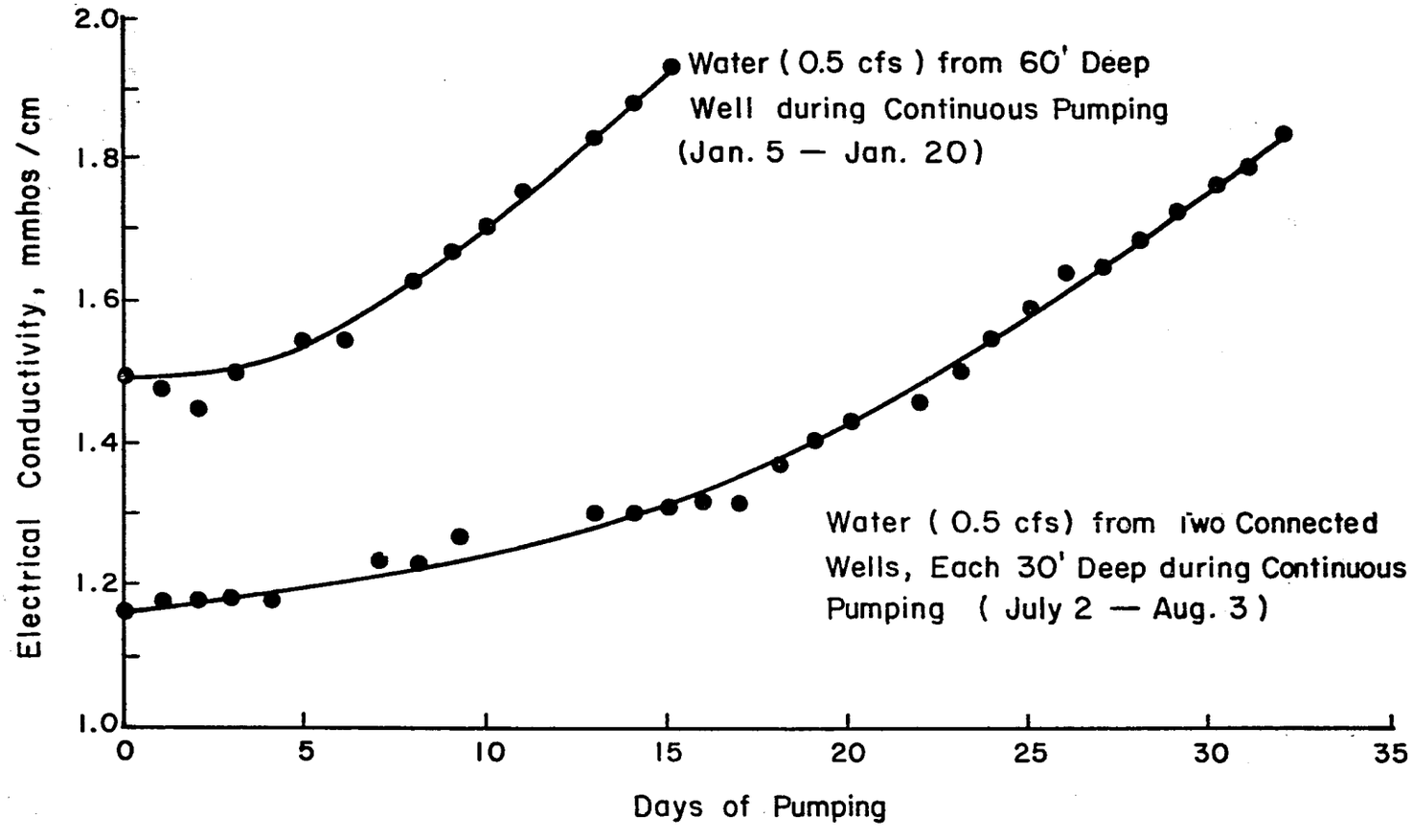


Figure 9. Salt content of water which was being pumped.

small increments, measuring the drawdown between increments, until drawdown inside the two well screens was the same.

The pump connected to these two wells was started on July 2, 1976 and was run until August 3. Salinity profiles at the observation wells were measured and the rise of the saline-fresh water interface is indicated in Figure 8. The salinity of the pumped water was also measured daily and is plotted as the bottom curve in Figure 9.

In general the water pumped from the two 30' deep wells had considerably less salt than the water pumped from the single 60' deep well. The rise of the saline-fresh water interface below the two shallow wells also appears to be slower, except for the high rise indicated as occurring under well #3 during the July 30 to August 3 period. This high rise of the interface is however, probably an anomally caused by a malfunction of the measuring system. The old observation well T_{2-4} at this point, had a "sand bridge" in it, caused by filling the original slotted open pipe with sand faster than the sand was settling down through the water in the pipe. Consequently, the bottom of the 120' deep pipe was not full of sand and could act as conductor of water and salt. During the course of this pumping run, this "sand bridge" broke and the sand settled down to the bottom of the well leaving the top 60' of the well open, and it apparently acted as a conductor, allowing the saline water from 60' depth to be transmitted to higher levels in this pipe.

Sand was poured into this observation well on August 4, so that only the top 20' remained open.

It was known that T_{2-4} had this void. When the pumping was from T well #1, this long void was practically parallel to hydraulic equipotentials and caused no problem. However, when water was pumped from T well #2 the void in this well cuts across hydraulic equipotential lines, allowing water and salt to flow through the void.

The new observation well T_{1-5} was located next to T well #2 partly because we knew T_{2-4} observation well had this void. These new "observation wells" were bored with a bailer, then after the plastic tubes and sampling heads had been anchored in place in the well, the casing was pulled out. It was assumed that the sandy aquifer would collapse inward and fill the hole as the casing was removed. However, the almost identical salt contents at 60, 70 and 80 ft. at the T_{2-5} site (as shown in Figure 10), after the well was turned on, indicate that this portion of the bore did not collapse when the casing was removed, and was conducting saline water from below 80 feet up through this open bore where it was contributing to the salinity of the 50 and 40 foot layers. Since

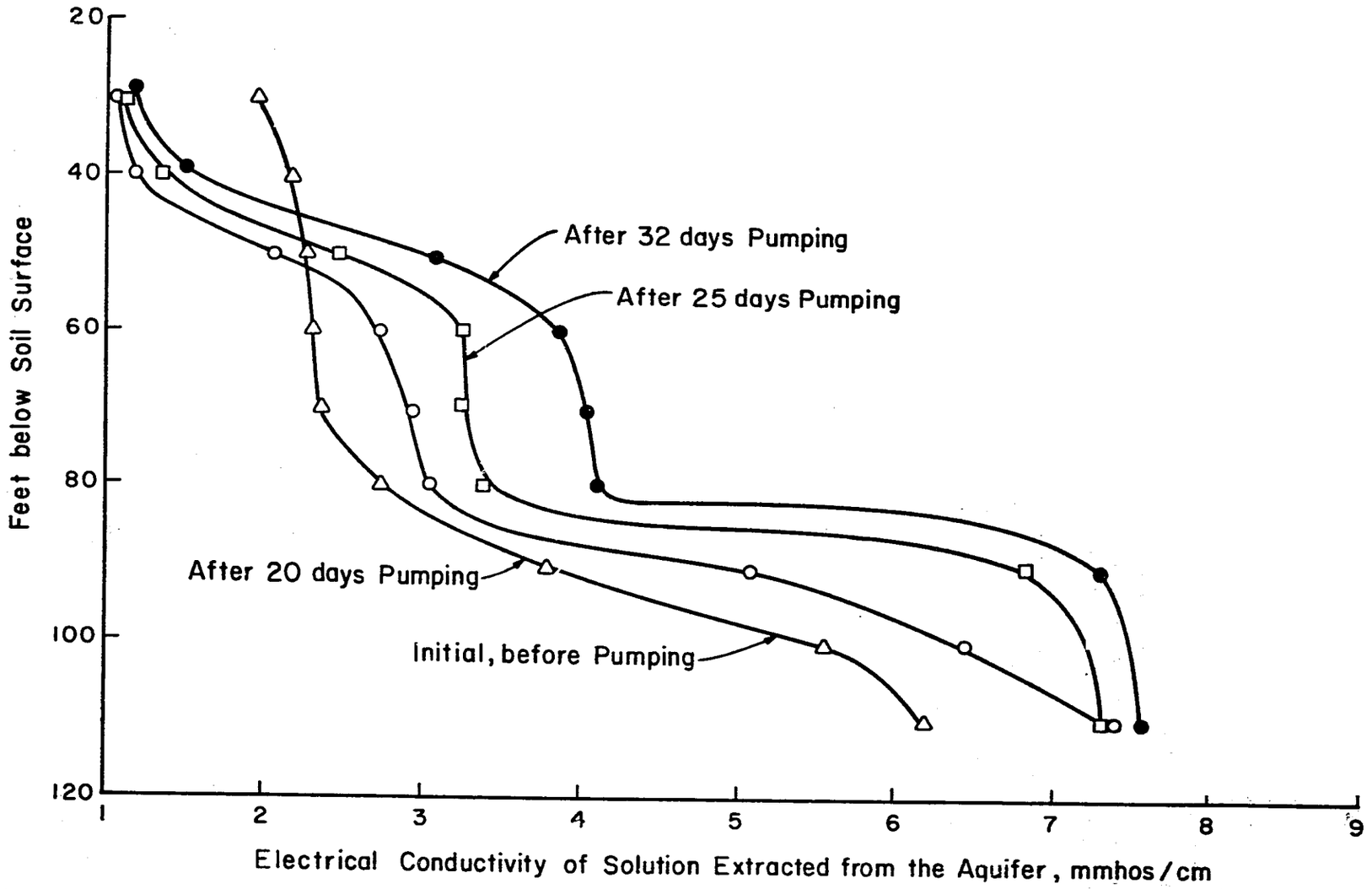


Figure 10. Salinity as a function of depth in the new observation well T_{1-5}.

the stream lines would lead from the top of these shallow wells toward the well screen, rather than through the filled upper portions of the bore where the salinity collects, it is not possible to calculate the contribution of these open bores to the salinity increases noted in Figure 9 in the pumped water, or to the highest dashed line indicating the s-fw interface under Well #3. It is possible that the rise under well #2 is the rise that would also occur under well #3. However, there is also a possibility that there is a localized impermeable layer under well #2 which is preventing transmission of water from lower to higher layers under #2.

To determine which of these two possibilities is causing the observed phenomena, the saline-fresh water interface will be allowed to settle for about 4 months, to near its original level. Hopefully the sides of the observation bore at T_{1-5} will cave in. Whether or not this has happened will become obvious as soon as pumping begins.

If this bore does not close itself and thus eliminate its contribution to upward salt movement, a mercury manometer will be attached to the relevant sampling tubes to measure the hydraulic heads and their gradients under and around wells #2 and #3. From an analysis of these gradients, it will be possible to detect layers with low or high permeability and determine and estimate effects of such inhomogeneities on the pattern of salt movement. The two wells will also be pumped alternately for about 10 minutes each at 0.25 cusecs and the salinity of the water pumped from each well will be determined.

The fraction of the water pumped out of the well which has come from the saline water displacing fresh water can be estimated from the volume of the cone times the pore space of the aquifer divided by the amount of water pumped.

The cones were reasonably conical at the single 60' deep well on the 5th, 9th and 15th day after pumping and their dimensions were approximately as indicated in Table 1.

Table 1. Approximate dimensions (feet) of the cone after 5th, 9th and 15 days of pumping and amounts of water pumped.

Volume of Water Pumped ft^3	Days of Pumping	Approximate Cone Dimensions			% from Saline Water Displacement
		Height ft	Radius ft	Volume ft^3	
216,000	5	14	80	94,000	43
388,000	9	24	90	203,000	52
648,000	15	32	110	404,000	62

Where the volume of the cone was calculated from the equation $V = \pi r^2 h/3$ where h is the height of the cone and r is its radius.

It appears that continued pumping results in a larger and larger fraction of the pumped water coming from displacement of fresh water by saline water. This is probably a result of the interface coming closer to the well so that a larger fraction of the stream lines are coming through the saline zone and of the relative stabilization of the ground water surface cone after prolonged pumping.

At present the following conclusions may be drawn:

(1) The rate of rise of the saline water cone was almost a linear function of the time for which the single well was pumped at 0.5 cusecs.

(2) During the first 10 days after pumping, the rate of fall of the cone was about half as fast as its linear rate of rise. However, the rate of fall decreased rapidly and traces of the cone persisted 5 months after the pump was stopped.

(3) As pumping is continued a larger and larger fraction of the pumped water comes from displacement of fresh water by the rising saline water rather than lowering of the water table in the vicinity of the well.

(4) The salinity of the pumped water was reduced by 25 percent by using two wells with screens from 8 to 30' in depth instead of one well with screen from 10 to 60 feet depth. (This percentage reduction in salt content of water pumped may be even larger when observation wells are not serving as conduits for the rise of saline water to the surface.

Compound Well

The installation shown in Figure 11 was constructed during April and May of 1976. A set of observation sites were located around this well in a manner similar to those shown around the first well in Figure 1. These observation sites allowed sampling of the solution at ten foot intervals from 30 down to 120 ft depth.

Pumping was planned to begin at this installation in mid August, but the monsoon rains brought the water table to one foot from the surface and the pump motors had to be pulled out to prevent their immersion. The larger pump in the fresh water zone was started on October 28 when the water table was at a depth of 5.7 feet below the mean ground surface as indicated in Figure 12.

The salinity of the pumped water increased as indicated in Figure 13 from a 1.7 mmhos/cm to 2.0 mmhos/cm during the

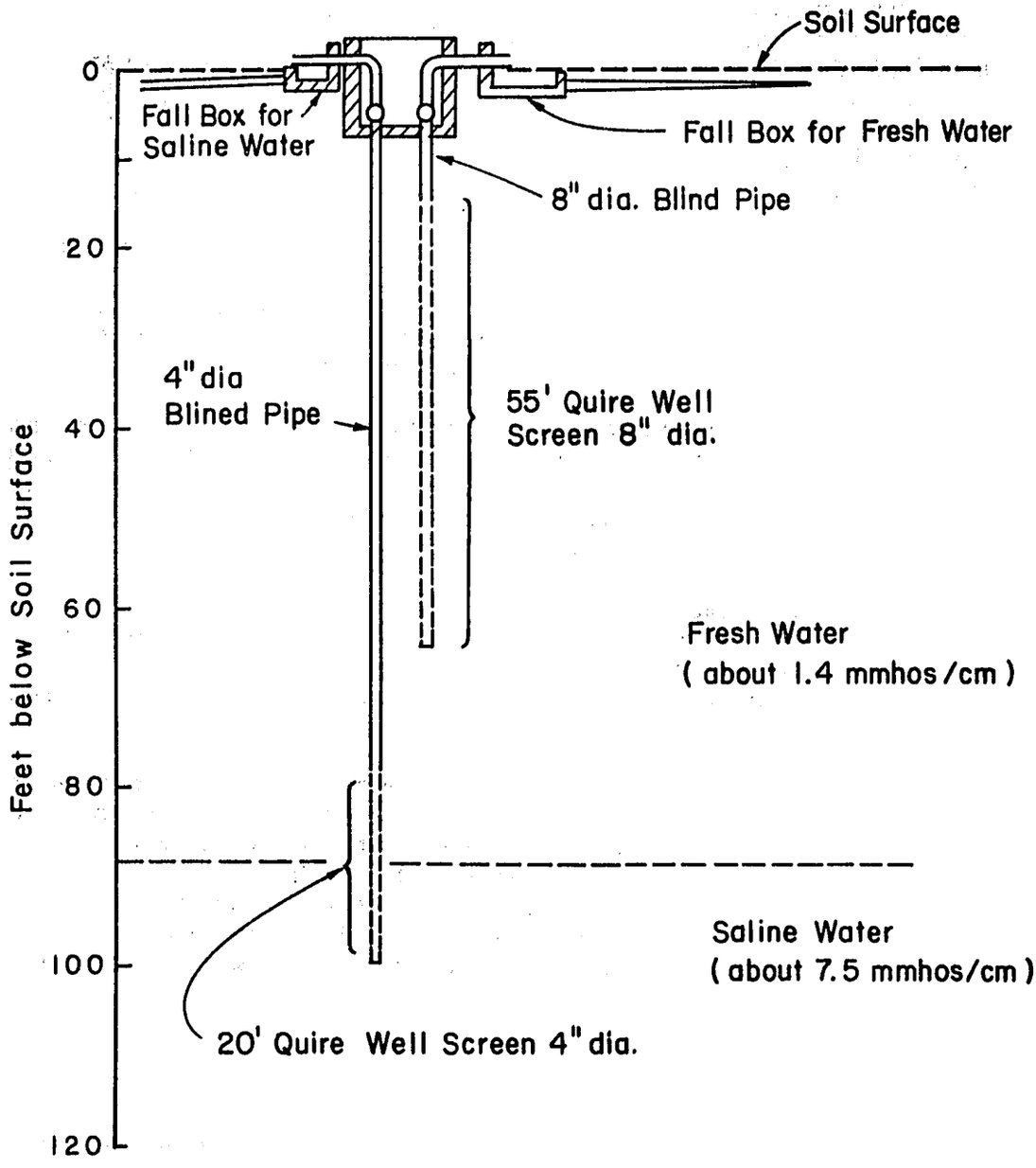


Figure 11. Compound well testing installation.

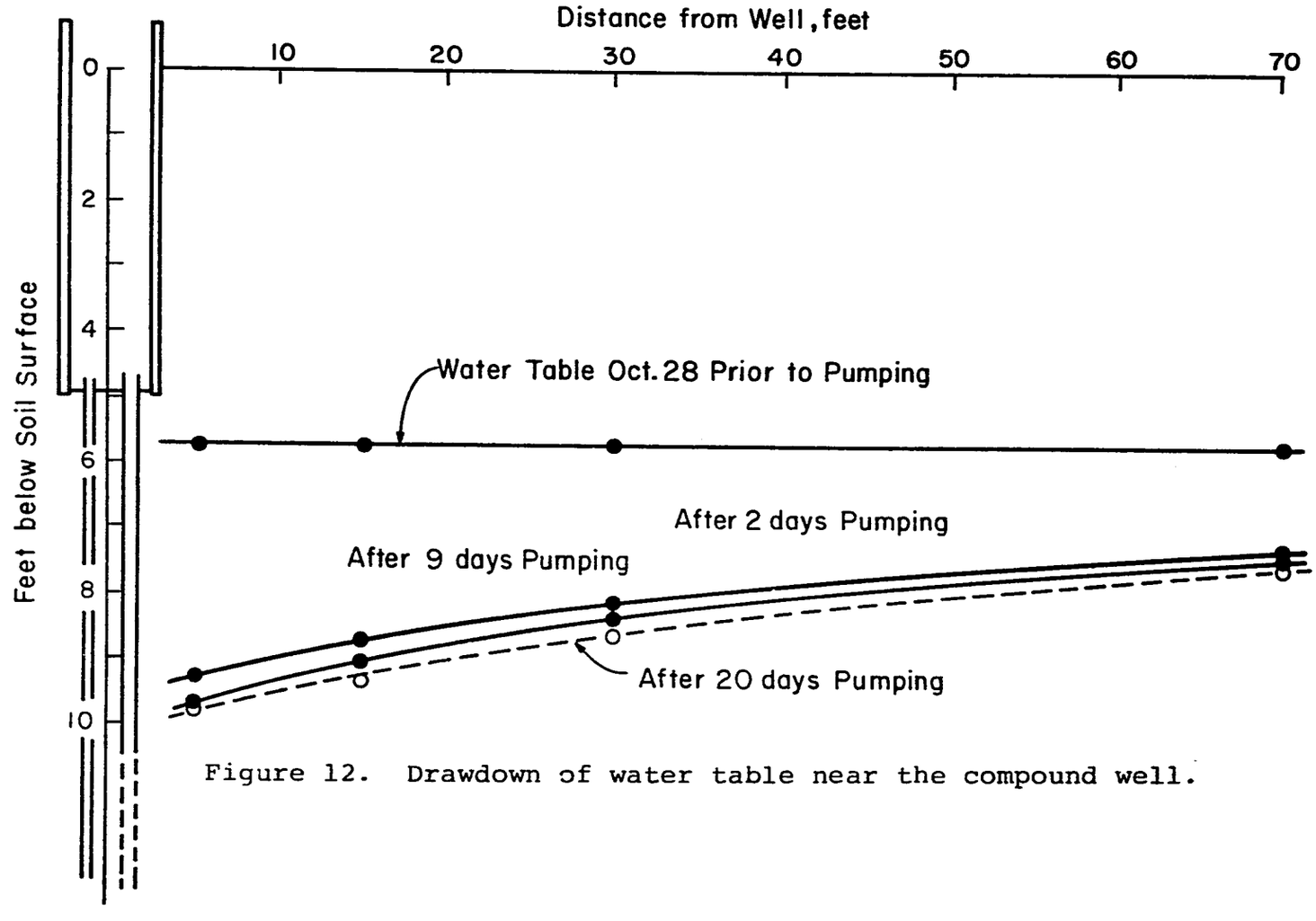


Figure 12. Drawdown of water table near the compound well.

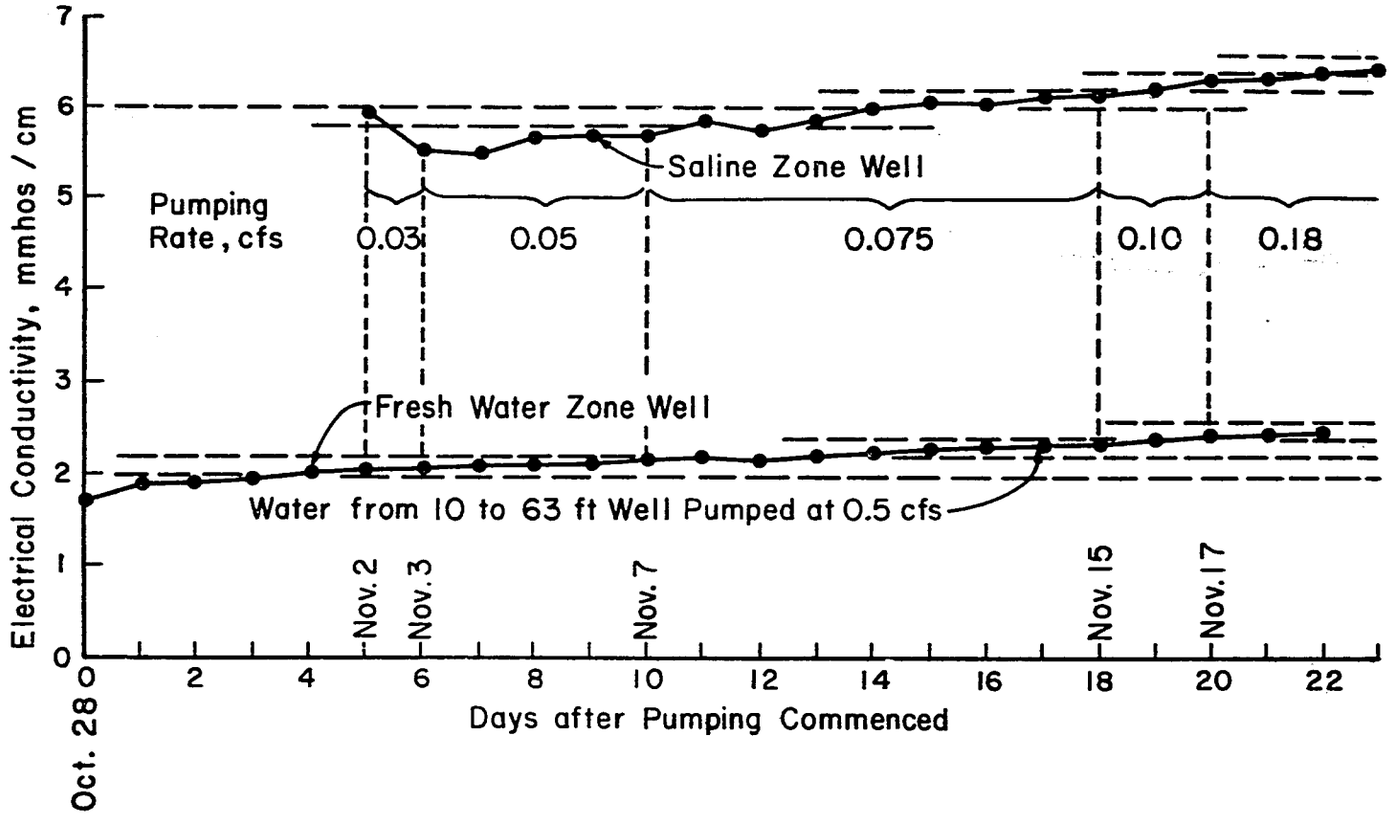


Figure 13. Discharge rate and salinity of "Saline" and "Fresh Water" wells in compound well installation.

first four days of pumping (at a rate of 0.5 cusecs). The salinity profiles were determined at the observation sites and profiles for the D_{2-2} and D_{2-5} sites are shown in Figures 14 and 15. Since the salinity ranged from about 1.5 to 7 mmhos/cm the isoconcentration line of 4 mmhos/cm was chosen as the interface. The 4 mmho isoconcentration line at 4 days is plotted in Figure 16. The objective of the small well with its screen in the saline area is to intercept saline water rising from below the main well, so that water pumped from the main well will have better quality. One day of pumping this saline water interceptor well at 0.03 cusecs (while the main well kept pumping at 0.5 cusecs) did not appreciably improve the quality of the water. In fact, the salt content of the water appeared (Figure 13) to continue its increase. Consequently the rate of pumping at the interceptor well was increased to 0.05 cusecs (while the main well continued pumping 0.5 cusecs). After 4 days of pumping at this rate it was obvious that the salinity of the water was still increasing.

Subsequently the rate of pumping the interceptor well was raised from 0.075 to 0.10 to 0.18 cusecs on the 10th, 18th and 20th day of pumping successively, while the main well continued pumping at 0.50 cusecs. None of these rates of pumping the saline well were sufficient to reverse the time trends toward higher salinity in the pumped water (Figure 13) and toward higher coning of the saline water below the main well (Figure 16).

This failure of pumping rates in the interceptor well of up to 36 percent of those in the main well to reduce the salinity, or even maintain the salinity is disappointing. It had been hoped that pumping of a relatively small amount (i.e. 10 percent of the rate of the main pump) of saline water by the interceptor well would stabilize the stream lines into the two wells and allow separation of the saline and fresh water. The primary reason for continuing increase in salinity of the pumped water is indicated in Figure 17 where streamlines have been sketched in qualitatively for the case in which pumping of the interceptor well is about 40 percent of the pumping from the main well. Note that the origin of most of these stream lines is the underlying saline portion of the aquifer and consequently long term pumping will salinize the upper portions of the aquifer. The difference in density between the saline and fresh water tends to balance the hydraulic pressure gradient force causing the upward lift of the saline water cone. When similar phenomena are considered for oil and water, the difference in density is about 0.2 gm/cc. However the difference in density of water containing 500 ppm salt and 5500 ppm salt is only 0.005 gm/cc and the resulting gravitational force tending to hold the cone down is only 1/40 as large. The fact that this gravitational force is still

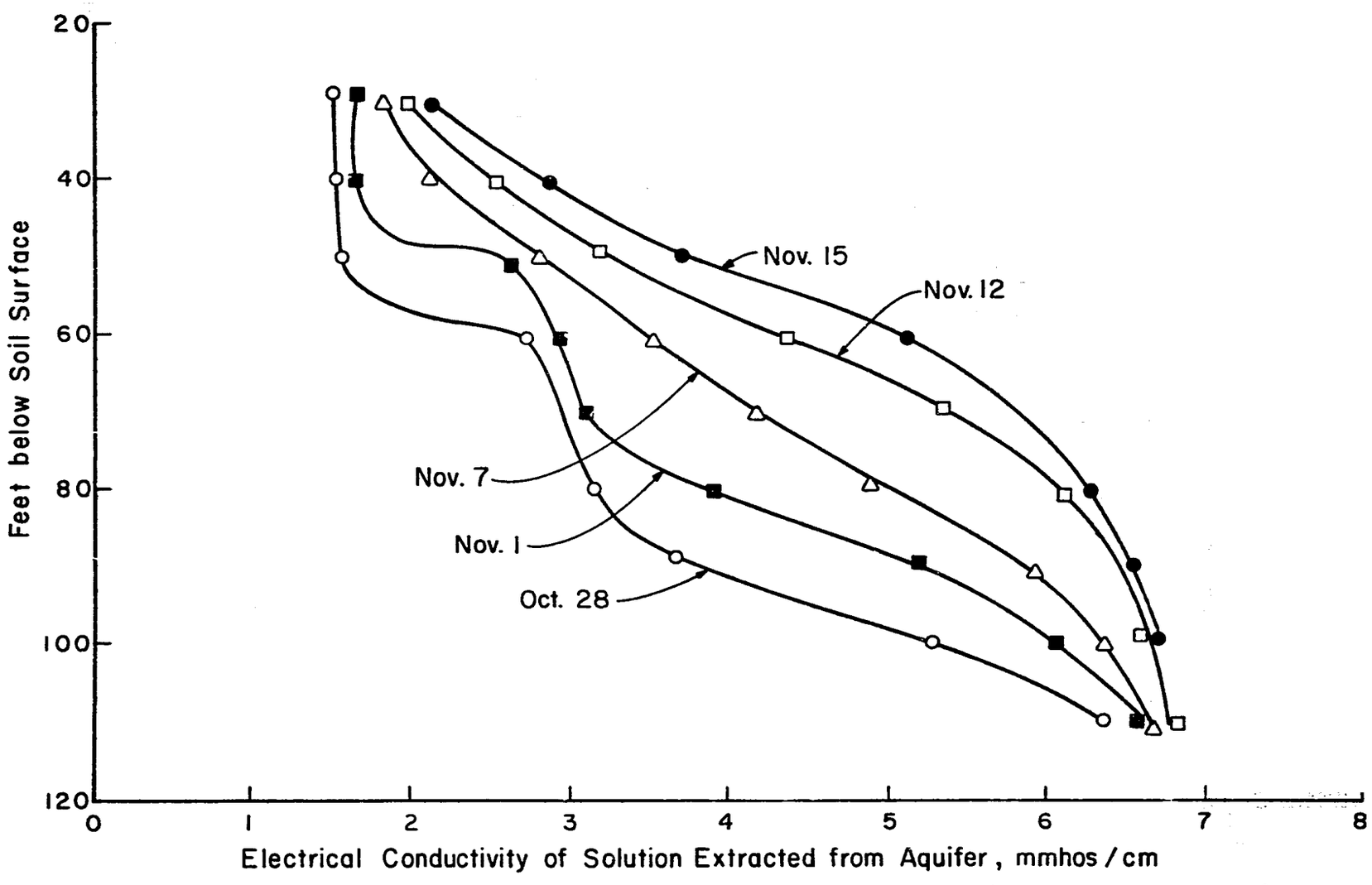


Figure 14. Salinity profiles at the D_{2-2} observation site adjacent to compound well during pumping which was initiated on Oct. 28, 1976.

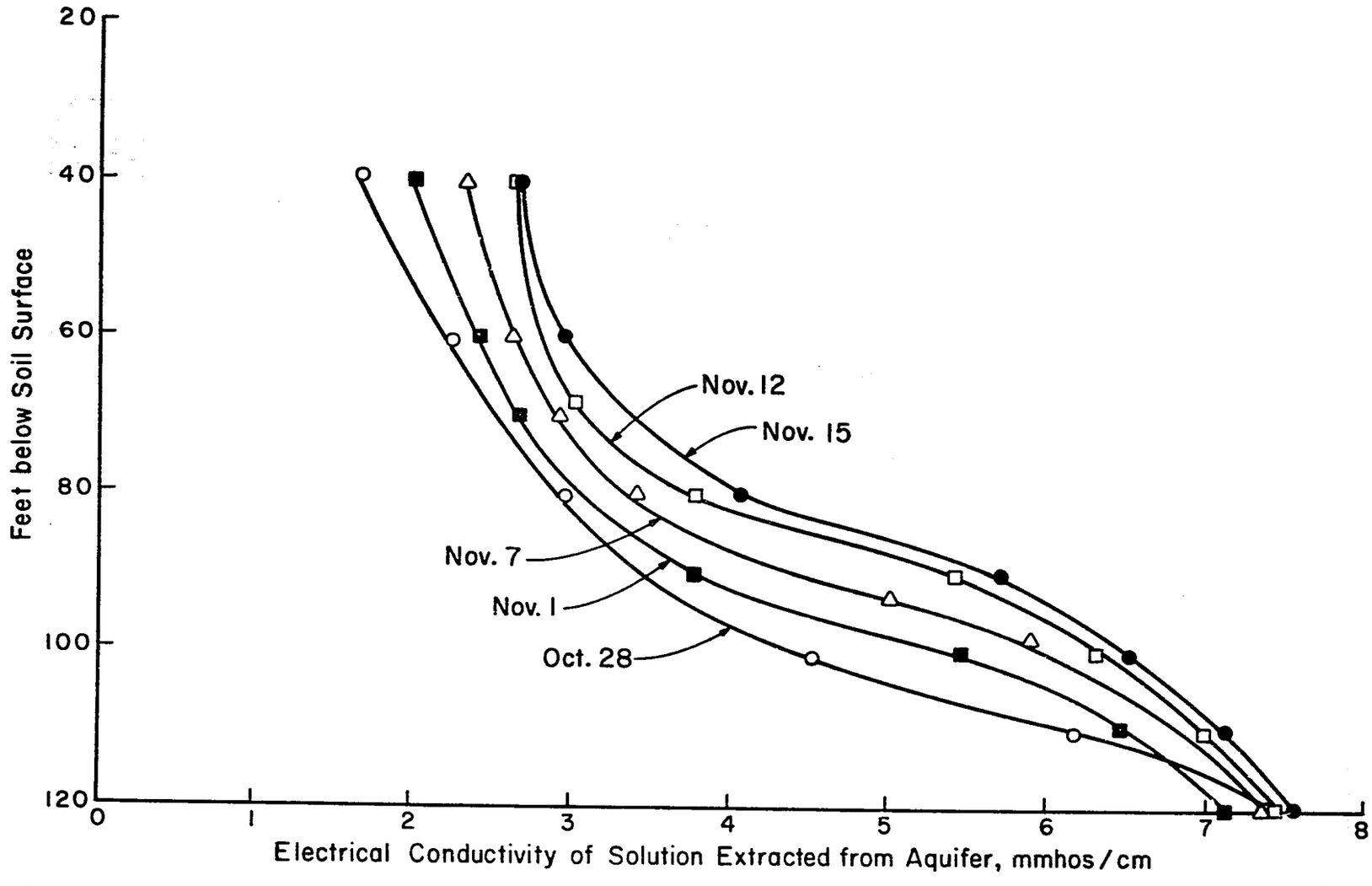


Figure 15. Salinity profiles at the D_{2-5} observation site adjacent to compound well during pumping which was initiated on October 28, 1976.

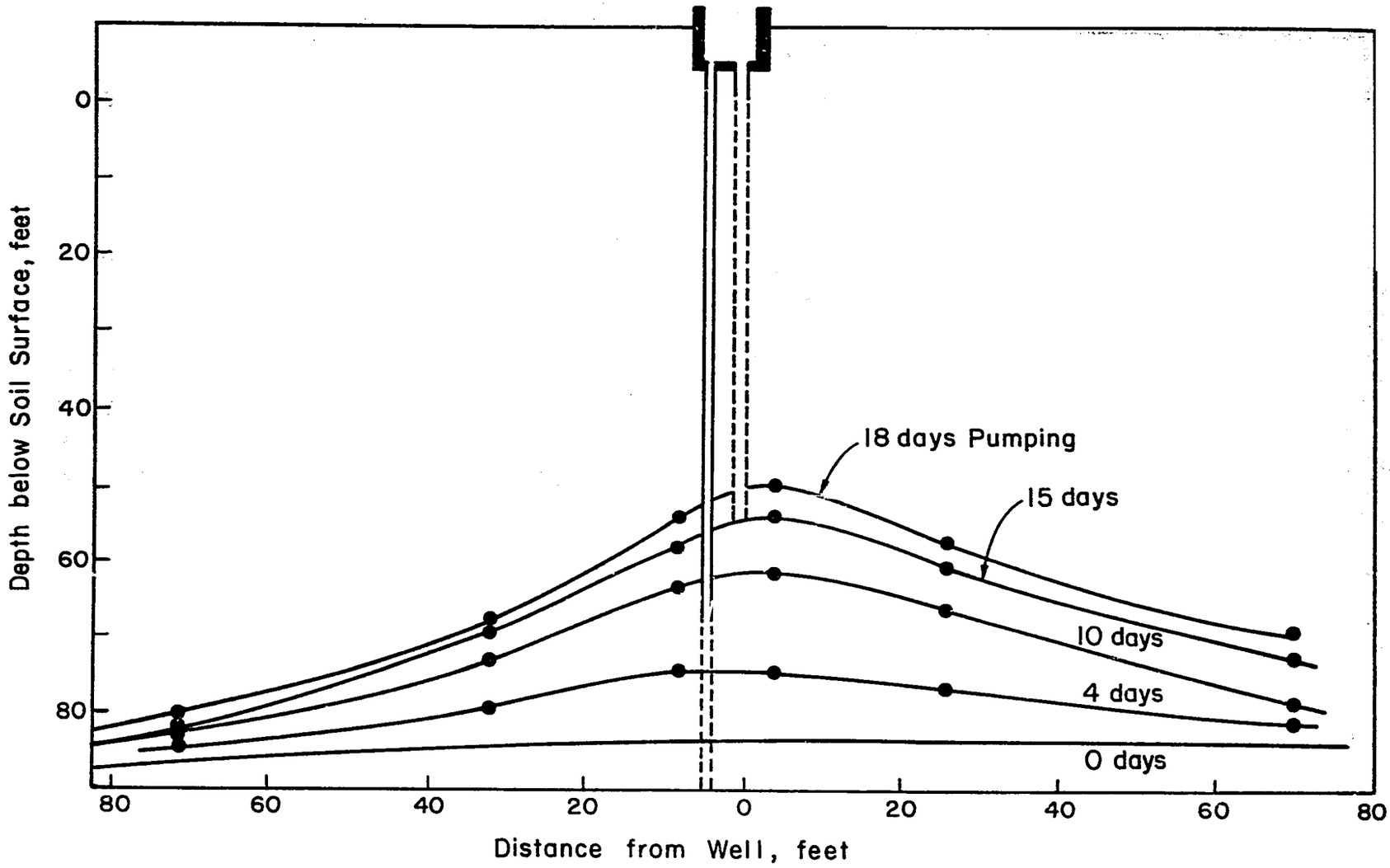


Figure 16. Effect of pumping the compound well on the saline-fresh water interface.

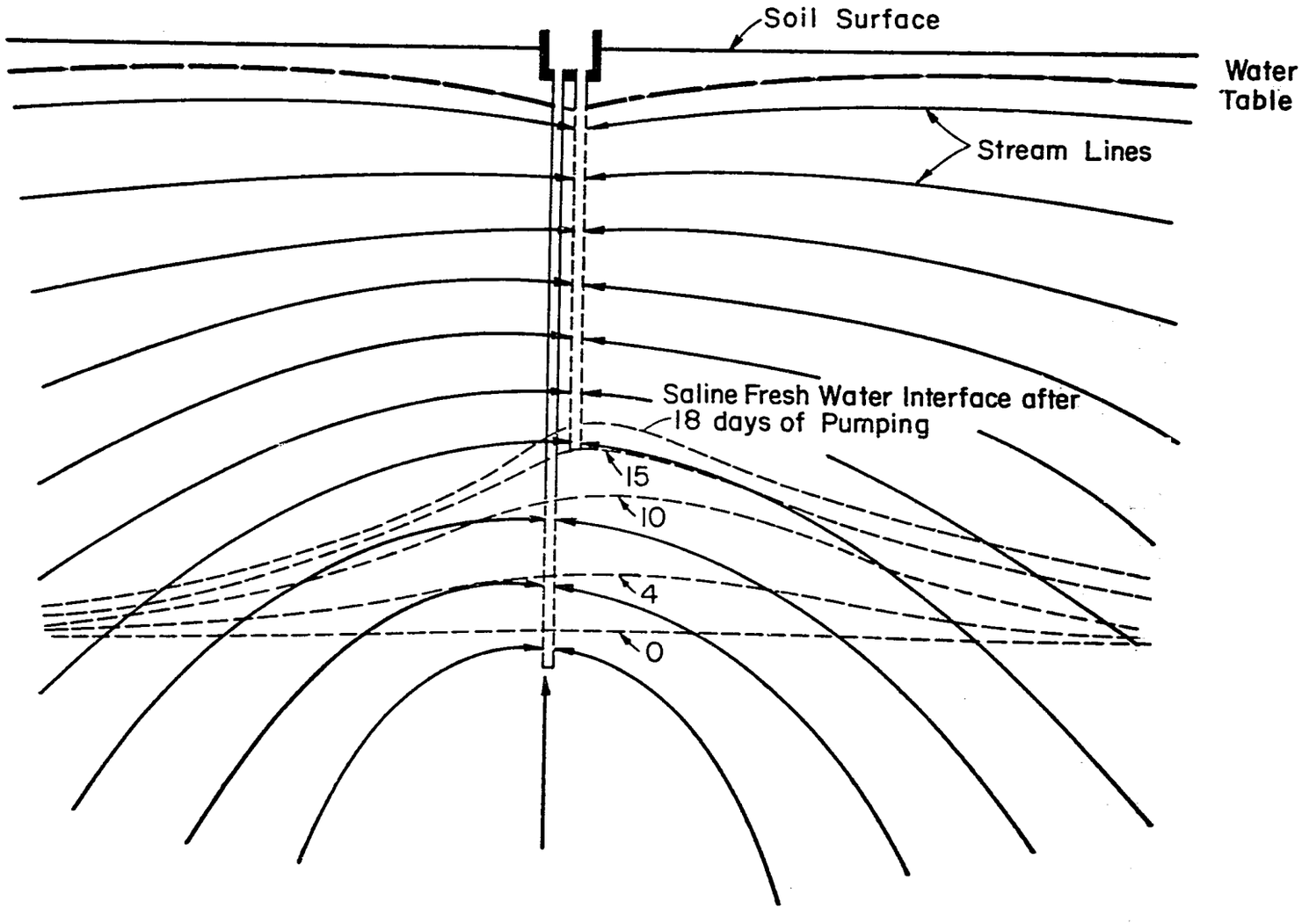


Figure 17. Stream lines and saline-fresh water interfaces before and during pumping.

appreciable is indicated by the recession of the cone of a single well as shown in Figure 7. However, the hydraulic gradients caused by pumping the well are definitely the dominant forces when the pumps are operating.

It would be possible, by increasing the pumping rate of the interceptor well to values as high, or higher than those of the main well to hold down the concentration of water pumped from the main well. However, the amount of salt that would have to be pumped and disposed is large (i.e. see upper curve of Figure 13).

The conclusion that more saline than fresh water will have to be pumped to maintain a steady state pumping system in which the saline layer does not continue to rise is born out by the calculations of the origin of water coming to the single simple well, as shown in Table 1. Note that as time progresses, a larger and larger fraction of the pumped water comes from displacement of the fresh water by saline water and the fraction of pumped water coming from water table recession and lateral transmission of fresh water from greater distance through the fresh water layer decrease (partly because the thickness of the fresh water layer is decreasing).

Needed Further Studies of Compound Well Installation

The rate at which the cone falls after pumping due to gravity alone will be compared to the rate at which it falls while only the interceptor pump is running should be measured to determine whether small capacity interceptor wells of this type can be used economically to pull down the saline-fresh water interface and enlarge the capacity of the fresh water reservoir from which the main pump can draw at a later date. Changes in the salinity profile should be evaluated to determine how much dispersion and mixing of the saline and fresh water layers takes place as this interface moves up and down.

A new installation should be considered in which a well is inserted deep (screen from 200 to 350') into the saline zone and pumped to cause an appreciable "enlargement of the fresh water reservoir" in areas where the fresh water layer is now too thin to use as a supplementary source of irrigation water. This deep well should be accompanied by a shallow multiple well installation which could most efficiently extract the best quality water from the newly constructed fresh water reservoir. Some of the potentials and problems of this type of installation are outlined in greater detail in the attached "Monsoon Flush" discussion paper.

Summary and Tentative Conclusions

Salinity of water pumped at a rate of 0.5 cusecs from two wells with screens from 8 to 30' deep was 75 percent of the salinity of water pumped at 0.5 cusecs from one well whose screen section was from 10 to 60 feet. Greater reductions are possible, but in the case of the coupled 30' wells it was possible to pump water continuously for over 32 days before the salinity of the water reached 1.9 mmhos/cm whereas water pumped at the same rate from the single well reached that salinity within 15 days. The coupled wells were spaced 100 feet apart and this was sufficient to eliminate most of the reinforcement of the saline water cones.

During 15 days of pumping at a rate of 0.5 cusecs from a single well with a screen section 8" in diameter and from 10 to 50 feet deep the peak of the saline water cone rose to 60 feet from the surface which was 32' above the original saline-fresh water interface. Following the pumping the cone peak receded to 72 feet below soil surface within 25 days. However, 164 days after pumping a significant portion of this cone still persisted. This slow rate of return of the saline-fresh water interface to original levels indicates the possibility of building even localized fresh water reservoirs by pumping from the saline layer and during monsoon or other times when the aquifer can be recharged.

An interceptor well placed below a main well was pumped at rates up to 36 percent of the rate of the main well, but was not effective in keeping down the saline cone or keeping the salinity of the water within limits acceptable for irrigation.

The water table draw down, saline-fresh water interface coning and elementary hydraulic considerations show that most of the water pumped from the fresh water layer in regions where saline water lies within 100 feet of the surface is replaced by saline water moving up from below rather than by lateral transmission of fresh water or by air (water table draw down).

Consequently, in using existing or new shallow fresh water layers recharge will need to be localized, within a few furlongs of the point where the water is to be pumped out of the aquifer. Lateral transfer of fresh water in a thin layer overlying a thick layer of saline water in response pumping of wells is accompanied by the lateral transfer of much larger amounts of saline water and a rise in the saline-fresh water interface near the wells.

Appendix 17

SALINE WATER PUMPAGE AND THE "MONSOON FLUSH" AS A MEANS FOR BUILDING FRESH WATER STORAGE AND REDUCING SALINITY, WATER LOGGING AND FLOODING IN THE CENTERS OF THE PUNJAB DOABS

CSU Water Management Team

CSU DISCUSSION PAPER
November 1976

SCARP Tubewells

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

Recharge to the aquifer from the rivers has pushed salt water to the centers of the doabs and the layers of fresh water in the centers of these doabs are often so thin that pumping for irrigation use is not feasible. This is a self aggravating problem because lack of pumping in these areas leaves the water table high, so when monsoon rains come, there is no room in the aquifer for this good fresh rain water. It accumulates on the surface, causing flood conditions and runs off slowly through the available drains. The net effect is loss of this good water to the sea, retention of saline water in the aquifer and negligible increase in thickness of the layer of fresh water.

It was hoped that continued pumping of fresh water from the wells in the fresh water area would reduce the hydraulic pressure there and allow the saline water mounds in the centers of the doabs to subside as a result of movement of the saline water back toward the rivers. In other words the thickness of the fresh water layers should tend to decrease near the rivers and increase in the center of the doabs. If this process is occurring, it is so slow that it has not yet provided an appreciable thickening of the layer of fresh water in these "saline groundwater zones" in the centers of the doabs.

Shifts to Shallower Wells in Marginal Areas

In fact, deep (275 ft.) high capacity (2 to 4 cusecs) SCARP tubewells placed near the saline mounds where the fresh water layer was from 300 to 600 feet deep have continued to draw saline water from below them and in hundreds of cases farmers have demanded that these saline deep wells be closed. In many of these cases the same farmers have dug shallower (60 to 150 ft.) tubewells with lower capacities (.5 to 1.5 cusecs) and are obtaining water of satisfactory quality for irrigation as indicated qualitatively by the shallower private wells near the saline water mound in Figure 1.

Areas Where Saline Water is Within 50 Feet of the Surface

At present the SCARP program is not directly helping these most badly salinized and waterlogged areas. Crop production is severaly limited by both the salinity and the limited water supply (generally about 1 cusec/300 acres) during heavy water use seasons.

It has long been recognized that removal of some of the saline water would help solve this problem by lowering the saline, fresh water interface. However, there has been considerable reluctance to pump saline water because (1) no one wished to pay the cost and (2) there is concern that saline water added to the river will damage downstream lands which use river water for irrigation. These are substantial reasons and should eventually be evaluated in depth, but a preliminary evaluation is now needed and is attempted as follows:

The cost of pumping saline water should be evaluated and compared to its benefits. Let us assume that we want to add 20 million acre feet of fresh water storage capacity to the center portions of these doabs, from which water can be pumped during high demand seasons and which can absorb 20 million acre feet of water during the monsoon flooding periods. This can be done by extracting 20 million acre feet of saline water from the centers of these doabs. The salt content of these waters is about 5000 parts per million or about 7 tons per acre foot of water. Deposition of all this salt on downstream lands would not be a good practice. However, during the monsoon season, a large portion of the water flowing down the Indus goes to the sea, and this may be used as a carrier to move most of this salt to the sea.

Consequently, let us assume that the water must be pumped from the saline zone of the aquifer to the rivers during the two months of each year when most of the river water is going to the sea.

Assume for discussion purposes, pump capacities of two cusecs, pump lifes of 20 years (when run only 2 months of each year) and well depths of 350 feet, with blank casing from 0 to 200 feet and screen from 200 to 350 feet. Then each well, if run continuously for two months (monsoon) of each year would pump 240 acre feet of water per year, or 4,800 acre feet of water in twenty years.

Extraction of 20 million acre feet of water would require the installation of about 5000 wells. If each of these costs Rs 300,000, the total cost of building this 20 million acre feet of fresh water storage capacity in the saline central portions of the doabs will be Rs 1,500,000,000, or about 6 percent of the cost of reservoir type surface storage. In making this comparison, however, it should be recognized that reservoir storage can serve the additional purpose of electric power production.

Filling of this storage reservoir in the aquifer would be from excess water during monsoon rains (which would decrease flooding and crop damage), from canal and water-course seepage, and from the overirrigation which occurs in some spots as a result of unlevel land and at certain seasons when irrigation and rainfall exceed crop needs. During this period of saline water pumping (fresh water reservoir building) extraction would exceed recharge and the overall water table should recede to reduce the waterlogging.

The wisdom of pumping saline water into drains which are already often overloaded during monsoon season should be questioned. However, in these areas where the ground water is near the surface the soil profile quickly fills up under present conditions and additional rainfall runs off. When pumping occurs, for each acre foot of water pumped, an acre foot of storage is made available for the excellent quality rain water. Consequently, there will be little, if any, extra load on the drains. Moreover, the downward movement of this excellent quality water will move salts which have accumulated in the surface down through the profile and play a major role in reducing the salinity in the plant root zone.

Since a pumping system will be needed to extract water from the new fresh water layer for irrigation, and since this irrigation will be needed in times other than the monsoon rain period the possibility exists of using the same power unit for both functions. The electric motor used for pumping saline water during monsoon periods could be used for pumping irrigation water during periods of high demand for irrigation water. This multiple use of the electrical connection and motor could reduce the "reservoir building" and "pumping" costs.

Salinity Increases in Downstream River Water

About 40 million acre feet of water now escapes to the sea during the monsoon season (July 20 to Sept. 20) and about 10 million acre feet of water is diverted at points below the doabs in question for irrigation purposes. Consequently, if one million acre feet of water at a salinity of 5000 ppm is pumped into the river each year, it will be diluted by a factor of 50, and the increase in salinity of the river water would be about 100 ppm during the monsoon season. During other seasons the salinity in the river water should actually be decreased because there would be a reduction in the amount of saline drainage waters flowing out of the doabs.

The increase in salinity (100 ppm) of downstream water caused by creation of the "fresh water reservoirs" in the saline aquifers of the Punjab doabs during the monsoon still leaves the monsoon water in the "very good" category. However, it must be admitted that the extra salt in the water tends to decrease yields, and a proposal for creating fresh water reservoirs in this manner would need to evaluate the decrease and provide some compensation to the Sindhi users to be acceptable to all concerned. This could be done by reducing diversions of river water to the canals feeding the doabs by a certain percent of the increased fresh water pumping capacity. For instance, if 5000 wells with a capacity of 2 cusecs are pumping half the time during the 300 day non-monsoon portion of the year, they will pump 3 million acre feet of water per year. Allowing the Sindhis 20 percent of the pumped water would amount to reducing diversions at the Punjab doab canal headworks by 0.6 million acre feet per year. This would be available for diversion in the Sind.

Studies have been conducted in other countries to determine the decrease in value of water for irrigation purposes when the salinity of that water is increased. These negative values could be compared to the positive values of the added water available to determine the fraction of the extra water that should be made available to the Sind.

Basically, this extra water available (whether used in the Punjab or the Sindh) would come from seepage from canals, and watercourses and localized over-irrigation (which are presently not pumpable and are causing the extreme waterlogging and salinity problems in the centers of the doabs) and from excess monsoon rains (which presently cause flooding and crop damage) which would be absorbed into the fresh water aquifer.

Data Needed to Evaluate the Potential of the "Monsoon Flush" as a Means of Transporting Saline Water to the Ocean and Allowing Creation of Fresh Water Storage in Saline Portions of Punjab Doabs

1. Will sufficient electric power be available to run the tubewells (i.e. 5000 tubewells of 2 cusecs each) and what will it cost?

2. How much mixing of saline and fresh water will take place as the saline water recedes and as the saline-fresh water interface rises and falls as water is alternately pumped from the saline and fresh water zones of the aquifer.

3. What is the value of water used at various seasons in the Sind?

4. What is the value of water used at various seasons in the saline ground water areas of the Punjab?

5. What is the decrease in value of water use to increases in salinity of the order of 100 ppm (i.e. increases from 200 to 300 ppm)?

6. What is the value of the flood damage that could be averted if the soil and aquifer in the centers of the doabs had increased capacity to absorb the water?

   a. How fast can monsoon rain water be absorbed into the soil and aquifer? This will determine whether monsoon season pumping increases the load on the drains and what portion of the air filled porespace above the water table can be filled by monsoon rain.

   b. How much yield reduction occurs in crops as a result of surface flooding in the Northern Punjab?

   c. How much damage occurs to stored grain, straw, and to roads which could be averted if the monsoon rain water could infiltrate into the soil in the centers of the doabs?

7. What is the cost of shallow skimming wells, joined in tandem to a single pumping unit? How does this compare to costs of water pumped from individual small capacity (0.2 to 0.5 cusec) wells with kerosene motors?

8. What would be the rates of lateral encroachment of saline water into pumped areas if the scheme were implemented on a limited area (i.e. 100,000 acres)?

9. What would be the value of lowering the water table 10 feet and providing 50 percent more water in the heavy water demand seasons? Ball park estimates from long time farmers in this area are that this would allow them to increase wheat yields by 50 percent and Kharif yields by 100 percent.

10. What is the urgency of this "monsoon flush" program? If this method of salt removal and formation of fresh water storage for flood control and irrigation is feasible now, how soon will the construction of additional storage on the rivers eliminate or reduce the potential of this monsoon flush for accomplishing these purposes?

Data is available which will allow estimates on several of these questions. Is the potential of this type of improvement program sufficiently great to warrant research to fill the information gaps? Is it sufficient to warrant the planning of a research-cum pilot project type of program?

Appendix 18

PRIVATE TUBEWELLS IN SCARP-II WATER COSTS AND UTILIZATION

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Economics Section[2]

Introduction

Water is one of the most limiting factors in agricultural production in Pakistan. On order to overcome the limitations of short water supply during certain times of the year, as well as to relieve the twin menaces of waterlogging and soil salinity, the government has installed a number of SCARP* public tubewells. However, in addition, private farmers have also installed tubewells. Since 1960 there have been over 100,000 private tubewells installed. Most of these tubewells have been installed in areas where the farmers did not have a perennial supply of canal water or in areas that were not commanded by canals. In the SCARP areas, especially in areas commanded by perennial canals, it has been assumed that the canal water supply supplemented by the SCARP water precludes the need for private tubewells.

The purpose of this research work is to explore the extent of development of private tubewells in a SCARP area. The sample includes private tubewells from the 110,000 acres of the Mona scheme of SCARP-II, as well as private tubewells outside of the Mona scheme. The private tubewells are divided into wells located on land served by perennial canals, by nonperennial canals, and on land uncommanded by canal water. The purpose of the study is to explore the costs of production of water from private tubewells, both diesel and electric, and to determine how the total water supply available affects the degree of utilization of the private tubewells. Data on productive life of different tubewell components as well as data on actual tubewell pumping rates (measured in cubic feet per second) is presented.

This study was conducted during the months of June, July and August, 1975. The questionnaire (Mona files) was tested in May, 1975, and then administered by the Economics Section of the Mona Scheme under Chaudhry Muhammad Hussain, Senior Research Officer in Economics. Flow rates from

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[1]Member of the Field Staff, Water Management Research Project, Colorado State University.
[2]Mona Reclamation Experimental Project
*Salinity control and reclamation project

twenty percent of the wells were measured using the Purdue coordinate method for measuring tubewell discharge. This work was carried out under the supervision of Barkat Ali, Junior Research Officer in Economics.

Data Collection

Data was collected from 192 owners and operators of private tubewells. This includes all the private tubewells in the Mona project as well as 87 private tubewells outside of the project. These were divided into the different classifications as illustrated in Table 1.

Table 1

A Breakdown of Tubewell Data - 1975

	Perennial Area	Nonperennial Area	Uncommanded Area
Within Mona Scheme			
Electric	10	8	15
Diesel	18	9	38
Outside Mona Scheme			
Electric	0	1	75
Diesel	1	6	4
Total:	29	24	132

Total tractor driven: 7

Total number: 192 tubewells

It is obvious from this table that the uncommanded area does have the majority of the private tubewells, but that 16% and 13% of the tubewells are located in the perennial and nonperennial areas, respectively.

The farmers were initially interviewed in the field near their tubewells. This allowed the interviewers to cross check the data, such as outlet size, motor horsepower, etc. Data concerning number of hours operated was cross checked as close as possible against the number of barrels of fuel used or the number of KWH's of electricity consumed. However, due to the poor record systems of most farmers, this data must be considered to be only approximate.

The data concerning the actual flow rate of the tubewells was collected during a second interview visit. A random sample of approximately 20% of the 4" tubewells and 15% of the 5" and 6" tubewells was selected. These wells were started, allowed to run long enough for the flow to stabilize and then coordinates of the stream of water flowing freely from the end of the horizontal pipe were measured. The tubewell discharge was then read off the appropriate horizontal and vertical coordinates from the proper table[1].

Component Life

The active life of a producing well is dependent upon the strainer material used. The farmer in Pakistan has a wide selection of strainer materials, each of which has different properties. The farmer can opt for the most inexpensive material, that of coir (coconut fiber) rope, or he can select the most expensive material, brass. The rope strainer has a very low cost compared to the other strainers, but it also has a relatively short life. The brass strainer is quite dear, but it should have a much longer life. Table 2 details the average lives for the different strainers surveyed in this sample.

Table 2

Strainer Material	Number	Average Life (years)
Rope	40	7.70
Cement	20	9.30
Plastic	6	10.80
Brass	3	10.70
Iron	15	8.80

Theoretically, brass should have an extremely long life but from this survey the brass strainer did not have any longer life than the plastic; however, the sample for both of these is quite small. The rope strainer did have the shortest life, yet, compared to the costs (currently Rs 20/feet for rope and Rs 60/feet for brass), it did not appear to be uneconomical.

The life of the strainer is quite often directly affected by the condition of the bore or the pack around the strainer. The packing material, if any at all, is rarely

[1] "Measuring Tubewell Discharges by the Purdue Coordinate Method", Tom Trout and Alan Early, CSU Methodology Series #2.

known since the farmers are usually not technically knowledgeable concerning this aspect, but the farmers are able to determine when the bore has failed. The average life of the bore for the different areas is in Table 3.

Table 3

Average Bore Life

Area		Life	Costs* (Rs)	Costs/Foot (Rs/ft)
1.	Perennial electric	8.00	700	5.93
2.	Non-perennial electric	6.00	762	7.43
3.	Uncommanded electric	6.00	1193	8.79
4.	Perennial diesel	8.00	536	4.95
5.	Non-perennial diesel	8.00	855	7.47
6.	Uncommanded diesel	8.00	550	4.94
7.	Non-perennial electric	8.00	1100	10.00
8.	Uncommanded electric	7.00	934	7.80
9.	Perennial diesel	7.00	500	4.17
10.	Non-perennial diesel	9.00	316	3.10
11.	Uncommanded diesel	10.00	360	3.27
12.	Tractor driven	10.00	502	5.02
	AVERAGE:	7.92	692	6.07

*Costs for the bore alone at original costs.

The costs per foot of bore varies from around 3 Rs/ft up to as high as 10 Rs/ft. The average depth of bore is about 114' with a per unit cost of 6.07 Rs/ft. The life of the bore is a relatively short time of not quite eight years. However, the low cost of reboring (assuming the screens can be reused) makes it not unusual to find wells that have been rebored a number of times.

The depth to water table is important both in terms of the yield of the well and in terms of the production costs per acre-foot of water pumped. The average depths of water across the different areas are detailed in Table 4.

Table 4

Average Depth to Water Table

Area		Depth of Bore (feet)	Depth to Water Table (feet)
1.	Perennial electric	118.5	18.9
2.	Non-perennial electric	102.0	7.8
3.	Uncommanded electric	135.0	15.0
4.	Perennial diesel	108.3	15.7
5.	Non-perennial diesel	114.4	7.2
6.	Uncommanded diesel	111.4	15.2
7.	Non-perennial	110.0	10.0
8.	Uncommanded	119.8	15.5
9.	Perennial diesel	130.0	20.0
10.	Non-perennial diesel	106.6	14.3
11.	Uncommanded diesel	110.0	23.5
12.	Tractor driven	100.0	10.4
	AVERAGE:	113.8	14.5

The depth to water table varies across the sample area from 7.2 feet to 20.0 feet with an average of about 14.5 feet.

Tubewell Production Costs

The costs of producing an acre-foot of water at the discharge pipe are a function of the fixed costs of the tubewell and its accompanying facilities and the variable costs associated with the hours of actual operation. The capital costs of the tubewell include: the initial costs of boring the well, digging the pit, purchasing and installing the strainer pipe and the blind pipe, connecting the pump and motor/engine, construction of the pump house and motor house, and building a discharge box for the outflow. Figure 1 illustrates how these capital costs have increased over time for 4", 5", and 6" electric tubewells, respectively. Figure 2 illustrates the same relationships for diesel wells. From these figures it appears that capital investment costs for private tubewells have increased approximately 70% since 1965. The variable costs for fuel have also increased since 1965. Diesel fuel has risen from 2.25 Rs/imperial gallon to 4.5 Rs/imperial gallon. During the same time period electricity rates have risen from approximately 5.8 Paisa/KWH to 9.5 Paisa/KWH. Costs of other variable inputs such as lubrication oil, repair parts and operation labor have also risen quite substantially.

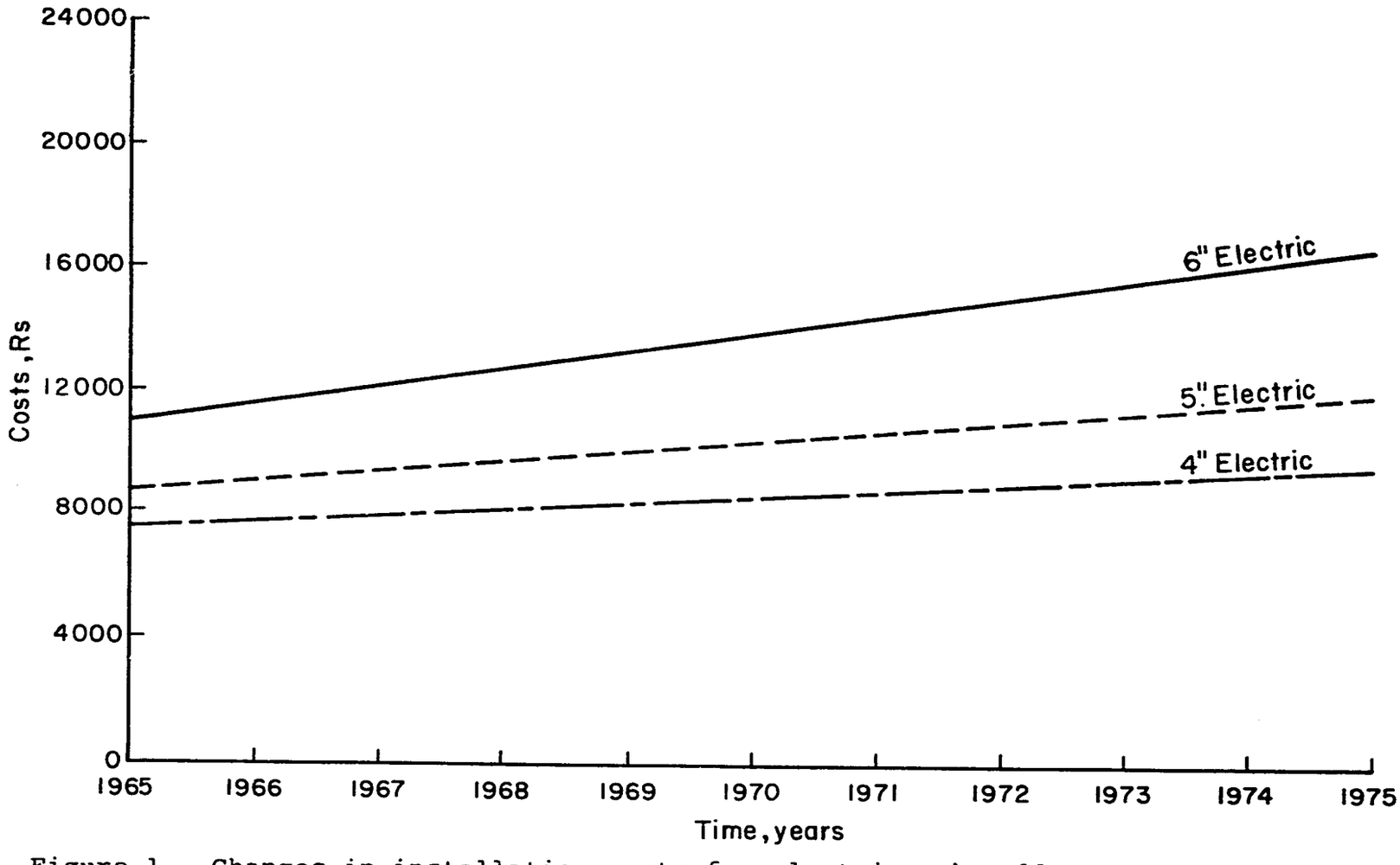

Figure 1. Changes in installation costs for electric tubewells.

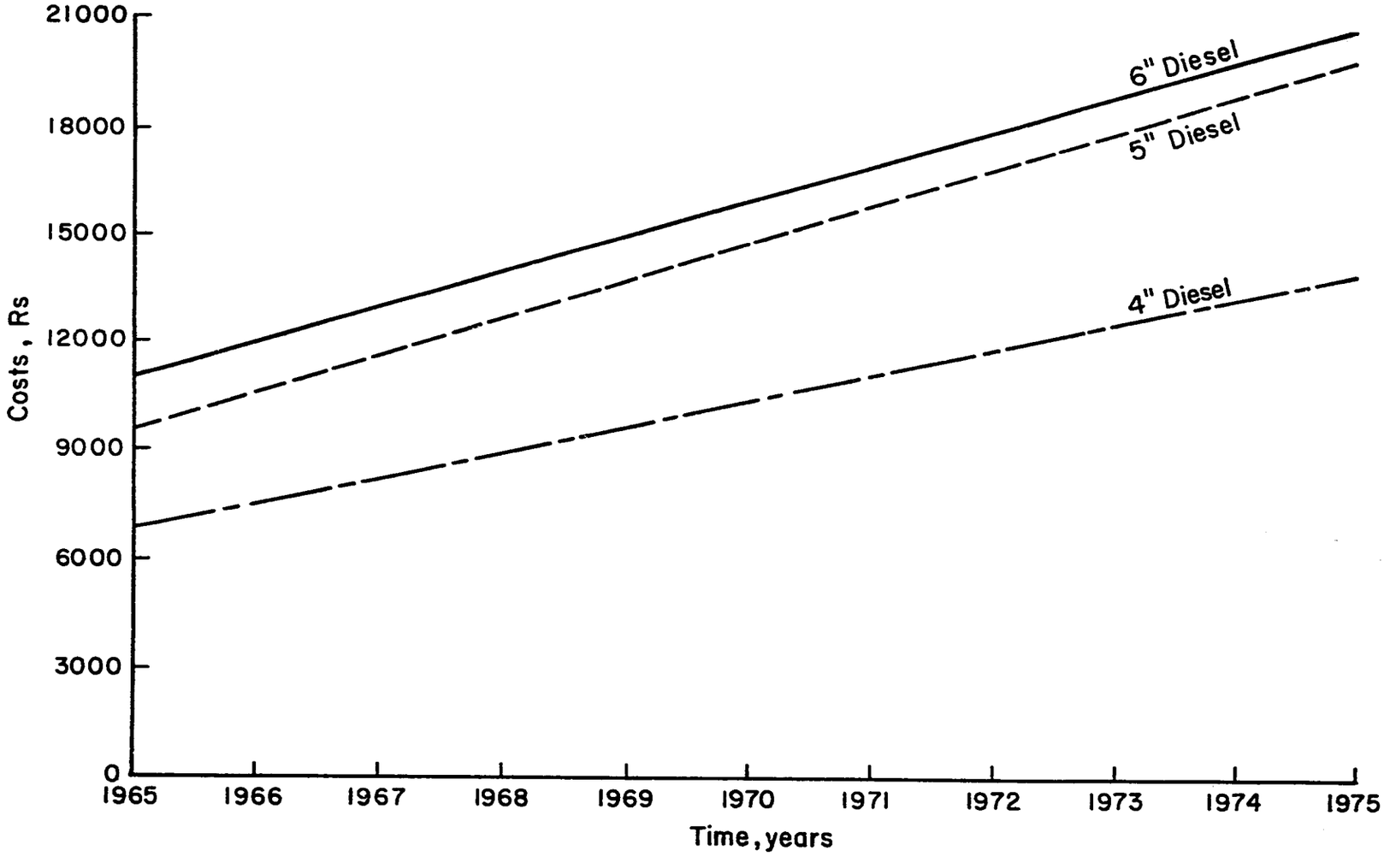

Figure 2. Changes in installation costs for diesel tubewells.

The overall average costs for the 4" discharge tubewells across the entire area is presented in Table 5. This data is amortized at a 10% rate.

Table 5

4" Tubewells - Overall Average Production Costs*

Component	Cost (Rs)	Average Life (years)	10% Amortized Cost (Rs)
Motor	4498	12	660.13
Pump	870	7	178.71
Blind pipe	658	13	92.63
Screen	763	7	156.73
Bore	1072	7	220.20
Pit	815	11	125.48
Motor house	1407	11	216.62
Pump house	780	9	135.44
Discharge box	444	9	77.10
	11307		1863.04
Average annual fuel and lubricant costs			2297.00
Average annual repair costs			271.00
Total without operator labor			4431.04
Average annual operator hours			1872.00
Total with operator labor (1 Rs/hr)			6303.04
Average acre-feet pumped annually			129.72
Costs per acre-foot of water pumped			34.16 Rs/AF
Costs per acre-foot of water including operator opportunity costs			48.59 Rs/AF

*These prices are original costs and do not represent current costs.

The average costs per acre-foot of water pumped are 34.16 Rs. If the opportunity costs of operator time are included at 1 Rs/hr, the cost per acre-foot pumped increases to 48.59 Rs. Due to both low discharge (average .87 cusecs) and the low percentage of utilization (about 23% assuming a total possible hours of operation of 22 hours/day x 365 days/year = 8030 hours/year). The overall average production costs for the 5" discharge tubewells across the entire area is detailed in Table 6. This data is also amortized at a 10% rate.

Table 6

Tubewells - Overall Average Production Costs*

Component	Cost (Rs)	Average Life (years)	10% Amortized Cost (Rs)
Motor	5866	13	825.81
Pump	1050	8	196.81
Blind pipe	781	12	114.62
Screen	1178	8	220.80
Bore	785	8	147.14
Pit	366	10	59.72
Motor house	1584	10	257.80
Pump house	982	9	170.51
Discharge box	921	10	149.89
	12463		2143.10
Average annual fuel and lubricant costs			3597.49
Average annual repair costs			1128.19
Total without operator labor			6868.78
Average annual operator hours			1992.22
Total with operator labor (1 Rs/hour)			8861.00
Average acre-feet pumped annually			220.86
Costs per acre-foot of water pumped			31.10 Rs/AF
Costs per acre-foot of water including operator opportunity costs			40.12 Rs/AF

*These prices are original costs and do not represent current costs.

The average cost per acre-foot of water pumped is 31.10 Rs. When the opportunity costs of operator time are included, the cost per acre-foot pumped increase to 40.12 Rs. This is slightly less than the cost for 4" tubewells and is a result of the higher discharge (average 1.33 cusecs) and the higher percentage of utilization (about 25%). However, this unit cost of tubewell water is still quite high because the number of acre-feet of water pumped per year is small.

Table 7 contains the overall average production costs for the 6" discharge tubewells across the entire area. The data is amortized using a 10% rate.

Table 7

6" Tubewells - Overall Average Production Costs*

Component	Cost (Rs)	Average Life (years)	10% Amortized Cost (Rs)
Motor	7016	14	952.42
Pump	1165	9	202.29
Blind pipe	816	13	114.88
Screen	1422	8	266.54
Bore	793	8	137.69
Pit	764	10	124.34
Motor house	1628	11	250.65
Pump house	1356	10	220.69
Discharge box	1421	10	231.27
	16381		2500.27
Average annual fuel and lubricant costs			5963.51
Average annual repair costs			1462.76
Total without operator labor			9927.04
Average annual operator hours			2890.00
Total with operator labor (1 Rs/hour)			12817.04
Average acre-feet pumped annually			349.25
Costs per acre-foot of water pumped			28.42 Rs/AF
Costs per acre-foot of water including operator opportunity costs			36.70 Rs/AF

*These prices are original costs and do not represent current costs.

The average cost per acre-foot of water pumped from a 6" tubewell is 21.42 Rs. Including the operator opportunity costs, the average cost per acre-foot increases to 36.70 Rs. Again, these costs are slightly lower than the 4" and 5" tubewells due primarily to the higher discharge (average 1.70 cusecs) and the higher percentage of utilization (about 36%).

The data for the overall averages does not really reflect the time or expected costs for a certain area, because the costs of producing water are dependent upon the amount of pumping, the depth to water table and whether the tubewell is electric or diesel. The amount of pumping is determined by the available water supply in an area. An area that has

both perennial canal water as well as SCARP tubewell water is unlikely to pump as much water as an area that is only served with SCARP tubewell water. In order to explore how the production costs vary over the different areas with diesel and electric tubewells, production costs were calculated for the different categories. A summary of the results is presented in Table 8.

Table 8

Summary of Tubewell Production Costs by Canal Supply and Power Source

Area Type	Cost Excluding Operator (Rs./A.F.)	Cost Including Operator (Rs./A.F.)
Within Mona		
1. Perennial electric	25.17	32.64
2. Non-perennial electric	29.08	38.39
3. Uncommanded electric	21.16	35.37
4. Perennial diesel	40.72	48.73
5. Non-perennial diesel	23.33	31.82
6. Uncommanded diesel	25.73	33.82
Outside Mona		
7. Non-perennial electric	34.28	43.31
8. Uncommanded electric	32.90	40.76
9. Perennial diesel	43.96	52.77
10. Non-perennial diesel	18.31	25.64
11. Uncommanded diesel	22.37	30.72
12. Tractor driven	18.44	25.56

A comparison of these 1960-1975 average costs with 1976 costs indicates the rate of inflation and how it affects the per acre-foot costs of tubewell pumped water. 1975-1976 current installation costs are presented in Table 9 for diesel components and Table 10 for electric components.

Table 9

1975-76 Diesel Tubewell Costs (Rs.)[1]

Component	4" Discharge	5" Discharge	6" Discharge
Motor	9600	12000	13000
Blind pipe	1200	1590	1800
Strainer	1500	2000	2500
Bore	720	800	850
Pit	600	700	800
Motor house	1400	1500	1600
Pump house	700	900	1100
Discharge box	500	800	1200
Pump	1200	1300	1500
TOTAL	17420	21590	24350

[1]These costs may not include all installation and hook-up charges.

Using the same average fuel, lubricant, repair, and operator costs as presented in Table 6, the average cost per acre-foot of water pumped from a 5" tubewell installed in early 1976 would be 37.1 Rs/A.F. without operator opportunity costs and 46.2 Rs/A.F. including operator opportunity costs.

Table 10

1975-76 Electric Tubewell Costs (Rs.)[1]

Component	4" Discharge	5" Discharge	6" Discharge
Motor/Pump	4200	5000	6000
Blind pipe	1200	1590	1800
Strainer	1500	2000	2500
Bore	720	800	850
Pit	600	700	800
Motor house	1400	1500	1600
Pump house	700	900	1100
Discharge box	500	800	1200
TOTAL	10820	13290	15850

[1]These costs may not include all installation and hook-up charges.

Again assuming the same average fuel, lubricant, repair, and operator costs from Table 6, the average cost per acre-foot of water pumped from a 5" electric tubewell installed in early 1976 would be 33.9 Rs./A.F. without operator opportunity costs and 43.7 Rs./A.F. including operator opportunity costs.

From Table 8, the average production costs per acre-foot of water pumped without operator labor costs are 36.62 Rs. for perennial areas, 26.25 Rs. for non-perennial areas, and 25.54 Rs. for uncommanded areas. The lower costs of water in the latter two areas reflect the additional pumpage required to provide water to the crops during times of inadequate or no canal supplies.

Cropping Intensity

Cropping intensity is partially related to water supply. The water supply on the different areas varies depending upon the type of command area. The highest water supply is found on the perennial canals combined with SCARP wells, and the lowest supply is found on the uncommanded areas served by SCARP wells. The benchmark study for the Mona area (1965-66) found cropping intensities of 121%, 104%, and 101% for

perennial, non-perennial and uncommanded areas, respectively[1]. This is before the introduction of the SCARP wells. A re-study during 1970-71 of the Mona area indicates an average cropping intensity of 134% for perennial areas, 120% for non-perennial areas, and 112% for uncommanded areas[2]. This increase is attributed mainly to enhanced water supplies provided by the SCARP tubewells.

The above data can be compared to the cropping intensities found on the sample farms having, in addition to public water supplies (canal and/or SCARP tubewell), private tubewell water. These comparisons are presented in Table 11.

Table 11

Cropping Intensities (%)

Year	Perennial	Non-perennial	Uncommanded
1965-66	121%	104%	101%
1970-71	134%	120%	112%
1975 with private tubewell	167%	127%	124%

The average increase in the cropping intensity between 1970-71 and 1975 on perennial canals having private tubewells is 33%, the change in cropping intensity on non-perennial canals is 7% and on uncommanded areas the change in cropping intensity is 12%. These changes can be at least partially explained by the increased flexibility provided by the private tubewell water. However, while these cropping intensities are higher than the average, water is apparently adequate for up to 200% intensity on the perennial areas with private tubewell water. Failure of cropping intensity to reach 200% indicates additional constraints to increased cropping intensity.

The average farm size (total acres) utilizing a single private tubewell on a perennial canal is 77.5 acres. The average farm size utilizing a single private tubewell on a

[1]Chaudhry, Ali Muhammad, Haider Ali Chaudhari, Muhammad Rafique Raza, and A. R. Rizwani. Socio-Economics Bench-Mark Survey of Mona Project, West Pakistan Agricultural University, (Lyallpur, 1966-67).

[2]Muhammad Hussain. Changes in Net Income of Area Being Irrigated with Different Amounts of Canal and Tubewell Water during 1970-71. Publication No. 37, Mona Reclamation Project, (Mona, March 1975).

non-perennial canal is 53 acres and the average farm size utilizing a private tubewell in the uncommanded area is 66 acres. The relationship between the size of a farm in the perennial area and the size of a farm in the non-perennial area reflects the difference in water supply between the two areas. The scarcity of water supplies per acre in these uncommanded areas results in lower cropping intensity as was reflected in Table 11.

Operating Schedule

The operating schedules of the private tubewells reflect the crop-water demands on their crop mix. All the areas in general follow similar cropping rotations and their patterns of pumping are also the same. However, the areas with less public water pump their private wells a greater percentage of the time. Table 12 details the pumpage hours by area and month.

Table 12

Tubewell Running Hours per Month

AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL
1	262	249	166	175	117	118	249	246	201	171	172	210	2335
2	115	113	123	125	34	26	95	173	185	175	183	186	1530
3	219	202	243	261	35	56	205	261	171	156	158	187	2154
4	129	119	121	116	39	38	86	134	121	90	86	114	1261
5	120	128	112	92	23	21	106	171	244	280	256	248	1803
6	205	210	228	232	95	100	192	219	177	166	148	183	2150
7	196	206	172	192	--	--	--	160	166	180	248	288	1808
10	346	200	133	208	8	8	61	82	220	220	198	207	1892
11	350	350	350	350	27	64	108	225	206	162	127	212	2532
12	240	230	264	301	60	23	86	150	181	151	164	184	2040
Average:	218	201	191	205	44	45	119	182	187	175	174	202	1950

From the above table it is apparent that the months of May and June are the months when the private tubewells are pumped least and December, January, February, and March are the months of maximum demand on the private tubewells. Even during these months the wells are not pumped more than 30% of the time available.

Private Tubewells, SCARP Wells, and Canal Water

The average cost per acre-foot of water pumped from 6" private tubewells is 36.7 Rs./A.F. at the outlet pipe. Since most of the private tubewell water in the Mona area is distributed to fields near the tubewell, there is not the massive problem of overtopping and system losses found on most of the main watercourses. It is estimated that approximately only 20% of the private tubewell water is lost between the discharge pipe and the farmer's nakkas. Therefore, 6" private tubewell water costs about 45.9 Rs./A.F. delivered to the farmer's nakkas. This can be compared to the costs of SCARP tubewell water pumped in 1974-75 at the Mona project. Table 13 provides the cost data for SCARP water.

Table 13

Cost of SCARP Tubewell Water
Mona Project 1974-75 (constructed 1965)

Components	Cost (Rs)	Average Life (year)	10% Amortized Costs (Rs)
Tubewell/Equipment	50241.70	18	6125.97
Building & Distribution Structures	12438.10	25	1370.31
Electrification*	26126.39	30	2771.49
	88806.21		10267.77
Average annual electricity costs			9906.00
Workcharges for operators			1295.59
Maintenance & repairs			3362.09
Transport & miscellaneous expenses			1208.13
TOTAL:			26039.58
Annual acre-feet pumped annually			1100.00
Costs per acre-foot of water pumped			23.67 Rs,/A.F.

*Electrification is included due to the fact that it is subsidized and is not self-liquidating.

The SCARP water is actually cheaper at the outlet pipe than the private tubewell water by 13.03 Rs./A.F. However, since the SCARP well is located at the head of the watercourse and must travel down the main channel along with the canal water, there is more distribution loss associated with the SCARP water. Only about 50% of the SCARP water reaches the farmer's nakka. Due to this high percentage of loss, this

water costs about 47.3 Rs./A.F. delivered to the farmer's nakka. So, while the SCARP water is cheaper than the private tubewell water by about 13 Rs./A.F., by the time the water reaches the farmers' fields the SCARP costs about 1.4 Rs./A.F. more.

However, if we compared private tubewells to SCARP tubewells at 1975 prices, we find that these relationships no longer hold. Current SCARP wells, including electric grid, are running about 350,000 Rs. for 1.5 cusec well. Current 6" private tubewells are about 16,000 Rs. for electric tubewell and about 24,000 for diesel tubewell. Assuming the operation and maintenance costs are the same as last year, the SCARP water costs about 50.5 Rs./A.F. of water pumped and the private 6" tubewell about 42.7 Rs./A.F. pumped for electric and 46.2 Rs./A.F. pumped for diesel. If we again apply the same percentage of water lost in the system, SCARP water costs about 101 Rs./A.F. delivered to the farmer's nakka and 6" private electric diesel tubewell water about 57.75 Rs./A.F. delivered to the farmer's nakka. Canal water compared to the water from private tubewells or SCARP wells is almost always better quality. It is also provided at a subsidized rate to the farmers. However, due to the poor maintenance of the distribution system, the canal water received at the farmer's nakka is not as inexpensive as is often stated. For example, recent studies on a number of watercourses have shown losses to average about 6% of mogha flow for 1000 feet of watercourse. With a canal allocation of 1 cusec for 350 acres and a theoretical flow during rabi season of 24 weeks, the total water provided to the watercourse during rabi is 11.5 acre-inches per acre, or .96 acre-feet per acre. Using the 6% loss per 1000 feet, a farmer near the head of the watercourse with a wheat field 5,000 feet from the mogha receives 0.67 acre-feet per acre. With a water tax of 10.4 Rs./acre, an acre-foot of water delivered to the farmer's nakka costs 69.33 Rs./A.F. Hence, while the water near the mogha is extremely inexpensive, by the time it reaches the tail it is just as expensive as private tubewell water. This phenomena helps to explain why private tubewells are usually located near the middle or the tail of the watercourse.

Appendix 19

EFFECT OF WITHIN FIELD ELEVATION DIFFERENCES ON COTTON STANDS AND YIELDS

Mohammad Mohsin Wahla and John Reuss[1]

INTRODUCTION

Leveling of irrigated fields is a well accepted practice in many areas of the world. This practice is presently being promoted in Pakistan as a method of improving yields and conserving irrigation water. Farmers and agricultural advisors alike generally accept the practice as beneficial, but reliable data quantifying the effect of elevation differences within fields on yields and water use are rare. In order to better understand the effect of poorly leveled fields on crop productivity, stands and yields of cotton in 15 fields in the Mona project area, Sargodha District, were investigated.

METHOD

Fields were selected by Agricultural Extension staff during October 1975. Basis of selection was simply that the farmer was aware that a significant elevation difference existed within the field. For this study a field is considered to be a single bunded area. Field size varied from one-half acre to slightly over one acre.

In each field two plots were first located so as to include the highest point within the field in one plot and the lowest land in the other. A third plot was then located at a middle elevation between the high and low plots. These 20 x 20 foot plots were carefully marked. Extreme field edges or borrow areas were avoided and selection was made without regard to crop growth.

Elevations were determined at four points within each plot. In most cases these were determined by depth of water at the final irrigation, but where no irrigation was applied after plot selection elevations were determined by means of a dumpy level. Elevations reported are the average of the four measurements.

Soil samples were taken for salinity evaluations from the 0 to 6 inch layer of the high and low elevation plots. Soil textures varied from sandy loam to clay loam.

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[1]Senior Research Officer (Extension) WAPDA Mona Reclamation Project, and Agronomist CSU Water Management Project, respectively.

The number of stalks within each plot area was counted. Cotton harvested from each plot at each picking date was weighed and recorded. The number of pickings varied from five to seven.

RESULTS

Soils proved to be generally non-saline with the exception of the high elevation plot at site number five where the electrical conductivity of the saturation extract (EC_e) was 8.0. All other EC_e values were below 2.50. Apparently salinity was not a major factor limiting yields in these particular fields.

The elevation differences between the high and low spots was generally between 3.7 and 5.0 inches (Table I). The minimum elevation difference was 3.0 inches and the maximum 10.6 inches. Mean elevation difference between high and low was 4.65 inches. Mean elevation difference between high and medium plots was 2.09 inches.

Stands were definitely reduced in the low plots as compared to the high or middle. Average number of stalks was 124.2, 129.8, and 79.6 in the high, middle, and low respectively (Table 1). This reduction in stands in the low plots was highly significant (probability <<.005). The mean stands in the middle and high elevation plots were not significantly different. In a few locations there appears to be substantial differences between high and middle plots, but these differences are not consistent as in some cases high elevations have the most dense stands and in some cases the middle elevation. With the design of this trial there is no way to determine whether these cases are due to elevation effects or random sampling errors within fields.

The reduction of yields on the low elevation plots was also very marked. Average yields were 7.45, 8.12, and 3.78 maunds per acre on the high, middle and low plots respectively (Table 2). The reduction in yield in the low plots as compared to the high and middle was very highly significant (probability <<0.005 by paired t tests). The difference between high and middle plots could not be shown to be statistically significant. The means are very similar but there are instances where yields from the high plots are much larger than the middle elevation plots and other cases where the middle plots were much superior. Here again it was not possible to be sure whether these differences are due to treatments or to sampling error. However, it seems likely that in some cases the farmers may have applied sufficient water to adequately irrigate the high spots and [illegible] caused excessive water and yield reduction on the [illegible] elevation areas, while in other cases yields were reduced on the high spots due to insufficient water. Thus average

Table 1. Elevation Differences and Cotton Stand within Fields

Location No.	Elevation Difference High	Elevation Difference Mid	Elevation Difference Low	Stand High	Stand Mid	Stand Low
		Inches*		Stalks per 400 Ft^2		
1	0	2.2	4.4	191	172	182
2	0	1.6	4.7	120	108	82
3	0	2.1	4.3	82	170	21
4	0	2.0	4.0	146	98	54
5	0	2.0	4.0	112	108	68
6	0	1.0	3.0	286	314	211
7	0	2.0	3.7	123	136	82
8	0	2.5	4.0	38	34	28
9	0	2.0	4.0	70	195	65
10	0	3.2	6.0	77	76	41
11	0	3.2	10.6	73	71	48
12	0	1.5	4.0	96	78	29
13	0	2.5	5.0	143	157	81
14	0	1.5	4.0	187	87	80
15	0	2.0	4.0	119	143	122
Mean	0	2.09	4.65	124.2	129.8	79.6
Standard deviation		.60	1.78	61.8	67.9	54.6

*Elevation below mean of high plot.

Table 2. Effect of Elevation Differences Within Fields on Yields of Cotton Lint at 15 Sites

Site	Number of Irrigations	Yield High	Yield Mid	Yield Low
		Mds per acre		
1	4	6.04	8.38	4.42
2	4	5.36	8.93	5.27
3	3	3.74	6.13	2.59
4	1	6.81	4.42	1.62
5	1	3.66	2.21	1.87
6	3	7.83	5.45	3.66
7	3	11.23	13.53	4.17
8	3	7.57	9.06	3.91
9	3	8.17	10.46	5.10
10	3	2.55	13.27	2.59
11	2	6.30	3.32	1.23
12	3	7.40	5.19	2.64
13	4	7.23	7.87	3.45
14	3	10.00	10.93	4.47
15	4	17.82	12.59	9.76
Mean		7.45	8.12	3.78
Standard Deviation		3.68	3.61	2.07

yields on both high and middle elevation areas are likely to have been reduced by uneven water application.

All attempts to relate either yield or stand reduction in the low plots to number of irrigations applied were unsuccessful. Apparently the effect of water standing in these areas from the monsoon rains was sufficient to cause the reductions observed. We were also unable to relate the magnitude of elevation differences within fields to these yields or stand differences.

Calculation of the regression of mean yields at each site on number of irrigations did indicate a probable increase in yields as number of irrigation increased. The regression equation is:

$$y = 1.58 + 1.66\ I$$
$$r = 0.60$$

Where y is yield in maunds, I is number of irrigations and r is the simple correlation coefficient. The probability of no effect is <0.05, indicating that while a general relationship probably exists the number of irrigations only accounts for about 36 percent of the variation in yield.

The question arises as to whether the yield reduction observed was caused entirely by the reduction of stand in the low plots or whether other factors were also involved. In order to examine this relationship we calculated the yield per 1000 stalks (Table 3). The results are highly variable. In some cases yields per plant were lower in the low elevation plots while in other cases they were higher. The means were 0.665, 0.712, and 0.559 maunds per plant for the high, medium and low elevation respectively, and were not demonstrably different by t test at the 10 percent level. However, by calculating the regression of the percentage change in yield per plant on percentage change in stand the following relationship was obtained:

$$y = 37.84 - .23\ x$$
$$r = .73$$

Where y is the percent reduction in yield of the low elevation plots as compared to the middle elevation, and x is the corresponding percentage change in stand, the probability of no effect is <0.01.

This indicates that where stands were not affected or only slightly reduced the yield per plant was reduced in the low areas. Where stands were drastically reduced the yield per plant generally increased byt total yield per acre was of course reduced. Apparently stand reduction is a major factor in causing the reduced yields in the low spots but even if stands are not affected lower yields can be expected.

Table 3. Effect of Elevation Differences within Fields on Yields of Cotton per 1000 Plants

Site	Yield		
	High	Mid	Low
	Mds per 1000 Plants		
1	.290	.447	.223
2	.410	.759	.590
3	.418	.331	1.130
4	.428	.414	.275
5	.300	.187	.252
6	.251	.159	.159
7	.838	.913	.467
8	1.829	2.447	1.282
9	1.072	.496	.720
10	.304	1.063	.580
11	.792	.429	.235
12	.707	.611	.835
13	.464	.460	.391
14	.491	1.154	.513
15	1.375	.808	.735
Mean	.665	.712	.559
Standard Deviation	.455	.565	.335

It is difficult to accurately assess the average yield reduction on a field basis from this data. The yield in the low spots averages only about one-half that from the high and middle areas, but we are unable to determine exactly what percentage of the field is represented by the low spots. If they represent one third of the area the reduction in yield on a whole field basis would be about 16 percent. The low yielding plots probably represent less than one third of the area but undoubtedly some yields are reduced at the middle elevation due to over-irrigation while in other fields yields are reduced on the high spots due to under-irrigation.

Excess water use as a result of uneven fields is substantial. The fact that average yields on the high and middle elevation plots were similar indicate that farmers tend to apply sufficient water for the high area resulting in drastic over-irrigation on the low areas. Water applied to low areas was 4.65 inches more than applied to high area and 2.54 inches more than applied to middle plots. In order to irrigate the high spot at least 2 inches of unneeded water were applied to the remainder of the field, so perhaps 6 acre inches of water in excess of that needed by the crop would be applied in three irrigations. This water is not only lost to the farmer for his current crop production but will contribute to high water table and salinity problems in the area.

SUMMARY

In this study we have demonstrated that cotton yields are reduced to approximately 50 percent in the low areas of unleveled fields. While the study does not allow precise evaluation of the fraction of the area on which this reduction occurs, we estimate overall yield reduction at one-sixth of the total yield. This reduction was caused largely by reduced stands but yields were also reduced where little or no stand reduction occurred. We also estimate that at least 6 acre inches per acre of water that did not contribute to increased crop growth were applied to these fields as a result of their uneven condition.

ACKNOWLEDGEMENTS

The successful completion of this project required the efforts of many people. The authors greatly acknowledge the efforts of Agricultural Assistants Moh'd. Bashir Zafar and Ghulam Mohy-ul-din; Field Assistants Moh'd Tufail, Ali Ahmad, Habib Ullah, Ghulam Rasul and Lal Khan; for their efforts in collecting the field data and Junior Agricultural Engineer Moh'd Afzal for help in obtaining the elevations.

We would particularly like to acknowledge the help of the farmer cooperators who so kindly made their fields available for use in this study, and the contribution of Dr. W.D. Kemper, CSU Chief of Party, who suggested the investigation.

Appendix 20

CONSUMPTIVE USE OF IRRIGATION WATER BY MAJOR CROPS IN PAKISTAN[1]

C.J. deMooy[2], H.M. Bhatti[3], M.A. Cheema[4], M. Khalid[5] and W.T. Franklin[6]

Abstract

Periodic gravimetric determinations of soil moisture profiles to a depth of 60 inches indicated consumptive use of water by wheat, berseem, cotton and wheat crops of 22.6, 29.0, 33.9 and 18.5 inches, respectively. Daily rates of actual and potential evapotranspiration are discussed.

Reliable measurements of the consumptive use of water of field crops produced under good management conditions are much needed for sound planning of irrigation water use. Experimental fields at PARI, Lyallpur, have provided such information for wheat, berseem and cotton.

Methods and Procedures

The experimental fields for consumptive use determinations were laid out in triplicate as part of a larger study on water quality which is presented elsewhere.[7] Canal water was used for irrigation. Soil samples were taken to a depth of 60 inches before and after every irrigation, at planting and harvest time for gravimetric moisture analysis. Additional moisture sampling was carried out at various times for scheduling of irrigation water application.

Irrigation frequency was decided on the basis of available moisture left in the soil in combination with weather conditions, appearance of the crop and field

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[1]Paper presented at CENTO Panel Meeting on the Optimum Use of Water in Agriculture at Nuclear Institute for Agriculture and Biology, Lyallpur, Pakistan, March 3-5, 1975.

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[6]Assoc. Prof., Agronomy Department, Colorado State University, Fort Collins, Colorado.

[7]C.J. deMooy, H.M. Bhatti, M.A. Cheema, M. Khalid, W.R. Schmehl and W.T. Franklin. The effect of water quality on crop yield and chemical characteristics of the soil. Prog. Rept., CSU, WMRP, Islamabad, 1975.

operations. The amount of irrigation water to be applied was calculated each time from the soil moisture deficit in the root zone of the crop compared with field capacity. The consumptive use data presented are based on the amounts of soil moisture used between irrigations augmented with rainfall and actual pan evaporation observations for the days between irrigation and first possible access to the field thereafter. Graphic interpretation methods were used to estimate the amount of evapotranspiration occurring between soil sampling and the following irrigation.

Potential evapotranspiration estimates for the individual seasons were obtained using Jensen-Haise equation, mean maximum and minimum temperatures, and solar radiation data from existing meteorological stations nearby.

Crops were grown in the following sequence:

wheat, rabi 1971/72
sorghum/maize fodder, kharif 1972
berseem, rabi 1972/73
cotton, kharif 1973
wheat, rabi 1973/74

Results and Discussion

The soil moisture data collected during the wheat growing season of 1971/72 are presented in Table 1.

The crop was planted on November 23, 1971, and was harvested on April 28, 1972. The mean yield was 45.6 maunds per acre. Graphical reproduction of the total moisture content of the soil profile in inches of water during the growing season is shown in Figure 1. Pan evaporation data and intrapolation completed the picture. The graph shows low rates of evapotranspiration (E_t) during December and January. After February 1 the rates increased. The soil moisture observation points mostly follow a definite trend except between February 18 and March 9. When an anomaly occurs in the data, graphical interpretation results in a better estimate of moisture use than the difference between first and last soil moisture determination during that period.

The actual evapotranspiration curve drawn from mean daily rates calculated for the five periods and adjusted for rainfall, is shown in Figure 2. The actual E_t started low at 0.06 inches per day in December and rose to 0.29 inches per day at its peak during March. Potential E_t calculated from weather data using the Jensen-Haise equation remained below the actual E_t during February and March but agreed closely with actual E_t at the beginning and the end of the season. Crop coefficients calculated from these data would be larger than unity ($E_{ta}/E_{tp} > 1$). This may occur in certain seasons and not in others. The point needs further study.

Table 1. Amount of moisture present in the soil profile under wheat at several times during rabi 1971/72, PARI, Lyallpur.

Depth of soil (inches)	Rauni	Irrigations 1		2		3		4		
	At planting	Before next irri.	After irri.	Before next irri.	After irri.	Before next irri.	After irri.	Before next irri.	After irri.	At harvest-ing
0-6	1.05	0.69	1.69	1.21	1.58	0.69	1.70	0.54	1.21	0.51
6-12	1.23	0.93	1.72	1.19	1.91	0.70	1.73	0.66	1.25	0.61
12-24	2.39	2.03	2.78	2.36	2.91	1.82	2.91	1.86	2.54	0.98
24-36	2.55	2.28	2.71	2.42	2.81	2.19	2.90	2.26	2.69	1.56
36-48	2.49	2.30	2.56	2.49	2.58	2.41	2.60	2.24	2.56	2.06
48-60	2.29	2.47	2.40	2.44	2.41	2.51	2.53	2.65	2.77	2.19
Total	12.00	10.70	13.86	12.11	14.20	10.32	14.37	10.21	13.02	7.91

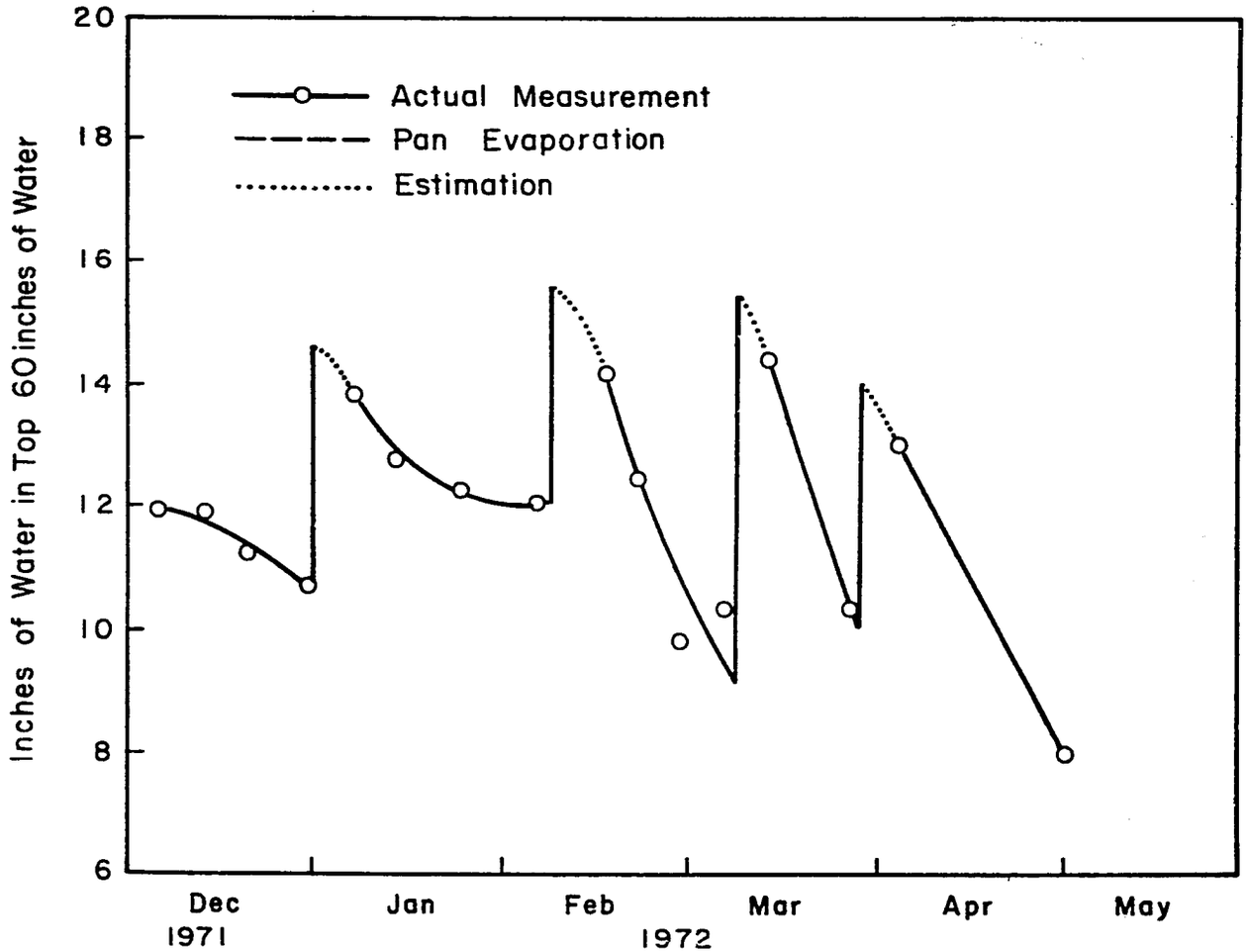

Figure 1. Variation in soil moisture content under wheat 1971-72, PARI, Lyallpur.

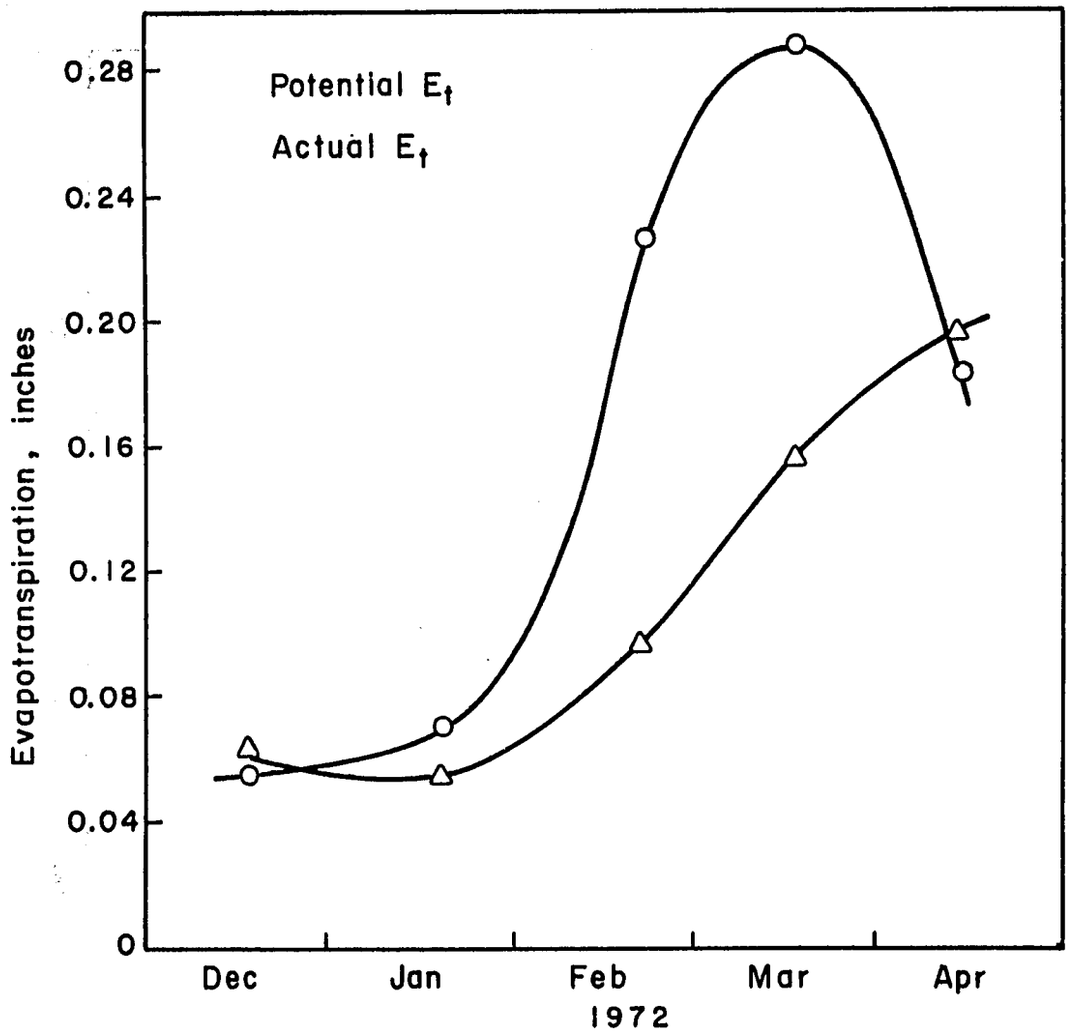

Figure 2. Actual and potential E_t rates for wheat grown during Rabi, 1971-72, PARI, Lyallpur.

The total consumptive use of water by wheat as determined from soil moisture contents and 0.6 inches of rainfall during the growing season from November 23, 1971, to April 28, 1972, amounted to 22.8 inches. Another independent measurement of the consumptive use was provided by the amount of irrigation water applied during the season corrected for the soil moisture differential between planting and harvesting. This total including rainfall also amounted to 22.8 inches. Holding tank facilities in the field and water ducts permitted exact measurement and delivery of irrigation water to the plots. The close agreement between the two values suggests that the results are reliable.

Similar experimentation with berseem grown during rabi 1972/73 resulted in the actual and potential evapotranspiration curves presented in Figure 3. Actual E_t fluctuated mainly between 0.08 and 0.10 inches per day from October through January, then increased to a high of 0.28 during the mid April harvest season. One spurious value of 0.35 inches per day was found during October, however. Actual and potential E_t followed a remarkable parallel course which would suggest a crop coefficient equal to 1.

The total production from five cuttings of berseem was 491 maunds per acre and the consumptive use of water for the period October 7 to April 21 was 29.0 inches. The total rainfall during this period was 1.2 inches and is included in the consumptive use.

Cotton was grown during kharif 1973. The season was characterized by heavy monsoonal rains which caused extensive flooding in the Punjab province. Rainfall during August exceeded the infiltration capacity of the soil and runoff occurred. The estimate for consumptive use of the crop during this period was corrected for runoff from the plots. Daily rates of pan evaporation were used to estimate real water use from the time that the soil was saturated by rainfall on August 5 until September 6 (Figure 4). The graph illustrates rather well the difficulties encountered in consumptive use studies with summer crops. The best possible interpretation of this graph resulted in the actual evapotranspiration curve presented in Figure 5. Actual E_t started at 0.16 inches per day in June and increased slowly to 0.28 inches per day in August after which a gradual decline occurred until the end of the season. The potential E_t also is presented in Figure 5. Its curve follows approximately that for actual E_t. The potential E_t curve showed a downward trend toward the monsoon season and a minimum during August due to cloud cover and humidity. Actual E_t was high during this time but the value represents an estimate made under wet conditions. Growth of the cotton crop was somewhat rank owing to excess moisture. The yield of seed cotton was 18.2 maunds per acre. The total consumptive use of water

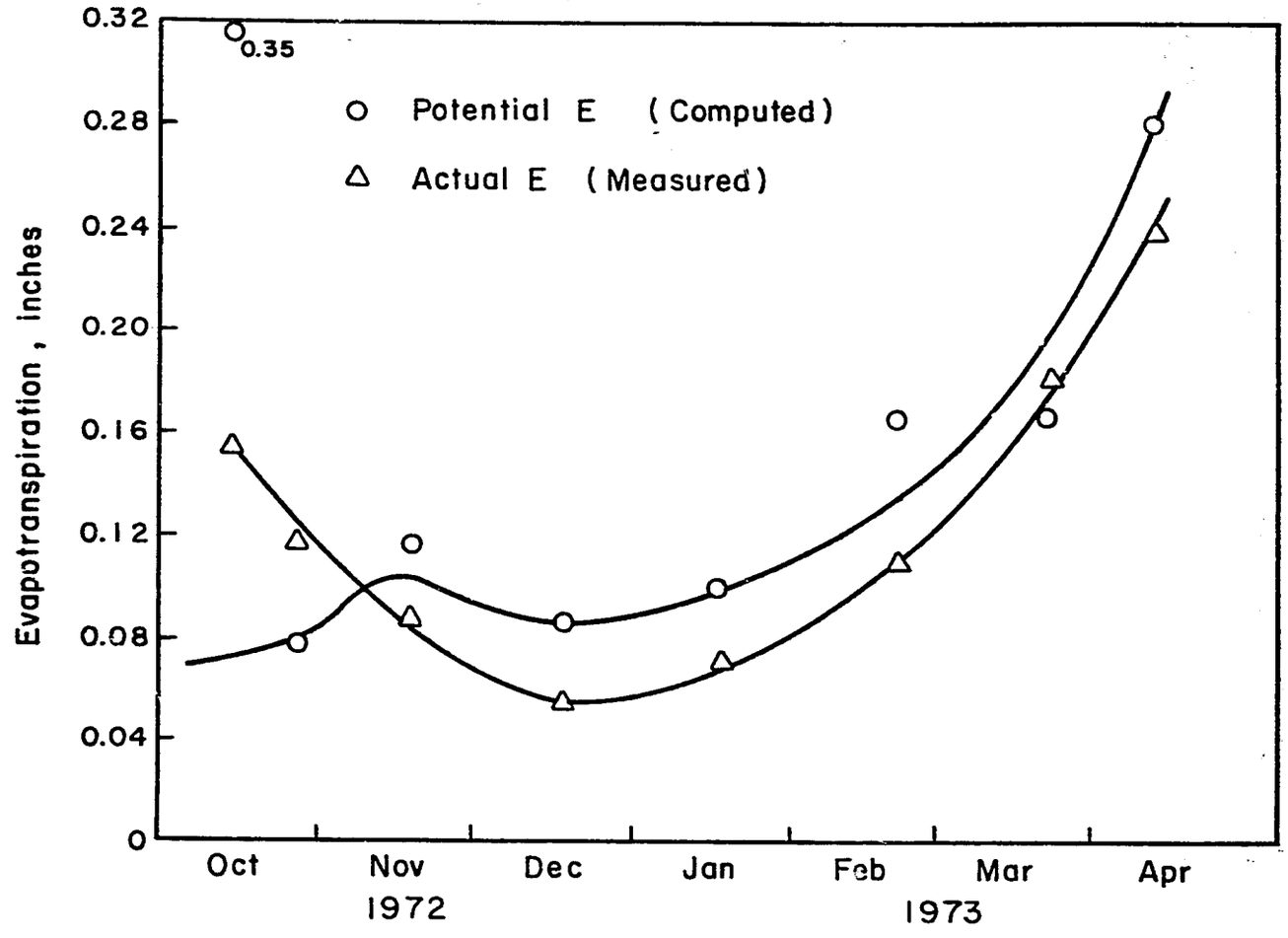

Figure 3. Actual and potential E_t rates for berseem grown during rabi 1972-73, PARI, Lyallpur.

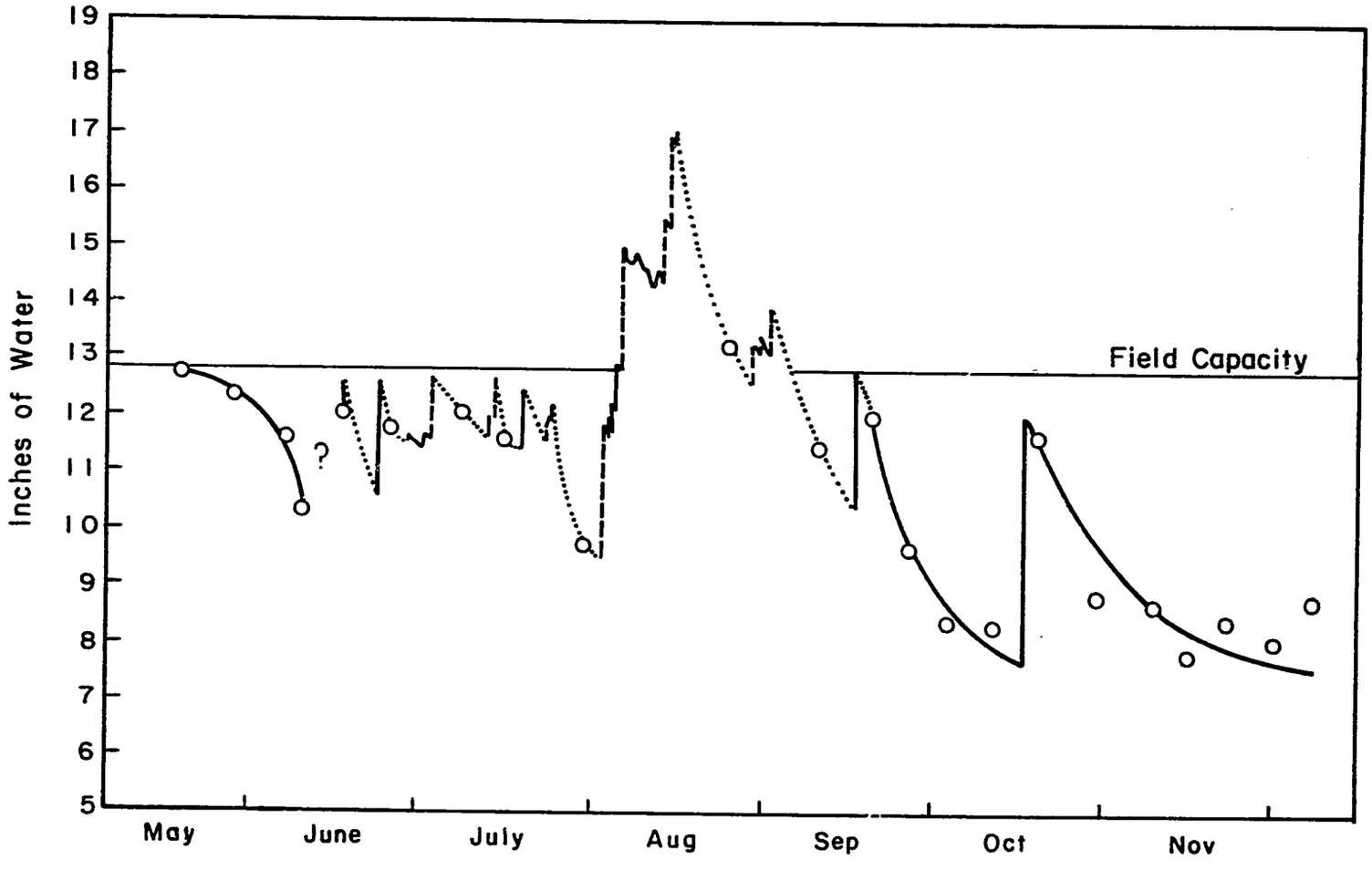

Figure 4. Inches of water present in top 5 feet of soil under cotton at PARI, Lyallpur, 1973.

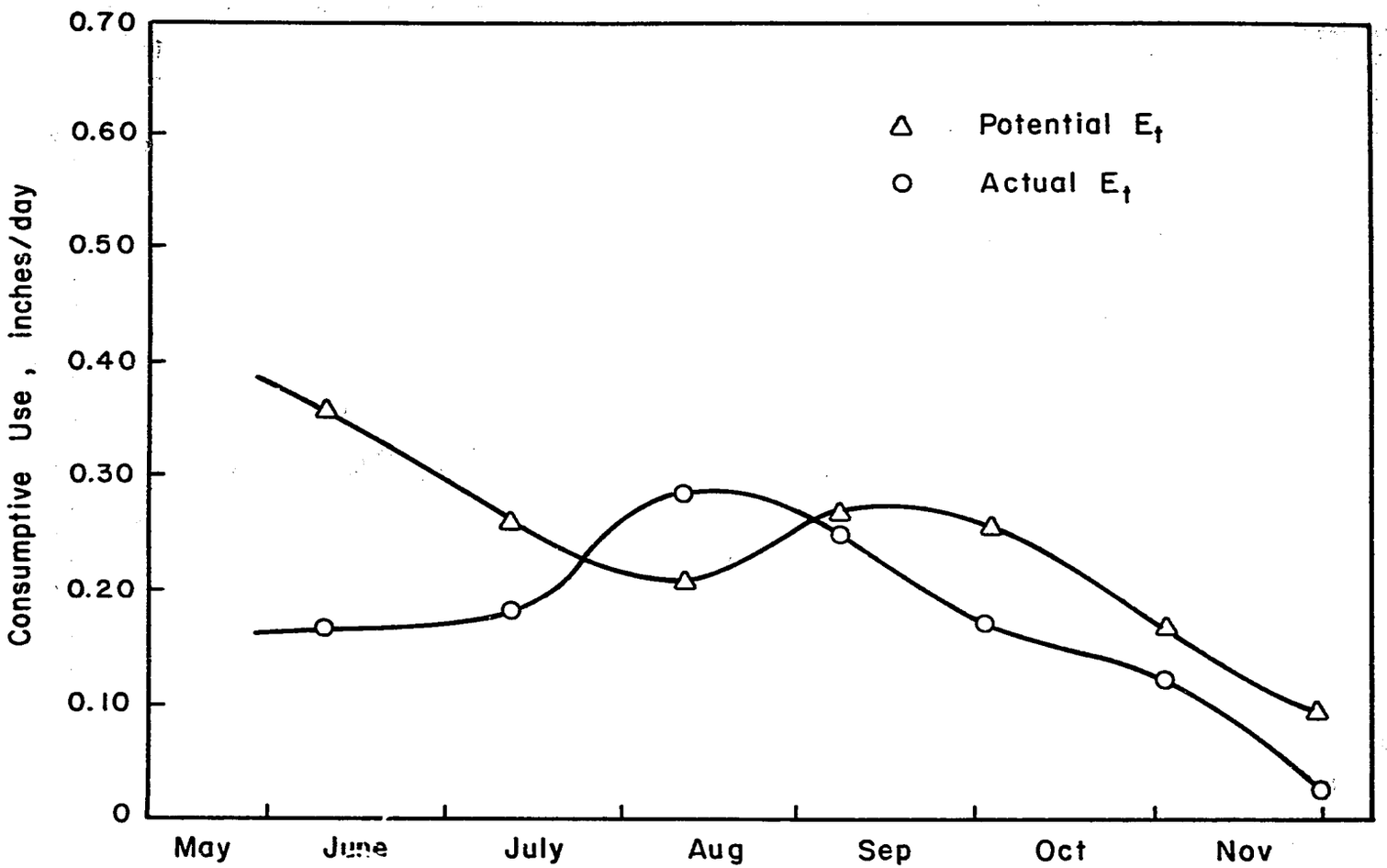

Figure 5. Potential and actual evapotranspiration from cotton at PARI, Lyallpur, 1973.

between May 24 and December 8, 1973, amounted to 33.9 inches. This value included 5.7 inches of rainfall for the growing season but excluded the monsoonal rains which were recorded between August 5 and September 6.

The last crop grown in the sequence was wheat which was sown late after cotton on January 9, 1974. Consequently, the growing season was one month shorter than in 1971/72. The graphs of soil moisture content fluctuations during the season and evapotranspiration rates are presented in Figures 6 and 7. Actual and potential E_t remained close together until the end of March. The actual E_t started from approximately 0.07 inch per day in January and leveled off at 0.25 inch per day in April as the potential E_t climbed to 0.33 inch per day (Figure 7). The total consumptive use was 18.5 inches including 0.4 inches rainfall as compared with 22.8 inches in 1971/72.

The effective depth of rooting during the development of the various crops can be estimated from the distribution and withdrawal of water from the profile during the season. Block diagrams were made from the original soil moisture profile records. The diagrams indicated an effective depth of rooting for berseem of 24 inches until early November. Later soil moisture was withdrawn from at least 3 feet of soil.

Wheat appeared to utilize water to a depth of 3 feet until the third irrigation during February. After the third irrigation water was effectively used from the 4th foot and during April also from the 5th foot of soil (data not presented here).

Cotton used water from 2 feet of soil until the beginning of the monsoon rains in early August. After the monsoonal period noticeable withdrawal and discharge of water occurred to a depth of 5 feet.

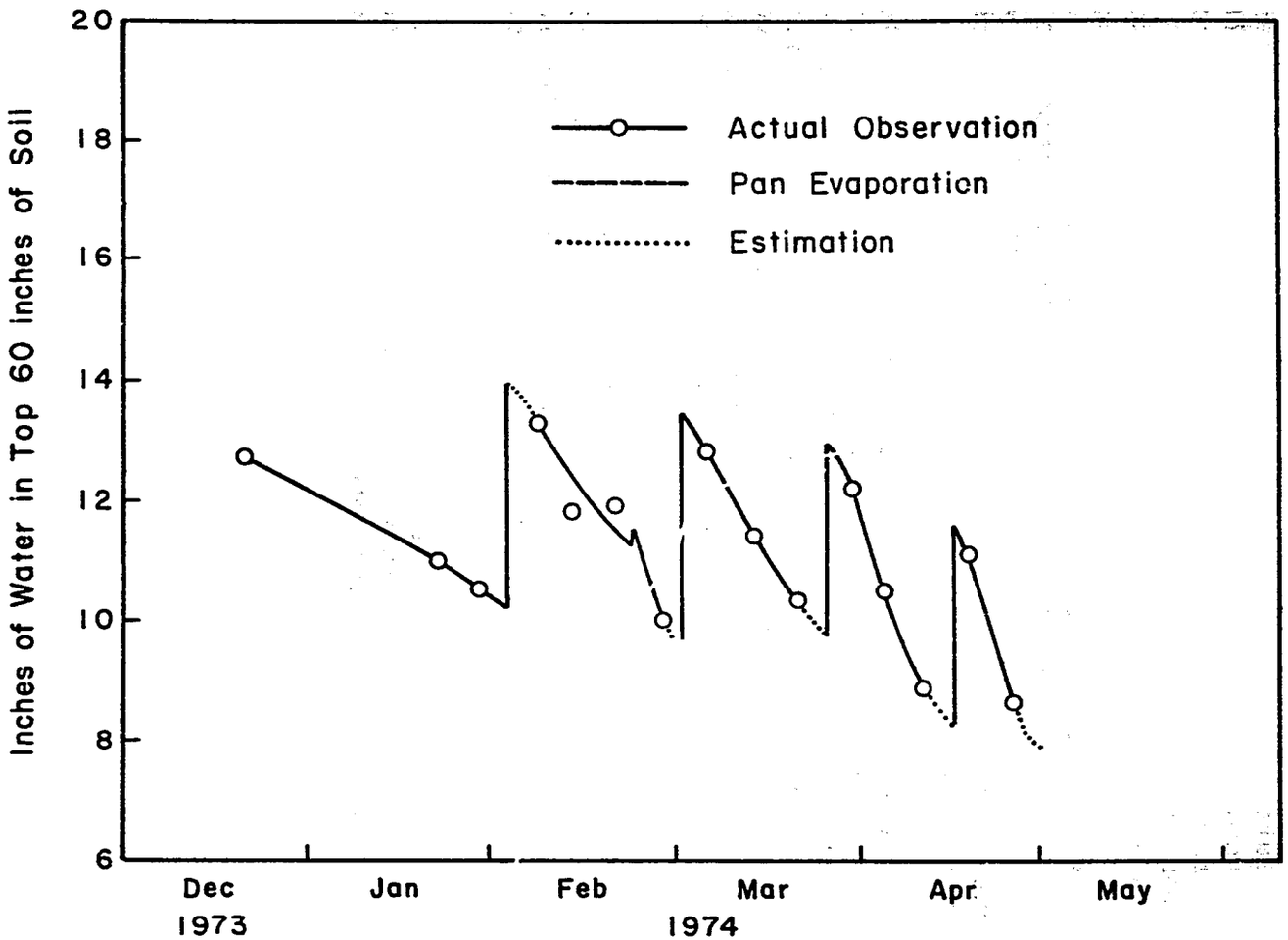

Figure 6. Variation in soil moisture content under irrigated wheat 1973-74, PARI, Lyallpur.

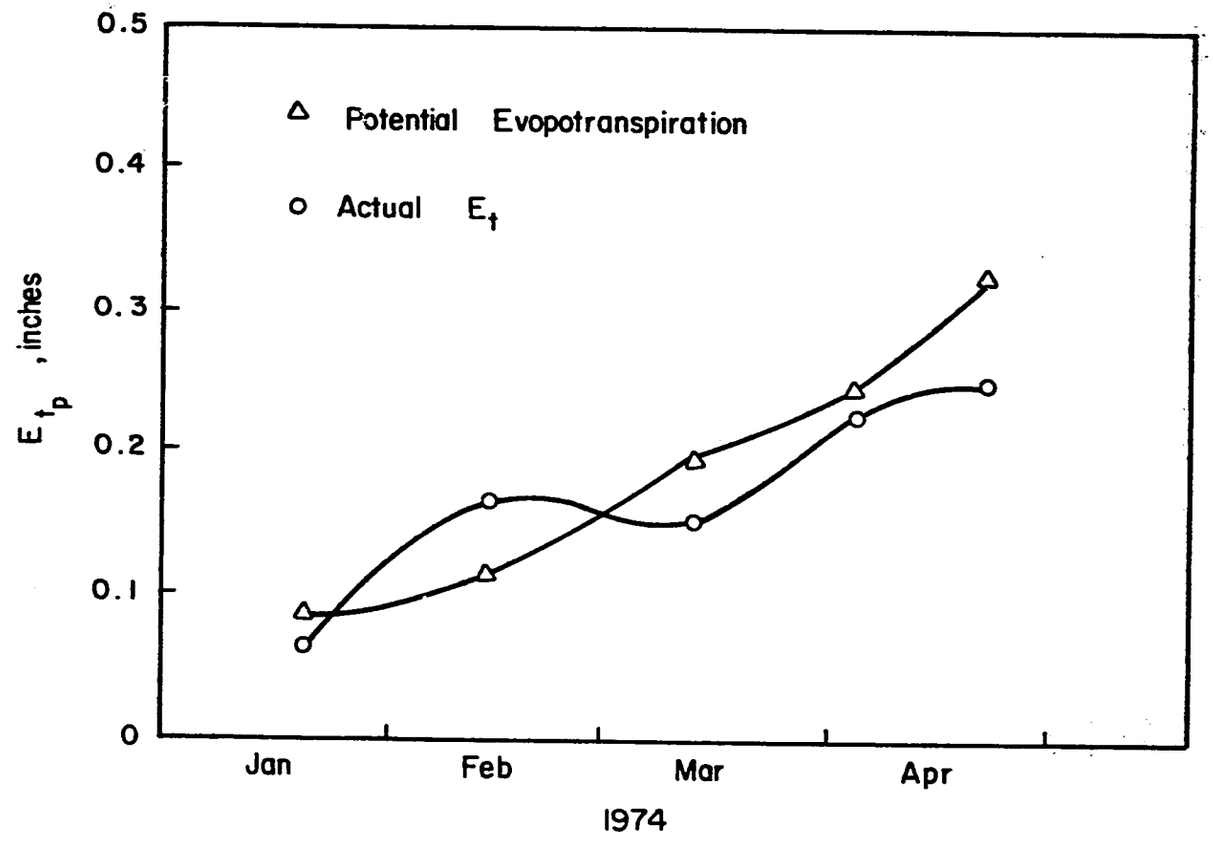

Figure 7. Actual and potential E_t rates for wheat grown during rabi 1973-74, PARI, Lyallpur.

Appendix 21

CONSUMPTIVE USE OF WATER UNDER OPTIMUM MANAGEMENT CONDITIONS FOR MAJOR CROPS IN PAKISTAN

S.A. Bowers and Shahid Ahmad[1]

Although Pakistan possesses excellent soils, ideal climate, and perhaps the world's largest irrigation system its yields for many irrigated crops are among the world's lowest. Of the constraints contributing to such low yields perhaps the most readily identified include shortage of water, improper irrigation practices, inadequate fertility, etc.

In order to overcome these more obvious constraints and contribute towards increasing Pakistan's crop yield this project was organized. Through the efforts of Dr. D.J. deMooy the project was initiated in 1975 for the purpose of determining the consumptive use of water by the major Pakistani crops under optimum management conditions. A secondary objective was to train Pakistani scientists in consumptive use measurements and optimum management techniques.

The project consists of seven experimental sites located throughout Pakistan. The location of each site is shown in Figure 1. the name of the principle investigators and the institutions with which the sites are associated are as follows:

Principal Investigator	Institution	Site Location
Ch. Hayat Moh'd Bhatti	Punjab Agricultural Research Institute	Lyallpur
Abdul Hamid	Agricultural Research Institute	Tarnab
Ghulam Nabi Kalwar	Sind Agricultural College	Tandojam
Ghulam Haider	Mona Reclamation Experimental Project	Bhalwal
Ch. Mahmood ul Hassan	Land Reclamation Dept.	Lahore

The Agricultural Research Institute at Tarnab has responsibility for two sites; one at Peshawar and the other at Bannu. The Land Reclamation Department in Lahore also is responsible for two sites: Mian Channu and Bhakkar.

This Consumptive Use of Water Project is supported with Pl-480 Rupees for a five year term beginning in 1975. Each site is funded individually. The project administration is

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Figure 1. Location of experimental sites in consumptive use of water projects.

through Pakistan's Agricultural Research Council. Colorado State University provides an advisor for the technical aspects of the project.

PROCEDURE

Crops selected for each site depend on the local conditions and crop adaptability. However, the experimental procedures at all sites were very similar and in general follow the pattern used by Haider, et. al. (3) in their study of the consumptive use of water by wheat.

All experiments contained three moisture treatments; i.e. irrigation was initiated when the moisture content of a specified indicator soil depth reached a preselected stress level. The stress levels were based on the soil moisture retention curve. While the particular stress levels varied with the soil texture a common selection was 1 bar, 4 bar, and 7 bar tension.

The soil irrigation indicator depth varied with the crop. For example, for wheat most sites sampled the 0-6 inch depth to determine the time of the first irrigation and sampled the 0-12 inch layer for all subsequent irrigations. Irrigation water was measured onto each individual plot by means of a Cutthroat flume (5). The amount of water applied was sufficient to restore a five foot profile to field capacity.

In addition to the moisture treatments most sites used two fertility treatments, high (optimum) and low. The common treatments selected were 150-75-30 and 50-0-30.

The experimental designs were a randomized complete blocks analyzed as a 2 x 3 factorial. Both yield and water use data were subjected to an analysis of variance.

The actual seasonal consumptive use was determined by a strict accounting of all soil moisture additions and depletions. All treatments are sampled to a five foot depth at sowing, at harvest, before and after each irrigation, before and after each rainfall, and at periodic intervals throughout the season. Soil moisture contents were determined gravemetrically.

Besides determining yields and consumptive water use, attempts were made by many sites to determine the crop coefficients as defined below:

$$D_c = \frac{ETa}{ETp} \qquad (1)$$

Where K_c = the crop coefficient

ETa = actual evapotranspiration

ETp = potential evapotranspiration

Potential evapotranspiration is estimated using the Jensen-Haise equation (4). This empirical equation is of the following form:

$$E_{tp} = C_T (T - Tx) R_s$$

Where C_T = air temperature coefficient which is derived for a particular area from long term mean maximum and mean minimum temperatures for the month of highest mean air temperatures

T = the mean daily air temperature

T_x = the intercept on the temperature axis of the graph relating air temperature to solar radiation.

R_s = the daily solar radiation expressed as an equivalent depth of evaporated water in inches/day.

Clyma and Chaudhary (2) discussed the calibration and application of equation two for Pakistan conditions. In general, those sites calculating E_{tp} use their discussion as a guide. Unfortunately, most sites do not have the equipment to record air temperatures and solar radiation, the two primary inputs into the Jensen-Haise equation. Where applicable data is secured from recording sites belonging to the Water and Power Development Authority (WAPDA).

To facilitate training and technical guidance, visits are made bimonthly to each site by either the CSU advisor or the project assistant coordinator. In addition, training sessions were organized in Islamabad by Dr. C.J. de Mooy and at Lahore by S.A. Bowers and Mr. Shahid Ahmed.

RESULTS AND DISCUSSION

Results from these experiments are reported in an Annual Technical Report published by the Agricultural Research Council, Islamabad, Pakistan (1). The 1975 annual report was released too late (April 1976) for inclusion in the CSU, 1975 Water Management Research Project Annual Report. Since PL-480 funds were not released to the various sites until March 1975 only results for maize were included in ARC 1975 report. A summary from the 1975 Maize results is as follows:

1. Punjab Agricultural Research Institute, Lyallpur

The experiment with maize used the 1, 3, and 5 bar tensions, for 0-12 inches of soil depth, as three levels of soil moisture stress and two fertility levels (50-0-50 and 150-75-50) in a randomized block design with six replications (each treatment plot size, 100 x 26 feet).

The irrigations were applied to the maize crop 13.1 percent, 10.6 percent and 8.4 percent moisture on dry weight basis, for 1, 2 and 4 bar tensions respectively. The soil moisture samplings were taken from two replications and the irrigations were determined from pre-irrigation soil moisture contents which was calculated from soil moisture samplings down to 60 inches. The consumptive use was calculated from the soil moisture samplings. The main conclusions are given below:

a. The consumptive use of water for maize crop under different moisture stress i.e. 1, 2 and 4 bar tension was 20.47, 19.70 and 21.75 inches, respectively.

b. The potential evapotranspiration calculated from Jensen-Haise was 16.92 inches which is less than the actual evapotranspiration.

c. Moisture stresses did not show any significant effect on yield because the moisture levels were more or less the same due to abnormal rains in early season.

d. The overall yield of maize was low due to abnormal weather. However, there was significant difference between the two fertility levels.

2. Agricultural Research Institute, Tarnab

Two sites were selected for the study; one in farmer's field at PanjPir, Swabi; and the other at Serai Naurang, Bannu. The experiment was done on maize crop using 1, 3 and 7 bar tensions for 0-6 inches of soil depth as three levels of soil moisture stress at two fertility levels i.e. 80-0-40 and 120-80-40 in randomized block design with three replications (each treatment plot size, 58 x 28 feet).

The moisture levels for Swabi, determined from soil moisture characteristic curve, were 15.25, 10.6 and 7.8 percent moisture on dry weight basis for 1, 3 and 7 bar tensions. But due to the abnormal rains no irrigation was applied and the soil moisture data were not sufficient to compute consumptive use. The irrigations applied at Bannu were at 1, 3 and 7 bar tensions equivalent to 13.4, 12.7 and 10.4 percent moisture on dry weight basis. The irrigations were applied without measurement. Likewise Swabi, data for Bannu do not warrant any conclusions.

3. Sind Agriculture College, Tandojam

Cotton, maize and rice crops were tried for consumptive use estimations. For maize and cotton crops, there were three moisture levels i.e. 1, 4 and 7 bar tensions at 0-6 inches soil depth; and four fertility levels i.e. 0-0, 50-25, 100-50 and 150-75 NP with uniform 30 pounds per acre K as

basal dressing. There were four replications in randomized block design.

The consumptive use for cotton was calculated by adding the amount of irrigation and the amount of rainfall. The irrigation amounts used for cotton were 35.8, 33.4 and 30.5 inches for 1, 4 and 7 bar tensions. The highest yield was obtained when crop was irrigated at 4 bar tensions at 100-50-30 fertility level. The consumptive use for maize was estimated from the amounts of irrigations applied. The water used was 27.5, 23.9 and 20.7 inches for 1, 4 and 7 bar tension. Significant increase was obtained with high fertility level i.e. 150-75-30 with moisture level at 1 bar tension. The yield obtained was 50.28 maunds per acre at 1 bar tension and 50.91 maunds per acre at 4 bar tension at high fertility level.

The paddy rice (IRRI-6 and IRRI-198 varieties) was transplanted at different moisture stresses. The moisture levels were 15 cb, 34 cb, 50 cb and continuous flooding. The irrigations were applied after 4, 7 and 10 day intervals equivalent to 15, 34 and 50 centi bars. Due to closure of the canal water supply the moisture levels could not be maintained properly, therefore, it was not possible to compute consumptive use for rice crop.

4. Mona Reclamation Experimental Project, WAPDA, Bhalwal

The consumptive use study was done on maize crop on medium to fine textured non-saline, non-alkali soil with ground water table at 15 feet. Three moisture levels i.e. 1, 3 and 5 bar tensions for 0-6 inches of top soil depth equivalent to 13.3, 10.1 and 8.0 percent moisture on dry weight basis; and two fertility levels i.e. 50-0-30, and 150-75-30, were used in randomized block design with four replications (each treatment plot, 51 x 28 feet). Due to frequent rains 3 and 5 bar tensions could not develop. The data collected for 1, 3 and 5 bar tensions were, therefore, averaged.

The main conclusions are:

a. The consumptive use of water for maize was calculated as 12.16 inches.

b. Crop coefficient for maize was 0.19 in the beginning and went up to 0.82 at maturity. The crop coefficient for maize season was 0.62.

c. The yield of crop was significantly higher at high fertility level.

5. Land Reclamation Directorate, Lahore

The sites were selected for the experiments; one at Bhakkar and the other at Mian Channu. No work could be done on maize as the crop had been harvested when this phase of the project started.

6. General

The foregoing results are very preliminary in nature and do not warrant any conclusions due to abnormal weather and lack of experience. However, a good start has been made. It is planned to standardize the techniques and impart training to the researchers. Particularly following points need special attention in next reports:

a. Soil moisture characteristic curves.

b. Mechanical and chemical analyses of experimental sites.

c. Measurement of irrigation water and determination of timing and amount of irrigation.

d. Detailed field observations on agronomic practices.

e. Consumptive use calculations for each site from soil moisture contents variation graph (e.g. Mona site in this Report: Figures 6, 7 and 8.

The above comments recognize the inadequacy of much of the first years work. Primarily, lack of experience and organizational problems were the main constraints in the project.

Inspections and visits to each site during 1976 show continuous improvement in the quality of the work at most sites. During this year most sites have experiments involving wheat, cotton, and maize; particular sites also have experiments with sugar cane and rice.

At this writing, 1976 experimental results have not been received from the various sites. Cotton is presently being harvested with the maize harvest soon to follow. Despite the obvious improvement in management there still exist problems throughout the project. Most pressing is the lack of solar radiation data. Most sites are located in areas where radiation data is not available. Accordingly, recording pyranometers and maximum-minimum thermometers have been ordered for each; delivery is expected prior to the end of 1976. An additional problem concerns an excessive turn over of project personnel which has caused some difficulty in project continuity.

Perhaps the most serious project problem of 1976 was climate. The monsoon season was the wettest in recorded history. Excessive rainfall and the resulting floods not only prevented visitation to most sites for a period of two months, but also resulted in serious stand problems at these locations. In addition, the excessive moisture will complicate calculations of consumptive use and the corresponding crop coefficients.

The future role of CSU will be to continue trying to upgrade the technical aspects of the work as well as training of personnel. Although the generated data will continue to be published by the Agricultural Research Council in the consumptive use of water Annual Technical Report; the results will be utilized in irrigation scheduling, and other water management research in Pakistan.

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Appendix 22

ESTIMATION OF CONSUMPTIVE USE OF WATER FOR WHEAT UNDER OPTIMUM MANAGEMENT CONDITIONS[1]

G. Haider, M.A.R Farooqi and C.J. deMooy[2]

CHAPTER I

INTRODUCTION

Pakistan is predominately an agricultural country. In spite of favorable conditions of soils, irrigation water and climate, agriculture in the country suffers from under production both in terms of yield per acre and production per farm worker. The country is heavily dependent on agriculture for food and fibre requirements of the ever increasing population. In order to cope with these requirements, it is essential to increase food and fibre production not only to attain self sufficiency but also to the extent of exportable surplus for earning foreign exchange.

Agriculture in the country mainly depends on irrigation. Unfortunately, present irrigation supplies in the country are inadequate. In major part of the canal irrigated areas, one cusec of water is provided for 350 acres whereas the same quantity is hardly sufficient to meet the water requirements of crops including leaching requirements, for 100 to 150 acres. Inadequate irrigation supply is one of the major constraints in agricultural production. The irrigation supplies can be improved in two ways:

1. Exploiting new resources, i.e., construction of more dams and tubewells, and

2. Conserving the existing irrigation supplies by making the most efficient use of the available water through

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[1]Joint contribution of CSU and the Directorate of Mona Reclamation Experimental Project Central Monitoring Organization Master planning Division, Mona Colony, Bhalwal, May 1975.

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reduction of undue wastages such as seepage, over spilling, leakage, over-irrigation of crops, etc.

The former method of improving irrigation supplies is very expensive and time consuming. It will take decades before such programs are executed. The latter method, however, affords an opportunity of adopting quick measures to increase the irrigation supplies by reducing the loss of existing irrigation supplies. The International Commission on Irrigation and Drainage has also stressed the need of conservation of the existing supplies on a world wide scale when they pointed out:

"Conservation of water supplies is becoming increasingly important as the demand continues to increase and new sources of supply become harder to find. The time is rapidly approaching when the only additional natural water supplies available will be those salvaged from loss through transpiration, evaporation, consumptive waste, inefficient storage and transportation practices. Principles of conservation require that full use be made of our natural water supplies, and the greatest results probably can be accomplished on most irrigation projects by a reduction in amount of water lost through seepage during transportation to the farmers fields."

Irrigation experts are of the opinion that by checking the conveyance and field application losses, water savings of the order of that provided by Tarbella Dam can be effected. Another major source of saving irrigation water is to irrigate the crops when required and to apply water just sufficient to meet the actual water requirement of the crops. By over-irrigation water is not only wasted but crop yields are also adversely affected. Similarly, by under-irrigation the yield of crops is drastically reduced. In order to conserve the irrigation supplies and to increase crop yields, it is essential to know the actual consumptive use water requirements of crops grown in the country. The knowledge of consumptive use of major crops will not only enable the cultivators to make the most efficient and economical use of the available irrigation supplies but will also help the planners to fix more realistic and reliable targets of crop acreages and production.

Wheat is one of the most important food crops in Pakistan. It occupies by far the largest area under crops. The Government of Pakistan is doing everything within her means to increase wheat production to attain self-sufficiency in food. Little field work has been done to determine the consumptive use of wheat in Pakistan. Although, estimation of water requirements of wheat have been made by certain workers, their estimations are either based on bypothetical calculations made by using climatological data or on lysimeter studies. Reliable information about actual water requirements of crops based on carefully conducted field studies is lacking. Consequently, this study

was carried out to estimate the consumptive use water requirement of wheat under optimum conditions of management, mineral nutrition, and water supply on demand indicated by soil moisture tension.

Mona Reclamation Experimental Project was conceived as a pilot project, to develop new criteria for the optimum use of land and water resources and to formulate new concepts, for obtaining the rapid development of agriculture in the Indus Plains. In order to achieve these objectives, an area comprising of 1,100,000 acres was selected in the North Central Portion of Chaj Doab (Figure 1). The project came into operation during November 1965. One of the major objectives of this project was to develop new criteria for the optimum use of water resources. The present study was undertaken in Mona Reclamation Experimental Project, in collaboration with Colorado State University, USAID. The data presented in this report was collected during rabi 1973-74.

CHAPTER II

REVIEW OF LITERATURE

Considerable work has been done on consumptive use of crops by various workers in different countries. In Pakistan as well some work has been done on estimation of consumptive use of water of crops by certain workers but their findings are either based on estimation made in lysimeters, or from calculations using empirical coefficients developed from climatological data. Little work has been done in the country on estimation of consumptive use of crops in the field, based on soil moisture depletion method. The findings of various workers are however, reported as follows:

By computations

Blaney and Criddle (1957) calculated the evapotranspiration amounts for wheat to be 16 inches. Similarly, Asghar and Ahmad (1962) and Revelle et al (1964) reported that evapotranspiration amounts in case of wheat was 14 and 13 inches, respectively. M/s Hunting Technical Services Ltd., (1966) calculated consumptive use of water for wheat in Hyderabad area to be 16.3 inches. These findings were based on hypothetical calculations using climatological data.

Dastane, (1966) worked out correlations between values of actual consumptive use and those computed by using various empirical equations in optimum moisture regions. In case of wheat the correlation values for Penman, Thornthwaite and U.S. Open Pan Evaporation Methods were 0.982, 0.939 and 0.998 respectively. He reported that total evapotranspiration in case of wheat was 13.0 inches.

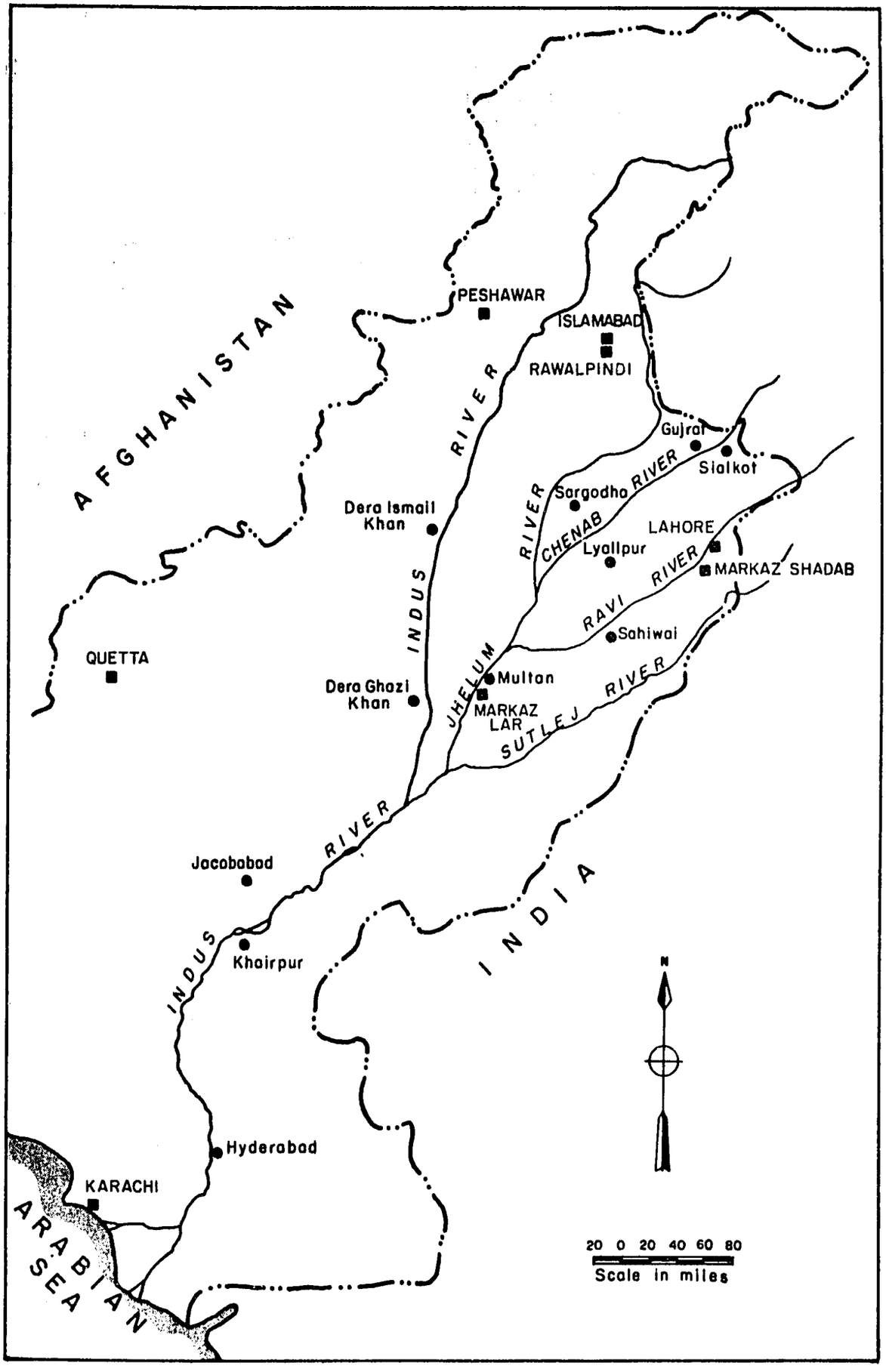

Figure 1. Location map, Mona Reclamation Experimental Project.

M/s Harza Engineering Company, Int. (1968) determined the consumptive use of water of various crops using the evaporation index method. The findings were based on studies carried out in USA. The computation from USA to determine crop use coefficients were modified to make them applicable to conditions in Pakistan. Based on hypothetical calculations they reported that consumptive use of water for wheat was 15.87 inches. The Ministry of Agriculture (1971) computed the consumptive use of different crops using climatological data. It was found that the consumptive use coefficient (K) for wheat was 0.61 for Ludhiana and Poona districts of India.

Clyma (1973) advocated the Jensen-Haise method for estimating evapotranspiration for crops. He estimated mean annual potential evapotranspiration for Sargodha to be near 6 feet per year. With wheat during rabi and cotton during kharif, evapotranspiration ranged from 3.6 feet in a wet year to 4.0 feet in a dry year. He calculated net evapotranspiration amounts of wheat grown in Sargodha under wet and dry seasons as 6.8 and 16.3 inches respectively.

Lysimeter studies

In a lysimeter study Asghar et al (1962) found that wheat crop used 19.87 inches of water during its growing season, when the water table was kept at 10.5 feet. In a similar lysimeter study Hussain (1970) calculated the water requirements of crops in West Pakistan. He found that the consumptive use of wheat was 13.27 inches. He further reported that the consumptive use for wheat (indigenous) and wheat (Mexipak) was 13.34 and 20.54 inches respectively. Using climatological data, the author worked out the crop coefficients (K) for wheat to 0.50.

Ali, et al (1973) calculated the consumptive use of common crops in lysimeters keeping the groundwater table at various depths. They used climatological data and worked out empirical consumptive use coefficients. They found that the consumptive use of wheat (Mexipak) grown with the groundwater at a depth of 5, 7 and 9 feet was 21.50, 19.0 and 19.2 inches, respectively.

Field studies

Khan, et al (1968) while comparing the effect of varying quantities of water on yield of wheat (Mexipak) found that the water requirement of wheat was 20.6 inches. They observed that this delta of water was optimum for obtaining maximum yields. These findings were, however, not based on actual consumptive use estimations. Hussain and Asghar

(1969) reported that water requirements of wheat grown at various places in West Pakistan varied from 13.50 inches to 23.88 inches.

Assifi (1970) estimated that consumptive use of wheat grown in Helmand Valley Shamalan was 20.10 inches. He tabulated the monthwise consumptive use of water and concluded that the minimum requirement was in the month of January and maximum in May.

Unpublished data from Punjab Agricultural Research Institute, Lyallpur and Directorate Mona Reclamation Experimental Project, Ghalwal indicated that wheat should be irrigated at 25 percent of the available moisture left in the soil and at 65 percent of the field capacity respectively.

CHAPTER III

PROCEDURE

Selection of site:

One acre field of medium to fine textured, non-saline, non-alkali soil was selected in Mona Project area during kharif, 1973. The field was lying fallow at the time of selection. It was properly leveled. In the process of leveling the top 6 inches of soil from one-fourth of the area (replication 4) was removed and spread over the remainder of the field. The soil texture in replication 4 plots was relatively coarse compared with the other replications. Chemical and physical characteristics of the soil are given in Table 1. To ensure that the crop would not use groundwater the site was selected so that the water table was at least 15 feet below the surface.

Treatments:

Moisture and fertilizer treatments were applied in 3 x 2 factorial design with 4 replications. The following treatments were applied:

Treatment	Number	Description
Soil Moisture Stress	3	Irrigation was applied at moisture stress level of 1, 2 and 4 bar tensions at a depth of top 0-6 inches (treatments M_1, M_2 and M_3, respectively.
Fertility (N, P_2O_5, K_2O)	2	High: 150-75-30 (treatment F_1) Low: 50-0-30 (treatment F_2)
Replications	4	R_1, R_2, R_3, R_4

Total number of plots 3 x 2 x 4 = 24

Table 1. Initial Physico-Chemical Condition of the Soil

A. PHYSICAL ANALYSIS

Sampling depth (inches)	Clay (%)	Silt (%)	Sand (%)	Textural Class	Field Capacity (%)	Bulk Density (g/cm^3)	Wilting Point (%)
0-6	24.58	34.62	40.37	Loam	18.6	1.52	6.9
6-12	32.42	36.17	31.50	Clay Loam			
12-24	35.21	35.21	29.58	Clay Loam			
24-36	35.83	35.12	28.62	Clay Loam			
36-48	36.25	35.87	27.96	Clay Loam			
48-60	36.58	34.85	28.83	Clay Loam			

Infiltration Rate

Inches of water percolated after (hours)					
1	2	3	4	5	6
0.97	1.30	1.42	1.68	1.78	1.87

A. CHEMICAL ANALYSIS

Sampling depth (inches)	Salinity			Fertility		
	ECe x 10^3	SAR	pH	N (%)	P_2O_5 (ppm)	K (lbs/acre)
0-6	1.6	2.8	8.0	0.10	2.5	390
6-12	1.5	3.1	8.1			
12-24	1.3	3.6	7.9			
24-36	1.4	3.3	7.8			
36-48	1.3	3.4	7.8			
48-60	1.5	3.4	7.8			

Field Layout:

The field was divided into 24 plots of equal size. Individual plot bunds and field watercourses were so constructed that all the plots had direct access to water. The plot size was 51' x 28' i.e., 1/30th of an acre. The layout plan is presented in Appendix I of this paper. A fine seed bed was prepared before sowing of wheat.

Fertilizer application:

Two rates of fertilizer viz., high and low, were applied. The high rate NPK consisted of 150-75-30 whereas the low rate represented the fertilizer application on the average farm of 50 lbs of N per acre. A blanket application of 30 lbs. of K_2O was applied over the entire area to eliminate any chances of K deficiency. The fertilizer doses were applied in two parts. All phosphorus and potash were applied to the respective plots just before sowing. Half the nitrogen at the high rate also was applied before sowing. The remainder and all the nitrogen at the low rate were applied at the time of first irrigation. The nitrogen was applied in the form of urea and diammonium phosphate, phosphorus in the form of diammonium phosphate and potash in the form of potassium sulphate. The calculated quantities of fertilizer were broadcast in the respective plots and mixed with the soil by plowing.

Sowing of wheat:

Wheat variety Chenab-70 was sown in rows 9" apart with the help of a rabi drill on 17 November, 1973. The seed rate used was one maund per acre. Germination of wheat started after about one week and was completed within two weeks. Germination was very good. Wheat was also sown in all the fields surrounding the experimental area to avoid oasis effect. The details of various cultural operations carried out are presented in Appendix II of this paper.

Irrigation:

The soil moisture tension curve was determined in the laboratories of the Central Monitoring Organization, Lahore, on samples from surface and sub-surface soil using porous plate and pressure membrane before the experiment was laid out (Appendix III, this paper). The irrigation was given at 3 levels of moisture stress i.e., at 1, 2 and 4 bar tensions; each aimed at optimum production of wheat. The three moisture stress levels amounted to 13.3, 11.0 and 8.6 percent by weight of moisture, respectively, in the top 6" of soil. This corresponds to 54.7, 35.0 and 14.5 percent of the available moisture remaining in the top 6" soil or to 71.5, 59.9 and 46.2 percent of field capacity, respectively. The field capacity of the soil was 18.6 and wilting point 6.9 percent. These plots were irrigated as soon as the desired stress was reached

in the top 0-6 inches soil. Pure tubewell water, the chemical composition of which is given below, was used for irrigation.

pH	Conductivity micromhos/cm	TDS ppm	SAR	RSC me/l
7.5	900	576	2.8	0

The schedule of irrigation is presented in Appendix IV of this paper.

The depth of irrigation to be applied to each plot was calculated from the pre-irrigation soil moisture content. To find out the moisture status of the soil, moisture samples were taken at sowing and before and after each irrigation down to a depth of 5 feet i.e., from 0-6, 6-12, 12-24, 24-36, 36-48 and 48-60 inches depth. The quantity of each irrigation applied was calculated on the basis of moisture deficit of the soil as indicated by pre-irrigation moisture sampling. Each irrigation restored the moisture level of the soil down to 5 feet depth to field capacity. This was done to prevent loss of water through leaching. For the purpose of applying the measured quantity of irrigation water, a cutthroat flume of 4" x 3" size was installed near the point where the water entered the field. The time required to obtain the desired depth of irrigation for each plot was calculated from the following formula:

$$t = \frac{d \times a}{q}$$

where t is time in hours, d is depth of water to be applied in inches, a is area in acres and q is discharge of the outlet in cusecs. A flow of 1 cusec per hour is practically equal to 1 acre inch of water.

Installation of tensiometer and gypsum blocks:

Tensiometers and gypsum blocks were installed in 2 replications to indicate crop needs for irrigation water. The tensiometers and gypsum blocks were placed at depths of 9" and 18". They were used only to assist in determining the correct timing of irrigation. The quantity of irrigation water needed was calculated from the field capacity of the surface 5 feet of soil minus the water content of soil measured gravimetrically on samples taken before each irrigation.

Moisture sampling:

The first soil sampling for moisture estimation was done at the time of planting of wheat and the subsequent moisture samplings were carried out as close before and after every irrigation as possible. Moisture samples were also collected in between irrigations to check depletion of moisture in the

soil. After each substantial rain, moisture samples were also taken. Final moisture sampling was done at the time of harvest. Soil samples for moisture estimation were taken at an interval of one foot to a depth of 5 feet with the exception of surface layer which was divided into 0-6 and 6-12 inches depths. Each sample was composited from 2 randomly located spots in each plot. The samples were dried in the oven at 105 degrees C. to a constant weight and moisture was calculated on dry weight basis.

Rainfall:

Rainfall data was collected from the rain gauge station at Miani Rest House which was about two miles from the experimental site. The record of rainfall is given in Appendix V of this paper.

Lodging of wheat:

Due to a wind storm on 16 March 1974, heavy lodging of wheat occurred. Other windstorms on 25 March 1974 and 29 March 1974 followed by rains caused most of crop to lodge. The intensity of lodging of crop at harvest is given in Appendix VI of this paper.

Consumptive use computations:

Wheat was sown on 17 November 1973 and harvested on 30 April 1974. Four irrigations were given to 1 and 2 bar tension plots and two irrigations to 4 bar tension plots. The consumptive use of water for wheat was worked out by two independent methods. Firstly, by gravimetric measurement of soil moisture depletion wherein consumptive use was calculated by adding the water loss between soil samplings i.e., after and before irrigations, plus pan evaporation for three days after each irrigation, plus rainfall (assuming all rainfall was effective), plus actual evapotranspiration estimated from soil moisture depletion graph for the days not otherwise accounted for (Figures 5 to 7). These days included water loss from the time of last sampling before each irrigation up to the actual time of irrigation, and water lost from the end of the 3rd day after each irrigation (pan evaporation accounted for the first 3 days after each irrigation) up to the actual time of soil sampling after each irrigation. The estimates were made by extrapolation of the graph of soil moisture depletion. Dividing the total water used between two irrigations by the number of days between these irrigations, the consumptive use per day was also calculated.

Secondly, the estimation of the consumptive use was also made by adding the total quantity of irrigation water applied during the growth period of wheat plus or minus the difference in soil moisture at sowing and harvest time. Potential evapotranspiration for wheat was also calculated by using Jensen-Haise equation (10 and 11).

Yield estimation:

Yield estimation was made through crop cutting method. For this purpose an area of 45' x 24' was harvested from each plot and yield per acre was calculated. The crop from the harvested area was separately thrashed, winnowed and weighed for yield estimation. The details of wheat yield are given in Appendix VII of this paper.

CHAPTER IV

RESULTS AND DISCUSSION

Consumptive use:

The consumptive use of water was determined by two independent methods. Firstly, by measurements of soil moisture depletion in the field and secondly by adding the total quantity of water, i.e. irrigation plus rainfall, applied together with the difference in soil moisture present at sowing and harvest time. The results presented in Tables 2 to 4 are derived by the former method. The data show that the consumptive use of water for wheat (Chenab-70) was 18.10, 18.37 and 13.92 inches when the crop was irrigated at 1,2 and 4 bar tensions, respectively. Measurements of consumptive use based on the total amount of irrigation applied resulted 19.52, 18.73 and 16.07 inches for 1, 2 and 4 bar tension treatments, respectively (Table 5). The consumptive use values derived from gravimetric estimations agree closely with those obtained from the total amount of irrigation water applied. The latter values for the 1 and 4 bar tension levels were somewhat higher indicating possible seepage losses.

It is obvious from Tables 2-4 that there was no significant difference in consumptive use of water for 1 and 2 bar tension treatments, as measured by soil moisture depletion method. At the 4 bar tension level, the consumptive use was significantly lower compared with 1 and 2 bar tensions. The low consumptive use in 4 bar tension plots was probably due to the moisture stress imposed. As a result the vegetative growth of crops in these plots was comparatively less than 1 and 2 bar tension plots.

The experimentally obtained evapotranspiration rates at different stages of wheat growth and the potential evapotranspiration rates as computed by the Jensen-Haise equation (10 and 11) are presented in Figures 2 and 3. The data indicate that the experimentally obtained values of evaporation rates agree fairly well with the potential evapotranspiration rates during the active growth period of the crop i.e., between January 15 to March 30. At the early and late stages of growth, the experimentally obtained values were low compared with the calculated values of evapotranspiration. This is to

Table 2. Computation of consumptive use of water for wheat 1973-74 (Moisture level M_1^+)

Irrigations	Rauni		10-1-74		12-2-74		9-3-74		5-4-74	
Soil depth inches	At Sowing 17-11-73	B.N.I.* 3-1-74	A.I.** 16-1-74	B.N.I. 8-2-74	A.I. 21-2-74	B.N.I. 5-3-74	A.I. 18-3-74	B.N.I. 29-3-74	A.I. 13-4-74	At Harvest 30-4-74
0-6	1.10	1.19	1.75	1.10	1.37	0.96	1.31	1.03	1.40	0.54
6-12	1.31	1.32	1.56	1.37	1.40	1.22	1.33	0.98	1.42	0.81
12-24	3.07	3.03	3.20	3.00	3.22	2.94	2.92	2.53	2.90	2.28
24-36	3.03	2.94	3.16	2.66	2.86	3.11	2.98	2.75	2.71	2.55
36-48	3.09	2.70	3.15	2.88	3.50	3.24	3.13	2.94	2.92	2.77
48-60	2.94	3.05	3.16	3.00	3.48	3.31	3.26	3.11	3.07	2.92
Inches of water in 0-60" of soil	14.54	14.23	15.98	14.01	15.83	14.78	14.93	13.34	14.42	11.87
Water used between samplings	0.31		1.97		1.05		1.59		2.55	
Pan evapo.	0.00		0.31		0.34		0.61		0.59	
Rainfall	0.50+0.20+0.30 = 0.55		0.40+0.05 = 0.45		0.85+0.05 = 0.90		0.05, (0.60+0.30) = 0.05		(0.15+0.08) 0.00	
Estimation from graph	0.23		0.31±0.10 = 0.41		0.63+0.28 = 0.91		2.47+0.85+0.30 = 3.62		1.56+0.10 = 1.66	
Water used between irrigations	1.09		3.14		3.20		5.87		4.80	Total = 18.10
No. of days between irrigations	54		33		25		27		27	
Consumptive use/day (inches/day)	0.020		0.095		0.128		0.217		0.178	

Consumptive use of water by the crop over the whole period = 18.10".

+M_1 = Irrigation given at 1 bar tension

‡ Compensation made in estimation

* B.N.I. = Before next irrigation

** A.I. = After irrigation

Table 3. Computation of Consumptive use of water for wheat 1973-74 (Moisture Level M_2^+

Irrigations	Rauni	10-1-74		12.2.74		9-3-74		5-4-74	
Soil depth inches	At Sowing 17-11-73	B.N.I.* 3-1-74	A.I.** 16-1-74	B.N.I. 8-2-74	A.I. 21-2-74	B.N.I. 5-3-74	A.I. 18-3-74	B.N.I. 30-3-74	A.I. 13-4-74	At Harvest 30-4-74
0-6	1.11	1.22	1.81	1.17	1.10	0.89	1.37	0.95	1.56	0.59
6-12	1.47	1.44	1.61	1.48	1.37	1.19	1.46	0.99	1.54	0.90
12-24	3.11	3.15	3.33	3.28	3.15	2.86	3.11	2.47	3.11	2.32
24-36	3.20	3.01	3.29	2.68	3.31	3.00	3.13	2.71	2.79	2.77
36-48	3.18	2.94	3.22	2.94	3.39	3.09	3.22	2.90	2.88	2.58
48-60	3.22	2.86	3.28	2.98	3.39	3.28	3.31	3.11	3.07	2.98
Inches of water in 0-60" of soil	15.2	14.62	16.54	14.53	15.71	14.31	15.60	13.13	14.95	12.14
Water used between samplings	0.67		2.01		1.40		2.47		2.81	
Pan evapo.	0.00		0.31		0.34		0.61		0.59	
Rainfall	0.05+0.20+0.30 = 0.55		0.40+0.05 = 0.45		0.85+0.05 = 0.90		0.05+0.60, (0.30)‡ = 0.65		(0.15+0.08)‡ 0.00	
Estimation from graph	0.12		0.26+0.15 = 0.41		0.39+0.21 = 0.60		1.30+0.53+0.30 = 2.13		1.15 + 0.20 = 1.35	
Water used between irrigations	1.34		3.18		3.24		5.86		4.75	Total = 18.37
No. of days between irrigations	54		33		25		27		27	
Consumptive use/day (inches/day)	0.025		0.096		0.130		0.217		0.176	

Consumptive use of water by the crop over the whole period = 18.37".

+M_2 = Irrigation given at 2 bars tension

‡ Compensation made in estimation

* B.N.I. = Before next irrigation

** A.I. = After irrigation

Table 4. Computation of consumptive use of water for wheat 1973-74 (Moisture Level M_3^+)

Irrigations	Rauni		10-1-74		14-3-74	
Soil depth inches	At Sowing 17-11-73	B.N.I* 3-1-74	A.I.** 16-1-74	B.N.I. 11-3-74	A.I. 30-3-74	At Harvest 2-5-74 30-4-74
0-6	1.11	1.20	1.68	0.77	1.10	0.51
6-12	1.34	1.36	1.59	0.99	1.13	0.70
12-24	2.83	2.88	3.16	2.43	2.64	1.93
24-36	3.05	2.77	3.20	2.71	2.64	2.25
36-48	3.07	2.94	3.07	2.92	2.79	2.38
48-60	3.05	2.85	3.13	3.05	2.88	2.70
Inches of water in 0-60" soil depth	14.45	14.00	15.83	12.87	13.18	10.47
Water used between samplings	0.45		2.96		2.71	
Pan evapo.	0.00		0.31		0.68	
Rainfall	0.05+0.20+0.30 = 0.55		0.40+0.05+0.85‡ 0.05+0.65 = 2.0		(0.05+0.60)‡ 0.30+0.15+0.08 = 0.53	
Estimation from graph	0.30		0.17+0.26+0.10 = 0.53		2.80 + 0.10 = 2.90	
Water used between irrigations	1.30		5.80		6.82	
No. of days between irrigations	54		63		49	
Consumptive use/day (inches/day)	0.024		0.092		0.139	

Consumptive use of water by the crop over the whole period = 13.92"

$+M_3$ = Irrigation given at 4 bars tension

‡ Compensation made in estimation

* B.N.I. = Before next irrigation

** A.I. = After Irrigation

Table 5. Consumptive use of water of wheat from measurement of irrigation water applied (inches).

Source	Moisture stress level (bars) 1	2	4
Amount of irrigation applied	13.77	12.50	9.01
Rainfall	3.08	3.08	3.08
Differential at sowing and harvest	2.67	3.15	3.98
Total	19.52	18.73	16.07

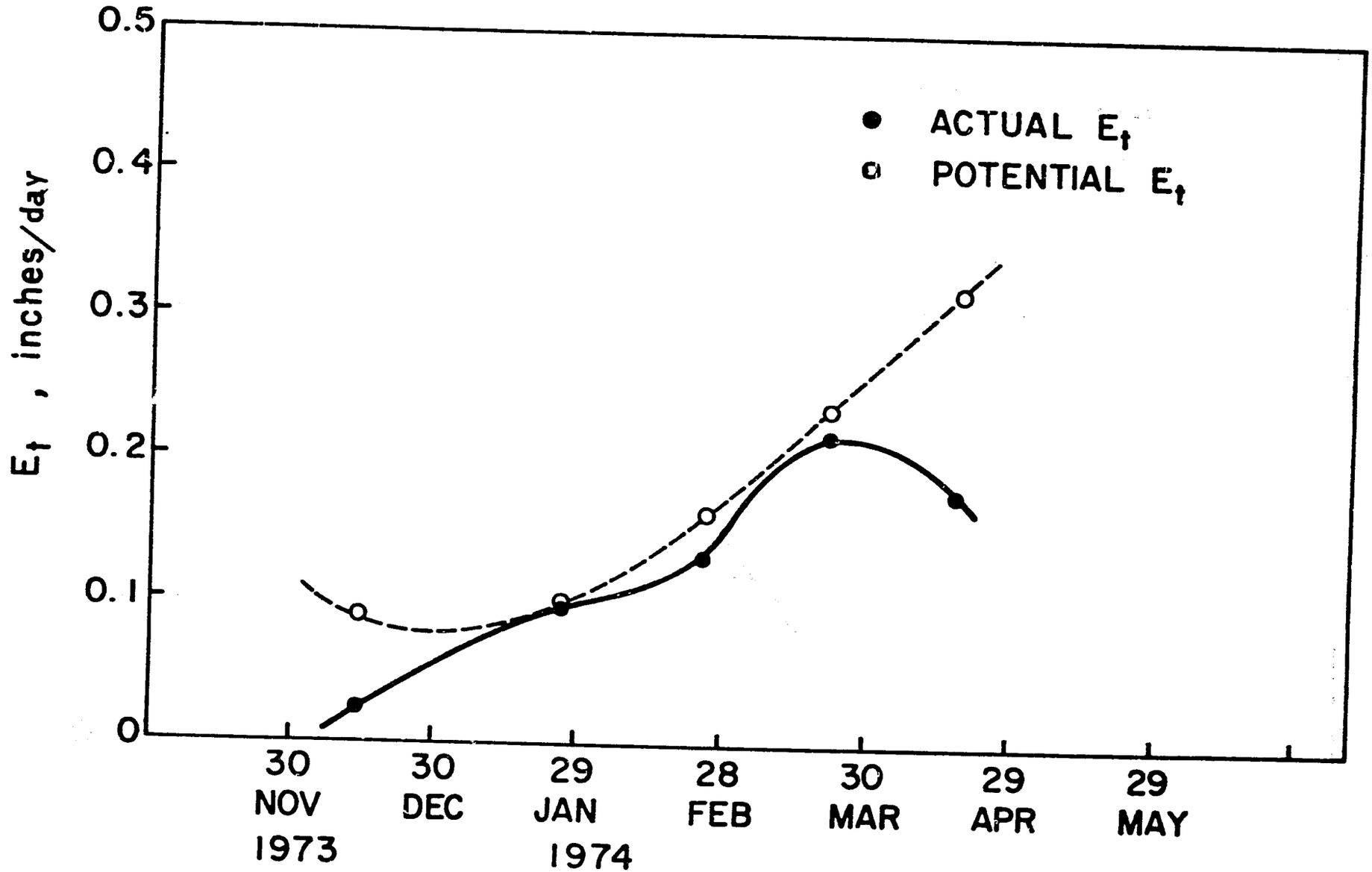

Figure 2. Actual and potential E_t rates for wheat irrigated at 1 bar tension in surface 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

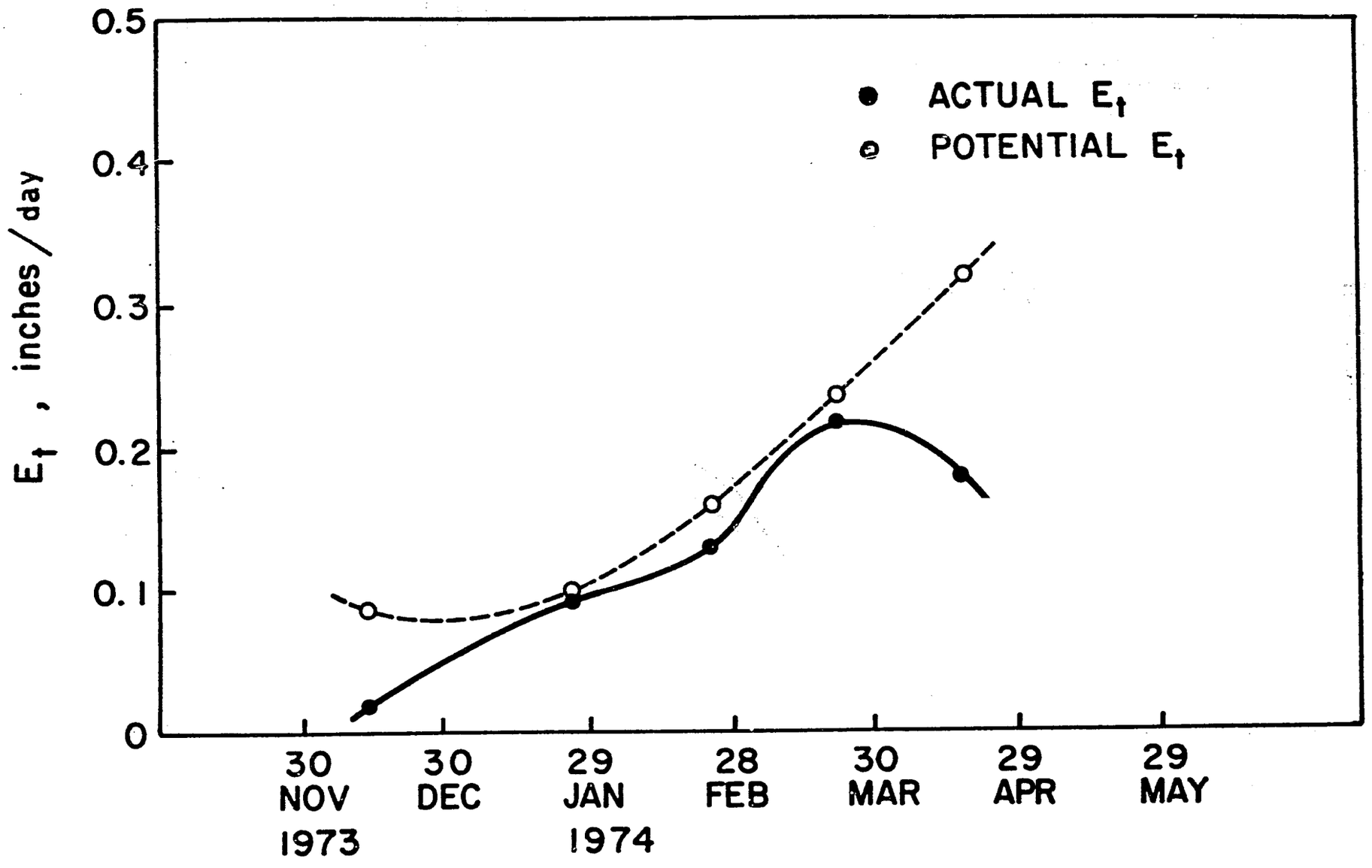

Figure 3. Actual and potential E_t rates for wheat irrigated at 2 bars tension in surface 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

be expected because during the early stages the plants are small and the crop cover is incomplete as such the soil moisture is not used to its full potential. Similarly, at the late growth stage i.e., near maturity the plants dry up and hence transpire less water. The main source of water loss during these stages is through evaporation. In 4 bar tension plots, the experimentally obtained rates of evapotranspiration were low throughout the growth period compared with the calculated rates (Figure 4). This may be due to moisture stress imposed in this treatment. From Figures 2, 3 and 4 it is seen that during March evapotranspiration rates were the highest. During this period, the weather starts getting hot, the canopy cover is complete and this combination of factors raises the water requirements of the plants. The actual and potential evapotranspiration rates for the 1, 2 and 4 bar stress levels are given in Appendices VIII and IX of this paper.

The distribution of moisture in the soil up to 5 feet depth, during the growing season of wheat, is shown in Figures 5 to 7. It is seen from these figures that moisture in the soil increased after each irrigation and then started decreasing as the soil moisture depleted due to evapotranspiration. A similar trend was observed after each rain. In the 1 and 2 bar tension plots the total moisture in the soil up to 5 feet depth varied between 12 and 18 inches (Figures 5 and 6), whereas in the 4 bar plots total moisture in the soil varied between 10 and 17 inches (Figure 7).

For 3-4 days after irrigation, the actual evaporation from the field surface approaches the rate of evaporation from an open pan. The soil is too wet for moisture sampling to be carried out and daily open pan evaporation measurements were used to estimate evapotranspiration for the period from irrigation up to three days after irrigation. When soil sampling was delayed beyond 3 days after an irrigation for any reason, the rate of evapotranspiration for the period from the end of 3rd day after irrigation up to the actual sampling date was estimated from the soil moisture depletion graphs (Figures 5 to 7). Extrapolation of the curves presenting measured evapotranspiration was used also to cover the period between soil sampling and the next irrigation.

Crop coefficients (Kc) were calculated from potential and actual evapotranspiration data presented in Tables 2, 3 and 4 and Figures 2, 3 and 4. The crop coefficients for wheat grown during rabi 1973-74 are presented in Figures 8 and 9. The mean values for 1 and 2 bar tension plots (Figure 8) are higher than at the 4 bar stress level shown in Figure 9. The coefficients varied between 0.14 and 0.98 depending on the stage of growth. The average Kc values for the growing season for the 1 and 2 bar treatments came to 0.74 and that for 4 bar tension plots to 0.57. The values are lower than those reported by Dastane (7) but are higher than the one given by

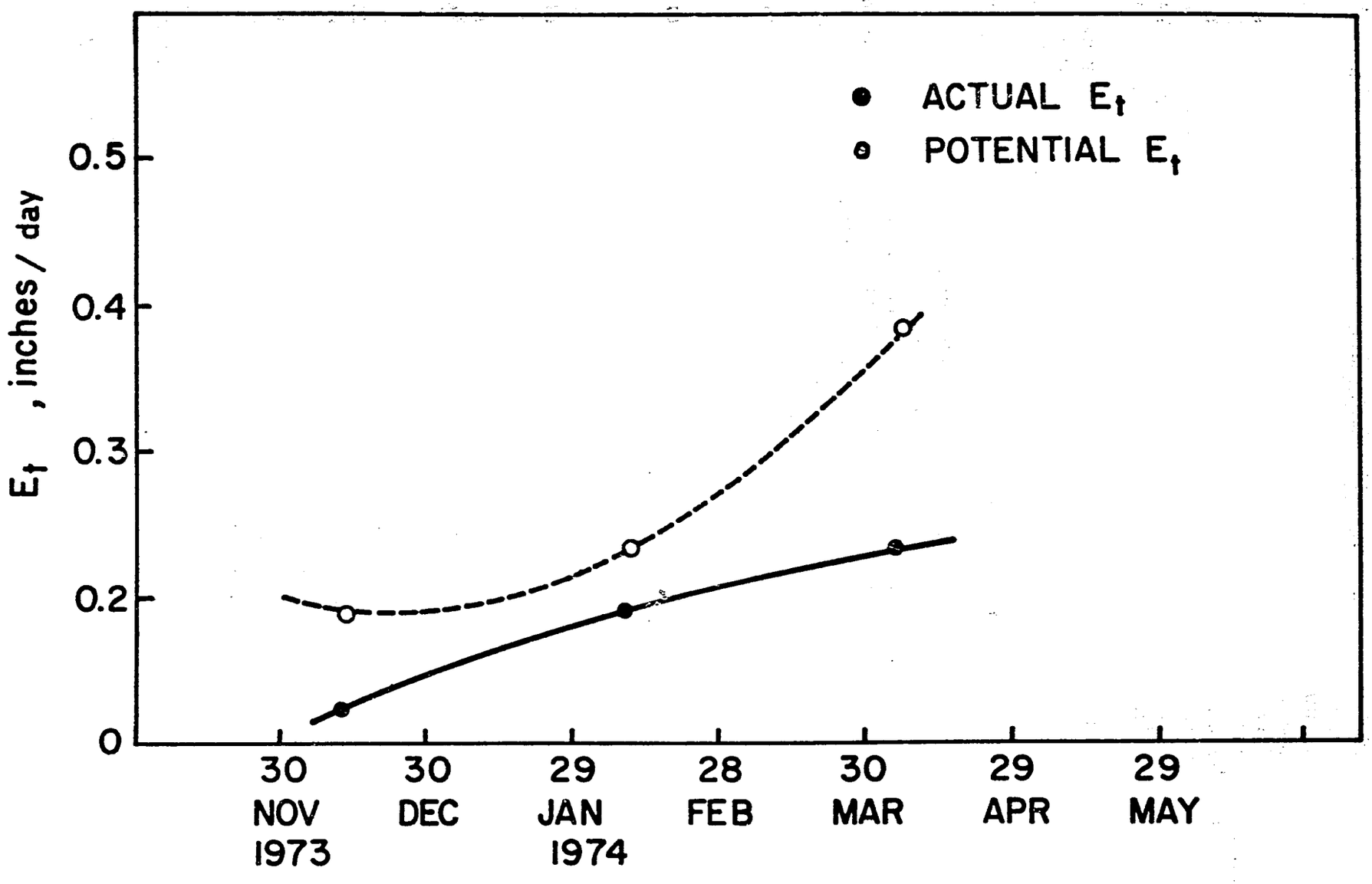

Figure 4. Actual and potential E_t rates for wheat irrigated at 4 bars tension in surface 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

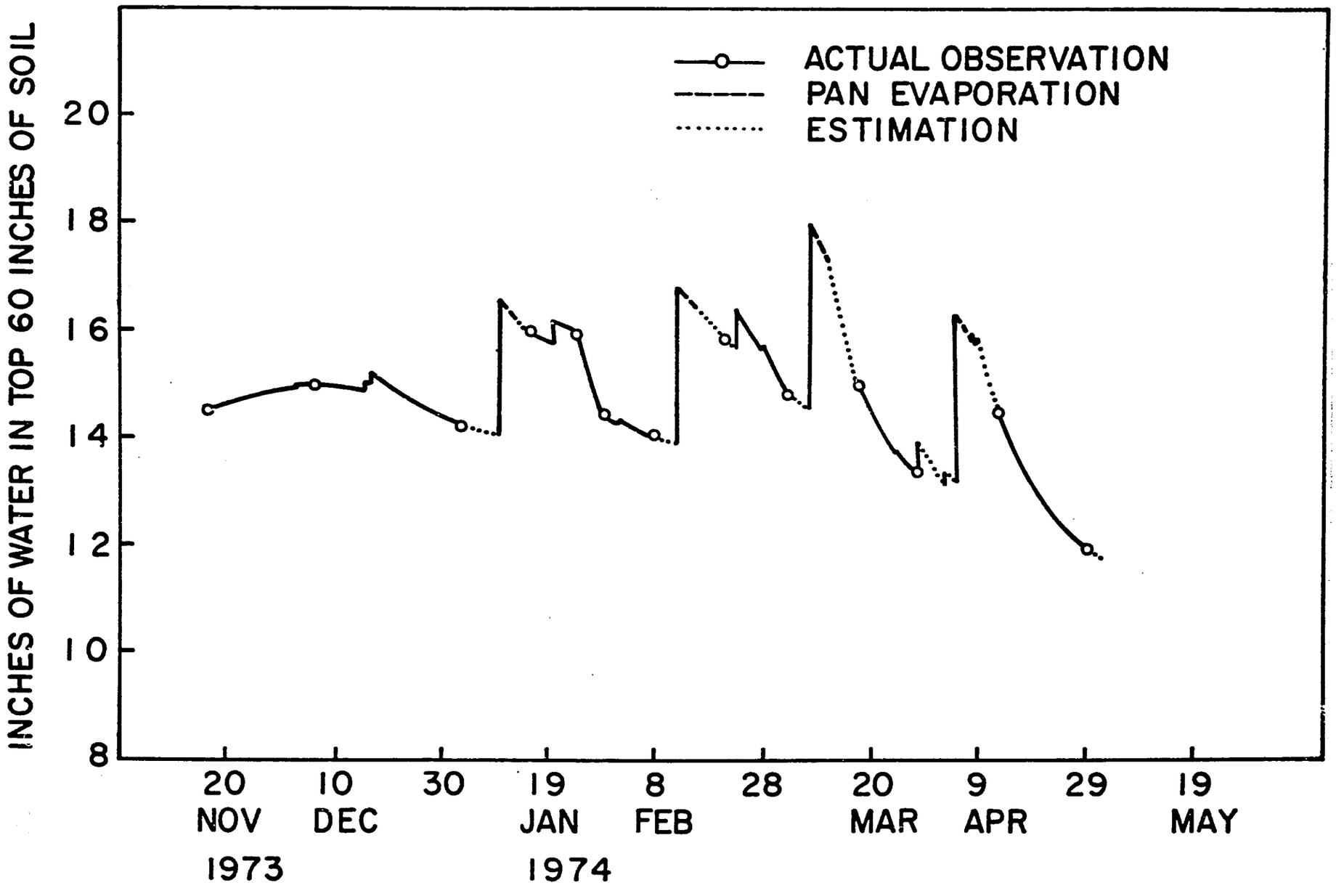

Figure 5. Variation in soil moisture content under wheat irrigated at 1 bar tension in top 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

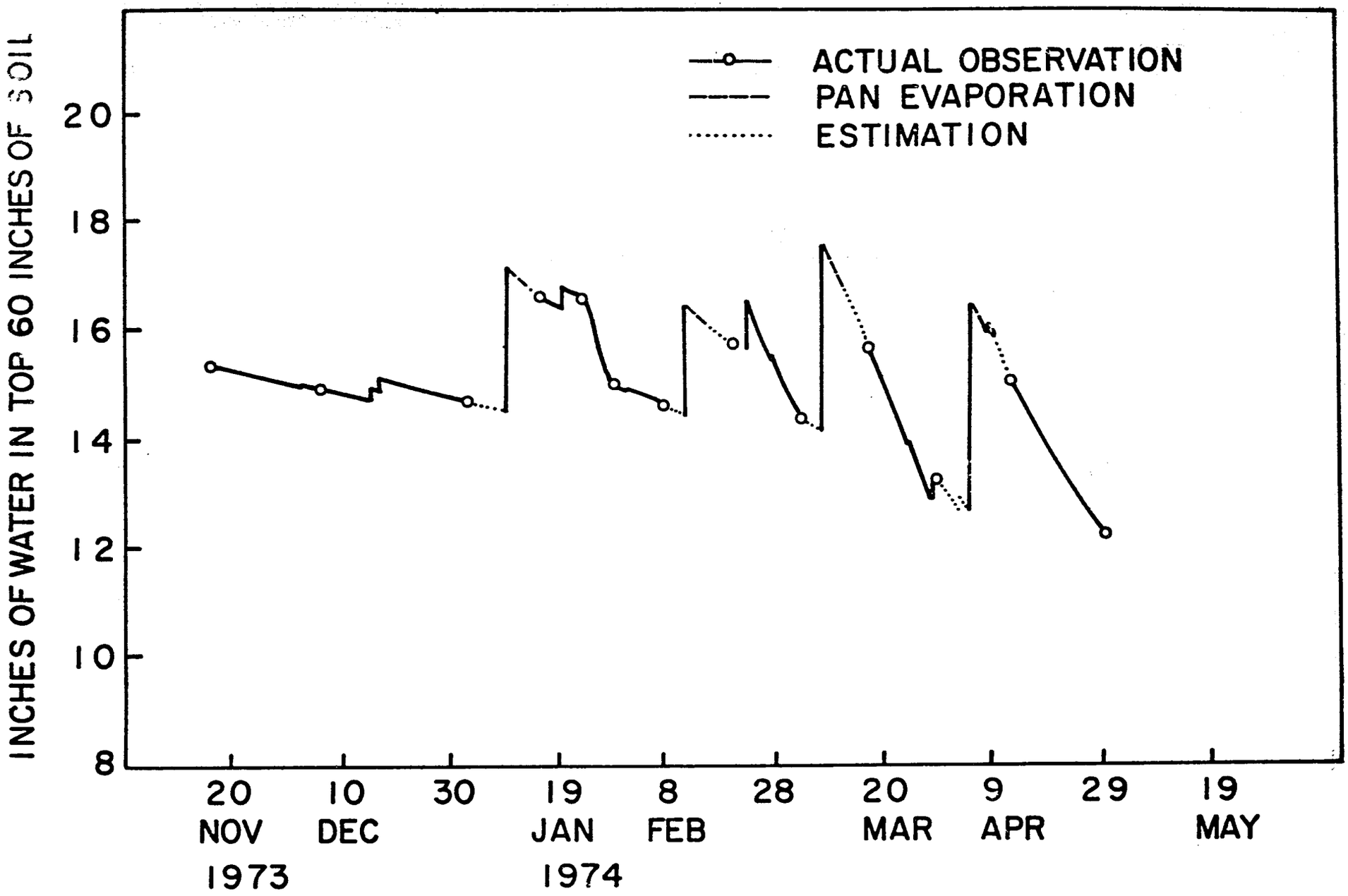

Figure 6. Variation in soil moisture content under wheat irrigated at 2 bars tension in top 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

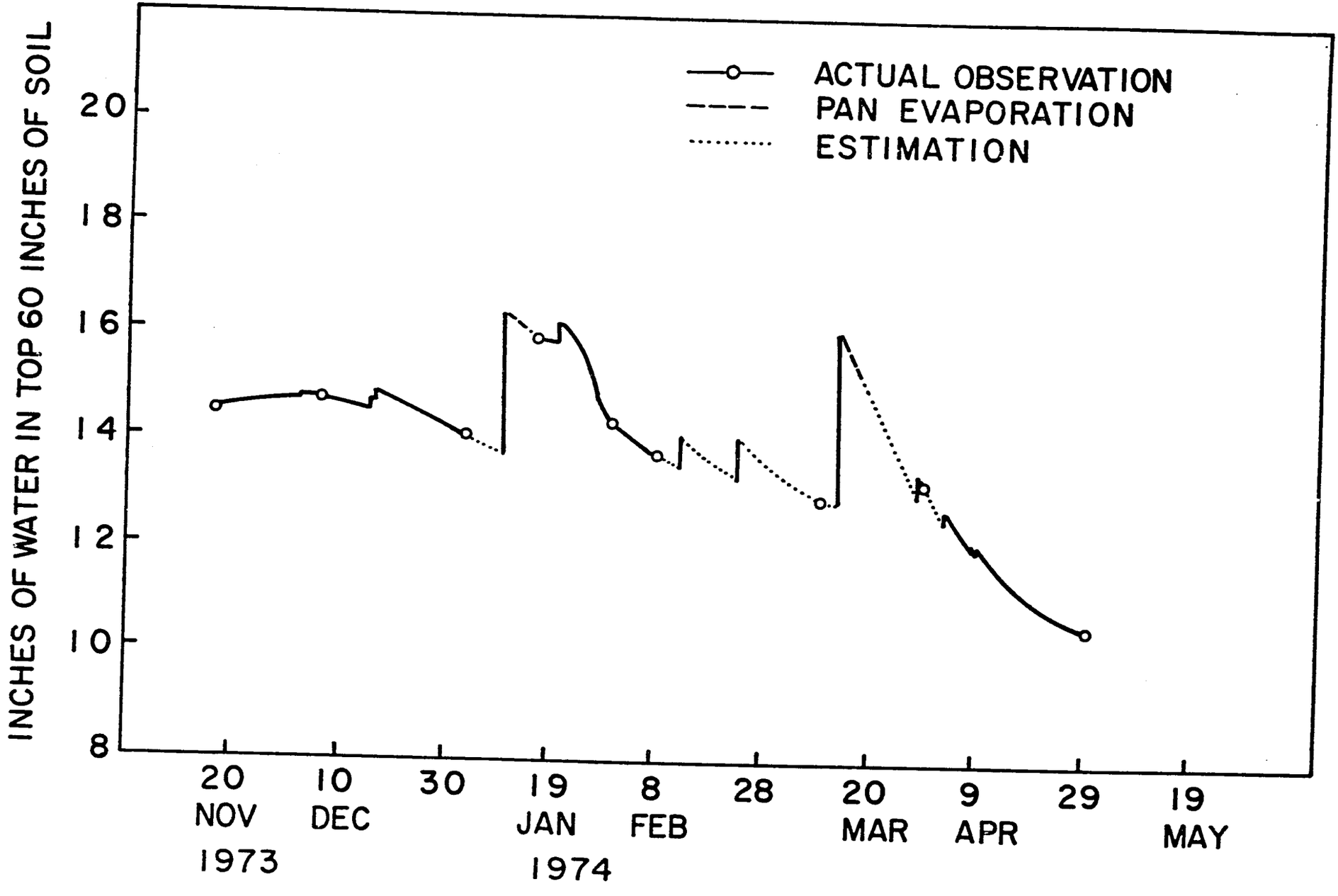

Figure 7. Variation in soil moisture content under wheat irrigated at 4 bars tension in top 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

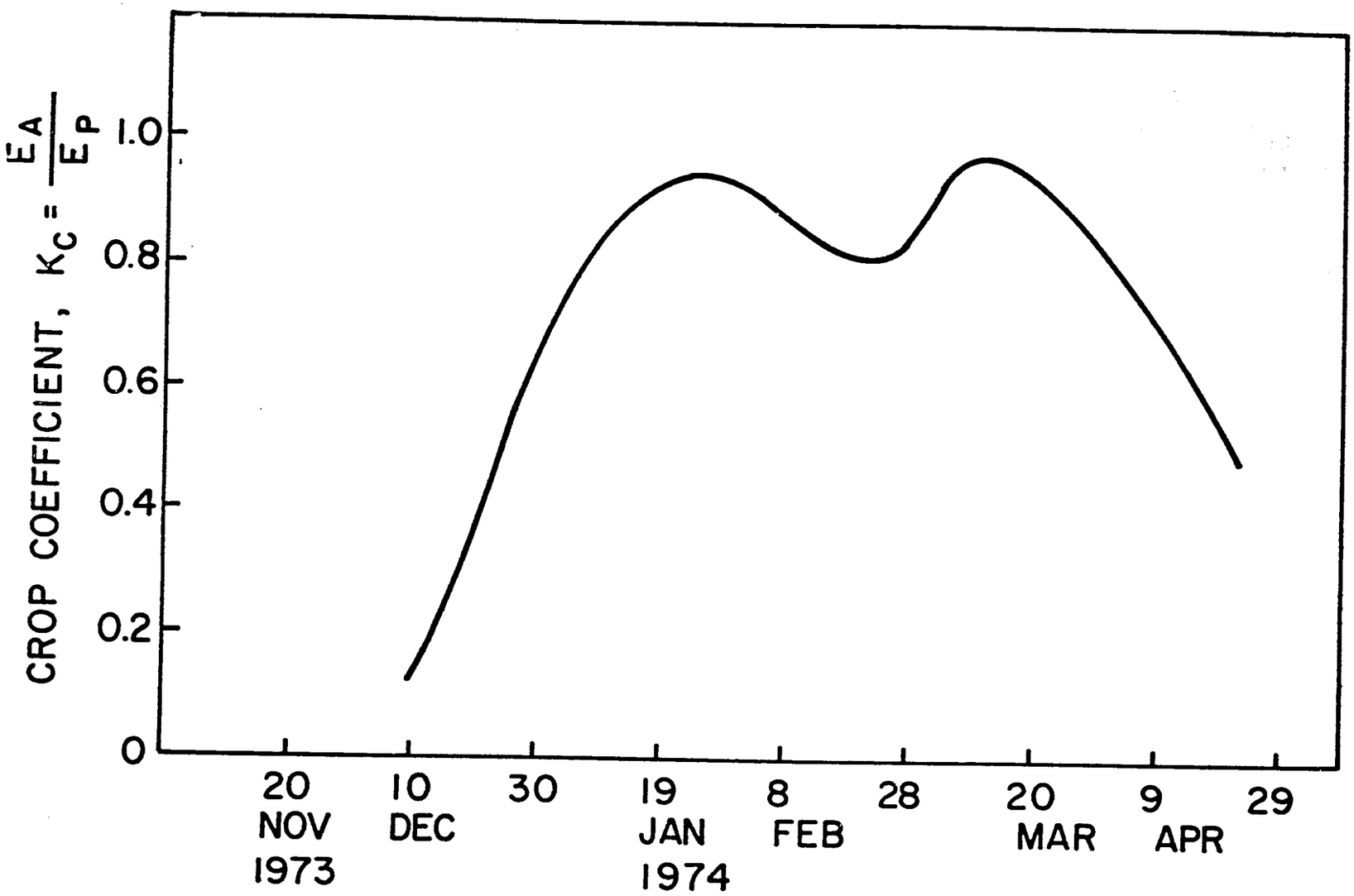

Figure 8. Crop coefficient $K_i = \frac{E_{ta}}{E_{tp}}$ for wheat irrigated at 1 and 2 bars tension in surface 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

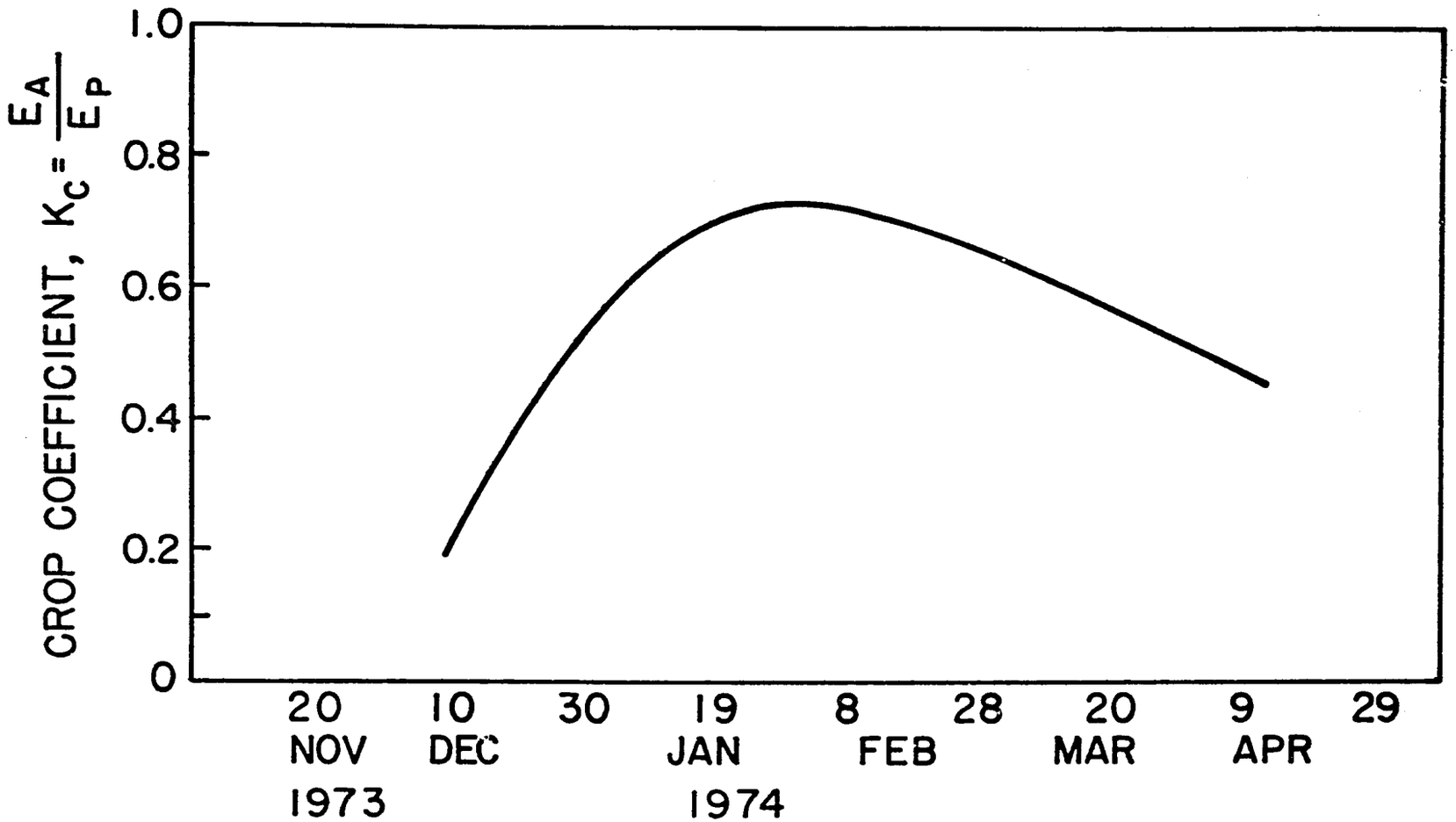

Figure 9. Crop coefficient $K_i = \frac{E_{ta}}{E_{tp}}$ for wheat irrigated at 4 bars tension in surface 6 inches of soil during rabi 1973/74, Mona Reclamation Experiment Project, Bhalwal.

Hussain (8). The depression in the curve during the months of January and February is difficult to explain. This may be due to reduction in actual evapotranspiration caused by unusually heavy fog during this period or random variation.

Wheat yield:

Average wheat yield from different treatments varied between 46 to 50 maunds per acre (Table 6). Under optimum growing conditions a yield of 60 to 70 maunds or more can be obtained. Several factors, such as storms, unusually heavy fog and general weather conditions may have contributed to a reduced yield level, especially in F_1, M_1 and M_2 plots. Severe wind and rain storms caused heavy lodging especially in the high fertility plots. Furthermore, unusually thick fog which persisted for a period of about 10 days during the month of February might have adversely affected the wheat yield. Average wheat yield from optimum input demonstration plots in the Mona area was 44.6 maunds per acre during 1973-74 compared with 47.2 maunds per acre during 1972-73.

Although vegetative growth of wheat in F_1 plots appeared comparatively better, statistical analysis showed no significant difference in yield among treatments. This may be due mainly to the severe lodging of wheat in F_1 plots which reduced the margin of yield between F_1 and F_2 plots. In general, lodging especially when occurring at grain development stage, markedly reduces the yield of wheat crop.

The data reported in Appendices VI and VII of this paper confirm that where there was severe lodging in F_1 plots, the wheat yield from these plots was less than the corresponding yield of F_2 plots of the same replication e.g., plots No. 2, 5, 6, 7, 10 and 16 versus plots No. 3, 4, 8, 12 and 18. On the contrary, where lodging was minimum, the yield from F_1 plots was considerably higher than that of F_2 plots e.g., plot number 20, 21 and 22 versus plots number 19, 23 and 24 (Appendix VI). It is further pointed out that the general yield level of wheat in the plots of replication 4, i.e., (plots number 19 to 24) was low compared with other plots, due to the fact that the soil in these plots is comparatively lighter in texture. Moreover, during leveling the top 6 inches of soil from these plots was removed and spread over the other plots.

The winter rainfall was well distributed throughout the growing season of wheat (Appendix V), as such the yield difference among treatments remained non-significant.

From the above discussion it follows that the consumptive use of water for wheat was 18.10, 18.37 and 13.92 inches, when the crop was irrigated at 1, 2 and 4 bars of stress, respectively. There was no significant differences in yield among various

Table 6. Wheat yield as affected by different treatments.

Sr. No.	Treatment	Yield Maunds* per acre
1	M_1F_1	49.19
2	M_1F_2	48.54
3	M_2F_1	49.75
4	M_2F_2	48.86
5	M_3F_1	48.29
6	M_3F_2	46.94

* one maund - 82 pounds

F_1 = 150-75-30 NPK

F_2 = 50-0-30 NPK

M_1 = Irrigation at 1 bar tension

M_2 = Irrigation at 2 bar tension

M_3 = Irrigation at 4 bar tension

treatments. Therefore, considerable amounts of water can be saved by accepting a certain degree of moisture stress and irrigating accordingly. The consumptive use of water found at 1 and 2 bar tension agree fairly well with the previous findings of Asghar et al (3), Ali et al (1), Khan et al (12), Hussain and Asghar (9) and Hussain (8), for Mexipak wheat. The consumptive use delta for 4 bars stress level is, appreciably lower than those reported by these authors. This, however, agrees with the findings of Blaney and Criddle (5), and Hussain (8) for indigenous wheat. The results also reveal that wheat when irrigated at 14.5 percent of the available moisture left in the top 6" soil or a 46.2 percent of the field capacity gave as good a yield as when at 35 percent and 54 percent of available moisture or at 60 and 70 percent of field capacity.

CONCLUSIONS

This interim report based on data from one season collected during rabi 1973-74 is still in progress. A final report will be issued at the conclusion of the experiment. From the data reported in this manuscript the following tentative conclusions are drawn:

1. The consumptive use of water for wheat came to 18.10, 18.37 and 13.92 inches when the crop was irrigated at 1, 2 and 4 bars of moisture tension, respectively.

2. There were no significant differences in wheat yield among any treatments. Therefore, water can be saved by applying a certain degree of moisture stress and restriction of the total amount of moisture available to the crop from irrigation, rainfall and soil reserves to about 14 inches.

3. During the active growing period of wheat, the experimentally obtained values of evapotranspiration agreed reasonably well with the potential evapotranspiration rate calculated by the Jensen-Haise equation under 1 and 2 bars stress level. At early and late stages of growth, the experimentally obtained values were lower than the calculated ones as expected. In plots allowed to reach 4 bars stress level, however, the actual evapotranspiration rates remained lower than the calculated ones.

4. When irrigated at 14.5 percent of the available moisture left, in the top 6" soil or at 46.2 percent of the field capacity, the wheat crop gave as good yield as when irrigated at 35 percent and 54 percent, available moisture or at 60 percent and 71 percent of the field capacity, respectively.

5. Crop coefficient, relating actual to potential evapotranspiration, averaged 0.74 for the 1 and 2 bar stress plots and 0.59 for 4 bar stress plots.

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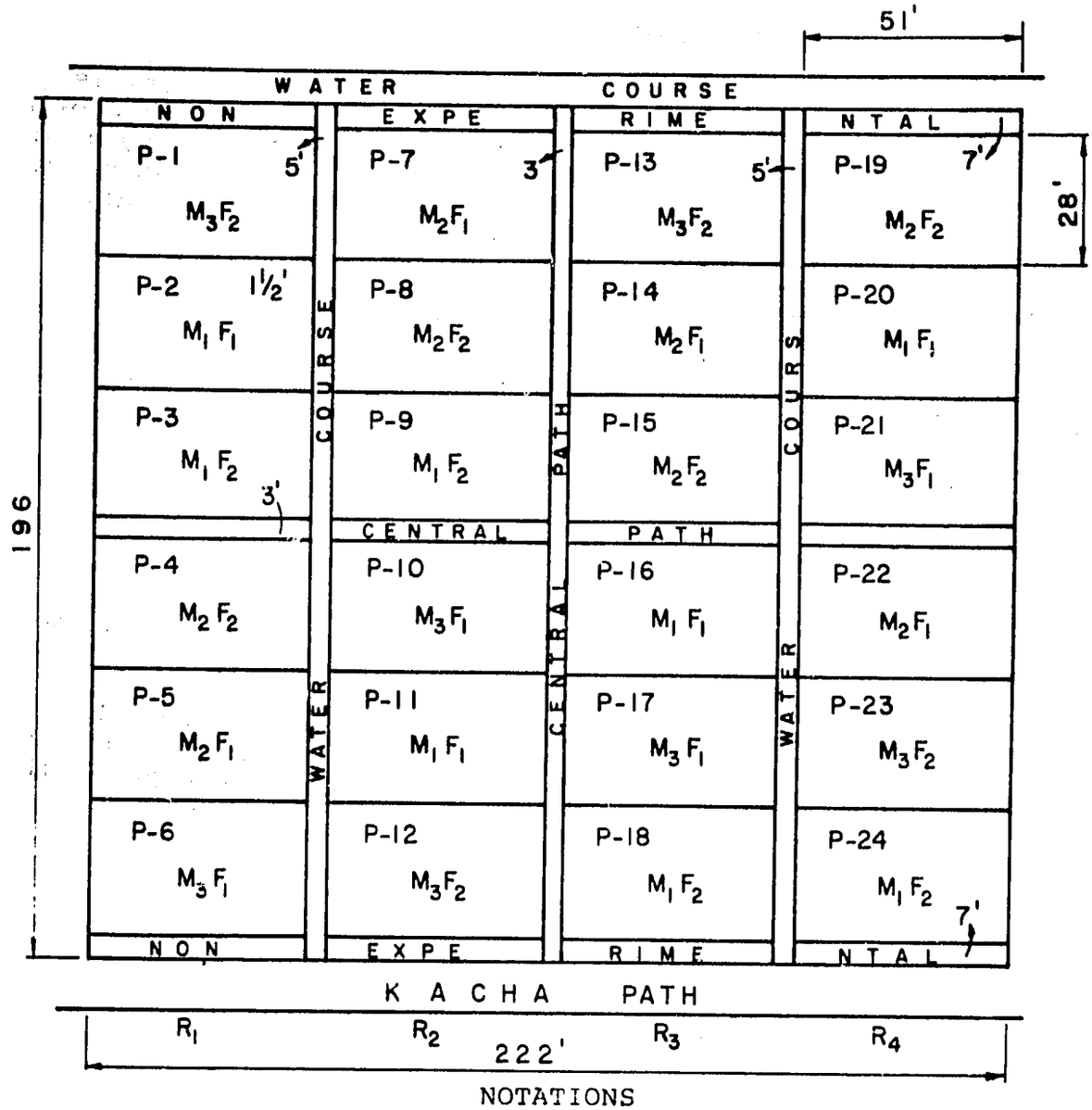
Appendix I. Layout Plan of Consumptive Use Experiment



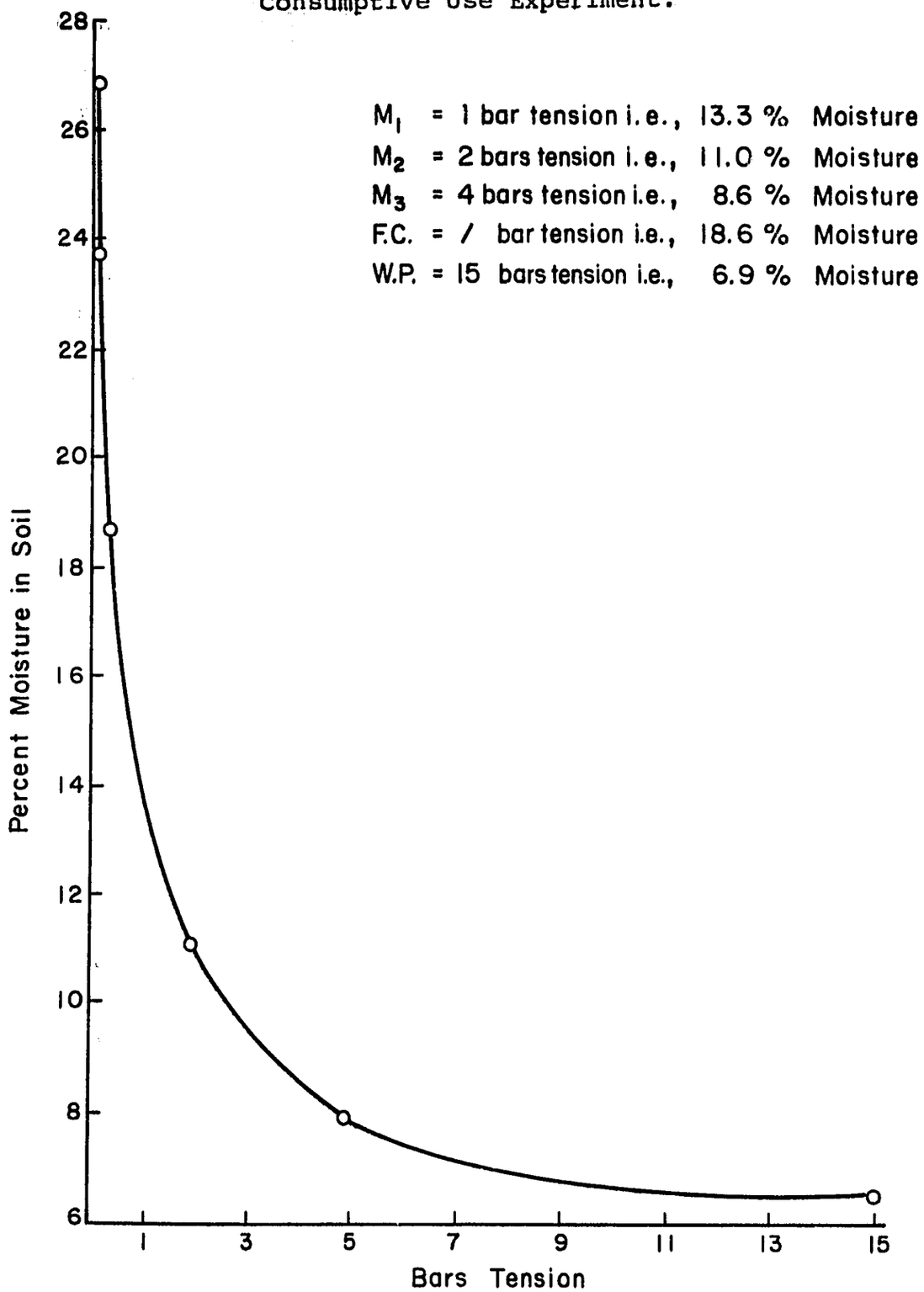
NOTATIONS

P	Plot Number	M_3	4 bar tension
R	Replication	F_1	150-75-30
M_1	1 bar tension	F_2	50-0-30
M_2	2 bar tension		Net Plot Size 51' x 28'

Appendix II. Details of cultural operations for wheat 1973-74.

Leveling	Field was not level. Initial leveling was done with the help of tractor and bullocks. Final leveling was done by manual labor. The field was precisely leveled before sowing of wheat.
Seedbed preparation	
No. of plowings	6 by tractor
No. of plankings	3
Date of sowing	17-11-1973
Fertilizer (lbs. per acre)	
F_1 (NPK)	= 150-75-30
F_2 (NPK)	= 50-0-30
Hoeing	One
Weedings	Three casual weedings as and when needed was also performed.
Attack of rats	The attack was observed on 27-2-74. At the very first observation, zinc sulphite tablets were kept in plots.

Appendix III. Moisture Characteristic Curve of Soil at Consumptive Use Experiment.



Appendix IV. Irrigation Schedule for Wheat (1973-74)

Plot No.	Treat-ment	Depth of irrigation applied in inches 10-1-74	12-2-74	9-3-74	14-3-74	5-4-74	Total (in.) Irrigation
2	M_1F_1	3.02	2.85	2.97	-	3.56	12.40
3	M_1F_2	3.02	-	3.78	-	4.27	11.07
11	M_1F_1	2.79	2.86	3.11	-	5.17	13.93
9	M_1F_2	2.75	-	4.39	-	5.23	12.37
16	M_1F_1	2.42	3.41	4.81	-	5.40	16.04
18	M_1F_2	3.27	4.68	4.37	-	6.72	19.04
20	M_1F_1	3.42	1.72	1.88	-	3.82	10.84
24	M_1F_2	3.93	3.20	3.10	-	4.24	14.47
Average							13.77+3.08=16.85
5	M_2F_1	3.14	-	5.08	-	5.75	13.97
4	M_2F_2	3.18	-	4.77	-	6.06	14.01
7	M_2F_1	2.92	-	4.86	-	5.53	13.31
8	M_2F_2	2.64	-	3.86	-	5.70	12.[illegible]
14	M_2F_1	3.14	-	5.54	-	5.33	14.01
15	M_2F_2	2.56	-	4.70	-	5.03	12.29
22	M_2F_1	3.73	2.57	2.77	-	4.09	13.16
19	M_2F_2	2.42	1.32	1.55	-	2.36	7.65
Average							12.50+3.08*=15.58
6	M_3F_1	2.79	-	-	5.34	-	8.13
1	M_3F_2	3.48	-	-	5.27	-	8.75
10	M_3F_1	2.47	-	-	5.71	-	8.18
12	M_3F_2	3.02	-	-	6.42	-	9.44
17	M_3F_1	3.76	-	-	6.06	-	9.82
13	M_3F_2	2.41	-	-	5.25	-	7.64
21	M_3F_1	3.30	1.86	-	3.82	-	8.98
23	M_3F_2	4.19	3.35	-	3.65	-	11.19
Average							9.01+3.08*=12.09

*Rainfall during growing period = 3.08"

Appendix V. Rainfall During Growing Season of Wheat 1973-74*

Date	Inches
3.12.1973	0.05
16.12.1973	0.20
17.12.1973	0.30
20.1.1974	0.40
1.2.1974	0.05
23.2.1974	0.85
28.2.1974	0.05
25.3.1974	0.05
29.3.1974	0.60
3.4.1974	0.30
8.4.1974	0.15
9.4.1974	0.08
Total	3.08

*Recorded at Miani Rest House Rain Gauge Station.

Appendix VI. Lodging of Wheat 1973-74.

Lodging Condition	Plot Numbers									
	F_1					F_2				
	R_1	R_2	R_3	R_4	Total	R_1	R_2	R_3	R_4	Total
Severe (>75%)	2,5 & 6	7& 10	16	-	6	-	-	-	-	-
Moderate (25-75%)	-	-	14& 17	-	2	1,3 & 4	8,9 &12	-	-	6
Minimum (<25%)	-	11	-	20,21 & 22	4	-	-	13, 15&18	19,23 &24	6

Notations: F_1 = 150-75-30 pounds NPK

F_2 = 50-0-30 pounds NPK

R = Replication

APPENDIX VII. WHEAT YIELD AS AFFECTED BY VARIOUS TREATMENTS

Plot No.	Treatment		Yield (maunds* per acre)
2	M_1F_1		46.12
11			54.65
16			44.72
20			51.25
		Total	196.74
		Average	49.19
3	M_1F_2		49.33
9			51.97
18			54.30
24			38.56
		Total	194.16
		Average	48.54
5	M_1F_2		49.14
7			47.03
14			52.16
22			50.65
		Total	198.98
		Average	49.75
4	M_2F_2		49.26
8			52.74
15			49.90
19			43.54
		Total	195.44
		Average	48.86
6	M_3F_1		48.22
10			46.73
17			50.65
21			47.57
		Total	193.17
		Average	48.29
1	M_3F_2		52.48
12			52.96
13			49.64
23			32.88
		Total	187.76
		Average	46.94

Notations:

* one maund = 82 pounds

M_1 = 1 bar tension

M_2 = 2 bar tension

M_3 = 4 bar tension

F_1 = 150-75-30

F_2 = 50- 0-30

APPENDIX VIII. CROP COEFFICIENTS FOR WHEAT IRRIGATED AT 1 & 2 BARS TENSION (MEAN)

Period		Et_A	Et_P	Daily Kc	Monthly (Average) Kc
Dec.	10-12	0.013	0.093	0.14	
	13-15	0.02	0.09	0.22	
	16-18	0.025	0.085	0.29	
	19-21	0.03	0.085	0.35	
	22-24	0.037	0.082	0.45	0.37
	25-27	0.044	0.081	0.54	
	28-30	0.05	0.08	0.63	
Jan.	31- 2	0.055	0.08	0.69	
	3- 5	0.06	0.08	0.75	
	6- 8	0.065	0.082	0.79	
	9-11	0.07	0.084	0.83	
	12-14	0.075	0.036	0.87	
	15-17	0.080	0.088	0.91	0.86
	18-20	0.084	0.09	0.93	
	21-23	0.088	0.095	0.93	
	24-26	0.093	0.10	0.93	
	27-29	0.097	0.102	0.95	
Feb.	30- 1	0.10	0.107	0.93	
	2- 4	0.10	0.11	0.91	
	5- 7	0.104	0.117	0.89	
	8-10	0.107	0.123	0.87	
	11-13	0.11	0.13	0.85	0.85
	14-16	0.113	0.136	0.83	
	17-19	0.117	0.144	0.81	
	20-22	0.122	0.150	0.81	
	23-25	0.128	0.158	0.81	
	26-28	0.140	0.166	0.84	
March	1- 3	0.155	0.174	0.89	
	4- 6	0.170	0.182	0.93	
	7- 9	0.185	0.190	0.97	
	10-12	0.195	0.20	0.98	0.93
	13-15	0.205	0.21	0.98	
	16-18	0.21	0.218	0.96	
	19-21	0.214	0.227	0.94	
	22-24	0.218	0.235	0.93	
	25-27	0.218	0.245	0.89	
	28-30	0.217	0.255	0.85	
April	31- 2	0.215	0.265	0.81	
	3- 5	0.212	0.274	0.77	
	6- 8	0.208	0.282	0.74	
	9-11	0.203	0.292	0.70	
	12-14	0.195	0.300	0.65	0.67
	15-17	0.185	0.310	0.60	
	18-20	0.180	0.319	0.56	
	21-23	0.165	0.330	0.50	
	Growing season average			0.74	

Et_A = Actual evapotranspiration.

Et_P = Potential evapotranspiration as calculated by Jensen and Haise's formula.

Kc = Et_A/Et_P

APPENDIX IX. CROP COEFFICIENTS FOR WHEAT IRRIGATED AT 4 BARS TENSION

Period		Et_A	Et_P	Daily Kc	Monthly (Average) Kc
Dec.	10-12	0.02	0.091	0.22	
	13-15	0.025	0.089	0.28	
	16-18	0.028	0.089	0.31	
	19-21	0.032	0.088	0.36	0.37
	22-24	0.037	0.086	0.43	
	25-27	0.040	0.086	0.47	
	28-30	0.045	0.086	0.52	
Jan.	31- 2	0.049	0.087	0.56	
	3- 5	0.052	0.089	0.58	
	6- 8	0.056	0.090	0.62	
	9-11	0.060	0.092	0.65	
	12-14	0.064	0.095	0.67	0.67
	15-17	0.067	0.098	0.68	
	18-20	0.070	0.10	0.70	
	21-23	0.074	0.103	0.72	
	24-26	0.077	0.107	0.72	
	27-29	0.080	0.11	0.73	
	30- 1	0.084	0.116	0.72	
Feb.	2- 4	0.087	0.120	0.73	
	5- 7	0.09	0.125	0.72	
	8-10	0.092	0.130	0.71	
	11-13	0.095	0.135	0.70	
	14-16	0.099	0.140	0.71	0.70
	17-19	0.10	0.146	0.68	
	20-22	0.104	0.153	0.68	
	23-25	0.107	0.159	0.67	
	26-28	0.11	0.165	0.67	
March	1- 3	0.112	0.172	0.65	
	4- 6	0.115	0.180	0.64	
	7- 9	0.118	0.185	0.64	
	10-12	0.120	0.194	0.62	
	13-15	0.122	0.20	0.61	0.60
	16-18	0.125	0.21	0.60	
	19-21	0.127	0.22	0.58	
	22-24	0.130	0.230	0.57	
	25-27	0.130	0.24	0.54	
	28-30	0.133	0.25	0.53	
April	31- 2	0.136	0.26	0.52	
	3- 5	0.139	0.27	0.51	
	6- 8	0.140	0.28	0.50	0.50
	9-11	0.140	0.295	0.47	
	Growing season Average				0.57

Et_A = Actual evapotranspiration.

Et_P = Potential evapotranspiration as calculated by Jensen and Haise's formula.

Kc = Et_A/Et_P

Appendix 23

TOWARD OPTIMUM MANAGEMENT PRACTICES FOR PRODUCTION OF MAIZE IN IRRIGATED AREAS OF THE PUNJAB

Rehmat Ali, Bashir A. Sabir, and C.J. deMooy[1]

Summary

Traditional practices of maize production are the major cause of the extremely low per-acre yields occurring in many areas. It was found that average maize yields can be doubled and often much more than that by application of a package of improved practices. These practices included good seedbed preparation and precision land leveling, the use of good quality seed of High Yielding Varieties, row planting, increased use of fertilizers, correct irrigation practices, and good weed and pest control measures. There were indications that bedding with the accompanying furrow irrigation and also the use of farmyard manure could raise the yield of maize to higher levels.

Introduction

Maize yields in farmer's fields in the irrigated areas of the Punjab are generally low. As a result the net income per acre from kharif crops is minimal and could be very much improved by application of known technology and good management. Optimum management requires a combination of improved practices. Improvement of one single factor may not necessarily be effective in raising the yield of the crop. Better timing and management of irrigation water, for instance, cannot be very effective unless the land first has been leveled. Even good care of two major factors such as irrigation and soil fertility may fail to raise yields if the weeds are allowed to go out of control. Finally, it is obvious that all other improvements will remain without result if proper care is not taken to have a good crop stand. Also, a heavy infestation of corn borers during the season can remove all that was gained by various improvements initially. Farmers in some areas have a problem obtaining good stands especially due to crust formation at the surface of the soil or early monsoonal rains. Such factors could explain the general lack of initiative in making any change in cultural operations. Furthermore, some improvements require a certain financial investment which means a financial burden on small farmers.

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[1]Senior Research Officer and Junior Research Officer, Mona Reclamation Experiment Project, WAPDA; and Agronomist, CSU Field Party, respectively.

With this in mind, it becomes important to demonstrate the benefits to be gained from improved management. To this end, the present experiments were designed and laid out in farmers' fields.

Methods

Experiments were conducted in randomized block design with two replications in the chakbandi of tubewells No. MN-78 and MN-122 at the Mona Reclamation Experimental Project near Bhalwal during Kharif 1974 and 1975. At each location, 5 to 7 acres of land were precision leveled with a tractor and scraper and divided into strips measuring 27.5 x 635 feet. Each strip was assigned a certain treatment. In addition, adjointing land was secured to serve as unleveled control plots under management of the local farmer.

The treatments were designed to include completely traditional operations on one plot (Treatment 1) and step by step improvement on the others (Treatments 2 to 7). Eleven treatments were designed, nine of which were applied at any particular site during one season. Other treatments were included to test interesting concepts which may lead to further increases in yield or labor-saving practices such as tillage and planting by tractor (Treatment 8), incorporation of farmyard manure (Treatment 9), furrow irrigation with planting on ridges (Treatment 10) and broad-bed construction (Treatment 11). A brief description of the treatments is as follows:

Treatment 1 -- Traditional practices carried out by the farmer on unleveled land with little use of fertilizer.

Treatment 2 -- Traditional practices carried out by the farmer on leveled land.

Treatment 3 -- Traditional practices carried out by the farmer on unleveled land with improved rate of fertilizer application.

Treatment 4 -- Traditional practices carried out by the farmer on leveled land and with improved fertilizer use.

Treatment 5 -- Improved practices with bullocks except for broadcast sowing and lack of weed control.

Treatment 6 -- Improved practices with bullocks, row planting with kharif drill and partial weed control.

Treatment 7 -- Improved practices with bullocks, row planting and good weed control.

Treatment 8 -- Improved practices, tillage and planting with tractor, good weed control.

Treatment 9 -- Improved practices with bullocks, row planting, use of farmyard manure and good weed control.

Treatment 10 - Improved practices, row planting on ridges, furrow irrigation, and good weed control.

Treatment 11 - Improved practices, row planting on broad beds, furrow irrigation, and good weed control.

The treatments were allocated at random within each replication in the field. Improved practices consisted of extra care in tillage and seedbed preparation using the power source at hand, use of a high yielding variety, good quality seed, and careful irrigation water management. The timing of irrigation was decided by crop needs as indicated by the moisture content of the soil to a depth of one foot rather than by fixed schedule. The amount of irrigation water applied was that required to restore the soil to field capacity. Other improvements were added to certain treatments but were not necessarily part of every improved management plot. Neither were they restricted to improved management plots only. These improvements included precision land leveling, bedding, furrow irrigation, row planting by Kharif drill or dibbler, use of tractor for tillage and planting operations, fertilizer and manure application, weed and insect control.

The experimental plots were sown on July 17 and 18 with the exception of Treatments 1 and 3 in replication No. 1 which were sown by the farmer 2 days later. The sowing dates in 1975 were August 2, 4, and 5. Treatments 1 and 3 were sown by the local farmers 1 week earlier. Improved management plots were sown at a more heavy rate than usual and thinned to a stand after 2 weeks. Weeding was done with the khurpa as often as necessary for good control. This varied from 1 to 5 times on the various plots depending on the conditions. Insect pests were controlled by 2 sprayings. The first of these was applied during the first half of August using Basadin at the rate of 6.5 lb per acre. The second spraying was applied during the second half of August in 1974 and the first week of September in 1975 using Navcron at the rate of 0.8 lb per acre.

Rainfall records were kept in 1975 (Table 1). The total rainfall between March and October was 25.87 inches of which 17.70 inches fell during July, August and September.

Table 1. Monthly total rainfall, Mona 1975.

Month	Rainfall(in.)	Month	Rainfall(in.)
March	1.34	July	7.81
April	3.20	August	6.44
May	-	September	3.45
June	3.63	October	-

Results

Treatment details and the yields of grain obtained are summaried in Table 2.

Land Leveling

Precision land leveling had a pronounced effect on grain yield at TW78. In 1974, the effect amounted to 12.26 maunds per acre under traditional fertility conditions and 13.50 maunds per acre at the improved rate of fertilization.

In 1975, a noticeable carry-over effect of 6.44 maunds per acre was recorded. It should be realized, however, that these yield benefits were not due to land leveling alone but may have been partly caused by improved pest control. Application of pest control measures coincided with the leveling (Treatments 1 to 4 in Table 2).

The benefits of land leveling are uniform wetting of the field and shorter time requirements for irrigation than in unlevel fields. Therefore, land leveling results in water savings. Whereas it is customary for farmers to continue irrigating until the high spots are covered with water, such waste of extra water is not necessary on leveled land. High and low spots both have detrimental effects on yield. High spots would not have sufficient contact time with the water and depressions would receive excessive amounts of water causing low irrigation efficiency. Maize is sensitive to droughts as well as excessively wet conditions. Furthermore, nitrates are apt to be leached by excess water infiltrating in depressional areas. Appreciable amounts of irrigation water were saved by the land leveling operation as evidenced by the fact that the desired amount of water was applied in somewhat more than one-half the time it used to take to irrigate the fields. Yet, the land was not perfectly level in 1974 due to settlement of the soil in the filled areas. As a result high and low spots developed with 1 to 3 inch difference in elevation between high and low. The spots showed differences in stand and yield of grain. Sample areas measuring 10 x 10 feet were harvested separately from high, medium and low spots in each plot at maturity and stand counts were made. The results are presented in Table 3. Although the sample yields shown are not representative for entire plots, they indicate marked differences between high and low spots. Depressional areas generally showed a marked reduction in stand compared with average elevations and a very much lower yield than either high or medium spots.

Soil Fertility

Fertilizer application was less effective than anticipated on unleveled land as well as on leveled land. Application of 150 lb of N and 75 lb of P_2O_5 per acre raised the

Table 2. Yields obtained in optimum management trials with maize at Mona Reclamation Experimental Project, Bhalwal, Kharif 1974 and 1975. (means of 2 replications in mounds per acre)

Treatment No.	Treatment Characterization: Irrigation and General Management	Land Leveling	Irrigation Method	Method of Sowing	Variety	Power Source	Fertilization (lb/ac) N	P_2O_5	K_2O	Weed Control	Pest Control	Yield 1974 TW78	Yield 1975 TW78	Yield 1975 TW122
1	Traditional	Unleveled	Basin	Broadcast	Desi	Bullocks	25	0	0	Poor	None	18.13	6.56 1/	2/
2	Traditional	Leveled	Basin	Broadcast	Desi	Bullocks	25	0	0	Poor	Good	30.39	–	6.54
3	Traditional	Unleveled	Basin	Broadcast	Desi	Bullocks	150	75	0	Poor	None	22.17	15.40	2/
4	Traditional	Leveled	Basin	Broadcast	Desi	Bullocks	150	75	0	Poor	Good	35.67	21.84	8.08
5	Improved	Leveled	Basin	Broadcast	Neelum	Bullocks	150	75	0 3/	Poor	Good	36.58	23.10	12.03
6	Improved	Leveled	Basin	Kharif drill	Neelum	Bullocks	150	75	0	Medium	Good	39.75	–	–
7	Improved	Leveled	Basin	Dibbling (1974) Kharif drill (1975)	Neelum	Bullocks	150	75	0	Good	Good	36.75	44.28	26.18
8	Improved	Leveled	Basin	Drill	Neelum	Tractor	150	75	0	Good	Good	33.26	47.74	20.12
9	Improved	Leveled	Basin	Dibbling (1974) Kharif drill (1975)	Neelum	Bullocks plus 20 T manure (1974) 75 plus 10 T manure (1975)	50 75	50 50	0 0	Good	Good	41.00	47.93	–
10	Improved	Leveled	Ridge/Furrow	Bibbling	Neelum	Bullocks	150	75	0	Medium	Good	–	44.80	20.45
11	Improved	Leveled	Broad Beds	Dibbling	Neelum	Bullocks	150	75	0	Good	Good	–	34.80	30.35

1/ No N was applied by the farmer.
2/ Crop failure due to poor stands on unlevel land and excess moisture in low spots.
3/ N applied in 3 equal doses at sowing, knww-high and hip-level, respectively, under imporved management.
4/ In addition to the 1975 treatment, 150 lb/acre of N and 75 lb/acre of P_2O_5 were applied in 1974.

Table 3. Mean stand counts as plants/acre and grain yields in maunds/acre on high, medium and low spots in an experimental maize field at Mona, 1974.

Treatment No.	Microrelief	Stand	Yield
2	High	18295	77.3
	Medium	24176	51.0
	Low	18077	23.1
4	High	16988	60.2
	Medium	20255	49.4
	Low	139[illegible]	28.3
5	High	18513	61.9
	Medium	25918	54.3
	Low	12633	27.2
6	High	11979	53.4
	Medium	18731	70.3
	Low	12197	30.6
7	High	18731	59.9
	Medium	21345	60.3
	Low	19602	28.6
8	High	16771	54.8
	Medium	20038	67.7
	Low	13721	10.9
9	High	18513	19.1
	Medium	21345	41.5
	Low	16553	55.1
Mean	High	17113	55.2
	Medium	21687	56.4
	Low	15246	29.1

yield of maize only 4.04 maunds on unleveled land at TW 78 in 1974 compared with 25 lb of N as applied by the farmer and 8.84 maunds per acre in 1975 with a second dose of 150 lb. of N and 75 lb of P_2O_5 (Table 2). On leveled land at TW 78 in 1974 the effect of fertilization with N and P was 5.28 maunds. Yields were extremely low on newly leveled land at TW 122 and fertilizer application had very little effect (1.54 maunds per acre). It appears that factors other than leveling and soil fertility kept maize yields at a low level.

Other Improved Practices

Further improvements did not have a large effect on yield in 1974. The change from local variety to good quality seed of Neelum with split applications of N and careful irrigation practices raised the yield by only 1 maund to 36.58 maunds per acre (Treatment 5). Row planting and better weed control in addition to the practices of the previous treatment produced 39.75 maunds per acre (Treatment 6). The highest yield was obtained by the use of 20 tons of barnyard manure and a reduced amount of N and P fertilizer (Treatment 9) in addition to factors applied in Treatment 6. Treatment 9 produced 41 maunds per acre in 1974 (Table 2). The manure treatment also doubled the infiltration rate of water in the plots. Under certain conditions, e.g. in case of salt-affected soil an increased rate of infiltration may be an important improvement. The application of 20 tons of manure was not profitable here in view of the small yield increment obtained (1.25 maund) over Treatment 6. The yields attained in the experiments were generally low. Much higher yield levels could be realized especially from improved management plots but for extensive damage by birds.

In 1975 the manure plots at TW 78 again produced the highest yield, this time with 10 tons of manure application per acre. Weed control appeared to be the most significant factor during kharif 1975 both at TW 78 and TW 122 as follows from comparison of Treatments 7 and 5 (Table 2). Land preparation and planting by tractor was not superior to bullock operations when taking into account the results from both years.

Bedding Techniques

Bedding with 2 rows per bed showed some promise at TW 122 where Treatment 11 produced the highest yield. Both ridge/furrow configuration and broad-bed techniques need to be further perfected in future years. Shaping of ridges and broad beds and fertilizer placement can be further improved when effective bullock implements have been developed. A suitable ridge shaper-planter combination was constructed for experimental use in 1975. This equipment can be readily modified for broad-bed construction. A pore planter is mounted on the

ridge shaper so that a firmly shaped ridge or broad bed is produced with seed placement at uniform depth in an ideal seed bed. Row placement of fertilizer can be readily accomplished with the same equipment by mounting another pore on the shaper, 2 inches beside and 2 inches below the planter pore and approximately 10 inches further to the front. The equipment can be manufactured very cheaply at local workshops. It is not until such supporting equipment has been proven to be effective and acceptable to the farmer that the concept of kharif crop production on ridges or broad beds can be expected to gain widespread application.

Inter-row cultivation for effective weed control is another prerequisite for high yields of maize. Neither can farmers be expected to accept bedding techniques for field crops unless a simple bullock-drawn cultivator is available to keep the rows clean without need for excessive amounts of hand labor. When a suitable cultivator has been devised, the entire production system of maize on ridges or broad beds will be ready for testing in the field and acceptance by the farmer.

Appendix 24

IMPROVED SOIL AND WATER MANAGEMENT PRACTICES FOR OILSEED PRODUCTION[1]

M. Hanif, F.A. Akhtar, Aleemud Din, C.J. deMooy[2]

I. Introduction

The annual domestic consumption of oilseed in Pakistan is approximately 400,000 (4-lakh) tons and is increasing with the growing population of the country.

The annual production of vegetable oil of about 220,000 tons is short of the requirements by 180,000 tons. Pakistan is investing about 150 million rupees of foreign exchange per annum to cope with the situation. Importation of vegetable oils seriously affects the developing economy of the country.

Various scientific, technological, and extension programs aiming at self-sufficiency in edible oils are in progress.

Several brassica species including mustard are important oilseed crops in Pakistan. The growing period of these crops synchronizes with wheat. The possibilities for increasing the area under rabi oilseeds are limited in view of the national interest in boosting wheat production. There is also considerab emphasis on irrigation and other farm resources for cereal production. The obvious solution to the problem is to increase the per-acre yields of oilseeds by making optimum use of the limited irrigation and other farm resources which are available. The present study is an attempt in this direction and focuses on consumptive use of water, fertilization, good crop protection measures and other optimum crop management practices.

II. Methods and Materials

An oilseed experiment with Brassica juncea COSS was conducted in a farmer's field at the Shadab Pilot Project approximately 15 miles southwest of Lahore.

In addition, demonstration plots of a relatively simple nature were laid out in farmers' fields at nearby locations.

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[1]Joint contribution from Punjab Department of Agriculture, Lahore, Pakistan, and Colorado State University

[2]Agronomist, Development Assistants, Punjab Water Management Project, Department of Agriculture, Punjab, Lahore and Professor of Agronomy, Colorado State University, respectively

The experimental variables included traditional and improved treatments in irrigation, fertility and plant protection, as described in Table 1.

Table 1. Treatment combinations applied to oil seed crop at Shadab, 1975/76.

Treatment Number	Description
1	Traditional fertilization (50 lb/ac of N at sowing), traditional irrigation, no crop protection practices.
2	Improved fertilization (70 N + 50 P_2O_5), traditional irrigation, no crop protection practices.
3	Improved fertilization, improved irrigation practices, no crop protection.
4	Improved fertilization, improved irrigation practices, crop protection with Solvisex.

A randomized block design was used with 2 replications. Demonstration plots consisted of treatments 1 and 4 only.

A. Soil Characteristics

The soil of the experimental area was medium textured. Soil samples were taken from the 0 to 6 inch layer and chemically analyzed for total soluble salts, pH, soil organic matter content and available phosphorus. The data shown in Table 2 indicate a nonsaline soil of calcareous nature and low available P content. Physical analysis was conducted to determine the saturation percentage and moisture retention capacity at various tension levels by means of the pressure membrane. The results are presented in Table 3. The moisture percentage at 6 bars tension was estimated at 12.5 percent by weight by graphical interpretation of the data.

Table 2. Chemical characteristics of soil at experimental site, Shadab Pilot Project, 1975.

Depth (Inches)	Electrical Conductivity (mmhos/cm)	pH	Soil organic matter (%)	Available P (ppm)
0-6	0.80	8.3	0.51	2.72

Table 3. Moisture retention characteristics of soil at experimental site, Shadab Pilot Project, 1975.[1]

Depth (inches)	Saturation Percentage	Soil tension (bars)				
		1/3	1	5	10	15
0-6	34	24.8	18.9	14.6	12.0	9.0

[1]Laboratory data courtesy of Central Monitoring Organization (WASID) of the Water and Power Development Agency, Lahore.

B. Land Preparation and Sowing

The fields were precision land leveled with the help of a tractor and scraper to a specification of 0.1 foot. Seed bed preparation was done with a tractor-drawn cultivator. The fields were plowed 3 times, followed by one planking.

The oilseed varietv Raya L-18 (Brassica juncea COSS) was sown broadcast at the rate of 3 seers per acre on October 26, 1975 and incorporated by means of another planking operation.

C. Soil Fertility

Commonly, farmers use 50 lbs cf N per acre for oilseed crops, all of which is applied at sowing. This practice was followed in the traditional management plots. The treatment for improved plots in the experiment consisted of 70 lbs per acre of nitrogen and 50 lbs per acre of phosphorus. All phosphorus and 45 lbs of nitrogen were applied at sowing. The remaining nitrogen was applied at first irrigation on December 4. The source of phosphorus was DAP which contains 18 percent nitrogen. The remaining nitrogen was applied as urea. Improved plots in the demonstration areas received 60 lbs of N and 25 lbs of P_2O_5 per acre.

D. Irrigation

The traditional irrigation treatment consisted of the usual practices followed by the cooperating farmers.

The improved irrigation treatment was based on a 6-bar soil tension criterion. Irrigation water was applied to the field when the soil moisture reached the 6 bar tension level at a depth of 0 to 12 inches which is equivalent to 12.5 percent moisture by weight at the site. The quantity of irrigation water applied was based on the amount of depletion of soil moisture from field capacity in the total root zone.

For this purpose, separate soil samples were taken with the help of a King tube from 0 to 12, 12 to 24, 24 to 36 and 36 to 48 inches at a number of randomly chosen sites in the

plots. The samples were weighed and oven-dried at 105 degrees centigrade to constant weight for moisture determination.

The amount of irrigation applied was determined by use of the following equation for each 12 inch layer of soil and adding the calculated requirements of the individual layers:

$$d = \frac{(Pc - Pw)b \cdot t}{100}$$

where d = depth of irrigation water in inches

Pc = soil moisture percentage by weight at field capacity

Pw = soil moisture percentage by weight prior to irrigation

b = oven-dry bulk density in gm/cm^3

t = thickness of soil column in inches

A Cutthroat flume with dimensions 15 x 8 inches was installed in front of the first field outlet to measure the discharge of the water channel. The time required to supply the required depth of water to each plot was calculated with the help of the following equation:

$$5 = \frac{d \times a}{q}$$

where

t = time in hours

d = depth of water in inches

a = area in acres

q = discharge of irrigation water in cubic feet/second

E. Meteorological Observations

A small meteorological unit was established at the experimental station to measure pan evaporation and rainfall. The data on daily maximum and minimum temperatures and solar radiation for the period from 1963-1973 were collected from Chuharkana Station.[1] This station is situated at a distance of 15 miles from the experimental site at 31 degrees 45' latitude, 73 degrees 48' longitude and an elevation of 800 feet above mean sea level.

[1]Annual reports of the Surface Water Hydrology project, Water and Soil Investigation Division, WAPDA.

Potential evapo-transpiration for the growth season of the crop was calculated with the help of the Jensen-Haise equation:[1]

$$Etp = C_T(T - T_x)R_s$$

where Etp = the potential evapo-transpiration in inches/day

C_T and T_x = temperature coefficients calculated from saturation vapor pressures at prevailing mean maximum and minimum temperatures and elevation of the site

T = mean daily air temperature

R_s = solar radiation expressed as the equivalent depth of water evaporated in inches per day

The equation was calibrated as follows with data from the period 1963-1973:

$$Etp = 0.0123(T - 16.68)R_s$$

The rainfall data recorded at the station are presented in Table 4.

Table 4. Rainfall recorded during growth season of Raya L18 at Chung

Date	Amount (inches)
January 27, 1976	0.05
January 31, 1976	0.57
February 2, 1976	0.24
February 18, 1976	0.07
February 20, 1976	0.45
February 25, 1976	0.22
March 9, 1976	0.22
March 15, 1976	0.24
March 16, 1976	0.63
TOTAL	2.69

[1]Jensen, M.E. and H.R. Haise. 1963. Estimating evapo-transpiration from solar radiation. Journ. Irrigation and Drainage Div. ASCE, Vol. 89, No. IR4.

F. Consumptive Use of Water

Actual consumptive use of water was estimated by two methods:

1. By adding the amounts of irrigation water applied during the season augmented with the amount of precipitation and the difference in soil moisture stored in the root zone at sowing and harvest.

2. By gravimetric determination of soil moisture depletion in root zone to a depth of 48 inches.

The daily actual evapotranspiration occurring was worked out by the latter technique and compared with the potential evapotranspiration calculated with the calibrated Jensen-Haise equation.

Crop-coefficients (K_c) were determined by means of the following equation:

$$K_c = ETa/ETp$$

where

K_c = crop coefficient

ETa = actual evapotranspiration in inches/day

ETp = potential evapotranspiration in inches/day

G. Crop Protection

The plots receiving improved crop-protection practices were treated with Solvisex GR 10 percent at the rate of 30 lbs/acre at preflowering stage.

H. Harvesting

All plots were harvested at maturity on March 29, 1976 with the help of manual labor. Two squares of 11' x 11' were placed randomly in each plot, harvested and thrashed. The yields were converted into maunds/acre and expressed on air-dry basis.

III. Results and Discussion

A. Crop Yield

Fertilization - Improved fertilization, 70 lbs/acre of N and 50 lbs of P_2O_5 had a pronounced effect on oilseed production. The yield was 6.68 maunds per acre under traditional fertility management and 13.43 with the suggested improvements in fertilization (Table 5). Both, the additional 20 lbs of N and the 50 lbs of P_2O_5 presumably had beneficial effects. Since no P at all was applied under traditional

Table 5. Mean Yield of Oilseed Crop and Irrigation Water Applied to the Experimental Field.

Treatment Description	Mean Yield[1] (mds/acre)	Irrigation Water[2] Applied (inches)
Traditional fertilization (50 lbs N), traditional irrigation, no crop protection	6.68 a	5.75
Improved fertilization (70:50:0), traditional irrigation and no crop protection	13.43 b	5.75
Improved fertilization, improved irrigation and improved crop protection practices	13.93 b	4.80
Improved fertilization, improved irrigation and improved crop protection practices	15.68 b	4.80

[1]Averages followed by the same letter were statistically non-significant at the 0.05 level of probability.

[2]Excluding three inches of rauni irrigation.

management, it is believed that restoration of the N:P balance played an important role in the response. The difference was statistically significant at the 0.05 level of probability. It shows that oilseed production can be doubled with judicious fertilizer use.

Irrigation - The total amount of water applied to fields under traditional management by the farmer was 5.7 inches in two irrigations. Under improved irrigation practices, a total of 4.0 inches of water was applied in two irrigations as required by the procedure of restoring the root zone to field capacity each time the surface 12 inches of soil had dried to 6 bars tension. The demonstration plots also received two irrigations under both treatments which amounted to 6.3 inches under traditional and 5.0 inches under improved management. The results indicate that the local practices worked out fairly well although approximately 1 inch of water could have been saved per acre of crop grown. There was a trend towards slightly higher yields from irrigation improvements which was not statistically significant.

Crop Protection - When crop protection with Solvisex was added to improved fertilization and irrigation practices, the yield increased from 13.93 to 15.68 maunds per acre. This trend was not statistically significant but field observations indicated that the crop benefited from application of Solvisex Gr. 10 percent at the rate of 30 lb/acre at the preflowering stage.

Optimum Management Practices - The total package of improved practices raised the yield from 6.68 to 15.68 maunds/acre. This significant increase in production was confirmed by results obtained from demonstration plots where traditional practices yielded 6.3 maunds and improved management 15.4 maunds/acre. The average increase in yield was approximately 140 percent.

Optimum management refers to the most profitable combination of all production factors involved. Each factor also must be applied at its optimum rate. Although the fertilizer rates and irrigation treatment were carefully selected, the oilseed experiments reported here could not be designed to determine the optimum rates of fertilizer and water. it is anticipated from the response obtained that yields can be raised further by higher rates of fertilizer application, especially nitrogen. Since such responses are subject to seasonal variation, future experiments will have to be conducted over a range of weather conditions.

B. Consumptive Use of Water

In addition to the yield information the nature of the experiment permitted calculation of the amount of

consumptive use of water of a crop grown under good management. Consumptive use was determined from:

1. The records of soil moisture fluctuation which were measured gravimetrically to a depth of 48 inches during the season. The soil moisture data are shown graphically in Figure 1. Water used between the date of irrigation and the next soil moisture sampling was estimated by extrapolation and from open pan evaporation records (Table 6). The total amount of water used amounted to 11.42 inches.

2. The amount of irrigation water applied (4.8 inches) augmented with precipitation (2.69 inches) and the differential in soil moisture content at sowing and harvest (3.68 inches). The total of 11.17 inches agreed fairly well with that arrived at by the previous method.

Actual evapotranspiration during the season is shown in Table 6 for 3 periods separated by irrigations. The consumptive use was 0.048 inch per day for the period until the first irrigation on December 4. It increased to 0.070 inch between first and second irrigation and to 0.090 between second irrigation and harvest. The potential evapotranspiration as calculated by the Jensen-Haise equation was 0.109, 0.078 and 0.103 inch per day, respectively, for the same periods. Both actual and potential evapotranspiration rates are shown in Figure 2.

The curves indicate that the actual ET of the young crop remained considerably below the potential ET during November and December. From about January 1 to February 15, ET was equal to potential ET during the time the crop canopy was closed whereas after that the actual water use leveled off towards maturity of the crop. These relationships are expressed as crop coefficients (K_c) in Table 7 where:

$$K_c = \frac{ETa}{ETp}$$

Table 7. Crop coefficients (K_c) for oilseed Raya L18 at Shadab, 1975/76.

	November	December	January	February	March
1-10	0.33	0.68	0.97	1.00	0.75
11-20	0.44	0.80	1.00	0.98	0.56
21-30	0.59	0.91	1.00	0.85	-

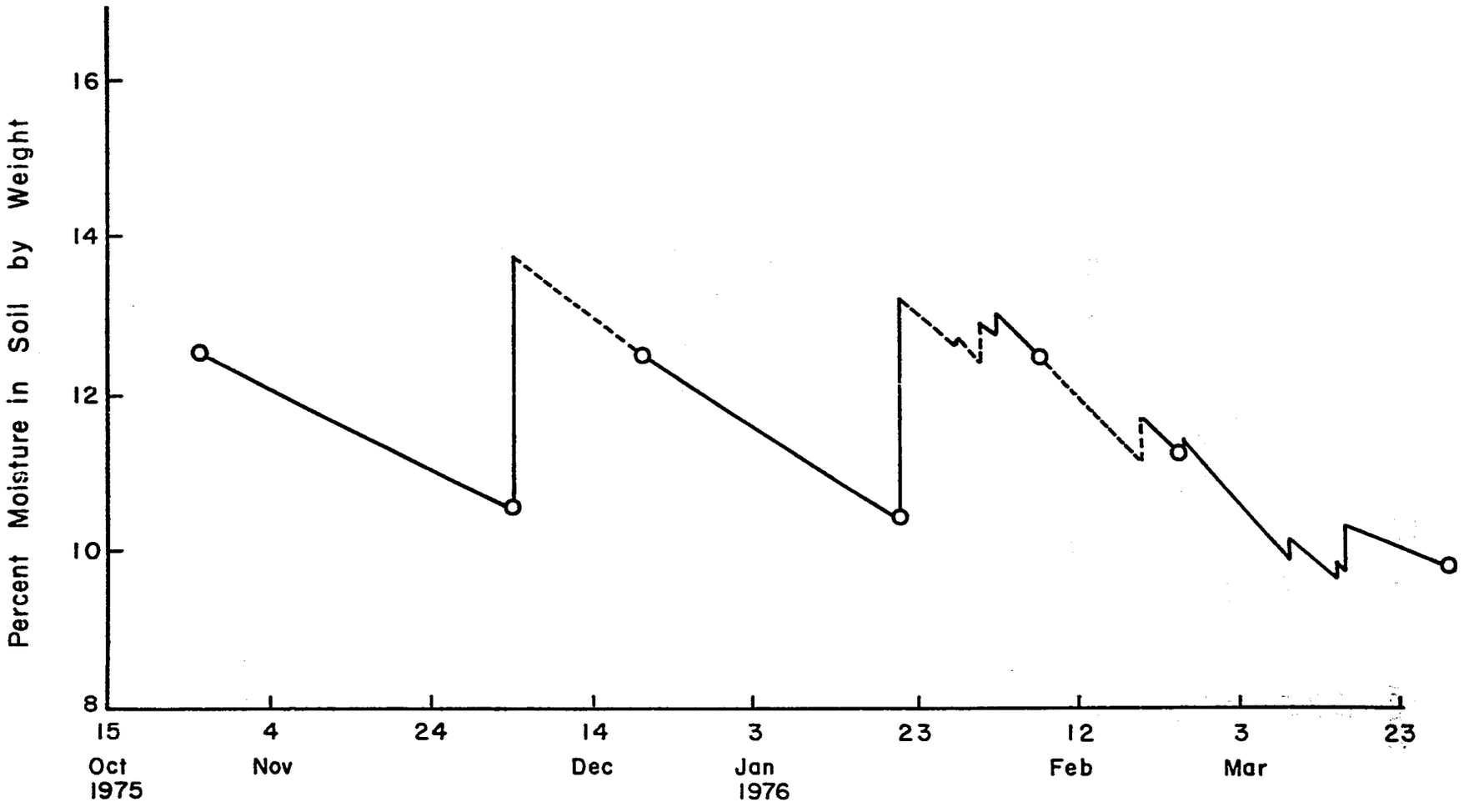

Figure 1. Soil moisture fluctuations under oilseed during the 1975/76 season at the experimental field, Shadab.

Table 6. Computation of Consumptive Use of Water (Inches) for Oilseed Crops at Shadab, Rabi 1975/76, by Gravimetric Soil Moisture Determination.

	Rauni Irrigation		First Irrigation (4 Dec 1975)		Second Irrigation (21 Jan 1976)		
	At Sowing 26 Oct 75	B.N.I.[1] 6 Dec 75	A.I.[2] 20 Dec 75	B.N.I. 21 Jan 75	A.I. 5 Feb 76	A.I. 24 Feb 76	At Harvest 29 Mar 76
Soil Depth (inches)							
0-12	2.70"	2.42"	3.00"	2.41"	2.95"	2.62"	2.32"
12-24	3.33	2.76	3.20	2.88	3.10	2.86	2.52
24-36	3.25	2.60	3.07	2.53	3.25	2.87	2.42
36-48	3.20	2.80	3.23	2.60	3.15	2.85	2.54
Total amount of water in 0-48" soil column	12.48	10.58	12.50	10.42	12.45	11.20	9.80
Water used between samplings	1.90		2.08		2.65		
Pan evaporation	0		0.22		0.09		
Estimation from graph	0		1.08		0.71		
Rainfall	0		0		2.69		
Total amount of water used between irrigations	1.90		3.38		6.14		
Number of days between irrigations	40		48		68		
Consumptive use (inches/day)	0.048		0.070		0.090		
Potential evapotranspiration	0.109		0.078		0.103		

[1] Before Next Irrigation

[2] After Irrigation

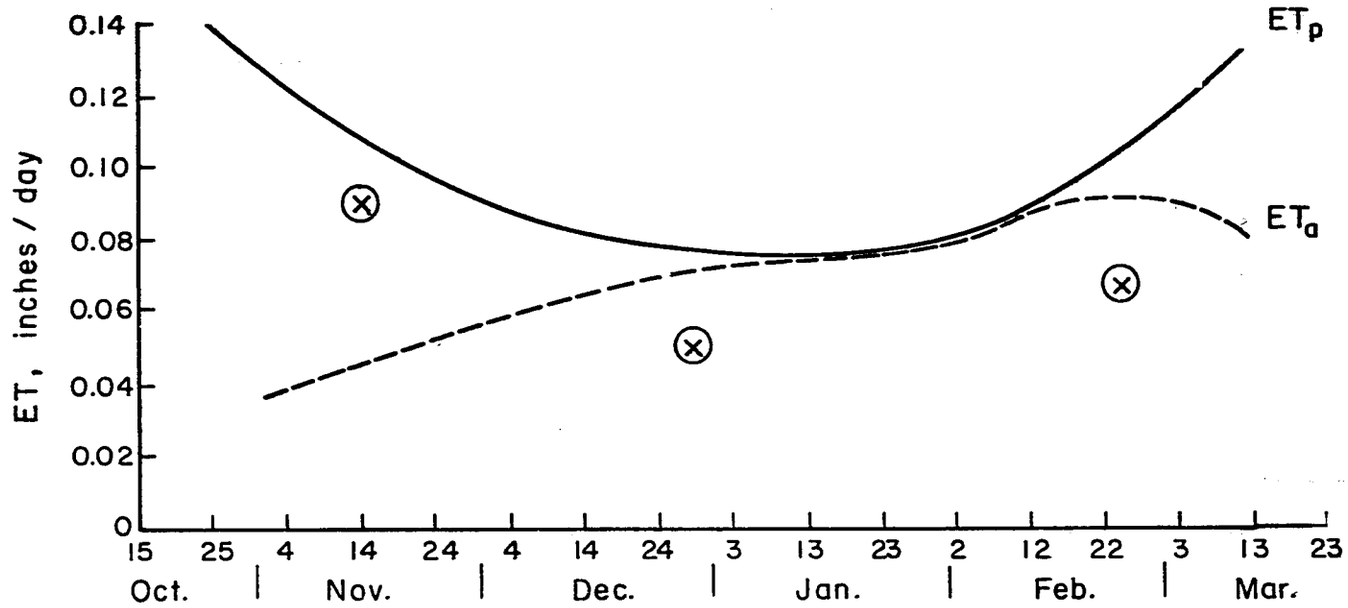

Figure 2. Actual (ETa) and potential evapotranspiration (ETp) under oilseed crop at Shadab, 1975/1976.

C. Economics of Crop Production

Traditional Management - The cost of production of raising one acre of Raya L-18 in traditionally managed fields was found to be Rs 743.95/acre as compared with returns of Rs 501/acre (Table 8). Thus it was observed that farmers raising their oilseed crop by indigenous methods are operating at a loss of Rs 242.95/acre. The farmers absorb their losses by ignoring the value of personal labor and land.

Fertilization - Application of fertilizers at the rate of 70 lb of N and 50 lb of P_2O_5 turned the production loss into a net profit of Rs 188.30 per acre (Table 8). The benefit/cost ratio for improved fertilization for oilseed was 6.75 (Table 9).

Irrigation - Improved irrigation practices were applied to plots which also received the higher rates of fertilization. Improved irrigation did not involve additional cost but decreased the cost of production by Rs 9.00/acre. The savings in cost of production were accompanied by Rs 37.50/acre extra returns in addition to those resulting from improved fertilization.

The numberical value of the benefit/cost ratio for improved irrigation was infinitely high because there was improvement in both costs and returns.

Crop Protection - Improved crop protection practices applied in addition to improved fertilization and irrigation involved an additional cost of Rs 52.20/acre. The investment resulted in an increase of Rs 131.25/acre in returns from the crop. The benefit/cost ratio for improved crop protection practices was 2.51 (Table 9).

The Total Package - The total package of improved management was highly rewarding. The improvements involved an additional expenditure of Rs 117.70/acre against traditional management. However, the returns from this investment amounted to Rs 675.00/acre. The benefit/cost ratio for the total package of improvements was 5.71. At such high benefit/cost ratios, most farmers will be interested in improvement opportunities provided that credit is available for the necessary investments.

IV. Conclusions

1. A package of improved practices in oilseed crop production involving more balanced fertilizer rates, irrigation, and crop protection measures raised the yield from 6.68 to 15.68 maunds/acre or 135 percent.

Table 8. Production Costs and Benefits for Various Farm Operations in Oilseed Production at Farm Gate in Shadab, Kharif 1975-76 (rupees/acre).

Category	Treatment 1	Treatment 2	Treatment 3	Treatment 4
COSTS				
Lease of agricultural land				
170 days @ Rs 600/acre/annum	279.45	279.45	279.45	279.45
Land and seedbed preparation				
3 plowings @ Rs 15/plowing	45.00	45.00	45.00	45.00
1 planking @ Rs 5/planking	5.00	5.00	5.00	5.00
Sowing				
1 plowing @ Rs 15/plowing	15.00	15.00	15.00	15.00
1 planking @ Rs 15/planking	5.00	5.00	5.00	5.00
Seed				
2-1/2 seers @ Rs 3.00/seer	7.50	7.50	7.50	7.50
Fertilization				
Urea @ Rs 75/bag	75.00	75.00	75.00	75.00
D.A.P. @ Rs 75/bag	0	75.00	75.00	75.00
Irrigation				
@ Rs 10/acre inch	57.00	57.00	48.00	48.00
Plant Protection				
Solvisex Gr. 10% 30 lbs @ Rs 1.74/lb	0	0	0	52.20
Wages of farmer				
@ Rs 1/acre/day	170.00	170.00	170.00	170.00
Land Revenue and Other Taxes	15.00	15.00	15.00	15.00
Harvesting Charges				
4 man days @ Rs 10/day	40.00	40.00	40.00	40.00
2 bullock days @ Rs 10/bullock day	20.00	20.00	20.00	20.00
Miscellaneous Charges				
Transport of Fertilizer, etc.	10.00	10.00	10.00	10.00
TOTAL COSTS	743.95	818.95	809.95	862.15
RETURNS				
Value of crop @ Rs 75/md	501.00	1007.25	1044.25	1176.00
PROFITS				
Net Profit	-242.95	188.30	234.80	313.85

Table 9. Costs and returns for improved crop management practices in oilseed production - Shadab, Rabi 1975-76.

Treatment No.	Category	Additional Cost of Production (Rs/acre)	Additional returns (Rs/acre)	Additional profit (Rs/acre)	Benefit/ Cost Ratio
1	Fertilization	75	506.25	431.25	6.75
2	Irrigation (in addition to Treatment 1)	-9.00	37.50	46.50	high
3	Crop protection (in addition to Treatment 2)	52.20	131.25	79.05	2.51
4	Total improvement package	118.20	675.00	556.80	5.71

2. Fertilization with 70 lb of N and 50 lb of $P_2)_5$ per acre raised the yield from 6.68 to 1e.re maunds/acre. This accounted for 75 percent of the total yield improvement.

3. Improved irrigation practices applied in addition to fertilization tended to raise yields slightly to 13.93 maunds per acre and saved one inch of irrigation water.

4. Crop protection with 30 lbs per acre of Solvisex Gr 10 percent added another 1.75 maunds to the yield.

5. Improved management practices on demonstration plots led to comparable results. Yields were raised from 6.3 to 15.4 maunds per acre, or 144 percent.

6. The consumptive use of water of the crop as determined by gravimetric methods amounted to 11.42 inches when 6 bars of soil moisture stress were allowed to develop to a depth of 12 inches before irrigation water was applied.

7. Consumptive use of water estimated from irrigations, rainfall and soil moisture differential between sowing and harvest was 11.17 inches.

8. Actual evapotranspiration rates were determined. These were 0.048, 0.070, and 0.090 inches per day for the periods October 26 to December 4, December 4 to January 21 and January 21 to March 27, respectively.

9. Crop coefficients, K_c, were calculated from actual and potential evapotranspiration rates. The K_c gradually increased from 0.33 during the early part of the season and were approximately equal to 1 between January 1 and February 15 before decreasing to 0.56 towards maturity.

10. Under traditional management farmers were unable to make a profit and lost as much as Rs 242.95 per acre of oilseed crop grown. Using proper fertilization, farmers earned Rs 188.30. Improved irrigation raised profits per acre to Rs 234.80 and additional crop protection measures to Rs 313.85.

11. Benefit/cost ratios for the improved practices were found to be very favorable. The investment for fertilization carried a benefit/cost ratio of 6.75. Improved irrigation practices reduced production costs. The benefit/cost ratio was, therefore,

infinitely large. Crop protection cost Rs 52.20 per acre with a benefit/cost ratio of 2.51. The total package of improvements cost Rs 118.20. The associated benefit/cost ratio of 5.71 is highly important for economical oilseed production.

Appendix 25

THE FERTILIZER RATIO CONCEPT

John Reuss and Sam Johnson III[1]

INTRODUCTION

The concept of plant nutrient ratios has long been utilized by agronomists and appears to be particularly prevalent in Pakistan. Production experts often express concern that the nutrient ratios utilized by the farmers are not optimum for a particular crop (4). These concerns are reflected in the press and are considered by those charged with planning production and imports. Agronomists interested in plant nutrients may thus find themselves designing experiments to determine the optimum ratios of plant nutrients for different crops grown under different conditions.

For the sake of simplicity we will limit this discussion to two nutrients, nitrogen and phosphorus and the resulting N/P ratios. This is appropriate because these fertilizer elements are the most widely used in Pakistan and crops often respond to their use. However, combinations involving other nutrients or crop inputs are subject to the same principles.

I. THE RATIO CONCEPT

First we must recognize that the concept of an optimum ratio does not simply refer to a single rate of N and P_2O_5. Suppose we recommend that 90 lb N and 45 lb P_2O_5 be applied. The N/P ratio of this dose is, of course, 2:1. If this ratio only applies to this single rate or dose the concept of ratio would be trivial. In order for N/P ratio to be a meaningful concept it must apply more generally over the range of rates that may be effectively utilized.

Thus, there are certain principles inherent in the concept of an optimum ratio for a given crop that are often not understood or at least are not clearly stated. First, an optimum ratio requires that a generalized N - P response surface exists that is reasonably valid for the population of fields with which we are concerned. Secondly, the economic optimum ratio will depend on the relative price of the two inputs. Finally, the concept of an optimum ratio would place severe constraints on the geometry of the response surface. Let us first examine the effect of relative prices.

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II. ECONOMIC CONSIDERATIONS

The relationship between optimum ratio and relative price of the nutrients is a key concept. Suppose we have experimentally determined under a given set of conditions the combinations of N and P, applications that will result in a maize yield of 40 mds/acre. Plotted on a graph such as Figure 1, these combinations constitute a contour line on the response surface, or what is known as an isoquant (2). The two straight lines with negative slopes are isocost lines (2). The broken line has a slope of -2 and all points along that line represent an equal total fertilizer cost if the price of N is twice that of P_2O_5. The solid isocost line has a slope of -1 and all points on this line represent an equal total fertilizer cost if the price per lb of N and P_2O_5 is the same.

For any N/P cost ratio the least cost combination to produce 40 mds/acre occurs at the point where the slope of the 40 md. isoquant is equal to the N/P cost ratio. In mathematical terms this optimum is described as the point where:

$$\frac{dP}{dN} = \frac{C_N}{C_P} \qquad (1)$$

Where P and N are the ratio of nutrients applied at any constant yield and C_N and C_P are the costs per lb. of the two nutrients. Thus, Equation 1 states that the first differential of nitrogen applied with respect to phosphorus applied at constant yield is equal to the N/P cost ratio. At this point the optimum ratio of the two inputs is achieved. If these isoquants take the usual shape as shown in Figure 1, the optimum ratios of N and P are obviously dependent on the relative N and P price. The previously stated principle, that optimum ratios are dependent on the cost price ratios of their inputs, arises from these relationships.

Next, we shall examine the constraints these relationships impose on the nature of the N - P response surface if the concept of an optimum N/P ratio is to be valid. If this response surface is represented by yield contours on a graph such as that shown in Figure 2, any straight line passing through the 0.0 point represents a fixed N/P ratio. For a complete validity of the optimum ratio concept, all isoquants (contours) that any such line might cross, must be crossed at the same slope. If the slope of the contours are not equal along any such line, it means that for the price ratio represented by these slopes the optimum ratio of N and P varies with the nitrogen (or phosphorus) cost constraints imposed on the geometry of the response surface by this concept. An interesting exercise would be to define these constraints in mathematical terms so that mathematical response surface models could be similarly constrained and the effect on goodness of fit examined with various data

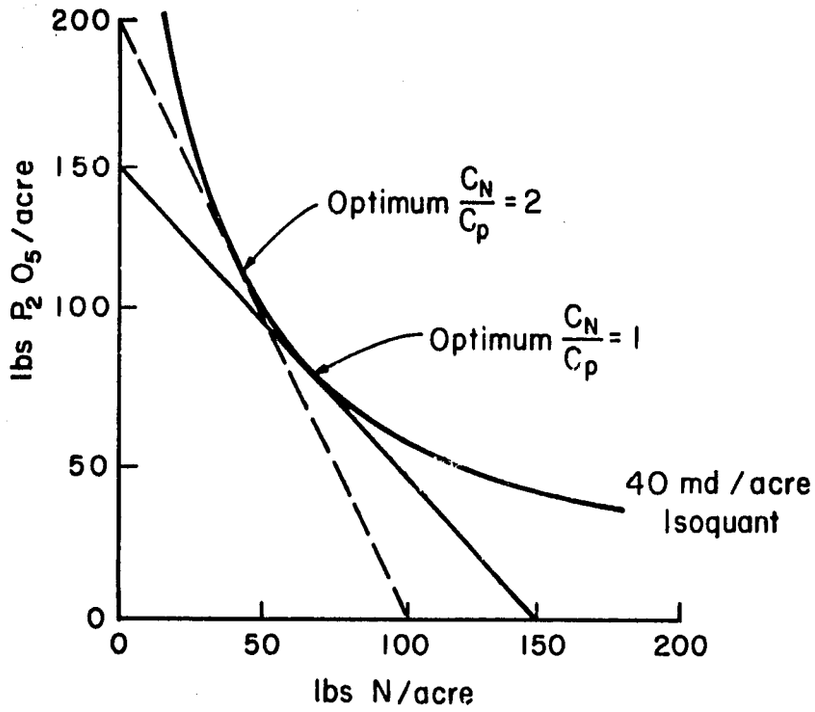


Figure 1. Illustration of determination of optimum combination of N and P for two different N/P price ratios for a sample 40 mds/acre isoquant.

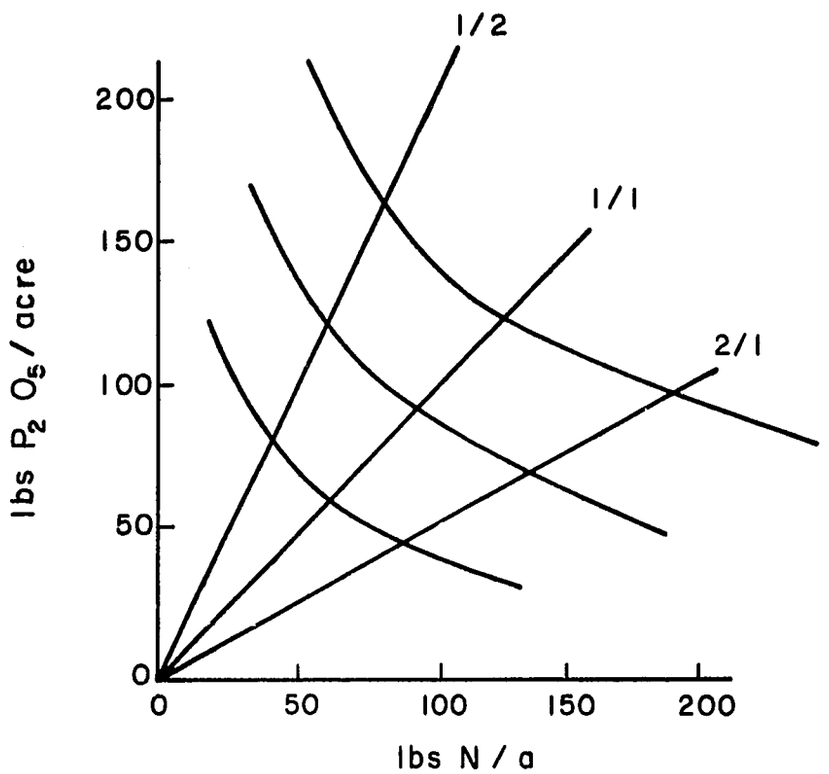


Figure 2. Graphically constructed yield isoquants that appear to satisfy the optimum ratio constraints over the range of N/P ratio from 1/2 to 2/1.

sets. This exercise is unfortunately beyond the scope of the present analysis.

One special case to be considered is the possibility of a response surface of the type shown in Figure 3(1). If the response is of this type the two nutrients cannot substitute one for the other. The particular surface shown in Figure 3 assumes the bends in the yield isoquants occur at a constant N/P ratio represented by the dashed line. Even surfaces that do not allow substitution may not have this property, in which case the optimum ratio would not be independent of fertilizer rate.

Most published two nutrient response surfaces are not in fact of the type shown in Figure 3, but are rather of the type where substitution dependent on price ratios is allowed. However, we must recognize that most published response surfaces have been determined by a least squares fit of mathematical models that would not allow the non-substitution type of surface. Even if the true surface were of this type a good fit might be obtained from one of the commonly used second order polynomials that would indicate that a moderate amount of substitution was permissible. This possibility should be considered in the interpretation of any data set. The model shown in Figure 3 will be further discussed in Section III.

It should also be emphasized that in an economic sense whenever the isoquants "bend back upon themselves" or have positively sloped segments they are no longer within the economic range of production (3). The parallel dashed lines in Figure 4, indicate the points at which the isoquants bend back upon themselves. The lines OC and OL join these points and form the boundaries for the economic region of production. These isoclines (lines, OC and OL) then define the boundaries outside of which our agronomic experiments have no relevancy in terms of economic optimum productions. Such regions are not uncommon in nutrient response surfaces, as when high nitrogen rates result in lodging and loss of yields in small grains.

Fortunately, the ratio concept does not necessarily need to be strictly valid for all possible N/P cost ratios to be agronomically useful. The regular contours shown in Figure 2 would probably meet the criteria sufficiently well to be useful in the range of N/P cost ratios from 1/2 to 2.

III. AGRONOMIC CONSIDERATION

For the moment let us reconsider the response surface shown in Figure 3 that does not allow for substitution between the two nutrients. In fact, this is the surface that would be generated if the system strictly follows one of the oldest

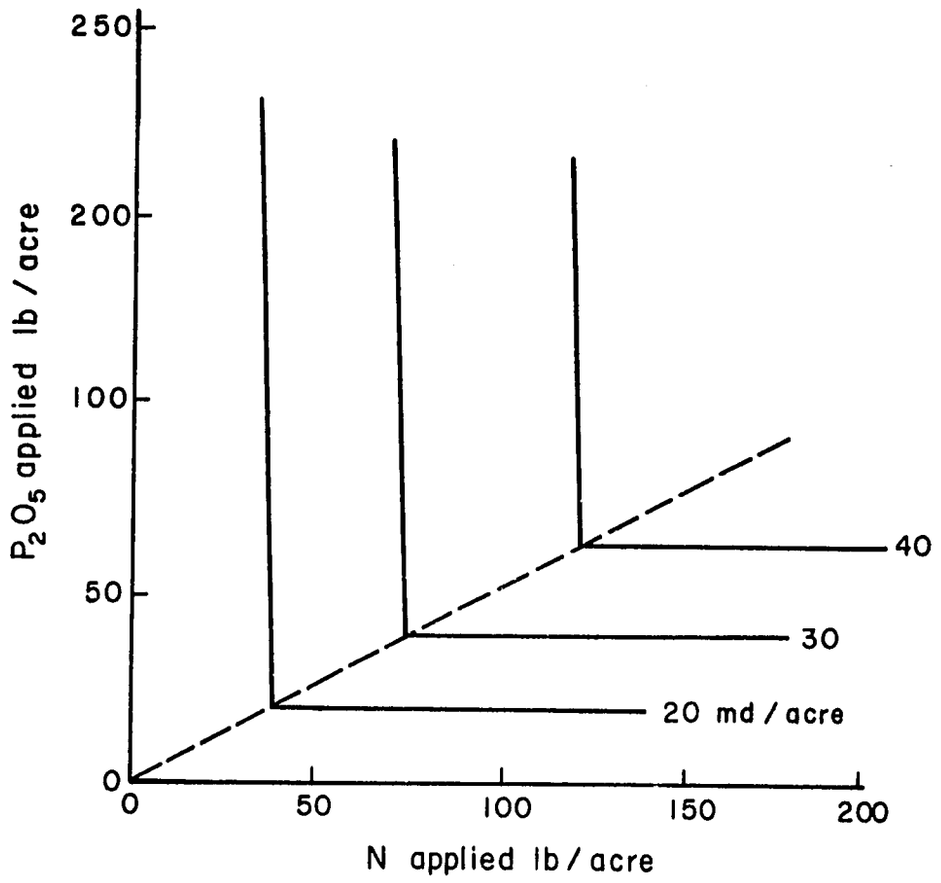


Figure 3. Yield isoquants for an N/P response surface for which no substitutes are allowed and the optimum N/P ratio is independent of rate applied.

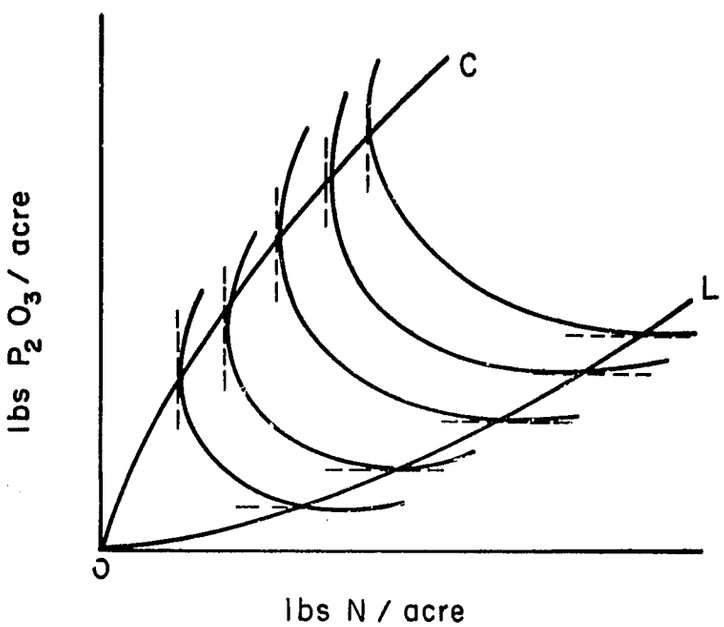


Figure 4. Isoquant map and the relevant range of production.

concepts in plant nutrition, that of limiting factors. According to this concept, if one factor or nutrient is limiting, additional increments of other nutrients will not increase production. Published response surfaces typically have regions where substitution is effective and other regions where it is not. Thus, if one is in sufficiently short supply, it becomes a limiting factor. As mentioned above, it behooves us to be extremely careful in interpreting data from field experiments that we do not in fact create an area in which substitution is allowable by fitting a mathematical model that could not accomodate the surface shown in Figure 3.

Considering the above discussion, it seems anticlimactic to question the agronomic validity of the ratio concept. Many plants use the elements N and P in about a 10/1 ratio, or on the basis of N to P_2O_5 would be about 4.4/1. Since the efficiency of uptake is usually less for applied phosphorus than for nitrogen, particularly in the season of application, we often find recommended N/P ratios for non-leguminous crops of about 2/1.

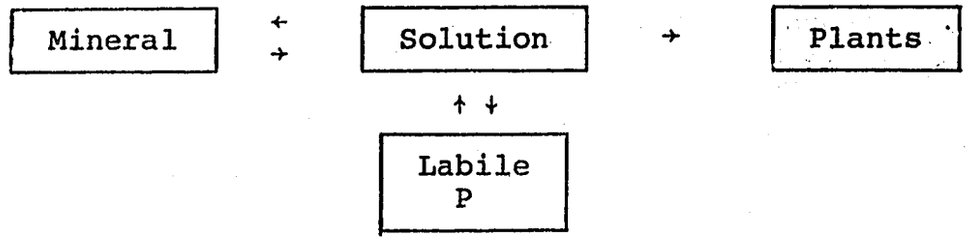
One of the assumptions stated above that must be met for the concept to be valid is that there is a general response surface that will be valid for a particular crop over some geographic area or some particular group of soils. This includes not only the general form of the surface but that the initial levels of N and P, available to the crop without additional fertilizer should be reasonably constant. In practice they are far from constant and the apparent response surfaces obtained from different fields may be drastically different. Thus, the response surface defined from a field experiment will be that starting from some initial N and P values which we will call N_i and P_i. The actual surface we plot is in fact that of:

$$\text{Yield} = \int\{(N_i + N_a),\ (P_i + P_a)\}$$

Where N_a and P_a are amounts applied. Thus from different fields we are examining different regions of the surface. An N_i and P_i are usually unknown, conclusions drawn concerning the optimum ratios or the validity of the ratio concept may vary drastically from site to site.

The above assumes that the response surface is the same across a site and only the origin varies. In fact, the amount of fertilizer required to produce a given response may vary drastically on different soils. Consider for instance the phosphorus system which can be schematically represented by Figure 5.

Figure 5. Schematic representation of the soil phosphorus system



Only a very small fraction of the total P in the soil in solution form at any one time. This is in equilibrium with a somewhat larger pool of so-called labile P. This equilibrium is different in different soils. In some soils the labile pool may be relatively small but will maintain a relatively high solution concentration. This is adequate for plant needs until the pool is depleted, but this condition may occur rapidly. Thus, the capacity to supply P may be low, but it can be supplied at a relatively high intensity, i.e. solution concentration. Such soils could be expected to give large response to a minimum application of P but the applied P would be rapidly depleted.

The equilibrium in other soils may be such that the labile pool must be very large before the solution concentration is sufficiently high to maintain maximum plant growth. Thus, these soils have a large capacity to supply P, but at low intensity. In these systems a large application would be required to obtain maximum response per unit of P applied to that crop could be small, and the response surface would appear quite different from that of the soils having a low P capacity associated with a high intensity.

This paper, of course, cannot cover all aspects of the supplying power of the soils for plant nutrients but should be sufficient to illustrate some of the technical and economic limitations of the ratio concept. Raising an alarm over the Pakistan farmers' improper fertilizer ratio not only serves no useful purpose but also illustrates a lack of knowledge of the technical-economic relationships involved. A blanket recommendation for the whole country such as a N/P ratio of 2/1 will not be valid for all areas or farmers.

Farmers in different stages of adoption of improved practices will be applying widely different rates. There is no sould basis for assuming that ratios should be the same for different doses. Actually, most fertilizer experiments would have to be drastically redesigned in order to adequately test the ratios concept, even for fixed cost/price relationships.

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Appendix 26

FERTILITY-WATER INTERACTION EXPERIMENTS ON RICE AT KALA SHAH KAKU (1976)[1]

A. Majid, M. Saddique, J. Reuss[2]

INTRODUCTION

During the past three years trials involving rates of nitrogen fertilizer and irrigation frequency have been conducted by the Rice Research Institute in cooperation with the Colorado State University water management team.[3]

Part of the variation is apparently due to inherent differences in site fertility, a problem that is common in this type of investigation. Probably more important, however, is the fact that simple irrigation frequency does not adequately define the moisture regime. In the previous experiments long intervals between irrigations were acceptable in wet seasons but not in dry seasons. The difficulty of imposing water variables under conditions of erratic rainfall are formidable, as it is usually not possible to impose water stress on field plots during periods of high rainfall. It would seem appropriate to define our water variable in terms of potential evapotranspiration minus rainfall rather than simple irrigation frequency. With this procedure it is possible to compensate for moderate amounts of rainfall by using it to replace irrigation.

OBJECTIVES

The objectives of the trials are:

1. To define the water x nitrogen relationship for high yielding rice in the Punjab.

2. To utilize this information in formulating appropriate fertility and water management recommendations.

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[1]Progress Report, November 1976.

[2]Director and Assistant Plan Physiologist, Rice Research Institute and Agronomist, CSU Water Management Project, respectively.

[3]See report entitled "Fertility and Water Interaction Experiments on Rice at Kala Shah Kaku." prepared for Rice Production Seminar, Larkana, May 31 thru June 1, 1976, by A. Majid, J. Eckert, J. Reuss and S. Johnson III.

PROCEDURE

The incomplete factorial design using five nitrogen and five irrigation levels similar to that used in the past was utilized. Expected weekly evapotranspiration (ET_p) values were developed by a graphical interpolation of the monthly values given by Clyma and Rafique Chaudry[1] (Table 1). The ET_p appears to be almost constant at 1.7 inches/week during much of the rice growing season.

Table 1. Weekly rainfall at Kala Shah Kaku during the 1976 rice season and potential evapotranspiration based on historical data.

Dates	Rain (inches)	ET_p (inches)
7/2 thru 7/8	0	2.0
7/9 - 7/15	2.23	
7/16 - 7/22	2.68	1.9
7/23 - 7/29	2.23	1.8
7/30 - 8/5	7.96	1.7
8/6 - 8/12	7.92	1.7
8/12 - 8/19	0.99	1.7
8/20 - 8/26	1.98	1.7
8/27 - 9/2	1.57	1.7
9/3 - 9/9	4.89	1.7
9/10 - 9/17	0	1.7
9/11 - 9/24	0	1.6

The irrigation treatments were designed to replace various fractions of the ET_p minus rainfall as follows:

No.	Water replaced weekly (inches)
1-1	0.7 (ET_p - R)
1-2	1.0 (ET_p - R)
1-3	1.3 (ET_p - R)
1-4	1.6 (ET_p - R)
1-5	1.9 (ET_p - R)

Where ET_p is the potential evapotranspiration, R is the actual rainfall and the coefficients 0.7, 1.0, 1.3, 1.6 and 1.9 are the fractions of ET_p minus R to be replaced. In practice the ET_p minus R was calculated weekly and multiplied by the coefficient. If the result was greater than 2.0 inches the calculated amount of water was applied to the plot. If

[1]Clyma, W., and Rafique Chaudry. 1975. Water Management Tech. Report No. 40. Colorado State University, Fort Collins, Colorado. 16 pp.

the result was less than 2.0 inches the plot was not irrigated that week and (ET_p - R) was carried over and added into the next weeks calculation.

Nitrogen rates selected were 0, 50, 100, 150 and 200 lbs N per acre. The complete treatment set is shown in Table 2. The original intention was to apply all of the 50 lb rate, one-half the 100 lb rate and one-third of the 150 and 200 lb rates at seeding. The remainder of the 100 lb rate plus one-third of the 150 and 200 lb treatments were to be applied in a second application with a final application of one-third to the 150 and 200 lb/acre treatments. Due to heavy rains, the second application was delayed and the second and third applications were combined in the first week of September.

Table 2. Treatment set for 1976 Irrigation x Nitrogen Experiment on Rice

Treatment No.	Nitrogen lbs/Acre	Irrigation
1	0	I-1 = 0.7 (ET_p - R)
2	100	-do-
3	200	-do-
4	50	I-2 = 1.0 (ET_p - R)
5	150	-do-
6	0	I-3 = 1.3 (ET_p - R)
7	100	-do-
8	200	-do-
9	50	I-4 = 1.6 (ET_p - R)
10	150	-do-
11	0	I-5 = 1.9 (ET_p - R)
12	100	-do-
13	200	-do-

Plot size was 12 ft by 20 ft with an 8 ft wide buffer plot between created plots. Three replications were used in a randomized block design. The plant spacing was 9 by 9 inches. The harvest sample consisted of 200 plants. After harvesting the paddy was tested for moisture and yields were converted to a 14 percent moisture basis.

The high yielding IR 6-945 variety was used. Plants were transplanted the first week in July and all plots were flooded at that time. A basal dose of 100 lbs P_2O_5/acre was applied to all plots prior to sowing.

In order to control the amount of water applied to each plot a constant level was required in the water channel. This was maintained by means of an overflow system allowing excess water to flow over the check in the main channel. Water was applied through syphon tubes and the amount controlled either by measuring the depth in the plot or by timing the application depending on whether or not the plot contained water at the start. Details of the method of water application are given in a separate report.

RESULTS

This experimental procedure, like most field irrigation experiments, is subject to the limitation that moisture stress can be attained only when rainfall is less than evapotranspiration plus percolation. Thus irrigation variables cannot be applied when high rainfall occurs. The "normal" rainfall pattern at Kala Shah Kaku would allow stress to develop on the low irrigation treatments during much of the growing season. However, a total of over 33 inches of rain were recorded between 1 July and 5 September, 1976 so no stress could be applied before early September. All plots were continually flooded by rainfall and some runoff and surface drainage occurred. Unfortunately the runoff and surface drainage could not be measured. Water application began 10 September and three weekly applications were applied, ending 24 September. The irrigation actually applied to each treatment is shown in Table 3. As a result of the short time the irrigations were applied the procedure of skipping an irrigation when less than 2.0 inches were required, caused the increments of total water applied to be unequal. Actual applications were 2.2, 3.2, 6.5, 7.9, and 9.3 inches for treatments I-1, 2, 3, 4, and 5 respectively.

Yields of dry paddy are shown in Table 4. Highly significant yield differences occurred. The experiment can also be analyzed as a 3 by 3 factorial by dropping treatments No. 4, 5, 9, and 10. When this is done we find significant irrigation and irrigation by nitrogen interaction.

These differences are modest but still are important even though a water variable could only be applied during the final three weeks of the growing season. Maximum hields of 72.6 mds/acre were obtained from irrigation treatment I-4 i.e., 1.6 (ET_p - R) and 150 lbs N/acre. However, very acceptable yields of about 68 mds/acre resulted from both the I-1 treatment with 100 lbs N/acre applied and the 1-2 with 50 lbs N.

No economic analysis has yet been applied to this data. The experiment is designed to be interpreted by fitting a response surface by regression analysis and this has not yet been done. In this very wet year good yields were obtained with the I-1 and I-2 treatments which supply less

Table 3. Dates and amounts of irrigation applied to fertility irrigation experiment on rice, 1976.

Treatment No.	Date	Application (inches)	Total (inches)
I-1	10 Sept.	nil	
	17 Sept.	2.24	
	24 Sept.	nil	2.24
I-2	10 Sept.	nil	
	17 Sept.	3.20	
	24 Sept.	nil	3.20
I-3	10 Sept.	2.20	
	17 Sept.	2.21	
	24 Sept.	2.25	6.46
I-4	10 Sept.	2.40	
	17 Sept.	2.72	
	24 Sept.	2.75	7.87
I-5	10 Sept.	2.85	
	17 Sept.	3.23	
	24 Sept.	3.25	9.33

Table 4. Yield of rice in maunds of paddy per acre (14 percent moisture) from water-fertility interaction experiment (1976).

Irrigation Treatment	N rate, 160/acre				
	0	50	100	150	200
5. 1.9 (ET_p - R)	53.4		71.3		63.7
4. 1.6 (ET_p - R)		63.9		72.6	
3. 1.3 (ET_p - R)	60.1		69.8		71.4
2. 1.0 (ET_p - R)		67.8		67.6	
1. .7 (ET_p - R)	51.1		68.1		63.7

water than is normally applied to rice. Previous results[1] show quite satisfactory yields with irrigation frequencies of 15 or more days in two of the three previous years. While long term records indicate that we have recently been in a cycle of heavier than average monsoon rains, it would still appear that if water availability is limiting rice acreage it may generally be more advantageous to increase acreage to the point where less than optimum is applied. Most years the resulting yield decreases apparently will be modest. Further analysis from an economic point of view will be required before recommendations can be formulated.

[1]See Majid et al. 1975, cited pp 1.

Appendix 27

FERTILITY WATER INTERACTION EXPERIMENTS ON RICE AT KALA SHAH KAKU[1]

A. Majid, J. Eckert, J. Reuss and S. Johnson[2]

INTRODUCTION

During the past three years experiments involving water management variables have been conducted at the Rice Research Institute at Kala Shah Kaku by Institute staff members in cooperation with the Colorado State University, Water Management Team. These trials involve nitrogen rate and irrigation frequency variables. The paper presented here is a general progress report and is not intended as a formal research paper. The conclusions are based on graphical interpretations rather than a response surface model fitted by mathematical techniques. This approach was taken in order to arrive at a general interpretation that would be available to share with the participants in this seminar. It is not intended as a complete or final analysis of the data.

PROCEDURES

The basic design utilized was an incomplete factorial involving; 5 nitrogen rates (0, 50, 100, 150, and 200 lbs. N/A) and 5 irrigation frequencies as shown in Table 1. In the 1973 trials treatment No's. 2, 3, 11, and 12 were omitted. Three replications in a randomized block design were used in all cases. No phosphorus was applied to the 1973 trials, but in 1974 100 lbs. P_2O_5/acre was applied to all treatments.

Plot size was 8 ft, 3 in x 20 ft. A buffer plot of the same size was located between each experimental plot to minimize effects of lateral movement or leakage through bunds. At each scheduled irrigation three inches of water were applied unless standing water remained on the plot from previous irrigation or rainfall, in which case sufficient water was applied to attain an average water depth of 3 inches on the plot.

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[1]Prepared for Rice Production Seminar Larkana, May 31-June 1, 1976. Joint Contribution of Rice Research Institute, Kala Shah Kaku and Colorado State University Water Management Team.

[2]Director and Assistant Plan Physiologist, Rice Research Institute and Field Party Members of Colorado State University's Water Management Project in Pakistan.

Table 1. Basic design for irrigation frequency x nitrogen trials on IR6-945 rice.

Treatment No.	Nitrogen Lbs. N/Acre	Irrigation Frequency Days
1	0	5
*2	100	5
*3	200	5
4	50	10
5	150	10
6	0	15
7	100	15
8	200	15
9	50	20
10	150	20
*11	0	25
*12	100	25
13	200	25

*Treatments Omitted in 1973.

Standard analysis of variance were performed. However, for purposes of presentation as a response surface the confidence interval for the treatment means are more appropriate. These are calculated by the standard formula.

$$CI_{(.05)} = t_{.0t}(S.E._{mean})$$

RESULTS

Agronomic Evaluation:

The irrigation frequency x nitrogen response surfaces obtained from these experiments varied considerably among the three years. In 1973 (Fig. 1) a maximum yield of 80 mds/acre was obtained with 100 lbs. N/acre and a 5 day irrigation interval. The number of treatments was limited that year, but it appears that the yield may have declined slightly as the N rate increased to 200 lbs/acre. Yields in excess of 55 mds/acre were obtained with 0 and 50 lbs. N/acre, indicating a high fertility site. The 5 day irrigation intervals gave the highest yields, but a yield of 60 mds/acre was obtained with 100 lbs. N/acre and an irrigation interval of 25 days.

The situation was quite different in 1974. This site was also quite fertile as yields in excess of 40 mds/acre were obtained without additional nitrogen fertilizer when irrigation intervals were less than 15 days. In 1974 intervals greater than 15 days resulted in low yields at all nitrogen levels. Yields dropped below 20 mds/acre at 25 day intervals and below 40 mds/acre at 20 day intervals. If irrigation intervals exceeded 10 or 12 days it was not possible to substitute nitrogen for irrigation as a production input.

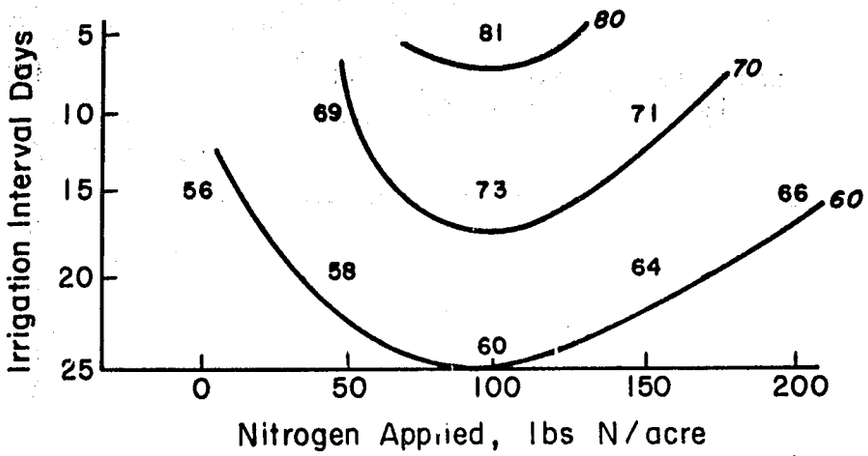

Figure 1. Irrigation interval x nitrogen production surface (mds/acre) for IR6-945 site at Kala Shah Kaku in 1973. Five % confidence interval = 5.6 mds/acre.

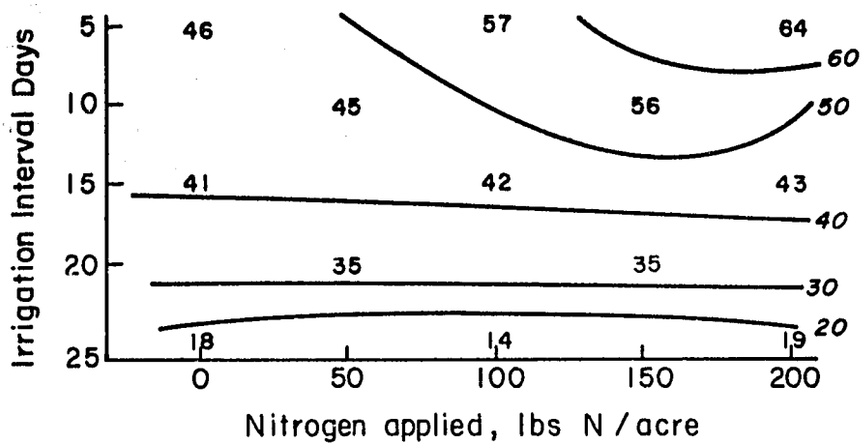

Figure 2. Irrigation interval x nitrogen production surface (mds/acre) for IR6-945 site at Kala Shah Kaku in 1974. Five % confidence interval = 6.8 mds/acre.

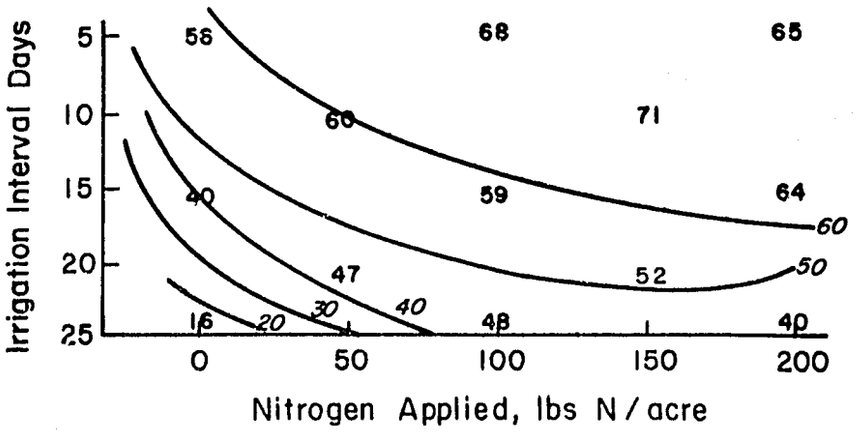

Figure 3. Irrigation interval x nitrogen production surface (mds/acre) for IR6-945 site at Kala Shah Kaku in 1975. Five % confidence interval = 4.8 mds/acre.

In 1975 a more classic response surface was obtained. Yields were very low (16 mds/acre) on the 0 N with 25 day interval treatment, but at the 5 day interval 56 mds/acre was obtained with no added nitrogen. Similarly 40 mds/acre were obtained with 100 lbs. N/acre and 25 day irrigation intervals. The maximum yield of 71 mds/acre resulted from 10 day irrigation intervals and 150 lbs. N/acre. In this situation the two inputs could be substituted for one another depending on their relative cost.

The differences in production surfaces was apparently largely due to the rainfall pattern. The July through September rainfall totaled 29 inches in 1973 and 23 inches in 1975 while the total for these months in 1974 was only 11 inches. Thus the actual water stress imposed by the longer irrigation intervals was undoubtedly much greater in 1974 than in either 1973 or 1975. In general fertilizer response is obtained up to about 100 or 150 lbs. N/acre, but in a dry season with irrigation intervals longer than about 12 to 14 days no response would be expected. The results also indicate that simple irrigation intervals are not a completely satisfactory criteria for defining irrigation treatments in this type of research.

Optimal Combination of Resources

In determining his operating input combinations a rice farmer must pay heed to relative input prices if he is to minimize the cost of producing a given output or maximize output for a given level of cost. In the long run the farmer must do this to obtain the maximum attainable profit.

Assuming that nitrogen fertilizer and water are the two most critical variable inputs (holding other inputs constant as was done in the series of experiments) and denoting quantity of irrigations as I and quantity of nitrogen as N it is possible to define the cost of using any volume of I and N. The total cost of $\bar{C}$ of using any volume of I and N is $C = rI + wN$ where r and w are the unit prices of I and N, respectively. In our specific case, suppose it costs 20 Rs. per irrigation and 1.5 Rs. per unit of nitrogen. If the farmer is to spend, for example, 200 Rs. for water and fertilizer inputs the following combinations are possible: 200 Rs = 20 Rs I + 1.5 Rs N, or $I = 10 - .075\ N$. Similarly if 30 Rs is to be spent on water and fertilizer inputs, the farmer can purchase combinations that satisfy the following relationship: $I = 15 - .075\ N$. The solid lines in Figure 4 are called <u>isocost curves</u> because they show the various combinations of inputs that may be purchased for a stipulated amount of budget expenditure.

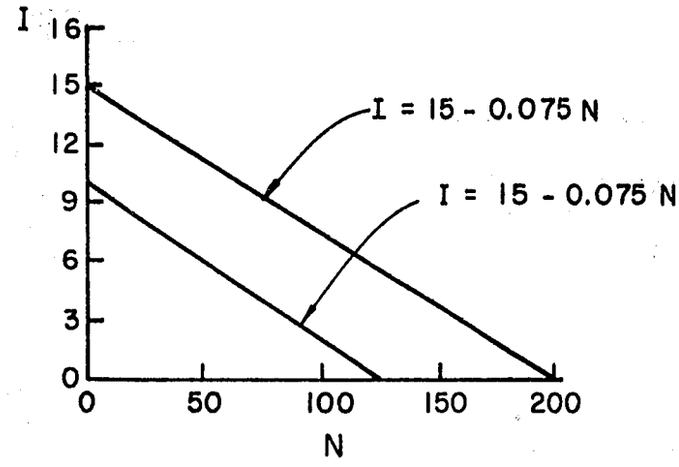

Figure 4. Isocost curves for I = 20 Rs and N = 1.5 Rs.

In order to determine the maximum output attainable one must know the input prices for irrigation and for nitrogen fertilizer as well as the total amount of money per acre available for these inputs. From this information isocost curves can be developed and these curves can be combined with the production response curves to select the optimum mix of inputs for a given budget or to minimize the cost for a desired production level. Using the response curves from 1975 research at Kala Shah Kaku and input prices of 20 Rs per irrigation and 1.5 Rs per unit of nitrogen the optimal input mix is graphically illustrated in Figure 5.

From Figure 5 the optimal input combination to minimize the costs for 40 maunds of rice per acre is approximately 5 irrigations (18 day intervals) and 10 pounds of nitrogen. To minimize the inputs cost for 50 maunds of rice per acre the farmer should apply approximately 7 irrigations (13 day intervals) and 20 pounds of nitrogen. Similarly, to minimize the input costs for 60 maunds of rice per acre the farmer should apply approximately 9 irrigations (10 day intervals) and 63 pounds of nitrogen.

The price of fertilizer is fixed by the government, but the price of an irrigation varies according to: allocated water supply, to delivery system efficiency, to water source (public or private), to location on the watercourse, and labor

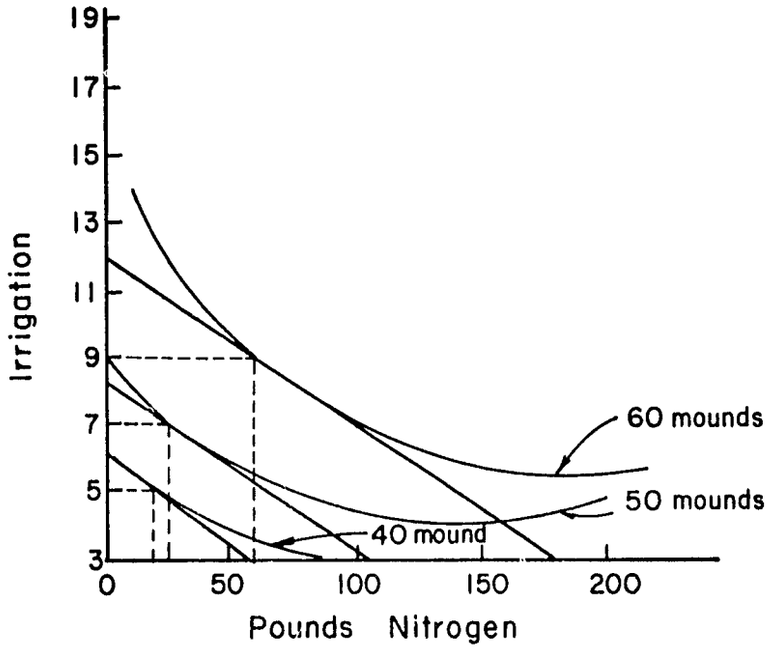

Figure 5. Optimal input combinations to minimize costs - 1975.

costs. In order to take the variable cost of irrigation into account a series of graphs such as in Figure 5 were fit assuming a range of irrigation costs from 15 Rs per irrigation up to 60 Rs per irrigation. These results are presented in Table 2.

Table 2. Optimal Input Combinations to Minimize Costs - Kala Shah Kaku 1975.

Input Prices Per Irrigation and Pound Nitrogen	Yield Level: 40 Maunds		50 Maunds		60 Maunds	
	Units: I = Irrigation, N = Nitrogen					
	I	N	I	N	I	N
I = 15 Rs, N = 1.5 Rs	5	5	8	12	10	50
I = 20 Rs, N = 1.5 Rs	5	10	7	20	9	63
I = 30 Rs, N = 1.5 Rs	5	25	6	35	7	85
I = 40 Rs, N = 1.5 Rs	4	45	5	50	6	103
I = 50 Rs, N = 1.5 Rs	4	55	5	58	6	116
I = 60 Rs, N = 1.5 Rs	3	63	5	67	5	127

This table illustrates that as the farmer wishes to increase his yields he must increase either his frequency of irrigation and/or his amount of nitrogen fertilizer. As the cost per irrigation increases to keep the same yield the farmer can substitute nitrogen fertilizer for irrigations.

Similar tables for 1973 and 1974 research results are presented in Tables 3 and 4.

Table 3. Optimal Input Combination to Minimize Costs - Kala Shah Kaku 1974.

Input Prices Per Irrigation and Pound Nitrogen	Yield Level: 40 Maunds*		50 Maunds		60 Maunds	
	Units: I = Irrigation, N = lbs. Nitrogen					
	I	N	I	N	I	N
I = 15 Rs, N = 1.5 Rs	6	0	10	80	15	162
I = 20 Rs, N = 1.5 Rs	6	0	19	100	15	167
I = 30 Rs, N = 1.5 Rs	6	0	8	115	14	172
I = 40 Rs, N = 1.5 Rs	6	0	8	125	14	182
I = 50 Rs, N = 1.5 Rs	6	0	7	130	14	187
I = 60 Rs, N = 1.5 Rs	6	0	7	135	14	193

*A flat curve indicating very little fertilizer response.

Table 4. Optimal Input Combinations to Minimize Costs Kala Shah Kaku 1973.

Input Prices Per Irrigation and Pound Nitrogen	Yield Level: 60 Maunds		70 Maunds		80 Maunds	
	Units: I = Irrigation, N = lbs Nitrogen					
	I	N	I	N	I	N
I = 15 Rs, N = 1.5 Rs	7	10	8	58	18	90
I = 20 Rs, N = 1.5 Rs	7	13	7	67	18	91
I = 30 Rs, N = 1.5 Rs	7	25	6	77	18	92
I = 40 Rs, N = 1.5 Rs	5	37	6	80	18	95
I = 50 Rs, N = 1.5 Rs	5	50	6	90	18	97
I = 60 Rs, N = 1.5 Rs	4	63	6	96	18	100

While in general the same relationships found in Table 2 (1975) hold for 1974 and 1973, that is, to increase yields it is necessary to increase frequency of irrigation and/or amount of nitrogen fertilizer. However, where 1973 was a very wet season and it was possible to obtain quite high yields with less frequent irrigations, 1974 was a very dry season and more frequent irrigations were needed to obtain acceptable yields.

Appendix 28

DIRECTIONS FOR APPLICATION OF CONTROLLED AMOUNTS OF WATER WITH SIPHON TUBES

John O. Reuss[1]

The rice plots at Kala Shah Kaku in 1976 are 12' x 20'. The graphs shown here are developed for this size plots and siphon tubes 5.5 feet in length and having a 2 inch inside diameter. The calibrations need to be checked with field measurements, but should provide an initial basis for water application. In these calibrations it is necessarily assumed that a constant water level can be maintained in the supply channel. Fluctuations in the supply channel will result in errors.

Graphs are supplied for use with three conditions. Figure 1 would be used only when the water level in the plot is below the outlet during the complete delivery or most of the delivery. The conditions for use of Figure 2 are more common. If the plot does not initially contain water, but the plot will fill above the end of the siphon outlet during filling use Figure 2. If the plot contains water at the start use Figure 3.

Method 1 (Fig. 1) Use only when siphon outlet will be free during all or most of the delivery (seldom use on rice).

A. Determine head difference between water channel and center of outlet pipe. This may be estimated by determining difference between water level in outlet channel and plot surface and subtracting 1.1 inches. Use the ruler and plastic tube for this determination.

B. Now determine minutes per inch for this head from Figure 1. Multiply amount needed (in inches) times the minutes per inch. The product is the minutes required

Method 2 (Fig. 2) Use when the plot is not covered with water, but will be covered during irrigation.

A. Determine difference between water level and ground surface (L). Use Fig. 2. Find the amount of water required on the lower axis. Follow this line vertically till you reach the appropriate "L" line. Read minutes from left side of graph.

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[1]Agronomist, CSU Water Management Project Field Party.

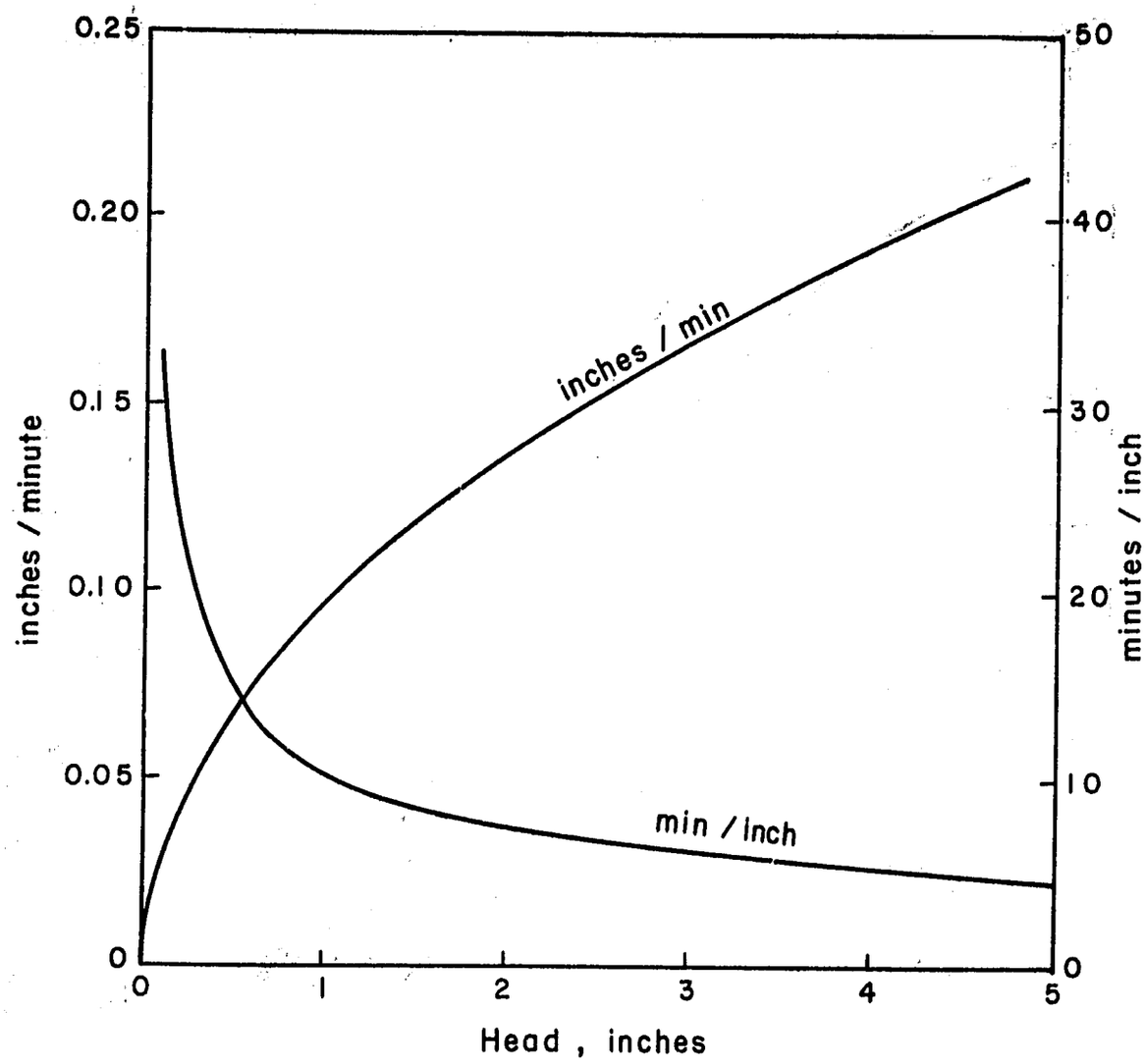

Figure 1. Delivery as a function of head.

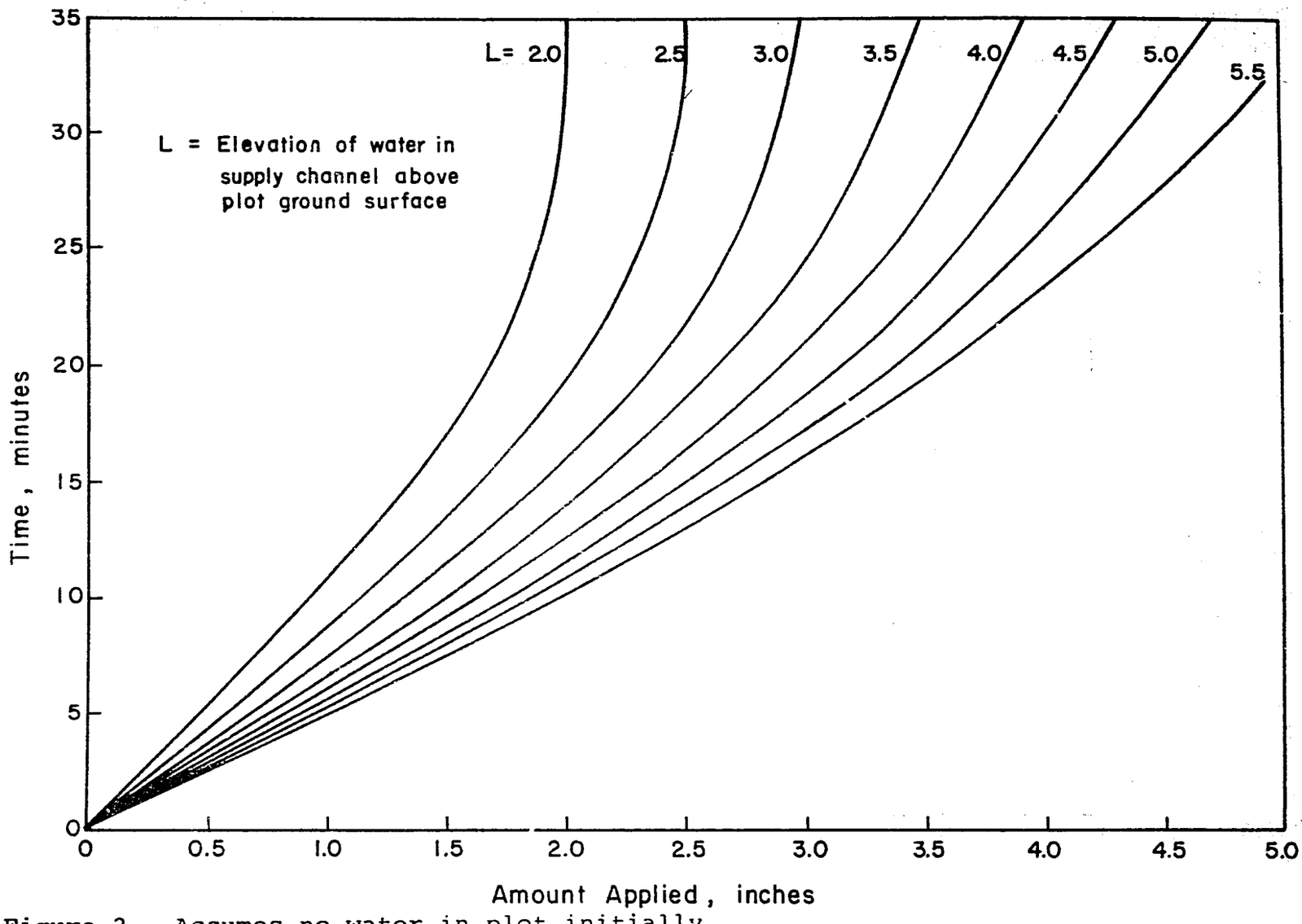

Figure 2. Assumes no water in plot initially.

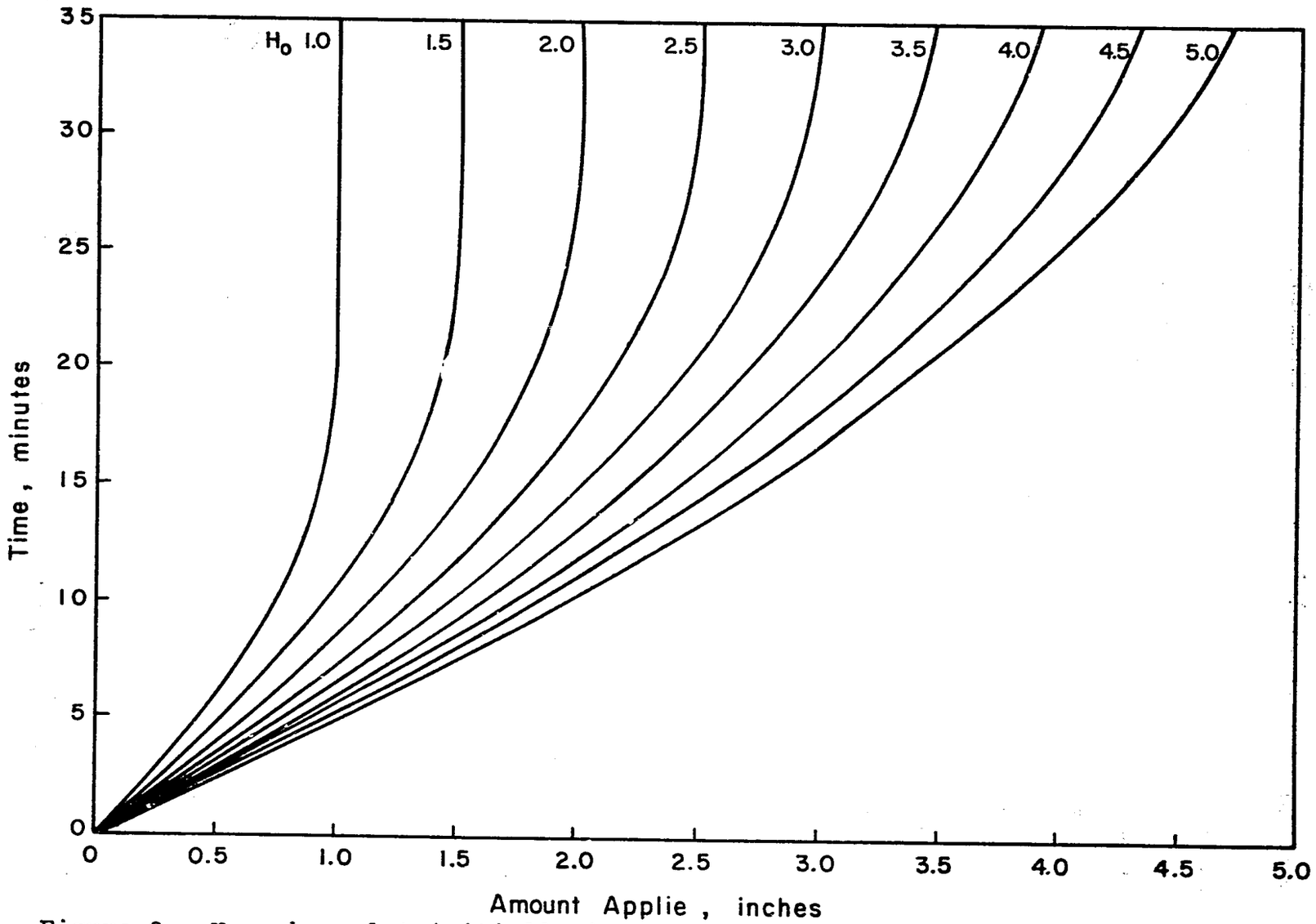

Figure 3. Use when plot initially is covered with water.

Method 3 Use if surface of plot is covered by water.

A. If outlet pipe is not below water level remove some soil so that it will be beneath the water.

B. Measure initial head difference between water level in channel and that in the plot.

C. Read time required in minutes from Figure 3 for the amount of water needed and the H_o measured.

Preparation of Graphs for Siphon Tube Calibration on Rice Plots

The calculation of the time required for a given water delivery to field plots may be complicated by the tendency for the head to diminish as the level in the plot rises. The accompanying graphs take this into account, but they do assume that the water level in the supply channel is maintained constant during delivery. The graphs were developed in the following manner:

Calibration data of 2 inch plastic siphons for 4.5 and 6.5 ft. long tubes furnished by Dr. Early indicated that the flow is proportional to the square root of the head as shown in Eq. 1.

$$Q = a\ H^{\frac{1}{2}} \tag{1}$$

Where Q is the delivery, a is a constant and H the head. The data for the 6.5 ft tubes fit the square root relationships very well while there was some deviation in the results from the 4.5 foot tube. At any rate the relationships should be satisfactory for this purpose. Interpolating between the deliveries of the two lengths it was estimated that for a 5.5 foot tube the relationship can be described by (2).

$$Q = 0.77\ (H)^{\frac{1}{2}} \tag{2}$$

Where H is in inches and Q in acre inches per day. For a 12' x 20' plot this becomes

$$Q = 0.0971\ (H)^{\frac{1}{2}} \tag{3}$$

When Q is expressed in inches/minute. Q may be described as dV/dt where V is the volume of water in the plot expressed in "plot inches", so Eq. (3) can be written:

$$\frac{dV}{dt} = .0971\ (H)^{\frac{1}{2}} \tag{4}$$

A plot of Eq. (4) is shown in Figure 1. However, the change in head with respect to volume dH/dV is a constant that in

these units is equal to 1. Thus, as the depth of water on the plot increases the net head decreases by the same amount, so that

$$\frac{dH}{dV} = 1 \tag{5}$$

Rearranging 5 and integrating we find that

$$H = H_o + V \tag{6}$$

Where H_o is the initial head difference. Substituting into (4) we have

$$\frac{dV}{dt} = .0971\ (H_o + V)^{\frac{1}{2}} \tag{7}$$

Which integrates to (8)

$$-2\ (H_o - V)^{\frac{1}{2}} = C + 0.0971t \tag{8}$$

Where t is in minutes. Evaluating the constant of integration and rearranging we have

$$t = 2\ \frac{H_o^{\frac{1}{2}} - (H_o - V)^{\frac{1}{2}}}{.0971} \tag{9}$$

Thus for any initial head difference (H_o) and any amount to be applied the necessary time can be calculated. Figure 3 was prepared from this relationship.

Figure 3 of course assumes that the plot is initially covered with water, in which case the measurement could actually be made by simply measuring depth before and after. This procedure can certainly be used as a check on the calibration. If the outlet flow is free the calibration can be gotten from Figure 1 which is calculated from Eq. (4).

Unfortunately a common condition will be that in which a period of free flow is followed by submergence and decreasing head. An approximation is furnished in Figure 2. The assumption of free flow is made until delivery reaches 1.125 inches per plot (the center of the delivery tube). After that time the decreasing head of Eq. (9) is assumed.

It appears that if a head of at least two or more inches can be maintained the error resulting from moderate head fluctuations will be relatively small, but if net operating heads of less than one inch are required, small head fluctuations would cause substantial errors.

Appendix 29

HELPING FARMERS IDENTIFY AND ACHIEVE THEIR POTENTIAL FOR WATERCOURSE IMPROVEMENT[1]

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A. Objective

The purpose of this project is to improve water management and thereby help farmers in developing countries to increase their crop production. After observing the need for water, the obvious losses along the watercourses and damage to crops adjacent to the watercourse by seepage, it was determined that this was an aspect of water management that should be investigated, that this should be done by direct measurement and not by accepting previously published estimates.

B. Identification of Potentials for Improvement

1. Magnitude of Losses

Initial measurements at the Mona Reclamation Experimental Project showed that up to 80 percent of the total water supply that is available from the mogha and the tubewell is lost when the water is flowing to the lower end of the watercourses and that an average of about 50 percent of the water does not reach the fields. These losses were startling to the Mona Project Director. Previous estimates by foreign consulting firms had indicated losses of the order of 10 percent from the courses and the director questioned these new measurements. He was invited to participate in these measurements and came to the field and satisfied himself that these measurements were being taken in a correct and systematic manner. He then became a strong supporter of further efforts to evaluate the water losses from watercourses

[1]Contribution from Colorado State University and the Mona Reclamation Experimental Project, WAPDA. Portions of the work were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/Washington Research Contract No. AID/ta-c-1100.

[2]CSU Water Management Field Party, Chief-of-Party.

[3]CSU Water Management Field Party Members.

[4]Mona Reclamation Experimental Project Personnel.

and helped to push a proposal through the Pakistan and USAID bureaucracies to evaluate various methods for decreasing this water loss.

The CSU field party presented these water loss figures to USAID, pointed out the apparent potential for increasing water supplies to the fields by up to 100 percent and proposed that a watercourse evaluation team including two young engineers be set up to further evaluate this possibility. The USAID Mission in Pakistan provided the funds to hire these engineers to assist in the evaluation of watercourse losses. The concept that losses were only about 10 percent (and therefore potential for increased delivery was only about 11 percent) was deeply ingrained in the literature and minds of personnel involved in water management planning. There was widespread reluctance of these personnel to accept a new concept of 50 percent loss and a consequent potential for increasing water supply to the fields by up to 100 percent through watercourse improvement. In general, their attitudes were that such high losses might be occurring in a few isolated instances but the average watercourse losses must be near the old estimates.

2. Extent of Losses

Measurement of losses was extended from the Mona project area to projects in the vicinity of Mona, Lahore, Lyallpur, and Multan. Similar rates of loss were observed (Clyma et al 1975).

There was some concern that installation of the flumes, which often raised the operating level of the water a few inches in the watercourse immediately upstream from the flume, might be at least a partial cause of the high loss rates observed. To help evaluate these flume measurements, other measurements, involving ponding in sections of the watercourse and observing the recession of the water surface, were used to determine the rates of loss (e.g. Kemper et. al. 1975). This latter method showed that loss rates were dependent on level of water in the watercourse. However, when the stretch of the watercourse from which the flume measurements were taken was sufficiently long (i.e. 2000 feet or more) and the rise in water surface caused by the flume was less than a couple of tenths of a foot, this rise was reasonably localized to the vicinity of the flume and the average rates of loss measured were close to those obtained by the ponding and recession method when the recession measurements were taken with water at the operational level.

Continued reluctance on the part of planning personnel to accept the concept of high watercourse loss rates built stronger financial and moral support for obtaining a good and complete set of measurements. This led to the financing

by USAID of a cooperative study with WAPDA involving about 40 watercourses in areas selected to represent the major cropping sections of the Punjab and the Sind (forthcoming report by Early et. al.). This controversy also helped induce a strong component of watercourse loss measurement in a World Bank survey which involves continuous measurements over two cropping seasons, of watercourse losses, irrigation application efficiencies, and other factors affecting the production of the farm unit. The Water and Power Development Authority was involved in both these surveys and all parties were interested in the same information. Since the World Bank financed survey followed the USAID financed survey, WAPDA was able to utilize the personnel trained in the USAID-financed survey in the World Bank-financed survey.

The USAID-financed survey found that steady state losses on these watercourses averaged about 40 percent (Early et al 1976). Studies in which the total amount of water let into a watercourse and the total amount of water leaving the watercourse through the nakkas into the fields were measured (Kemper et. al. 1976b) show that an additional 10 or 20 percent of the water is used in filling the watercourses, wetting the banks or is lost in situations where bunds or banks break or wash out in the extremely fragile watercourse systems presently existing in Pakistan. Combination of these data indicates that an average of about 50 percent of the water which leaves the mogha and the tubewell in the Punjab and the Sind is lost and does not reach the fields.

C. Methods for Achieving the Program

1. Utilizing existing techniques and contractor construction.

In order to start the evaluation program moving as rapidly as possible, contractors were hired to construct a range of concrete and masonry lined watercourses including rectangular and trapezoidal cross sections with thickness of floors and walls varying from 2 to 13 inches. One 4000 foot section was built with no lining but was elevated so the bottom of the watercourse was near the ground surface level and all of the water could be drained out to adjacent farmland.

2. Will farmers maintain improvements?

The degraded conditions of most watercourses supports the contention that group action to maintain watercourses is difficult to organize under the conditions in Pakistan where between 20 and 100 farmers share the watercourse. Consequently, there are some who believe that the emphasis on watercourse improvements should be primarily on improvements which require little maintenance. However, there are watercourses where farmers have successfully organized cleaning and maintenance programs.

3. Economic analysis of contractor constructed improvements.

Shortly after these watercourses were planned, brick costs increased from 70 to 230 Rupees per thousand and the cost of cement increased from 12 to 20 Rupees per bag. The price of contractor hired labor rose from 3 to 6 Rupees per day. Consequently the prices on these pakka (concrete or masonry) lined watercourses constructed by contractors was high, ranging from 25 to 60 Rupees per linear foot of watercourse depending upon the dimensions and wall thickness as well as contractors profit margins. Partially as a result of government controls on food prices there was not a commensurate increase in the value of farm products. Consequently, the benefits/costs ratio of pakka lined watercourses drop below 1, except for stretches in channels where water is flowing almost every day where the benefits/cost ratio could get up to 2 or more depending upon the efficiency with which the farmers were using their water to produce crops (Eckert et. al. 1975).

In spite of the increasing cost of labor to the contractors there is a continuing surplus of labor, particularly during certain seasons in the rural areas. During these slack seasons this labor can be obtained for less than Rs 6 per day. Many farmers consider their own time to have a low value during these seasons.

4. Involvement of the farmer factor in these studies.

A disturbing attitude concerning these test watercourse sections is evident among the farmers. Since the "government" had built these sections, the farmers took little responsibility for their maintenance. Discussions with farmers with small holdings indicated that it would be difficult for them to raise capital to pay contractors to construct watercourses. If watercourse improvement was to take place using contractors to build the watercourses, the initial cost would have to be borne primarily by the government with hopes that his might be recovered from the farmers as their system increased its productivity. The demand for the government's resources in so many other development areas appears to preclude this possibility. Deletion of the contractor and involvement of the farmer in the construction process appears to be necessary in matching needs and resources.

5. Studies to analyze specific causes of water losses and evaluate methods by which rural labor can be used to achieve watercourse improvement.

A comparison of newly constructed watercourses with old watercourses (e.g. Kemper et. al. 1975b) showed that losses

from old watercourses ranged from .3 to .8 cusecs per 1000 feet. Losses from newly constructed watercourses ranged from .03 to .2 cusecs per 1000 feet. Loss of water from old watercourses is high because of porous banks which become more permeable with time as insects, worms, roots, and rodents increase the number of channels that carry the water through the banks. The permeability of the banks of old watercourses (that is more than 5 years old) is commonly from 4 to 10 times the permeability of soil in adjacent fields. Consequently, when new watercourses are constructed with compacted banks the rates of loss are generally less than 25 percent of those in old watercourses.

Reconstructing the banks using the soil that was previously in those banks and removing part of the organic matter does not rid these banks of the insects and worms. The rodents soon return and the banks retain or rapidly regain a large portion of their permeability.

Measurements (e.g. Kemper et. al. 1975b) showed that most of the loss was in the upper portion of banks near the water surface. A simple procedure for packing an earthen core in the middle of the banks was devised and tested. This procedure reduced the loss rates from test sections to less than 25 percent of their original rates (Kemper & Akram 1975).

In the vicinity of junctions of the watercourse, there is weekly borrowing of soil to build dams to direct water from one branch to another of the watercourse. A major portion of this soil is eroded away each time these dams are broken to allow water back into the dammed branch. The result is extensive borrow pits, thin banks, and obvious zones of weakness in the water channel where the banks break frequently and there is almost continual leakage. Measurements (Kemper & Akram 1975a) showed that 45 percent of the loss from a watercourse occurred within 30 feet of these junctions.

In general, it became apparent that rebuilding of the banks and channels to proper cross sections, compacting those banks and improvement of these junctions can be accomplished by farm labor and can reduce the losses from most watercourses to about 20 or 30 percent of the loss occurring in old watercourses. However, borrowing of the soil at junctions is a weekly practice which degrades the watercourses. Control structures which can change the water from one branch of a watercourse to another are a primary need in bringing about an improved and reasonably maintainable watercourse.

6. Control Structures

The steel slide gates used to control water in the pakka lined sections on the watercourse work fairly well when they are constructed and installed properly. However, since Pakistan must import its steel, the costs of these gates exceeded Rs. 500 each. This plus their installation costs makes them economically unfeasible for use by Pakistani farmers. Consequently, lower cost control structures were designed. Cement is manufactured in Pakistan and concrete control structures of various designs were built and tested. These included concrete pipes with a forty-five degree angle and collar and a lid flush with a bank with 1:1 side slope as shown in the bottom segment of Figure 1. Because of difficulty in getting good compaction around these pipes, cutoff walls of concrete on the inside of the watercourse bank, as shown in Figure 1, were often a practical necessity to prevent washouts alongside these structures. Wooden forms were being used in construction of the lids and these warped slightly when wet, the result being the lids did not fit the collars properly. The manufacturer was invited to the field and spent several hours working with and observing the performance of these structures and talking with the engineers and farmers who were working with them. He then had steel forms machined and since that time has been doing a good job of maintaining the quality and precision necessary to produce satisfactory concrete control structures. These control structures are built with a special groove designed to be filled with mud. If this mud seal is made properly there is no leakage. However, the farmers frequently do not take the time to make this seal. The result is a small amount of leakage, generally less than 0.01 of a cusec. Foam rubber gaskets on these lids reduce this loss to less than 0.001 of a cusec (Trout & Akram 1975) and appear to last for at least a couple of years unless they are removed by mischievous children! This removal occurs frequently when the control structures are near thoroughfares and the lids are removed from the structures so the gaskets are easily accessible to the children.

The variant of these concrete control structures currently most popular for use at diversions involves panels such as shown in Figure 2 with circular orifices into which round lids fit. The present cost of the panels is Rs. 50 for a 21" x 21" x 3" panel with a 15 inch diameter orifice and Rs. 60 for a 26" x 26" x 3" panel with a 20 inch diameter orifice.

Even when the farmers fail to properly fill the mud groove the loss of water through these panels is sufficiently small that it is generally less than the losses which the farmers have had in the past when they had parallel watercourses whose purpose was to reduce the number of offtakes

from the main channel. These concrete control structures also reduce the time which a farmer spends in turning a 4 cusec stream of water from an average of almost 20 minutes to less than 5 minutes.

7. Economic Considerations

The above studies indicated that about half of the water loss could be saved by earthen improvements constructed by the farmers. Cost analysis (Eckert et. al. 1975) of such improvement plus concrete control structures to prevent rapid degradation of junction areas indicated that such improvement would cost about Rs. 2 per foot for a watercourse carrying 4 cusecs. Of the watercourse improvement methods under study, this low cost labor intensive method appeared to have the highest benefits/cost ratio.

D. Farmer Participation in Test Branch Improvement

1. Convincing the farmer

Having concluded that earthen improved watercourses built by farmers had great potential an engineer was sent to convince the farmers on Branch I of the test watercourse that they should work with him to make such improvements. These farmers were negative to the suggestion, (for details see Khan Moh'd. Chandawana 1975) partly because the branch watercourses on either side of them had been improved with pakka lining at no cost to the farmers served. This group of farmers on Branch I was being asked to not only accept a lesser degree of improvement, but to do the work themselves. They were told that there were no more pakka lined sections planned and immediately concluded that the government people had pocketed the money which was meant to build their watercourse! It was only after an extension agent, who had considerable credibility with these farmers, had talked to them at length that the farmers were willing to cooperate on this project. At first only a couple of these farmers were convinced. They began working alone and were subjected to considerable ridicule and social pressure from the other farmers to hold out for more government aid. However, as a result of their faith in the word of the extension agent and their dogged persistence the other farmers finally joined them.

2. Farmer production rates compared to those of contractors

During the hot, humid month of August, these farmers improved over 2000 feet of watercourse with a labor input of about 1/2 of a man hour per foot of watercourse. This was a small faraction of the labor time used by contractors who had built a nearby earthen improved section. Part of this

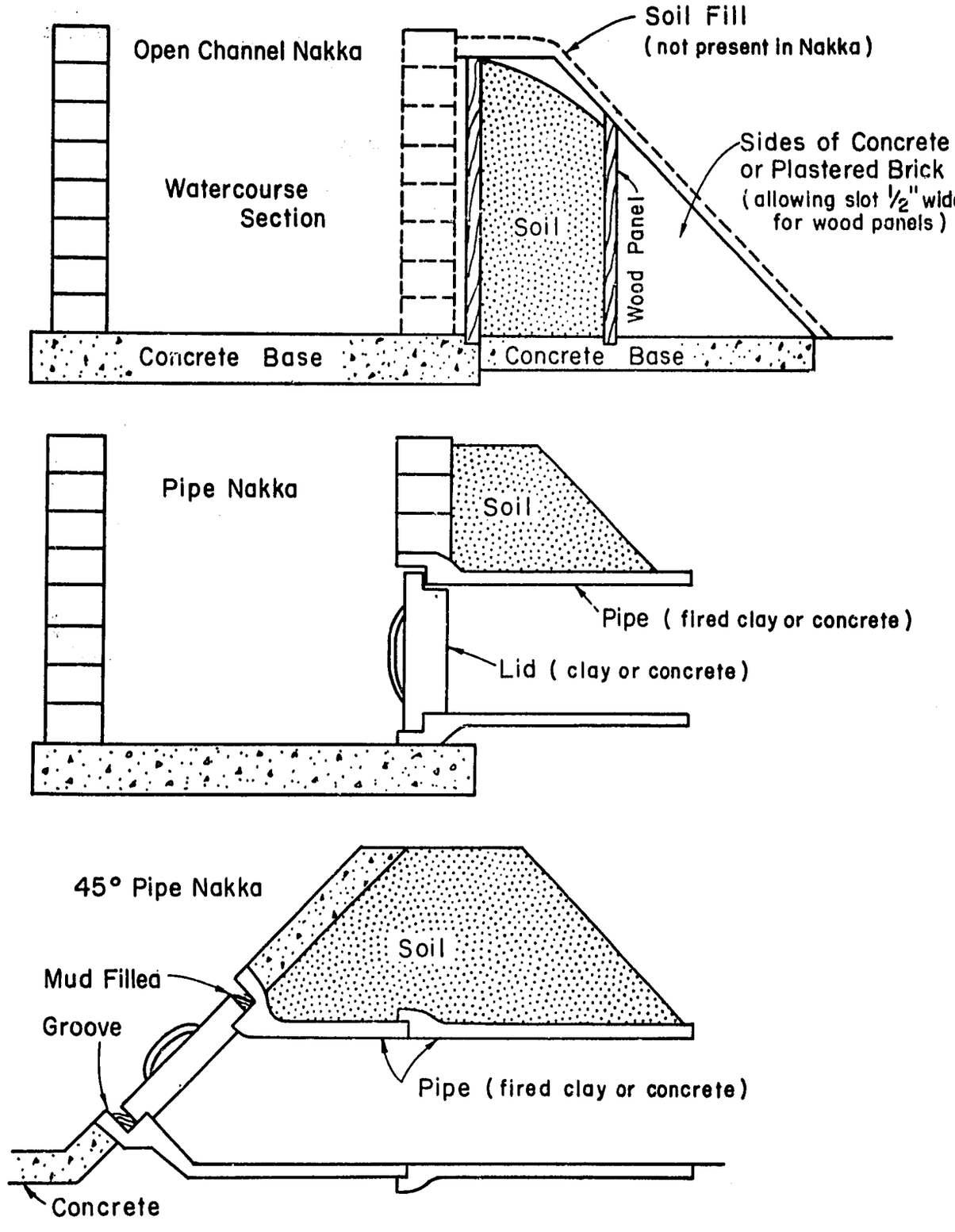

Figure 1. Nakka designs.

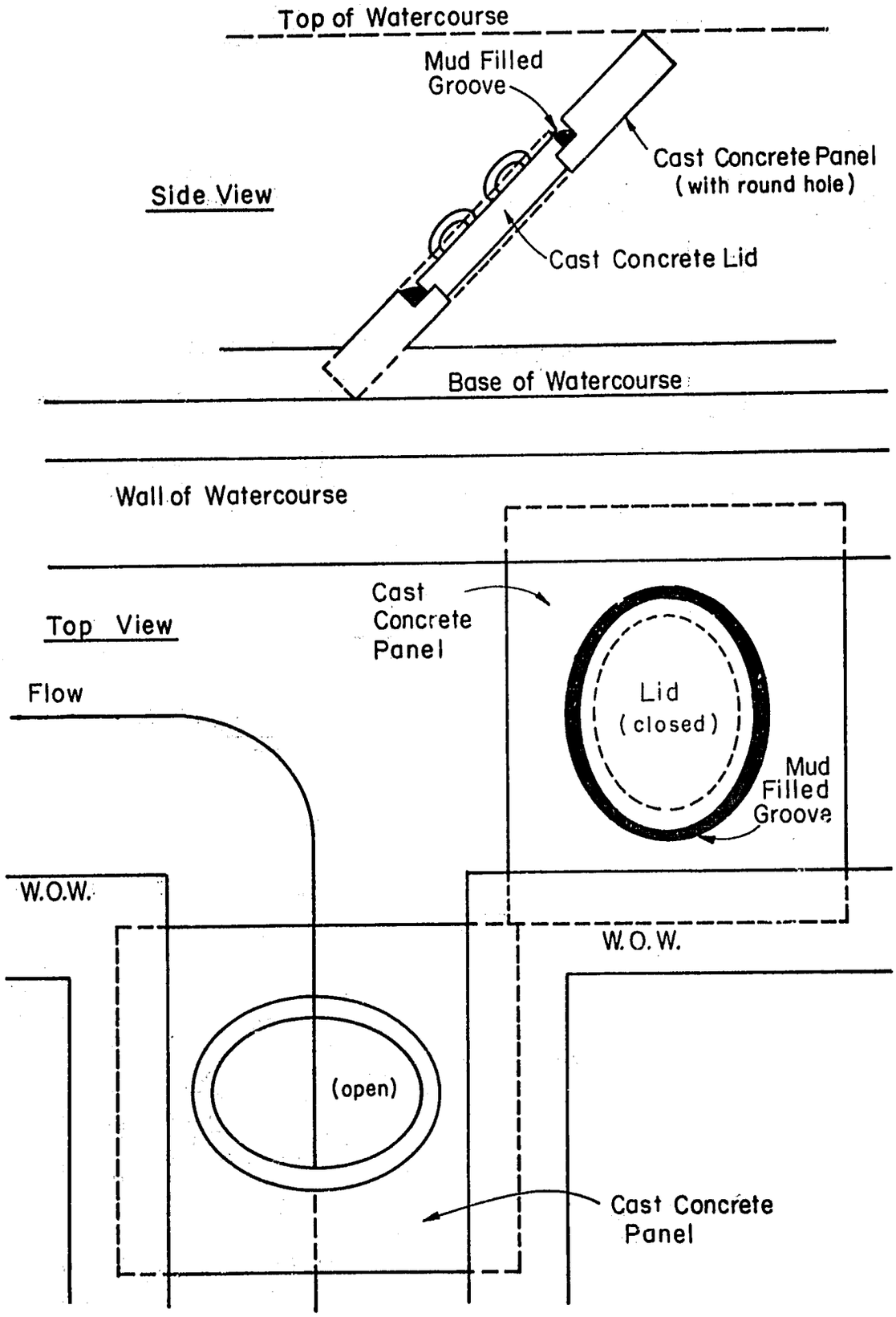

Figure 2. Diversion Structure.

difference was due to the necessity of the contractors making certain that carefully designed specifications were precisely followed. Engineers provided alignments and elevations to the farmers on Branch I but they allowed the farmers to vary about ± 2" on these elevations during construction. The watercourse built by the contractor was built higher and required the movement of more soil from the borrow pits into the bed. However, a major factor in the difference in time spent is that farmers working on their own projects moved from 2 to 3 times as much earth per man hour as did laborers hired by contractors.

3. Costs and benefits of improvements

Concrete control structures used on this farmer constructed branch were the 20" diameter orifice size and were purchased and installed at a cost of about Rs. 150 per structure. The average cost on this section including the value of the farmers' labor was approximately Rs. 2 per foot.

Before improvement, the water losses were high (0.8 cusec per 1000 feet) due to overtopping, excessive leaking at several bad junctions, and a large number of rodent hole type leakages (Kemper, Clyma & Ashraf 1975). After the initial improvement, the loss still exceeded 0.4 cusec per 1000 feet and there were many observable leaks along the watercourse. When these observable leaks were closed, the loss was reduced to less than 0.3 cusec per 1000 feet. Improvement of short sections using compacted cores in the banks (Kemper & Akram 1975) indicated that the loss could be reduced to 0.1 cusecs/1000 feet. However, the seepage was not damaging appreciable amounts of adjacent land and the farmers were getting an average of 0.5 cusecs more water to their fields than they had been getting before. Since they were satisfied with their watercourse and were not anxious to do the additional work that would have saved the extra water, we did not press them to do so. They receive water in this watercourse for about 17 hours each week and consequently the improvement will save them about 40 acre feet of water per year. Evaluating this water at Rs. 100/acre foot (the cost of SCARP water delivered to the field from SCARP wells valued at 1975 prices) indicates that these farmers receive a return of Rs. 4000 per year* for their initial investment in labor and structures of about Rs. 4000. However, realization of these benefits will be dependent on the degree to which they maintain the watercourse.

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*This does not include the benefits derived from decreased seepage damage to crops adjacent to the watercourse. This damage included substantial reductions in yield in about 4 acres of land along this branch prior to the improvement. This damage was eliminated.

4. Farmer attitude toward maintenance of watercourses constructed by contractors as compared to those constructed by themselves.

The group of farmers served by the watercourses constructed by themselves and the group of farmers served by the watercourse constructed by contractors, were encouraged to set up a maintenance and cleaning program which would maintain their increased delivery and would prevent leakage damaging crops on adjacent lands. The benefits were described to both groups and both groups verbally committed themselves to such programs. The farmers on Branch I, who constructed their own watercourse, have maintained their watercourse in good condition to date without reminders from the project staff. The group who had their watercourse constructed for them have required reminders and urging for each of their maintenance efforts to date.

When one of the farmers who had grudgingly helped to construct his own watercourse was asked why he was so willing to maintain it, he replied, "When you've worked as hard in the hot sun as we did to improve your watercourse, you are not willing to lose those benefits for a few extra hours on a charpoy."

E. Selection of First Pilot Watercourse for Farmer Improvement

1. Criteria used for selection in survey results

The benefits/cost ratio of earthen improvement plus pakka control structures, as done by the farmers on Branch I, exceeded the benefits/cost ratio of the other types of improvement as had been predicted by Eckert,et.al. (1975). Consequently, it was decided that this method of watercourse improvement should be field tested on a full size watercourse as a potential component of a nation-wide development program. The extension service personnel were asked for a list of twelve watercourses where improvement was needed and where farmers were interested in making such improvements. From these twelve watercourses, six were selected for further consideration. This selection was based primarily on expression of interest by the farmers, past record for cooperativeness among the farmers, distance from the headquarters, records of cropping intensity and leadership judged to be present in the group of farmers. Measurements were then made on these six watercourses including the flow of water coming from the tubewell and the mogha, the degree to which the water in the watercourse was backing up, submerging the mogha and reducing the flow from the canal, losses in the main channel and some of the branches and cropping intensity. Land ownership was determined and the amount of water provided per unit served was calculated and plotted against the intensity of cropping for these six watercourses. There was

a strong positive correlation between water available per acre and cropping intensity except for one watercourse (at Tubewell 56) where the cropping intensity was considerably higher than the lines drawn through the other points. Five small privately owned tubewells (which are used an average of only 20 hours a month) and additional water received from the canal at night apparently allow the farmers on this watercourse to increase their cropping intensity appreciably. This limited data supports the conviction that even within the SCARP areas intensity of cropping is increased by increasing the water supply.

The farmers served by the watercourse at Tubewell 56 had one of the highest cropping intensities. However, their desire for additional water, the high losses from their watercourse, their reputation for cooperativeness and the leadership obviously available within their group resulted in their watercourse being chosen as the first pilot watercourse. After this choice was made, the farmers were asked to hold a meeting at which they chose a four-member committee to represent them in considering this improvement.

2. Factors which convinced farmers that they should make improvements

The members of this committee were invited to come and see the improvements which the farmers had made on branch I. One of the committee members came. He observed the opening and closing of one of the control structures and appeared to be particularly impressed with the neat appearance of the watercourse and the wide and substantial nature of the banks which, in these areas of few improved roads, often become the local thoroughfares.

While this committee member was on this tour he asked how much labor it would take to improve his watercourse to the same state and was told it would take about one half hour for every foot of watercourse improved. He was also told that it was probable that the water supplied to fields on his watercourse could be increased an average of 50 percent by such improvement. He stated at a later date that it was the realization of this potential for improvement that was the main factor in causing him and the other farmers to conclude that they should go ahead with this project. However, the credibility of the extension agent and the engineers that were giving him these facts undoubtedly played a major role in acceptance of the program by these farmers.

F. Plan, Schedule and Essential Preparations for Improving the First Pilot Watercourse.

1. Objectives

The extension agent and one of the engineers constructed a map of the whole watercourse similar to that shown in Figure 3 and met with the farmers to determine their objectives. It was agreed to cooperatively improve the main channel and major branches (indicated in Figure 4) which had been designated by the irrigation department and for which a right-of-way had been authorized. This included about 28,000 feet of watercourse. Farmers stated that their primary objective was to obtain more water and that they were willing to do whatever the engineers recommended to obtain an increased water supply. The farmers were told that the increased water supply would soon be lost if they did not maintain and clean their new watercourse. They agreed in principal to do this and discussed the possibility of hiring a watercourse watchman (Khal Chowkidor) to help them.

2. Base Surveys and Design for Improvement

A topographic survey of the watercourse command area (940 acres) was begun, determining four elevations within each bunded area. However, this amount of detail took a lot of time, transportation was not available to get the surveyors to the site on some days and eventually the number of elevations taken was reduced to one per bunded area or about one per acre on the major portion of the watercourse. Measurements were taken (Table 1) of the water loss in the main channel and main branches of the watercourse for a full week since the irrigation turns of the farmers are on a weekly rotation basis. The engineer taking these measurements often worked about 12 hours a day. Measurements were not taken during the nights. Measurements on other watercourses have shown that nighttime losses exceed daytime losses because washouts and leaks often run all night without being detected.

There were several thousand feet of parallel watercourses (indicated by dashed lines in Figure 3) involving two and sometimes three watercourses built side by side in this command area. In a major portion of these watercourses, banks separating the main channel and the side channel(s) had been trimmed to where they were only 6 to 10 inches thick and frequently leaked as shown in Figure 5. This coupled with the normal complement of rodent holes was resulting in a loss of about 0.1 cusec more per thousand feet from the main channel when it was adjacent to parallel side channels. In one of these side channels sufficient water was leaking from the main channel that the farmer was using this "extra water supply" to provide an "automatic" weekly irrigation for an acre of sugar cane which was in the field adjacent to this

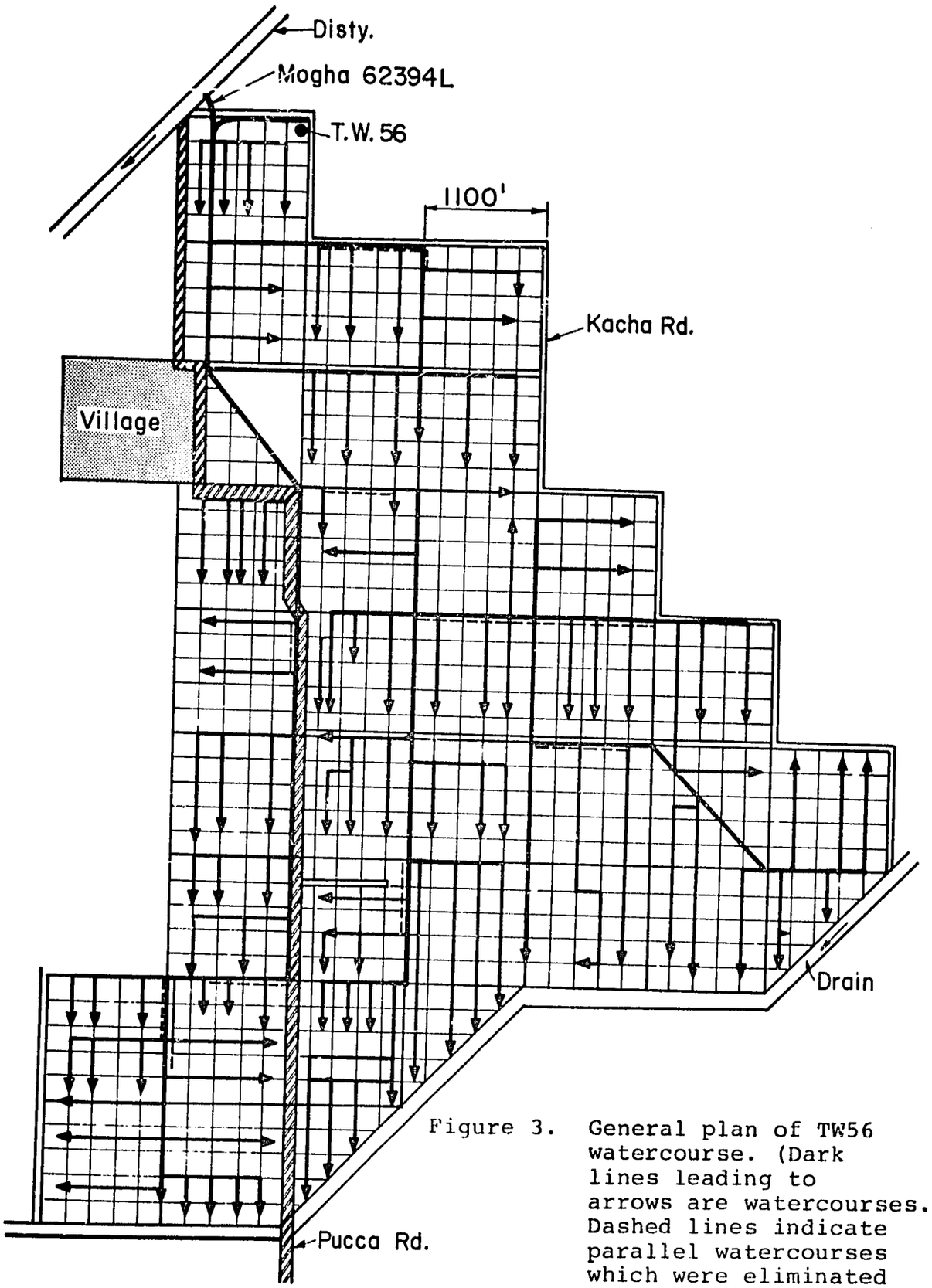


Figure 3. General plan of TW56 watercourse. (Dark lines leading to arrows are watercourses. Dashed lines indicate parallel watercourses which were eliminated in the improved watercourse.)

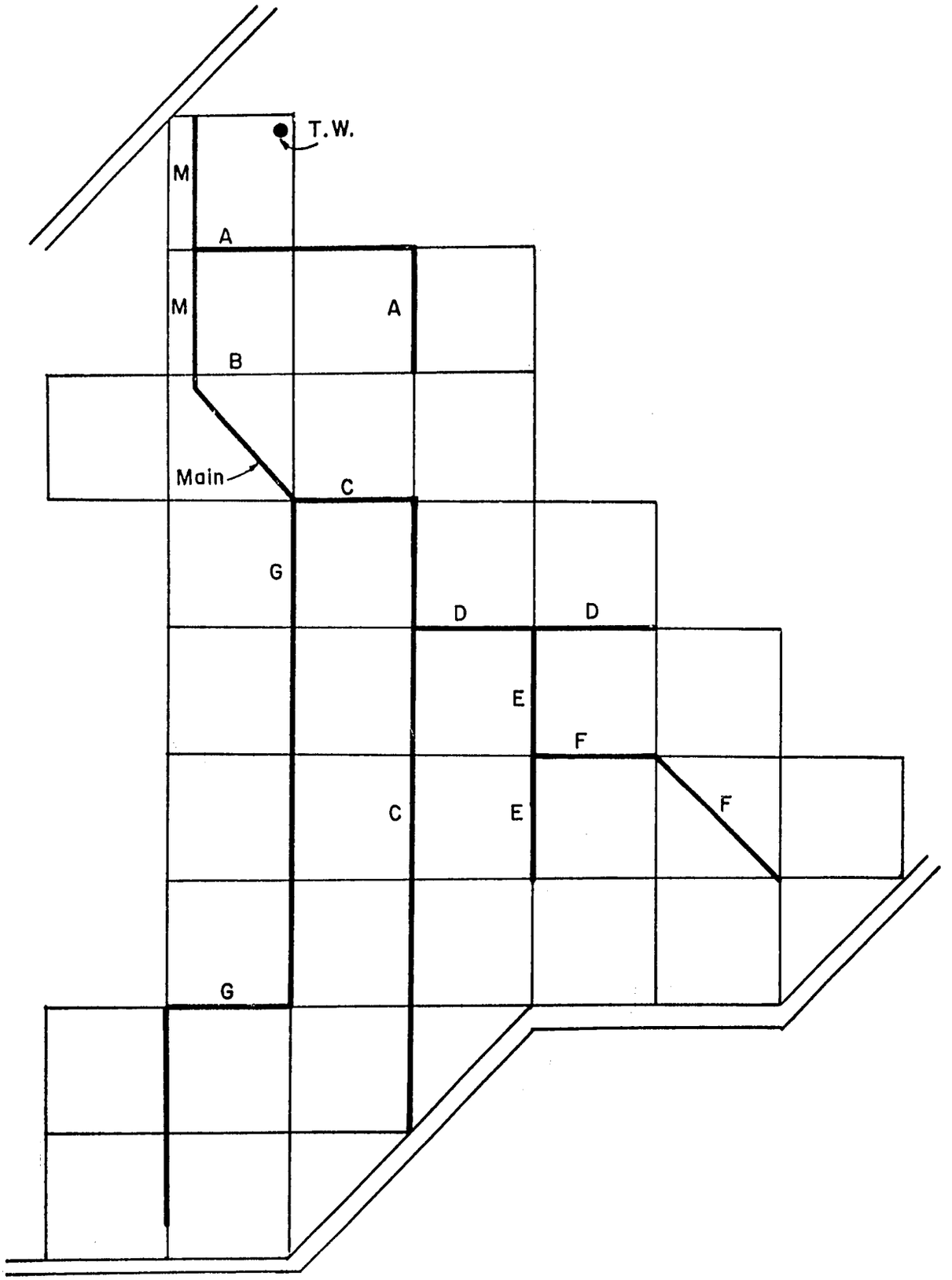


Figure 4. Main channel and main branches (authorized) which were improved. (Letters A through G designate branches discussed in text heavy lines indicate watercourse channels.)

Table 1. Watercourse Losses for TW 56 before Improvement

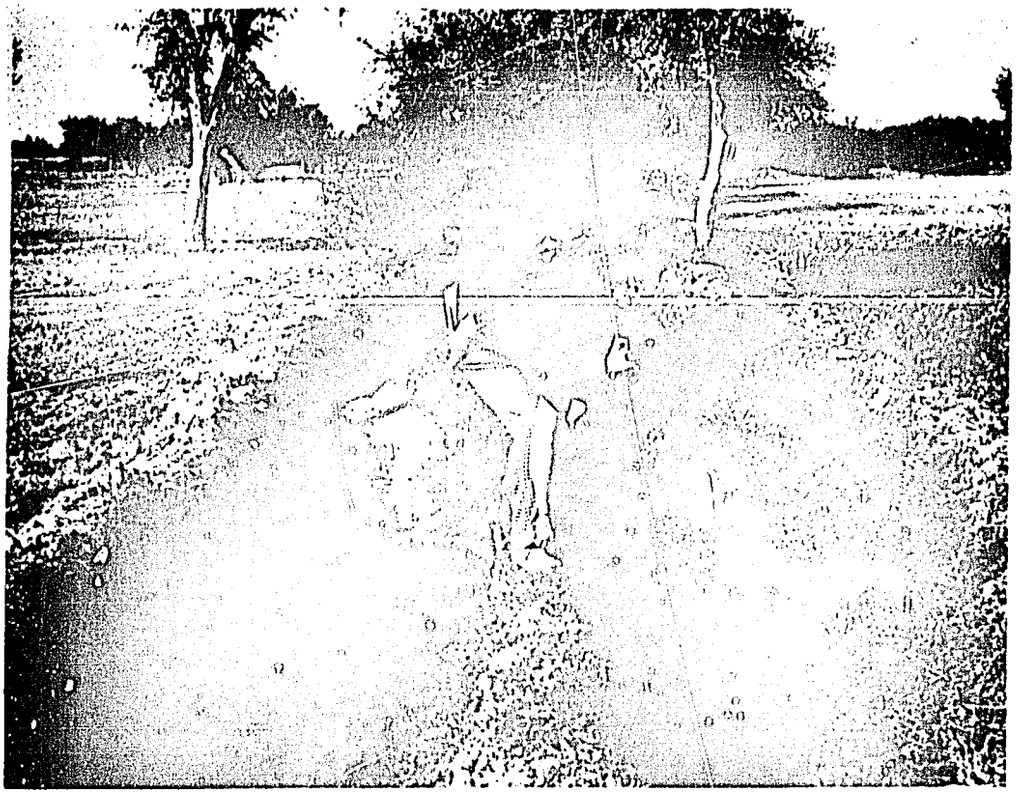
Sheet No. and Date	Beginning (Cusecs)	End (Cusecs)	Loss (Cusecs)	Distances (feet)	Loss Rate (cusec/1000 ft)	Delivery Efficiency (%)	
	Main 1/						
(12)19 Nov 75	4.40	3.90	0.50	3,320	0.15	89	
(15)20 Nov 75	4.80	4.20	0.60	3,520	0.17	88	
	Main + A 2/						
(11)18 Nov 75	4.60	2.45	2.15	2,440	0.88	53	
(10)18 Nov 75	4.60	3.19	1.41	2,080	0.68	69	
(19)18 Nov 75	4.60	2.50	2.10	4,270	0.49	54	
	Main + C 2/						
(1) 15 Nov 75	4.48	2.24	2.24	9,000	0.25	50	
(2) 15 Nov 75	4.48	1.40	3.08	9,500	0.32	31	
	Branch C 3/						
(17)20 Nov 75	4.20	2.70	1.5	5,480	0.27	64	56 4/
(16)20 Nov 75	4.20	2.97	1.23	3,680	0.33	71	63 "
(14)19 Nov 75	3.40	2.20	1.20	2,580	0.47	65	57 "
(13)19 Nov 75	3.40	2.60	0.80	1,340	0.60	75	66 "
(18)20 Nov 75	4.20	1.75	2.45	6,290	0.39	42	37 "
	Main + G 2/						
(8) 17 Nov 75	1.88	0.64	1.24	10,960	0.11	34	
	Main + C + C + E + F 2/						
(7) 15 Nov 75	4.48	1.31	3.17	8,800	0.36	29	
(6) 15 Nov 75	4.48	2.65	1.83	8,800	0.21	59	
(5) 15 Nov 75	4.48	2.65	1.83	9,000	0.20	59	
(4) 15 Nov 75	4.48	2.30	2.18	9,500	0.23	51	
(3) 15 Nov 75	4.48	0.90	3.58	10,000	0.36	20	
Average	4.20	2.36	1.84		.36	51	

1/ From the mogha to Malik Nawaz's dera

2/ From the mogha to the field

3/ From Malik Nawaz's dera to the field

4/ From the mogha to the field assuming 88 percent efficiency in the main channel



'igure 5a. Parallel main and branch watercourse separated by trimmed bank.

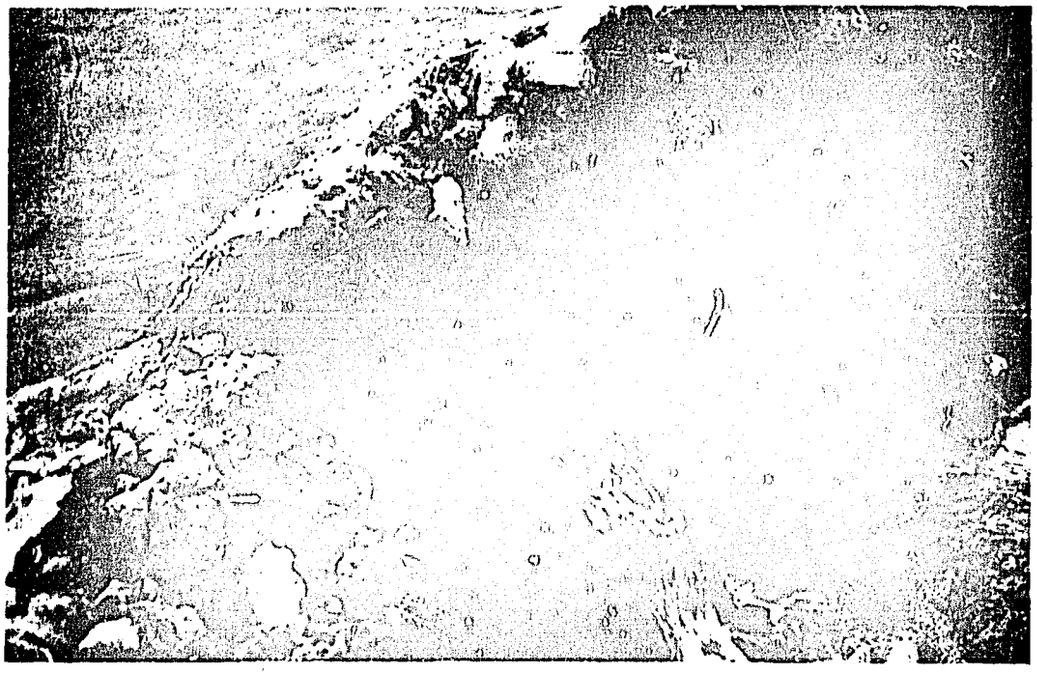


Figure 5b. Leakage through trimmed bank to the branch when water was in main watercourse.

side channel. This allowed him to save his legal water supply for the other crops which he wished to irrigate. However, in a major portion of these parallel channel systems the extra leakage through these banks served no purpose other than keeping these parallel side channels partly full of water.

As part of the general design for improvement, it was decided to eliminate these parallel side channels. The original purpose of these parallel side channels had been to reduce the number of takeoffs from the main channel since it was recognized that these takeoffs, or junctions were the primary sources of leakage from the watercourse. Recent development of reasonably low cost control structures which leak less than one-hundredth of a cusec makes the replacement of 900 feet of these parallel watercourses with two control structures an hydraulically and economically positive step.

As a first approximation for the design, it was assumed that if 0.5 feet of freeboard above operating level of the water in the old sub-branches at the junctions, water could be carried satisfactorily to all the fields. These preliminary criteria were used partially because the topographic survey had not been completed before the farmers wanted to start working. However, further considerations and observations indicated that the flow in the main watercourse is significantly increased by the improvement and consequently more head is required to push this greater flow through these sub-branches to the fields.

The degree to which these sub-branches are to be cleaned and enlarged becomes a factor in the design of the main channel and major branches. Having designed the operating level at the junctions equal to the old level there were two acceptable alternatives for the farmers. One is that they split their water and use two sub-branches to carry the larger supply. The other is that the farmers enlarge their sub-branches and keep them sufficiently clean that they will deliver the water to the fields without causing over-topping of their own sub-branch banks and a back up of water into the main branches which can even cause overtopping there. The farmers elected to increase the size of their watercourses because they had by this time experienced the larger water supply; were impressed with how fast the water could be pused across their fields to give them more uniform intake time. They were willing to give up the land for an enlarged watercourse rather than lose the advantages of working with a large stream of water.

Some instances of inadequate freeboard on this initial pilot watercourse indicate that the design should be based on the topographic map and that consequently, this complete map should be available before the design is begun. For the present, it is being assumed that the farmers will improve

their sub-branches sufficiently to carry away their water at a grade of about 0.3 of a foot per thousand feet.

One of the main factors involved in design is the number of culverts and check structures needed on the watercourse and it is essential to coordinate with the farmers on their number and placement. Coordination with the farmers takes more time than the actual design work. Culverts or check structures which do not cause an appreciable head loss are larger and generally more expensive than those which cause moderate amounts of headloss. Low cost check structures designed for minimal headloss were not available. Consequently in some watercourse sections, where it was essential to take water to fields with high elevations, double orifices were used side by side, rather than a single orifice, which reduced headloss from 0.12 feet to 0.03 feet at the check structure. Improved designs for check structures for minimal losses are needed.

The number of essential check structures is a function of the slope of the watercourse. If the slope of the watercourse is less than 0.3 feet per thousand feet, and some extra freeboard can be added to the banks of the watercourse for a few hundred feet above the check structure, the check structures can be spaced as much as a thousand feet apart. However, if this is done the farmer who has to fill up this full length of watercourse will object. A readjustment on his irrigation turn alloting him the additional time necessary to fill up this additional portion of the watercourse and taking that time away from the individual who no longer has to fill this section of the watercourse will be a just and usually necessary solution. Such readjustments of the waribundi schedule are an essential complement to efficient design.

3. Farmer Organization and Agreements on Improvements to be Made and Work to be Done by the Farmers and by Research Project Staff

Farmers organization for this project was informal. The committee representing the farmers was essentially the three most prominent community leaders plus one person who had extensive land holdings and was the acknowledged village skeptic on community improvement projects. This fourth man was placed on the committee to assure his cooperation. He was never required to do any of the committee work.

The farmers agreed to do all of the earth work which involved the removal of the watercourse banks and rebuilding these banks to proper cross section with earth that was free of coarse organic matter. They also agreed to bring the soil into the borrowed areas at the degraded junctions and other places where earth was needed using their karahs and

bullocks, or their tractors and a scraper provided by the project. In fact, the project tractor was used with the scraper to bring part of this earth into these junctions and the farmers brought in the rest. The farmers also agreed to move the bricks, sand, cement and concrete control panels from the central location to which they were delivered to the sites where they were needed on the watercourse. The project engineers agreed to set the alignment and the level of the watercourse at hundred foot intervals including bed and bank elevations and channel widths. The project engineers also agreed to install the necessary control structures and culverts.

One of the major items of discussion with the farmers was the need for places for animals to come to drink and to bathe in the hot weather. The farmers considered these to be essential. The engineering staff questioned their necessity. Observation of the watercourse indicated that many of the badly degraded sections had reached their deplorable state as a result of buffalo entering, wallowing in and coming out of the watercourse at that point. Even at the junctions, the poor condition of the banks was commonly a combined result of soil borrowing and buffalo activity. Consequently, it was agreed that there would be three buffalo watering and bathing stations at selected locations along the watercourse. Later it was agreed that a fourth station should be installed. These consisted of brick walls around an enlarged section of the watercourse with ramps leading down into the section which could be traversed by buffalo. Since no criteria for design of these were available, designs were developed by the engineers in consultation with the farmers. Washing stations at which the village women could wash clothes were incorporated at some of these buffalo bathing stations. These were installed at junctions where borrowing of soil had already achieved much of the needed excavation and considerable masonry needed for the diversion structures could also be used as part of the walls of the bathing station.

Another major damaging factor to the watercourse was the sediment brought in with the canal water. This was deposited primarily in the top 2000 feet of the watercourse, required removal several times per year and had resulted in banks built up to 6 feet high and 10 feet wide which were taking considerable amounts of land out of production. It was noted that in the immediate vicinity of the mogha, where these banks are commonly the highest, there was no extra sediment. The farmers pointed out that the paved road approached the watercourse at this point and that sediment removed from this section of the watercourse was taken away by trucks and bullock carts to be used as an admixture in brick making operations, to lighten the soil texture in gardens, to fill low areas in fields, etc. The farmers raised a question as to whether we could make a larger portion of the sediment come

out near the mogha where it could be easily utilized and would not take their land out of production. Consequently, a sediment trap section was constructed in the first 200 feet of the watercourse. The watercourse was excavated to a depth one foot below the bed of the pakka mixing structure and the bottom of the sediment trap section was excavated to a width of at least 6 feet. This gives an initial cross-section for flow at least 3 feet by 6 feet or 18 square feet. At a flow rate of 4 cusecs the average velocity will be 0.22 feet per second. In the rest of the watercourse the flow rate was designed to be at least 0.5 feet per second and, consequently, most of the sediment which settles in the watercourse should be deposited in the sediment trap. An estimate of the amount of sediment accumulated along this watercourse and the number of years that it had been in use indicate that about 6000 cubic feet of sediment have been settling in this watercourse per year. Since this trap has a maximum capacity of about 1000 cubic feet, it will have to be cleaned out several times per year. During the monsoon season when the sediment load in the canals is high it may even require weekly cleaning. Six weeks after construction this sediment trap had collected about 600 cubic feet of sediment. Compressed soil cement blocks made of this silty sediment were initially more fragile than blocks made of regular soil with higher clay content. However, the sediment blocks are harder and stronger than the clay blocks after curing. These preliminary findings indicate a potential use of watercourse sediment for making low cost construction materials.

The dashed lines in Figure 3 indicate parallel watercourses which were eliminated in the new plan. The improved branches of the watercourse (A through G) and the main branch (M) are shown in Figure 4. A typical section of the channel existing before the earthen improvements is shown in Figure 6. This same section, after reconstruction by the farmers to the designed specifications is shown in Figure 7. In general, the cross section of the channel was changed using the procedure shown in Figure 8, removing the porous thin old banks and building new compacted banks of clean soil.

An outline of the organizational framework of this pilot watercourse improvement project is shown in Figure 9. This project was conducted under the overall direction of the Mona Project Director. However, in the course of this project he was promoted and given additional responsibilities in Lahore and consequently, most of the direction of this project from the WAPDA side was by the project coordinator. Activities of the primary personnel are given below.

Project Coordinator

This was the primary contact man with the farmers. He was chosen because he had, in his extension activities, built

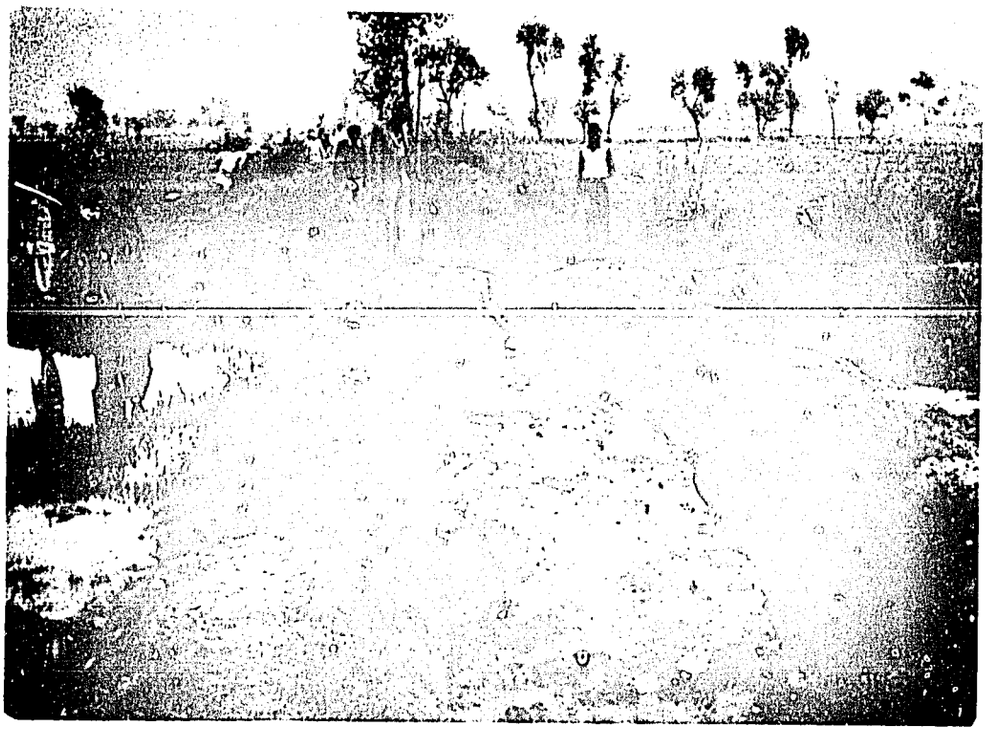


Figure 6. Typical section of tubewell #56 watercourse prior to improvement.

Figure 7. Same section as shown in Figure 6 where the banks and channel were built by farmers to the designed size.

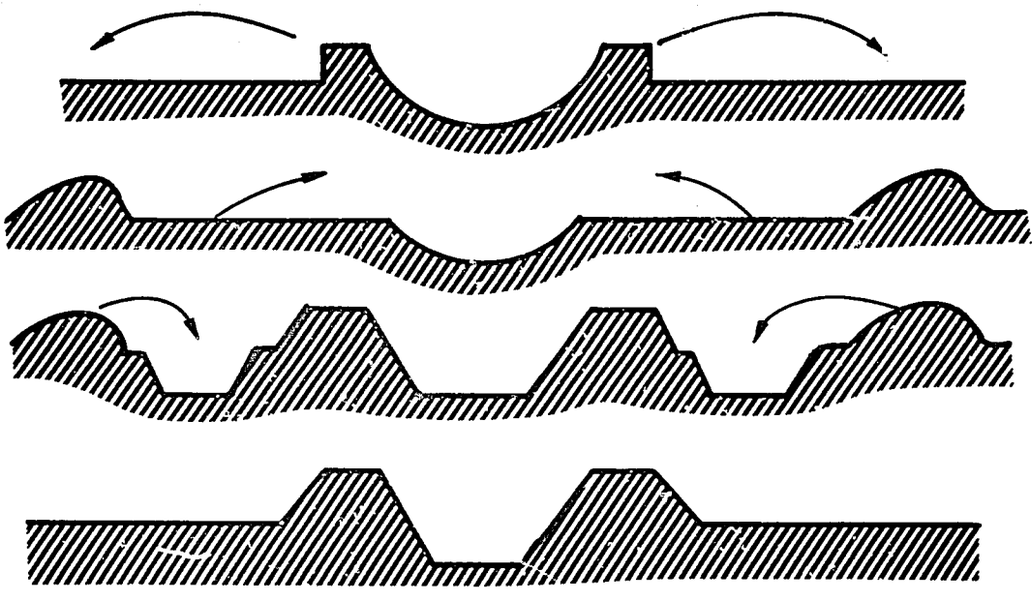
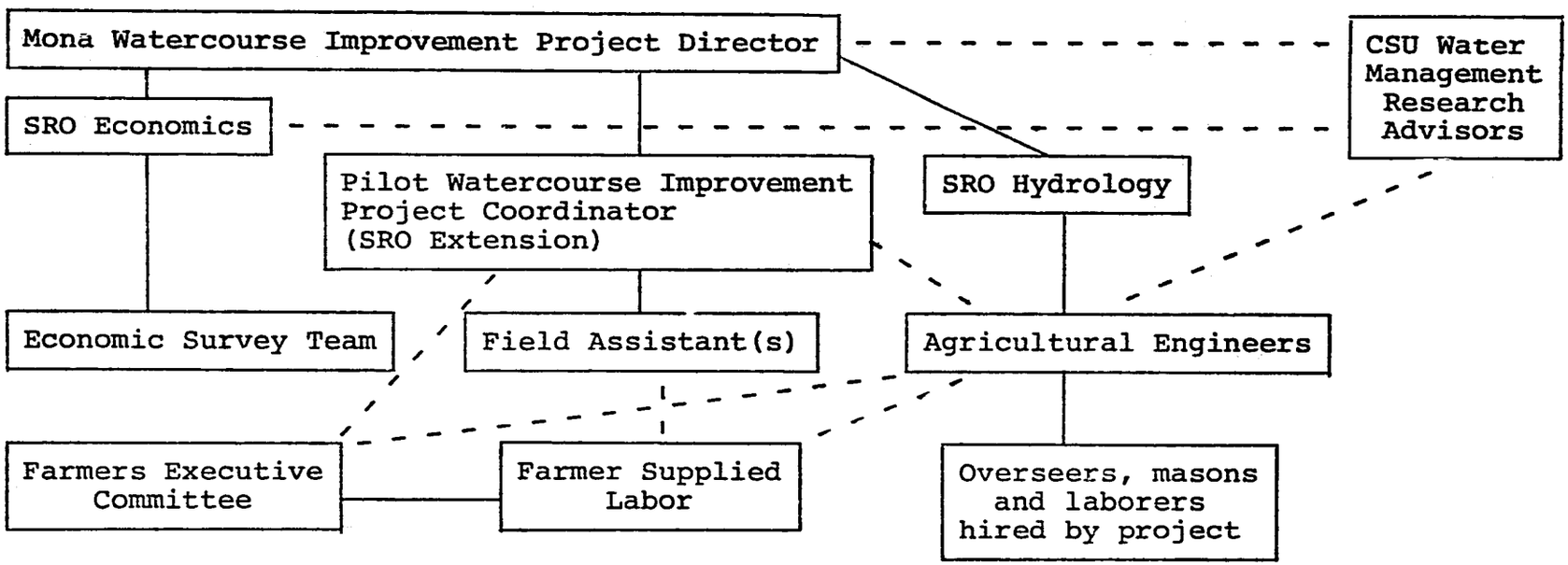


Figure 8. Labor intensive reconstruction of watercourse.

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.
4. Desired cross section earthen improved watercourse.

Figure 9. Organizational Framework of Pilot Watercourse Improvement Project



up credibility with the farmers. He held a succession of meetings with the farmers and during the 50 days of construction spent most of his time at that construction site, supervising the project and resolving problems as they arose. It was his responsibility to call the agricultural engineers to work as help was needed. The field assistants were directly responsible to him.

Agricultural Engineers

They measured the loss of water from the watercourse before and after improvement. They did the surveying for the topographic map and designed the watercourse and the structures with advice from the CSU advisors, made out lists of materials needed and submitted them to the senior research officer in hydrology who ordered these through the executive engineer of the Mona project. The agricultural engineers also set the alignment and elevations of beds and banks, widths of the cross section to be constructed by the farmers and they gave daily supervision to the overseers, masons, and laborers who were constructing the structures, such as the buffalo bath indicated in Figure 10.

Farmers' Executive Committee

These men were responsible for getting the farmer supplied labor on the job each day. They conferred each day with the project coordinator and the agricultural engineers on design matters and alignment disputes that had not been anticipated. They were "in charge" of the project, although they leaned heavily on advice from the coordinator and other advisers.

Farmer Supplied Labor

They removed the banks as indicated in Figure 8, dug the cross sections to the prescribed depths and then built the banks to the prescribed heights and widths, pulling most of the grass and roots out of the soil before it was packed into the banks. The lengths to be done each day were measured by a respected elder with a bamboo measuring stick. If a farmer was not able to supply the labor to build the designated cross section on a particular day, that section was simply left undone until the farmer could have it done. Unfinished sections were very obvious and resulted in considerable social pressure on these tardy farmers to get their work done.

Economic Survey Team

These men conducted the bench mark survey of cropping intensity and made estimates of yields prior to the improvement. This bench mark survey was checked against data collected by the extension field assistants and potwari

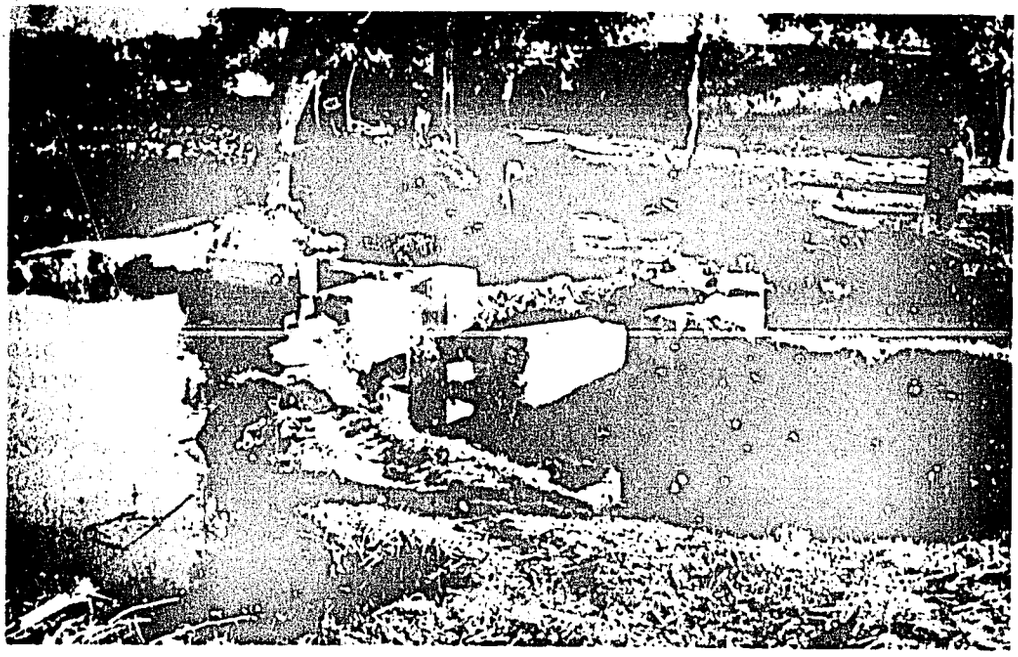


Figure 10a. Degraded junction prior to improvement.

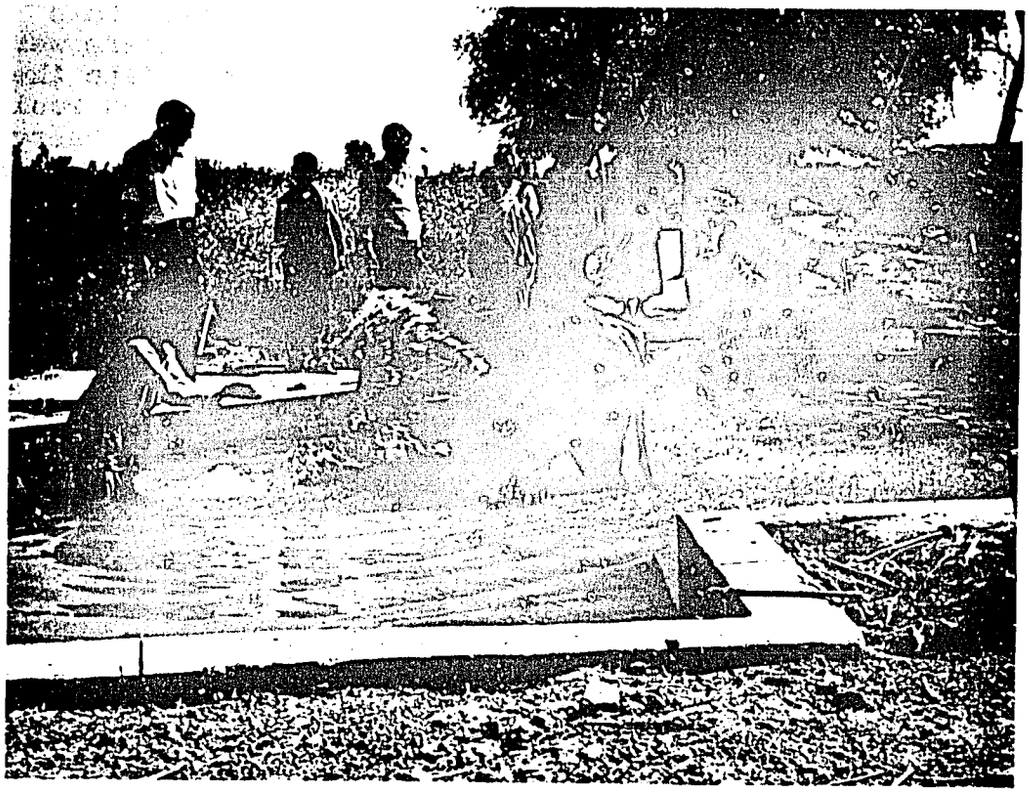


Figure 10b. After construction of a watering and bathing station at this same point.

records. They also kept independent estimates of the amount of labor supplied by the farmers and other inputs which went into this watercourse.

In general, the solid lines in Figure 9 indicate supervisory responsibilities while the dash lines indicate advisory relationships.

The agricultural engineers working with CSU advisors also made other measurements including irrigation application efficiencies, headlosses at structures of various designs and sizes, how funneling of water to the structures could decrease the headloss, amount of riprap needed to control erosion of the channel, whether sod could be used to control erosion on the branch channels, whether compaction and riprap overlay could take the place of the extended and expensive cutoff walls normally recommended at the control structures, whether parallel watercourses lost more water than the additional pakka nakka required to replace the parallel watercourses, etc.

The initial plan was to compact the banks very carefully as the watercourse was built. However, practical difficulties precluded the use of the small bullock drawn roller designed for this compaction. The farmers in general did not see the need for, and therefore did not always achieve this packing as they built the banks. Consequently, there were many observable leaks when the water was allowed into these branches. It was then decided that a finishing crew would work on each of these branches until there were no observable leaks and until the heights of the banks were up to the designed levels. To the farmers this seemed to be an "add-on" and they were reluctant to commit their labor to this final stage of the improvement process. In response to urging by the project coordinator they did take a 2-day swing over the watercourse with about 20 men closing some holes. This was not done when the water was in each of these watercourses and consequently, many of the leaks were not plugged, the lack of freeboard at many points was not apparent, and consequently, banks were not brought up to the proper design level at many stretches. By this time the farmers were getting anxious to go back to their farming.

Each working man was assigned about 20 feet to do each day. They generally began after the farm chores were done in the morning (shortly after eight o'clock). Depending on how hard he worked and what emergencies called him away during the day, the farmer could finish his sections anywhere between 1:00 pm and sundown. Sometimes these were left to be finished the following day.

The original schedule had been to start on December 18 and to finish by February 15. They were always ahead of

schedule, completing the main construction effort by the second of February having worked every Sunday and every holiday except one Eid.

The farmers' executive committee had first suggested that each group of farmers served by a branch would work on that branch. However, before the work was started they changed their minds and decided that they should all work together, each farmer being assigned a section of the watercourse to do each day in proportion to the number of acres of land which he owned. Having everyone work together in this manner offered several advantages in terms of supervision and provision of engineering help for alignment and elevations. The larger group probably brought increased social pressure to bear on those who might otherwise have delayed or avoided making their contribution in smaller groups.

Having everyone work together requires that all have agreed to participate in the project. In future cases if a few individuals refuse to participate in the project, the branch(es) which feed their fields might be deleted from the improvement project and the rest of the farmers might still improve their watercourses. However, in this project having all of the farmers involved and working together was obviously an efficient and successful operation.

5. Farmers Choice

The Mona project technical staff, the American advisors, and one of the farmers agreed on December 17 to begin construction on the 18th of a certain section on the watercourse where it would be convenient to demonstrate the techniques that were to be used. The engineers arrived at the designated time on the 18th and began setting up the alignment and the elevations for the bed and banks in this portion of the channel. The farmers did not appear and after about an hour the project coordinator went up to check on the farmers and found that they had begun work on the top end of that section of the watercourse under the direction of some of their leaders. This seemed to be a strong indication on the part of those leaders that they wanted to make the decision on such matters and consequently the engineers and advisors moved up to the head of this branch to set the alignment and elevations where the farmers wanted to work. About an hour of work time was lost as a result of this change and there was some concern that having this happen on the first day might reduce the enthusiasm of the farmers for the job. However, they were all on hand the next day and the project coordinator cooperated effectively with their executive committee in scheduling the work on the rest of the sections.

To advertise the forthcoming project, the project coordinator had painted about a dozen small signs in Urdu in the watercourse area, which stated that "if you will make the watercourse straight and make the other essential improvements you can double the water supply to your fields. Making the watercourse precisely straight has little to do with saving water. However, most of the farmers had either read, or had someone read to them, the message of the signs. Consequently, when some of the engineers and advisors suggested that some of the slight meanderings of the watercourse could be left in and save more than half of the anticipated labor in many sections, the executive committee members desired to make it straight even if it did require twice as much work as was essential. This required filling in many sections of the old watercourse. Where these fill sections were not properly compacted this fill would not hold the 1:1 slope and slumped and slipped back into the new watercourse to some extent when the watercourse was filled with water.

6. Problems and their Resolution

In several sections of the watercourse, farmers on one or both sides of the watercourse wished to have the watercourse moved onto the other farmers land. Solving these problems was left to the farmer's executive committee who generally tried to follow the original channel as closely as possible.

Some farmers who had no legally designated channel to bring water to their land had previously requested that the Irrigation Department designate a 500 foot section of a watercourse running through their neighbor's land as the legal channel to serve their land. This designation takes the land to be used for the authorized channel out of control of the original owner and provides a 16 foot right of way from which soil can be borrowed to construct the watercourse. Even though the owner can be compensated for this, this particular ownder did not want to lose this land and was contesting this request. Authorization of this channel had been approved by the subdivisional officer but the case was awaiting an appeal to the executive engineer. In the meeting with the farmer's executive committee the owner apparently was pressured into a verbal agreement to allow the new watercourse to go across the end of his land. The working crew promptly dug the 500 foot section of improved watercourse through his land. A day or so later the father of the owner, who was also a co-owner of the land, appeared on the scene, objected violently to allowing their land to be used for this purpose, and insisted that the watercourse should be moved back to a position precisely on the property line, which would have required destroying this newly built 500 foot section of the watercourse and building another one.

This confrontation was temporarily resolved by the executive committee agreeing to not put in concrete structures on this section and agreeing that if the executive engineer did reverse the decision authorizing this section as part of the authorized watercourse, that the watercourse would be moved back to the property line.

Although the farmers served by this watercourse generally have a reputation for being able to work together, several confrontations of this type developed and a couple of them resulted in tense situations, in at least one of which a farmer had to be restrained from inflicting physical damage on an executive committee member. It was obvious that the executive committee of such a group of watercourse users must have a great deal of leadership ability, social standing and personal courage if they are to successfully resolve the multitude of decisions and problems that occur as this "life line" of their crop production systems is modified.

H. Increased Water Supply and Its Cost

According to the general plan for SCARP areas, there is supposed to be about 1 cusec of water provided for each one hundred and fifty acres of land. Consequently, on this 900 acre watercourse a flow of about 6.00 cusecs would have been the expected authorized supply. The records showed an authorized supply of 2.75 cusecs from the distributary and 2.7 cusecs from the tubewell, for a total of about 5.5 cusecs. As indicated in Table 1, when both the tubewell and canal were providing water the flow was about 4.6 cusecs of which about 2.7 cusecs were coming from the tubewell and an average of only about 1.9 cusecs was coming from the distributary. Information from the Irrigation Department showed that the level of water in this distributary was averaging about two inches below the designed operating level. The farmers petitioned the Irrigation Department to clean this distributary. The Irrigation Department promptly cleaned the distributary which brought the operating level back up to near the design level.

Under the conditions existing prior to December 1975 when tubewell #56 was delivering its water to the watercourse the level of water rose in the watercourse until it was near the water level in the distributary. Flows through this mogha when the tubewell was running were measured at between 0.6 and 2.5 cusecs. To avoid this problem the new watercourse was designed so its operating level at the mogha would be about 6 inches lower than the old watercourse. This new watercourse was given at least a foot of freeboard at the upper end so that when it was necessary to push the water up onto high lands near the mogha the banks would not overflow. There is some unavoidable submergence of the mogha during irrigations of these highlands when the tubewell

is on. However, as soon as the point of water delivery to the fields moves down to land whose level is not so close to the level of the water in the distributary, the water level in the watercourse drops and the authorized flow is delivered through the mogha to the watercourse (unless the farmers have not cleaned the watercourse for so long that the grass and sediment are causing high levels of water in the watercourse).

As a result of these changes the delivery of water from the tubewell and the distributary now generally ranges from 5 to 6.5 cusecs. (However, about 0.3 cusecs of this is due to a siphon being partially plugged that takes water to another watercourse from the tubewell. This should be cleaned out sooner or later by the owners of this other watercourse.)

The average ED (Efficiency of delivery) for the watercourses measured was 51 percent before they were improved and 77 percent for the watercourses measured following improvement. However, the average length of the sections measured following improvement was shorter and a better comparison is the average loss per 1000 feet of watercourse, which was 0.36 cusecs before and 0.20 cusecs after improvement. If the increased supply following improvement of this watercourse had been imposed on the old watercourse, the percentage delivery efficiency would have decreased further because of overtopping of some sections and general filling of the watercourse to higher levels which causes more leakage since the upper portions of these banks are more porous. The improvement increased both the total amount of water delivered to the farm and the efficiency of delivery as shown in Tables 1 and 2. In general this has increased the water supply to the farmers fields by an average of over one cusec. Considering that this extra water flows to the fields for 320 days per year, the total savings per year are over 640 acre feet of water. The cost of SCARP tubewell water on the new schemes is about Rs 50 per acre foot at the tubewell and data shows about half of this reaches the field so its cost at the field is about Rs 100 per acre foot. Using this figure as a value for the water saved by the improvement gives the farmers a return of over 64,000 rupees per year.

The cost of this watercourse improvement included about 12,000 man hours of unskilled labor, 2000 man hours from extension personnel and 600 hours of agricultural engineering personnel. These professional hours could be reduced to half of this amount in an operational development program where research was not an important component of the overall project.

Approximately 120 control structures were used and the precast panels and lids for these structures cost Rs 60

Table 2. Watercourse and Total Flow at T.W. 56 Watercourse following Improvement

Date	Flow in Watercourse Beginning (Cusecs)	End (Cusecs)	Loss	Distance (feet)	Loss Rate (Cusecs/1000 ft)	Delivery Efficiency (%)
	Main 1/					
6 Feb 76	2.55	2.25	0.30	2200	.14	88
19 Feb 76	2.92	2.80	0.12	3980	.03	97
23 Feb 76	5.30	4.50	0.80	3980	.20	85
26 Feb 76	2.60	2.55	0.05	1100	.05	98
4 Mar 76	6.15	5.59	0.56	3980	.14	91
	Main + A 2/					
2 Feb 76	6.50	5.37	1.13	3300	.34	83
24 Feb 76	5.70	4.60	1.10	3300	.33	81
26 Feb 76	2.60	2.00	0.60	4400	.14	77
26 Feb 76	2.55	2.00	0.55	3300	.17	78
	Main + C					
4 Feb 76	2.97	1.95	1.02	6180	.17	66
5 Feb 76	2.00	1.34	0.66	9480	.07	67
20 Feb 76	5.73	3.95	0.78	6180	.13	86
4 Mar 76	6.15	3.19	2.96	9480	.31	52
	Branch C					
4 Mar 76	5.23	3.19	2.04	5500	.37	61
	Main + C + D					
13 Feb 76	6.65	4.35	2.30	8380	.27	65
20 Feb 76	5.73	4.10	1.63	6180	.26	72
	Main + G					
7 Feb 76	5.50	3.45	2.05	9480	.22	63
16 Feb 76	6.60	4.15	2.45	9480	.26	63
23 Feb 76	5.30	4.15	1.15	6180	.19	78
	Branch G					
23 Feb 76	4.50	4.15	0.35	2200	.16	92
Average	4.66	3.54	1.12		.20	77

1/ From the mogha to Malik Nawaz's dera

2/ From the mogha to the field

each for a total of 7200 rupees. The installation cost on these including the brick, cement, mortar and masons and laborers time averaged about 100 rupees per structure. In addition, about 10 cubic years of riprap at the cost of about Rs 25 per yeard were necessary to reduce erosion in the vicinity of structures of the main channel. This adds about Rs 25 to the cost of installation and procurement of each of these structures on the main channel for a total cost of about 185 Rs per check structure. Control structures taking water out of the main channel and check structures in branches cost about Rs 160 per structure, and the total cost for the control structrues was about 30,000 Rs.

Twenty new or replacement culverts (24" in diameter and 8' long) were installed at a cost of approximately Rs 200 each. This cost may be further increased by the need for wingwalls or riprap to reduce erosion, maintain adequate length for tractor crossings and minimize headloss. Figuring these culverts at a final cost of Rs 250 each for 20 culverts gives a total of Rs 5,000 for culverts.

The four buffalo baths are being used by many small boys who find them a pleasant place to swim and it will be interesting to see whether the buffalo can displace them during the hot months. They also turned out to be rather expensive installations costing an average of about 3500 rupees. Ten to 15 percent of this cost would have been necessary to form the proper junctions and bring in soil to fill the borrow pits that existed at these points if the buffalo baths had not been built.

An estimate of the total cost of improving this watercourse would be around Rs 70,000 (30,000 for control structures, 5000 for culverts 14,000 for buffalo baths, 12,000 for labor, 5000 for extension personnel and 4000 for engineers) of which about Rs 10,000 could have been omitted if research and a few experimental errors had been eliminated. Thus, the cost, including the buffalo baths, averaged slightly more than Rs 2 per foot of watercourse improved and there is some question as to whether the buffalo baths are a necessary part of the improvement. Assuming the water saved is worth Rs 100/acre foot and 640 acre feet of water are saved annually the farmers will almost recover the total investment during the first year from the value of the saved water. Reduction in crop damage due to reduced seepage will give added benefits.

The structures should last 10 or 20 years but the improved earth banks will require regular maintenance to keep them from developing leaks. The channel will require regular cleaning to keep down the vegetative growth and to remove sediment which escapes past the sediment traps. The sediment trap itself will also need to be cleaned several

times a year. It is estimated that between 4,000 and 8,000 man hours of work per year will be necessary to maintain the watercourse in its present condition. The recently hired khal chowkidor will provide about 2000 hours of that time but it will be necessary for the farmers to provide the additional man hours from their labor resources at times when this labor is in surplus.

It appears possible for the farmers to maintain this additional supply of water gained from watercourse improvement at a cost of about 10 man hours of labor per acre foot of water with a small additional capital outlay necessary to replace the control structures as they are damaged or wear out.

I. Additional Steps Needed to Optimize Production Using this Increased Water Supply

It cannot be assumed that increased water supplies at the nakka will automatically result in a concommittant increase in production. The farmers need help to change their cropping practices to efficiently utilize the increased supply.

It appears that a plan to aid farmers should have two main components; 1) Land leveling to utilize water more efficiently, and 2) Assistance in planning changes in cropping practices and obtaining the necessary inputs. Various research programs which provide information on specific crops or practices have been conducted by the CSU team members and their cooperators. However only a small part of the variables that must be considered can be covered in these types of projects. It becomes necessary therefore to synthesize production systems based on these data and a general knowledge of fundamental crop needs, the physical environment of Pakistan, and the needs and capabilities of the cultivators. The research component then becomes a matter of evaluating the present system, followed by pilot use of proposed systems and documentation of the performance of the systems and their adoption. There must also be a feedback of information for continual improvement of the proposed systems.

Land leveling has been a component of the previous programs and efforts will be made to provide technical assistance for leveling on the watercourse recently improved and on those to be improved in the future. Further assistance in actual leveling should be provided on a sufficient number of fields so that the value of this practice in efficiently utilizing the increased water supplies can be quantified and documented.

The actual planning and instituting of changes in cropping practices that will increase production is the most difficult task facing the team at present. It is much easier to plan experiments that evaluate a small number of cultural practices on a given crop. Large experiments using various crops and cropping systems generally will not give clear straightforward answers.

Our approach is to use water requirements as a focal point. Climatic records are being examined and water needs for various crops as a function of time are being plotted for normal and dry years. With this information it is possible to predict irrigation requirements for any crop mix and to evaluate these requirements in relation to supply available. Changes in cropping mix, planting dates, or irrigation practices can be suggested to best match the supply and needs of the crop. Such programs will be tested on cooperators farms as well as experimental farms. These will be coupled with advice on fertilizer and cultural practices.

J. Resume of Findings and Additional Information Needed to Evolve a Development Program.

Research and experience on the watercourses studied to date have shown:

1. About 50 percent of the water is lost from the average watercourse in Pakistan.

2. Earthen improvements can save most of the water currently lost from watercourses.

3. Concrete control structures can be manufactured at nominal cost which leak less than 0.01 cusecs when closed properly.

4. Farmers will often reject improvement programs and/or refuse to maintain improvements if they have not made personal investments in the planning and construction phases.

5. Farmers remained enthusiastic for forty days while working in a large group (about 35 workers) on an improvement project, where each worker was assigned about 20 feet of watercourse (large enough to carry 5 cusecs) to reconstruct per day.

6. Parallel watercourses commonly used to reduce numbers of outlets from the main channel, can be eliminated by installing more concrete control structures and the resulting saving in water and land is greater than the costs.

7. When earthen improvements are made by farmers on their main channel and main branches, losses are reduced and the supply of water at the lower end of the watercourse is often more than doubled. This requires cleaning and enlargement of the sub-branches carrying water to the farmers' fields, or splitting of the increased supply into two or more sub-branches.

8. Pakka pools with ramps designed to allow animal watering and bathing have concentrated the animal and small boy activity and greatly decreased degradation of the banks, but costs were near Rs 3500 per ppol that can accommodate 10 buffalo at a time.

9. Engineering design factors and procedures found to facilitate improvement include:

a. Identification or construction of concrete or masonry benchmarks (about one per 25 acres) to facilitate the topographic survey and subsequent watercourse construction is a good investment of time.

b. The design and elevations of the watercourse should be based on the topographic information rather than previous operating levels because the increased flow of water flowing through unimproved farmers sub-branches will raise the level of water in the main channels if the banks are not elevated.

c. Riprap is necessary to prevent erosion below the structures on the main channel. Sod can provide adequate protection at most structures on branches which carry water less than two days per week.

d. Compacted earth fill and undisturbed soil, when wetted, will generally retain a slope of 1:1 if the soil is not sandy. Uncompacted soil will not retain this slope when wetted.

e. Head losses with given flows through the round submerged orifices of control structures in standard installations can be predicted and when measured to $\pm$ 1mm these head losses can be used as reasonably accurate estimates of the rate of water flow.

On this first pilot watercourse improvement project a deliberate effort was made to have several engineers and extension personnel participate so they could gain experience in this type of work. The pressure for trianing will increase as time for initiation of the national water management improvement program approaches. However, on at least one watercourse, only the essential technical staff should

participate to make sure that this essential staff (one experienced engineer plus one apprentice engineer plus a team leader and one Agr. Officer (with special training in water management) are adequate to do the job.

Training guidelines and aids developed to help this team do their job should be printed using metric units, since Pakistan is converting to the metric system this year.

Permanent concrete structures which can be efficiently used as control and measurement structures need to be designed and tested.

Check structures which cause negligible head loss and are reasonable in cost need to be designed and tested.

The earthen improved watercourses will degrade rapidly if not maintained. Amounts and type of maintenance needed to maintain the improved water supply should be determined over at least 3 years.

Maintenance and component replacements needed to maintain leakage at control structures down to acceptable levels should be determined.

This first pilot watercourse was selected because excellent leadership and cooperative attitudes were obvious among the farmers. Our experience on other watercourse improvement projects indicates that most watercourses will have less inherent leadership and cooperation. It will be necessary to develop capabilities for leadership and motivation in the government hired personnel which can supplement the farmer leadership when necessary and can bridge social cleavages among different factions of the farmers. Guidelines for resolving water management conflicts must be developed and taught to the team leaders, watercourse engineers and water management specialists who will be working with the farmers on such improvement programs. Guidelines for helping farmers evaluate their problem, understand their potential for improvement and mobilize their labor resources to accomplish the improvement are also essential.

The sections of this watercourse were made precisely straight, which often required filling the old channel and digging another channel 2 or 3 feet away. In many stretches, banks with no visible leaks were destroyed and remade. Expensive buffalo watering and bathing pools were constructed with pakka sides and ramps to prevent degradation of the banks (i.e. Figure 10). Concrete control structures paid for by the government were installed at all major junctions.

The total cost of improvement could be reduced to less than one third and the capital input could be reduced

to less than 1/4 of the cost of this pilot watercourse project (total cost about Rs 80/acre) and a major portion of the water savings may be possible through a proposed "essential improvements" program. These essential improvements would consist of: 1) Building cross sections of channels and banks to proper dimensions, but allowing the new channel to follow the slight meandering of the old channel, 2) Filling borrow pit areas around junctions and building full size compacted banks and providing some extra soil at junctions to be used for dam construction, 3) Compacting cores in banks which are leaky but have proper dimensions , and 4) Construction of essential animal watering and bathing pools using compacted earth banks, sloped at about 3:1 as ramps for entry and exit of animals. Analysis of data on location and magnitude of losses indicates that 60 or 70 percent of the water savings obtained in the pilot watercourse improvement program could be achieved through this essential improvements program. It has special attraction in that it could probably be implemented by extension agents with short course training, and its rate of implementation would not be so limited by the limited supply of engineers.

The success of the development program will depend on whether the personnel implementing the program can make the farmers aware of their potential for reducing watercourse losses, for increasing application efficiency and for using their new water supply to increase acreage of crops and yields/acre and help them achieve those potentials.

The success of these implementers will depend on the development of a sound technical program and a quality training program, which will both train and inspire the participants to help the farmers.

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Most important of all are the farmers who did the work. We wish to express special appreciation to their leaders, Khan Moh'd. Chandawana at Branch I, T.W. 78, and Chaudhry Moh'd. Ashraf, Malik Moh'd Nawaz and Behader Khan, the executive committee of the farmers at Tubewell 56 watercourse, who grasped the potential for improvement, motivated their fellow farmers to do the work, and showed great wisdom in settling the many questions and disputes that arose in the process of these improvement programs.

Appendix 30

WATERCOURSE IMPROVEMENT: TUBEWELL 56R DURING RAMAZAN[1]

Mohsin Wahla, Malik Moh'd Iqbal, W.D. Kemper
and S.A. Bowers[2]

Background

To convince the farmers served by Tubewell 56-L that they should improve their watercourse, three meetings were held during November and December 1975. Ch. Mohammad Anwar, a leading farmer from the area served by Tubewell 56-R also attended the second meeting. Since then he has been eager to have such improvement on his watercourse but unfortunately one-third of the shareholders on his watercourse were from another village known as Gughiani. Farmers of Ghughiani are known as the "drones of the Bhalwal Tehsil." This was one of the main factors that was preventing Ch. Mohammad Anwar from mobilizing all of the farmers on his watercourse to compete with the farmers of Tubewell 56L watercourse for the first watercourse improvement program. Even after the benefits accruing to the farmers when the watercourse 56L was improved were obvious, Ch. Anwar could not bring the shareholders on his watercourse to agree to contribute to the improvement.

Meantime the farmers on another next door watercourse (serving Tubewell 51) went ahead with the second watercourse improvement program.

The positive response of the farmers to these improvement programs and an increase of about 50 percent in the average water delivery to the fields lead administrators in USAID, the Gov't of Pakistan and the Gov't of the Punjab the Sind and the NWFP to include this type of watercourse improvement as a major component of the loan funded water management development program.

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[1]Contribution from the Mona Reclamation Experimental Project, Colorado State University and the Water Management Development Projects in the Punjab, the Sind and the Northwest Frontier Provinces. Portions of this work were supported by USAID contracts AID/ta-c-1100 and USAID/Pakistan agreement 204-75.

[2]Senior Research Officer in Extension and Training, MREP; Jr. Agr. Engineer, MREP; Field Party Chief, CSU; and Soil Physicist, CSU, respectively.

To help get this program started in the three Provinces, the Mona Reclamation Experimental Project and CSU agreed to provide 3 weeks of training to 4 men each from these 3 provinces. The Mona staff with assistance from Mr. Saddiq Shafiq, Mr. Mushtaq Gill and the CSU advisers prepared a set of notes on the technical and sociological aspects of how to work with farmers to improve their watercourses. In addition to learning from these notes, the trainees were to be taken to the field to interact with the farmers and participate directly in the various aspects of watercourse improvement. These trainees were scheduled to arrive about September 1st when the main part of the Monsoon rains are usually over. However, there was more rain than usual and it rained so much during the first week of September that it was not possible to take these trainees to the field. It had also become obvious in August that we would not be able to reach the watercourses at Tubewells 140 and 127, where we had planned to provide the field training, because the roads leading to them were not paved and were under water as a result of the floods. Consequently, the primary criteria for selection of this "training watercourse" became its proximity to a paved road which was not inundated.

Based on these criteria, Mr. Wahla selected the farmers served by the watercourse at Tubewell 56R. He contacted Ch. Mohammad Anwar, and told him there was a possibility for him and the other farmers of his watercourse to work with us to improve their watercourse. Mr. Anwar replied "My arms are open but my biradri[1] is posthumous." Mr. Wahla then outlined a program with Mr. Anwar to convince Mr. Anwar's biradri that they should undertake a watercourse improvement project. On the next day a general meeting of the shareholders was called which was attended by all the farmers except those from village Gughiani. The assembled farmers were taken for a walk along the watercourse where Mr. Wahla helped them realize the magnitude of their water losses. After this examination of the watercourse they all sat in the dehra[2] of Ch. Mohammad Anwar for discussions. Ch. Mohammad Anwar and Ch. Mohammad Akbar raised the point that "their major water loss was in the section of the watercourse which passed through the village"[3] and requested that this

[1]Biradri is a brotherhood, or group of supporters.

[2]A building owned by a farmer which is not generally the living quarters for his family.

[3]In fact, there was little loss of water from this section that ran through the village because the banks were compaced with heavy traffic. Occasionally the water backed up in this section due to lack of cleaning in the downstream sections and then overtopping occurred at a few points in this section through the village where human and animal traffic had worn the banks down. This loss was obvious to the farmers, their families and the other two-thirds of the village inhabitants whose lands are served by other watercourses. However, the farmers had obviously decided that improvement of this section through the village was their first priority and there was nothing to be gained from arguing the point with them at this meeting.

section be constructed of masonry and that the research project should pay the cost. Realizing that this would be a fairly large cost, Mr. Wahla then asked what the farmers were going to contribute. Assembled farmers replied that they would only provide labor for the earthen improvement work. Mr. Wahla replied that unless the farmers were willing to share the costs, masonry work on the watercourse would not be possible. A bargaining session ensued and it was agreed that the 1100 ft. of watercourse passing through the village would be lined by the project and that the farmers would pay for their own control structures, including purchase of the panel nakkas, bricks, cement, sand and masonry work.[1]

In this meeting three members of the watercourse executive committee were selected. These were:

1. Ch. Mohammad Anwar
2. Fayyaz Hussain Shah
3. Ch. Mohammad Adbar

The shareholders from village Ghughiani still needed to be convinced. To accomplish this, Mr. Wahla made an appointment to take Fayyaz Hussain Shah (religious man) and Ch. Mohammad Anwar to Gughiani village after evening prayer. Due to a previous murder in that village which had seriously divided the inhabitants into two groups, it was necessary to meet with each group separately. Each group was told that the other was ready to help with the improvement if their group would help. The response of the first group was positive,

[1]Building of this lined section through the village was undoubtedly a major incentive which obtained the farmers cooperation. It is reasonably in line with the provisions of the proposed new loan financed development program, which will allow concrete and masonry lining where needed. Observing the rapid deterioration of section of improved earthen watercourses adjacent to the village at Tubewell 51 watercourse, the generally poor condition of "mature" earthen watercourses as they go through villages (e.g. Tubewell 81 watercourse and Banni village), and the heavy use of these village watercourse sections for clothes washing, vegetable washing, bathing etc., it is apparent that intensity of auxiliary use should be included as a criteria for financing pakka (concrete or masonry) improved sections, along with water loss which is the primary criteria now considered in the development program. The purpose of cost sharing is not simply to save water, but is to motivate farmers to help themselves. The investment of government funds in motivating farmers will be most effective when we learn the farmers' priorities and design the incentives program accordingly.

but the second group argued that "we cannot work with the other group since we have killed their man and they may take revenge" Mr. Wahla and Mr. Shah then suggested that they need not come personally but could send their servants, because the other group had no enmity toward their servants. They agreed to the proposal and Mohammad Saida (Chaudhary man) was selected as the executive committee member to represent the village Gughiani farmers.

The training team was eager to know which watercourse they should start working on. While the farmers at Tubewell 56R watercourse were generally agreed to the project it was the month of Ramazan[1] and there was considerable question as to whether good support could be gained for the improvement work during this month. September is a hot month in Pakistan (temperatures generally in the 90 to 100 degree F. range during midday) and it is physiologically impossible to work hard for a day without water and difficult to go that long without food. After discussing this problem the three executive committee members from Chack 10 village and Mr. Wahla went to the farmers' homes and gathered them together in a meeting to determine their willingness to work during this period. After a short speech in which it was pointed out that improving their use of water and crop production was also Allah's will, these farmers agreed to work during Ramazan. The following decisions were made in that gathering.[2]

1. The improvement work will be started on September 18, 1976.

2. Working hours will be from 6 to 12:00 or till one completes his share.

3. The improvement will be started at the head of the watercourse and will be in successive sections along the watercourse of 600 to 1000 feet per day.

4. The length assigned to each farmer each day will be in proportion to the amount of land which he owns in the watercourse command area.

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[1]A month when Muslims normally abstain from food and drink from before dawn to after sunset.

[2]The meeting had been convened quickly and informally and the Gughiani farmers were not present. They were informed of the decisions, but they had not, in fact, agreed to cooperate on this schedule. This was not an ideal situation, but was a result of "emergency action."

5. The farmers will deposit their money for the structures with Fayyaz Hussain Shah at the rate of Rs 250/structure.

6. Structures will be purchased by the farmers directly from the manufacturer with the MREP and CSU personnel helping them make this contact.

7. The watercourse should be constructed straight (rather than following its existing meanders to reduce labor).

8. Farmers will provide the labor at the rate of 2 men/square[1] of land owned.

9. Dismantling of the old banks and uprooting of shrubs and trees in the first 1400 feet, where the banks are high and there are a lot of trees, bunch grass and bushes, will be done collectively.

10. In the other sections of the watercourse, farmers are to uproot their trees which are standing within watercourse right of way one day before improvement of that section.

11. There will be two days holiday for Eid-ul-Fitar.

On the basis of the decision by this main group of farmers, the training team went ahead and began the topography survey, water supply measurements, water loss measurements and collecting the other data prerequisite to the design of the new watercourse and evaluation of the improvement. The team of trainers and trainees collectively designed the improved watercourse to properly supply water to all commanded acres. The design was then taken to the farmers to make sure that it met their needs.

In previous improvement programs where the costs of the control structures were paid by the project this stage was difficult because almost every farmer demanded check structures immediately following each nakka where he planned to take water from the main branch. This had resulted in conflicts with the engineers who were trying to keep the total head loss through check structures low so the water level would be high enough to properly serve all the legally irrigated fields. However, on this watercourse where the farmers were paying for thier own check structures they did not ask for more check structures, but sat with the engineers to find ways of cutting down the number of check structures on the watercourse from 18 to 15.

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[1] A "square" is approximately 25 acres.

On September 18 the mogha was closed, a call was made through the loudspeaker at Chak 10 village and all the farmers from that village were at work by 9 o'clock. Only half of the farmers from Gughiani village came to work on the first day, but on the next day they were all there. The trainees and their leaders collectively set the alignment and elevation of the watercourse for the first few thousand feet under the direction of Malik Moh'd Iqbal, who continued this work after the trainees left on Sept. 21.

The improvement work progressed peacefully except on the third day when the improvement work approached a corner where the marker stone was missing. Sighting along a couple of existing concrete structures which were assumed to be on the property line Mr. Iqbal concluded that the watercourse was 15 feet from the property line. He conveyed this information to the executive committee and they instructed him to change the location of the new watercourse to the property line. The result was that Mr. Ahmad Khan would lose a strip of land 15 feet wide and several hundred feet long which he and his family had considered theirs for over 30 years. He was understandably unhappy with this decision and decided to appeal to Mr. Wahla and Mr. Kemper. By this time construction had begun on this section and the trainees were helping set alignments and elevations and generally interacting with the farmers. When Ahmad Khan came and requested an appeal of this decision, the trainees were asked what they thought should be done. The conclusion was that the project personnel should provide only technical advice and should emphasize to the farmers that their executive committee was in charge of the project and had the final decision making authority. Using these guidelines the engineers suggested that their surveying instruments be used to sight from existing corner stones further down the line, which were still in place. The executive committee was asked if they would like to have this line run again, more carefully. The executive committee requested that this be done and obtained agreement from the farmers to accept this line before it was determined. This careful survey showed that the property line went even further into the property which Ahmad Khan's family had assumed they owned. In fact, building the watercourse on the real property line would mean removing several of Mr. Ahmad's producing citrus trees. He accepted the survey, but appealed to the executive committee to leave the watercourse where it was being built and allow him to keep his trees. His acceptance of the accuracy of the survey may have been improved by the fact that he was taken along and invited to look through the instrument. It is probable that he did not understand the technicalities involved, but he obviously felt that his case was being fairly treated. After this incident there were no appeals against decisions of the executive committee.

The farmers deposited their money with Mr. Fayyaz Hussain Shah. We took Ch. M. Anwar and Fayyaz Shah to the concrete structure fabricator at Sargodha and told him that this was his chance to expand his business to the private sector where he would not have to deal with all the problems of obtaining money from government institutions. He asked the farmers how many precast pannels and lids they wanted and how and when they were going to pay for them. They said they needed 40 panels and about 30 lids, were ready to make a down payment immediately and complete the payment on delivery if he would give them a good price. He smiled, agreed to a price that was 25 percent less than he had been charging government agencies and they parted charmed with each other. Obtaining this bargain allowed the executive committee to rebate part of the money which they had collected to the farmers. This gave the committee more credibility, made the farmers feel even better about the project, and may have been a factor in the fact that not one of the farmers objected to digging the borrow pits which were necessary to provide earth for the improved banks, even though this digging destroyed appreciable portions of their kharif (summer) crops. After one week without irrigation water, the farmers decided to construct an alternate channel which allowed the water to bypass the village during the five week period that was necessary to build the masonry section through the village.

Survey and Design of the Watercourse

This was a cooperative exercise in which Mr. Moh'd Akram and Malik Moh'd Iqbal and Moh'd Azeem Cheema, from the Mona staff and Mr. Shafiq Sadiq and Mushtaq Gill of the Punjab Agriculture Department guided trainees from the Punjab, the Sind and the Northwest Frontier Provinces in survey and design procedures. The design procedures were basically those outlined in "Aids for Watercourse Design", a mimeographed guide produced by the CSU field party.

The control structures used were all the 26" x 26" panel type set into the watercourses with brick masonry supports and sidewalls. The openings in these panels are 20" diameter orifices into which reinforced concrete lids fit to stop the water.

In general the side slopes of the watercourse were kept at 1:1 and freeboard of 6" was designed and was allowed to go up to 12" where extra soil was available that was not needed elsewhere. In general 0.2 ft. of additional height is added to the banks to allow for settling.

These farmers had observed the functioning of the sediment trap on TW 56R watercourse and wanted one on their watercourse too. This trap was one foot deeper and two

feet wider than the rest of the watercourse and extended from the mogha to the junction (see Figure 1 with Tubewell 56, a distance of about 140 feet).

No additional culverts were planned and head losses at existing culverts were estimated for design purposes.

One low cost buffalo bath was planned at the intersection of the main channel with Branch B.

Construction

The technical aspects were supervised by Mr. Malik Moh'd Iqbal and two field assistants, with consultation as needed from Mr. Wahla and Mr. Kemper. Wherever possible the executive committee was administratively in charge.

To accelerate construction and the early use of the watercourse of the 1100 ft. masonry section, a contractor was hired to do that part of the work.

The farmers provided all the labor for the earth work they worked for 20 days during the period from Sept. 18 through October the 18th, as indicated in Table 1, contributing about 4030 man hours to the work. By October 18th wheat planting season had arrived and the labor was needed on the farms. The channels had all been built to approximately the proper dimensions, but the banks were not up to design specifications at many points, they had not been packed properly and there were still many obvious points of leakage. The farmers agreed to complete some of these earthen improvements during December and January when the canal will be closed and there is little need for water. At that time the masonry structures at the junctions of the channel with Tubewells 56 and 57 will also be constructed. These structures will add about Rs 1400 to the cost and the earthen improvements will require about 1100 man hours of labor.

The farmers have installed 34 of the planned 40 control structures and their total cost for control structures will be less than Rs 10,000.

About 160 hours of engineering time were spent on the watercourse and about 300 hours of field assistants' time. Figuring their time at Rs 6 and Rs 3 per hour respectively the cost of their time would total about Rs 3700.

The basic cost of improving 11,400 feet of watercourse will be about Rs 20632.

The experimental low cost buffalo bath and 220 ft. of low cost masonry lining may add an additional Rs 5000 to this cost.

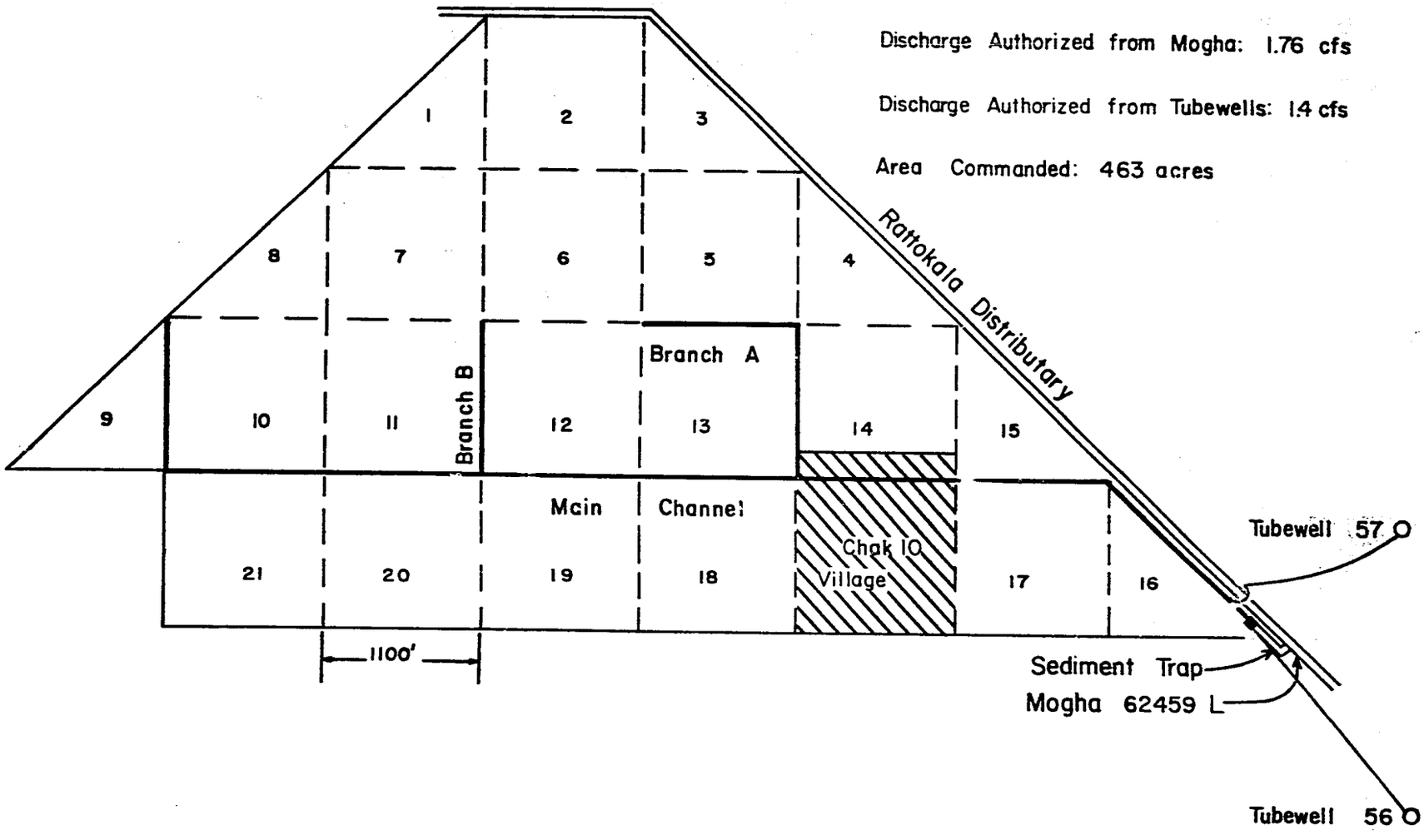

Figure 1. Map of area commanded by the watercourse serving tubewell 56L.

Table 1. Labor Provided by Farmers

Date	Number of Farmers including committee members working on the watercourse	Total number of hours per day
18-9	43	266
19-9	43	252
20-9	44	270
21-9	47	199
22-9	41	255
23-9	42	282
24-9	48	213
25-9	41	249
Eid-ul-Fitr	--	---
28-9	46	236
29-9	45	346
30-9	33	177
1-10	37	147
2-10	30	197
3-10	26	205
4-10	31	183
6-10	17	70
7-10	13	76
9-10	23	152
10-10	23	127
18-10	26	130
	TOTAL	4032

Table 2. Estimate of Costs of Improvement of the Watercourse Serving TW 56L (Excluding the cost of the Masonry Section through the Village).

Labor to Date	
Farmers, 4032 hours @ Rs 1/hour	Rs 4032
Engineers, 160 man hours @ Rs 6/hour	1920
Field Assistants, 300 hours @ Rs 3/hour	1800
Labor to Date	
Farmers, 1000 hr @ Rs 1/hour	1000
Engineers, 50 hours @ Rs 6/hour	300
Field Assistants, 60 hours @ Rs 3/hour	180
Estimated total labor cost	9232
Materials and Installation	
Farmers 40 structures @ Rs 250 each	Rs 10,000
Junction Structures	1,400
Installation and materials cost	11,400

The 1100 foot masonry section through the village, including one heavy duty brick culvert and two other light weight crossings will cost about Rs 45,000.

Benefits

The long term benefits and costs will involve value of the used water in terms of increased crop production, costs of maintenance, etc.

However, the only immediate assessment available is the change in loss and in delivery efficiency.

Due to the short time between deciding to improve this watercourse and the actual improvement and less than full supply during this time interval, the loss measurements taken prior to improvement are not useful for comparison. Following the improvement, measurements of loss were taken and are shown in Table 3.

To obtain estimates of the change in flow and delivery efficiency, farmers were asked how long it took them to irrigate an acre with full supply (mogha plus both tubewells flowing). This irrigation was further defined to be other than a first irrigation following cultivation.

The information shown in Figure 2 was obtained. Delivery efficiencies are estimated at any point by dividing the time required at 0 distance by the time at the distance desired. If one assumes that the full supply flow at the junction with TW 57 was 3.3 cusecs, as was measured following improvement, the farmers were applying about 4.5 inches of water per irrigation (which indicates the need for some leveling). It also indicates that following the improvement the flow at the TW 57 intersection had been increased by about 35 percent, which was probably due to a lower level of water in the watercourse allowing more water to come through the mogha and to the removal of obstructions in the channels which bring tubewell water to their watercourse.

Table 4 shows that the measured delivery efficiencies following improvement are about 5 percent higher than those calculated from farmers estimates of time to irrigate an acre. However, in making these calculations it is assumed that farmers at the head and tail of the watercourse are irrigating with equal efficiencies. This assumption may be inaccurate due to factors such as land being more level at one end or the other, by farmers at the top end having a larger flow which allows them to cover the surface more quickly and give more uniform intake time over their fields, etc.

However, accepting the farmers estimates and making these simplifying assumptions it can be concluded that

Table 3. Losses from TW 56 R Watercourse after Improvement

Distance from TW 57 Intersection (feet)	Loss Rate Total (cusecs)	Loss Rate Cusecs 1000 ft	Loss Rate % 1000 ft	Delivery Efficiency %	Flow at Intersection Cusecs
4450 feet (through diversion	0.90	0.20	8.1	64	2.50
2000 feet (main channel)	0.10	0.05	4.5	91	1.10
6600 feet (to end of branch B)	1.05	0.16	4.75	69	3.35
8300 feet (main channel	1.30	0.16	4.75	61	3.30

Table 4. Delivery Efficiencies Before and After Improvement Based on Farmers Estimated Irrigation Times and Comparisons with Measurements of Loss Following Improvement.

Distance from TW 57 Intersection (feet)	Delivery Efficiencies Calculated from Farmers Estimates of Time To Irrigate One Acre: Before Improvement	Delivery Efficiencies Calculated from Farmers Estimates of Time To Irrigate One Acre: Following Improvement	Delivery Efficiencies Measured Following Improvement
6600	53%	62%	68%
8300	42%	56%	61%

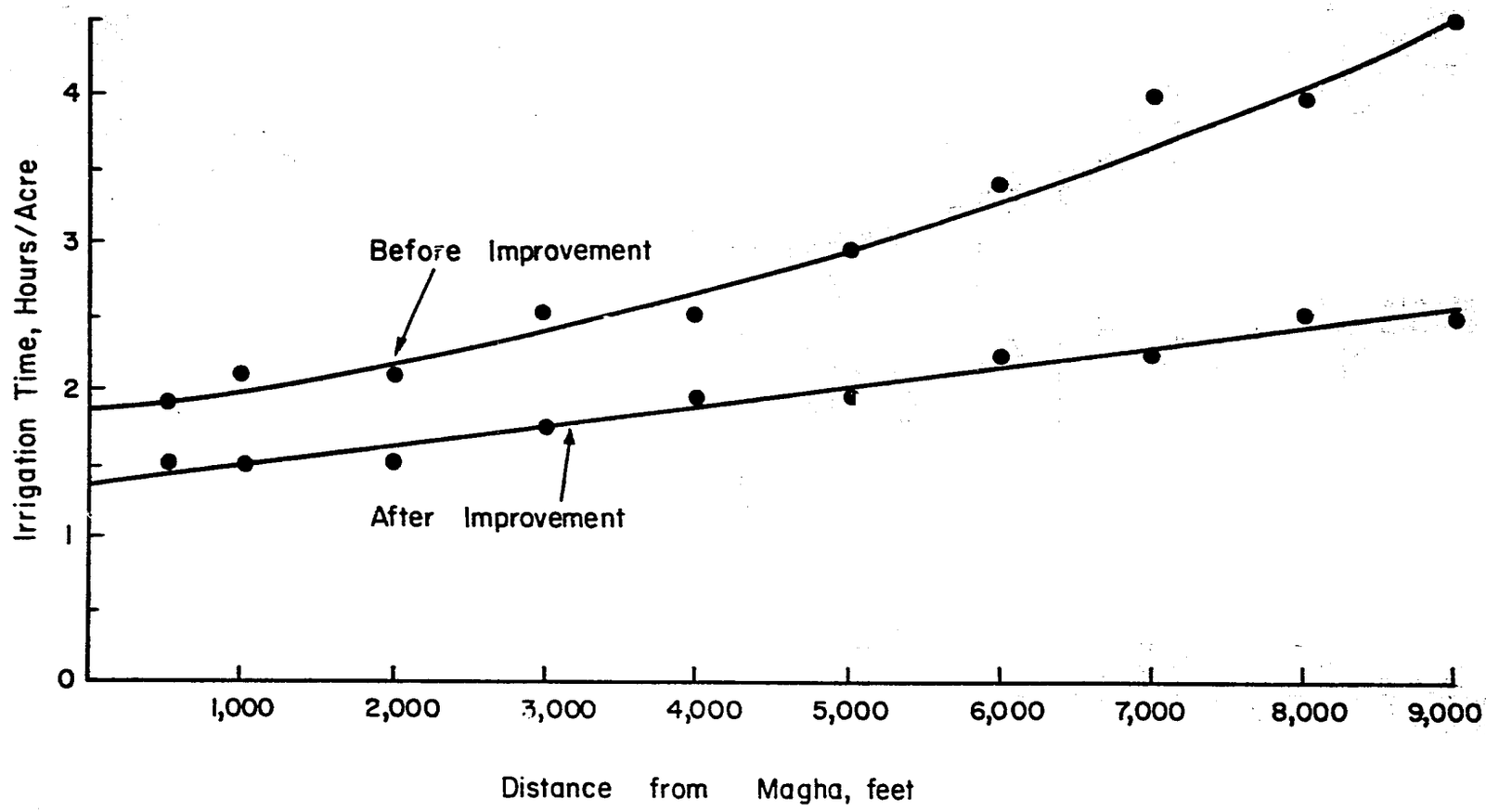

Figure 2. Farmer estimates of time to irrigate fields when tubewells and mogha were all providing water (before and after improvement).

the delivery of water to the average farmer's fields was increased by about 50 percent as a result of the improvement. Part of this increase was due to the increased supply and part to the increased delivery efficiency.

SUMMARY OF FINDINGS

I Watercourse Improvement: Tubewell 56 during Ramazan

Farmers were willing to support a labor intensive watercourse improvement program during the month of Ramazan. The laborers ate and drank during the working day, apparently on the assumption that the inherent virtue of the improvement project justified breaking their fast.

The farmers primary reason for wanting the improvement program was to provide a masonry section through the village where the occasional losses were an obvious nuisance and the intensity of auxiliary use (for washing clothes, washing vegetables, bathing, animal watering, etc.) was extremely high. The farmers realized the high cost of building such a masonry section and were willing to pay the complete costs of their control structures and provide all the labor for the earthen improvements as "part of the bargain" to obtain the masonry section through their village.

The cost of the improvement of 11,400 feet of improved earthen channel with concrete control structures was about Rs. 1.8/foot, including the labor of engineers, field assistants, masons, farmers and their servants, and materials for installing the control structures. The observable benefits were an increase in water delivery to farmers fields of about 50 percent due partly to increasing the supply by 30 percent and partly to increasing the delivery efficiency of the channels by another 5 to 10 percent if a good job is done of "finishing" this watercourse in January.

When the government is paying for the check structures farmers demand many more than are essential which results in conflicts with the engineers. On this project where farmers were paying for thier own, they were very reasonable and worked in close cooperation with the engineers to reduce the number of check structures to a minimum.

The manufacturer of the concrete pannel and lid type control structures was willing to decrease his price by about 25 percent to farmers who paid an advance and completed payment on delivery; as compared to his price to government agencies where payment often requires months and extensive paper work.

Involvement of project personnel in socio-legal decision making and disputes between farmers can be minimized by

clearly defining their role as technical advisers and supporting the water users executive committee as the decision making body in these matters.

ACKNOWLEDGEMENTS

The help of the extension staff at Mona is appreciated.

The Mona Reclamation Experimental Project director Mr. Moh'd Munir Chaudhry and the Executive Engineer, Mr. Abdul Hamid were particularly helpful in providing materials, reviewing the program and making several suggestions for improvement.

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Our particular thanks for assistance in the training and design sessions are due to Mr. Sadiq Shafiq and Mr. Mushtaq Gill who played a leading role in those sessions.

We also express our appreciation to the Water Management Trainees whose enthusiasm, assistance, and willingness to work overtime allowed the completion of the survey and design in about one week.

Most important of all are the farmers who did the work. Our special appreciation goes to them and particularly their executive committee who spent many hours organizing this project and solving the problems whose solutions made this project a success.

Appendix 31

IRRIGATION ADVISORY ASSISTANCE

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I. INTRODUCTION

On-farm water management involves many components. Improved delivery systems can increase the supply of water, but this increased supply will only result in increased production if it is effectively utilized. The farmer is faced with the dual problem of deciding on a crop mix that will meet his economic and subsistence needs within the limitations of the available water supply, and the apportioning of his water supply among his crops within the limitations of the warabundi or weekly turn system.

The program presently being undertaken has three major components: 1) matching the cropping pattern on the individual farms to the probable available supply; 2) helping the farmer to decide on the best use of his available water at each weekly turn to minimize both over-irrigation and crop stress; and 3) assembling a suitable data base for 1 and 2 above. Each of these components are described in separate sections below.

The pilot program is being conducted at the Mona Reclamation Experimental Project near Balwhal in Sargodha district. Five farms were selected in July and projections developed for the remainder of the kharif season. However near record rainfall tended to maintain soils at near saturation during monsoons so that irrigation advising was unnecessary. The program was restarted for rabi season with a goal of 10 participating farms, seven of which had been selected and records started prior to 25 Nov. 1976.

II. OBJECTIVES

Specific objectives of this program include:

1. To devise methods of projecting farm water requirements and identifying periods of potential deficiency and excess.

2. To test these projections and provide recommendations for cropping changes based on these projections in actual farm situations.

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3. To devise and test a simple soil water budgeting system for week to week use in advising farmers on irrigation.

4. To assemble and analyze the necessary data base for the above objectives including expected rainfall and potential evaporation throughout the season for representative locations in Pakistan and appropriate crop coefficients.

III. PROJECTING SEASONAL NEEDS

Seasonal irrigation requirements for a planned cropping mix on a farm unit are projected by use of the Irrigation Planning Proforma. A copy of this proforma designed for the third quarter of 1976 is shown in exhibit A.

The crop and field information is entered on the left hand side. Four fields or groups of fields can be projected on each sheet. For purposes of this planning exercise several fields of the same crop may be grouped if their planting dates are nearly equal or if they have similar crop cover at the start of the planning period.

Note the predicted potential evapotranspiration (Et_p) in inches per week are included on the form along with predicted rainfall for a dry year (defined as the minimum expected 9 years out of 10). The source of this information is described in Section V below as are the crop coefficients (K_c). The actual evapotranspiration in inches/week is now calculated by

$$Et_a = K_c(Et_p)$$

and is entered on the proforma for each week and for each group of fields after which the demand is calculated. Demand (D) is defined as:

$$D = Et_a - \text{expected rain}$$

and has the units of inches/week. The total weekly acre inches required for each field or froup of fields or a particular crop are now calculated by multiplying demand by the number of acres. The total weekly acre inches are then obtained by summing the requirements for all fields. In order to evaluate the adequacy of supply for a given cropping mix it is, of course, necessary to have an estimate of supply. At present this is supplied by actual measurements taken at the farm location on the watercourse but it may also be estimated from known mogha and tubewell deliveries combined with estimates of delivery effiencies appropriate for the distance from the mogha and the general condition of the watercourse. The most useful evaluation procedure devised to date is to calculate a weekly deficit in acre in/acre where deficit is defined as demand minus supply.

EXHIBIT A

IRRIGATION PLANNING PROFORMA - THIRD QUARTER (1976)

Farmer		Oct 1-7	Oct 7-14	Oct 15-21	Oct 22-28	Oct/Nov 29-4	Nov 5-11	Nov 12-18	Nov 19-25	Nov/Dec 26-2	Dec 3-9	Dec 10-16	Dec 17-23	Dec 24-31
Location	ETp(in)	1.40	1.30	1.20	1.10	.98	.91	.84	.77	.70	.63	.56	.55	.5
	Rain (dry year)	.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crop	Kc													
Field	ETa													
Acres	Demand(in)													
	Acre(in)													
Crop	Kc													
Field	ETa													
Acres	Demand(in)													
	Acre(in)													
Crop	Kc													
Field	ETa													
Acres	Demand(in)													
	Acre(in)													
Crop	Kc													
Field	ETa													
Acres	Demand(in)													
	Acre(in)													

If the values are consistently negative more water than required is available and consideration should be given to increased utilization by either increasing cropped acres or increasing the proportion of crops using larger amounts of water which are generally high value crops. Periods of positive deficits are, of course, moisture short periods. Utilization of stored moisture allows us to tolerate some consecutive deficits but if these consecutive positive values exceed expected soil water storage, stress is anticipated. This allowable accumulated deficit we generally take to be about 3 inches, but it may be less if crops are young and/or shallow rooted. Conversely late season deep rooted crops, such as cotton, can tolerate a larger deficit. We generally find that some stress periods will occur during dry seasons if the water supply is well utilized.

IV. FIELD OPERATION AND WEEKLY ADVISING

The first contact involves interviewing prospective farmers for interest. Farms are then selected on the basis of farmer cooperativeness and farm size of a range of small and intermediate farmers (0-50 acres) is desired.

After the farm is selected the irrigation planning proforma described in Section III above is completed and the overall supply-demand evaluated. The basic water budgeting is accomplished using the irrigation record proforma (Exhibit B). Records for two fields can be kept on each sheet. General farm and crop information is entered on the left hand side. The weekly water turn dates are filled in on the top line, each column representing one week. The second line is the Et_p expected for the individual week and is taken from historical data as shown in Section V below. The third line is the weekly rainfall. This is the actual rainfall that occurred that week and not the historical rainfall used in the projections described above, and therefore cannot be filled out until at the most two days prior to the turn when the final decision on the use of the water for that turn is made.

The next five lines apply to individual fields. First the K_c, which again is taken from the tables in the next section, is determined by the characteristics of the individual crops and the stage of growth. The Et_a is again calculated from K_c and Et_p and entered. The deficit for the week is now calculated by subtracting the actual rainfall from the Et_a. (Perhaps some changes in terminology should be considered for future proformae as deficit has a somewhat different meaning here from the usage on the previously described irrigation planning proforma.) The accumulated deficit is now determined by simply adding the current deficit to the previous accumulated deficit. This accumulated deficit is the key parameter in the system as it determines whether or not soil moisture depletion has reached the stage where irrigation

EXHIBIT B

IRRIGATION RECORD PROFORMA (RABI 76-77)

Farmer _____	Rates								
TW No. _____	ETp								
Crop _____	Rain								
Field _____	Kc								
Square and Killa _____	ETa								
Acres _____	Deficit (ETA-Rain)								
Date Sown _____	Accumulated (Deficit)								
Date Rauni _____	Date/Irrig. Expected								
	Date Applied								
Field _____	Kc								
Square and Killa _____	ETa								
Acres _____	Deficit (ETA-Rain)								
Date Sown _____	Accumulated (Deficit)								
Date Rauni _____	Date/Irrig. Expected								
	Date Applied								

should be advised at a particular turn. Optimum deficits are discussed below but in general we use approximately 3 inches. If the deficit has reached or is approaching this optimum deficit irrigation is advised. When irrigation is applied the accumulated deficit is set to zero and the process starts over.

It should be noted that the weekly deficit may be negative so that the accumulative deficit decreases. In practice we do not allow negative values of the accumulative deficit as this would exceed the available storage capacity and the excess water would be expected to be lost through percolation or runoff. Negative values of accumulative deficit are therefore set to zero. The irrigation record proforma for a given field is always started at an irrigation date when the accumulative deficit can be assumed to be zero.

The final two lines to be filled out are the predicted date of irrigation and the actual date. The predicted date is used in planning water needs in the immediate future. It is arrived at by calculating the actual Et_a for the next two or three weeks and projecting when the optimum deficit would be reached assuming zero rainfall. If predicted optimum deficits suggest that on a particular date in the future more fields will require water than can be supplied, the field staff suggests that some of these fields be irrigated at the previous turn.

If a period of several weeks occurs in which more fields require irrigation than the supply permits it is necessary to apply priorities. Several priority schedules have been worked out, and these may vary with the wish of the individual farmer. In general vegetable gardens and other food crops for domestic consumption are given highest priority followed by the forage required for animal maintenance. The third priority is high value crops grown for sale such as rice or sugarcane, while lower value market crops are assigned lower priority.

An additional phase of the field program involves validation of the method used in predicting soil water depletion. Ten fields in the program have been selected for gravimetric soil moisture sampling to monitor the accuracy of the budgeting system. These fields are sampled before and after each irrigation, so that the loss in water that is measured can be compared with the accumulated deficit from the Irrigation Record Proforma. Five cores are taken from each field by one foot increments. The cores are not composited but each increment of each core is analyzed separately by determining weight loss on oven drying. These separate analyses allow us to statistically evaluate the precision of the soil water measurements.

V. DATA BASE FOR IRRIGATION ADVISING

Temporary data base

In order to carry out the program described above it is necessary to have information on the potential evapotranspiration, and the expected rainfall in the area concerned as well as on the crop coefficients. The tables shown here were assembled as a temporary data base in the Mona project area.

The potential evapotranspiration values (Tables 1 and 2) were devised from those given by Clyma and Rafique Chaudry (1975), using the Jensen-Haise method(1963).These authors give monthly values which were plotted and weekly values were developed from the plots.

The wet, normal, and dry rainfall values were developed from ten years data from the Mona Reclamation Project (July 1965-July 1975). These were developed by calculating accumulative monthly totals for each year for both the rabi and kharif season. The kharif data appeared to be normally distributed in this form but rabi data was obviously skewed. A square root transformation on the data expressed in millimeters appeared to result in a normal distribution for the rabi data. From these values the mean and standard deviation along with the upper and lower 10 percent one tailed 10 percent points were computed. These monthly values were plotted as a function of time, and weekly values were interpolated from the plots. These results are probably a reasonable approximation but more detailed analysis with a longer time base are required for final use. The cumulative procedure biases estimated the lower 10 percent point slightly toward low values at the start and high values at the end but the effect probably is not serious. It does avoid a problem of biasing the results toward lower probabilities for the total season that occur if consecutive probabilities are calculated on the simple monthly means.

The crop coefficients shown in Tables 3, 4 and 5 are approximate. They are largely developed using an estimate of 0.3 to 0.4 at emergence, estimating time to effective cover and using a linear or slightly sigmoid interpolation from emergence to full effective cover or maturation, but higher values are used for rice and sugarcane. In addition major sources consulted were Blaney and Hanson (1965), Clyma and Rafique Chaudry (1975), and Haider et al. (1975), as well as various annual reports and other unpublished sources.

The variation in K_c values for wheat as a function of time of planting reflect the tendency of the later planted varieties to establish full effective cover more rapidly than the earlier plantings.

TABLE 1

Expected Weekly Potential Evapotranspiration (ETp) and Rainfall for Mona Project During Kharif Season

Week	Dates (1976)	ETp (inches)	Expected Rainfall Wet	Normal (inches)	Dry
1	1 - 7 May	2.0	0.51	0.20	0.0
2	8 - 14	2.1	.55	.20	0.0
3	15 - 21	2.1	.61	.20	0.0
4	22 - 28	2.2	.61	.20	0.0
5	29 - 4 June	2.2	.61	.23	0.0
6	4 - 11	2.2	.61	.32	0.0
7	12 - 18	2.2	.61	.42	.03
8	19 - 25	2.1	.70	.48	.12
9	26 - 2 July	2.0	.82	.65	.28
10	2 - 9	1.9	.99	.77	.46
11	10 - 16	1.8	1.17	.90	.78
12	17 - 23	1.7	1.40	1.02	.92
13	24 - 30	1.7	1.60	1.13	.97
14	31 - 6 Aug	1.7	1.76	1.22	1.04
15	7 - 13	1.7	1.90	1.29	1.06
16	14 - 20	1.7	1.85	1.38	.90
17	21 - 27	1.7	1.13	1.26	.81
18	28 - 3 Sept	1.7	1.26	1.16	.63
19	4 - 10	1.7	.86	.96	.41
20	11 - 17	1.7	.75	.51	.32
21	18 - 24	1.6	.45	.40	.16
22	25 - 1 Oct	1.5	.29	.22	.09
23	2 - 8	1.4	.23	.16	.05
24	9 - 15	1.3	.12	.12	0.0
25	16 - 22	1.2	.06	.01	0.0
26	23 - 29	1.1	.06	.01	0.0

TABLE 2

Expected Weekly Potential Evapotranspiration (ETp) and Rainfall for Mona Project During Rabi Season

Week	Dates (1976)	ETp (inches)	Expected Rainfall Wet	Normal (inches)	Dry
1	Oct 29 - 5 Nov	0.98	0.06	0.01	0.0
2	6 - 12	.91	.06	.01	0.0
3	12 - 19	.84	.06	.01	0.0
4	20 - 26	.77	.09	.02	0.0
5	27 - 3 Dec	.70	.23	.04	0.0
6	4 - 10	.63	.43	.06	0.0
7	11 - 17	.56	.43	.07	0.0
8	18 - 24	.55	.43	.08	0.0
9	25 - 31	.55	.35	.08	0.0
10	1 - 7 Jan	.55	.23	.08	0.0
11	8 - 14	.56	.18	.08	0.0
12	15 - 21	.60	.18	.08	0.01
13	22 - 28	.63	.20	.10	.09
14	29 - 4 Feb	.67	.26	.22	.11
15	5 - 11	.73	.36	.28	.12
16	12 - 18	.79	.43	.32	.12
17	19 - 25	.91	.54	.32	.12
18	26 - 4 Mar	1.02	.69	.32	.11
19	5 - 11	1.14	.75	.32	.08
20	12 - 18	1.26	.75	.31	.07
21	19 - 25	1.37	.75	.30	.08
22	26 - 2 Apr	1.48	.68	.27	.09
23	3 - 9	1.55	.45	.26	.11
24	10 - 16	1.67	.45	.25	.11
25	17 - 23	1.78	.45	.23	.09
26	24 - 30	1.86	.51	.22	.02

TABLE 3

Approximate Weekly Crop Coefficients for Some Common Kharif Crops in the Sargodha Area

Week	Dates (1976)	K_c Cotton	Lucern	Mature Citrus	Sugar cane	Rice	Bajara
1	1 - 7 May	--	.90	.60	.44	--	--
2	8 - 14	--	.90	.60	.50	--	--
3	15 - 21	.20	.90	.60	.55	--	--
4	22 - 28	.28	.90	.60	.60	--	--
5	29 - 4 June	.36	.90	.60	.66	--	--
6	5 - 11	.44	.90	.60	.72	--	.3
7	12 - 18	.52	.90	.60	.80	--	.4
8	19 - 25	.60	.90	.60	.86	1.0	.5
9	26 - 2 July	.68	.90	.60	.92	1.0	.6
10	3 - 9	.76	.90	.60	.98	1.2	.8
11	10 - 16	.84	.90	.60	1.04	1.4	.9
12	17 - 23	.92	.90	.60	1.10	1.6	1.0
13	24 - 30	1.00	.90	.60	1.10	1.8	1.0
14	31 - 6 Aug	1.00	.90	.60	1.10	2.0	1.0
15	7 - 13	1.00	.90	.60	1.10	2.0	1.0
16	14 - 21	1.00	.90	.60	1.10	2.0	1.0
17	22 - 27	1.00	.90	.60	1.10	2.0	1.0
18	28 - 3 Sept	.96	.90	.60	1.10	2.0	?
19	4 - 10	.92	.90	.60	1.10	2.0	?
20	11 - 17	.88	.90	.60	1.05	1.6	?
21	18 - 24	.84	.90	.60	1.00	1.6	?
22	25 - 1 Oct	.80	.90	.60	1.00	1.5	?
23	2 - 8	.75	.90	.60	.95	1.4	?
24	9 - 15	.68	.90	.60	.90	1.4	?
25	16 - 22	.61	.90	.60	.90	1.2	?
26	23 - 29	.56	.90	.60	.90	1.0	?

TABLE 4
Proposed Crop Coefficients for Wheat

Week	Oct			Nov			
Oct	15	22	29	5	12	19	26
15-21	1.0						
22-28	.4	1.0					
29-Nov 4	.4	.4	1.0				
Nov							
5-11	.5	.4	.4	1.0			
12-18	.6	.5	.4	.40	1.0		
19-25	.7	.6	.5	.40	.4	1.0	
26-Dec 2	.75	.7	.61	.50	.4	.4	1.0
Dec							
3-9	.8	.75	.7	.60	.5	.4	.4
10-16	.9	.8	.8	.75	.6	.5	.4
17-23	.95	.9	.90	.90	.75	.6	.5
24-30	1.0	.95	.95	.95	.90	.75	.6
31-Jan 6	1.0	1.0	1.0	1.0	.95	.90	.8
Jan							
7-13	1.0	1.0	1.0	1.0	1.0	.95	.9
14-20	1.0	1.0	1.0	1.0	1.0	1.0	1.0
21-27	1.0	1.0	1.0	1.0	1.0	1.0	1.0
28-Feb 3	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Feb							
4-10	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11-17	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-24	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25-Mar 3	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mar							
4-10	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11-17	1.0	1.0	1.0	1.0	1.0	1.0	1.0
18-24	.9	.9	.9	.9	.9	.9	.9
25-31	.8	.8	.8	.8	.8	.8	.8
April							
1-7	.7	.7	.7	.7	.7	.7	.7
8-14	.6	.6	.6	.6	.6	.6	.6
15-21	.5	.5	.5	.5	.5	.5	.5

TABLE 5

Temporary Crop Coefficients for Rabi Fodder Crops

Days After Planting	Kc
0-6	.40
7-13	.50
14-20	.60
21-27	.70
28-34	.80
35-41	.90
42-48	1.00
49-55	1.0
56-62	1.0
63-69	1.0
70-76	1.0
77-83	1.0
84-90	1.0
91-97	1.0
98-104	1.0
105-111	1.0

Revised Data Base

A program is presently underway to establish a data base for additional locations and using techniques that avoid the problems of making weekly interpolation of Et_p and rainfall. In order to evaluate the appropriateness of using historical Et_p instead of current values in the operational program confidence limits are also required.

We have collected daily rainfall, temperature and solar radiation data from three stations in the Punjab. These are Chaur Kana (near Lahore), Sargohda and Muzzafaragarth (near Multan). These data have been transferred to punch cards and processing is underway.

Several variations of Et_p calculations are being investigated. Constants for the dry season and monsoon season Et_p calculations were developed from long term June and August temperature data as recommended by Clyma and Rafique-Chaudry, except that the July through September period was included in the monsoons rather than only July and August. Daily evapotranspirations were then calculated for all years for which solar radiation data are available (generally 10 or 11). Rolling 7 day means over all years were then calculated. Plots of these for Sargohda are shown in Figures 1 and 2. A rather disturbing phenomena occurs in the kharif season as an abrupt drop occurs at the beginning of July and an abrupt rise at the start of October. This is a result of the change in constants in the Jensen-Haise equation for the two seasons. At present we are attempting to determine whether this type of transition truly reflects the system, and if not what modification may be appropriate.

The rainfall results are being processed using rolling means with various time lengths in order to minimize random fluctuation while preserving as much of the true climatic effects on as short a time scale as possible.

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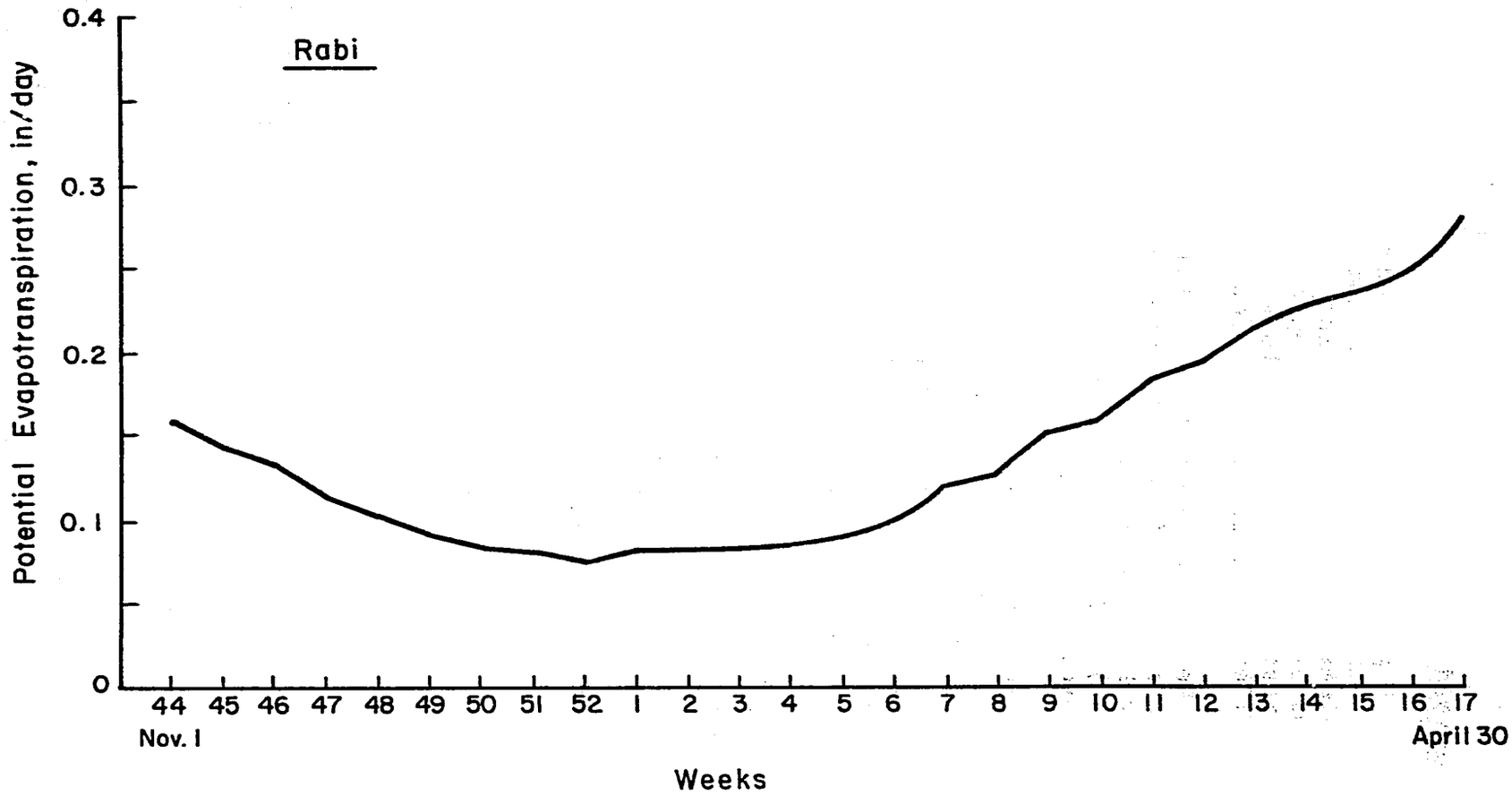

Figure 1. Weekly mean potential evapotranspiration for rabi season at Sargodha (November through April) by the Jensen-Haise method using June temperatures to calculate the constants.

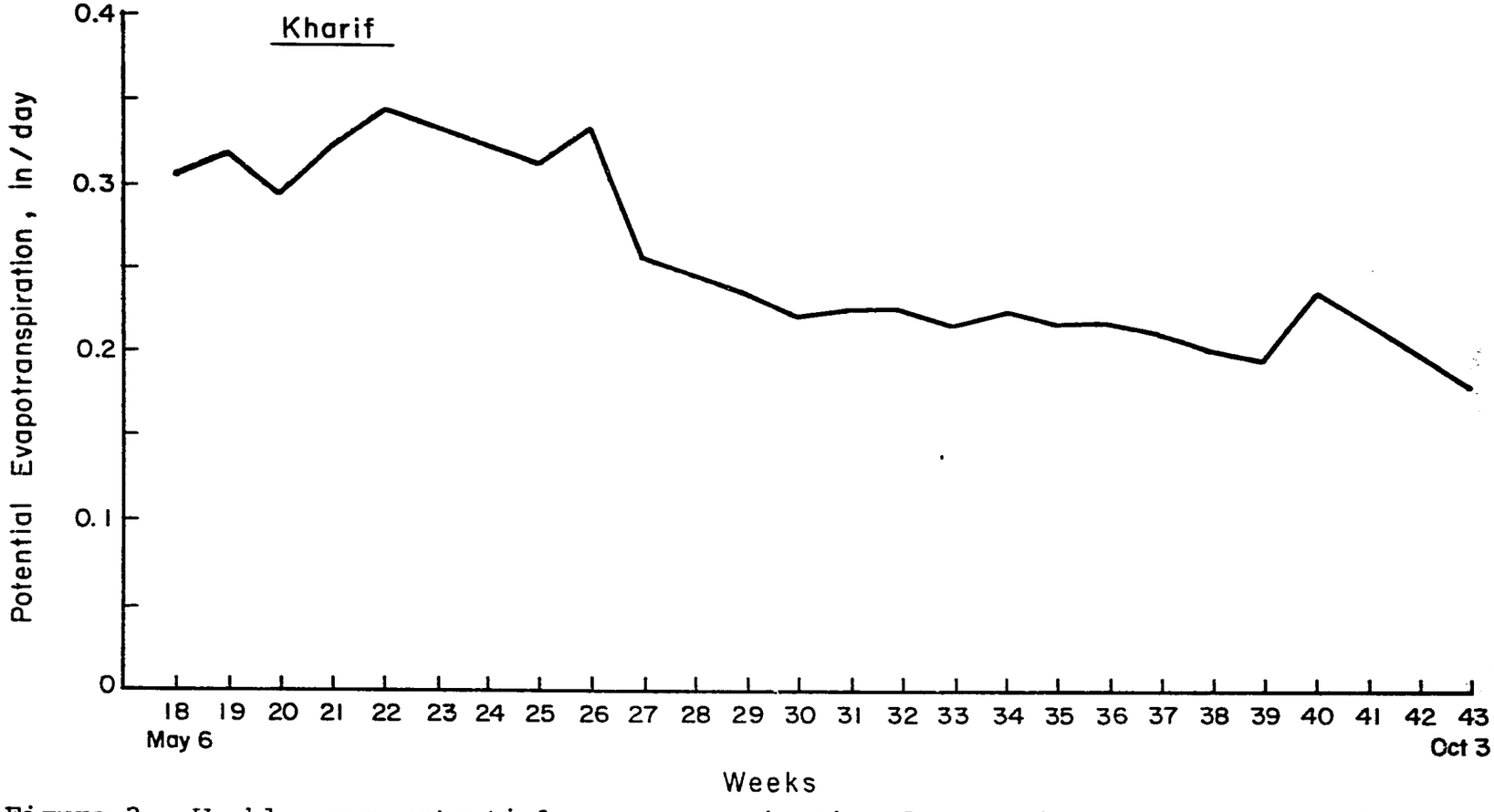

Figure 2. Weekly mean potential evapotranspiration for kharif season at Sargodha by the Jensen-Haise method using August temperatures to calculate the constants during July - September and June temperatures the remaining months.

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Appendix 32

WATER PROBLEMS IN THE INDUS FOOD MACHINE

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Irrigation water management for increased agricultural output is currently a very high priority development area. The major international donor agencies have realized that it is not sufficient to build massive dams and extensive irrigation schemes. It is also necessary to provide funding to improve the water delivery efficiency and to increase the degree of sophistication of on-farm water management. However, these agencies may well discover that improving on-farm water management is a more complicated task than building dams or providing capital intensive facilities. The socio-economic climate at the farm level does not readily lend itself to rapid change.

The purpose of this paper is to analyze some of the practical, field level water management problems that restrict the output of agricultural products in many developing countries. The examples provided in the paper use the Indus Basin as the sample area. Since this area has been irrigated under an extensive water delivery system for over 80 years the problems currently existing provide a representative sample of problems that must be overcome before an irrigation scheme can be successfully implemented.

This paper examines, both in technical and socio-economic terms, factors that prevent the rapid expansion of food production. A case is made, presenting data from a number of studies and surveys, that it is not enough to simply provide more water, more seeds or increased availability of fertilizers. The underlying institutional factors go deeper than a lack of inputs and require extensive philosophical and institutional changes.

INTRODUCTION

Pakistan lies within the watershed of the Indus system of rivers in what is usually referred to as the Indus Basin. This is one of the great river systems of the world with a mean annual flow of 142 million acre feet (MAF). This is ten times the virgin flow of the Colorado River in the Western United States and over two times the mean annual water production of the Nile River (Tipton, 1959). Pakistan has a total area of 306,900 square miles of which about half is

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comprised of foothills and mountains and the remainder is the Indus Plains and Thar Desert. Of this land lying in the Indus Plains about 117,000 square miles (75,000,000 acres) are classified as cultivable lands. Precipitation over the Indus Plains is generally less than 20 inches. In the center of the Plains the mean annual precipitation is less than 5 inches with the bulk of the rainfall occurring during the summer monsoons of July, August, and September. During the spring and fall essentially no precipitation occurs.

Due to the relatively low rainfall and sub-tropical arid to semi-arid climate supplemental water supplies are required in order to support an extensive agricultural system. Presently about 33 million acres are irrigated in the Indus Basin with an additional acreage of about 8 million acres under dryland or rainfed cultivation (U.S. Agency for International Development, 1975). The deep alluvial soils of the Indus Plains combined with the extensive irrigation system and favorable climate provide tremendous potential for an "Indus Food Machine" (Falcon, 1976). Yet, with all its agricultural potential, Pakistan has some of the lowest per acre yields in the world. Table 1 compares Pakistan's yields to those of other countries growing the same crops under comparable conditions.

Table 1. Comparative Crop Yields (U.S. Agency for International Development, 1975).

Crop	Yields in pounds/acre			
	Wheat	Rice	Maize	Seed-Cotton
Country				
Pakistan	1100	2100	900	900
E. Punjab	2100	1800	1500	950
Egypt	2750	4750	3250	2100

Although Pakistan has recently made substantial gains, wheat yields are still only half the level in East Punjab and forty percent of those in Egypt. Rice yields have increased and now exceed those of East Punjab, but are still less than half of those in Egypt. Cotton yields are only 40 percent of Egypt's despite the fact that in both countries cotton is grown under irrigated conditions and is a major export earner. Numerous reasons can be cited for their low yields, but we have chosen to concentrate on problems associated with water supplies at the field level and extension of new knowledge and technologies.

BACKGROUND

It is estimated that an average of 142 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 the Sind. Of the 92 MAF at the canal headworks, 29 MAF are lost in the main canal and distributory system before the watercourse mogha.[1] To this 63 MAF available at the watercourse head is added the approximately 30 MAF contributed by some 125,000 tubewells in the public and private sectors to make 93 MAF available to the watercourse (Early, 1975). Extensive research by the Colorado State University Water Management Team has established that between 20 percent and 70 percent of this water is lost between the mogha and the field nacca (individual field diversion) Clyma, et. al., 1975 and Clyma and Corey, 1974). The magnitude of the delivery system losses is mainly determined by the frequency of cleaning, the quality of maintenance of the watercourse, the length of the watercourse, and the total quantity of water available at the mogha. Table 2 presents system delivery measurements from a sample of watercourses in the Punjab and the Sind. Delivery efficiencies ranged from 27 to 90 percent. If it is assumed that an average of 45 percent or 37 MAF is lost in the watercourse between the mogha and the field nacca, this leaves 56 MAF available for the farmer to apply to the field. For the 33 million acres of irrigated land there is then 56 MAF of surface water or about 1.7 AF/acre available for the cultivator in weekly increments at the edge of his field to apply to his mix of crops as he sees fit.

Present water management research in Pakistan is examining different techniques to reduce these delivery system losses. During the early 1970's emphasis was placed on cement and brick lined watercourses, but with costs ranging from 15 to 40 Rs.[2] per foot and a typical watercourse having over 12,000 feet of channel it soon became obvious that it was not possible to line all 87,000 watercourses in Pakistan.[3] Recent work on cooperative improved watercourses where the farmers provide the labor and the government provides the

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[1] In Pakistan the canal water is distributed through the minor canals and flows out of the turnout (mogha) to a village level watercourse (200-900 acres). There are no headgates at the moghas and if a particular canal has water in it there is water in every watercourse on that canal.

2 Ten Pakistan rupees (Rs.) equals approximately one U.S. dollar. (1976)

3 For the curious: with an average cost of 20 Rs/ft at 12,000 ft and 87,000 watercourses the total cost is, Rs. 20,880,000,000 or 2.088 Billion U.S. dollars.

Table 2. Pakistan Delivery System Losses (Clyma, Ali, Ashraf, 1975 and Early, Lowdermilk, 1976)

Watercourse Location	Flow at Mogha Q_1 (cusecs)	Flow at Field Q_2 (cusecs)	Distance (ft) S	Loss Rate[a] cusecs/1000 ft	In. Loss Rate[b] cusecs/1000 ft	Delivery[c] Efficiency %
Mian Channu	2.75	2.00	5000	0.150	.064	75
Multan	2.10	1.30	9170	0.087	.052	60
Multan	1.90	1.40	3000	0.167	0.102	75
Shadab	0.60	0.30	2500	0.120	0.277	50
Lyallpur	2.40	1.10	1320	0.985	0.591	45
Lyallpur	1.40	1.03	6000	0.062	0.051	75
Lyallpur	1.50	0.50	5200	0.192	0.211	35
Lyallpur	1.40	1.30	1100	0.091	0.067	90
Mona	2.80	2.20	3300	0.19	0.073	75
Mona	3.2	2.2	4920	0.20	0.076	70
Mona	2.5	2.00	3880	0.13	0.058	80
Sargodha	2.37	1.65	1100	0.65	0.329	70
Thatta	.63	.17	2500	0.18	0.524	27
Dumballo	1.8	.83	8330	0.12	0.093	46
Dadu	1.75	1.05	1800	0.39	0.284	60

a $\frac{Q_1 - Q_2}{S}$

b $\text{In } \frac{Q_1}{Q_2} \div \frac{S}{1000}$

c Delivery efficiency, E_d is defined as: $E_d = \frac{\text{Flow at the Field}}{\text{Flow at the Mogha}} \times 100$

technical advice has resulted in a technique for earthen improved watercourses that cost less than 2 Rs. per foot of watercourse (Colorado State University Water Management Team, 1976). The pilot projects completed have demonstrated that this type of earthen improved watercourse will double the amount of water delivered to the tail of the watercourse and reduce the overall losses by 40-50 percent. Another experiment that is presently underway is a technique for making only the essential improvements that are necessary to eliminate the major sources of loss along the watercourse (Bowers, 1976). This includes bringing the banks, where necessary, up to proper freeboard, rebuilding the watercourse junctions as required, plugging all the obvious holes, and improving the nakkas so that they seal properly. This type of improvement scheme is designed to cost less than .5 Rs. per foot of watercourse and to reduce losses by a minimum of 25 percent. The most importnat consideration for the latter scheme is the fact that the main ingredient needed is labor provided by the rural sector. This essential improvements scheme requires much less outside advice and capital and can be completed by the farmers as they have time available. However, none of these watercourse improvement schemes, including cement lining, are maintenance free and in order to continue to gain the increased water supplies the farmers must implement a canal cleaning and maintenance program. This program has to be more than a simple weeding and desilting, and needs to include repairing banks, plugging holes and fixing nakkas.

In order to facilitate watercourse improvement and maintenance schemes, the farmers need to form some type of water users' association (Radosevich, 1975). This association can be informal or formal, but as a minimum must provide strong enough leadership to ensure that the watercourses are properly improved and maintained and provide rules which protect the rights of the individual shareholders. As this association proves its worth it can expand its function into knowledge dissemination and cooperative purchasing and marketing.

Once the farmers have learned how to improve their watercourses and to obtain additional water supplies they must then learn how to most efficiently utilize this additional water. The next section examines the on-farm level water management problems that restrict the Pakistani farmer's production.

CONSTRAINTS - INDIVIDUAL

Pakistan's famous canal system is the end product of a long line of trial and error experiments by a highly trained and motivated group of engineers and physical scientists (Buckley, 1905). The majority of the research involved

delivery of the water down the canals to the distributaries and directly to the moghas. Little attention, however, was paid to the important social questions relevant to the efficient utilization of the water at the on-farm level. In particular the training necessary to make the transition from rain fed or dryland agriculture to irrigated agriculture was not provided. This lack of knowledge and training has resulted in extensive mismanagement of the precious water.

In order to investigate the level of farmers' knowledge concerning plant-soil-water relationships, a number of different surveys have been designed and administered. One survey was designed to investigate the farmers' conceptions about how plants remove water from the soil and what is the effective range for this process. Table 3 presents the farmers' estimates of the depth of root penetration for certain crops compared to actual rooting depths for these crops.

From the percentage responses compared to the usual rooting depth it is obvious that farmers have very little knowledge of the effective rooting depth of the crops. The same farmers were asked to estimate the depth of penetration of water in their fields. Their responses are presented in Table 4. These results illustrate that farmers also do not understand the effective holding capacity of the soil profiles as 5 inches of water in most soils in the Punjab will wet up to 30 inches. In certain seasons farmers are often observed to be over-irrigating a crop by a factor of 2-3 times the actual water requirements which probably is a direct result of the fact that farmers do not understand the depth of storage of soil moisture or the plant's ability to extract water from this moisture reservoir with its long and extensive root system.

In another set of interviews, farmers were also asked to describe how they determine when a crop needs to be irrigated. Table 5 contains the responses to this question. Forty percent of the farmers reported "by the appearance of the soil surface" while 31 percent reported "by the date of last irrigation." No farmers reported checking the sub-soil for moisture. Responses from a similar survey are presented in Table 6. Again, the majority of the farmers are deciding to irrigate by upper soil or crop appearance. Farmers were also vague about describing what specific characteristics of plants actually indicate stress. None of the farmers reported checking the sub-soil for moisture nor did they seem to really understand the significance of this technique.

As part of the same set of interviews farmers were also asked how they decide when to stop applying water to a given field. These results are contained in Table 7. The farmers close the water supply by depth and by time. None of these

Table 3. Farmers' Estimates of Depth of Root System for Selected Crops (Lowdermilk, Clyma and Early, 1975).

Values in the columns indicate number of farmers selecting that root depth range. Values in brackets ( ) indicate the percentage of farmers selecting that root depth range.

Crop	2.5"	3-4"	4.5-6.5"	7-12"	15-16"	24-36"	Actual[a]
Cotton	1(3%)		4(11%)	17(48%)	9(26%)	2(9%)	5'-6'
Berseem	17(49%)	18(51%)					2'
Sugarcane[b]	1(3%)	5(14%)	16(46%)	11(31%)	2(6%)		2'-3'
Wheat	13(37%)	16(46%)	6(17%)				4'-5'
Rice	7(20%)	18(51%)	10(29%)	1(3%)			9"-12"

[a]A properly irrigated crop in a deep, well drained sandy loam soil.

[b]Seven farmers (20%) reported 1-1.5 inches of root depth, eight farmers (23%) reported 2.0 inches for berseem.

Table 4. Farmers' Estimate of Depth of Penetration of Water if Five Inches were Ponded on Their Fields (Lowdermilk, Clyma and Early, 1975).

Depth (inches)	No. Reporting	% of Total Respondents
.50	1	3%
1.00	12	33%
1.25	1	3%
1.50	7	19%
2.00	6	17%
2.50	2	5.5%
3.00	2	5.5%
Don't Know	5	14%

Table 5. Farmer's responses to: "When water is available, how do you decide what particular crop needs irrigation? (Lowdermilk, Clyma and Early, 1975).

Rank of Importance	Date of Last Irrigation	Appearance of Soil Surface	Appearance of Plants	Plant Size	God's Will or Don't know
Most Important	11(31%)	14(40%)	9(26%)	1(3%)	-
Next Important	2(6%)	15(43%)	14(40%)	0 -	4(11%)

Table 6. When to Irrigate (Mona Reclamation Project and Johnson, 1976).

Factor	Number of Positive Responses	Percentage of Total
Last date of irrigation	0	0%
Appearance of Crop	30	79%
Inspecting soil by digging	0	0%
Appearance of the upper soil surface	6	16%
Whenever water is available	2	5%

Table 7. When to close the water (Mona Reclamation Project and Johnson, 1976).

Criteria	Number of Positive Responses	Percentage of Total
When water covers all the high spots	9	24%
When water has reached the end of the field	14	37%
When you see sufficient depth of water	9	24%
By knowing the exact time for the area	6	15%

methods necessarily provide the amount of water actually required by the crop and two of them, covering the high spots and waiting until water reaches the end of the field, almost certainly lead to over-irrigation and wasted water.

To document how much water is wasted due to improper application criteria it is necessary to take quantitative studies of irrigation practices. Only with the introduction of the Cutthroat flume by the Colorado State University Water Management Team have such field measurements become practical. Table 8 presents the data measuring irrigation applications during a time when the watercourse received both canal and tubewell water. Similar data from other watercourses is also available. This tendency to put on 3 to 5 inches when only 1 to 2 inches are required leads to very poor application efficiencies. Table 9 presents a set of irrigation application efficiencies measured on traditionally farmed fields. From this table it is apparent that over 90 percent of the irrigations observed had an application efficiency of 60 percent or less.

Data from other watercourses in non-SCARP[1] areas of the Punjab and the Sind yield the same type of results except that the number of under-irrigations[2] is increased. The data from the last two tables indicates that application efficiency is extremely variable, not only by area but by time of the year. However, across Pakistan, throughout the year, it is unlikely that the average application efficiency exceeds 65-70 percent.

The overall irrigation efficiency is the product of the delivery efficiency times the application efficiency. With the wide range in the two efficiency measurements this number can vary from as low as 10 percent to 80 percent. Table 11 presents a set of data for different watercourses in various agro-climatological zones in Pakistan. From Table 11 the average overall irrigation efficiency over seven different agro-climatological zones and 19 different watercourses is 44 percent. Accepting this 44 percent as the average overall irrigation efficiency means that, of the 93 million acre feet available at the mogha, only 41 MAF are actually applied to the root zone for the crops. Accepting a delivery efficiency of 60 percent and an average application efficiency of 70 percent, out of the 93 MAF available at the mogha only 39 MAF are actually available at the root zone. <u>This means that 54 MAF are lost once the water comes under control of the farmers</u>.

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[1]SCARP = Salinity Control and Reclamation Project.

[2]Under-irrigation = water applied less than water needed in root zone.

Table 8. Distribution of amounts of water applied (Wayne Clyma, Arshad Ali, Moh'd Ashraf, 1975).

Application Depth (inches)	No. of Evaluations	% of Total Evaluations
0 - 1.0	0	.0
1 - 2.0	11	28.0
2 - 3.0	12	30.0
3 - 4.0	10	25.0
4 - 5.0	7	17.0
Totals	40	100.0

Table 9. Irrigation Application Efficiencies[a] Observed at Traditionally Farmed Fields (Clyma and Corey, 1974).

Application Efficiency Interval	No. of Observations for Each Crop				Total for Interval	% of Total No. of Observations	Accumulated %
	Wheat	Sugarcane	Fodder	Rice			
0-10%	2	4	4	3	13	20%	20%
10-20%	8	5	2	2	17	26%	46%
20-30%	2	8	4	2	16	25%	71%
30-40%	2	2	3	-	7	11%	82%
40-50%	-	1	-	1	2	3%	85%
50-60%	-	-	2	1	3	5%	90%
60-70%	-	1	-	-	1	2%	92%
70-80%	-	-	-	-	-	-	-
80-90%	-	-	-	-	-	-	-
90-100%	-	4	1	-	5	8%	100%
Totals	14	25	16	9	64	100%	

[a]Application efficiency = $\frac{\text{Amount of water stored in the root zone}}{\text{Amount of water applied to the field}} \times 100$

Table 10. Irrigation Application Efficiencies (Early, Ali and Lowdermilk, 1976).

Location	No. of Observations	Mean Application Efficiency	Median Application Efficiency	% Under-Irrigations
Lyallpur	61	75.6%	75.0%	26%
Gujrenwala	18	51.1%	51.4%	7%
Lahore	23	100.0%	100.0%	100%
Muzaffargarh[1]	35	89.0%	97.0%	24%
Dadu[1]	44	80.0%	89.0%	17%
Thatta[1]	25	69.0%	63.0%	5%

[1]Measured at middle of watercourse

Table 11. Overall Irrigation Efficiency by Watercourses and by Agro-Climatological Zones (Early, Ali and Lowdermilk, 1976).

Location	Mean Deliveries Efficiency (%) E_d	Application Efficiency (%) E_a	% Overall Irrigation Efficiency E_1 $E_1 = E_a \times E_d$
Muzaffargarh	47	93	44
WC[a] 1	37	96	36
WC 2	51	91	46
Bahahwalpur	66	96	63
WC 1	82	96	79
WC 2	65	98	64
WC 3	59	87	51
WC 4	58	100	58
Dadu	60	79	47
WC 1	44	72	32
WC 2	65	67	44
WC 3	66	88	58
Thatta	30	58	17
WC 1	31	71	22
WC 2	26	41	11
WC 3	28	84	24
Lyallpur (b)	68	75	51
Sargodha (c)	47	69	32
Multan (d)	58	97	56

(a) WC = a separate watercourse, (b) Lyallpur = combined 2 watercourses, (c) Sargodha = one watercourse, (d) Multan = combined 4 watercourses.

The above examples and figures can be repeated on almost any watercourse in Pakistan. They are by no means unique events and simply serve to illustrate the need for training farmers to be both better maintainers of their irrigation systems and better managers of their irrigation water. The question that immediately arises is who will provide this leadership and training to the farmers?

CONSTRAINTS - EXTENSION

The obvious source of advice and training for on-farm water management as well as other farm activities should come from the existing agricultural extension services. In order to explore the effectiveness of the existing agencies established to assist farmers, a series of interviews were conducted with a sample of farmers. The object of the interviews was to determine how many farmers had knowledge of the government officials and the number of contacts with them over the last three months. The results of these interviews are summarized in Table 12. It is apparent from this information that most farmers had no contacts with government workers other than the canal patwari and did not know the name of the appointed government workers other than the canal patwari. The few contacts the field assistants or agricultural assistants made in the period were with large or influential farmers on the watercourse (Table 13). The field assistant is the Agriculture Department's main link with the farmers. These workers are usually high school graduates (10 grades) with one or two years of general agricultural training with the Department's training institutes. In the Lahore Region, for example, there is an estimated ratio of one field assistant for about 1,245 farms and 12,400 acres which is about 1 for every 30 watercourses. Given the low level of training, inadequate supervision, low pay, and lack of transportation it is not difficult to understand why the field assistants are only able to contact a small percentage of the farmers in their area. More farmers know fertilizer agents than field assistants and the majority of the farmers know the canal patwari because this individual is responsible for checking all crops cultivated for each season and determining canal water assessments.

The question arises, will the addition of more staff, especially at the field assistant level, increase the current low level of agricultural production of the farmers? The answer to this question requires an examination of the technical level of competence of the field assistants. At a special meeting with 20 field assistants in Sargodha area, they were asked to list all the late varieties of high yielding wheat recommended by the Government to the farmers in their area. Table 14 illustrates that a number of the field assistants are confused about the proper late variety. Chenab 70 is not a late variety nor is Mexi Pak 65. Sundall is the

Table 12. Farmer's knowledge of contacts with agricultural personnel. N = 37. (Lowdermilk, Clyma and Early, 1975)

Department Official	Know official's name or someone in Agency Office (No. of farmers)	%	Number of contacts in period of last three months: None	1-2	3-4	5
Agricultural Ass't	1	2.7	34	3	-	-
Field Assistant	2	5.4	34	1	-	-
Development Assistant	8	21.6	29	5	2	1
Bank	4	10.8	31	3	-	1
Cooperative Department	1	2.7	34	1	-	-
Fertilizer Store	9	24.3	26	6	-	-
Canal Patwari	23	62.1	12	-	21	2
Canal Zelladar	-	0	35	-	-	-
Overseer	-	0	35	-	-	-
Sub-Divisional Officer	-	0	35	-	-	-

Table 13. Percentages of farmers who report some and no contacts with Field Assistants (Lowdermilk, Clyma and Early, 1975).

Farm Size (acres)	No Contacts	Some Contacts
2.5 - 7.5	88.7%	11.3%
7.5 - 12.5	83.9%	16.1%
12.5 - 25.0	78.9%	21.1%
25.0 - 50.0	66.7%	33.3%
50.0 and over	34.1%	65.9%

Table 14. "Please list all of the late varieties of high yielding wheat recommended by the research station at Lyallpur for the area." (Early, Lowdermilk and Johnson, 1975).

Variety	No. of Field Assistants to list this	%
SA 42	19	95
Blue Silver	11	55
PARI 73	9	45
1372	5	25
Chenab 70	3	14
Mexi Pak 65	5	25
Sundall	9	45

variety recommended mainly for the barani (rainfed) areas. A second question related to fertilizer application rates for high yielding varieties was asked. The results of these responses are summarized in Table 15. From Table 15 it is again apparent that there is quite a bit of confusion concerning the amount of fertilizer to apply and the type that is best to apply. The field assistants were also asked the same question as the farmers concerning the rooting depth of the major crops for their area. Their responses are presented in Table 16. It is evident that many field assistants did not know how to respond to this question. It is also clear that they hold a concept of rooting depth similar to that of the farmers. They, like the farmers, have no training in this respect.

CONSTRAINTS - INSTITUTIONAL, TECHNICAL[1]

At the farm water management level the main institution that directly affects the farmer is the Irrigation Department. This section examines the distribution of canal water in terms of the relationship between the farmers and the Irrigation Department.

Irrigation Department

The original canal system was designed to minimize the human control over the water supplies. Water is allocated all the way through the canal system down into the watercourse in fixed proportions. This system is designed to eliminate or lessen the opportunity for petty governmental officials to engage in corrupt practices at the expense of the farmers. However, the fact that overall there is a shortage of water and farmers are usually searching for additional water supplies serves to lead to attempts to circumvent the system since the main source of additional water is through Irrigation Department officials. Farmers must deal with three or four lower level officers from the Irrigation Department. Chief among these (and most important to all farmers) is the Patwari. It is the duty of the Patwari to check crops at time of sowing and harvest and to record all crop failures and crops cultivated on every acre of land on watercourses under his review. The major work of the Patwari, to make crop assessments for canal revenue, gives the Patwari an opportunity to make arrangements between himself and individual farmers. Table 17 indicates the percentage of farmers that pay fasalana[2] from a 25 percent sample on 16 watercourses. In return

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[1] Lowdermilk, Freeman and Early are publishing additional materials having to do with farmer's relationships to the bureaucracy.

[2] Fasalana - a traditional gift to the Patwari usually paid in kind in return for concession.

Table 15. How much fertilizer and what types should you apply to obtain 50 Mds/acre yields witn the high yielding varieties of wheat? (Early, Lowdermilk and Johnson, 1975)

Type of Fertilizer	Responses*
Urea	11
Triple Super Phosphate	11
Potash	3

*Some Field Assistants gave no response whatsoever

Amounts of Fertilizer to Apply	No. of F.A.'s Recommending
1 bag of Nitrogen	4
1 bag of DAP	4
2 bags of Nitrogen	12
2 bags DAP	6
1 bag Triple-Super Phosphate	8
1/2 bag of DAP	1
1/2 bag of Triple-Super Phosphate	1

When to Apply Nitrogen Fertilizer	No. of F.A.'s Recommending
Before sowing	11
After about 20 days	7
Second irrigation	6

Table 16. Give your estimate of the rooting depths of the following crops (Early, Lowdermilk and Johnson, 1975).

Inches/Feet of Root Penetration	Maize	Wheat	Rice	Berseem	Cotton	Lucerne	Potatoes	Weeds Along Canal
0" - 3"	10	7	5	7	-	1	4	-
3" - 6"	7	10	7	6	1	4	8	-
6" - 12"	1	-	1	1	4	2	4	-
12" - 18"	-	-	-	-	2	2	1	-
19" - 24"	-	-	-	-	2	-	-	1
30" - 36"	1	1	1	-	6	-	-	3
36" - 42"	-	-	-	-	1	-	-	1
42" - 48"	-	-	-	-	-	-	-	1
48" or more	-	1	1	1	3	3	-	5
Actual Depth	3-5'	4-5'	9-12"	2'	5-6'	5-6'	1.5'	2.5' 3-5'

The numbers in the columns indicate how many field assistants responded to that rooting depth for that crop.

Table 17. Proportion of sample farmers who pay fasalana to Patwari in cash, kind, or both (Lowdermilk, Early and Freeman, 1975).

	Number of Farmers	Percent
Do not pay fasalana	61	36.1
Do pay fasalana	101	59.8
No response	7	4.1
Total	169	100.0

for the payment the Patwari can effect a reduction in farmer abiana (tax) by: (1) falsely claiming hailstorm damage or some other act of God such as flooding or earthquake, (2) cultivated land can be falsely declared fallow, (3) healthy plants can be falsely declared as having been struck by disease, and (4) seeds can be falsely declared as completely or partially failing to germinate. The amount of payment seems to be a negotiated arrangement between the farmer and the Patwari.

The second most important official for the farmers is the canal overseer. Since it is illegal for the farmers to alter their mogha in any way, the overseer must be called upon to repair a defective mogha or to make an illegal mogha enlargement. Bribes necessary to obtain and maintain an illegal mogha alteration are negotiated individually by farmer representatives from each petitioning watercourse. The major factors determining the size of the bribe appear to be the number of cultivated acres on the watercourse and the magnitude of the enlargement requested. In sample villages payments have ranged from a minimum of Rs. 600 to Rs. 6000 (Lowdermilk, Early and Freeman, 1975). An accepted rule of thumb is often taken as 100 maunds of wheat. In addition, overseers are often bribed up to Rs. 1000 to make justifiable and needed mogha repairs to bring the flow back up to the allocated flow.

For farmers located in the Salinity Control and Reclamation Project (SCARP) areas one of the most important government officials is the public tubewell operator. This man is responsible for operating the public tubewell and hence with his power to turn on and off the tubewell he becomes a potential source of corruption. In a small survey, taken over a portion of a SCARP area, over 82 percent of the farmers interviewed complained that they were required to make payments to the tubewell operator in order to obtain their proper water share. Since farmers in SCARP areas are required to pay double water rates this additional payment to the operator is a further burden.

In addition to direct dealings with the lower level officials the farmers have indirect dealings with the Irrigation Department in terms of water delivery. Unplanned and unannounced canal closures are the rule rather than the exception. Rarely, if ever, does the farmer have any advance notification of a closure of his distributary canal. This lack of communication creates a situation where the farmer deems it best to irrigate even if the crop does not need the water simply as a hedge against the uncertainty of receiving water when it is actually needed.

CONCLUSIONS

Peasant farmers are often classed as "illiterate," "resistant to change," "conservative," "tradition bound," etc., but a reason for their low adoption rates may often be the lack of proper advice or simply bad advice from poorly trained field workers. Quite often, even if the advice is correct for the larger farmers, the variability in the response often results in situations where the potential return does not equal the expected return. This assumed resistance to change could be the rational response of a farmer to poor or highly variable advice given by an untrained field worker. It is a great anomaly in Pakistan to have the world's largest contiguous irrigated area and yet to have a majority of farmers and field staff that do not understand irrigation. There is presently no training available in Pakistan in proper water management and irrigation practices. To date no government organization has given attention to water management problems of the farmers. The combination of lack of knowledge concerning irrigation practices and no government advice or assistance has resulted not only in some of the world's lowest yields, but has also salinized and waterlogged large areas of the Indus Basin.

It is easier to identify the existing problems than, given the capital constraints of a developing country, it is to solve them. However, after examining the data from Pakistan it is possible to make a few general recommendations that are practical and implementable.

1. The government or developing authority must make an all out commitment to maintain high delivery efficiency in the watercourses. This entails a high level of political and administrative involvement and requires that the administrators assigned to the project be dedicated, competent, professionals. Farmers must also be committed to maintaining the system and, where necessary, disciplinary alternatives should be available.

2. Simple extension bulletins in the local language concerning crop water demands and irrigation practices should be printed and extensively distributed to the farmers in the irrigation scheme. These bulletins would depend extensively on the use of diagrams and pictures to explain how plants use water and at which stages they are most sensitive to water stress. These bulletins are not meant to replace the extension service but are a means of increasing its effectiveness.

3. The irrigation canals and distributaries need to be properly maintained at their original design specifications. This requires allocating a large enough budget to operations, maintenance and repair (OM&R) so that the staff is able to

carry out the needed work. The OM&R staff should also be compensated at a level high enough to minimize the temptations for corruption within the unit.

4. Provisions need to be made during the original design period for some type of farmers' users organization. This group will ease the communications problems within the project and will facilitate the motivation of the farmers. If provisions are made to funnel a certain percentage of the water fees back into the organization it will have both the incentives and the means to carry out an action on-farm level program.

5. A water management oriented extension staff needs to be developed and assigned in sufficient number to reach the majority of the cultivators in the project area. These men must be knowledgeable about modern irrigation practices as well as plant-soil-water relationships for their ecological area. These men also need to know how to maintain the watercourse level distribution systems and to work with the farmers to ensure that this maintenance is continuously performed.

As developing countries invest capital in large scale irrigation systems the expected benefits may fail to materialize. The transition from dryland farming to irrigated farming requires a complex combination of technical and social institutions that do not evolve automatically. The planning and developing authorities must take into account on-farm level problems if they wish to successfully implement a project. Lack of planning or incomplete planning will lead to a situation where inefficiency and corruption combine to defeat the original purpose of the investment. Poor operation can also bring about irreversible ecological damage as rich agricultural areas are waterlogged and salinized. Irrigated agriculture is a critical element in the world's quest to increase food production and it requires careful attention at the on-farm level in order to actually improve the physical and economic welfare of the project recipients.

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Appendix 33

IMPROVED SOIL, WATER AND CROP MANAGEMENT FOR INCREASED FARM PRODUCTION IN PAKISTAN[1]

Mohammad Hanif and C.J. deMooy[2]

I. INTRODUCTION

Plant nutrients, HYV technology and crop management practices have been widely used as tools to increase farm yields. However, the concept of proper water management is new in Pakistan and little work has been done to include this aspect in the struggle to raise crop production.

The main source of water in our country is the monsoon rains and, with the completion of the Mangla and Tarbela reservoirs and follow-up projects, we are able to store 16 MA of water for continuous supply during peak demand seasons. Now we must learn to utilize this resource to best advantage. The water requirements of the various crops grown under high standards of management are being measured experimentally in another CSU-supported program operating throughout Pakistan. In addition, it is necessary to find a practical combination of desirable irrigation practices with sound fertilizer and crop management. The new procedures must be made acceptable to the farmers under local conditions. Extravagant and other undesirable use of scarce water must be avoided. The present study is an attempt in this direction and focuses the attention on the potential contribution of irrigation water in interaction with fertilization, crop protection and cultural management of wheat, maize fodder, sorghum, and cotton crops.

II. MATERIALS AND METHODS

This research was conducted at IRDP Markaz Shadab near Lahore, and at Lar near Multan. Wheat, sorghum, maize (fodders) were grown in 1974 and 1975 at Chak Mohlanwal of the Shadab Pilot Project. A cotton crop was sown 370 kilometers further south at Chak 2-Faiz of IRDP Center Lar, District Multan. Experimental sites were selected in farmers' fields with similar history where watercourse rehabilitation and land leveling activities were underway as part of a Joint IRD/CSU Water Management Research Program. In addition, demonstration

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plots of a more simple nature were laid out. The distribution of plots was chosen to include various kinship groups at Mohlanwal and Chak-2 Faiz. The locations of the trials are indicated in situation sketches (Figures 1 and 2).

A. SOIL CHARACTERISTICS

The soils were generally medium in texture (loam), except Site No. 11 where the soil was somewhat coarser (sandy loam), and free from salinity-alkali problems. Soil samples were taken from all sites for physico-chemical analysis. All profiles were calcareous in nature. The pH of the soils was 7.8 to 8.2. Soil phosphorus was determined with 0.5 N NaHCO extractant following Olsen's method. The available P contents of the soil were in the range of 2 to 4.5 ppm. Average values of saturation percentage, field capacity and permanent wilting point (PWP) for the soil were 39, 24 and 12, respectively. The characteristics of individual sites are presented in Table 1. The field capacity values did not coincide with 1/3 bar data determined from samples in the laboratory shown in Table 2. The permanent wilting point at Site 11 was relatively low (5.2 percent) and was due to coarse texture of the soil at the site. Individual moisture retention curves were determined from laboratory data for Sites No. 1, 6 to 8, 9 and 10, and 11. These are presented in Figures 3 and 4 respectively. The average bulk density of the 0 to 12 inch soil layer was 1.45 g/cm^3.

B. TREATMENT COMBINATIONS

The general design of field experiments consisted of a series of treatments ranging from traditional practices to the best package of improved practices known today. Between these two extremes were several treatments combining some but not all desirable practices. Important variables included were precision land leveling, methods of sowing, soil fertility, irrigation practices and plant protection measures. Treatment details varied from crop to crop and from site to site. Generally, each factor was tested at a traditional and at an optimum level.

a. Leveling

The effect of land leveling was included where the original land surface was very uneven or the fields too small and irregular in slope (Sites 8, 9, 10 and 11). The land was leveled to $\pm$ 0.10 foot specifications.

b. Seedbed Preparation

Seedbed preparation was done either by desi plow or with tractor and cultivator. Traditional seedbed preparation for all crops was carried out with the desi plow and sohagha

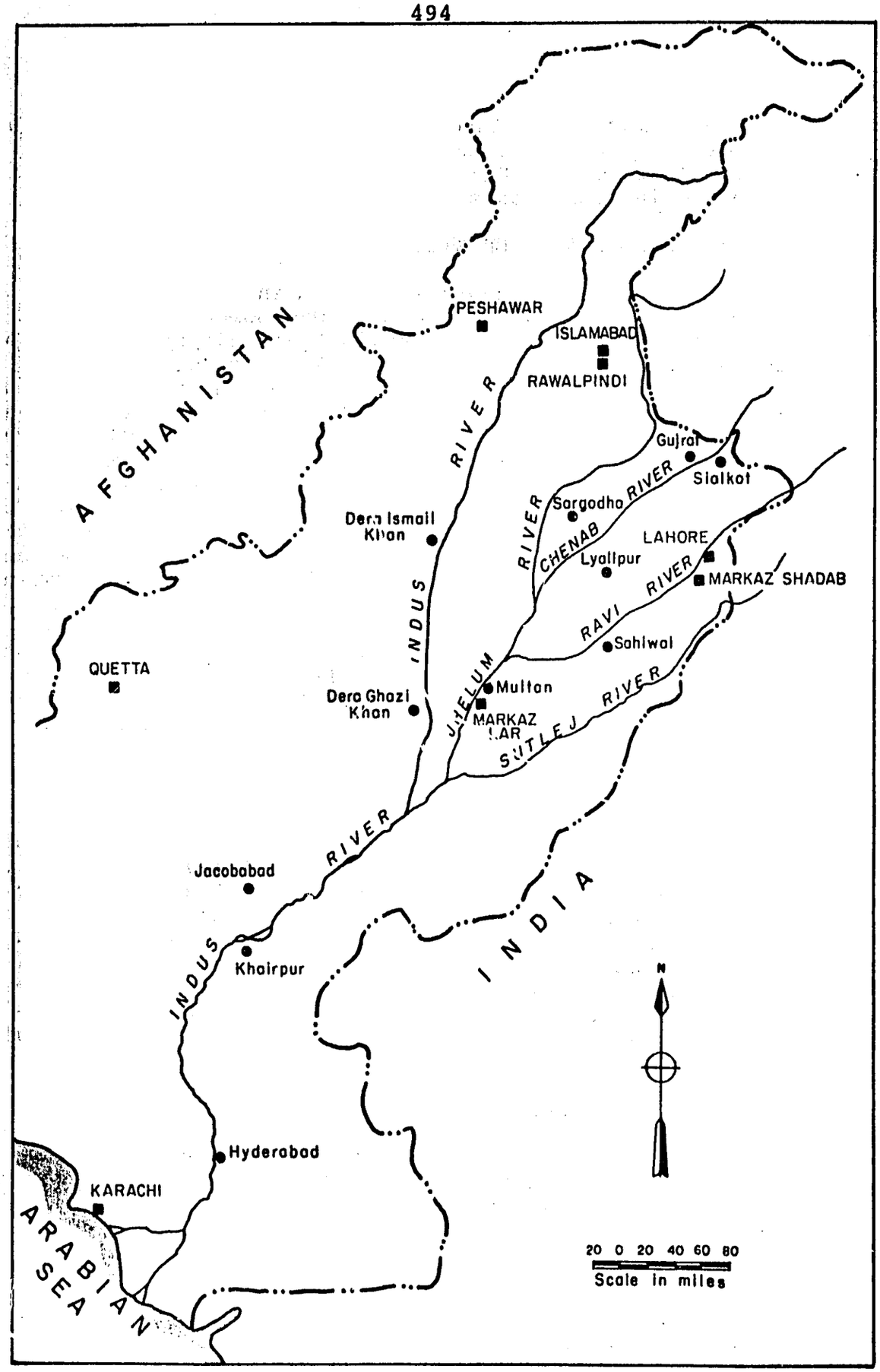

Figure 1. Location map of experimental sites for wheat, maize and sorghum in Shadab Pilot Project, Lahore.

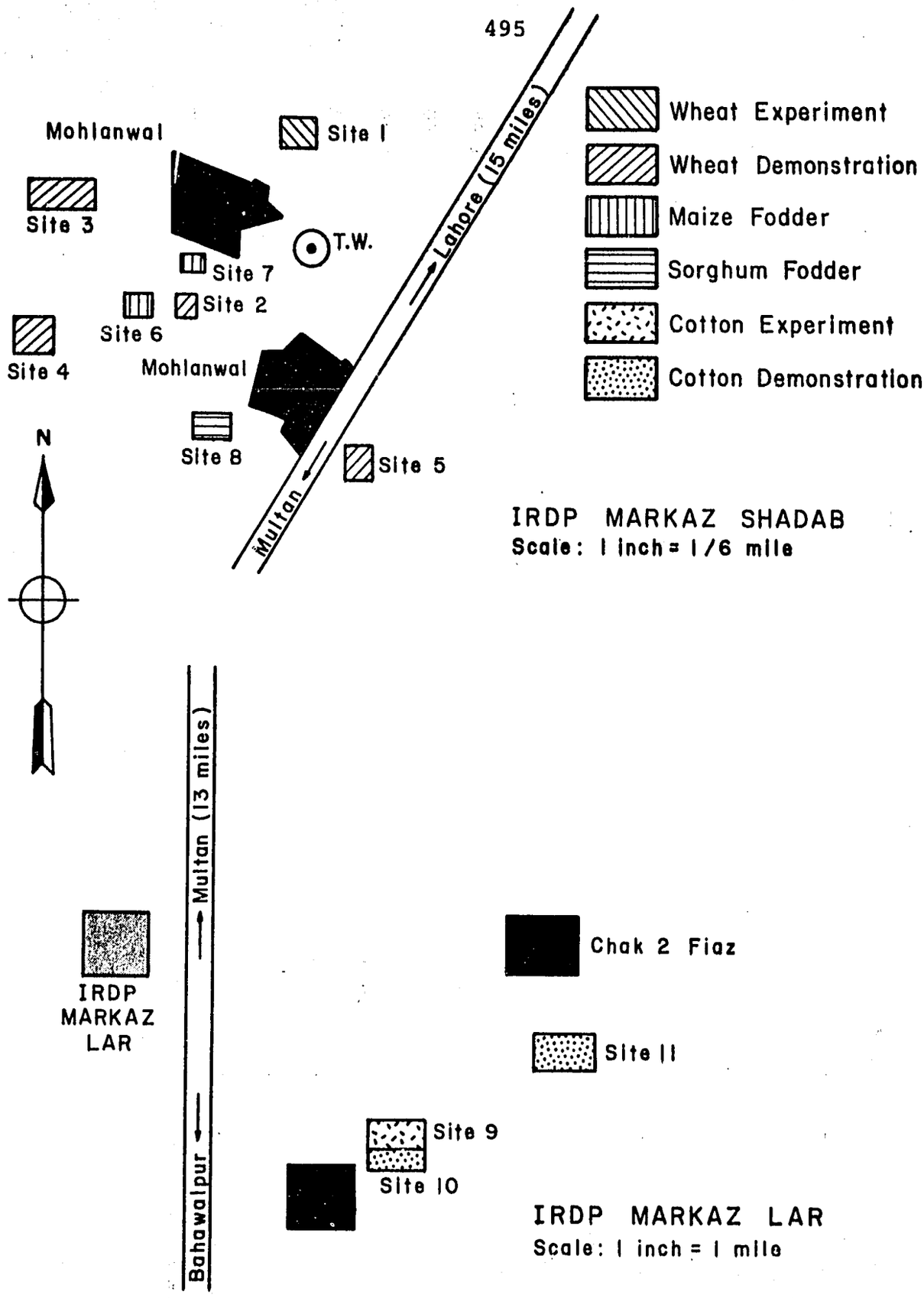

Figure 2. Location map of experimental sites for cotton in IRDP Markaz Lar, district Multan.

Table 1. Characteristics of field trial sites in Shadab and Lar, 1974/75.

Site No.	Name of farmer	Crop	Year	Size of area (acres)	Number of treatments	Available P (ppm)	Saturation (%)	Yield capacity (%)	Bulk density
1	M. Hussain	wheat	1974/75	1	5	2.4	37	21.2	1.51
2	M. Saleem	wheat	1974/75	0.5	2	4.0	43	25.8	1.49
3	A. Raoof	wheat	1974/75	2	2	2.2	38	23.7	1.59
4	Amir Ali	wheat	1974/75	1	2	3.4	38	-	1.49
5	Din Mohd.	wheat	1974/75	1	2	3.9	40	-	1.44
6	M. Saleem	maize	1975	1	2	3.9	40	27.0	1.45
7	Jan Mohd.	maize	1975	1	2	3.5	45	26.0	1.40
8	M. Hussain	sorghum	1975	1	2	3.5	40	26.0	1.45
9	Ahmed Yar	cotton	1975	1	7	4.5		25.0	1.41
10	-do-	cotton	1975	1	2				
11	Din Mohd.	cotton	1975	9	2	2.9	29	15.8	1.29

Table 2. Moisture retention characteristics of the soil at experimental sites

Site	Sample	Tension (bars) 1/10	1/3	2/3	2	5	6	15
1	1	-	27.5	19.0	15.6	14.8	-	12.5
	2	-	26.5	20.5	14.6	13.9	-	12.2
9, 10	1	35.1	27.9	-	16.4	-	11.1	8.9
	2	38.3	32.1	-	17.2	-	13.9	12.5
11	1	-	18.2	12.4	-	6.2	-	5.2
	2	-	19.2	13.6	-	6.3	-	5.4

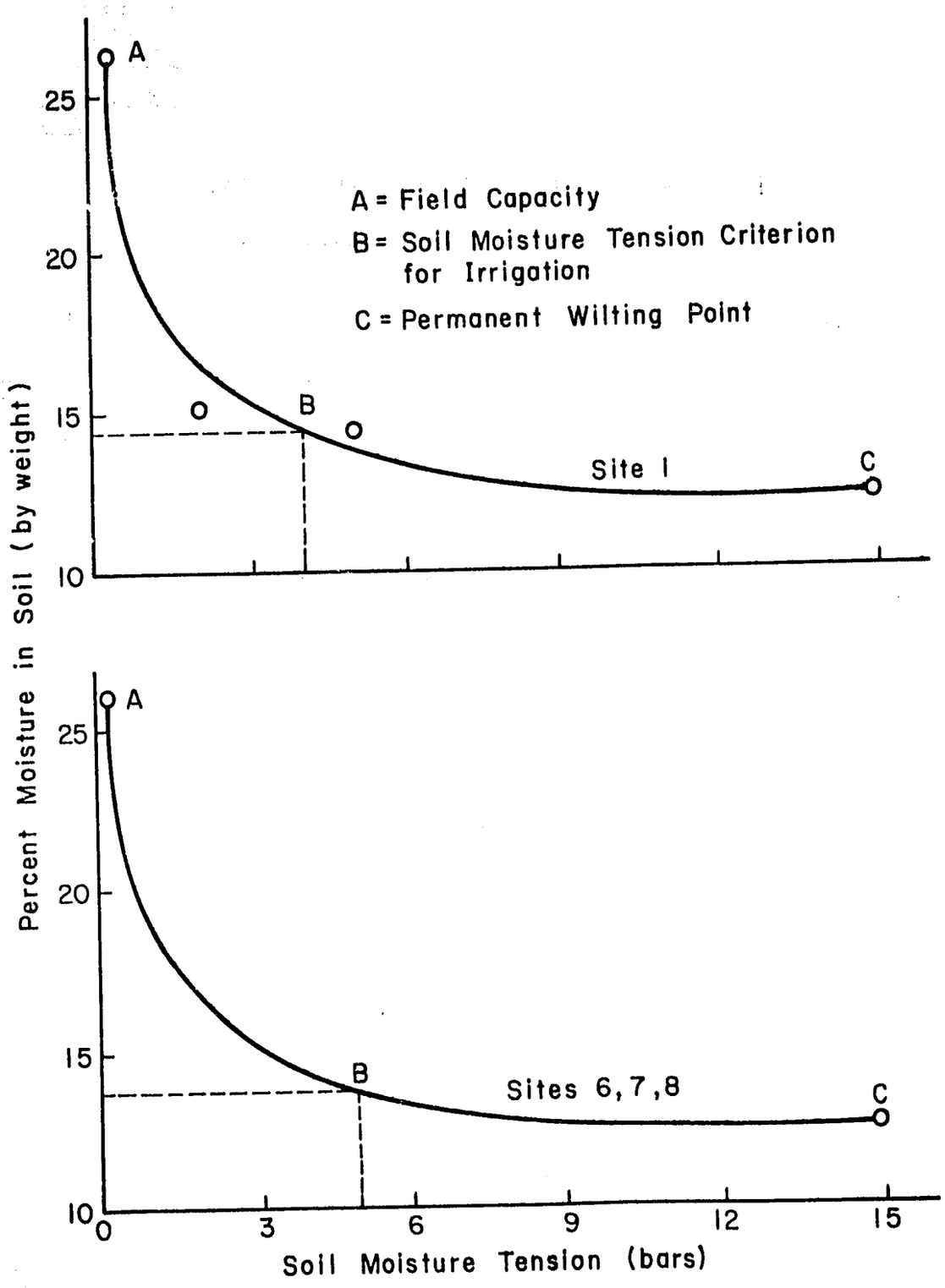

Figure 3. Soil moisture retention curves for Sites 1, 6, 7 and 8, Shadab.

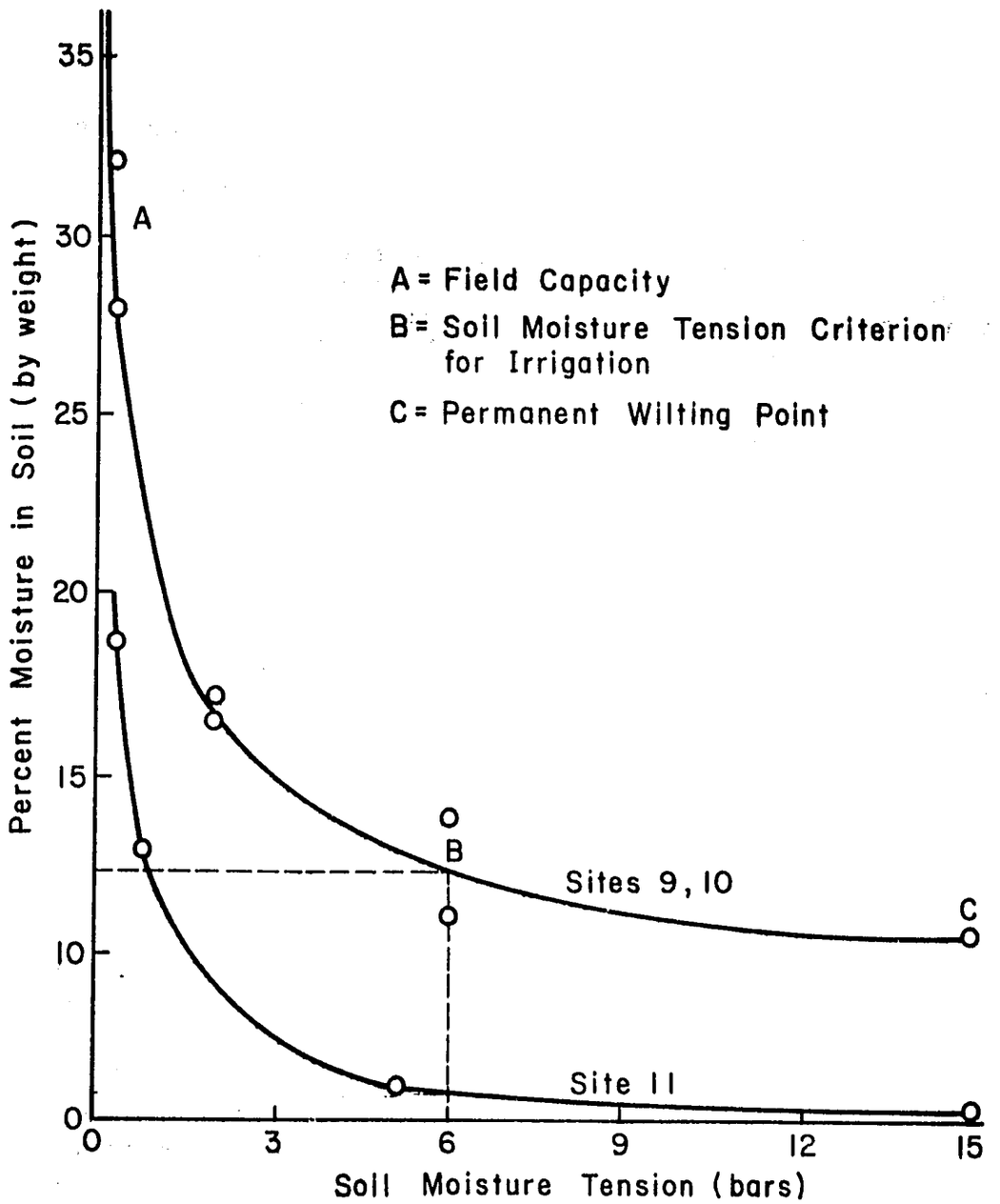

Figure 4. Soil moisture retention curve for Sites 9, 10 and 11, Chak 2-Faiz, district Multan.

following local practices. Where tractor power was available a cultivator was used for improved land preparation (Sites 1, 2, 6, 8 and 11).

c. Sowing

On plots sown by traditional methods the seed was broadcast and incorporated into the soil with a final plowing. Seed distribution and depth of placement are irregular by this method. Sowing in rows with a pora is an improvement over broadcasting and results in better depth control (Sites 1 and 5). At sites 2, 3 and 4 the improved plots were sown with a rabi drill. The wheat trials were sown between mid November and mid December 1974. Maize and sorghum fodders were sown by broadcast method on June 8 and 9, 1975. The maize variety J_1 was planted at Sites 6 and 7. Seed of a local variety was used for sorghum. Improved cotton fields were planted with a seed drill. The row spacing was 24 inches and the varieties used were F 149 and Delta Pine cotton.

d. Soil Fertility

A socio-economic survey was conducted by IRDP in collaboration with CSU to determine the traditional fertilizer level for various crops. It was observed that farmers in general apply 50 lbs of N to wheat and cotton. Therefore, the low fertility level of traditional plots in the present study consisted of 50 lbs of N in the form of urea applied at sowing to wheat and cotton crops whereas no fertilizer was applied to traditional fields of maize and sorghum fodders. The high fertility rate was 130 to 155 lbs of N and 75 lbs of P_2O_5 per acre for wheat depending on location. The source of phosphorus was DAP which contains 46 percent P_2O_5 and 18 percent N. All phosphate and 80 to 105 lbs N were applied at sowing. The remaining nitrogen was applied as urea in two equal doses at 25 lbs each at first and second irrigation. In case of fodders, 50 lbs of N was applied at sowing for improved fields and 25 lbs additional N was applied at first irrigation. For cotton, 45 lbs of N and 50 lbs of P_2O_5 were applied at sowing and 50 lbs additional N was applied at second irrigation, making a total application of 95:50:0.

e. Irrigation

Traditional irrigation treatments were left to cooperating farmers. Improved irrigation procedures were based on water requirements of the crop as indicated by soil moisture depletion in the root zone. For wheat, it was decided to apply irrigation water when the soil moisture tension in the root zone reached 4 bars. This was equivalent to 14.3 percent moisture by weight in the local soil. Irrigation of maize and sorghum fodder were planned at 5 bars tension which occurred at 14 percent mean moisture content of the 0 to 12 inch layer of soil at the experimental site. Cotton fields

under improved management were irrigated at 6 bars soil moisture tension. This tension corresponded with 12.5 percent moisture by weight on the loam soil at Sites 9 and 10, and 6 percent moisture in the sandy loam at Site 11.

The quantity of irrigation water applied to each crop was the quantity necessary to restore the soil moisture to field capacity over the full depth of rooting of each crop. For this purpose gravimetric soil moisture determination was carried out prior to each irrigation.

Core samples were taken from each 12 inch layer to a depth of 48 inches, and oven dried. The moisture deficit was calculated for each sampling depth on the plots receiving the improved irrigation treatment. The equation used to convert the observed soil moisture percentage into inches of water needed was:

$$d = \frac{(Pc - Pw)b.t}{100}$$

where d = depth of irrigation water in inches

Pc = soil moisture percentage by weight at field capacity

Pw = soil moisture percentage by weight prior to irrigation

b = oven dry bulk density in g/cm^3

t = thickness of sampled layer in inches.

The total amount of irrigation water to be applied was obtained by adding the calculated requirements of the individual layers.

Field capacity was measured in the field by moisture sampling. The soil was covered with a jute bag and sampled 3 days after irrigation for wheat fields and 2 days after irrigation for maize, sorghum and cotton crops. Bulk density was determined from the same samples after drying. The amount of irrigation water applied was measured with the help of a cutthroat flume. The nakkas were closed as soon as the proper amount of water had been applied.

The depth to the groundwater table exceeds 25 feet at both experimental locations (Mohlanwal and Chak Faiz 2).

f. Plant Protection

The wheat was treated with agrosan fungicide against rust attack. No other plant protection measure was adopted for wheat. No pesticides were applied to maize and sorghum crops. However, regular plant protection measures were adopted for the cotton crop. Cotton fields were dusted with

Benzene Hexa Chloride Conc. 10 percent at a rate of 20 lbs/acre on June 23-24, 1975, against Chroto gonous as a precautionary measure in the improved plots receiving good plant protection treatment. The plots were also sprayed with broad spectrum pesticides such as Malathion EC 57 percent emulsifiable concentrate at the rate of 2 lbs/acre on July 20-21, 1975. The pesticide was diluted with water to 0.005 percent concentration of active ingredient and applied by manual labor with the help of a Solo Knap Sack Sprayer. Two sprays of Thiodon 35 percent emulsifiable concentrate were applied on August 6-7, 1975 and August 20-21, 1975, against boll worm and sucking insects. This pesticide was diluted with water to a concentration of 0.005 percent active ingredient and applied with a Solo Knap Sac Sprayer.

g. Interculture and Hoeing

One hoeing was performed on improved wheat plots after the second irrigation to remove weeds when the soil was in wattar condition. No such operation was carried out for maize and sorghum crops. Improved cotton plots received one hoeing after first irrigation and one interculture with the local plow after the second irrigation.

C. EXPERIMENTAL LAYOUT

The wheat experiment at Site 1 contained 5 treatments and the cotton experiment at Site 9, 7 treatments. These experiments were laid out in randomized block design with 2 replications. Other trials were more simple with 2 treatments each.

D. HARVESTING PROCEDURES

The wheat plots were harvested in the second fortnight of April. The maize fields were harvested on August 7 and 8, 1975, and sorghum trials on August 25, 1975. Cotton fields were picked five times during the growth period, on October 15, November 4, 11, 28 and December 10. Three squares with dimensions of 11 by 11 feet were placed at random in each plot of wheat, maize, sorghum and cotton for harvesting. Yields were converted to maunds per acre. The yield of fodder is expressed on a green weight basis.

III. RESULTS AND DISCUSSION

A. YIELD EFFECTS

1. Field Experiment with Wheat

The field experiment conducted at Site 1 during rabi in 1974/75 consisted of 5 treatments in randomized block design which are summarized in Table 3 with the yields obtained.

Chenab 70 was sown on November 17 at a seed rate of 40 seers per acre. There were 2 replications. Treatment 1 with traditional practices produced the low yield of 24.1 maunds per acre. Treatment 5 with optimum management practices yielded 53.2 maunds per acre. Essentially, three factors were tested in this trial irrigation; fertility and sowing methods by means of the subtraction technique. Treatment 3 showed the effect of absence of improved sowing practices. In Treatment 4 irrigation management was absent whereas in Treatment 2 the fertility was lacking. The results show that broadcast sowing (Treatment 3) kept the yield 7 maunds below the maximum. Poor irrigation practices reduced the yield 3.6 maunds (Treatment 4). A major loss of 26.3 maunds occurred when fertilizers were withheld (Treatment 2). This indicates that fertility was the most important single factor in raising wheat yield. Irrigation practices did not have much effect on per-acre production but led to a saving of 10 inches of water for use elsewhere (Table 3). Analysis of variance indicated highly significant treatment effects at the 0.01 level of probability. Duncan's multiple range test showed that Treatments 1 and 2 differed significantly from treatments 3, 4 and 5.

2. Wheat Demonstration Plots

The demonstration plot technique was used to give a wider distribution to the experimental findings in the Mohlanwal area. Four demonstrations were laid out, each consisting of an improved and unimproved plot. The improved management included the use of either a rabi drill or a pora for sowing, application of 75 lbs P_2O_5 and 130 lbs N per acre as DAP and urea improved irrigation practices. Site 4 consisted of 4 acres of poorly leveled land which were precision leveled and provided with a new irrigation ditch through the center. The demonstration was divided into two subplots, one of which was established on an area from which 6 inches of surface soil had been cut and the other on an area of fill. The unimproved plots received traditional management as described earlier with the exception of Site 2. The farmer at this site chose to apply 75 lbs N per acre instead of the usual 50 lbs N.

The findings are summarized in Table 4. The package of improved practices nearly doubled the yield of grain at every site. Furthermore, at least 8 inches of water were saved by the improved irrigation practices and in one instance 11.5 inches. This water could be made available to increase the acreage under crops. When applied on a national scale such water use efficiency would provide an appreciable boost in grain production. Chenab 70 produced higher yield than SA 42 but a comparison between the 2 varieties is not valid because the latter is specially suited for late sowing. At Site 4 which had been leveled before sowing, the fill areas yielded

Table 3. Mean yields of grain and amount of irrigation water used by wheat, Mohlanwal, rabi 1974/75.

Treatment number	Treatment	Irrigation[1/] (inches/ acre)	Yield (maunds/ acre)
1	Sowing with pora, low fertility (50 lbs N at sowing), traditional irrigation	24.5	24.1 a*
2	Sowing with pora, low fertility improved irrigation	14.5	26.9 a
3	Broadcast sowing, high fertility (75 lbs P_2O_5 and 80 lbs N/per acre at sowing) 75 lbs N in 2 equal subsequent doses at 1st and 2nd irrigation, improved irrigation	14.5	46.2 b
4	Sowing with pora, high fertility, traditional irrigation	24.5	49.6 b
5	Sowing with pora, high fertility, improved irrigation	14.5	53.2 b

[1/] Excluding rainfall amounting to approximately 3 inches.

* Means followed by the same letter were statistically not significantly different at 0.01 level of probability.

Table 4. Grain yields and amounts of irrigation water used by wheat in demonstration plots at Mohlanwal, rabi 1974/75.

Site number	Sowing date	Variety	Seed rate (seers/ac)	Method of sowing	Irrigation (in/ac)		Yield (maunds/ac)	
					Traditional	Improved	Traditional	Improved
3	Nov.18	Chenab 70	40	drill		13.0		62.4
				broadcast	21.0		33.8	
4	Nov.20	Chenab 70	40	drill & pora		13.5		46.1 fill area 41.6 cut area
				broadcast	25.0		22.5	
5	Nov.25	SA 42	50	pora		17.0		37.0
				broadcast	25.0		20.3	
6	Dec.14	SA 42	40	pora		17.5		36.5
				broadcast	25.0		19.1	

4.5 maunds more grain than those from which several inches of surface soil had been removed.

3. Maize and Sorghum Demonstration Plots

The crop yields and amounts of water applied to each plot are presented in Table 5. The data show that improved practices nearly doubled the yield of fodder. The yield of maize fodder produced under traiditional practices at Site 6 was 193.5 maunds fresh weight per acre and with improved practices 373.5 maunds per acre. At Site 7, the fields with traditional practices yielded 234, and improved practices 405 maunds per acre. The mean yield values for both sites were 213.8 and 389.5 maunds per acre for traditional and improved practices, respectively. Most of this effect was due to the fertilizer treatment because canal closure and continuous monsoon showers interfered with water management at all sites. Site 6 was irrigated twice, i.e. June 17 and July 20, Site 7 once on July 14 and Site 8 once on July 11. The data in Table 5 show that there was little difference in the amount of water applied between control treatment and improved practices.

4. Field Experiment with Cotton

The cotton yields obtained in the field experiment ranged from 7.3 maunds per acre for traditional management to 16.5 maunds per acre under optimum management conditions for the variety F 149 (Table 6). The yield of Delta pine cotton tested in this study under optimum conditions was 15 maunds per acre. Analysis of the variance indicated highly significant treatment effects at the 0.05 level of probability. Several factors contributed toward the improved yield level. The experiment was designed in such a way that each of the Treatments 2,3,4 and 5 was lacking certain improvement as compared with the optimum management (Treatment 6). The difference between Treatment 6 and the control plots (Treatment 1) showed the total improvement potential which amounted to 9.2 maunds per acre or 128 percent. The practice of broadcast sowing caused a yield loss of 6.9 maunds. It showed that line sowing with good depth control of the seed is important and that other improvements will not pay off without a good stand.

Omitting the improved fertilizer application was equally damaging to the yield and resulted in a loss of 6.7 maunds per acre. The reduction in yield was due partly to omission of the supplemental N nutrition at the second irrigation and partly to the absence of phosphatic fertilizer. Phosphate is highly important for increasing root proliferation and stimulation of metabolic processes and meristematic tissues.

Table 5. 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)	
6	maize	control	5.7	9	193.5
		improved	5.2	9	373.5
7	maize	control	3.2	9	234.0
		improved	2.7	9	405.0
8	sorghum	control	3.0	11	216.0
		improved	3.1	11	423.0

Table 6. Mean yield of cotton and total amount of irrigation water used at various levels of farm management during kharif, 1975, at Site 9, Lar, district Multan.

Treatment No.	Treatment Identification					Irrigation (inches/acre)	Yield* (maunds/acre)
	Fertility	Irrigation	Method of sowing	Plant protection	Variety		
1	traditional	traditional	broadcast	poor	F 149	20.5	7.3 d
2	traditional	improved	drilled	improved	F 149	15.3	9.8 cd
3	improved	traditional	drilled	improved	F 149	20.5	12.2 bc
4	improved	improved	drilled	poor	F 149	15.3	11.3 c
5	improved	improved	broadcast	improved	F 149	15.3	9.6 cd
6	improved	improved	drilled	improved	F 149	15.3	16.5 a
7	improved	improved	drilled	improved	Delta pine	15.3	[illegible]

*Means not followed by the same letter differed statistically at the 0.05 level of probability.

Proper timing and amount of irrigation contributed 4.3 maunds per acre to the yield after other improvements had been made and saved 5.2 inches of water per acre of land in addition to that. This excess water became available for irrigation of additional fields whereas it only would have leached nitrates from the root zone had it been applied to the soil under traditional management.

When plant protection measures were not applied as part of the improvement package, the yield was reduced 5.2 maunds per acre.

5. Cotton Demonstration Plots

The package of improvements investigated at Site 9 was applied to a field at Site 10 along side of another field which received traditional management. The findings confirmed that local cotton yields can be doubled by methods requiring only good care and small investment.

At Site 11 unlevel surface conditions required precision land leveling before further progress could be made. A tractor and scraper were used for leveling. A portion of the field was cut to a depth of 12 inches in the operation. It was decided to evaluate only the combined effects of fertilizer application and proper irrigation water management on the newly leveled land. The field was entirely planted in rows and received good care in plant protection. The portion with improved management was divided into three sections according to depth of soil removed during leveling. Section A had an average of 12 inches of surface soil removed, Section B 6 inches, and Section C 3 inches. Farm yard manure was applied to all three sections at the rate of 10 tons/acre to compensate for the loss of fertility and organic matter. The yields obtained and irrigation water used at Sites 10 and 11 are presented in Table 7. The data showed that cotton yields can be doubled with good care even in the first season after land leveling provided the leveling involved only minor cut and fill. Removal of 12 inches of surface soil severely depressed the yield of cotton to that of a traditional field during the first season. Six inches cut permitted slight improvement in production to 9.5 maunds per acre whereas 3 inches cut produced 135 maunds. By means of extrapolation, it may be estimated that the yield of cotton in sections where negligible cut and fill occurred would have amounted to approximately 18 maunds per acre (Figure 5).

B. ECONOMIC ASPECTS

Acceptance of suggested changes in crop management by the farmer can be expected only if the new practices are easy to apply, do not call for large investment, and are obviously highly profitable. The economics of the improved practices

Table 7. Mean yield of cotton variety F 149 and total amounts of irrigation water used under traditional and improved farm management during kharif 1975 at Sites 10 and 11, at Lar, district Multan.

Site	Treatment	Irrigation (inches/ acre)	Yield (maunds/ acre)
10	Traditional fertilization, irrigation, sowing and pest control	22	7.0
10	Improved fertility, irrigation, planting, and plant protection	14	14.2
11	Traditional fertilization, irrigation, improved plant protection and drill sowing	21	7.4
11	Improved fertility, irrigation, drill sowing and plant protection:	15	
	12 inches of soil removed		6.2
	6 inches of soil removed		9.5
	3 inches of soil removed		13.5

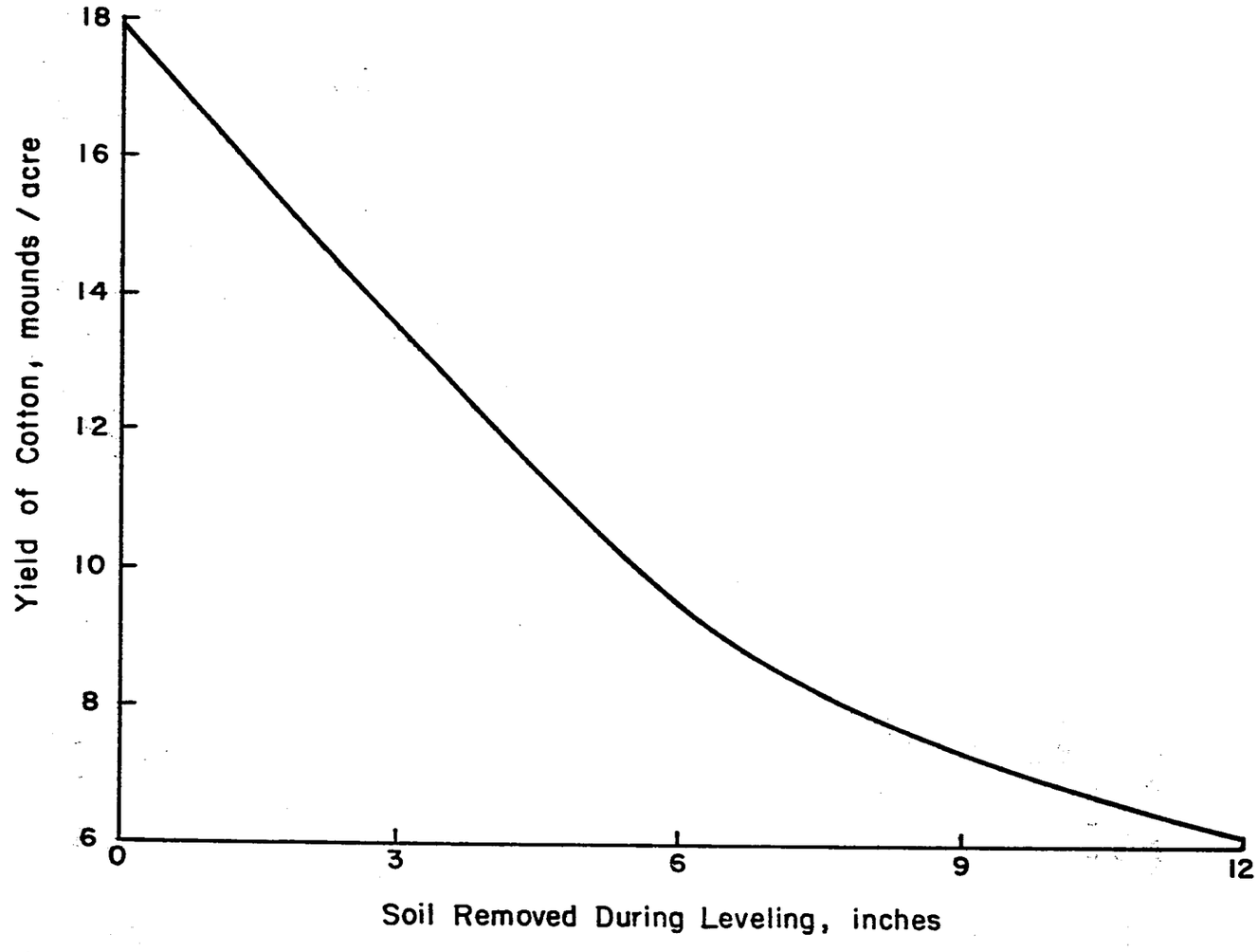

Figure 5. Yield of cotton in newly leveled field as affected by depth of soil removed, Site 11, Lar, district Multan.

discussed here are favorable and the returns associated with each improvement will be considered separately for the various crops under study.

1. Fertilization

a. Wheat Crop

The costs and returns of wheat production are strongly affected by the management practices adopted by the farmer. The net profit values presented in Table 8 are based on actual yields obtained in the experimental fields and on local prices. Fields managed in a customary fashion and producing 24.1 maunds of wheat brought a net profit of Rs. 54 per acre at standard government rates. Adjoining fields with good fertilizer management alone produced net profits of Rs. 957 per acre. The difference is that between mere subsistence and profitable farming. Considering a free market price of Rs. 42 per maund of wheat, the net profit per acre under traditional management was Rs. 155 (Table 9). Proper fertilizer use brought this value to Rs. 1165.

The additional costs and profits associated with improved fertilizer and other practices are summarized in Table 10. The suggested fertilizer rates carried benefit/cost ratios of 3.3 to 3.5.

b. Maize Fodder Crop

The economic interpretation of improved practices for maize fodder is based primarily on the cost of fertilizer investment. The cost of traditional production for 1 acre of maize was Rs. 394 and with improved practices Rs. 501. The profits increased from Rs. 675 to Rs. 1445 (Table 11). The benefit/cost ratio for improved fertilization was 8.2. It appears that the profit margin for unimproved fodder production is good but can be raised much higher by means of fertilizer use.

c. Sorghum Fodder Crop

Similar results were obtained with fertilizer use for sorghum. The cost of production for 1 acre of sorghum was Rs. 435 under customary management and Rs. 549 when fertilized. But the value of the fodder increased from Rs. 1080 to Rs.2115, and net profit from Rs. 645 to Rs. 1566 (Table 12). The benefit/cost ratio for the improvement was 9.1.

d. Cotton Crop

The values for costs and returns of cotton under traditional management are presented in Table 13. The data indicate that there was practically no profit (Rs. 5.61 per acre)

Table 8. Production costs and returns in rupees for wheat grown under various conditions at the standard government price of Rs.37/maund at farm gate in Shadab, rabi 1975.

Category	Treatment Number 1 (traditional)	2	3	4	5 (improved)
COSTS:					
Lease of agricultural land 180 da. @ Rs.600/acre/annum	295.89	295.89	295.89	295.89	295.89
Land & seedbed preparation					
5 plowings @ Rs 15/plowing	75.00	75.00	75.00	75.00	75.00
3 plankings @ Rs 5/planking	15.00	15.00	15.00	15.00	15.00
Sowing					
1 plowing @ Rs 15/plowing	15.00	15.00	15.00	15.00	15.00
1 planking @ Rs 5/planking	5.00	5.00	5.00	5.00	5.00
Seed					
40 seers @ Rs 40/maund	40.00	40.00	40.00	40.00	40.00
Fertilization					
Urea @ Rs 75/bag	75.00	75.00	187.50	187.50	187.50
DAP @ Rs 75/bag	-	-	112.50	112.50	112.50
Irrigation					
@ Rs 10/acre-inch	245.00	145.00	145.00	245.00	145.00
Weeding					
4 man days @ Rs 10/day	40.00	40.00	40.00	40.00	40.00
Wages of farmer					
180 days @ Rs 1/day (sowing, bund making, fertilizer application, cleaning of water channels, general water management)	180.00	180.00	180.00	180.00	180.00
Land revenue & other taxes	15.00	15.00	15.00	15.00	15.00
Harvesting charges					
6% of grain and Bhosa yield	73.66	81.98	141.20	151.69	162.62
Thrashing and winnowing charges					
10% of grain yield	89.17	99.53	170.94	183.52	196.84
Miscellaneous charges (as transport of fertilizer and seed)	10.00	10.00	10.00	10.00	10.00
Total costs	1173.72	1092.40	1448.03	1571.10	1495.35
RETURNS:					
Value of grain @ Rs 37/maund	891.70	995.30	1709.40	1835.20	1968.40
Value of Bhosa @ Rs 7/maund	336.00	371.00	644.00	693.00	742.00
Total returns	1227.70	1366.30	2353.40	2528.20	2710.40
NET PROFIT PER ACRE:	53.98	273.90	905.37	957.10	1215.05

Table 9. Production costs and returns in rupees for wheat grown under various conditions at open market price of Rs 42/maund at farm gate in Shadab, rabi 1975.

Category	Treatment Number 1 (traditional)	2	3	4	5 (improved)
COSTS:					
Lease of agricultural land 180 da. @ Rs 600/acre/annum	295.89	295.89	295.89	295.89	295.89
Land & seedbed preparation					
5 plowings @ Rs 15/plowing	75.00	75.00	75.00	75.00	75.00
3 plankings @ Rs 5/planking	15.00	15.00	15.00	15.00	15.00
Sowing					
1 plowing @ Rs 15/plowing	15.00	15.00	15.00	15.00	15.00
1 planking @ Rs 5/plankin	5.00	5.00	5.00	5.00	5.00
Seed					
40 seers @ Rs 40/maund	40.00	40.00	40.00	40.00	40.00
Fertilization					
Urea @ Rs 75/bag	75.00	75.00	187.50	187.50	187.50
DAP @ Rs 75/bag	-	-	112.50	112.50	112.50
Irrigation					
@ Rs 10/acre-inch	245.00	145.00	145.00	245.00	145.00
Weeding					
4 man days @ Rs 10/day	40.00	40.00	40.00	40.00	40.00
Wages of farmer					
180 days @ Rs 1/day (sowing, bund making, fertilizer application, cleaning of water channels, general water management)	180.00	180.00	180.00	180.00	180.00
Land revenue & other taxes	15.00	15.00	15.00	15.00	15.00
Harvesting charges					
6% of grain and Bhosa	80.89	90.05	155.06	166.57	178.58
Thrashing charges					
10% of grain	101.22	112.98	194.04	208.32	223.44
Miscellaneous charges	10.00	10.00	10.00	10.00	10.00
Total costs	1193.00	1113.92	1484.99	1610.78	1537.91
RETURNS:					
Value of grain @ Rs 42/maund	1012.20	1129.80	1940.40	2083.20	2234.40
Value of Bhosa @ Rs 7/maund	336.00	371.00	644.00	693.00	742.00
Total returns	1348.20	1500.80	2584.40	2776.20	2976.40
NET PROFIT PER ACRE:	155.20	386.88	1099.41	1165.42	1438.49

Table 10. Additional costs, profits, and benefit/cost ratios associated with improved practices for wheat production (rupees).

Improvement Factor	Other Conditions	Wheat Price (Rs/maund)	Added Costs	Added Profit	Benefit/cost Ratio
Fertilization	Traditional irrigation	37	397.38	903.12	3.3
		42	417.78	1010.22	3.4
	Improved irrigation	37	402.95	941.15	3.3
		42	423.99	1051.61	3.5
Irrigation	Low fertility	37	-81.32	219.92	high
		42	-79.0	231.68	high
	Optimum fertility	37	-75.75	257.95	high
		42	-72.87	273.07	high
Method of Sowing	Optimum fertility	37	47.32	309.68	7.5
		42	52.92	339.08	7.4
Total Package		37	321.63	1161.07	4.1
		42	344.91	1283.29	4.7

Table 11. Costs and returns of production of maize fodder under improved and traditional practices under the conditions prevailing at Shadab, kharif 1975.

Category	No Fertilizer (Rs/acre)	Improved Fertilization (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
Seed		
Cost of 32 seers of seed at Rs 40/maund	32.00	32.00
Irrigation		
Cost of water applied @ Rs 10/ acre-inch	45.00	40.00
Wages of farmer @ Rs 1.0/day	80.00	80.00
Land revenue and water charge	15.00	15.00
TOTAL COST OF PRODUCTION	393.51	501.01
RETURNS		
Value of crop		
213 maunds @ Rs 5/maund	1069.00	--
389.3 maunds @ Rs 5/maund	--	1946.50
PROFIT		
Net profit per acre	675.49	1445.49
Additional cost due to improved fertilization		107.50
Additional profit from improved fertilization		770.00
Benefit/Cost ratio for improved fertilization		8.2

Table 12. Costs and returns of production of sorghum fodder under improved and traditional practices and under the conditions prevailing at Shadab, kharif 1975.

Category	No Fertilizer (Rs/acre)	Improved Fertilization (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
Sowing		
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 1.0/day	100.00	100.00
Land revenue and water charge	15.00	15.00
TOTAL COST OF PRODUCTION	435.38	548.88
RETURNS		
Value of crop		
216 maunds @ Rs 5/maund	1080.00	--
423 maunds @ Rs 5/maund	--	2115.00
PROFIT		
Net profit	644.62	1566.12
Additional cost for improved fertilization		113.50
Additional profit from improved fertilization		921.50
Benefit/Cost ratio for improved fertilization		9.1

in growing unimproved cotton. In the absence of sufficient fertilizer, other improvements raised net profit to Rs.183 per acre. Including adequate fertilizer, however, the profits amounted to Rs. 756. The cost/benefit ratio for fertilization was 4.5 (Table 14).

2. Irrigation Practices

a. Wheat Crop

The use of proper irrigation practices alone raised the per-acre profit from Rs. 54 under customary conditions to Rs. 274 at the standard government rate of Rs. 37 per maund of wheat. The change did not require any investment but instead made irrigation water available for use elsewhere. Benefit/cost ratios for water management were high but cannot be given a numerical value because no costs were involved (Table 10). At the high fertility level introductions of improved irrigation practices raised per-acre profits from Rs. 957 to Rs. 1215 (Table 8). The benefits derived from improved irrigation were approximately equal with or without adequate fertility, thus indicating that the two factors are independent and had additive effects. At the open market price for wheat and traditional rate of fertilization the profits derived from 1 acre of wheat amounted to Rs. 155 and Rs. 387 with customary and improved irrigation, respectively (Table 8). With high fertility these values were Rs. 1165 and Rs. 1438 (Table 9). In addition to the higher income, it should be remembered that 10 inches of irrigation water were made available for application to other fields.

b. Cotton Crop

The returns from 1 acre of traditionally irrigated cotton with optimum fertility were Rs. 1342 which included Rs. 290 net profit. A change to improved irrigation increased the profit to Rs. 756 (Table 13). The benefit/cost ratio for irrigation improvement was 66.5 (Table 14). Five inches of water were saved in the process.

3. Line Sowing

The economics of line sowing and, where applicable, drill planting are discussed for wheat and cotton crops.

a. Wheat Crop

The effect of line sowing for wheat was tested at the improved fertilizer and irrigation level. The net profit per acre of broadcast sown wheat was Rs. 905 and with line sowing Rs. 1215 at Standard Government wheat price. At the open market price of Rs. 42/maund these values were Rs. 1099 and Rs. 1438, respectively. The benefit/cost ratio for line sowing was approximately 7.5.

Table 13. Production costs and returns in rupees for cotton produced under several different treatment conditions at LAR, kharif 1975.

Category	Treatment Number					
	1 (traditional)	2	3	4	5	6 (improved)
COSTS:						
Lease of agricultural land						
210 days @ Rs 400/acre/annum	230.14	230.14	230.14	230.14	230.14	230.14
Land and seedbed preparation						
4 plowings @ Rs 15/plowing	60.00	60.00	60.00	60.00	60.00	60.00
2 plankings @ Rs 5/planking	10.00	10.00	10.00	10.00	10.00	10.00
Sowing						
one plowing @ Rs 15/plowing	15.00	15.00	15.00	15.00	15.00	15.00
one planking @ Rs 5/planking	5.00	5.00	5.00	5.00	5.00	5.00
Seed						
7 seers @ Rs 1.55/seer	10.85	10.85	10.85	10.85	10.85	10.85
Fertilization						
Urea @ Rs 75/bag	75.00	75.00	112.50	112.50	112.50	112.50
DAP @ Rs 75/bag	-	-	75.00	75.00	75.00	75.00
Irrigation						
@ Rs 5/acre-inch	102.50	76.50	102.50	76.50	76.50	76.50
Weeding						
4 man days @ Rs 10/day	0	40.00	40.00	40.00	0	40.00
1 interculture @ Rs 15/interculture	0	15.00	15.00	15.00	0	15.00
Plant protection						
i) B.H.C 10%, 20 lbs @ Rs 0.53/lb	0	10.60	10.60	0	10.60	10.60
ii) Malathion EC 57%, 2 lbs @ Rs 2.72	0	5.44	5.44	0	5.44	5.44
iii) Triodan EC 35%, 6 lbs @ Rs 5.17	0	31.02	31.02	0	31.02	31.02
Wages of farmer						
210 farmer days @ Rs 1/day	210.00	210.00	210.00	210.00	210.00	210.00

(Continued)

Table 13. Production costs and returns in rupees for cotton produced under several different treatment conditions at LAR, kharif 1975. (Continued)

Category	Treatment Number 1 (traditional)	2	3	4	5	6 (improved)
Land revenue and other taxes	15.00	15.00	15.00	15.00	15.00	15.00
Picking charges 7% of yield	53.90	75.46	93.94	87.01	73.92	127.05
Miscellaneous charges (as transport of fertilizer and seed)	10.00	10.00	10.00	10.00	10.00	10.00
Total costs	797.39	895.01	1051.99	972.00	950.97	1059.10
RETURNS:						
Value of crop @ Rs 110/maund	803.00	1078.00	1342.00	1243.00	1056.00	1815.00
NET PROFIT PER ACRE	5.61	182.99	290.01	271.00	105.03	755.90

Table 14. Additional costs, profits, and benefit/cost ratios associated with improved management practices in cotton production (rupees).

Improvement factor*	Additional cost	Additional profit	Benefit/ cost ratio
Fertilization	164.09	572.91	4.5
Irrigation practices	7.11	465.89	66.5
Drill planting	108.13	650.87	7.0
Plant protection measures	87.10	484.90	6.6
Total package of improved practices	261.71	750.29	3.9

*All other practices improved

b. Cotton Crop

The effect of drill planting compared with broadcast sowing was evaluated under conditions of improved fertility and irrigation. Net profits per acre of cotton were Rs. 105 without and Rs. 756 with line sowing. The benefit/cost ratio for the operation was 7.0. It was observed that without line sowing and the ensuing good stands, other improvements including fertilizers were not very effective.

4. Plant Protection

Plant protection measures were tested only for cotton. The profits from 1 acre of cotton with and without pest control were Rs. 756 and Rs. 271, respectively, and the benefit/cost ratio was 6.6.

5. The Total Package

The optimum combination of fertilizers, irrigation and sowing practices for wheat raised the net profit per acre of wheat produced from Rs. 54 to Rs. 1215 at the Standard Government price of wheat or to Rs. 1438 at open market prices. The very large difference in profit is due to production of 29 maunds more wheat per acre at relatively small additional cost.

Fertility was the main factor in maize and fodder production under the prevailing conditions. Fertilizers and other attempted improvements increased the net profits per acre to Rs. 1445 for maize and Rs. 1566 for sorghum fodder.

Contributions from fertilizers, irrigation and sowing practices, and plant protection measures combined to raise the net profit from cotton growing from Rs. 6 to Rs. 756 per acre.

It is evident from the results that traditional wheat and cotton farmers are operating at a minimal profit which is barely sufficient to support their families. Their standard of living can be very much improved by acceptance of the agricultural practices suggested in this paper.

Possibly, net profits can be increased further, especially for fodder production in areas where a ready market for animal fodders exists.

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 that the quantities of fodder presently grown could be produced from one-half the current acreage by optimum use of fertilizers and water. Therefore, without a

change in total fodder production, land could be made available for wheat, rice, and maize culture to attain food autarky in Pakistan.

IV. CONCLUSIONS

1. The yield of wheat was raised from 24.1 to 53.2 maunds per acre by application of a package of improved management practices involving fertilizers, irrigation, and sowing methods.

2. Maize fodder yields were boosted from 213 maunds to 389 maunds per acre and sorghum from 216 maunds to 423 maunds per acre by means of improvements of which fertilization was the primary factor.

3. Cotton production was increased from 7.3 maunds per acre under conventional practices to 16.5 maunds by means of improved management practices involving fertilizers, irrigation, line sowing, and plant protection measures.

4. Demonstration plots with wheat further substantiated the findings that yields can be doubled by correct agricultural practices.

5. Precision land leveling operations affected wheat yields in the first season. Fill areas yielded 4.5 maunds per acre higher than cut areas.

6. Cotton yields were doubled on several demonstration plots. Removal of top soil due to precision land leveling reduced the yield during the first year in proportion to the depth of cut.

7. Improved irrigation practices resulted in a saving of 10 inches of water per acre of wheat and 5 inches of water in cotton crops.

8. Improved practices raised the net profits of wheat production from Rs. 54 to Rs. 1215 at Standard Government rate and to Rs. 1438 at open market price with benefit/cost ratios of 4.1 to 4.7.

9. Fertilizers were the primary component of the additional profit from wheat with benefit/cost ratios of 3.3 to 3.5, followed by line sowing with ratios of 7.4 to 7.5, and irrigation practices.

10. Improved practices of which fertilizer use was the primary factor increased the net profit per acre from maize fodder production from Rs. 675 to Rs. 1445, and that of sorghum from Rs. 645 to Rs. 1566. The associated benefit/cost ratios were 8.2 and 9.1, respectively.

11. Improved practices for cotton increased the net profit per acre from Rs. 6 to Rs. 756 with a benefit/cost ratio of 3.9. Line sowing and crop stand made the largest contribution to additional profit, followed by fertilizers, plant protection, and irrigation practices. The benefit/cost ratios of the component practices were 7.0, 4.5, 6.6, and 66.5 in that order.

12. Wheat, fodder, and cotton farmers can very greatly improve their annual incomes by adopting known improved practices. In the experiments under consideration the net profits increased approximately by Rs. 1100 to 1200 per acre of wheat and Rs. 700 to 900 for fodders and cotton. Agricultural development along the lines suggested would assist greatly in attaining food autarky in Pakistan.

V. ACKNOWLEDGEMENTS

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The authors wish to express their feelings of gratitude to the many IRDP personnel who assisted with various parts of the field work at several locations. Without their sincere and continued support the data for this study could not have been collected.

Appendix 34

CASE STUDY ON

IMPROVED FARM WATER MANAGEMENT IN PAKISTAN[1]

by
W. D. Kemper[2]

I. POTENTIAL FOR IMPROVEMENT

The Indus Basin Irrigation System and the limited water supply available are commonly the factors limiting the amount of land cultivated during a given season. Improved water management will, in general, help relieve this constraints on crop production. Delivery[3] and application[4] efficiencies have been estimated by many consultants in Pakistan over the last 20 years but surprisingly few measurements have been taken. Application efficiency measurements have now been taken throughout the crop seasons in normal rainfall years and results indicate an average application efficiency of approximately 40%. Steady state measurements of delivery efficiency in watercourses have averaged about 60%; however, actual delivery efficiencies are considerably lower because ten or more percent of the water entering the watercourse usually goes to operational losses, such as filling dead storage space in water channels, wetting dry banks, washouts of bunds, etc., which are not included in steady state loss measurements. Consequently, in the watercourses of the Punjab the delivery efficiency is about 0.5 and only about 0.2 of the water entering the watercourse is stored in the root zone for use by crops.

Average wheat production was increased from about 16 maunds per acre to over 40 maunds per acre on farmers' fields by applying water as needed and using optimum fertilizers.[5] The amount of water applied was reduced from an average of about 24 inches per acre to about 14 inches per acre when it was applied as needed.

These observations allow construction of the following table which indicates the existing and potential farm water

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1/Paper prepared for Technical Consultation on Land and Water Use in the Near East, Islamabad, Pakistan, October 18-20, 1976.

2/Agricultural Engineer and Agronomist, Water Management Research Project (CSU), Islamabad, Pakistan.

3/Delivery efficiency for watercourses=water entering fields/water leaving canal.

4/Application efficiency-water stored in root zone for plant use/water entering field.

5/1 maund=approximately 82 lb or 33.5 kg.

efficiency for wheat in Pakistan. Similar tables may be constructed for other crops and it can be concluded that there is a potential for increasing production by factors of from 5 to 10 using the amount of water presently available.

POTENTIAL FOR IMPROVEMENT

Farm water efficiency	Delivery efficiency	Application efficiency	Water use efficiency[1]	Farm water efficiency[2]
Existing	0.5	0.5	13	3.3
Potential[3]	0.8	0.6	34	16.3

1/Maunds of wheat/acre foot of water stored in root zone.
2/Maunds of wheat/acre foot of water delivered through the mogha (turnout), (calculated as the product of figures in the first three columns).
3/These are potential efficiencies which have been achieved and can be achieved on the "average" watercourse or farm with reasonable effort and management.

II. METHODS OF IMPROVEMENT

A. Delivery Efficiency

1. Identification and reduction of losses

a. Junctions

Almost half of the water lost from a watercourse is lost within 30 feet of the junctions due to the degraded nature of the banks and leakage and occasional washouts of the dam across the watercourse. Moving soil to fill borrow pits at the junctions and building the banks to proper cross-section with reasonable compaction can often increase the supply of water to the farmers' fields by 50%, but the only permanent solution is the use of control structures which close the channel to water flow without using soil. Rubber gasketed steel slide gates used in other countries are relatively expensive in Pakistan (around 500 Rupees, or $50 plus installation cost[1]) and commonly have considerable leakage. Concrete panels with a round opening or pipes, closed by concrete lids are more economical and satisfactory for controlling water at these junctions. The panel (or pipe end) and lid are installed at about 45 degrees from horizontal. Leakage is prevented by either a rubber gasket or a groove about an inch wide and an inch deep around the circumference of the lid which is designed to be filled with mud. These concrete control structures presently cost between 50 and 90 Rupees. When these lids are properly

1/Rupees 10 = approximately $US L.

closed, leakage through these nakkas (control structures) is generally less than .001 cusecs.

b. Upper portions of the banks

In Pakistan, a large part of the water loss from watercourses occurs in holes through the banks which are within 2 or 3 inches of the operating level of the water. The bottoms of these watercourses are usually fairly well sealed with sediment. However, when these watercourses are several years old the upper portion of the banks have permeability rates from 5 to 10 times that of soil in adjacent fields. This is due to a dense population of roots, worms, grubs, insects and rodents. Newly constructed banks have permeabilities similar to that of adjacent fields, if the soil used in the construction of the banks is reasonably compacted. Another procedure which has reduced the losses to less than 25% of the previous values is the removal of most of the freeboard portions of the banks compacting a core in the middle of the bank by pounding the resident soil downwards as far as possible, filling the trench made with soil, compacting again and then replacing the soil which constituted the freeboard and compacting it by foot. Low loss rates associated with the reconstruction of banks persist for at least a year. There has not yet been time to test the longevity of the loss reduction occasioned by the core compaction. In general a programme of maintenance is essential if improvements are to last more than a season or so. Concrete or masonry lining almost eliminates loss, reduces maintenance, and the advantages are apparent to the farmers. They strongly prefer this type of improvement, as long as they do not have to pay the cost.

c. Operational losses

Watercourses often have sections which are below the level of adjacent fields or lower than the bottom of the watercourse downstream. The water used to fill these low sections is lost to the farmers. Weak sections of the banks, dams and junctions frequently wash out during use of watercourses. This type of operational loss can be greatly reduced by the careful alignment of the bottoms of the watercourses and the installation of concrete control structures described above. Concrete or masonry lining will eliminate the operational loss associated with wetting a dry watercourse.

2. Economics of improving efficiency in Pakistan

The cost of materials for lining watercourses with concrete or masonry has ranged from $7 to $3 per foot of watercourse depending upon the size of the watercourse and the lining material used. Farmers can generally be convinced to supply most of the labor although they frequently have to go outside their village to find competent masons. If the

efficient in their water use and have the high yields shown in the last line of the previous table, and if water is the primary constraint to utilizing the available land for crop production, the value of the water saved by good lining and installation of sound control structures generally exceeds their cost on portions of the watercourses which carry water more than 2 or 3 days per week. However, on the branches which carry water only one day a week, or under conditions where the production is not optimized, only methods of improvement which require less capital are economically feasible.

There are about 20,000 feet of main channel and primary branches in the authorized watercourse serving a 500 acre command area. Reconstruction of these earthen watercourses to give the proper cross section and grade and concrete structures installed at the major junctions (approx. 125) for a cost of about $4,000 or about $8./acre of land served, of which $2 can be farmers' labor. The benefits of such reconstruction depend on the crops raised and the degree to which water is a constraint on cropping intensity and yields. To obtain a more general evaluation of the benefits derived they can be expressed in terms of the value of the water saved. Based on costs presented by Eckert et al. (1975), the value of the water saved in Pakistan in the first year by reduced pumping would exceed the cost of improvements.

The cost and benefit figures thus far obtained involved specific sets of farmers and experimental procedures which were being evaluated during the process of construction. The procedures involved have been tested on two watercourse command areas (about 900 acres each with about 30,000 feet each of authorized watercourse) in which the watercourses were improved under conditions similar to those expected in a development project. Average delivery efficiencies have been improved from 49% prior to improvements to over 65% following improvements. In the same operation the supply from the mogha was increased by lowering the top end of the watercourse so the full authorized flow could come from the canal. The total effect has been to almost double the supply of water to the farmers' fields. Time spent and the various costs involved are being monitored. The improvements and most economical procedures are being evaluated and additional pilot watercourse studies are being initiated. The performance of specialists is being evaluated to determine the level of education needed for individuals to grasp the essential components of watercourse improvement and to be able to pass this on to the farmers. The physical and socio-economic data observations taken on these pilot projects will form part of the basis for proposed national programmes for watercourse improvement in Pakistan.

B. Application Efficiency

1. Identification of inefficiencies and their reduction

The primary causes of low application efficiency in Pakistan are unlevel land and over-irrigation during the cool months and the monsoon season. The land can be leveled and a program for training technicians in precision land leveling is now underway in Pakistan. Improvement of the watercourses, as described above, to increase the flows and give the farmer better control of his water will allow more uniform application of water to fields. Practical methods to help farmers schedule their crops to use their water more efficiently and apply the proper amounts of water are being developed in Pakistan. It should be noted, however, that a farmers' knowledge of how much water he needs to irrigate must be accompanied by knowledge of the flow rate in his watercourse if he is to apply the proper amount of water. Fields are often irrigated in Pakistan to soften the soil sufficiently for plowing by bullock drawn native plows and to obtain proper soil moisture for reasonable stands. If seeding cannot take place during the few days (or hours) when the soil has the proper water content it is often necessary to irrigate again. Recent studies have shown that drilling into a dry field followed by irrigation can give satisfactory wheat stands and may be a water and fertilizer saving alternative.

Basin flooding is the normal method of irrigation in Pakistan and it requires a minimum of about two inches of water to convert a level plot. Consequently, when only a light irrigation is needed to soften the crust to allow emergence, etc., three or more inches of water are usually applied. Furrow irrigation with seed planted near the shoulders of the beds between the furrows allows wetting of the soil surrounding the seed using less than an acre inch of water per acre.

2. Economics of improving application efficiency

Farmers generally irrigate an unleveled piece of land until the highest area within the field is covered with water. This total volume of excess water is equivalent to about 4 times the volume of soil that would have to be moved to level this land (data indicates that the cost is about $\$3/yd^3$ of earth moved).

About 33 yd^3 of soil moved from a high to a low area will save an acre foot of water per year for an initial investment of $10 but the benefits will remain for several years. Other obvious benefits, such as higher yield (data show that yields of maize and cotton on farmers' fields are twice as high on the high as on the low areas of an unlevel field) and uniform soil water content for cultural operations, accrue from land leveling.

Evaluation of soil water content or potential to determine when to irrigate is costly in terms of equipment and/or labor

and can be justified for research only. Studies are now underway to develop methods for assisting farmers in planning their cropping patterns to fit their water supply and adjusting their irrigation practices to more effectively use their water supply. Guidelines for crop and water scheduling will be developed and transmitted to farmers through extension agents and other communication media. The benefits derived will depend on how many of the farmers can be contacted and motivated to make use of this information.

C. Water Use Efficiency

1. Crop stands

Poor crop stands, particularly in the Kharif (dry) season, are a major factor in low water use efficiency. Broadcast seeding, crusting of poorly structured soil above seeds and extremely high soil temperatures during germination are the major cause for these poor stands. Planting kharif crops on the shoulders of beds with water supplied in furrows between the beds has increased stands dramatically in research plots. Data show that capillary wetting of the soil above the seedling softens the crusts and reduces soil temperatures by 5 to 12°C enabling good stands to emerge.

2. Yield per plant

Little crop residue is returned to the soil and adequate yields depend heavily on application of nitrogen and phosphorus fertilizers. Even when these nutrients are applied, low yields often occur. In unleveled basin-flooded fields, yields in the low areas are commonly about half those in the higher areas. Stands are generally about 25% lower on the low areas, but the yield per plant is also lower indicating the possibilities of nitrate leaching and/or poor soil aeration in these low areas. At least partially successful remedies for this problem have been land leveling and proper irrigation.

D. Improving Water Management and Crop Production in Pakistan

Dissemination of the knowledge described above is necessary to obtain the potential benefits. Many of the best practices described are used by some of the better farmers. However, the good practices spread very slowly and the role of the better farmers acting as demonstrators is essential to the rapid spread of these practices to the inefficient farmer. Such extension efforts should include variants of all new technologies adaptable to the small farmers' resources, and opportunities to share or rent equipment which he cannot afford to own.

The role of the better managers is particularly essential for watercourse improvement and maintenance which requires an organized group effort. Fortunately, when farmers elect

officers for their watercourse improvement committees, they usually select the good managers as their leaders.

The facts presented above are based on data recorded in more detail in research reports, including those listed below, by water management scientists and engineers working with WAPDA, the Punjab Integrated Rural Development Programme (IRDP), the Punjab Agricultural Research Institute and the Colorado State University water management advisory team. Copies of these reports are available from the CSU office, USAID, Box 1028, Islamabad, Pakistan.

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Appendix 35

CRITERIA FOR IRRIGATION WATER QUALITY

by
Ghulam Hussain and Dr. J. O. Reuss*

INTRODUCTION

Irrigation waters are classed as fit, marginal or unfit for irrigation based on their potential to create conditions hazardous for plant growth. The parameters mainly considered for evaluation of questionable quality waters are total soluble salts (TDS ppm), sodium absorption ration SAR) and residual sodium carbonate (RSC) me/l. Their effect on soil and crops is interrelated. For example, a high value of one with a low value of other present in irrigation water is considered as safe for use of that particular water compared to the high values of all the parameters. Information in this area is limited under Pakistan conditions and needs further investigation. Therefore, an experiment is being carried out in lysimeters using 29 water combinations to study the combined effect of TDS, SAR and RSC on soil properties and plant growth.

PROCEDURE

Water:

Twenty-nine water combinations were selected using a central composite 2-star rotatable design. Lower and higher values of TDS, SAR and RSC were taken as 400-2600 (ppm), 1-16 and 0-7 (me/l), respectively for one star and 700-2300 (ppm), 3.5 - 13.5 and 1.2 - 6.8 (me/l), respectively for the other star. Two stars were considered necessary 1) to increase the number of observations and 2) to have more observations around the central water of TDS=1500 (ppm), SAR=7.5 and RSC=3.5 (me/l). The details of 29 water combinations are given in Table 1.

Light, medium and heavy soils were used in the experiment having the following analysis:

Soil type	Sat. %	pH	EC^e	SAR	Clay %	Silt %	Sand %
Light	28	8.00	0.85	2.77	13	22	65
Medium	31	8.15	1.50	2.74	21	34	44
Heavy	40	8.00	4.55	7.78	41	42	17

The crop rotation berseem-maize-wheat was followed on all types of soil.

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Table 1. Criteria for irrigation water quality combinations of TDS, SAR and RSC for the central composite 2-star rotatable design.

S.No.	Point at	TDS	SAR	RSC	S.No.	Point at	TDS	SAR	RSC
1.	Central point	1500	8.5	3.5	16.	Cube No. 2	846	4.0	5.6
2.	Cube No. 1	1024	5.5	2.1	17.		846	4.0	1.4
3.		1024	5.5	4.9	18.		846	13.0	5.6
4.		1024	11.5	2.1	19.		846	13.0	1.4
5.		1024	11.5	4.9	20.		2154	4.0	5.6
6.		1976	5.5	2.1	21.		2154	4.0	1.4
7.		1976	5.5	4.9	22.		2154	13.0	5.6
8.		1976	11.5	2.1	23.		2154	13.0	1.4
9.		1976	11.5	4.9	24.	Star No. 2	400	8.5	3.5
10.	Star No. 1	700	8.5	3.5	25.		2600	8.5	3.5
11.		2300	8.5	3.5	26.		1500	1.0	3.5
12.		1500	3.5	3.5	27.		1500	16.0	3.5
13.		1500	13.5	3.5	28.		1500	8.5	-
14.		1500	8.5	1.2	29.		1500	8.5	7.0
15.		1500	8.5	5.8					

The experiment was carried out in the field in concrete pipes 120 cm. long and 60 cm. in diameter. The pipes were buried in the soil in a vertical position to a depth of 105 cm. Light, medium and heavy textured, non-saline, non-sodic soils were taken from the surface 15 cm. layer of a field and after proper mixing were filled in the pipes up to a height of 105 cm. leaving the upper 15 cm. for application of irrigation water. The bulk density of all soils was kept as 1.5. The waters of different qualities were prepared in the laboratory by mixing sodium-chloride, calcium-chloride, sodium bicarbonate, calcium-sulfate, calcium-carbonate and magnesium-carbonate in suitable proportions. The irrigations were applied in 7.5 cm. increments for normal irrigations and 10 cm. for a pre-sowing irrigation. The total depth of water applied to each crop was approximately the same as applied by the farmers of SCARP areas.

Regression analysis:

The data collected to date was analyzed using different regression models. The regression models with different variables used are detailed below:

A. Variables for regression analysis

1) Independent variables

X_1	TDS	(Total Dissolved Solids)
X_2	SAR	(Sodium Absorption Ratio)
X_3	RSC	(Residual Sodium Carbonate)
X_4	Adj. SAR	(Adjusted Sodium Adsorption Ratio)*
X_5	Pre. SAR	(Predicted Sodium Adsorption Ratio)**
X_6	Ca/Mb	(Calcium/magnesium ratio)

Square Terms		Interactions	
X_7	$(x_1)^2$	X_{13}	$(x_1)\ (x_2)$
X_8	$(x_2)^2$	X_{14}	$(x_1)\ (x_3)$
X_9	$(x_3)^2$	X_{15}	$(x_2)\ (x_3)$
X_{10}	$(x_4)^2$	X_{16}	$(x_1)\ (x_4)$
X_{11}	$(x_5)^2$	X_{17}	$(x_1)\ (x_5)$
X_{12}	$(x_6)^2$	X_{18}	$(x_1)\ (x_6)$
		X_{19}	$(x_2)\ (x_6)$
		X_{20}	$(x_4)\ (x_6)$
		X_{21}	$(x_5)\ (x_6)$

*Adjusted sodium adsorption ration (Adj. SAR) is a value calculated based on the amount of tendency for CO_3+HCO_3, present in irrigation water, to dissolve or precipitate $CaCO_3$. Adj. SAR is calculated from the equation:

$$\text{Adj. SAR} = Na/\sqrt{\frac{Ca+Mg}{2}\,(1+(8.4-pHc)}.$$

Na, Ca, Mg are taken from water analysis (in me/l)

pHc is calculated by Langelier's equation which is

$$pHc = (pK_2' - pK_c') + {}_pCa + pALK$$

The last two terms of the equation are the negative logrithms of the molal concentration of C_a and of the equivalent concentration of titrable base ($CO_3 + HCO_3$), respectively while pK_2 and pK_c' are the negative logrithms of the second dissociation constant for H_2CO_3 and the solubility of $CaCO_3$, respectively, both corrected for ionic strength. (ref. L.C. Wilcox, U.S. Salinity Laboratory, Mimeo., Dec. 30, 1966.)

**Predicted sodium adsorption ratio (Pre. SAR) is a calculated value based on the assumption that equilibrium has reached in the soil when irrigated with a given quality irrigation water. This equilibrium calculation is based on the activities of the various ions involved and the equilibrium constants of the salts and ion pairs that can be formed. It was calculated using a computer program developed by Rai and Franklin (1973). The values used in our initial analysis assumed atmospheric CO_2 partial pressure $(3x10)^{-4}$ and that no concentration occurred in the profile. (ref. Dhanpat Rai and William T. Franklin, "Program for Computing Equilibrium Solution Composition in $CaCO_3$ and $CaSO_4$ Systems from Irrigation Water Compositions. Colorado State University, Fort Collins, Colorado, October 1973. Water Management Technical Report No. 29.)

2) Dependent variables

These are 9 in number and range from Y_1 - Y_9.

a) Electrical conductivity on the saturation extract. (ECe) = Y_1 - Y_4 for 4 depths i.e., D_1 - D_4 (0-15, 15-30, 30-60 and 60-105 cm).

b) Sodium adsorption ratio (SAR) Y_5 - Y_8 for 4 depths i.e., D_1 - D_4 (0-15, 15-30, 30-60 and 60-105 cm).

c) Y_9 - yield of individual crops.

B. Regression models

Model I $Y_i = bo + b_1 x_1 + b_2x_2 + b_3x_7 + b_4x_8 + b_5x_{13}$

Model II $Y_i = bo + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_7 + b_5x_8 + b_6x_9 + b_7x_{13} + b_8x_{14} + b_9x_{15}$

Model III $Y_i = bo + b_1x_1 + b_2x_4 + b_3x_7 + b_4x_{10} + b_5x_{16}$

Model IV $Y_i = bo + b_1x_1 + b_2x_5 + b_3x_7 + b_4x_{11} + b_5x_{17}$

Model V $Y_i = bo + b_1x_1 + b_2x_2 + b_3x_6 + b_4x_7 + b_5x_8 + b_6x_{12} + b_7x_{13} + b_8x_{18} + b_9x_{19}$

Model VI $Y_i = bo + b_1x_1 + b_2x_4 + b_3x_6 + b_4x_7 + b_5x_{10} + b_6x_{12} + b_7x_{16} + b_8x_{18} + b_9x_{20}$

Model VII $Y_i = bo + b_1x_1 + b_2x_5 + b_3x_6 + b_4x_{11} + b_6x_{12} + b_7x_{17} + b_8x_{18} + b_9x_{21}$

where bo = y-intercept when x_i-x_n independent variables are equal to zero(0).

b_1-b_9 = regression coefficients.

Out of these, the first four models were used to determine the effect of TDS, SAR and RSC on soil physico-chemical properties. The original design only provides for the TDS, SAR and RSC variables. However, the salts used to attain the desired values of TDS, SAR and RSC resulted in some rather wide fluctuations in Ca/Mg ratio. A preliminary examination indicated that this parameter may have been affecting wheat yields, it was included as an independent variable in the models V, VI, and VII which were used to evaluate the yield data in addition to models I - IV.

Initial results were reported by Qayyum and Sabir (1975)*. The present report reflects later data and additional statistical analysis.

RESULTS AND DISCUSSION

I. Effect on ECe and SAR of the soils

A computer analysis was run on ECe and SAR of the medium soil using first four regression models. Correlation, Coefficient (R) and Coefficient of determination (R^2) were determined by this analysis and are given in Table 2. The R^2 values x 100 gives the percent of the variation of the dependent variable that can be accounted for by the regression on the particular set of independent variables included in that model. In interpreting the R^2 values given in Table 2 we find it convenient to use model I which contains only terms in TDS and SAR as a reference. The percentage of variability in soil ECe and SAR accounted for by the effect of water TDS and SAR (model I) varies from 28-88 but after the first crop most of the values exceeded 50 percent. The R^2 values for predicting soil SAR were consistently higher than those for predicting ECe. The predictability among depths was quite varied but it appears that the prediction of the deeper values improved with time.

*Muhammad A. Qayyum and M. Fazil Sabir. "Criteria for irrigation water quality," presented at the CENTO Panel Meeting on Soil Salinity and Water Quality, Lyallpur, March 3-5, 1975.

Table 2. Coefficient of determination for the four regression models relating water quality parameters to the ECe and SAR of the soil.

Model	Depth	Berseem		Maize		Wheat	
		$ECex10^3$	SAR	$ECex10^3$	SAR	$ECex10^3$	SAR
I	1	0.281	0.514	0.301	0.804	0.318	0.480
	2	0.341	0.451	0.572	0.838	0.317	0.511
	3	0.416	0.440	0.810	0.881	0.534	0.599
	4	0.291	0.345	0.669	0.838	0.838	0.721
II	1	0.348	0.545	0.401	0.834	0.466	0.571
	2	0.379	0.546	0.635	0.880	0.423	0.540
	3	0.448	0.528	0.844	0.912	0.591	0.605
	4	0.342	0.344	0.683	0.849	0.764	0.696
III	1	0.249	0.441	0.325	0.663	0.321	0.354
	2	0.232	0.504	0.514	0.672	0.337	0.438
	3	0.272	0.609	0.721	0.750	0.524	0.457
	4	0.140	0.133	0.598	0.737	0.752	0.546
IV	1	0.219	0.490	0.247	0.547	0.590	0.554
	2	0.268	0.398	0.358	0.547	0.415	0.582
	3	0.273	0.604	0.601	0.662	0.366	0.426
	4	0.030	0.091	0.435	0.721	0.511	0.555

The comparison involving models I, III and IV can be made from the R^2 values as these models contain the same number of degrees of freedom. Models III and IV differ from model I in that the water SAR values in model I have been replaced by Adjusted SAR values in model III and predicted SAR in model IV. If R^2 values for individual depths and crops in models III and IV are compared with those in model I we find that in almost every case the model I R^2 values are higher. This shows that the use of Adjusted or Predicted SAR in place of the usual water SAR does not improve the prediction of the effect on the soil. Thus, these results do not support the simple substitution of the Adjusted SAR nor the Predicted SAR as Calculated here for the usual SAR values in evaluating water quality.

Comparisons involving model II cannot be made by use of R^2 values as model II contains the same terms as model I plus additional terms including RSC so the R^2 of model II will always be higher than model I even though prediction may actually be poorer. We must therefore, compare these variables on the basis of standard error of estimates (SEE) as shown in Table 3. The lower the standard error of estimate, the better the prediction. We see that model I has consistantly lower SEE values than model II. Thus, prediction of the effect of water on soil characteristics does not improve when RSC is included in addition to EC and SAR. Therefore, these data do not support the inclusion of RSC among the parameters used to evaluate water quality.

Further the indifidual correlation coefficient (not shown) show that SAR of water is more closely related to the final ECe and SAR of the soil than is TDS of the water. ECe and SAR of the soils are more highly correlated under the maize than under either berseem or wheat. The reason for the decline in correlation between the maize and wheat crop is not known.

II. Effect on Wheat (grain) and Berseem (green fodder)

The data is given in Table 4.

Table 4. R^2 and see values for the seven regression models relating water quality parameters to wheat (grain) and berseem (green fodder) yield.

Crop	Statistical value	Models I	II	III	IV	V	VI	VII
Wheat	R^2*	0.493	0.613	0.520	0.520	0.354	0.757	0.733
	SEE** (gm/pot)	50.7	48.7	49.4	57.4	38.9	38.6	40.5
Berseem	R^2	0.177	0.355	0.186	0.117	0.340	0.320	0.282
	SEE (gm/pot)	403.6	393.3	401.6	418.3	397.7	403.7	414.9

*R^2 = Coefficient of determination.
**SEE = Standard error of estimate.

Table 3. Standard error of estimate (SEE) for the four regression models relating water quality parameters to the ECe and SAR of the soil.

Model	Depth	Berseem		Maize		Wheat	
		$ECex10^3$	SAR	$ECex10^3$	SAR	$ECex10^3$	SAR
I	1	1.08	2.83	0.396	1.17	1.01	2.48
	2	0.46	2.04	0.366	1.17	0.90	2.20
	3	0.57	2.54	0.268	0.86	0.69	2.08
	4	1.22	2.54	0.377	0.98	0.67	1.73
II	1	1.14	3.01	0.403	1.19	0.98	2.49
	2	0.49	2.04	0.372	1.10	0.91	2.35
	3	0.61	2.57	0.268	0.82	0.67	2.27
	4	1.29	2.60	0.406	1.05	0.68	1.89
III	1	1.11	3.03	0.389	1.53	1.01	2.78
	2	0.50	1.94	0.390	1.66	0.89	2.35
	3	0.63	2.12	0.326	1.25	0.69	2.42
	4	1.34	2.72	0.416	1.25	0.63	2.11
IV	1	1.13	2.89	0.410	1.78	0.78	2.31
	2	0.49	2.15	0.449	1.95	0.84	2.03
	3	0.63	2.14	0.389	1.45	0.80	2.49
	4	1.42	2.79	0.493	1.29	0.89	2.08

The regression of wheat grain yields on water quality parameters was generally highly significant. The Standard Error of Estimate decreased slightly when RSC terms were included as compared to only TDS and SAR (model II compared to model I). However, the improvement due to RSC was not significant ($F(4.9) = 1.48$). The models V, VI and VII which included in term Ca/Mg ratio were much better predictors of wheat yield. The results indicate that high magnesium levels were highly detrimental to wheat in this experiment and this effect must be considered in addition to the several soil salinity factors if high water magnesium levels are encountered. Models VI and VII differ from models V in the substitution of Adjusted and Predicted SAR respectively for simple water SAR. Here again there is no evidence that use of these values improve prediction.

The effect on berseem yields was not significant. Whether this is due to the tolerance of the crop or the fact that berseem was the first crop grown so that the effects were not yet severe is not known. Analysis of the later data sets should clarify this point.

III. Effect of CO_2 Partial Pressures on Predicted SAR of Soil

Predicted SAR of the soil was calculated using different CO_2 partial pressures. Plots of predicted SAR viz water SAR for atmospheric partial pressure ($3x10^{-4}$ atmosphere) and 100 times atmospheric CO_2 and are shown in Figure 1. It appears that predicted SAR changes very little with increased CO_2 partial pressure when water SAR is low, but at high water SAR the predicted SAR is much lower at high CO_2 partial pressure. We would expect that the SAR of the soil and predicted SAR would be the same if the correct concentration factor and CO_2 partial pressures were assumed in calculation of predicted SAR. Thus, with the correct concentration factor and CO_2 partial pressure a plot of soil SAR viz predicted SAR would give a 1:1 slope with zero intercept.

In this experiment when water SAR was low the resulting SAR of the soil was higher than the water SAR as shown by the positive intercept in Figure 2. In soils the solution concentration increases from that of the water due to evapotranspiration. This concentration increase tends to result in increased SAR. However, CO_2 concentration in the soil tends to be higher than atmosphere CO_2 partial pressure resulting in decreased SAR due to solubilization of $CaCO_3$. The effect of increased CO_2 concentration on the relationship between water SAR and predicted SAR is shown in Figure 1. It appears that in our experiment these two factors are roughly cancelling each other and the equilibrium SAR obtained by the soil is roughly equal to the SAR of the water as shown in Figure 2.

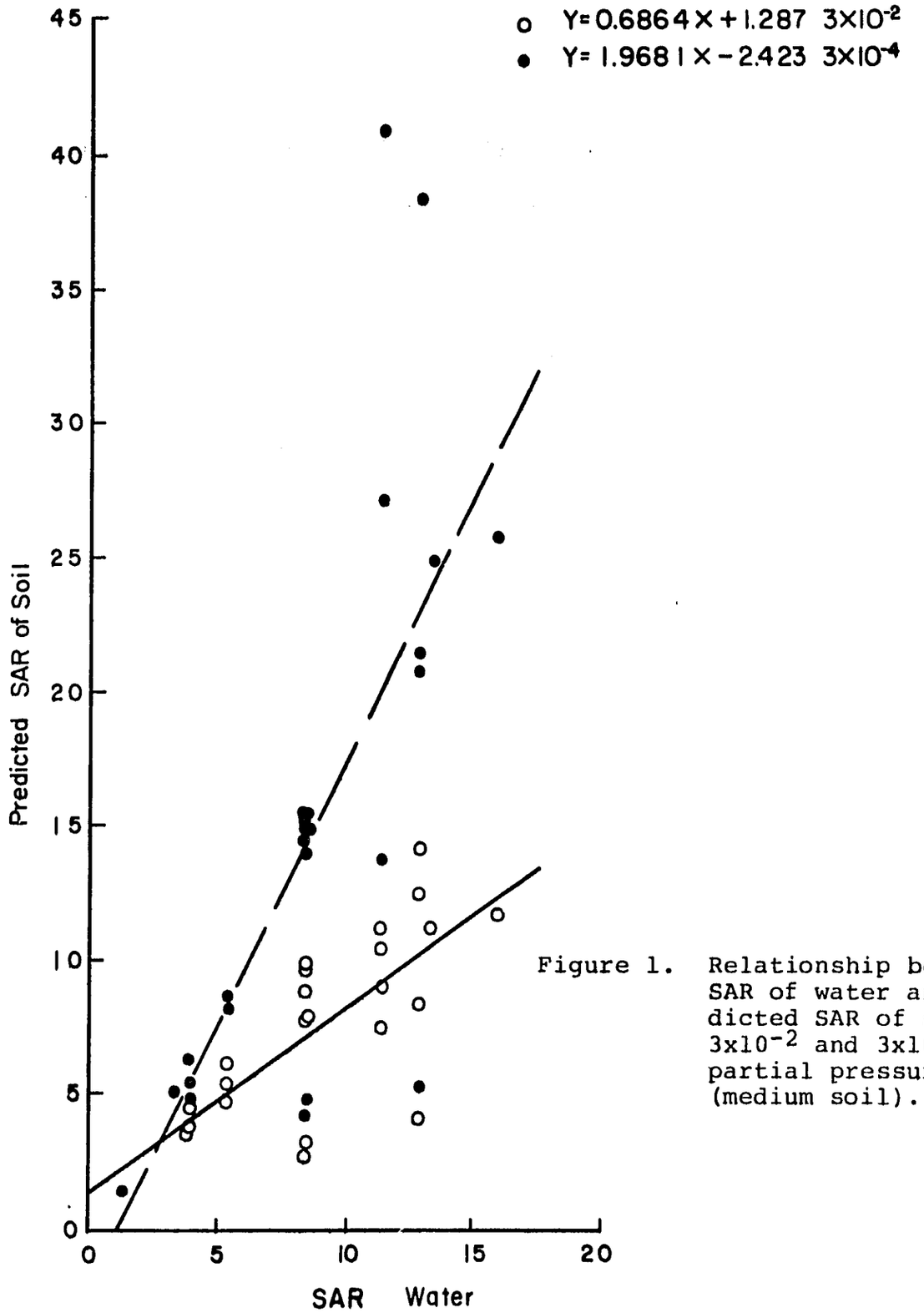

Figure 1. Relationship between SAR of water and predicted SAR of soil at $3x10^{-2}$ and $3x10^{-4}$ CO_2 partial pressure (medium soil).

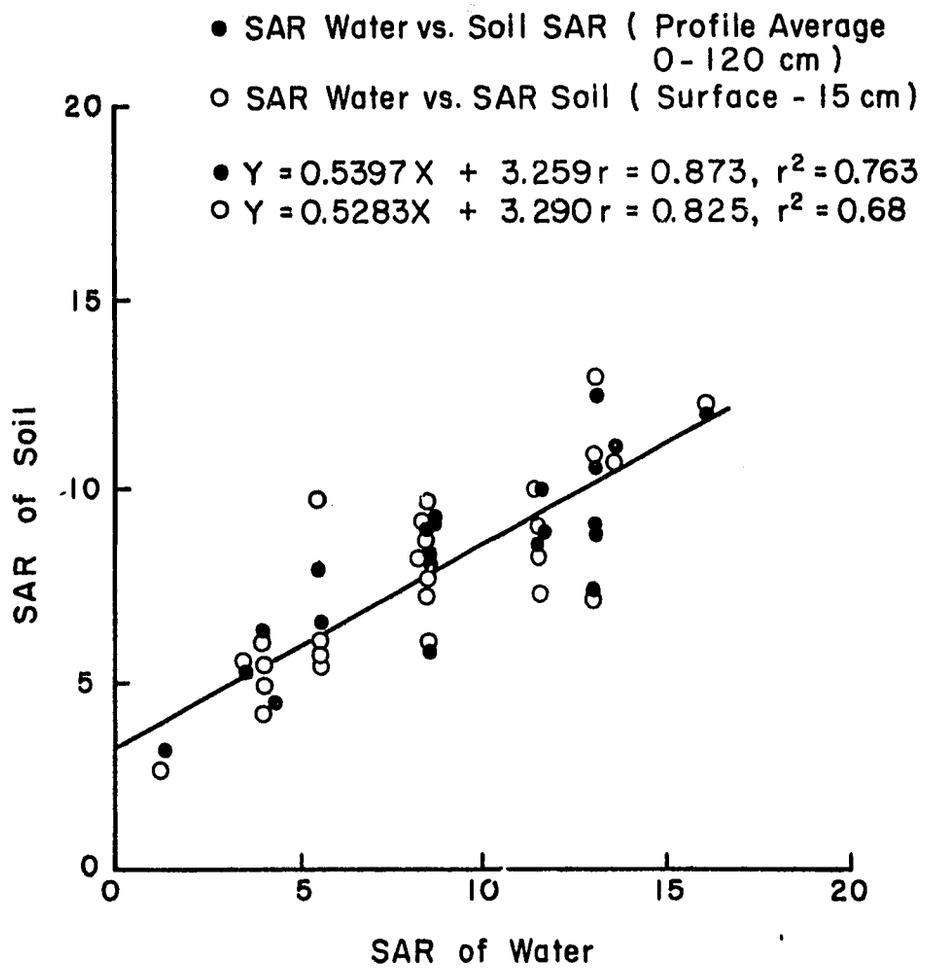

Figure 2. Relationship between SAR of water and SAR of soil (medium soil).

It also appears using predicted SAR as an independent variable rather than water SAR is not improving the prediction because

(a) these predicted SARS were calculated at atmospheric CO_2 partial pressure which is probably lower than that in the soil, and

(b) the concentration factor is not taken into account. It is possible that predicted SAR would be a better predictor of equilibrium soil SAR if the concentration factor and CO_2 partial pressure can be estimated.

Appendix 36

CROP YIELDS AND RATE OF SALINIZATION OF SOIL AS AFFECTED BY IRRIGATION WATER QUALITY OVER A PERIOD OF THREE YEARS[1]

C.J. deMooy, H.M. Bhatti, M.A. Cheema, M.R. Gill
M. Khalid, M. Rafiq, and W.T. Franklin[2]

Abstract

A field experiment with four water qualities and three leaching fractions in factorial combination was conducted for three years to relate crop yields to soil chemical conditions. It was found that the poorest water quality used converted the soil into a saline/alkali soil to a depth of approximately 12 inches. Noticeable increases in salt concentrations occurred to fully 5 feet depth and some raise in alkali to a depth of 2 feet. Under these conditions, yield losses of berseem and other fodder crops amounted to 25 to 29 percent. The salinity and sodium adsorption ratio of the soil were roughly linearly related to the quality of the irrigation water used and lend themselves to quantitative interpretation. Neither yield losses nor chemical deterioration showed a progressive trend despite continual input of salts with the irrigation water. This suggested that the environment exerted a balancing effect at least temporarily and under the conditions of the experiment.

Irrigation with saline tubewell waters has caused great problems to farmers, yet it is unavoidable in many instances. No damaging effects may be found at first, but slowly the soil becomes hard, the chemical conditions change and crop yields are reduced. Standards of quality for irrigation water and accompanying recommendations for agricultural practices how to manage marginal soil and water conditions are very much needed in Pakistan. These standards

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[1]Paper presented at the International Conference on Waterlogging and Salinity Sponsored by the Department of Civil Engineering, University of Engineering & Technology, Lahore, October 13-16, 1975.

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must be derived for local climatic and other factors and compared with those defined in the U.S.A. and elsewhere.[1]

The present paper reports experimental findings on the gradual deterioration of soil and the loss in yield occurring from long continued use of several different water qualities.

Methods and Materials

A 4 x 3 factorial water quality experiment was laid out at the Punjab Agricultural Research Institute in 1971 on non-saline, nonalkali soil of medium texture. Four water qualitie were used containing 175, 1000, 2000, and 2700 ppm total soluble salts (TDS), respectively. Canal water was used for the low salt treatment and pure tubewell water for the high salt treatment. The two intermediate qualities were obtained by mixing of tubewell and canal water. A mixing tank and cement ducts for delivery of the water to the plots were available. The tubewell water composition remained unaltered at 2700 ppm TDS, 15 SAR, and 3.5 RSC[2] over the three year period. Three leaching fractions were maintained for each water quality (Table 1). The field layout was a split plot design with water quality as main plots and leaching fractions as subplots. Subplot size was approximately 25 x 90 feet. There were 3 replications. The field was leveled. Optimum management and fertilizer practices were used.

Table 1. Leaching fractions used in water quality experiment, PARI, Lyallpur, 1971.

	Total soluble salts (ppm)			
	175	1000	2000	2700
Leaching fraction (LF)	0	10	15	30
	10	20	30	45
	20	30	45	60

The plots were irrigated when approximately 25 percent of the available moisture remained in the surface 12 inches of soil as indicated by soil moisture sampling in the canal water plots but taking into account weather conditions and timing of agricultural operations. The quantity of irrigation water to be applied was calculated from the moisture deficit of the soil profile compared with field capacity. Soil moisture sampling was carried out to a depth of 60 inches for this purpose before each irrigation. The leaching fraction was added to the amount of water calculated.

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[1] U.S. Salinity Laboratory. 1955. Diagnosis and improvement of saline/alkali soils. U.S.D.A. Handbook No. 60.

[2] SAR - sodium adsorption ratio; RSC - residual sodium carbonate.

Soil samples for chemical analysis were collected from all plots after the crop was harvested. The samples were taken from 0 to 6, 6 to 12, 12 to 24, 24 to 36, 36 to 48 and 48 to 60 inches. Chemical analysis included pH, electrical conductivity and Cl^-, SO_4^{--}, HCO_3^-, CO_3^{--}, Ca^{++} plus Mg^{++}, and Na^+ content of the saturation extract.

Crop yields were measured over the entire plot area with the exception of a 2-foot area all around to avoid border effects. The cropping sequence was wheat, rabi 1971-72, sorghum, maize, and bajra fodder, kharif 1972; berseem, rabi 1972-73; cotton, kharif 1973; wheat, rabi 1973-74, fodder, kharif 1974.

Results and Discussion

The crop yields obtained are presented in Table 2. The wheat yield of the first crop, wheat, was not affected by either water quality or leaching fraction. Inspection of the data in Table 2 indicates very little effect from the leaching fractions applied and the differences were not statistically significant. Later, it was found that the rate of water infiltration was greatly reduced on all plots receiving tube-well water. A considerable portion of the additional water applied for leaching may have evaporated.

The mean crop yields are summarized in Table 3 according to water qualities. The use of saline water reduced fodder production by 25 percent in 1972 and 29 percent in 1974. Statistical analysis showed that the water quality effect was significant at the 5 percent probability level. Fodder yields were almost identical in the two years. This is remarkable becuase salt effects would be expected to accumulate over the years. Heavy monsoonal rains during 1973 may have kept soil conditions in balance. Crop yields possibly tend to stabilize depending on climatic and other factors of the natural environment. The current experimentation must be continued to determine long term trends under local conditions.

The cumulative yield of 5 cuttings of berseem was reduced by 25 percent. Apparently summer and winter crops were similarly affected. Cotton yields showed a relatively small effect from salinity but analysis of variance indicated that the differences were significant at the 5 percent probability level. The cotton yielded highest with water of intermediate quality. The growth was too rank with canal water and the added moisture from the monsoonal rains whereas pure tubewell water affected growth and height of the plants too much to permit high yield of seed cotton.

The wheat crop in 1973-74 yielded poorly due to late planting and showed no effects from water quality. The several thousands of soil analyses available are presented

Table 2. Yield of various crops as affected by water quality and leaching fractions at PARI, Lyallpur (maunds/acre).

Water quality (ppm)	LF %	Wheat rabi 1971-72	Fodder kharif 1972	Berseem rabi 1972-73	Cotton kharif 1973	Wheat rabi 1973-74	Fodder kharif 1974
175	0	46.1	515	1032	17.7	16.4	493
	10	45.0	483	1034	18.6	16.0	468
	20	45.6	476	1028	18.2	16.4	515
1000	10	42.0	402	1133	19.7	16.4	426
	20	46.0	386	1040	18.6	11.5	413
	30	46.2	451	1128	19.1	14.8	404
2000	15	46.6	355	1007	19.0	12.7	424
	30	47.7	358	940	19.9	13.0	391
	45	49.2	434	956	19.8	16.2	424
2700	30	50.1	400	709	17.4	17.0	356
	45	46.8	370	691	18.7	13.1	361
	60	45.1	329	819	17.7	15.8	328

Table 3. Yield of various crops as affected by water quality at PARI, Lyallpur (maunds/acre).

Water quality (ppm)	Wheat 1971-72	Fodder 1972	Berseem 1972-73	Cotton 1973	Wheat 1973-74	Fodder 1974
175	45.6	491	1031	18.2	16.3	492
1000	44.7	413	1101	19.1	14.2	414
2000	47.8	382	968	19.6	14.0	413
2700	47.4	366	767	17.9	15.3	348

in summarized form. The distribution in the soil profile of electrical conductivity (EC), Cl^-, SO_4^{--}, Ca^{++} plus Mg^{++} concentrations and sodium adsorption ratio (SAR) of the soil saturation extract was affected by the quality of the irrigation water used (Figures 1 to 5). These values represent means from samples taken after all crops and include all leaching fractions and replications. The EC graphs show that the surface layer of the profile changed from a nonsaline to a saline soil (Figure 1) according to the standards set by the U.S. Salinity Laboratory. Similarly, the graphs of SAR indicate change from a nonalkali to alkali soil to a depth of 12 inches (Figure 5). The salts penetrated to a depth of at least 48 inches judging from the EC and sulfate ion contents. The chloride distribution suggests that also the fifth foot of soil had been affected (Figure 2). Ca^{++} and Mg^{++} were relatively low in the surface 12 inches and may have accumulated to some extent in the second and third foot below the surface when saline waters were used (Figure 4). The SAR of the soil increased significantly to at least 24 inches below the surface of the land. It may therefore be concluded that the soil was extensively damaged, chemically speaking, by the use of saline tubewell water.

The chemical characteristics of the soil after individual crops were compared by plotting the means for the values from 0 to 24 inches (Figures 6 to 10). The cropping sequence was wheat, fodder, berseem, cotton. The graphs for EC, Cl^-, SO_4^{--}, and Ca^{++} plus Mg^{++} suggest small differences only among crops (Figures 6, 7, 8 and 9). As was the case with crop yield, there was little evidence for progressive accumulation of salts with time. All entities were relatively low after the cotton crop which suggests that seasonal factors may tend to exert a balancing influence on the chemistry of the soil at least under the conditions at Lyallpur.

The SAR of the soil showed a different trend compared with the other indicators in that there was considerable build up with time (crops). Also the SAR of the soil decreased after cotton, however, suggesting that heavy monsoons reverted the build up of alkali (Figure 10).

Graphs of the mean values of the five chemical characteristics for all crops and leaching fractions to a depth of 24 inches are shown in Figures 11 to 15. (Leaching fractions did not have a pronounced effect on any soil property.) All indicators showed an approximate linear increase with water quality (TDS). Relating crop yields to the chemical condition of the soil, it is clear that the berseem and fodder crops were growing in saline/alkali soil when irrigated with pure tubewell water (Figures 6, 10, 11 and 15). Under those conditions the yield losses were 25 to 29 percent. Tubewell water diluted with canal water affected crops and soils to a lesser extent. It should be remembered that dilution by

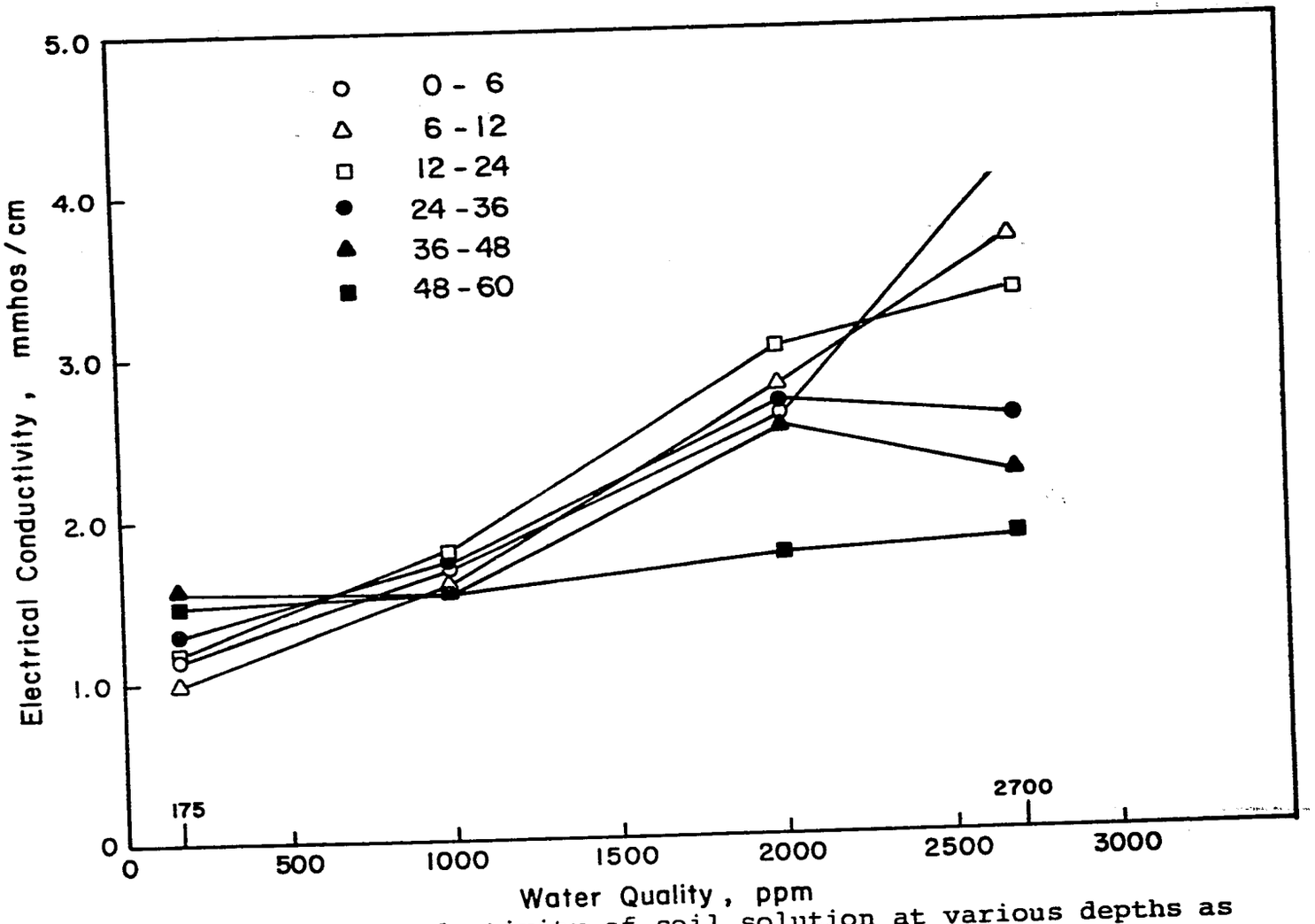

Figure 1. Electrical conductivity of soil solution at various depths as affected by quality of irrigation water, PARI, Lyallpur.

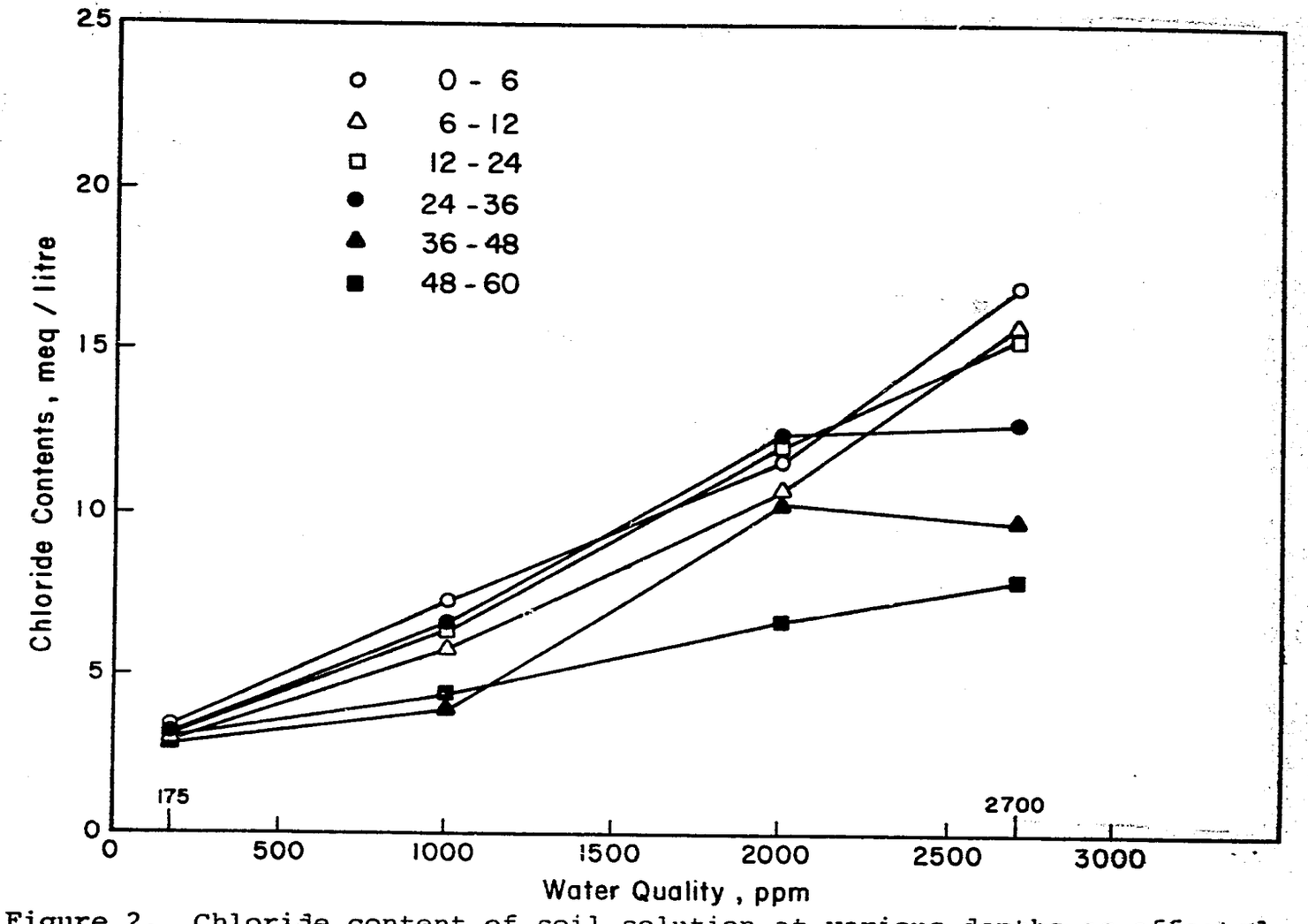

Figure 2. Chloride content of soil solution at various depths as affected by quality of irrigation water, PARI, Lyallpur.

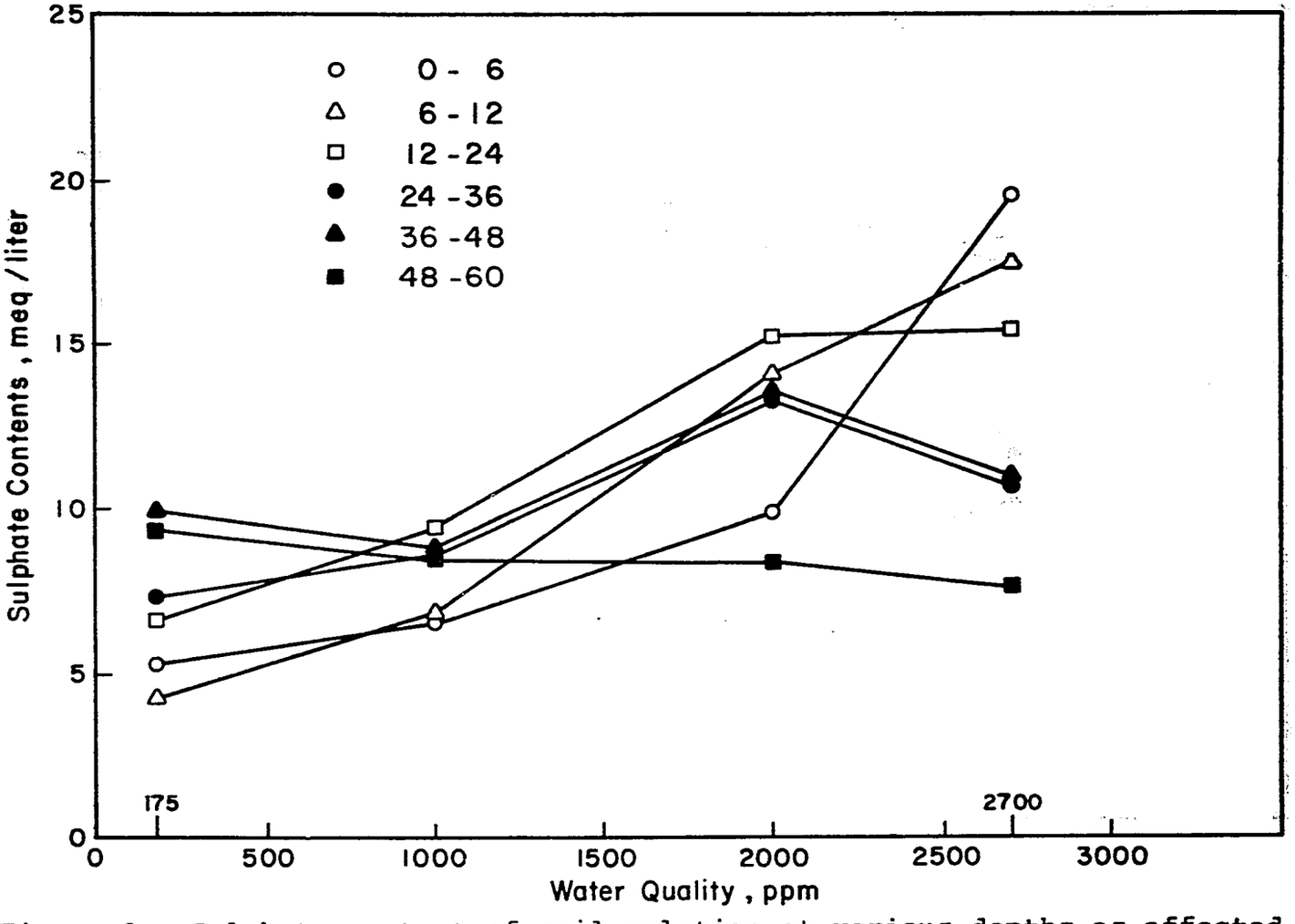

Figure 3. Sulphate content of soil solution at various depths as affected by quality of irrigation water, PARI, Lyallpur.

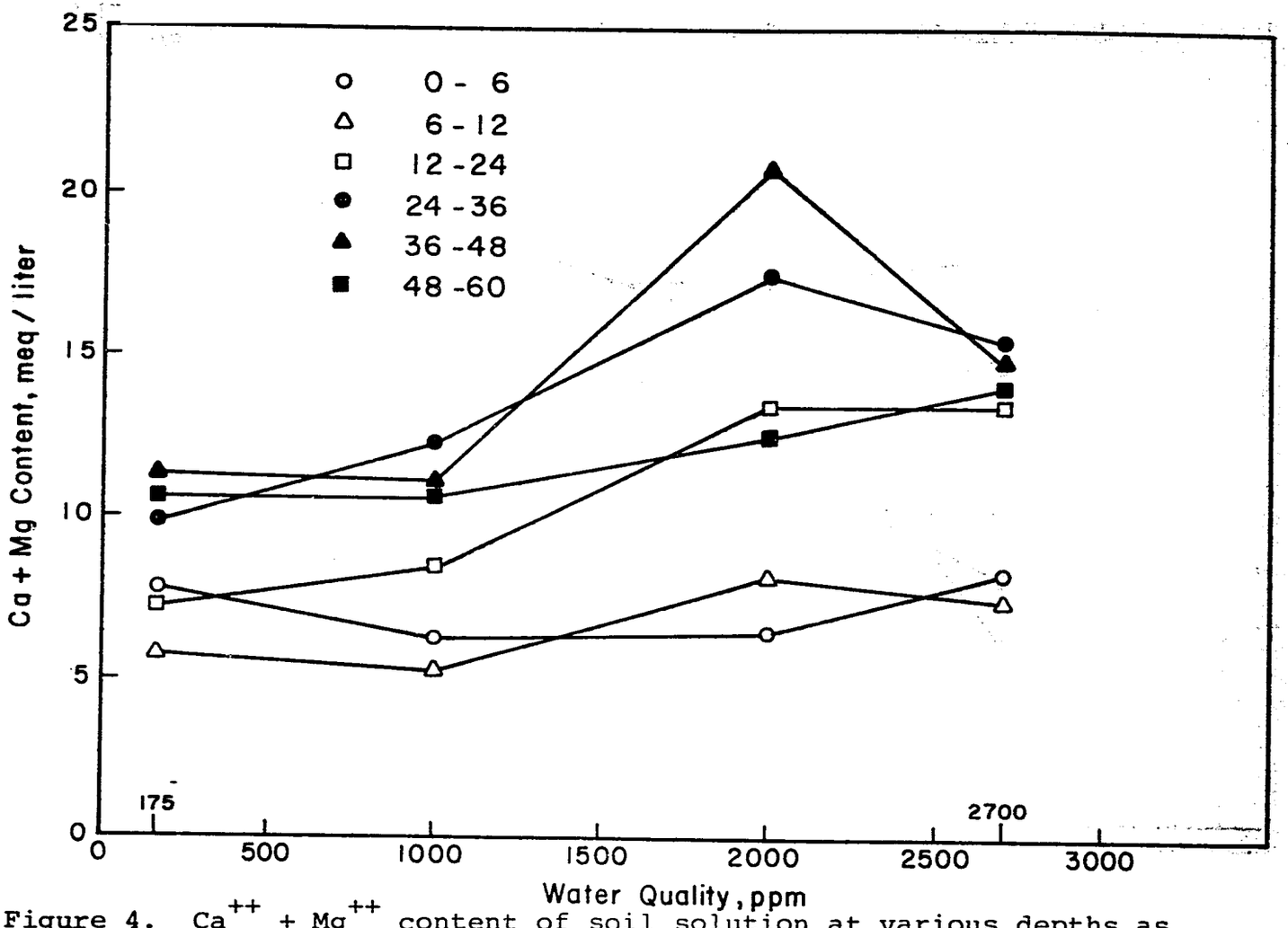

Figure 4. $Ca^{++} + Mg^{++}$ content of soil solution at various depths as affected by quality of irrigation water, PARI, Lyallpur.

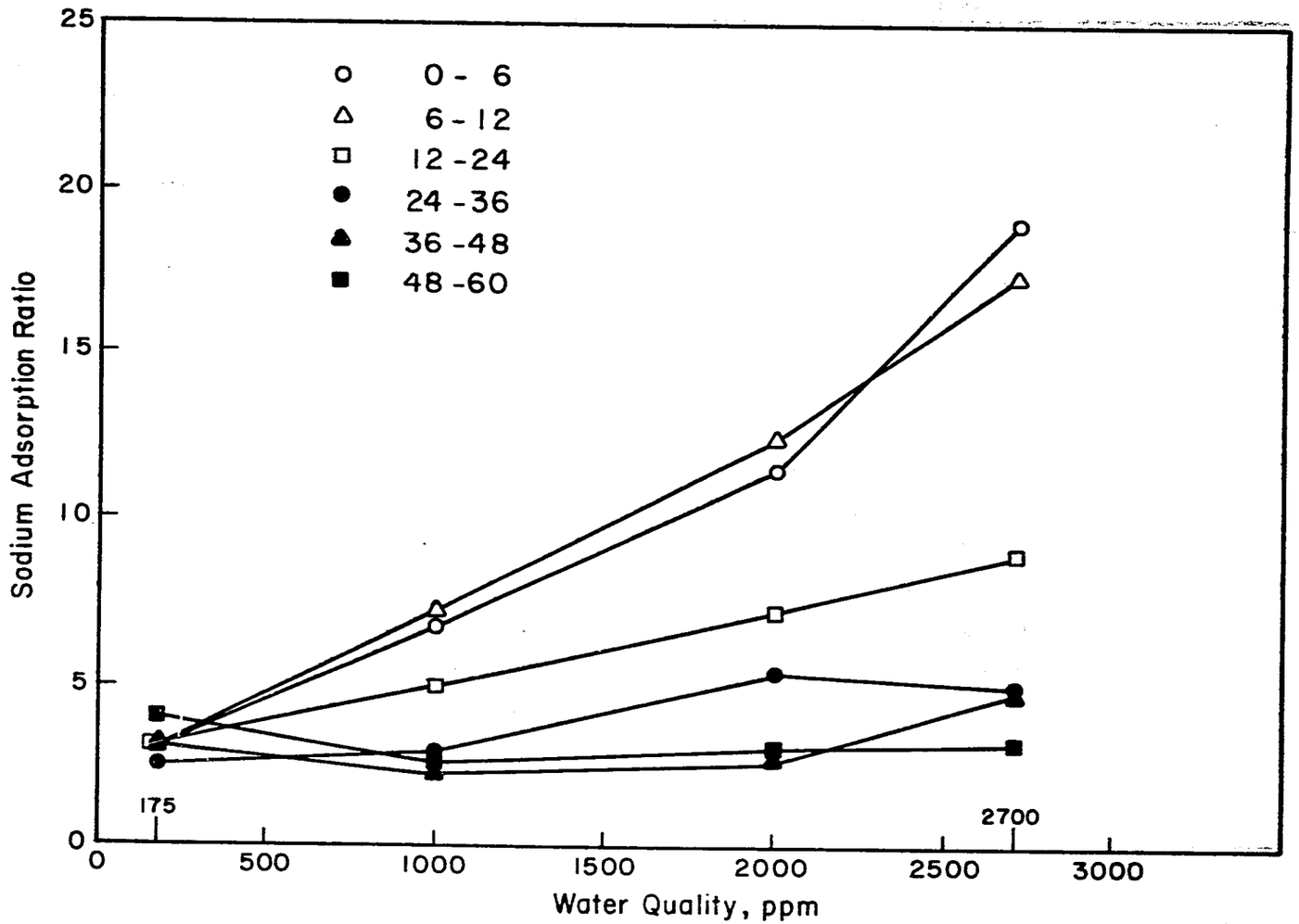

Figure 5. Sodium adsorption ratio of soil solution at various depths as affected by quality of irrigation water, PARI, Lyallpur.

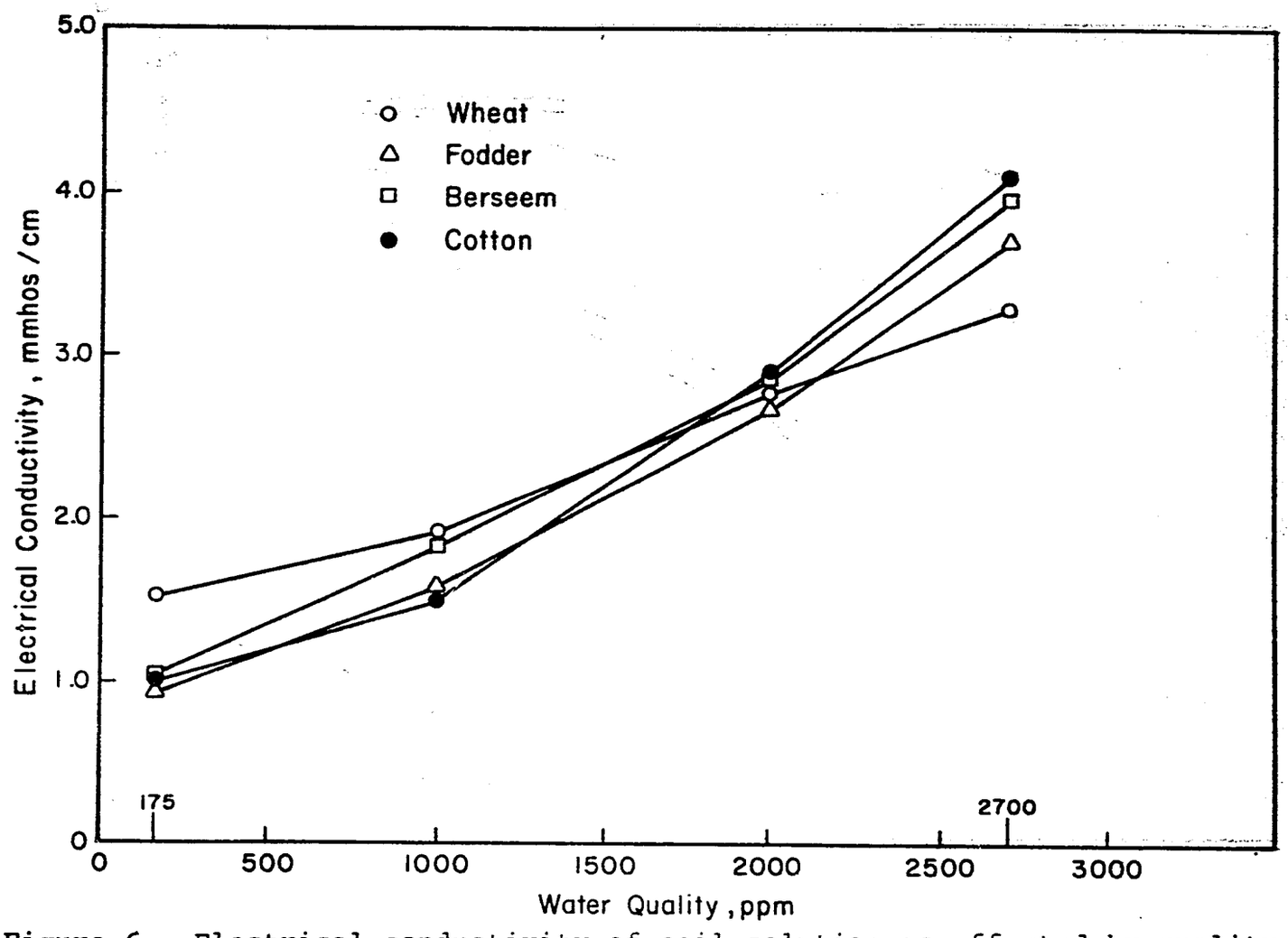

Figure 6. Electrical conductivity of soil solution as affected by quality of irrigation water applied to various crops, PARI, Lyallpur.

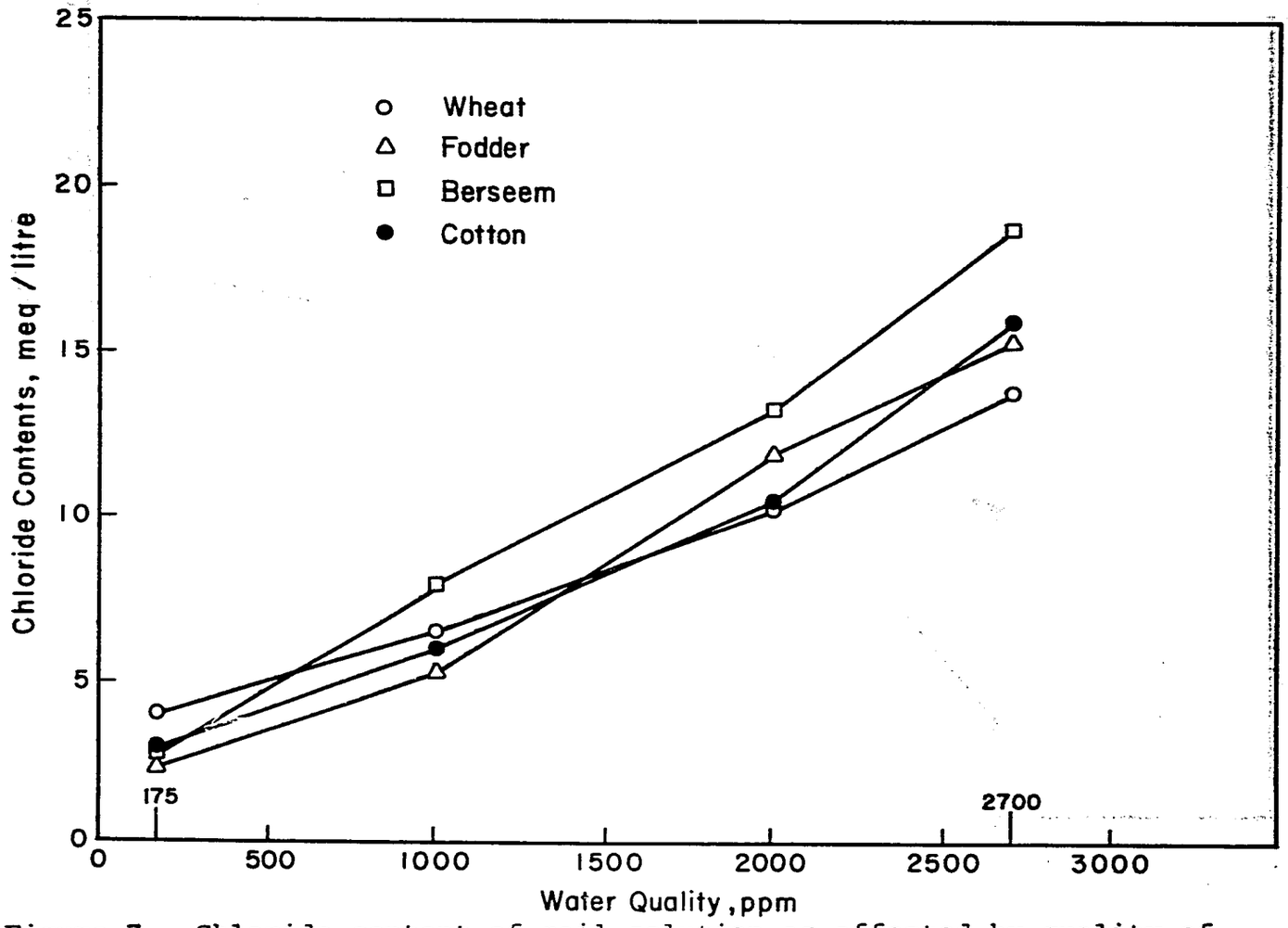

Figure 7. Chloride content of soil solution as affected by quality of irrigation water applied to various crops, PARI, Lyallpur.

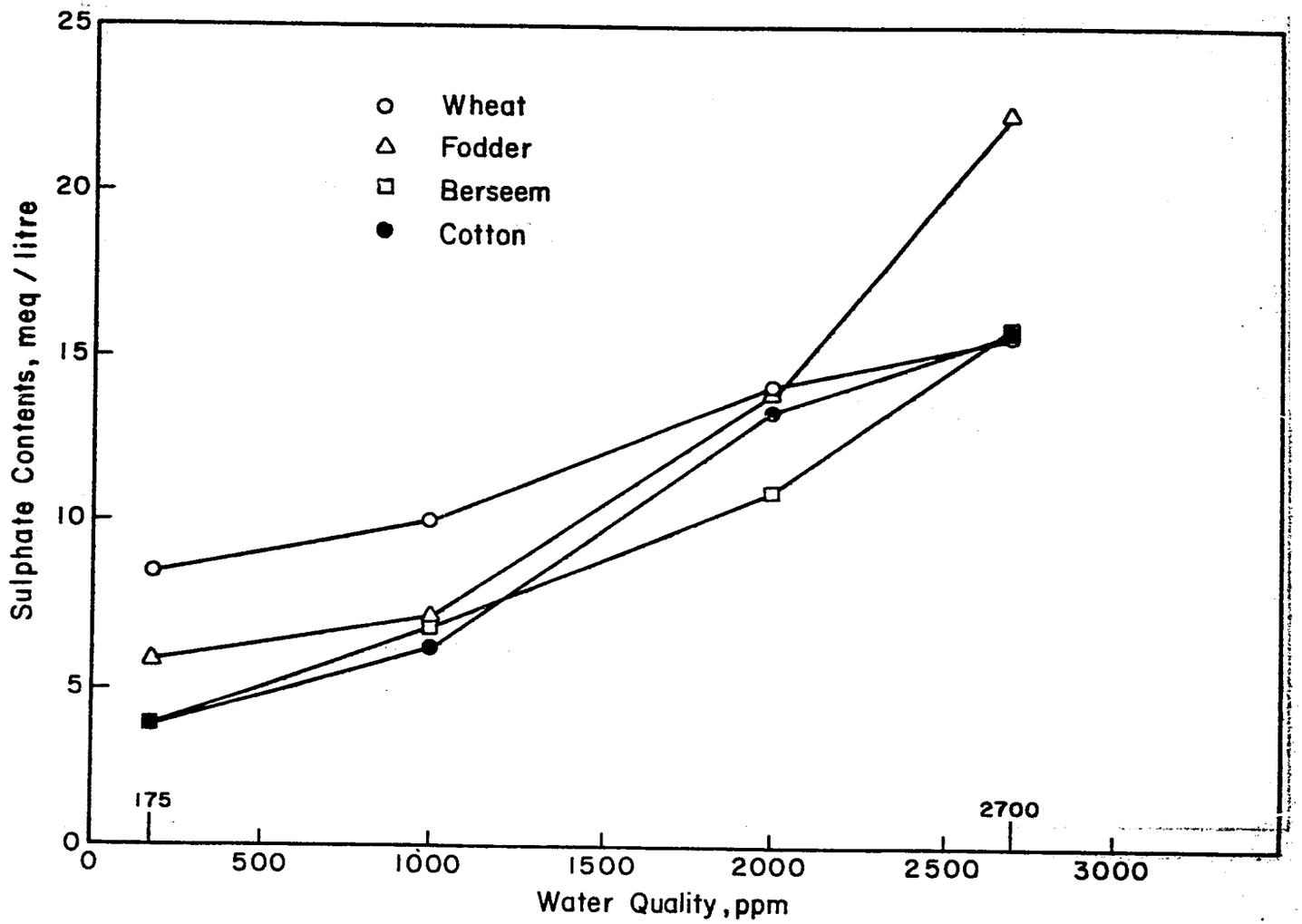

Figure 8. Sulphate content of soil solution as affected by quality of irrigation water applied to various crops, PARI, Lyallpur.

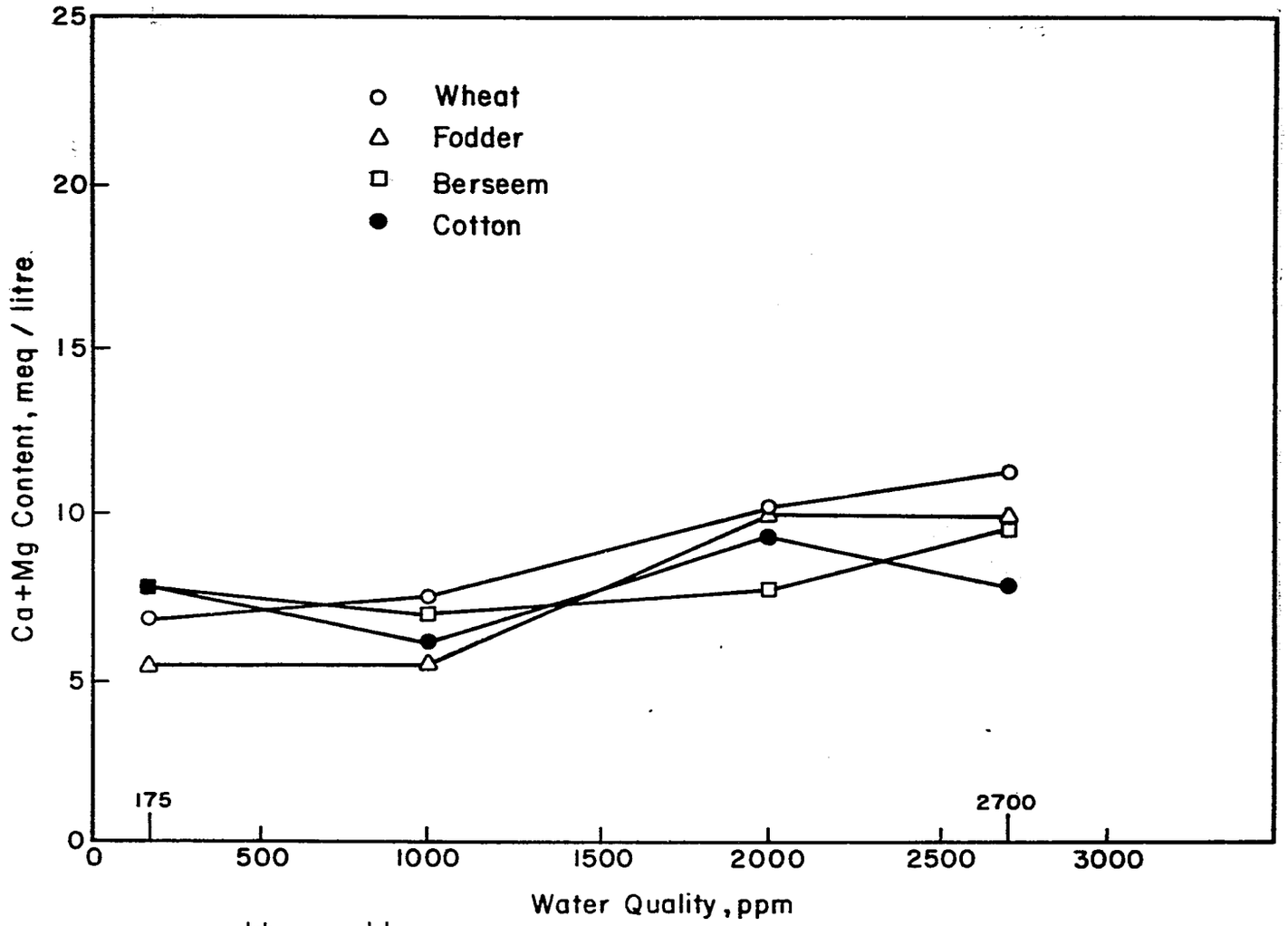

Figure 9. $Ca^{++} + Mg^{++}$ content of soil solution as affected by quality of irrigation water applied to various crops, PARI, Lyallpur.

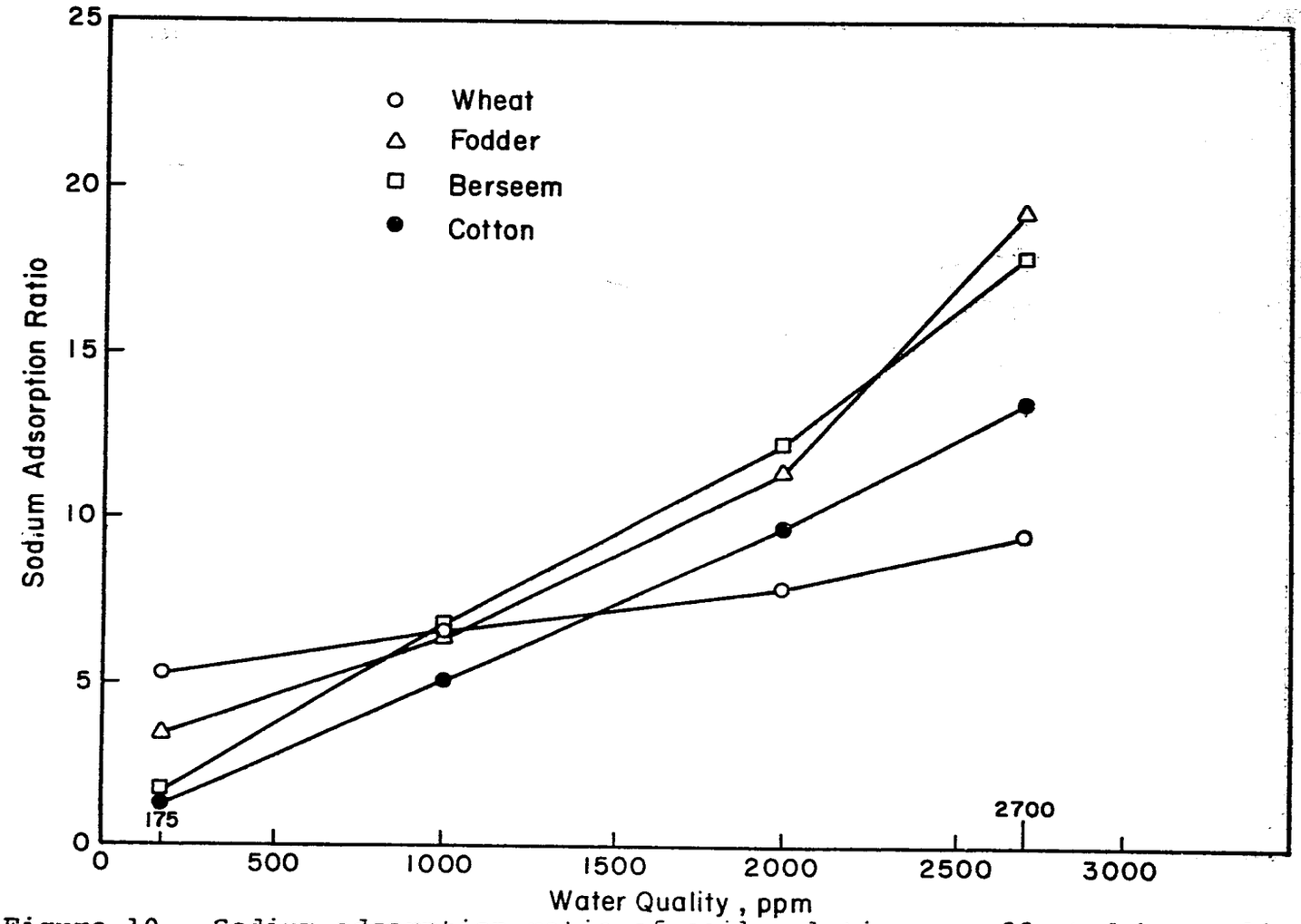

Figure 10. Sodium adsorption ratio of soil solution as affected by quality of irrigation water applied to various crops, PARI, Lyallpur.

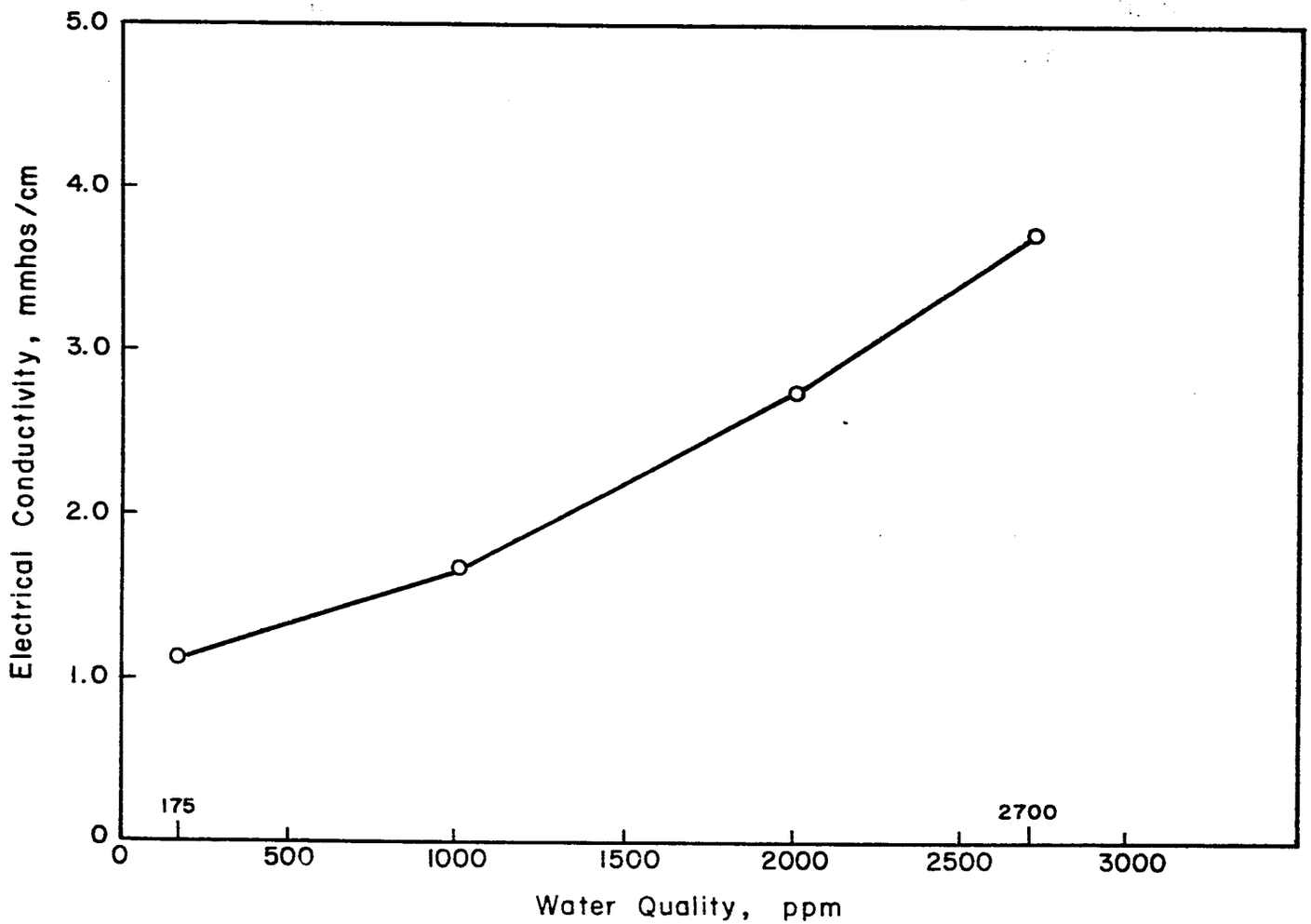

Figure 11. Mean values for electrical conductivity of saturation extract in top 24 inches of soil for wheat, fodder, berseem and cotton as affected by water quality, PARI, Lyallpur.

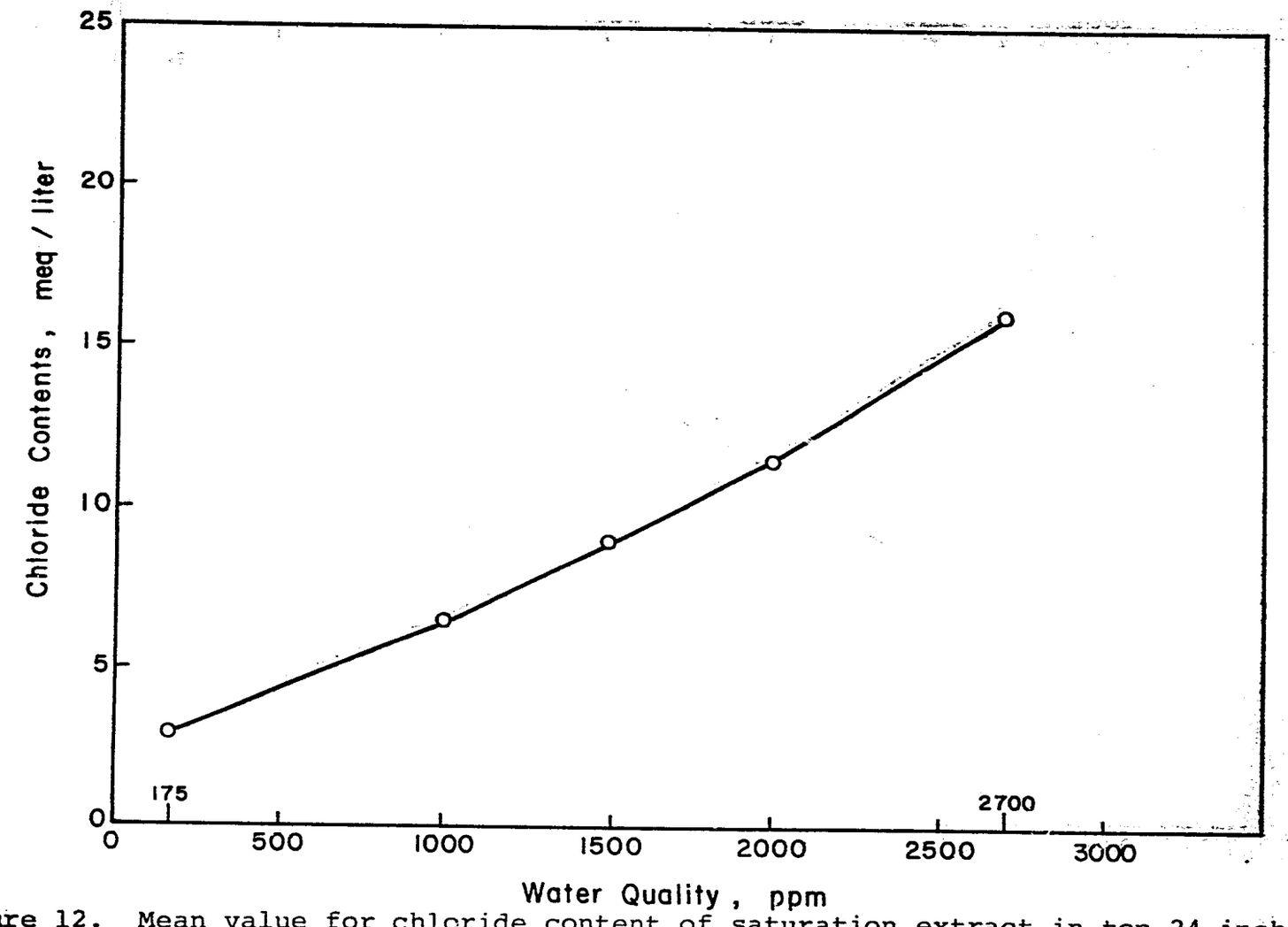

Figure 12. Mean value for chloride content of saturation extract in top 24 inches of soil for wheat, fodder, berseem and cotton as affected by water quality, PARI, Lyallpur.

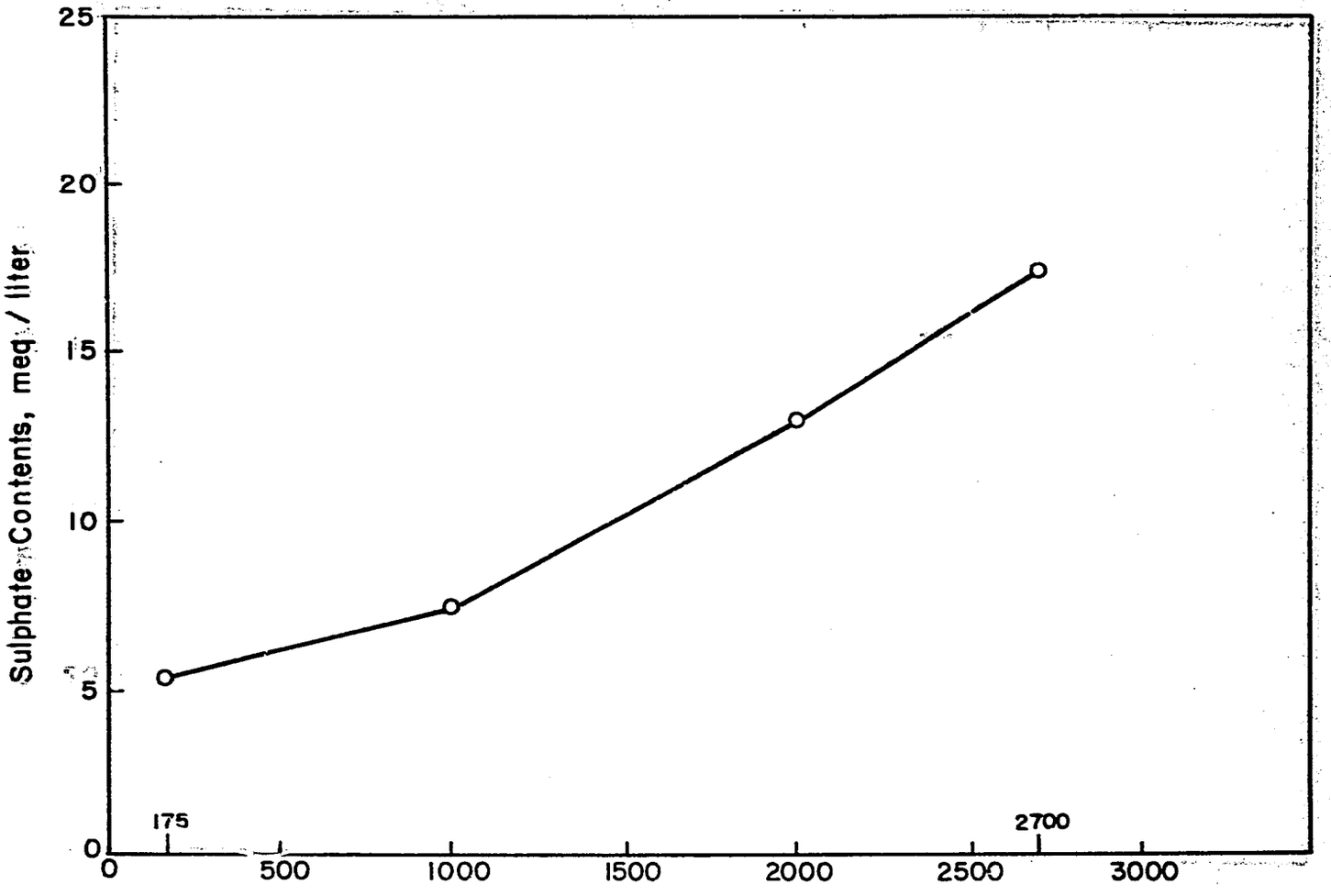

Figure 13. Mean values for sulphate content of saturation extract in top 24 inches of soil for wheat, fodder, berseem and cotton as affected by water quality, PARI, Lyallpur.

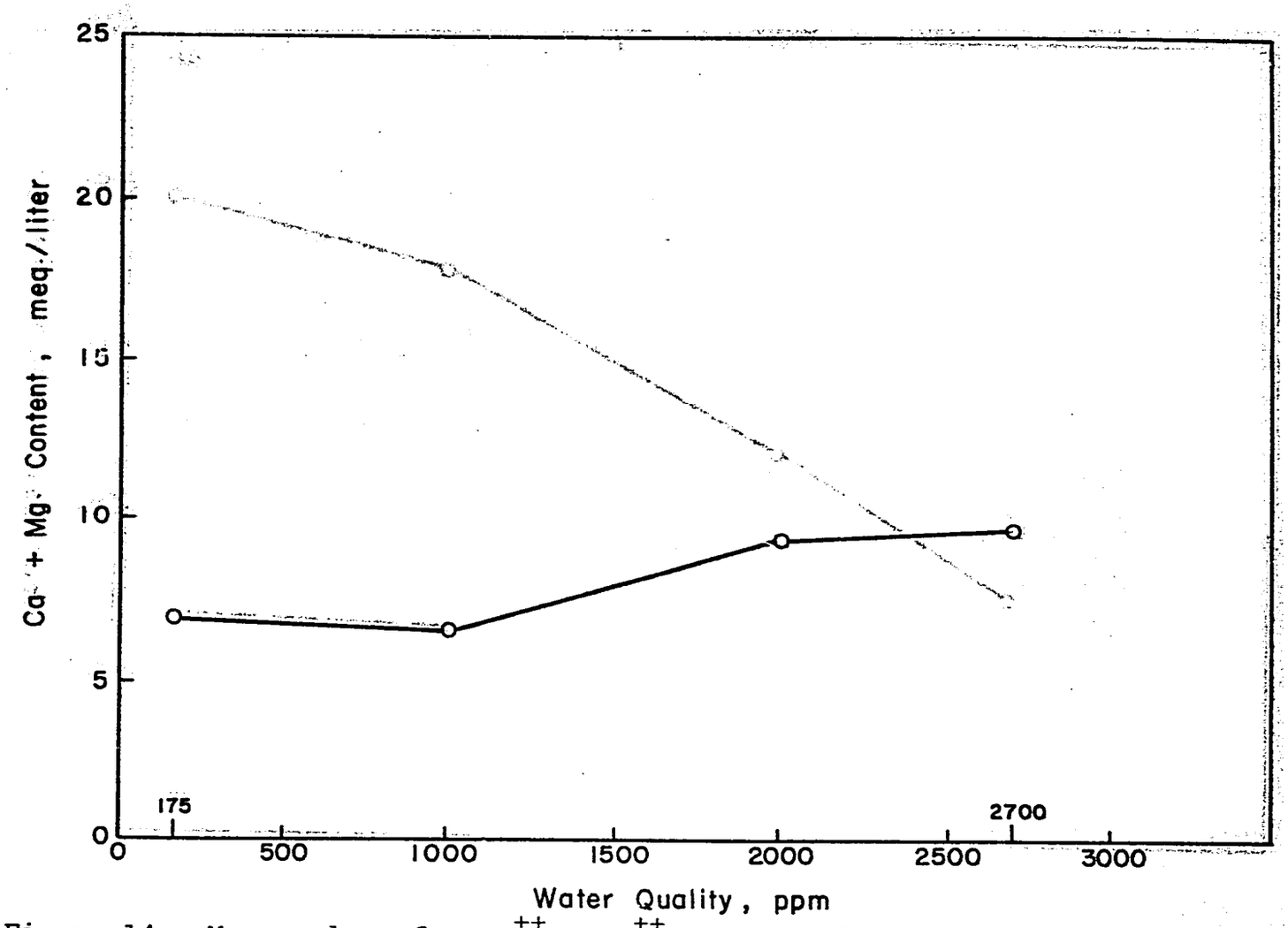

Figure 14. Mean values for ca^{++} + Mg^{++} content of saturation extract in top 24 inches of soil for wheat, fodder, berseem and cotton as affected by water quality, PARI, Lyallpur.

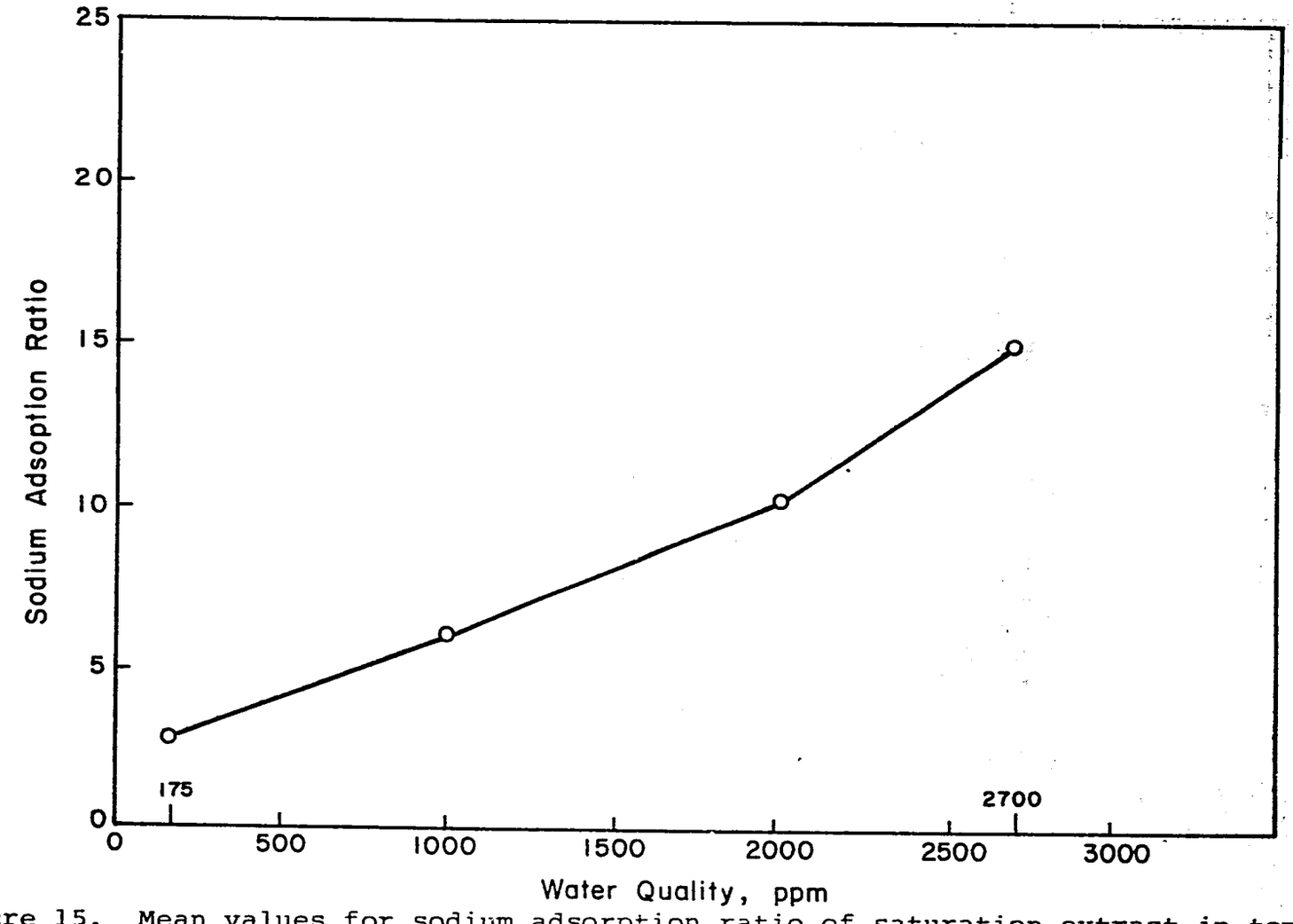

Figure 15. Mean values for sodium adsorption ratio of saturation extract in top 24 inches of soil for wheat, fodder, berseem and cotton as affected by water quality, PARI, Lyallpur.

means of mixing tubewell and canal water reduced both the salt content and the sodium adsorption ratio but the former more so than the latter. When the salt content was halved by a 1:1 dilution, the SAR was simultaneously reduced by a factor of approximately 0.7. The effect of any intermediate soil condition on fodder yield can be derived by intrapolation. Cotton as a deep-rooted crop escaped partially from the most saline and alkali layer of soil. The 24 to 36 inch layer of soil irrigated with tubewell water had a much lower salt content than the upper layers and the rooting zone of cotton extended considerably below that (Figures 1, 2 and 3). The alkali condition was a problem only in the surface 12 inches of soil. A large proportion of the cotton roots extended into deeper layers where the SAR fell to 8 or less (Figure 5). Moreover, the cotton received a large portion of its water requirement from rainfall which was reflected in relatively low salt contents and SAR at the end of the season compared with other crops (Figures 6 and 10). The conditions may have been even more favorable during the actual growing season than was indicated by the chemical data. Therefore, it would be desirable to make more frequent observations on the chemical condition of the soil during the season and to relate crop performance more closely to actual soil conditions.

The current experimentation should be further expanded to include other major crops and a greater variety of conditions for which water quality standards are being sought.

Appendix 37

USE OF GYPSUM STONES TO LOWER THE SODIUM ADSORPTION RATIO OF IRRIGATION WATER[1]

Bashir Ahmad, W.D. Kemper,
Ghulam Haider and M.A. Niazi[2]

Introduction

Many of the ground waters of the Indus basin have a sufficiently high Na^{+}/Ca^{++} ratio to be harmful to soils and crops. When the total salt contents of the tubewell waters are reasonably low the primary method of lowering this ratio is to apply extra Ca^{++} on the fields or in the water. Gypsum ($CaSO_4 \cdot 2H_2O$) is generally the most reasonably priced source of Ca^{++} in the solubility range needed in reclamation of land and amendment of water. Haider et al (1972) showed that use of gypsum in the reclamation of soils was effective, but economically questionable because of the high cost of gypsum. Its cost could be greatly reduced if the farmers could use "pit run" stone of large size (which sells for Rs 25 to 40 per ton at the quarry) rather than the powdered gypsum normally used in reclamation. The cost of powdering is around Rs 80 per ton.

Kemper et al (1975) showed that gypsum fragments less than 2" in diameter could provide all the gypsum desired in water flowing through beds of these fragments.

Inspection of "pit run" gypsum (as broken from the gypsum beds) indicated these stones are more commonly in the 5 to 50 kilogram size and range from about 13 to 30 cm in diameter. The question arose as to whether stones of this size could provide sufficient gypsum to water flowing past them to bring Ca^{++} in tubewell waters up to desired levels.

Haider et al (1974) found that gypsum stones (4 to 7 kilos) on the beds of watercourses lost from 0.10 to 0.15 percent of their weight per hour of exposure to the running water.

Dr. G.R. Sandhu, R.H. Qureshi and M. Hanif of the Nuclear Institute for Agriculture and Biology at Lyallpur

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[1]Research Report from the Mona Reclamation Experimental Project, WAPDA and the Colorado State University Water Management Research Team. Portions of this work were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/Washington Research Contract No. AID/ta-c-1100.

[2]Technical Officer, MREP; CSU Chief of Party; MREP Director of Research and JRO in charge of analysis at MREP, respectively.

have also been experimenting with lining and baffles in watercourses to see what configurations of stones could be used to bring sufficient quantities of gypsum into solution.

Results of both the Haider et al (1974) and Kemper et al (1975) studies could be extrapolated to indicate that water flowing through gypsum stone beds of reasonable length would dissolve as much gypsum as farmers could afford to pay for. The study reported herein was designed to field evaluate the feasibility of this method of application and provide practical guidelines for installations.

Location, Physical Setup and Procedure

Tubewell 91 in the Mona project area pumps water with a total dissolved salt concentration (TDS) of about 1500 ppm, containing about 3.6 meq/liter of Ca^{++} + Mg^{++}, 20 meq/liter of Na^{+} and 622 meq/liter of SO_4^{--}. The sodium adsorption ratio (SAR) of this tubewell water is about 16. This tubewell water is pumped at a rate of 2.2 cusecs (62 liters/sec or 60 "lisecs") and is mixed with about 1.7 cusecs (or 48 lisecs) or canal water which has 2.2 meq/liter of Ca^{++} + Mg^{++} and 0.4 meq/liter of Na^{+}.

The well water is dropped into a fall bax about 91 cm wide and 122 cm long. It spills out of this fall box into a concrete watercourse section 3 meters long, 60 cm wide and 70 cm deep. This watercourse joins the watercourse bearing the canal at a point about 35 meters from the tubewell. The waters then flow together to the fields served by this watercourse, which are from 30 to over 3,000 meters distant.

First the fall box and concrete watercourse section were filled with large gypsum stones up to 30 kilograms in size. Samples of well water were taken before the water went into, and after it came out of the gypsum section and were analyzed for Ca^{++} + Mg^{++}, Na^{+}, SO_4^{--} and total salts. The average height of the water in the concrete section was about 60 cm giving a cross section for flow of about 3600 square centimeters in this channel. Since the tubewell pumps about 2.2 cusecs (62 lisecs), the average flow rate in this section is 0.60 ft/sec (17 centimeters/second).

Next, successive sections of the earthen watercourse, which averaged about 180 cm wide, were filled with 6 to 30 kilogram stones to a depth of about 60 cm, which was the approximate average depth of the water. Again water samples were taken before and after this water went through the gypsum filled section and at distances of 90 and 920 meters from where the water mixes with the canal water. Samples of the canal water were also taken and analyzed.

The final length of the section filled with these 6 to 30 kilogram gypsum stones was 3 meters of concrete watercourse plus 17 meters of earthen watercourse.

Later the concrete and earth sections were emptied and refilled with stones 3 to 5 kilos in size.

A measure of the rate at which the water was dissolving away the gypsum stones was desired. Stones were identified by drilling a hole through each stone and attaching a colored wire and then were placed in the concrete or earthen sections among the other gypsum stones. The stones were weighed at intervals to determine the rates of dissolution.

The Na^{+} contents of the water samples were measured with a flame photometer, the Ca^{++} + Mg^{++} was determined by a versenate titration and the total dissolved salts were estimated from electrical conductivity measurements.

Results and Derivations

The rates at which gypsum stones dissolved away are shown in Figure 1 for stones in the concrete section (where average flow rate was 17 cm/second) and in the earthen section (where the average flow was 6 cm/second). While there is considerable variation, probably caused by the position of the stone in the watercourse, it is apparent that stone size and average flow rate of the water are affecting the percent of the gypsum which is dissolved per hour. The percent of gypsum stone dissolving per hour decreases about 60 percent as stone size increases from 3.5 to 18 kilos.

Even in the earthen section where the dissolution rate was slowest in this study it was still 3 or 4 times as rapid as the rates of dissolution measured by Haider et al (1974) on stones lying on the floor of a watercourse. Two probable reasons for higher dissolution rates in the present study are that:

1. all the surfaces of most of these stones have water passing them (whereas a stone lying on the bottom of a watercourse has at least one side buried in mud;

2. turbulence and solution velocity next to the stones are greater when the whole channel is filled with stones.

Assuming that the stones used in the first filling of these sections had an average weight the same as the average of those on which the weights were measured (i.r. 13 kilograms), the dissolution rates of the stones in the fall box and the concrete and earthen watercourse sections are shown

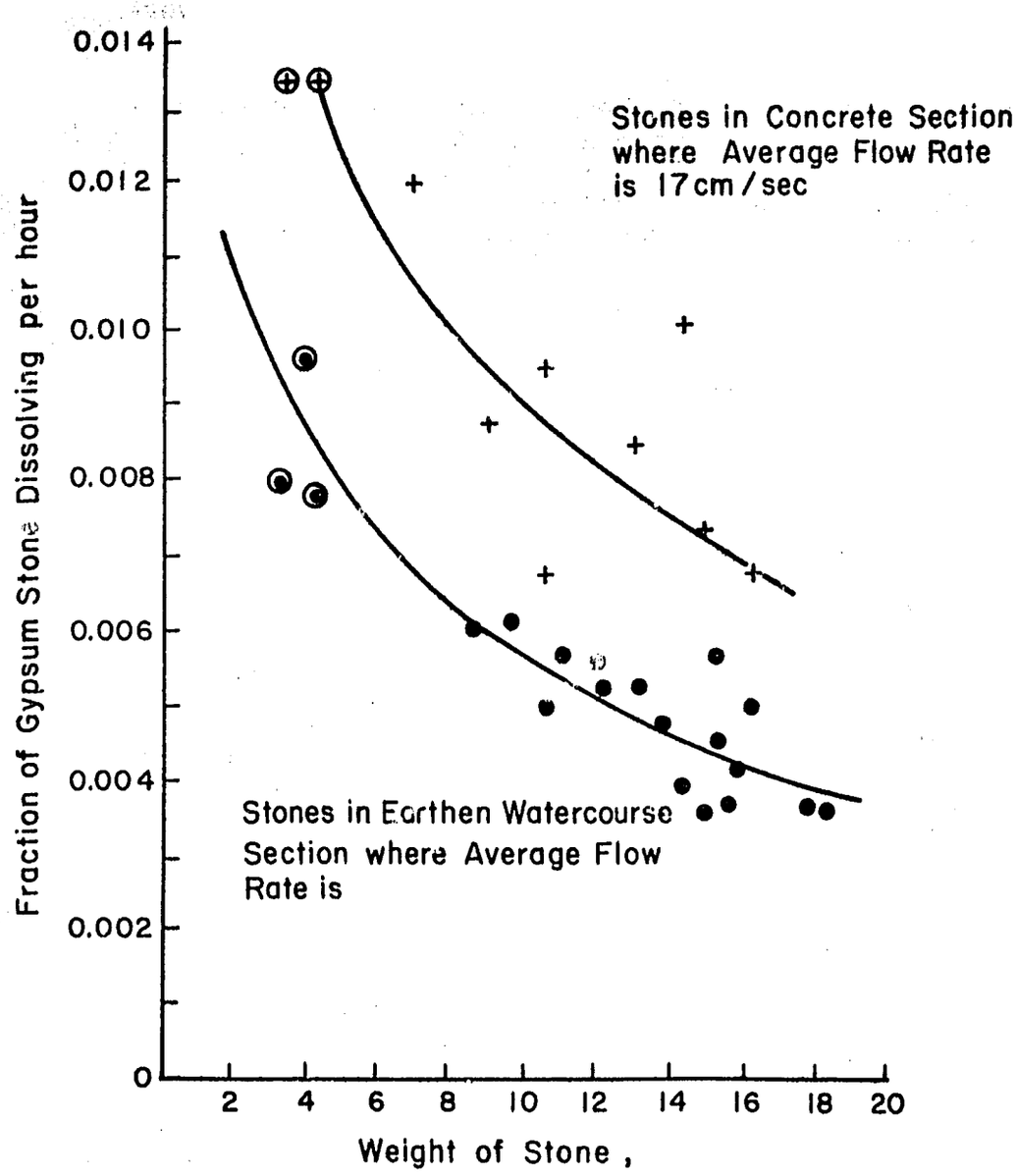

Figure 1. Dissolution rate of gypsum as affected by size of the stones and flow rate of the water.

in Table 1. The weight of gypsum in each section was estimated by assuming 40 percent of the space in the bed is filled with rock and 60 percent is pore space, accepting a density of 2.32 gm/cc for gypsum stones and multiplying these factors times the volume of the section filled. Assuming that all gypsum stones are being dissolved away at the same average rates as those measured, the rate at which gypsum was being dissolved away is shown in the last column of Table 1 for each section.

Table 1. Dimensions of Sections, Flow Rates, Measured Dissolution Rates and Estimated Gypsum Dissolved/ Section.

Section	Cross Section Area For Flow (cm^2)	Average Flow Rate $cm^3/cm^2/sec$	Dissolution Rate of Gypsum Stones (%/hour)	Gypsum in Section (metric tons)	Gypsum Dissolved per meter of W.C. length (tons/day)	Gypsum Dissolved in Given Section (ton/day**)
Fall Box			1.50	0.4		0.12
Concrete Channel	3,600	17	0.78	1.0	.053	0.16
Earthen Channel	10,400	6	0.46	16.5	.089	1.52

* Calculated assuming sections are 40/60 gypsums/holes and that gypsum has density of 2.32 gm/cc.

** Metric tons/20 hour "day".

The rate of weight loss of gypsum from the stones per meter length of the 10,400 cm^2 cross section earthen channel is over 50 percent more than the rate of gypsum being dissolved/ unit length of the concrete 3,600 cm^2 cross section channel. Although the more rapid rate of flow causes more turbulence and more rapid dissolution rate of gypsum stones in the flow path, this does not fully compensate the longer residence time of solution among the stones in the broader section where the water is running more slowly. Consequently when channels filled with gypsum stones are made wider and deeper, water passing through them will attain greater solution concentration than in a similar length of channel with smaller cross section.

Fitting the curves shown in Figure 1 to the points, the dissolution rates of the gypsum stones D, appear to be related to the size (weight), S, or the stones and the average flow rate, R, by the following approximate equation

$$D = G \sqrt{R/S} \qquad (1)$$

Where when D is the decimal fraction of the gypsum dissolved per second, R is in $cm^3/cm^2/sec$ and S is in grams it can be calculated that

$$G = 0.22 \tag{1a}$$

The increase in concentration dC_g (normality = equivalent weights per liter) of the solution as it passes through a bed segment dx in length is equal to the fraction D of the gypsum dissolving per second times the average equivalent weights $\bar{w}$ of solid gypsum per liter of bed volume ($cm^3/cm^2/sec$) of the water.

In equation form,

$$dc_g/dx = D\bar{w}/R \tag{2}$$

Substituting for D from equations (1) and (1a)

$$dc_g/dx = 0.22\bar{w}/R\ \sqrt{S/R}$$

Consolidating the R terms,

$$dc_g/dx = 0.22\bar{w}/\ \sqrt{RS}$$

Since R = Q/A, the total flow rate Q, (cm^3/sec) can be divided by the flow cross section A(cm^2) to obtain R in $cm^3/cm^2/sec$. Inserting this value of R in equation (3)

$$dc_g/dx = 0.22\bar{w}/\ \sqrt{QS/A} \tag{4}$$

(In our systems, about 0.4 of the bed volume was gypsum which has a density of 2.32 gms/cc and since the equivalent weight of gypsum is 86 grams, the equivalents of gypsum/liter of porous media,

$$\bar{w} = 0.4 \times 2.32 \times 1000/86 = 10.8$$

Rearranging equation (4) and substituting this value of $\bar{w}$:

$$dC_g/dx = 2.38\ \sqrt{A/QS}$$

Consequently, it appears that, in this flow range, the rate at which gypsum will be dissolved from gypsum stones will be proportional to A/Q where A is the cross-sectional area of the channel, and Q is the amount of water passing through the channel per unit time, and will be inversely proportional to S, the square root of the stone size.

The concentration of gypsum dissolved in solution will also be a function of the length of the section which is filled with stone and of the amount of Ca^{++} and SO_4^{--} ions already in the water. These variables may be included in the equation as follows. It is generally found that as solution passes

through a porous media composed of a slightly soluble, the rate at which the solution gains salt from the solid is approximately proportional to the concentration of the salts components in saturated solution minus the concentration of its components in the water which surrounds the solid (e.g. see Kemper et al 1975). In equation form this approximate general relation can be written as

$$dC_g/dx = K(C_{ge}-C_f). \tag{6}$$

Where for the present, K will be considered simply as a proportionality constant.

In equation (6) C_g is the concentration (normality of the gypsum added to the water by the stones. C_{ge}, the amount of gypsum that can be added before saturation is reached, can be estimated from equation (9) of Kemper et al (1975) which states:

$$C_{ge} = \frac{-C_{ci}+C_{si}\pm\sqrt{(C_{ci}+C_{si})^2-4(C_{ci}xC_{si})-C_s^{\,2}}}{2}, \tag{7}$$

where C_{ci} is the initial concentration of Ca^{++} in the water before it entered the gypsum stone bed, C_{si} is the initial concentration of sulfate, C_s is the total concentration of gypsum in solution at saturation (i.e. 0.03NO and all concentrations are expressed in normality. At tubewell 91, the initial Ca^{++} concentration, C_{ci}, is 0.0036N and the SO_4^{--} concentration, C_{si}, is about 0.007N, so according to equation (2), the concentration of gypsum, C_{ge}, that can be added to this tubewell water is 0.025N.

The value of K is a function of the channel cross section, A, the total flow rate of water through the channel, Q and of the average size (which we shall describe by their weight) of the gypsum stones. Using the relation for dissolution rate, as a function of flow rate (Q/A) and stone size (S) derived from the data of Figure 1 and expressed in equation (5)

$$K = K^* \sqrt{A/QS} \tag{8}$$

The value of K* can best be determined from the integrated form of equation (6) and substituting for K from equation (8)

$$dc_g/(C_{ge}-C_g) = K^* A/QS \quad dx \tag{9}$$

integrating equation (9) from the beginning of the bed of gypsum stones where x = b and $C_g = C_{gb}$

$$\ln \quad (C_{ge}-C_{gb})/C_{ge} = -K^* \sqrt{A/QS\ b} \tag{10}$$

Taking the exponential of each side of equation (10) and rearranging terms,

$$C_{gb} = C_{ge}(1-e^{-K^*b\ A/QS} \qquad (11)$$

The value of K* for the stone filled section studied at tubewell 91 can be estimated by using equation (10) with the value of C_{ge} = 0.025N calculated for this system and the concentration C_{gb} of 0.0024N of added gypsum that was measured at the outflow (where x = b = 1980 cm [65 feet]) from the inlet.

The value of K* obtained from equation (10) for our experimental system where A = 10,400 cm^2, Q = 62,000 cm^3/sec and S = 13,000 gm (measured in the stone filled earthen channel with large stones) is K* = 0.0136, and 1/K* = 73.5. This value of K* is essentially constant for the ranges of stone sizes and solution velocities encountered in this study. The effects of stone size, S, total flow rate Q and cross sectional area, A, of the channel can then be generally accounted for by inserting the value of K* = 0.0136 in equations (8), (10) or (11). Equation (10) can then be rearranged as

$$b = 73.5\ \ SQ/A \cdot \ln\ [C_{ge}/(C_{ge}-C_{gb})] \qquad (12)$$

to make calculations of length, b, needed to obtain desired additions C_{gb}, to the Ca^{++} concentrations. For instance, assume that we wish to bring the gypsum concentration of the water leaving the bed of stones to 0.008N, then we must add 0.0044 equivalents of gypsum/liter to the original concentration of 0.0036 and thus C_{gb} = -.0044. Then since C_{ge} = 0.025, S = 13,000, and Q·A = 6, equation (13) tells us that the bed length, b, will need to be 3,920 cm ≐ 39 meters.

Note that K* was selected to fit all the data in Figure (1), and is apparently a general constant, independent of stone size and solution velocity within the ranges of these variables used in this study. Consequently, equation (12) can be used for designing systems in which the flow rate and stone size variables are in these ranges. Care should be taken, when applying this equation to stone sizes averaging less than 3,000 gms or over 18,000 grams, and solution velocities (Q/A) less than 6cm/sec or over 17cm/sec, to check actual concentrations coming out of the bed and make sure they are sufficiently close to the desired concentrations.

The values of the Ca^{++} + Mg^{++} concentrations in solution in the bed as a function of distance from the front end (when the bed was filled from the front end of the concrete section to 17 meters below the lower end of that section) are shown in Figure 2.

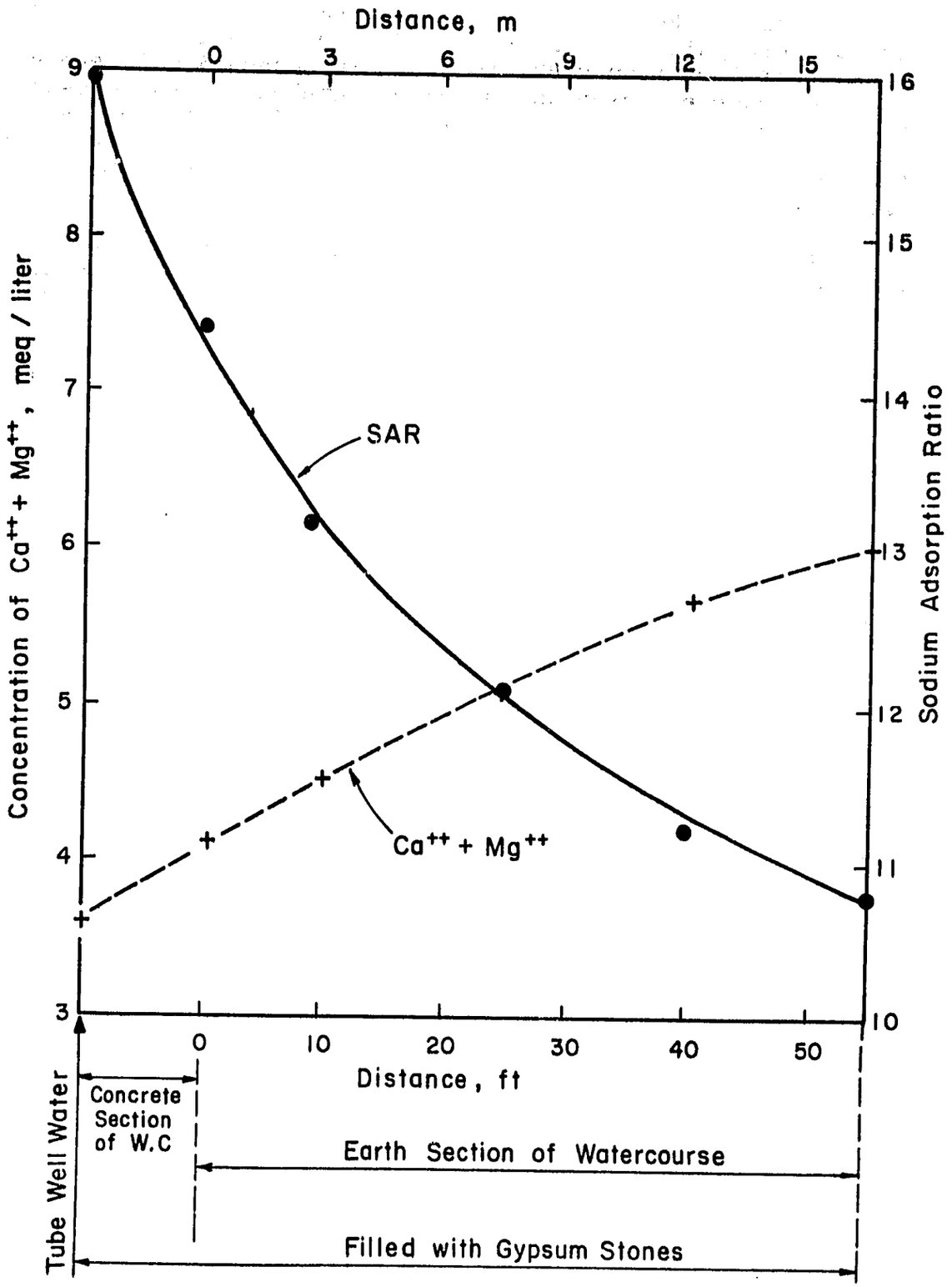

Figure 2. Changes in Ca^{++} and SAR of tubewell water as it passes through sections of the watercourse filled with gypsum stones.

It should be noted that the lowered SAR values in the gypsum were partially as result of an unexplained, but consistent drop from 0.021 to 0.019 in measured Na^+ levels of water samples taken as the water came out of the gypsum bed, compared to Na^+ in the well water. If this drop is disregarded as an instrumental vagary and it is assumed that the real Na^+ content is 0.021N all through the system, the SAR value after 17 meters would be 12 instead of 10.8.

About 11 meters after the water left the gypsum bed in this watercourse it joined the canal water as indicated in Figure 3. Samples of water taken at 90 feet and 3,000 feet (about 28 and 920 meters) down stream as shown in Figure 3 indicate that the ionic concentration of the water does not change appreciably as the water is carried thorugh the earthen watercourse to the field.

Conclusions

Gypsum stones 5 to 20 kilograms in size are a useable source of the Ca^{++} needed to bring down the SAR in sodic tubewell waters. The dissolution rate of the gypsum stones was proportional to the square root of the velocity of flow through the bed, and consequently the increase in concentration of the solution is inversely proportional to the square root of the flow velocity. The increase in concentration of solution was inversely proportional to the size of stones in the bed. Equations (10), (11) and (12) may be used to make the necessary estimations to design channels of the proper cross section and length to supply needed amounts of Ca^{++} to the water when the average size of the stones and the flow of water and initial ionic concentration of the water are known.

Suggested Procedure for Using Gypsum Stones to Increase Ca^{++} Content and Decrease SAR of Irrigation Water

1. Determine the Ca^{++} and Mg^{++}, the Na^+ and the SO_4^{--} concentrations of the water in the watercourse flowing from the canal, flowing from the tubewell and at a point downstream where they are thoroughly mixed.

2. Measure the flow rate Q of water from the tubewell and from the canal.

3. Knowing how much $Ca^{++} + Mg^{++}$ and Na^+ are in the water, compute how much added Ca^{++} would be needed to bring the SAR down to the desired level. (Note that the definition of SAR is not in standard concentration units but is

$$SAR = Na^+ / \sqrt{(Ca^{++} + Mg^{++})/2} \qquad (13)$$

where Na^+, Ca^{++} and Mg^{++} represent concentrations of the respective ions in milliequivalents per liter. The amount of

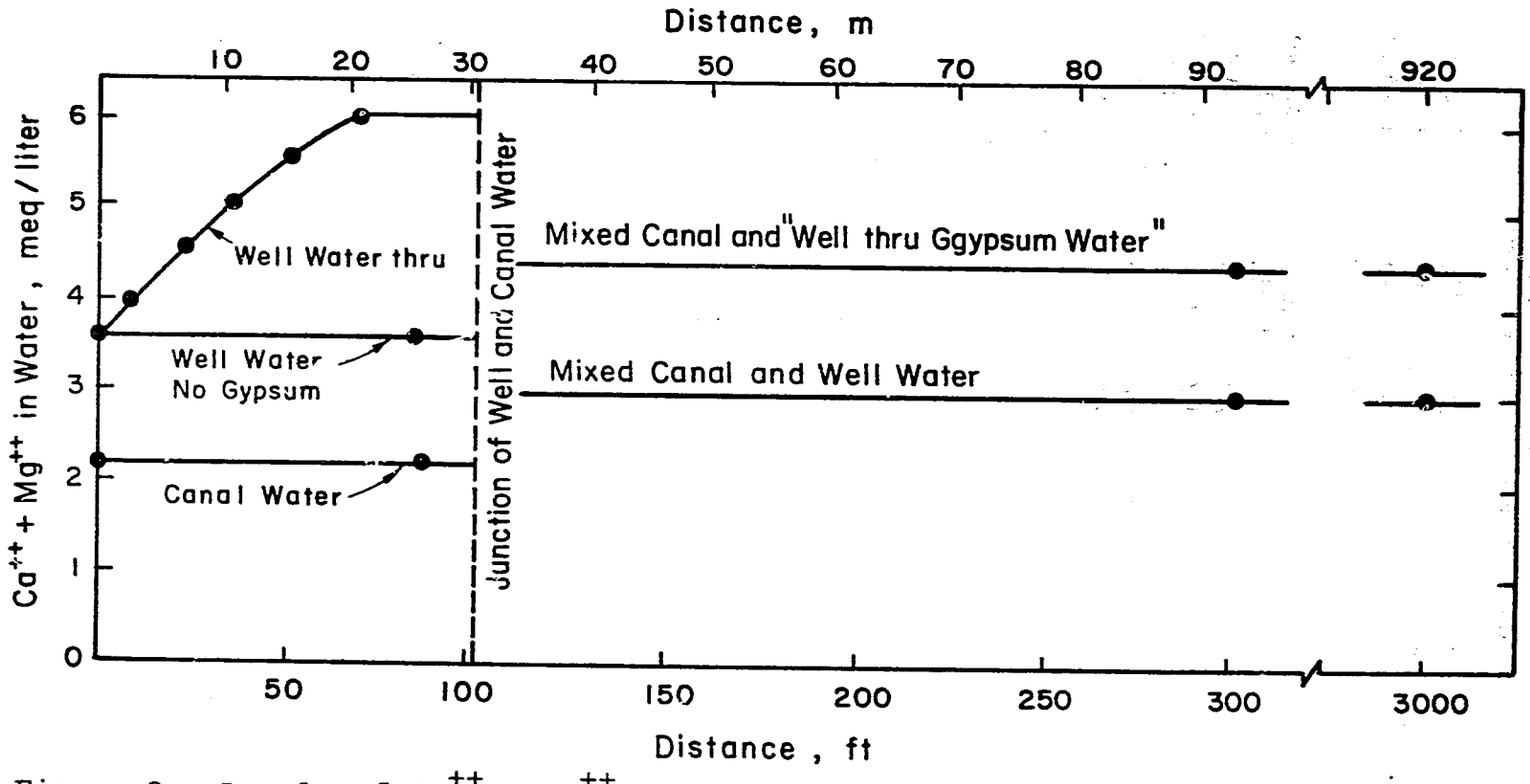

Figure 3. Levels of Ca^{++} + Mg^{++} in the watercourse serving tubewell MN 91, with and without gypsum stones in the channel from the tubewell.

Ca^{++} needed to bring the irrigation water to a desired SAR = SAR_d may be calculated by squaring both sides and rearranging equation (13)

$$Ca^{++} + Mg^{++} = 2(Na^{+}/SAR)^{2} \qquad (14)$$

For example, if Na^{+} = 16 meq/liter and the desired SAR is 8, the amount of Ca^{++} + Mg^{++} needed in the water is 8 meq/liter. If there is already 5 meq/liter in the water, the added Ca^{++} needed would be 3 meq/liter.

If the total flow of the canal plus well water is 5 cusecs (141 liters/sec) and the tubewell is supplying 3 cusecs (i.e. 85 liters/sec) then each liter of the tubewell water will have to carry 5 more milliequivalents of Ca^{++} to bring the concentration of the 141 liters/sec of watercourse water to the proper level. In other words, the increase in Ca^{++} concentration should be C_{gb} = 0.005N.

This value of C_{gb} may be used with the value of C_{ge} calculated from equation (7) where C_{si} and C_{ci} are for the well water) in equation (12) to calculate the length of the watercourse section that needs to be filled with gypsum stones. This length will depend on the rate of flow, Q in cm^3/sec, the flow cross section, A in cm^2, and the average size of the stones, S in grams, as shown in equation (12). To estimate S, weigh about 20 representative stones and calculate their average weight.

4. Remove all weeds and debris from the portion of the channel to be filled with gypsum stones. At the head of the section in which gypsum is to be placed the banks should be at least 30 cm higher than the normal operating water surface to accommodate the increase in elevation that takes place in the water surface when the gypsum stones are placed in the section. At the foot of this section banks should be at least 15 cm higher than the normal operating water surface.

There will be some headloss, as the water flows through the bed of stones, the actual amount depending on the size of the stones the fare of flow and the cross sectional area of the channel. The primary reason for placing the stones in the tubewell channel is the generally greater head available there as compared to the canal water channel, which commonly has little head to spare. Placing the gypsum in the water channel from the canal could decrease flow from the moghas on many distributaries in Pakistan.

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Appendix 38

FARM IRRIGATION CONSTRAINTS AND FARMERS RESPONSES: COMPREHENSIVE FIELD SURVEY OF FORTY WATERCOURSE SYSTEMS IN PAKISTAN

Alan C. Early, Max K. Lowdermilk and David M. Freeman[1/]

I. Purpose, Significance and Methodology of the Study

A. Introduction

1. Pakistan's Agricultural Potential

The agricultural sector of Pakistan possesses extraordinary resources for use in the production of food and fiber. Among these resources are deep alluvial soils, a favorable climate for year-round cropping and a large rural labor force to carry on these agricultural pursuits. Of major importance along with the above resources, is the Indus Basin Irrigation System. This 32 million acre system has tremendous production potential, much of which is unrealized. If efficient management techniques and policies could be developed to exploit the potential of the human and natural resources, this could easily become the most productive agricultural system in the world.

The purpose of this study is to answer the major question, "What are the significant farm level constraints confronting farmers in their irrigation systems which are presently responsible for low crop yields and crop production?" As a problem identification field survey the goal is to describe how farmers respond to selected constraints as they manage irrigation water for their crop production systems.

2. General and Specific Objectives of the Study

The general and specific objectives of the study are as follows:

a. To identify and describe the major physical, economic, social, and legal factors which explain the present irrigation behavior and cultural practices of farmers.

(1) To evaluate and compare watercourse delivery efficiencies, farmers' irrigation application efficiencies, and practices between:

(a) Major agro-climatic regions of Sind and Punjab Provinces.

(b) Private tubewell, public tubewell and nonsupplemented watercourses.

1/Agricultural Engineer, CSU Water Management Project, Pakistan; Sociologist, CSU Water Management Project, Ft. Collins; and Professor of Sociology, CSU, Fort Collins, respectively.

(c) Perennial, nonperennial and uncommanded watercourses.
(d) Regulated and nonregulated watercourses.
(e) Farm locations on the watercourse reach and between various types of farms

(2) To evaluate farmers' cropping intensities, cropping patterns, and crop yields in relationship to selected physical, economic, and social factors.

(3) To examine farmers' responses to selected institutional and legal constraints related to the distribution and use of irrigation water.

b. To provide data on selected physical, economic and sociological factors for utilization by the present water management improvement pilot program in Pakistan:

(1) To identify the extent, types, and magnitude of watercourse losses of a sample of watercourses from the major irrigated regions of Pakistan.

(2) To estimate the need for precision land leveling and improved farm layout systems.

(3) To examine the extent of both over and under irrigation by farmers in relationship to selected physical, social and economic constraints.

(4) To provide criteria to be utilized for objective selection of those farm and watercourse improvement activities that will have the greatest likelihood of success and payoff to farmer clients.

(5) To provide information about farm level problems which can be utilized in training extension personnel for on-farm irrigation advisory services to farmer clients.

(6) To provide sociological and economic data about the propensity of farmers to collectively organize to promote their common interests in water delivery, control, and application leading to improved means of farmer organizations for the water management pilot project.

(7) To provide data and methodologies which will be useful in designing evaluative procedures for the water management pilot program.

c. To compare data on selected sample watercourses with a 1966 watercourse study where the same watercourses were included in both studies.

(1) To compare differences in cropping intensities, cropping patterns, crop yields, and adoption behavior.

(2) To estimate differences resulting from the high yielding varieties (HYV[1]) program and private tubewell installations which took place after 1966.

d. To provide empirical field data for policy formulation related to the extent, types, and magnitudes of farm irrigation and crop management problems.

(1) To provide micro data about farmers' responses resulting from legal and institutional constraints which can be utilized for suggesting policy alternatives to provide more efficient distribution and use of public canal water.

(2) To provide data on information and knowledge constraints which limit risk taking in cropping decisions and adoption of improved management practices.

(3) To identify major farm level problems which may require intensive adaptive and applied research to find appropriate solutions.

e. To provide information and guidelines for use in future watercourse investigations.

(1) To suggest hypotheses which can be tested in future studies.

(2) To suggest guidelines for selection, training, and evaluation of field investigators.

(3) To suggest guidelines for field supervision and procedures for data collection, data management, and analyses.

3. Background with Respect to Need

Several factors combine to suggest the need for such a problem identification field survey of on-farm management problems at this time. These are: 1) The present state of agricultural production; 2) the realization of the critical role agriculture must play in

1/ HYV: High yielding varieties of the Green Revolution.

total economic development; 3) the widespread concern of international donor and technical assistance organizations; 4) the link with present and proposed development programs and more intensive investigations of irrigation problems; and 5) the world-wide felt need for such state of the art studies of irrigation systems to focus on issues and problem areas that can be solved with known technology and new forms of social organization.

First, as a recent World Bank special review[2] of Pakistan's agricultural sector states:

> "The agricultural situation in Pakistan has become increasingly grim over the past five years. The 1960's were exceptionally good years -- annual growth in agricultural production averaged 5.65 percent, well above growth in population, and per capita production steadily improved. Since 1970, the average annual rate of growth in population, at 3.0 to 3.5% has been much above the 0.45% annual rate of growth in agricultural production. Agriculture's poor performance in the 1970's cannot be explained solely in terms of adverse weather."

In balance, a number of factors have contributed to the lack of recent growth in the agricultural sector. Among these are the civil disturbances of 1971 leading to a war and the loss of East Pakistan, a period of transition in Governments, damage of floods from 1973 to 1976, the engineering problems of the famous Tarbella Dam, and the over optimistic expectations of the so-called Green Revolution in the 1965-1970 period. While no estimates are available as to the time, energies, and capital diverted from critical problems of the agricultural sector due to exogenous calamities, Pakistan lost several years in which attention was needed for policies and programs to transform her major economic sector which can still be called traditional agriculture. The HYV (high yielding varieties) program has stalled and acreage and yields of rice and wheat have remained about stable since 1971-72 with little progress in other crops. As a result of accelerated population growth rates since 1972, an average of 1.0 to 1.5 million metric tons of wheat have been imported. In 1974-75 an estimated $125 million of edible oils were imported against only $13.3 million in 1971-72. This has been at a time when the energy crisis, short supplies of world food reserves, and inflationary pressures raised prices on fertilizer, fuel, machinery,

2/World Bank, Pakistan Special Agriculture Sector Review, (five volumes) volume 1, agriculture Sector Review, World Bank, Washington, D.C., January 28, 1976, page prefice (i).

spare parts, steel, pesticides, and other sorely needed inputs for agriculture. These pressures have created critical debt repayments and "The net contribution from agriculture to Pakistan's balance of trade fell from $358 million in 1972-73 to $100 million in 1974-75."[3]

Secondly, There is a realization of the problem and the critical role irrigated agriculture must play in Pakistan's total development if the nation is to meet its development goals. The contribution of agriculture must include: 1) increased quantities of food and improved qualities of food to meet demands from rapid population increases and rising incomes; 2) greatly increased raw materials for local industry and exports for earning scarce foreign exchange; 3) increased rural employment and more equitable distribution of income; 4) and increased income for improved levels of living including better social services for rural people. It is now realized that the only way this can take place is through a comprehensive restructuring of the agricultural sector and the widespread infusion of new technology for increased agricultural growth. If there is any key to the modernization of any agricultural sector, it is the provision of new production possibilities which will enable farmers to increase per acre yields with decreasing per acre costs of production.

Thirdly, there is widespread concern of international donor and technical assistance agencies in the weak performance of agriculture which has one of the world's greatest resources in over 30 million acres of irrigated land, a modern storage and major canal system, an excellent climate for year-round cropping, and from good to relatively good groundwater resources under two-thirds of the largest single contiguous irrigated region known. Observers agree that the irrigated regions which now supply about 90 percent of total agricultural production has the potential for more than tripling present production.

As the Revelle Report stated over a decade ago, "In Pakistan we have the wasteful paradox of a great and modern irrigation system pouring its waters on lands cultivated as they were in the Middle Ages."[4] While there are exceptions such as the high yielding seed varieties, increased use of tractors and tubewells, especially by the middle and large scale farmers, when one approaches the farm level irrigation system one

3/See World Bank, volume 1, op. cit.
4/World Bank, Pakistan Special Agriculture Sector Review., op. cit., volume III, page 1.

does enter into an environment where traditional farmers are using century old methods with little results from their labors. The World Bank study states:

> "Essentially nothing has been done to improve the efficiency of irrigated agriculture in the last decade--the deficit in agricultural production in Pakistan can be related to unreliable irrigation supplies, inefficient water management, negligible water management extension services and persistent use of traditional irrigation and farming practices unsuited to modern agriculture. These constraints cannot be overcome by individual farmers or groups of farmers unaided. Until decisive action is taken by Government, irrigated agriculture will remain inefficient whatever investment in major works. Given these difficulties, it is not surprising that individual farmers are reluctant to invest in other material agricultural inputs necessary for acceptable yields because the basic input, water, is unreliable."[5]

Fourthly, this study is linked with present and proposed development projects and investigations of irrigation problems in Pakistan. For example, this study is directly linked with a pilot project of the Pakistan government with the United States Agency for International Development (USAID) financial and technical assistance for comprehensive improvements in 1500 watercourses throughout Pakistan to cost an estimated $44 million dollars. This first pilot project will include problem identification studies, rehabilitation of watercourses, precision land leveling, extension advisory services, farmer organization and program evaluation. The data of the present study have been utilized in the development of the project proposals, the training of engineers and extension personnel, and the design of evaluation and monitoring procedures. The World Bank in cooperation with the Water and Power Development Authority (WAPDA) have initiated an intensive watercourse command survey throughout the irrigated regions which will provide time series data from the farm level for two full cropping seasons. The present study was also done in cooperation with WAPDA and these data will enable WAPDA to improve its study and also provide useful information for WAPDA's Master Planning and Review Division. Other studies underway include an intensive soil salinity survey of the irrigated regions, a much needed investigation of the present extension system, and the present agricultural educational institutions.

5/World Bank, op. cit.

Also the World Bank proposes an additional comprehensive watercourse survey over the next five years. In common with all these investigations of on-farm problems in irrigated regions, except the soil salinity study, the present study examines similar physical, social, economic, and legal constraints. Therefore, these studies need to be linked for maximum benefit and efficiency.

Fifthly, as is described in more detail on pages to of this chapter, this study is a part of the ongoing efforts of the Colorado State University Water Management Research Team in Pakistan, which has been operating there since 1970.

Finally, with respect to the need for this study there is now a major emphasis for such state of the art studies of irrigation systems around the world by major development agencies. As we gain more understanding of how these systems work from problem identification studies, major problems which require further research can be isolated and solved. Much should be gained from a study of the Pakistan system which will have relevance for similar systems in other countries. The technologies for solving most engineering and physical irrigation problems are known, but very little is known about the processes and mechanisms of transfering these technologies. Still less is known about the complex interactions of physical, social, economic, and legal constraints on farmers and the interdisciplinary methods of identifying those constraints and viable solutions to farmers' problems. This study is an attempt to identify the pieces and to solve the puzzle.

B. Significance of the Research

The significance of this study is seen in the potential for improved water management in Pakistan, the central assumptions which guide the study, its relationship with past studies, the direct linkage with present research of the Colorado State University Water Management Research Program, and the potential of the special framework utilized for similar investigations in other low income countries.

1. Potential for Improved Water Management in Pakistan

The Indus Plains have been described as similar to the Piedmont alluvial plains at the foot of the San Bernadino of the San Gabriel ranges in western California. However, in size they are more similar to the Great Plains reaching Denver, Colorado, north to the Canadian border and east to about St. Louis. The Missouri River system in the United States is about the same order of magnitude as the Indus system. The

average annual flow of these rivers of the Indus system is estimated to be twice the flow of the Nile and ten times the flow of the Colorado River. It compares with the Danube in Europe and only with the Mississippi and Columbia rivers in the United States. The great plains of the Indus are said to be "one of the most homogeneous physiographic regions on earth."[6] The potentially rich soils from the young Himalaya and Hindu Kush Mountains cover an area of about 124,000 square miles where abundant solor energy and semi-arid climate, similar to the Imperial Valley of California, provides an excellent climate for many types of crops and year-round cultivation. Highly visible engineering achievements include 42 principle headworks, several large link canals, and two of the world's largest earth-fill dams, Mangla and Tarbella, which divert about 71 percent of the 140 million acre feet of river water. This water is conveyed by about 40,000 miles of canals to service roughly 78,000 individual farm watercourse command areas. About 200,000 miles of these farm watercourses provide irrigation water for 31.7 million irrigated acres of farmland or about three million farm units. However, in contrast to both the physical resource base and the development of modern diversion facilities of the irrigation system, little attention has been given to the almost 80,000 watercourses in the hundred year period required for the system to be developed.[7] Of the water diverted, only an estimated 30 percent is effectively stored in the root zones of crops. While losses are of a significant magnitude in the storage systems and conveyance canals creating major problems of water logging and salinity, most of the losses occur on the farm level watercourses, farmers' 1.5 million miles of field branch watercourses, and in farmers' fields. Watercourse conveyance losses must range from 20 to 25 MAF with an equivalent range of field losses resulting from inefficient irrigation practices and poorly maintained field ditches. While Pakistan has been waging a war in "The Twin Menace of Water Logging and Salinity" since partition in 1947 with about 6.5 million acres of actual or potentially affected lands, only very recently has it been seriously considered that the major losses on poorly constructed earthen watercourses, field ditches, and field losses might be significant contributing factors.

6/Michael, Aloys Arthur, The Indus Rivers, Yale University Press, New Haven, 1967, p. 29.

7/Chaudry, Muhammad Hussain, "Report on Irrigation in Pakistan" given at the sixth Near East-South Asia Regional Irrigation Practices Seminar, Ammon, Jordan, March 19 to 30, 1966, sponsored by the United States Agency for International Development and the Government of Jordan, 1966, p. 125.

The potential for improvement is great because solutions are available from known technology. The key factor will be how to transfer known improvements to farmers who must change their age-old irrigation behaviors and procedures for maintaining the farm system. While much is known technically about making more water available and delivering it to the farm system, little is known about the proper mix of policies and programs with sufficient incentives to change farmers' irrigation behavior. However, in Pakistan no such development program has been attempted until recently. There is reason to believe that if the technical and organizational solutions are carefully studied and are made appropriate to the needs of farmers by adaptive research with the right approaches, farmers will respond positively. Experience and data in Pakistan indicate that farmers do respond rationally when new production possibilities are made available. First, in the early 1960's Falcon and Gotsch[8] in intensive field studies showed that Pakistani farmers are very price responsive. Secondly, between 1965 - 1970 farmers installed about 10,000 private tubewells per year. Today, there are over 120,000 farmer owned tubewells to improve their control of water supplies. Thirdly, farmers of Pakistan have proven their response to high yielding seed varieties, a story that is well known internationally. A tidal wave of adoption took place between 1965-66 to 1969-70 as all classes of farmers increased their acreages of HYV of wheat from 12,000 to 6.6 million acres in only four years. Likewise, fertilizer use by farmers increased from only 70,487 metric tons in 1965-66 to 305,706 metric tons in 1969-70.[9] Finally, in 1975 and 1976 increasing numbers of farmers have adopted the innovation of precision land leveling which has been introduced in Pakistan. Farmers do in fact respond when they have production possibilities which are appropriate to their needs and which are transferred by means they accept as reliable and creditable. To date, no wide-scale program exists to help farmers improve their on-farm irrigation system and irrigation practices. Still far too little is known about the social, legal and political factors and the extent and magnitude of the physical and economic factors, therefore, a need for such a study as this exists to understand the relationships of these factors with the agronomic and physical factors.

8/Falcon, Walter P. and Gotsch, Carl H., "Agricultural Development in Pakistan: Lessons Learned from the II Five Year Period." Economic Development Report No. 6, Development Advisory Service Center for International Affairs, Cambridge, 1966.

9/F. Kahnert, et al., Agriculture and Related Industries In Pakistan, Development Centre of the Organization For Economic Cooperation and Development, Paris, 1970, p. 363.

2. Central Assumptions of the Study

Several basic assumptions guided the planning and design of 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 which have strong interdependence and dynamic interactions among them. We learn from farmers that they do not have simply one or more discrete problems but are concerned with the management or orchestration of a complex system. The well-known Revelle Report[10] using existing data in 1964 was one of the first comprehensive and integrated systems approaches used in Pakistan and this report calls for "a concentrated and simultaneous attack on all aspects of the agricultural problem." For example, the poor physical conditions of farm delivery systems resulting in high losses might be related to legal factors, social organizational factors, design factors, lack of knowledge of the extent and magnitude of losses of all these factors plus others. Likewise, farmers' low application field efficiencies and under irrigation may be related to water availability, unlevel fields, lack of knowledge, and inadequate sources of services and information. All these factors must likely have a high degree of interdependence and interaction 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. In other words the major building block of any agricultural irrigational system is the farmer client, therefore, he should have key focus in any investigation of irrigation systems. Unfortunately this has not usually been the case but we include an examination of the farmer's irrigation behavior, management practices, adoption behavior, his perceptions of farm problems, his level of knowledge of improved practices, his knowledge and utilization of institutional services, and the social organizational patterns in which he participates. Thirdly, we assume that the farmer is rational in his decision making and responds to incentives to the extent that his constraints will allow. Therefore we attempt to identify the major constraints and describe the types of responses farmers make to them. Fourthly, with the goal of increased crop production, increased quantities of water alone are insufficient. Many irrigation projects and improvement programs have failed to benefit farmers due

10/The White House-Department of Interior Panel on Waterlogging and Salinity in West Pakistan. Report on Land and Water Development in the Indus Plain (known as "Revelle Report" from the Head of The Task Force), U.S. Government Printing Office, Washington, D.C., 1964, p. 351.

to the lack of complementary inputs and conditions essential for increased crop production. Therefore, it is necessary to examine the availability and utilization of those inputs and services provided to farmers for increased production possibilities.

3. Relationship to Past Studies

There have been four major studies which have some relationship with the present study.

The well known "Revelle Report"[11] published in 1965 contains the results of a comprehensive systems analysis of the irrigation problems of the Indus Basin. While the panel of experts utilized only existing data and computer analysis, they made a significant contribution in making the point that the problems of irrigated farming in Pakistan must be examined in concert as a complex system which included physical, institutional, economic, social, and legal problems. This focus on the systems approach had some influence on the design of the present study and the variables included.

In the mid-1960's, watercourse studies were conducted for the International Bank For Reconstruction and Development by several consortia of international consulting firms. The studies in the lower Indus irrigated areas were completed by Sir M. MacDonald and Partners, and Hunting Technical Services Limited.[12] This study included 60 farm irrigation systems and involved a large number of expatriates. The watercourse study in the Punjab, or upper Indus Basin, was conducted by Sir Alexander Gibb and Partners[13] and Hunting Technical Services, and International Land Development Consultants, a consortium requested by the World Bank and called the Irrigation and Agriculture Consultants Association (IACA). This investigation also required a large foreign personnel input and covered 20 watercourse systems.

11/The White House-Department of Interior Panel on Waterlogging and Salinity in West Pakistan, op. cit.

12/MacDonald, Sir M., and Partners, and Hunting Technical Services Limited, Lower Indus Report, Watercourse Studies, Volume 10, Annexure, 1966. (In 30 volumes.)

13/Gibb, Sir A., and Partners, International Land Development Consultants N.V., and Hunting Technical Services Limited, Programme For the Development of Irrigation and Agriculture in West Pakistan, Volume 10, Annexure 14, 1966. (In 24 volumes.)

In 1968 Leiftinck et al[14] reported the "Indus Special Study" which was undertaken to develop a program for the optimum exploitation of the water resources available after implementation of the Indus waters treaty of 1960 for agricultural and power purposes. For the purpose of study of the irrigation and agricultural aspects, IACA prepared "A Programme for the Development of Irrigation and Agriculture in West Pakistan" which was used as input for the macroeconomic analysis of various allocations and programs on the economy of Pakistan and a linear programming analysis of potential irrigation developments, especially of public tubewells, and effects of postponing large storage reservoir construction. The report mentioned the importance of extension services and farmers' level of knowledge toward agricultural production, but few concrete recommendations were forthcoming on this important topic.

In comparison to the 1960's watercourse studies in both the upper Indus (Punjab) and the lower Indus (Sind), there are some similarities and basic differences in the present study. In both studies a number of similar factors were examined such as: Land use, cultivation practices, irrigation practices, yields of major crops, cropping intensities mechanization, marketing, input and credit availability and use, and extension services. Unlike the earlier studies which were conducted over two full cropping seasons or a full year, the present study does not contain time series data nor does it provide detailed information of labor inputs, animal husbandry, forestry, detailed farm cost and return data or soil survey information.

However the present study includes data on a number of important factors which were not measured in the 1960 studies. For example, all our data on canal deliveries to the farm irrigation systems, conveyance losses in watercourses and field branches, soil moisture deficiencies, and field application efficiencies were actually measured with Cutthroat flumes and other precision instruments. This was not done in either of the studies cited above. As one report states:

> "It was unfortunate that no measurements could be made of watercourse losses on the watercourses. This has meant in practice that we can only show the total water available to a watercourse and the manner in which that quantity was allocated to the crops grown. It

14/Lieftinck, P., A.R. Sadove, and T.C. Creyke. 1969. Water and Power Resources of West Pakistan -- A Study in Sector Planning (in 3 volumes). The Johns Hopkins Press.

is not possible to state the amount of water received by the crops."[15]

However, certain assumptions of the investigators did lead to some estimates which may have taken the focus off on-farm system losses for a decade. This will be discussed in more detail in a later section.

Another difference in the earlier studies and this investigation is that maps of watercourses and command areas were developed by surveying each area with instruments. Therefore all maps of watercourse profiles, general features, irrigation basins, nacca cuts, and topography result from instrument surveying. While we often used the Revenue Department maps as a guide, we could not place complete reliability in them for certain information. Also this survey includes ownership, caste-brotherhood, and crop maps for the season we were on the watercourse.

A significant difference in the surveys is that the earlier studies did not include a thorough investigation of sociological, organizational, and legal problems which also operate as major constraints on farmers' behavior. The Sir Alexander Gibb Report[16] gives only 18 pages in the set of 24 volumes to these problem areas with these words:

> "Although these matters (sociology) may be considered rather marginal to this study, and the disciplines involved in sociological analysis somewhat outside our strictly professional competence, they do enter into the general subjects of constraints on development."

Unlike former studies we place considerable stress on variables such as cohesion and conflict, power and influence, farmers' propensity to cooperate in collective activities, micro-level dejure water codes and regulations and defacto responses, and the linkages and interactions with service and regulatory agencies These variables were included because we assume that the kinds of organization which people create and maintain for the social control of irrigation water intimately affect the productivity of its use. We include a number of social, legal, and institutional variables because irrigation is a collective good. These factors, if understood sufficiently, may prove

15/Gibb, Sir A. and Partners, et al, volume 10, op. cit. p. 20.
16/Gibb, Sir A. and Partners, et al, volume 10, op. cit. p. 419.

to be of equal importance to physical and agronomic problems in understanding the system and searching for ways to improve its efficiency. As the resent World Bank review report on water management states:[17]

> "The technical input required to improve water management is relatively simple; the problem is to formulate practical programs on a large scale which will allow for the technical, social, legal, and political factors which have to be considered."

Unlike the earlier studies this survey did not have a large input of expatriates and one of the objectives was to carefully select, train, supervise and evaluate the work of young Pakistani engineers, agronomists, and social scientists. Only two expatriates participated in the field work both of whom had long prior work experience in Pakistan and local language skills. They spent long periods in the field providing intensive supervision of the quality of data and participation in actual data collection. One of the significant contributions of the survey was that of building up Pakistani capabilities for future studies.[18]

A minor difference is that we intentionally selected watercourses in the interior as well as on non-paved roads and market centers. Several of our sample watercourses were over five miles from paved roads, three were over eight miles, and one was about 20 miles from a paved road. Transportation facilities were adequate and supervisors with all team members shared living facilities in tents, rest houses, vacant schools, farmers' homes and under the stars. This close contact and continuous supervision not only helped maintain high team morale but also improved the quality of the data collected. In one of the 1960's reports[19] problems were reported about living facilities and access to villages:

> "In order to allow for easy supervision and more detailed study by the expatriate agriculturalists, watercourses within easy reach of motorable roads and not too far from rest houses were selected."

While access and logistics are important consideration in a field study, we feel that such procedures may

17/World Bank, Pakistan Special Agriculture Sector Review, Volume III, Annex on Water Management, op. cit. preface.
18/See photo glossary figures 1A, 2A, 2B, 2J.
19/Gibb, Sir A. and Partners, et al, op. cit. p. 5.

bias the sample because location from transportation systems, access to markets, and other services such as extension have influence on a number of important variables such as input availability, and cropping patterns.

Since the lower and upper Indus Basin studies in the early 1960's there has been a significant increase in private tubewells and also the impact of the Green Revolution which took place in the late 1960's and gave substantial increases in wheat production through 1971-72. In this study we document some of the influences on watercourses included in the earlier studies which also were purposefully included in the sample of this study.

The major limitations of this present study is the lack of time series data which the earlier studies provided. Investigations in these studies continued for two full cropping seasons. Therefore, they were able to collect valuable household and farm cost data and measured selected crop yields. Yield data reported in this study are for only three crops (wheat, rice, cotton) which was obtained by a special but simple accounting procedure from farmer interviews. Notwithstanding certain limitations described in more detail in the section on Methodology, this study does build on the earlier farmer studies cited and complements some of these data. It makes an attempt to supplement these studies in the areas described above.

4. Relationship with Present Research and Development Programs.

This investigation is an integral part of the Colorado State University Water Management Research Program in Pakistan and the present Water Management Improvement Project as mentioned earlier. It is also linked with present and future WAPDA watercourse surveys.

The Colorado State University Water Management Field Party members with support from campus staff have been active since 1970 in a comprehensive and integrated research program with a focus on problems related to improving farm irrigation systems and cultural practices for increased crop production. This program can be characterized as one that involves problem identification, applied and adaptive research to discover relevant solutions to a wide range of problems at the farm level involving agronomists, irrigation engineers, hydrologists, soil physics, sociologists, economists, water law experts, and an extension specialist. Major activities include intensive field

studies to document the extent, magnitude, and types of losses at the farm irrigation system level. Water budgeting and return flow problems related to water logging and salinity, consumptive use, irrigation scheduling, water-soil-plant interactions, leaching requirements, nitrate mobility in flooded soils, soil cementation or crusting, and evaluation of improved irrigation methods on level fields are subjects that have and are being investigated. Economic analysis of the cost-benefits of various farm practices and watercourse improvements have and are being made. A special study of the water laws and codes at both the macro- and micro-levels has been made and policy alternatives delineated for legal improvements and the organization of farmer water users into associations. Special sociological studies are also conducted to learn how to more effectively organize farmers for improvements and maintenance of their on-farm systems. Recently, major attention has been given to design, implementation, and evaluation of watercourse improvements for decreasing farm conveyance losses. These have ranged from relatively high cost improvements requiring much capital costs and engineering inputs through a series of decreasing cost improvements down to what is known as a process requiring a minimum of capital and engineering inputs. The minimum input rehabilitation model has had good acceptance by farmers and is being refined and evaluated. Farmers participate in all phases of the planning, implementation, and evaluation of these improvement systems and studies of farmer organization are being conducted. Special attention is also being given to the study of cropping systems and cultural practices to discover how farmers can more efficiently utilize the extra water saved from watercourse improvements. Prior to this applied research and demonstration effort, benchmark surveys including physical, social, economic, and agronomic factors are conducted and the data utilized to identify major problems to be solved. A reasonable time period after all improvements have been implemented including rebuilding the earthen watercourse, installation of specially researched and designed low cost Pacca Naccas (turn outs), junction boxes and other improvements such as extension services and land leveling, evaluative research efforts begin in order to determine the benefits received by farmers resulting from major treatments. Increasingly, this applied, adoptive and evaluative research has become the focus of the CSU Program.

In all these efforts Pakistani cooperators and their staffs are being trained in order to rapidly build up research capabilities. To complement the on-the-job training, carefully selected Pakistani personnel have also been provided graduate training at the

Colorado State University in Fort Collins, Colorado, in the fields of agricultural economics, agronomy, agricultural engineering, irrigation engineering, sociology, and water law. Since 1970 students have received such training.

The CSU Research Program in Pakistan presently cooperates with a large number of organizations which are WAPDA, the Water and Power Development Authority, both at the MONA Research Station and in watercourse surveys; the Agricultural Departments in the three provinces which have recently established special cells for the Water Management Improvement Pilot Project; the agricultural research stations including Punjab Agricultural Research Institute, Cotton and Rice Research Institutes and the TARNAB Research Institutes; with the Agricultural Universities in the three Provinces; and with the Agricultural Research Council which evaluates research proposals and provides funding.

The CSU program has produced brief research reports of their findings specially designed for well-defined sudiences which are regularily sent to a special list of individuals and officials who have influence in policy decision making. These unique vehicles of transfer of research knowledge have been instrumental in creating more awareness and interest in the magnitude of the problems and official concern to discover programs and policies for improvement of the on-farm system.

CSU researchers have supplied the major data input to the development of the Water Management Pilot Proposal and Program and are also participating in the training of watercourse engineers, water management extension advisors, and providing input in the evaluation of improvements. The present watercourse investigation, financed by the USAID Mission to Pakistan, has provided the Mission with data inputs on the extent, type, and scope of problems for the development of the proposal and program which in part is USAID financed.

The second phase of the present study which includes 22 watercourses in the lower Punjab and Sind was done in cooperation with the WAPDA master planning and review division and financed by the USAID Mission. The primary objectives of WAPDA participation was the selection and training of personnel for their investigation of 61 watercourses beginning in the Rabi season of 1976.

Individuals including engineers, agronomists, economists, and sociologists were trained and employed by WAPDA. The data and methodologies of this study are

made available to WAPDA for improvement of their longitudinal time study of the 61 watercourses in all irrigated areas of Pakistan which is designed to cover two complete cropping seasons. It is hoped that WAPDA and other organizations which conduct similar field studies will profit both from the strengths and limitations of the present study.

5. Framework for Developmental Research Process

The present survey represents only one stage of a unique developmental research process developed by CSU team members in Pakistan. As the initial stage which we call "problem identification." The aim is to identify and describe the major system constraints of on-farm irrigation and describe how farmers respond to these constraints. This first phase of the process is a comprehensive "State of the Art" study to determine what physical, social, legal, agronomic, and economic problems require research attention and policy decisions. Since successful problem solution requires careful problem identification, the next phase is one of adaptive and applied research efforts to find an appropriate solution. Where possible this second phase, as the problem identification phase, takes place on farms and under farm conditions but depending on the nature of the problem and the degree of risk for farmers in testing various solutions some solutions must be sought at research stations and in laboratories. Specified criteria including cost-benefit analysis are utilized to evaluate the appropriateness of the solution. Phase three is a verification period where the ability of farmers who adopt the solution is evaluated by adoption-diffusion research methodologies. Directly related to this and depending on evaluative results of adoption rates of the packages of improvements, stage four begins which is the further refinement and testing of the improved package on a pilot project basis. This phase of the process is monitored and evaluated for decisions about its applicability for a national program of wide-scale implementation. Unique master processes running through the five stages of this developmental research model are farmers' participation, on-the-job training of personnel, involvement of researchers in all phases at the farm level, and intensive testing and evaluation. This concept implies that there is no clear break between research findings, transfer of research results, and implementation. This participatory research development model is viewed as an important tool which will speed up the development process for low income nations. Experience in agricultural development in low income nations indicates that there is too large a gap between research and weak transfer agencies to expect it to be successfully

bridged in a short or medium time span. Experience also indicates that farmer participation at all phases is essential and that the feedback flow of communication from the farmer to extension and research personnel is usually lacking. The concept also is such that local researchers are forced to be intimately involved with farmers under farmers' conditions. This focus which requires an interdisciplinary approach at all levels also requires evaluative research methodologies all of which can be subsumed under the terms action-oriented research. This innovative concept centers on the word "management" and the many factors that any farmer must learn to orchestrate or manage for improved crop production. Therefore, we present the findings of this report for utilization in the research-development process outlined above for the purpose of assisting farmers and those who work directly and indirectly with them to improve Pakistan's crop production.

C. Methodology

1. The design of the study

Several important underlying philosophies were of paramount importance in the design of this farm water management research. The single most important philosophical tenent in conducting a survey of farmers' constraints to greater agricultural production was to emphasize the farmer client as the subject of the study and as the target recipient of programs and policies that hopefully will result from policy recommendations based on the research findings. The farmer-client was treated as an important and rational human being. His permission was sought before conducting the survey, the researchers designed approaches to build credibility with the farmers, and they lived in villages during the survey in order to increase informal interaction with farmers and make observations of subtle factors that might have importance to understanding the total farming picture. Notes on these informal discussions with farmers and observations were noted by field workers who maintained daily diaries which were checked by supervisors.

A second important philosophy was an attempt to conduct an interdisciplinary study instead of utilizing the conventional mono-discipline approach. Our approach to problem identification is based on the view that solutions to farmers' problems require a complex interwoven fabric of policies and programs that only an integrated interdisciplinary approach can yield. An important realization of earlier CSU research in Pakistan has been that what appear to be physical and agronomic problems of water losses and low crop yields have much

more complex economic, sociological and legal roots, which require an interdisciplinary team effort for identification and solution.

A third important philosophy was that actual measurements instead of global estimates not based on measurements are needed to quantify and determine the interrelations of complex farm management problems. While farmers and key informants must be questioned as to their perceptions of selected problems it is extremely important that field topography, watercourse profiles and slopes, along with field sizes, cropping patterns, conveyance be measured and crops inventoried, and application losses, etc., be measured in the field. This placed a heavy assignment on the field workers because in following the waribundi schedule day and night time irrigations and behavior had to be observed and measured.

A fourth important philosophy utilized was that most of these field efforts should be conducted by "host country nationals." Since there is a dearth of emphasis on field observations and measurements in collegiate academic programs, the survey involvement of expatriate personnel was largely for management, training, reliability checking and supervisory purposes. The young Pakistani engineers, agronomists and sociologists trained in this survey effort were funneled directly to a larger and longer duration study expanding on the methodologies developed herein. Our philosophical stance that carefully selected young Pakistanis are fully capable of conducting such research under very difficult conditions given proper training, support, surveillance, and incentives has been more than vindicated.

A principal consideration in the design of the study was the objective of obtaining wide areal coverage to determine on-farm water management conditions throughout the irrigated cropping districts of the Punjab and in the Sind. A primary consideration for selection of coverage was to give importance to the zones in the country which grow a preponderance of particular crops or have a primary cropping sequence through the Rabi (cool) and Kharif (hot) seasons. These zones have a particular crop ecological relationship to the environment, including the soils, depth to water table, climate, latitude, elevation, etc., to be discussed in detail in the reporting of the data. Another consideration was to gain coverage over a range of canal command systems as supplied by various barrages on the Indus River System.

The primary design of the research called for three basic approaches to data collection. First, was

interviewing farmers and key informants with structured schedules and a daily diary of notes maintained by each field worker including observations, conversations, and data relevant to the study. Second was the surveying and mapping of fields, outlets, crops and watercourses, using surveying instruments. Third was the measuring of watercourse conveyance losses and field application efficiencies using Cutthroat flumes and soil sampling tubes. These methodologies evolved from the approaches used in an earlier exploratory study reported by Lowdermilk, et al, 1975.[20] The techniques used in interviewing, mapping farmers' fields, and measuring irrigation efficiencies were made explicit in a special handbook designed for field worker use by Early, et al, 1975.[21]

An important factor in the design of the study was the short time available for the data collection. This restriction mandated a short time in each village. For the first phase, in the northern and central Punjab, a small team of approximately 10 members collected data in a village for as many weeks as there were watercourses studied in that village. For the southern Punjab and Sind Province denoted as the second phase of the study, a much larger team of researchers, totaling more than 45 members at times, spent 6 to 10 days in a given village to collect data on two to six watercourses, as the particular village case dictated. Some return trips to various villages were made to obtain missing data at later times. This type of study yields point data for one particular time and water supply situation. This point data applies only for that crop or only to that particular irrigation evaluation. The irrigation field application efficiencies are expected to be time dependent, varying with season, atmospheric demands for water, and water supply adequacy. This lack of time series data provides one of the primary limitations of this study.

2. Selection, training, and evaluation of the research team

Particular importance was placed on recruitment of surveyors with desirable personality traits. It was

20/Lowdermilk, M. L, Wayne Clyma, and A. C. Early. 1975. "Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab: System Constraints and Farmers' Responses." Water Management Technical Report No. 42, Colorado State University.

21/Early, A. C., M. K. Lowdermilk and Wayne Clyma. 1975. "Watercourse Survey Handbook," Colorado State University Field Research Team in Pakistan, Water Management Research Methodology Series No. 10. Mimeograph.

necessary to have workers who were primarily from agricultural backgrounds. Young Pakistanis were chosen who were from small farms in an attempt to recruit surveyors with empathy for the small farmers encountered in the survey. It was necessary that these young men be respectful and appreciate farmers, be honest in their interpersonal dealings, conduct quality interviews, record data objectively, make reliable measurements, possess sufficient physical stamina and commitment to work long hours and make night time evaluations, possess sufficient intelligence and desire to learn the field techniques required. The field workers also had to be adaptive and resourceful in meeting contingencies and unexpected occurrences which are commonplace in most field survey situations.

The selection procedure to meet these personal requirements involved three steps. The first step was for the individual to complete a personal data form and an attitudinal questionnaire designed to put the individual into hypothetical difficult job situations to test his reactions and predicted performance. Second was to interview the individual on his background, attitudes, and gain some knowledge of his technical competence. If the first two steps were successfully accomplished, the individual was invited to a field trial. During the field trial he was placed in many difficult situations which were intentially designed to be both physically and mentally stressful. During this week in the field his performance and reactions were evaluated by a senior agricultural engineer, using a specially prepared form. The individual also completed a self-evaluation form before and after the week in the field. After the field evaluation all three types of information were combined and evaluated to provide a composite rating for each candidate. Those with a certain stipulated threshhold score or higher were selected into the survey.

The field trial therefore was the initial period of training for successful applicants. The field trial was a training excercise in actual data collection under farm conditions. When the field survey was initiated the two senior investigators spent at least 90% of their time with the survey team in day to day training, surveillance, and evaluation of the on-the-job training effort. Periodically evaluation forms were completed by the supervisors, trainers, and trainees to ascertain progress in skill acquisition and development of interpersonal relations with team members and farmers. The primary purpose of these evaluations was to help each team member to identify and improve his strengths and weaknesses and not as a device to use as a threat. This approach along with others proved useful

in maintaining team morale and good quality of data throughout the survey.

3. The Sample and Sampling Procedures

The major criterion for the regional selection of village sites was geographical coverage of major cropping zones and major command areas of the barrage, subcomponents of the irrigation system. Four of the sites in Punjab were chosen for other reasons such as previous research-development activities. The survey of these four watercourses included an additional diagnostic exercise to determine farmer responses to an applied research/implementation program conducted by the CSU Pakistan program.

Six of the remaining twelve village sites were chosen to have one or more watercourses in common with the studies of the Upper and Lower Indus reported in 1966. The remaining six villages were chosen to be representative of a geographical area with the additional requirement that there be no exceptionally large landlords present. The sample was intentially biased toward the small farmer who ultimately was intended to be the target of a pilot implementation scheme to improve watercourses, level land, and extend improved water management technologies.

The primary sample village selection criterion was the agro-climatic zone, a combination of environmental influence and predominant agricultural crop sequence grown there. The principle influence of climate on crops is the demand for water that the atmospheric conditions extract as evapotranspiration as modified by the rainfall that falls in the vicinity. The water balance[22] of mean annual evaporation minus mean annual rainfall provides the moisture deficit for a given cropping environment and is directly related to the amount of water that must be supplied in irrigation. Data were taken from Gibb et al[23] on mean monthly rainfall to calculate a mean annual moisture deficit for 11 meteorological stations in the Punjab and Sind and

22/Water balance defined as per modified definition of Thornwaite, C. W., and J. R. Mather. 1955. "The Water Balance." Drexel Institute of Technology, Laboratory of Climatology. Publications in Climatology, Volume VIII, No. 1.

23/Gibb, Sir A. and Partners, International Land Development Consultants N.V., and Hunting Technical Services Limited. 1966. Programme for the Development of Irrigation and Agriculture in West Pakistan. Comprehensive Report, Volume 3. Annexure 4, Climate and Hydrology.

plotted on the map in Figure 1. Then zones of equal moisture deficit were located with respect to the irrigated lands of those provinces, and delineated on the map. The four important zones for this study were categorized as follows:

Low moisture deficit < 45 inches/annum
Medium low moisture deficit = 45 to 55 inches/annum
Medium high moisture deficit = 55 to 65 inches/annum
High moisture deficit > 65 inches/annum

The principal crops grown in the Punjab and Sind in the Kharif (warm) season include rice, cotton and fodder; in the Rabi (cool) season include wheat and fodder; and during both seasons are orchard tree crops (primarily citrus and mangos) and sugarcane, a perennial crop grown for 1 to 3 ratoons after a plant crop. These crop categories for Kharif/Rabi were used to categorize types of crop regions within the climatic zones. The crop category for the sample villages are shown on the map in Figure 2 in the approximate geographical position of the village.

Other important characteristics of the villages which played a role in the selection procedure included the presence of tubewells, and animal powered lifts or wells, the caste distribution or concentration and the origin of the inhabitants. The tubewell classification included public SCARP (Salinity Control and Reclamation Project) large output tubewells, privately owned small output tubewells and villages without tubewells. The water lift classification included the presence of Jhallars for raising water less than 3 feet from watercourse branch to high fields and Persian wells for irrigating from a large open well in lifts of more than 10 feet (see photo glossary Figure 6G to L). Caste dominance was a characteristic of a village that potentially could play a crutial role in the possibilities for village organization to control, improve, and manage collective or community goods such as watercourses. The villages were classified as to whether there was a single dominant caste or multiple castes without a single dominant group. In the Pakistan social context caste refers to ancestral, tribal occupational linkage rather than to strict cleanliness and social position. The origin of the people in the village reflecting time of village settlement, migration from outside areas. and entrenchment of village powers was another important characteristic of the sample. All of these characteristics were considered in selecting sample villages. In any one case one or more of these characteristics played the dominant role in the selection procedure.

Within a given village the sample farmers were chosen at random within three categories of head, middle, and tail thirds of the total watercourse length. During the first phase of the study a census of all farmers on a watercourse was completed and the primary decision makers' names were listed on small pieces of paper which were drawn from a hat to obtain some farms and farmers. Sample farmers were then interviewed, their farm land surveyed and mapped, and their warabundi irrigation turn evaluations of irrigations were conducted. In the second phase of the study sample farmers were selected simply by evaluating the irrigation of whoever was irrigating at a given time and conducting the interview and mapping after his evaluation was completed. The first approach had resulted in many missed evaluations and required many costly return trips to villages in an attempt to collect that information. Therefore approximately 32% of cases of sample farmers interviewed were left without irrigation evaluations. These 32% of farmers were not found to be irrigating during their warabundi turn in 2 to 4 visits to the site.[24] The second procedure yielded only 4% of the total number of farmers for whom there was missing irrigation data.

Key informants were chosen in each village based on several criteria. Firstly, they had to be long term residents of the area with a knowledge of the people and their activities. Secondly, they had to be a representative of one of the major social groups or brotherhoods in the area studied. Another key informant was also chosen in each village from the local shop keepers and artisans in the village. A final key informant was chosen as a person marginal to the existing social system in the village but also with long residence in the area. This marginal individual who was often a tenant, landless laborer, and/or a person of a different social group proved to be able to provide important information on group structures and especially conflict patterns regarding water distribution. (See photo glossary 3H.)

4. Data Collection Instruments

a. Types of Instruments

The field survey employed four general types of data collection instruments. These were the questionnaires, the irrigation evaluation booklets, the maps and general notes, daily diaries and other

24/This alone is substantial support of our findings to be reported in detail in Chapter III that trading of irrigation turns is a wide-spread practice throughout the sample watercourses.

miscellaneous methods of recording pertinent information supplied by key informants and official sources. All of these data collection instruments were of major importance to accomplishing the objectives of the investigation.

(1) Questionnaires

The questionnaires utilized were of four types. The collection of general information through a photographic record of problem areas of the watercourse command, tabulation of location factors and information from key village informants comprised the first questionnaire. The photographic record started at the mogha and proceeded down the watercourse to indicate watercourse alignment, silt mounds along the watercourse, buffalo wallows, crossing points for wheeled carts and vehicles, grass and weeds in the watercourse, trees growing along the edge of watercourses, leaky nuccas or field outlets, evidence of waterlogging and salinity, crop stands, evidence of unlevel fields, the size of a sample of bunded irrigation units, elevation of the watercourse with respect to the elevation of the field, major leaks and spills, presence of tubewells, Persian wells and jhallars, and various other features of the village, watercourse command area, and farmers' irrigation behavior.

The location factors included distances to paved roads, bus stops, railway stations, towns or cities, market centers, schools of various categories, health services, post offices, police posts, fertilizer agencies, and the offices of various Agriculture and Irrigation Department functionaries.

The key informant's information included his personal information, his knowledge of various Agriculture Department functionaries' names and location of their offices, general information about the frequency, duration of effort, and number of farmers involved in watercourse cleaning, information on the usual practices in that village with regard to extra-legal means of obtaining more water, who are leaders in getting watercourse maintenance completed, what sanctions are imposed against those who do not participate in cleaning and maintenance, the degree of influence of village leaders with the police and various Irrigation and Revenue officials, and general information regarding informal cooperation in matters of maintaining village Mosques and schools.

The second questionnaire focused on cohesion and conflict in the village. First, each sample farmer was asked to estimate the degree of influence of each member of the watercourse with respect to decisions about watercourse cleaning and maintenance, and the influence of the numbardar(s), panchayat, large landlord(s) village committee, caste groups, and brotherhoods in watercourse cleaning with respect to settling disputes and conflicts primarily related to land and water issues.

Secondly, the sample farmer was asked from whom he sought advice regarding a whole range of activities, including farming matters, water thefts, borrowing money, individuals who accompany him to visit various irrigation functionaries, trading irrigation turns, trading labor, watercourse matters and collective activities related to the Mosque.

Thirdly, other information about cohesion and cooperation in the village was sought in regard to the Mosque and religious matters, the school, and various arrangements and celebrations including weddings and ceremonies to indicate with what group(s) would such arrangements not be made.

Fourthly, the sample farmer was asked to list major conflicts that had occurred in the village in the last five years. In particular the individual was asked the source of the conflict, its intensity, the groups involved, its duration, and the degree and agency of resolution.

The third questionnaire was the basic sample farmer interview schedule[25] which contained four major headings or categories of items pertinent to his personal farming and family situation. These items included the personal characteristics of the respondent, his land use patterns including the type of holding, the degree of fragmentation, and his cropping patterns and intensity, the availability of agricultural inputs, credit and sources of credit, estimated yields for selected crops and fertilizer use by sample farmer.

The fourth questionnaire was specifically concerned with irrigation and adoption behavior, patterns of cooperation and the utilization of institutional services by the farmer respondent. Specific items were in seventeen categories as

25/A 25 percent stratified random sample of all farms on the watercourse command was taken. This sample was stratified on the basis of location on the watercourse reach as head, middle, and tail.

follows: Personal information regarding the farming operation, land owned and land operated and location of the land with respect to position on the watercourse, the irrigation schedule, warabundi for the watercourse where this farmer's land is located, the farmer's water purchase and trading frequency and persons with whom this was done, the farmer's opinion regarding preference for regulated or unregulated warabundi irrigation schedules.

The next item was the farmer's assessment of the power structure--leadership patterns on the watercourse, followed by the farmer's knowledge about water use and the water requirements of crops, the amount of advance information that the farmer receives regarding canal closures, water rationing, and rotation of watercourse/distributary turns and the farmer's assessment of how level his land is and how frequently he attempted to improve levelness of the fields.

The farmer was then asked his preference for the present warabundi turn system versus augmented supply with tubewells, or volumetric payment for water or water on a demand type allocation system. He was also asked if he would participate in a watercourse lining program in this village and if he would suggest a form of organization for such an endeavor and who the leaders might be.

The farmer was asked about the water purchases he made during the last rabi and last kharif seasons and the costs of those purchases, about his methods of solving water problems including someone stealing his water, increased faslana demanded, false entries in the khasrah record and attempts to decrease the size of the mogha outlet.

Next was a section on the farmer's knowledge, trial or testing and adoption behavior with regard to recommended technology and inputs for cropping wheat, followed by a section on the farmer's communication pattern including urban orientation and mass media information access and exposure. The final three sections were about the farmer's knowledge and use of institutional services, the farmer's knowledge about land leveling programs and watercourse improvement programs and the farmer's ranking of his present three most important farming problems and reasons for the ranking order.

(2) Irrigation data

The irrigation evaluation booklet that evolved during the course of this study is presented in Appendix I-B. The irrigation data collected included general information as to the farmer, his father's name, his kinship group and brotherhood group, his farm location on the watercourse, the date, the team members making the evaluation, the distributary and the canal on which the evaluation was made. The booklet contains charts for recording pertinent data taken as flume measurements for nacca field inlet discharge and mogha distributary outlet discharge, a chart for recording dimensions of the field, and crop information and length of irrigation interval. Next is a page for a sketch of the field layout and position indicating length of watercourse from mogha to nacca. There are also two tables for recording the soil moisture data both gravimetric percentage and estimated soil deficiency in inches of water. A table is included for the calculation of tubewell discharge. The last section of the irrigation evaluation booklet includes checklists on the watercourse condition, farmers' questions and responses to the measurements and observations on the farmers' irrigation behavior such as checking for leaks and spills, repairing leaks and spills, number irrigating, etc.

(3) Map data

Three general techniques were used in the collection of map data. First, an engineering level and staff rod were used for the measurement of the watercourse profile and preparation of the topographic map. These data were collected in field pocket-sized record books wherein a sketch of the field layout or tracing of an authoritative map of bunded units was attached and used as an index for the data.

Secondly, a plane table, alidade, and staff rod were used for the mapping of actual field units dimensionally to scale and the position and lengths of watercourses. Also added to this map while being prepared in the field were the crops growing in the field at that time and the position of the nacca cuts into all the fields mapped.

Thirdly, was the compilation of an ownership map which in phase 1 of the study included all

farmers on the given watercourses and in phase 2 included only the sample farmers. This was obtained by reconnaisance methods and interview of the farmers in the fields so they could indicate actual boundaries.

(4) General data

The general data often were very important to fully understanding the village or watercourse command area situation. This information came from unstructured conversations with all sorts of people including shop keepers, the Maulvi, the chaukidars, officials from the Agriculture Department and the Irrigation Department. The information ranged from how much damage was caused by the most recent flood to who steals water from whom. This information was recorded in a daily diary which everyone was encouraged to maintain. In some cases the information included publications or maps from official sources and in many cases the information came from people outside the village.

b. Approaches to Completion

The approaches used for collection of the field data on this survey emphasized the importance of the farmer client as an individual and approaching the farmer with courtesy and respect. It was also emphasized that all the survey members would observe a "no promises made" rule in return for a farmer's cooperation. The following subsections describe the important approaches which are specific to the type of information collected.

Another important philosophy of the field data collection process was the emphasis that the farmer's schedule was our schedule, that we engaged the farmer only when his work permitted and that we followed his irrigation turn whether it came in day time or night time.

(1) Questionnaire data collection

Questionnaire data were collected by structured pretested instruments from carefully selected key informants which usually numbered four to six well informed farmers representing major social groups and a 25 percent random sample of all farm decision makers on the command area of each watercourse. Interviewers were given intensive training in approaching farmers, gaining their confidence, administering the schedules, cross checking responses, and recording of data. Each interview was conducted no longer

than one and a half hours so as not to tire the respondent. Given the number of interviews to complete, one farmer would often be interviewed on two or more occasions at his convenience. Our time schedule was that of the farmer and while we tried to interview him each time in the field, some interviews were conducted at night at the end of a work day. It was often impossible to gain interviewer isolation; therefore, we utilized the presence of other farmers at the interview situation to confirm or deny some of the information reported. Various methods of quality control of the data are discussed in the preceding section.

Interviewers were trained and reminded throughout the survey about the special code of ethics printed in the survey handbook which was developed to guide our behavior and actions in village living and in data collection. This code of conduct appears in Appendix V. It includes some of the following principles: "As a guest, be mindful of the Islamic code of ethics in all relationships, gain credibility by personal friendliness; honesty, and competent hard work; make absolutely no false promises about what government might do or not do for securing data; never ask or insist on free food, lodging, etc., and take no fruit, vegetables, sugar cane, etc., from farmers' fields unless it is a gift; pay all bills in village shops and take no loans from villagers in cash or kind, identify closely with villagers by your manner, language, and dress; when there is free time identify closely with villagers such as attendance at Friday prayers and the Mosque on a regular basis and participation in religious and social functions; answer all farmers' questions about your work openly and honestly and always explain the purpose of your research when it is not understood; make it a policy to know the leaders of all major social groups and never show favoritism to any one or two; never take sides in sensitive arguments about religion and politics--always remain neutral; never become involved or even suspect in respect to women; and finally learn all you can about farmers who are the pillars of your nation."

While these principles may appear to be unrelated to team morale, productivity, and the quality of data, our experience suggests otherwise. Our whole approach was based upon high respect and appreciation for farmers as human beings and in evaluations of field data collectors we were

especially hard at this point. For the duration of the survey we faced few social problems which often occur between field workers and farmers, especially when the former act of "officers" demanding information from farmers which is not an uncommon practice in many field surveys. Farmers responded to our particular approaches positively by providing not only data which were checked and cross-checked for validity and reliability, but also by returning our courtesy with friendships, feasts, farewell functions and for several of our team members special requests for sermons in the village Mosque on Fridays. For all team members it was a learning experience and upon the completion of the survey all participants felt certain that they had learned much from farmers. A by-product of this survey will be a special publication on proven and appropriate methodologies for quality data collection from Pakistani farmers.

(2) Irrigation data collection

In collecting the irrigation evaluation data, an attempt was made to represent the efficiency of the system as it was without modification. If a leak was detected in the watercourse or in a bund between fields it was not pointed out to the farmer and our evaluator made no effort to close the leak. The losses and leaks were being measured in the survey. The important technique to completion of the irrigation data was following the water from mogha to field and recording physical data as well as behavioral information on what the irrigator did during the evaluation. A young villager was usually hired as a helper to provide information during the evaluation.

(3) Map data collection

In surveying the village and watercourse command areas, villagers were again hired as rod men for topographic as well as plane table surveying and to provide key information about the people and the village. All main watercourses and major branches were surveyed in profile. All fields were mapped and four topographic shots were taken in every small irrigation unit. Special efforts were made to obtain the farmers' consent to the survey and to answer all questions about our efforts while working in the field.

(4) General data collection

General data collection approaches were to move about in the village, purchase our food locally from village shops, hire local people as helpers, frequent the Mosque and observe Juma prayers. To facilitate our entry and possible future reentry to these villages a sound movie was presented the first and last nights of our stay. During this program, one of our senior field workers would describe our work to the audience and the objectives we hoped to accomplish with their cooperation. Usually we left each village with some sort of collective gift ranging from a Holy Quran to a hand pump for a village boys school.

(5) Approaches to completion of general data

In addition to questionnaire, irrigation, and map data collection procedures, several types of supplementary general data were collected. These included the construction of complete warabundi turns for all farmers of a command area which is used for selecting the random sample of forms and for developing a time budget for the allocation of minutes per acre of canal water for all farm units. Another form for general data were the daily diaries of each field worker who noted significant conversations with farmers and observations of farmers' behavior which related to the purposes of the survey. This information, while qualitative, helped to clarify certain issues and proved useful at points in cross-checking the accuracy of some data. The major purpose of this device was to sensitize all field personnel to the importance of using all occasions possible for objective observations of farmers.

Other approaches used for general data were visits to Irrigation Offices for information about regulated mogha discharge and rated cultivated command area, and permissible cropping intensities. Key informants also provided historical information related to village and canal system establishment. In village 107 with three moghas and a private jointly owned tubewell for each 75 acres of land, a special study was devised to identify small farmers' methods of planning, installation, and operation of their private tubewells established without government organizational involvement. A sample of the discharges of the 26 private tubewells of this village were measured using the Purdue coordinate method. Also the size pumping unit, horse power,

type and make of diesel engines were recorded. We also had an opportunity to have discussions with some local level irrigation officials about farmer problems and with police as to the incidence of court cases resulting from disputes, fights, etc., related to water matters.

These general data collection procedures described above provided the field teams with extra information to supplement direct data obtained by physical measurements, mapping procedures, and structured interview schedules.

5. Data Quality Control

Special procedures were developed for data quality control which include data management in the field, checks for validity and reliability of data, and the management of data for coding and computer analysis in the office.

a. Data management procedures in the field

Previously we described the field methods utilized in the collection of data and the special attention to proper interview procedures for collecting interview data. Several management procedures for collecting interview data. Several management procedures were followed in the field to assure good quality of data. Field investigators worked in teams with specified responsibilities for mapping, irrigation evaluations and interviews with key informants and sample farmers. Each team was supervised by an engineer with prior experience in the utilization of all methodologies. All watercourse profile maps, topographical maps, bunded unit and nacca-cut maps, the crop survey maps, and the land ownership maps were developed in the field and spot checked by supervisors each day. When the general features map was completed, it became the map on which all others were based. All survey data including benchmarks were entered in survey field books and each survey was properly closed at the end of the day. The work of surveyors was checked often in the field and evaluated. Where errors were identified the job was done over under careful supervision. The engineers conducting evaluations on field application efficiencies had specially designed summary forms in field booklets for all measurements. The supervisor checked the installations of flumes and a sample of the readings made from flumes to assure accuracy in measurements. The flumes at the

mogha with automatic stage recorders were checked carefully by the chief investigator at time of installation and periodically during the full weekly waribundi period. The irrigation evaluation field booklets maps were collected daily by the team leaders and all calculations were double checked and then entered on special evaluation summary forms. Likewise, all interview schedules were checked by the team leaders to ascertain if all questions had been answered. Caution was taken to see that all schedules, engineering field books, maps, etc., had proper identifiers including the village site, mogha number, farmer's name, farm unit location and data of the data collection. The individual who was responsible for the data collections wrote his full name on each form turned over to the team leader on a daily basis. Two methods were used to ascertain soil moisture deficiencies which were the feel method and the gravimetric method. These two methods were composed to determine measurement reliability. Before leaving a watercourse command area, all data were again checked for accuracy and completeness, labeled, and carefully stored in special metal trunks which were in the care of a designated individual.

b. Validity

The methods used in measurements had previously been tested over a period of time before the survey began. For example, an exploratory study had been previously conducted in the Lahore region of one watercourse for the purpose of testing methodologies in relationship to the interview schedules, all of which were in the Urdu language. The following questions had been answered to our satisfaction: 1) are the questions on the subject clear and unambiguous; 2) are the questions tapping something typical in the situation; 3) will the questions be answered by a large enough proportion of the sample farmers to have validity; 4) do the questions give responses with an expected and reasonable range of variation; 5) do the questions cover the phenomena to be investigated. The information received from respondents was also checked against dependable outside sources for accuracy. For example, the farmer's reports of land area cultivated, parcels of land, crops cultivated, tubewells, farm equipment, etc., were confirmed by observation of these items or information collected by other investigators such as those mapping fields and farm units. The external source of the Revenue Patwaris map was also used for checking accuracy of the data we collected on ownership, field location, size of holding, fragmentation,

etc. The initial information collected from key informants was also used in the field for cross checks against the information reported by the sample farmers. When discrepancies were found in such data, these were further cross-checked with other farmers. The daily diaries maintained by fieldworkers of observations and conversations with farmers often provided information which helped to clarify problematic data reported earlier by farmers in interviews. Mileage to institutional services such as markets, banks, etc., were checked by the drivers of the five mini-buses and vans used for the survey. When there were problems with the flume measurements due to damage in transport other flumes were brought in to check for accuracy and damage measurement instruments were repaired or replaced. Transits and telescopic alledades for field surveying were checked daily and corrected if they were not accurate. When found out of adjustment the survey work was redone.

Farmers' reports of the waribundi schedule were checked several times using groups or panels of farmers. Likewise, farmers' reports of the regulated discharge of moghas was checked externally with Irrigation Department records.

c. Reliability

A number of measures were taken to assure a high standard of reliability. For example, a 10 percent reliability check was designed into the survey for interview data. In actual practice 19 percent of all sample farmers were reinterviewed for selected items by an interviewer other than the fieldworker who conducted the first interview. The check-recheck results are compared statistically using a reliability coefficient and the results appear in Appendix I.

In the reading of flumes, two engineers made individual readings as a check against each other. Likewise, with soil moisture samples the two engineers both made estimates using the two methods described earlier. In order to achieve greater accuracy in the topographical survey for all watercourses in the second phase (22 command areas) four readings were taken per bunded unit. In the first phase for 18 watercourses, four shots were taken per sample farmer bunded unit with one shot per bunded unit for nonsample farmers. Likewise three soil moisture samples were taken for each bunded unit and estimated by both the "feel" and the gravimetric methods.

A major problem confronted in the Sind Province was that of language. Therefore, only our Sindhi speaking staff could conduct interviews with key informants and sample farmers except in two village sites settled by farmers from the Punjab. This slowed the work considerably and interviewers had to return on several occasions to complete missing interviews or complete gaps in the data.

The field work alone for this survey required about 20 man years not including the time of the chief investigators which was over one man year.

d. Data management in the office

Once the data were collected it was again evaluated in the office in Lahore before coding was begun. Though care had been taken in the field, inevitably data gaps were identified and some cases of questionable information appeared. In these cases a team of two experienced field workers was sent back to sites in the Punjab and Sind to complete these data gaps. All field maps were checked against data entered in the field books and drafters working for several months developed new maps. All irrigation evaluations and other data were rechecked and summarized on special forms.

The data with all field books, maps, questionnaires and daily diaries were sent to the Colorado State University for further evaluation and reduction. Two Pakistanis and one American proficient in the Urdu language prepared the data for coding with the help of a special staff. The period required for coding and analysis of data required 10 man years plus about 2 man years of the principal investigator's time.

The statistical package for the social sciences computer programs were used for the analysis due to its flexibility and availability of many types of statistical analysis including stepwise multiple regression, difference of means and variance, and many nonparametric methods of analysis. The data stored on tapes in our files comprises a data bank to which comparative data will be added in the years ahead.

6. Levels and Methods of Analyses

The levels of analysis for the survey data from the most specific to the most general were the bunded unit,

the farm, the watercourse, command area, the village, the cropping region and the climatic zone.

a. The bunded unit

The bunded unit is the smallest field that is irrigated as a single unit. Most of the irrigation evaluations were conducted on individual bunded units, whereas only a small percentage were conducted on a series of bunded units, or were called a block evaluation. In most of the cases of block evaluations, the farmer irrigated one plot first, then opened a nacca to an adjacent field and allowed water to irrigate the second field. The topographic information on the bunded unit is in two intensities, one elevation shot per bunded unit on phase 1 and four shots per bunded unit in phase 2. The maps in Appendix IV which contain the information on individual bunded units are the nacca map and the crop map. The bunded unit map indicates the size of the individual bunded units and the watercourse map indicates the proximity of the main watercourse and branches to the bunded unit. The general features map indicates the relationship of all four of the above factors to one another on one map. All this information was taken off the maps and tabulated by the office staff. Areas were measured using a planimeter.

b. The farm

The ownership map was used on a light table to overlay the ownership boundaries on the crop, bunded unit, nacca and topographic maps to provide a tabulation of crop acreages, distribution of bunded unit sizes, nacca count, and elevation difference across the farm parcel. In phase 1 of the survey this process was done for each farmer for the entire site, while in phase 2 this was done for only the sample farmers. Sample farmer data on crops, naccas, bunded units, topography and the estimated volume of excavation for leveling that farmers' largest parcel of land was tabulated, coded and entered into the master file for analysis. Each farmers' parcel was also measured with planimeter to determine area of each.

Questionnaire data were available on only a sample farmer basis. Irrigation data for one or more bunded units per farm were weighted on the basis of the mogha discharge and tabulated on the farm basis in the master file as mean values for application, delivery and farm irrigation efficiencies and loss rates as percent loss and cubic feet per second per thousand.

c. Watercourse command

The watercourse maps were used to delineate the watercourse command areas for the 11 sites which had more than watercourse. This map was then used as an overlay to separate the farmers' parcels onto the separate watercourses and the given parcels on boundary between watercourses. The watercourse command areas were also used to delineate boundaries on crop, nacca and bunded unit maps to permit the tabulation of crop acreages, number of naccas. The watercourse commands were planimetered to obtain area and checked versus the aggregate crop survey totals for reliability.

Farm level socio-economic and irrigation data were aggregated to provide watercourse level data.

d. The village

The village level information on naccas, crops, watercourse length, farmers parcels, bunded units and topography was obtained merely by aggregating the watercourse command area information for the 11 village sites. On six of the ownership maps of phase 1 the farmers' ownership/brotherhood units were delineated to show position relationships. The other four cases were complicated by the presence of 80 to 200 farmers and were not possible as in phase 2 where ownership was only available for sample farmers.

Watercourse command area socio-economic and irrigation data were aggregated to produce village level data.

e. The cropping zone

Seven cropping zone sequences were the primary bases for the initial coverage started by the survey. These were the Kharif/Rabi sequence of crops. Three of these were only represented once in the sample. These cases were rice/fodder, rice/fodder/wheat and fodder/wheat. Cotton/wheat occurred four times in the sample of 16 sites; rice/wheat occurred twice; sugarcane/wheat occurred twice; and mixed cropping and orchard occurred five times. Village level data on crops, naccas, bunded units, topography, watercourse lengths, ownership parcels, and areas were aggregated to obtain cropping zone information.

Village level socio-economic data and irrigation data were aggregated within common cropping zones to provide cropping zone level data comparisons.

f. The climatic region

Four climatic regions in terms of moisture deficit ranges were delineated. Village level data common to a region were aggregated to provide comparison across the regions. This was especially done for the sites with a specific cropping zone classification.

Appendix 39

SOCIO-ECONOMIC BENCH-MARK SURVEY TW56

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Introduction

In order to document changes occurring related to the introduction of a new technology or production technique it is first necessary to establish base line data that defines and appraises the existing conditions. A bench-mark study provides basic data on a variety of socio-economic conditions, such as, land utilization, cropping rotation, production practices, marketing and pricing, irrigation methodology, etc. The bench-mark study defines the universe for the planner and assists in locating problem areas.

Once a developmental project is implemented it is necessary to evaluate its degree of success. This evaluation also requires a bench-mark study in order to document the change before and after the implementation of the new technology. Benefit-cost ratios and efficiency measurements all are based on a with and without type of criteria and they require the base-line data gathered during the bench-mark survey.

The purpose of this document is to present the results of such a bench-mark survey for a single watercourse (tube-well 56) in the Mona Project. This data will represent the without or existing situation prior to a cooperative water-course improvement project. Future surveys will provide the data relevant to the situation.

This data was gathered using a field survey technique. The farmers were interviewed either in the village or on their farm. The data was collected in a questionnaire that had been field tested previously. Eight agricultural economists from the Economics Section of the Mona Reclamation project completed 36 interviews between 3-12-75 and 10-12-75. Reliability checks were not run on the interviews, but the data was cross checked thru personal contacts with selected farmers. The crop survey information was checked to see if it corresponded with the data collected in the interviews. With only minor variation the data collected from both sources was in close agreement.

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Village 10ML

The majority of the cultivators that work on the pilot watercourse live in village 10ML. This village dates from the early 1900's when the Lower Jhellum Canal was established. There are a few cultivators that lived in this area before the canal was constructed as well as a few refugees that settled in 10ML after partition. Table 1 details the distribution of the cultivators with respect to origin.

Table 1

Origin of the Cultivators on TW 56

	Local	Settlers	Refugees
Number	3	31	1
Percent of Total	3.5%	88.5%	3%

While the cultivators appear to be almost overwhelmingly dominated by settlers, that does not indicate that they are a homogeneous group. In fact, to the contrary, there are ten different castes represented on the watercourse. Table 2 presents the percentage distribution of the castes as well as the number of acres controlled.

Table 2

Caste Distribution and Acreage Controlled by Castes

	Number of Cultivators	Percent of Total	Total Number of Acres
Arain	2	6%	20.5
Chuhan	1	3%	16.5
Gujar	12	40%	364.0
Gundal	1	3%	18.0
Harral	1	3%	7.0
Janjua	1	3%	7.0
Khokhar	2	6%	129.5
Malik	2	6%	28.0
Raja	1	3%	12.5
Syed	8	27%	230.25

From Table 2 it is obvious that even though there are ten castes on TW 56 only three castes are dominant in terms of land holding. Between the Gujar, Syed and Khokhar castes over 720 acres are accounted for. These three castes control almost 80% of the land on TW 56 and undoubtedly represent one of the dominant influences in village 10ML.

Education is also a relevant variable in terms of village influence and prestige. The details of the educational levels of the cultivators from TW 56 are listed in Table 3.

Table 3

Educational Levels for TW 56 Cultivators

	Uneducated	Primary	Middle	Matric	F.A.	B.S.	M.A.
Number	15	10	3	2	2	2	1
Percent of Totals	43%	29%	8.5%	5.5%	5.5%	5.5%	3%

While the cultivators are primarily either uneducated or have only finished the primary level, there are enough individuals with higher level education to indicate that this watercourse is more progressive than the average.

Land Utilization and Cropping Intensity

The watercourse served by TW 56 and mogha #62394L covers a larger area than most watercourses in the Punjab. The gross area of the watercourse is approximately 928 acres. However, since one-half square is occupied by the school and graveyard and additional land is taken by roads and a government plot scheme the cultivable area is only 898 acres. The general details of this watercourse are presented in Figure 1.

The SCARP tubewell and the mogha are both located at the head of the watercourse (Figure 1). The amount of water distributed throughout the system varies both as a function of the quality of maintenance of the distribution system and the height of the land compared to the bed elevation of the watercourse at that point. In general, the further one moves down the watercourse system, the less water is available for irrigation. To explore how this phenomena affects the level and quality of agricultural production, the watercourse has been divided into three divisions: head, middle, and tail. Figure 2 details the areas designated in each of these divisions. These divisions will be one of the principle base line criteria since the watercourse improvement project will increase the amount of water delivered to the tail by a

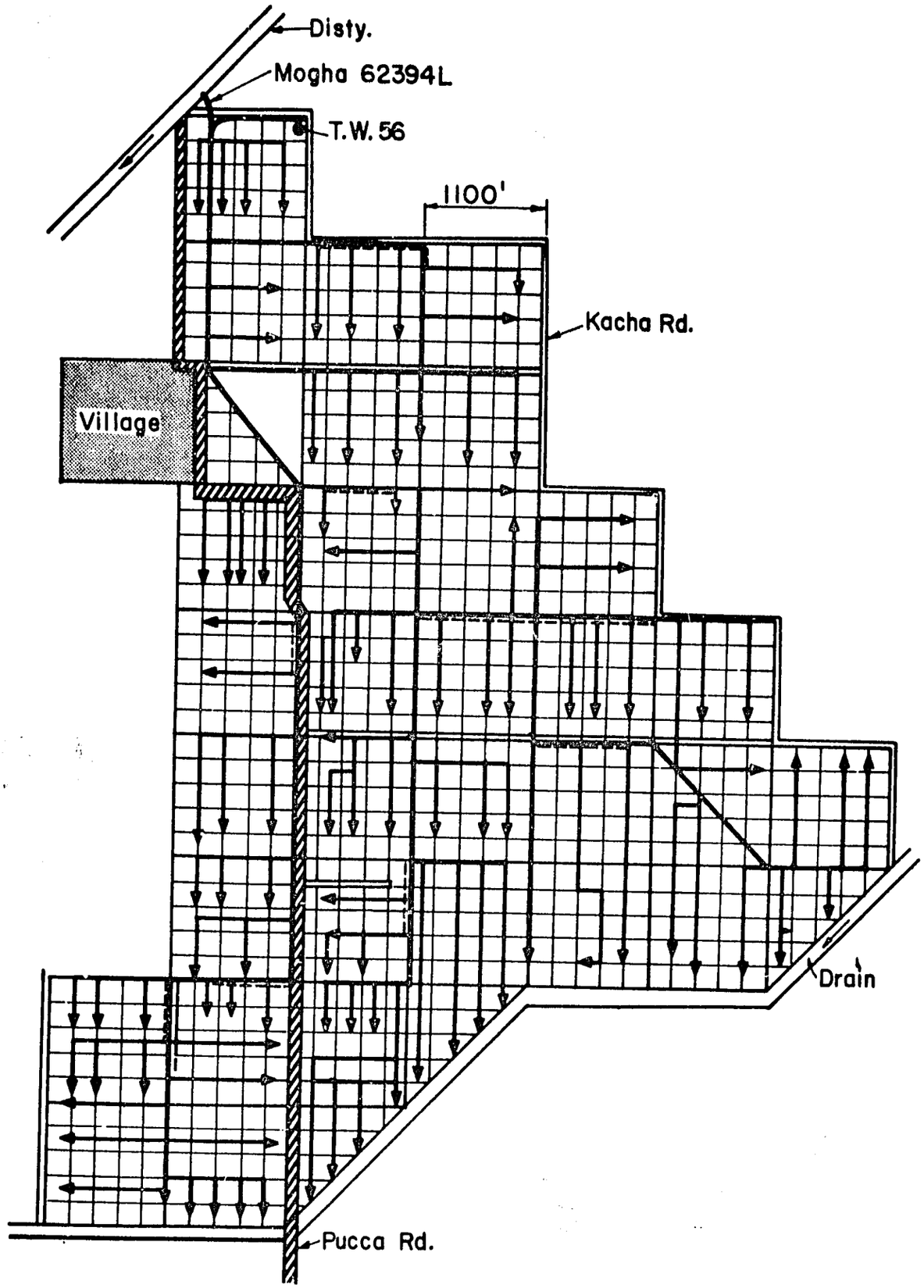

Figure 1. General plan of TW 56 watercourse. (Dark lines leading to arrows are watercourses. Dashed lines indicate parallel watercourses which were eliminated in the improved watercourse.)

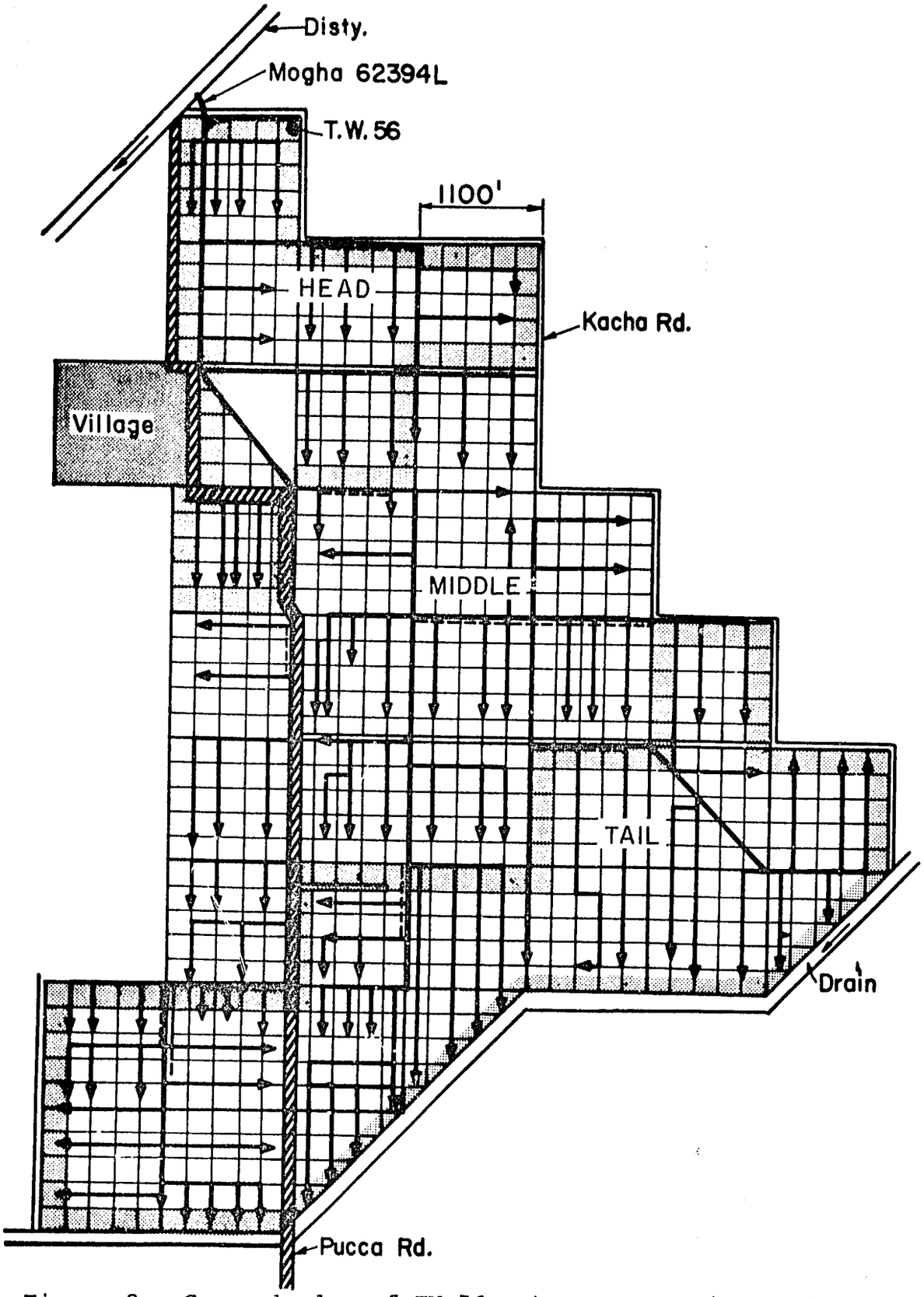

Figure 2. General plan of TW 56 watercourse. (Dark lines leading to arrows are watercourses. Dashed lines indicate parallel watercourses which were eliminated in the improved watercourse.)

substantial percentage. It is of interest to see how the land utilization and cropping intensities change as the amount of water available in the watercourse changes. The cropping intensity data for the past rabi and kharif seasons were gathered both from the Revenue Department records at the XEN* office in Rasul and also from a crop survey for the kharif season. The crop acreages for kharif 74 are presented in Table 5.

Table 5

Cropping Averages - Kharif 1974

Crop	Number Kanals	Number Acres
Sugarcane	533.25	66.66
Cotton	1299.25	162.41
Garden	1287.00	160.88
Garden (w/fodder)	188.22	23.53
Garden (w/vegetables)	106.00	13.25
Bajra and Jowar	167.50	20.94
Fodder	1031.25	128.91
Vegetables	213.00	26.63
Maize	20.00	2.50
Rice	194.50	24.31
Tobacco	18.50	2.31
Hemp	15.25	1.90
Total	5073.72	634.21
Cropping Intensity		70%

The cropping intensity for the kharif 74 cropping season was 70% with a wide variety of crops. The dominant crops (over 54%) were garden, cotton, and fodder. The crop intensities as they are distributed along the watercourse are detailed in Table 6.

*XEN - Executive Engineer

Table 6

Watercourse Distribution of Cropping Intensities Kharif 74

	Head	Middle	Tail
Number of Acres	182.8	337.5	407.8
Cropping Intensity	72.1	70.3	52.2

These reflect a decline in cropping intensity from the head to the tail. This decline is at least partially a function of the water availability.

The crop acreages for rabi 74-75 are detailed in Table 7.

Table 7

Crop Acreages - Rabi 74-75

Crop	Number of Kanals	Number Acres
Wheat	2305.25	288.15
Garden (Citrus)	940.00	117.50
Garden (w/wheat)	153.25	19.16
Garden (w/fodder)	754.25	94.28
Fodder	656.25	82.03
Pulses	31.25	3.91
Vegetables	14.25	1.78
Tobacco	1.25	0.15
Total	4855.75	606.96
Cropping Intensity		67.50%

The cropping intensity for the rabi 75 cropping season was 67.5% with the bulk of that (over 85%) consisting of wheat and citrus crops.

The average rabi cropping intensities as related to head, middle and tail on the watercourse are in Table 8.

Table 8

Watercourse Distribution of Cropping Intensities Rabi 74-75

	Head	Middle	Tail
Number of acres	182.8	337.5	407.8
Cropping Intensity	73.5%	70.25%	61.94%

Since availability of water does much to determine cropping intensity, it is apparent that the head and middle far dominate the watercourse in terms of available water.

Similar data taken from the Patwari* field records for Kharif 1975 are provided in Table 9.

Table 9

Crop Acreages - Kharif 75

Crop	Number Kanals	Number Acres
Sugarcane	408.75	51.09
Cotton	1140.25	142.53
Rice	107.00	13.38
Garden (Citrus)	2086.00	260.75
Lucerne	272.75	34.09
Pulses	15.50	1.94
Vegetables	24.00	3.00
Melons	349.00	43.60
Tobacco	50.50	6.31
Hemp	20.75	2.59
Bajra	814.50	101.80
Jawar	239.44	29.93
Maize	462.00	57.75
Total	5990.44	748.80
Crop Intensity		83%

*Patwari - Water Revenue Official

According to the Patwari records the TW 56 watercourse had a cropping intensity for Kharif 1975 of over 83%. However, a field survey was carried out by a member of the Mona extension staff and his findings are presented in Table 10.

Table 10

Cropping Acreages - Field Survey - Kharif 75

Crop	Number Kanals	Number Acres
Sugarcane	325.26	40.66
Cotton	1201.50	150.19
Rice	147.60	18.45
Maize or Bajra	648.00	81.00
Garden	1818.00	227.25
Garden (w/crop)	211.50	26.44
Vegetables	5.00	0.62
Lucerne	196.00	24.50
Melons	36.00	4.50
Total	4588.86	573.61
Cropping Intensity		63.8%

The data in Table 10 indicates a cropping intensity for kharif 1975 of almost 64%, which is 23% lower than the 83% cropping intensity from the XEN records. Part of this discrepancy may be explained by the date of the field survey (late October) as some of the crops were already off the fields, but the discrepancy in acreages of crops still in the fields is human error from one or both of the data sources.

Using the field survey records it is possible to examine the distribution of cropping intensities for kharif 1975. These are presented in Table 11.

Table 11

Watercourse Distribution of Cropping Intensities Kharif 75

	Head	Middle	Tail
Number of Acres	182.0	337.5	407.8
Cropping Intensity	69.3%	68.3%	56.0%

Again these reflect a decline in cropping intensity along the watercourse.

Direct field studies were carried out in January, 1976, to determine the cropping intensity for Rabi 1975-76. The results of this survey are summarized in Table 12.

Table 12

Crop Acreages - Field Survey - Rabi 1975-1976

Crop	Number Kanals	Number Acres
Wheat	2677.50	334.59
Berseem	840.33	105.04
Gram	31.50	3.94
Sugarcane	218.25	27.28
Garden	983.25	122.91
Garden (w/wheat)	301.50	37.69
Garden (w/fodder)	803.25	100.41
Lucerne	54.75	6.84
Vegetables	60.00	7.50
Total	5970.33	746.20
Cropping Intensity		83%

Table 12 indicates a Rabi 1975-76 cropping intensity of 83%. This reflects a 30-acre increase in garden from Rabi 1974-1975, as well as a 46-acre increase in wheat acreage. The distribution of cropping intensities along the watercourse are detailed in Table 13.

Table 13

Watercourse Distribution of Cropping Intensities Rabi 75-76

	Head	Middle	Tail
Number of Acres	182.8	337.5	407.8
Cropping Intensity	79.0%	83.0%	77.0%

The increase in cropping intensity in the middle section of the watercourse primarily reflects additional acreages of garden.

Farm Size

The farms on TW 56 are predominantly owner-operated farms with only a small number of tenant-operated farms. The total number of owners, owner-cum-tenants, and tenants on TW 56 are listed in Table 14.

Table 14

Farm Tenure - TW 56 - Fall 1975

	Tenants	Owner-Cum-Tenant	Owner
Number	7	3	25
Percent of Total	20%	9%	71%

Over 70% of the farms are owner-operated with only 20% tenant-operated. These farms vary in size from 100 acres to 7 acres with an average size of approximately 25 acres. Table 15 contains the distribution of farm sizes.

Table 15

Farm Size (acres)	Number	Percentage of Farms
1 - 12	9	26
12.1 - 25	15	43
Over 25	11	31

From Table 15, it is apparent that the watercourse, while having most of the farms in the range of 12.1 - 25 acres, has a significant percentage of the farms over 25 acres. In fact, there are six farms (17%) that have 50 or more acres or so, in terms of the national average farm size (approximately 12 acres), this watercourse has larger farm units. In terms of fragmentation, this watercourse is also atypical. Over 62% of the farms are a single unit and the average for the entire watercourse is less than 2 fragments per farm. Data related to farm fragmentation is in Table 16.

Table 16

Number of Fragments	Number of Farms	Percentage
1	22	63%
2	7	20%
3	4	11%
4	1	3%
Over 4	1	3%

The small number of fragments and large farm sizes indicate that the farms on TW 56 can be operated as larger units with more economies of scale in terms of equipment use and manpower utilization efficiency. This is again not typical of the majority of the watercourses in Pakistan.

The distribution of the size units along the watercourse is one of the variables often correlated with the tendency of finding more prosperous farmers closer to the head of the watercourse. In order to explore this the size of the units were compared to the location. These data are in Table 17.

Table 17

Farm Size (acres)	Head		Middle		Tail	
	Number	Percent	Number	Percent	Number	Percent
1.0 - 12	0	0%	4	11%	5	14%
12.1 - 25	2	5%	2**	5%	12**	32%
Over 25	2*	5%	6*	16%	4	11%

*Note: One 50-acre farm is both in Head and Middle and is double counted.

**Note: One 18-acre farm is both in Middle and Tail and is double counted.

From the table it appears that the larger farms are not clustered near the head, but tend to dominate the middle and tail of the watercourse. Therefore, for this watercourse, size of holding is not positively correlated with distance from the mogha.

Farm Labor

The majority of the farms are owner-operated and a large percentage of the farm labor is family labor. Some of these farms are joint farms with brothers or other relatives. The number of joint farms are detailed in Table 18.

Table 18

Joint Farms and Number of Partners

Total Number of Farms	Number of Farms Joint Operated	Total Number of Partners	Number of Acres
36	8	22	254.5

In addition to partners the farmers are also assisted by their children and permanent hired laborers. Table 19 contains the data relevant to permanent hired labor.

Table 19

Permanent Hired Labor

Total Number of Farms	Number with Permanent Hired	Number of Men	Number of Acres	Acres per Hired Labor
36	23	51	652.75	12.8

The normal wage payment practices on TW 56 is to pay the permanent laborer a set number of mounds of wheat per year and also to provide roti, cloth, some tobacco and shoes annually. The standard for TW 56 in 1975 was approximately 25 mounds of wheat plus about 770 Rs. worth of roti, etc. The average wage, when calculating wheat at its fixed market price of 37.5 Rs/md, was 1,706 Rs/year. Depending upon the assumptions made concerning total number of hours worked in a year, the hourly wage for permanent hired labor ranges from 0.70 Rs/hour to 1.00 Rs/hour.

Casual hired labor is needed mainly during harvest time but they may be used for weeding or other such tasks during the cropping season. However, the use of casual labor seems to be much more farm size specific than the use of permanent hired labor. Table 20 presents the number of hours of casual hired labor.

Table 20

Casual Hired Labor

Number of Farms	Number Using Casual Labor	Total Number Days Used	Number of Acres	Number Days per Acre
36	17	3,737	438.75	6.9

The average wage for casual hired labor was very consistant across the whole watercourse at 8 Rs/day, with only two farmers paying 10 Rs/day.

Although during much of the year labor is overly abundant, certain times of the year, particularly during harvest time, labor is a scarce resource. The percentages of farmers finding casual labor scarce during the different months are in Table 21.

Table 21

Scarcity of Casual Labor by Month

(Percentage of casual labor users claiming scarcity for that month)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
15%	15%	20%	55%	85%	70%	30%	20%	25%	45%	50%	45%

The months of April, May and June (harvest and threshing time for wheat) and the months of October, November, and December (harvest and threshing time for rice) are the times when casual labor is scarce. However, it is interesting to note that even during the scarce seasons not all farmers were having difficulty obtaining casual hired labor.

Casual labor is distributed along the watercourse with a definite bias toward the head and middle. Out of the 3,737 total days used, 580 of those were used on the head and 2,248 were used in the middle. Over 75% of the casual labor days were used on the head and middle of the watercourse.

Crop Yields

The major crops found on the watercourse at TW 56 are wheat, cotton, citrus, sugarcane and fodder. With a sugarmill at Bhawal (approximately 9 miles away) and a large contingent of citrus contractors, sugarcane and citrus are the most viable market crops produced on TW 56. Primarily due to poor yields and a depressed market, cotton is not as

important a crop and is being replaced by citrus. The relative changes in acreage of major kharif crops over the last year are presented in Table 22.

Table 22

Crop Acreage Changes Kharif 1974 to Kharif 1975

Crop	1974 Acreage (Acres)	1975 Acreage (Acres)	Change (Acres)	% Increase or Decrease
Sugarcane	66.66	53.75	-12.91	-19%
Cotton	162.41	143.50	-18.91	-12%
Citrus (all)	197.56	260.75	+63.13	+32%

Both cotton and sugarcane acreage are declining while citrus acreage has increased by 32% in the last year alone. As mentioned previously, cotton yields are declining and are insufficient to make cotton an economically competitive crop. Cotton is mainly now being cultivated for domestic use. The decline in sugarcane, however, cannot be explained solely in terms of economic factors but must be also a result of physical and institutional factors. This will be explored further in the next section.

The yields of the crops vary considerably along the watercourse both in terms of total yields and in terms of yield distribution along the watercourse. Table 23 lists the average yield data for the major crops on TW 56.

Table 23

Average Crop Yields and Ranges 1974-1975

Crop	Highest Yield	Lowest Yield	Average Yield
Sugarcane	400 Mds/Ac	200 Mds/Ac	268.3 Mds/Ac
Rice	25 Mds/Ac	5 Mds/Ac	17.7 Mds/Ac
Wheat	60 Mds/Ac	15 Mds/Ac	29.8 Mds/Ac
Citrus*	7000 Rs/Ac	1000 Rs/Ac	3420.0 Rs/Ac
Cotton	10 Mds/Ac	1 Mds/Ac	5.6 Mds/Ac
Fodder	400 Mds/Ac	100 Mds/Ac	205.0 Mds/Ac

*Citrus is sold on a Rs/Acre basis.

Wheat yields are quite good compared to the overall average for Pakistan, but cotton, rice, sugarcane, and fodder are all far below potential. The variation of these yields for the major crops along the watercourse is presented in Table 24.

Table 24

Distribution of Average Yields along Watercourse

Crop	Head	Middle	Tail
Rice	20.30 Mds/Ac	13.90 Mds/Ac	14.10 Mds/Ac
Wheat	47.00 Mds/Ac	28.80 Mds/Ac	24.35 Mds/Ac
Cotton	8.75 Mds/Ac	6.10 Mds/Ac	5.20 Mds/Ac
Sugarcane	400.00 Mds/Ac	237.50 Mds/Ac	252.60 Mds/Ac

From Table 24 it is apparent that the yields are highest toward the head of the watercourse and tend to decline as the distance from the mogha increases. Since the soil is generally the same type throughout the entire watercourse these declines in yields are partially a function of the availability of water. This factor can be documented by the decline in number of irrigations along the watercourse. Table 25 lists the average number of irrigations for the major crops with respect to watercourse location.

Table 25

Average Number of Irrigations by Crop and Watercourse Locations

Crop	Head	Middle	Tail	Overall
Wheat	4.33	3.25	2.36	2.76
Rice	10.33	7.13	10.08	9.09
Sugarcane	5.00	6.22	6.06	5.85
Citrus	3.50	5.29	3.21	3.87
Fodder	7.00	6.00	5.53	5.32
Cotton	2.50	2.22	1.44	1.67

Here, except for citrus and sugarcane, the average number of irrigations varies directly in proportion to the distance from the mogha.

The value of an irrigation in terms of yields can be calculated from Tables 25 and 26. These values are in Table 26.

Table 26

Mounds per Acre per Irrigation
(Mds/Ac ÷ Average # Irrigations)

Crop	Head	Middle	Tail	Overall
Rice	1.97	1.95	1.40	1.94
Wheat	10.85	8.86	10.32	10.79
Cotton	3.50	2.75	3.61	3.35
Sugarcane	80.00	38.18	41.68	45.86

From this table it is apparent that the value of an irrigation is not directly a function of the distance from the mogha. In fact in many cases the value of an irrigation increases as distance from the mogha increases. This can be explained by the fact that since less water is available at the tail of the watercourse, it has a higher value per unit. Too much water at the head of the watercourse often leads to fertility leaching. Of course, this generalization is also affected by management practices and this is not uniform across the watercourse.

Another factor directly affecting yields is the quality of the seed stock used. Data related to the source of seed supply is listed in Table 27.

Table 27

Seed Source

Crop	Provided by Self		Local Farmer Provided		Market Purchased	
	Number	Percent	Number	Percent	Number	Percent
Wheat	33	94%	2	6%	0	0%
Cotton	21	65%	6	19%	5	16%
Rice	16	76%	4	19%	1	5%
Sugarcane	17	68%	8	32%	0	0%
Citrus	0	0%	5	24%	16	76%
Fodder	17	47%	7	19%	12	34%

Even though TW 56 is located on an improved road, by far the bulk of the seed is provided by local farmers or is provided by the farmer himself. Only citrus, a crop that requires delicate grafting, is over 50% purchased from an outside source. The problems associated with mixing of seeds, rusts, diseases, and pests are all multiplied by the continued use of local seeds. A significant part of the low yields of crops such as cotton and sugarcane can be explained by the use of low quality local seed.

Marketing and Prices

The farmers that operate land on TW 56 market their products in Bhawal, in the Village 10ML, or directly in the fields. Sugarcane and rice are mainly marketed in Bhawal while cotton and wheat are marketed in Bhawal and in the village. Citrus is almost completely sold on contract directly in the field. Only two farmers with small orchards marketed their own citrus. Bhawal is about seven miles from TW 56 on paved roads, so marketing in Bhawal is not a particularly difficult or expensive process.

TW 56 is in the mill area for the Noon Sugarmill at Bhawal and, therefore, according to the Federal Sugar Act (1947) the farmers must market at least 80% of their sugarcane at the mill. Since the mill has a total monopoly on the sugarcane within the mill area, the management tends to use this sugarcane as a production line stabilizing resource. That is, they purchase all the sugarcane they can from outside of the mill area and when this source is not sufficient to meet the mill requirements they accept sugarcane from the mill area. This type of scheduling practice penalized the the mill area farmers as they are not able to harvest their sugarcane until the mill is willing to accept it, which may be as long as two months after the farmer wanted to take it out of the field. Combined with a 24-28 hour que outside the sugarmill, sugarcane becomes a troublesome crop that is often not worth the effort. Although sugarcane has the potential to be a very good cash market crop, the farmers are not increasing their acreage.

Citrus is sold directly to contractors either at flowering or budding. The contractor and farmer agree to a fixed price for the entire orchard and after that the farmer's responsibility is only to irrigate the orchard and spray it if necessary. The contractor provides a chowkidar* to guard the fruit once it begins to ripen and makes all arrangements for harvesting and marketing the crop. Therefore, in terms of effort involved in production, citrus is one of the easiest and simplest crops to cultivate. The farmer could, of course, receive more money if he marketed his crop himself and eliminated the middleman, but then he assumes the additional problems associated with harvest labor, transportation, and

*Chowkidar - watchman

market variation. For the majority of the citrus farmers on TW 56, the added income does not exceed the managerial costs and they are quite satisfied to stay with the contractor system.

Cotton is marketed both in Bhawal and to local buyers in the village. The prices for cotton are quite similar in Bhawal or the village. They vary more in terms of quality of the product than from market location. Some fodder is also marketed in Bhawal, but the bulk of the fodder is consumed on the farm to maintain livestock.

The prices received for the crops are usually quite consistant with the major exceptions being citrus. The government-fixed prices for wheat, sugarcane, and rice more or less dictate the level of price received, although there are some fluctuations from the official prices. Table 28 contains the average prices received in 1974-1975 as well as ranges for the major crops.

Table 28

Average and Max/Min Prices, 1974-1975

Crop	Max. Price Received	Min. Price Received	Average Price Received
Wheat	38.0 Rs/Md	30.0 Rs/Md	37.0 Rs/Md
Cotton	100.0 Rs/Md	68.0 Rs/Md	76.5 Rs/Md
Garden	700.0 Rs/Md	600.0 Rs/Ac	342.0 Rs/Ac
Rice	45.0 Rs/Md	30.0 Rs/Md	38.0 Rs/Md
Sugarcane	5.0 Rs/Md	4.25 Rs/Md	4.5 Rs/Md

Fertilizer Usage and Production Costs

The application rates of fertilizer varies both by crop type and by farm location. Table 29 presents the mean and modal fertilizer application rates for the major crops.

Table 29

Fertilizer Application Rates 1974-1975

Crop	Mean (lbs. N/Ac)	Mean (lbs. P/Ac)	Mode (lbs. N/Ac)	Mode (lbs. P/Ac)
Fodder	9.00	2.00	0.00	0.00
Sugarcane	63.00	21.70	50.00	0.00
Rice	44.25	3.00	50.00	0.00
Cotton	29.53	5.63	0.00	0.00
Wheat	65.91	21.21	50.00	0.00
Garden	33.04	18.26	0.00	0.00

Wheat is the most heavily fertilized crop, but even here the mode is only one bag per acre. The majority of crops are underfertilized in terms of nitrogen and all the crops are underfertilized in terms of phosphorous.

The location of the farm on the watercourse is also correlated with the application rate of fertilizer. This is illustrated in Table 30.

Table 30

Fertilizer Application Rate by Location
Major Crops TW 56 1975-1975

Crop	Head (lbs. N/Ac)	Middle (lbs. N/Ac)	Tail (lbs. N/Ac)
Wheat	96.67	56.11	61.43
Rice	46.67	36.88	45.00
Cotton	60.00	29.50	28.10
Sugarcane	70.00	54.29	55.88

All the crops at the head of the watercourse are more heavily fertilized than are the crops at the middle or the tail of the watercourse. This is possibly a result of the fact that the farmer is certain of a good water supply and is willing to invest in fertilizer. The farmers at the tail of the watercourse are uncertain about their water supply and are often unwilling to invest in fertilizer.

The production costs for the major crops vary more by production practices than by location on the watercourse,

although the additional investment in fertilizer does tend to raise the production costs at the head of the watercourse. However, these are easily recovered by the increased yields. If a farmer owns a tractor his production costs are different than if he only uses bullocks.

Using the data gathered from the field survey, it is possible to build a set of production cost budgets for the major crops (Table 31). These budgets are not precisely accurate as the questionnaire used was too brief to be completely precise. However, it is felt that these budgets are quite representative of the average production costs for the major crops. These budgets include the variable and fixed costs except land costs, management, and risk.

Table 31

Production Costs for Major Crops
TW 56 1974-1975 (Rs/Acre)

ACTIVITY	CROP				
	Wheat	Cotton	Rice	Sugarcane	Garden
Seed	37.50	15.00	10.00	125.00	100.00
Fertilizer	130.68	52.70	70.80	74.50	220.00*
Labor	77.51	63.00	45.00	92.00	75.00
Bullock Power	185.00	164.00	160.00	214.00	208.00
Taxes	35.00	66.00	64.00	120.00	110.00
Harvest Costs	112.00	61.20	86.00	120.00	------
Artesians & Tools	31.40	22.35	22.22	39.78	75.65
FYM	20.00	25.00	25.00	30.00	100.00
Miscellaneous	32.95	23.47	23.33	41.76	42.68
TOTAL	662.04	492.71	506.35	857.04	931.33

*Includes cost of spray

Taking the data from Table 31, it is possible to determine the net returns to land, risk, and management. These figures are detailed in Table 32.

Table 32

Average Returns to Land, Risk and Management - TW 56

1974 - 1975

Crop	Yield (Mds/Ac)	Price (Rs/Md)	Gross Return (Rs/Ac)	Costs (Rs/Ac)	Gross Margin (Rs/Ac)
Wheat	29.8	37.0	1102.60	662.04	+440.56
Cotton	5.6	76.5	428.40	492.71	-64.31
Garden		3420.0 Rs/Ac		931.33	+2488.67
Sugarcane	268.3	4.5	1207.35	857.04	+350.31
Rice	17.7	38.0	672.50	506.35	+166.15

It must be emphasized that these production returns are not completely compatible since crops such as sugarcane and citrus are in the field both rabi and kharif seasons and only yield a single return annually. Crops such as wheat, rice, fodder and, to some extent, cotton only require a single season and thus yield a double return from the same acre for the year. For example, an acre of sugarcane will return 330.31 Rs. to land, risk and management, while an acre of rabi wheat followed by kharif rice will return 561.81 Rs. to land, risk and management. With the ability to double crop an acre of land, the return from a crop that required an entire year must be greater than the return from a single rabi or kharif crop. Cotton, while classified as a kharif crop, is not harvested in time in the fall to follow with rabi wheat and, consequently, reduces the potential per acre return.

Citrus requires five to six years before the orchard is mature enough to be classed as a full producing crop. During the first four-five years the farmer does not receive any income from his orchard and must intercrop with wheat, fodder or vegetables in order to gain some return from his land.

The production practices for the crops are dependent upon low cost labor and bullock power. However, there are seven tractors located on the watercourse. Table 33 lists the details of these tractors.

Table 33

Tractor Statistics and Hours

Make	No.	H.P.	Hours Run Annually	Annual Expenditures	Fuel Consumed
Ford 4000	1	55	1040	8000 Rs	54 barrels
Ford 4000	1	62		6000 Rs	
Ford 4000	1	55		4000 Rs	
Byloss	1	55	400	10000 Rs	1000 gallons
Byloss	1	55	450	12000 Rs	1100 gallons
Int'l 1HB450	1	55	960	20000 Rs*	50 barrels
Int'l	1	33	240	8000 Rs	600 gallons
TOTAL	7		3090	68000 Rs	7280 gallons

*includes fuel

Two tractor owners did not provide complete data on their machines and annual operating costs. From the data provided and from other follow-up discussions, the average annual number of hours a tractor is used on TW 56 is estimated at 700 Hrs/year. If amortized over a ten-year life using current fuel and maintenance costs, this works out to be approximately 38.5 Rs/hour. Table 34 compares the production costs for wheat using bullock power and tractor power.

Table 34

Production Costs for Wheat 1974-1975

Bullock Power vs. Tractor Power (Rs/Acre)

Activity	Bullock Power	Tractor Power
Seed	37.5	37.5
Fertilizer	130.7	130.7
Labor	72.5	30.5
Power	185.0	192.5
Taxes	35.0	35.0
Harvest Costs	112.0	112.0
Artesians and Tools	31.4	60.4
FYM	20.0	20.0
Miscellaneous	32.9	32.4
TOTAL	662.0	656.0

From Table 34 it is apparent that the labor savings from using the tractor compensates for the 38.5 Rs/Hour costs of the tractor compared to 2.2 Rs/Hour cost of the bullock (Appendix B). However, this table does not show the time savings that is possible with the tractor compared to the bullocks. Quite often this time factor may be as important or more important than the production costs savings.

Irrigation Practices

The farmers on TW 56 were surveyed to determine what factors were important in terms of deciding when to irrigate and during irrigation when to stop the water. The farmers were first asked to tell which factor was most important to consider when irrigating a crop. Table 35 tabulates their responses.

Table 35

When To Irrigate

Factor	Number Positive Responses	Percentage of Total
Last date of irrigation	0	0%
Appearance of crop	30	79%
Inspecting soil by digging	0	0%
Appearance of the upper soil surface	6	16%
Whenever water is available	2	5%

Seventy-nine percent of the farmers irrigate by appearance of the crop. None of the farmers indicated that they inspect the soil where the roots are to determine if the crop needs irrigation, yet this is where the water supply for the plants is stored.

The farmers were asked to state how they decide when to stop applying water to a field. The compilation of these responses are in Table 36.

Table 36

When to Close the Water

Criteria	Number Positive Responses	Percentage of Total
When water covers all the high spots	9	24%
When water has reached the next corner	14	37%
When you see sufficient depth of water	9	24%
By knowing the exact time for the area	6	15%

The farmers close the irrigation water supply both by depth and by time. None of these methods necessarily provide the amount of water actually required by the crop and two of them, covering the high spots and waiting until the water reaches the next corner, almost certainly lead to overirrigation and wasted water.

Using the data provided by the farmers concerning area irrigated per turn, analysis was made to check the correlation betweenthe distance to the mogha and the number of acres irrigated per hour.

Linear regression provided the following curve:

$$Y = 0.789 - 0.037X \quad r = 0.453 \quad r^2 = 0.205$$

where Y = Acres Irrigated/Hour and X = squares from mogha. This relationship is significant at the 1% level but the number of squares from the mogha only explains 20% of the variation in number acres irrigated per hour. Another way to look at this equation is that for every 1100 feet from the mogha the farmer is able to irrigate 5% less acreage per hour.

The farmers were also surveyed concerning their future cropping patterns provided the watercourse improvement project doubles the quantity of water available for irrigation. Table 37 contains the farmers' responses.

Table 37

Changes in Cropping Intensities
Resulting from a Doubling of Canal Water

Crop	Acreage With Present Water Supply	Acreage After Double Water Supply	Percentage Increase Over The Present
Wheat	280.00	437.50	+56.25%
Cotton	137.40	183.50	+33.55%
Rice	24.42	96.50	+295.17%
Sugarcane	43.75	98.75	+125.71%
Citrus	222.00	336.50	+51.58%
Fodder	198.50	214.50	+8.06%
Vegetables	20.10	39.70	+97.51%
Total	926.17	1406.45	+51.86%

The farmers would increase their overall cropping intensities by over 50% if they had double the present water supply. Using the data in Table 37, the cropping intensity on TW 56 would go from around 148% to over 198%.

Future studies on TW 56 will determine if these estimates by farmers are accomplished both in terms of the water supplies and the acreage increases.

Private Tubewells

In addition to the canal water supplied by the mogha and the S.C.A.R.P. tubewell, there are six private tubewells located on the watercourse, of which five were active during 1974-1975. Three of the active tubewells rented out extra water at 10 Rs. to 20 Rs. per hour. All of the tubewells are fairly recent installations with the oldest one installed in 1971, and the most recent in 1975. The average installed cost varies from 4000 to 13000 Rs., with the average about 9000 Rs. Fuel and oil costs varied from 3000 to 500 Rs., with the average around 1500 Rs. The number of hours operated varied from 600 Hrs./Year to 190 Hrs./Year, with the average being 340 Hrs./Year. Using this data, the acre-foot costs of pumping private tubewell water are developed in Table 38.

Table 38

Private Tubewell Production Costs

Equipment	Life (Years)	Costs (Rs.)	10% Amortization (Rs.)
Pump and Engine	12	5500	807.18
Pipe and Filter	10	1800	292.95
Bore and Pit	9	700	121.55
House	12	500	73.38
Discharge Box	12	500	73.38
Total Fixed Costs		9000	1368.44
Average Operating Expenses - Fuel, oil, and maintenance			1500.00
Average Operator Labor			340.00
Total variable costs			1840.00
Total annual costs			3208.44
Average acre-feet pumped (340 hours @ 1.33 cusecs)			37.68
Average cost of an acre-foot of water at the outlet pipe			85.14 Rs./A-F

The costs of water produced from the private tubewells is about 85 Rs./acre-foot, which is almost exactly the same rate at which water is rented. When delivery losses are included, farmers are paying about 120 Rs. per acre-foot delivered to the field. This is extremely high compared to the canal water costs which are based on a fixed by crop per acre rate. These rates are listed in Table 39.

Table 39

Abiana Rates TW 56 1974-1975

Crop	Single Rates Rs/Ac	Double Rates Rs/Ac
Sugarcane (perennial)	32.80	65.60
(non-perennial)	31.20	62.40
Garden & vegetables (sanctioned)	25.60	51.20
(non-sanctioned)	20.80	41.60
Tobacco, cotton	16.80	33.60
Rice	16.00	32.00
Melons, fibers	14.40	28.80
Oil seed (Kharif)	12.00	24.00
Wheat, barley, oats	10.40	20.80
Maize	9.60	19.20

Since TW 56 is served both by canal water and public tubewell water, the farmers are required to pay double rates. However, even with double rates farmers on the head of the watercourse planting sugarcane will only pay a maximum of 20 Rs./acre-foot delivered and farmers at the tail probably pay no more than 60 Rs./acre-foot delivered. For crops such as wheat the canal water probably costs no more than 10 Rs./acre-foot delivered at the head or middle of the watercourse.

Appendix A

Tractor Costs Data

Assume a purchase cost of 70,000 Rs. with a salvage value after 10 years of 10,000 Rs. using the average of 700 hrs./year, the hourly costs are calculated at:

70,000 - 10,000 amortized over 10 years @ 10% = 9,765.00 Rs./yr.

Maintenance, fuel, oil, parts = 17,185.00 Rs./yr.

26,950 Rs./yr. - 700 hrs./yr. = 38.50 Rs./hr.

Bullock Costs Data (Per Pair)

Assume a purchase cost of 5,500 Rs. with a salvage value after 8 years of 500 Rs. Using an average of 857 hrs./yr., the hourly costs are:

5,500 - 500 amortized over 8 years @ 10%	=	937.20 Rs./yr.
Annual feed and miscellaneous costs	=	948.20 Rs./yr.
		1,885.40 Rs./yr.

1,885.40 Rs./yr. - 857 hrs./yr. = 2.2 Rs./hr.

Appendix 40

COMMUNITY AND IRRIGATION IN THE PAKISTAN PUNJAB--PHYSICAL AND SOCIOLOGICAL DIMENSIONS OF THE WATER MANAGEMENT PROBLEM[1]

David M. Freeman and Max K. Lowdermilk[2]

INTRODUCTION

The Problem and Approach

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

The central thesis of this paper, therefore, is that programs to improve the management of irrigation water must center

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1/The research reported in this paper was conducted under Contract AID/ta-c-1100 with the United States Agency for International Development. All reported opinions, conclusions or recommendations are those of the authors and not those of the funding agency or the United States Government. We wish to acknowledge the efforts of Professor Alan C. Early, Assistant Professor of Agricultural Engineering at Colorado State University and a member of the field party in Pakistan for his contributions to the gathering of the physical data pertaining to irrigation delivery and application efficiencies. In addition, the authors wish to acknowledge assistance with physical data analysis to Professor Gaylord Skogerboe, Codirector of the Colorado State University Water Management Research Program.

2/Respectively Associate and Assistant Professors of Sociology at Colorado State University, Fort Collins, Colorado 80523.

on the design and improvement of farmer irrigation organizations. After presenting the background and context of our research in Pakistan, this paper explores that thesis in the following manner:

1. First, selected data will be presented which reveals that irrigation in sample Punjabi villages and watercourses is characterized by low delivery and application efficiencies. (See Appendix A for a discussion of the sample and data collection methods.) The meaning of these data is that watercourses must be realigned and improved and that programs of land leveling are required. All of the many required components of an improved water management program must be focused on farmer organizations because it is only through such organizations that farmers can cooperate to improve and maintain their watercourses and deal effectively on a sustained basis with sources of knowledge, credit, and land leveling technology.

2. The analysis then turns to an examination of key components of Punjabi villages which are relevant to farmer water management decision-making on watercourses.

3. The paper proceeds to an investigation of existing patterns of water management behavior--patterns of farmer water trading, selling, stealing, and interactions with lower level irrigation officials.

4. Having noted that improvement in farmer water management must mean improvement in farmer organizations, the investigation probes into existing means by which village farmers cooperate to provide themselves with mosques and how they clean and maintain their watercourses. Each of these tasks require collective organization and we examine these facets of village life in the hope of discovering clues as to how farm organizations might be promoted.

5. After having examined the facts of village social life and after reviewing farmer patterns of managing water and cooperative organization, it becomes necessary to ask a difficult question: If one is to embark upon a water management improvement program, and if such a program requires meaningful farmer organization, how would one go about selecting those villages where farmers could be most responsive to programs of planned change in water management? In other words, which villages will be the most likely to support viable farmer water associations? Any answers to such questions must be highly tentative, but this last section of the paper will focus upon the outlines of an answer as best we can formulate it on the basis of findings to date.

Background and Context

The 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 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 more than 78,000 farm level watercourses. These structures, supplemented by over 100,000 private tubewells, provided an estimated 125-150 million acre feet of water for irrigation of about 35 million acres.

The overall pattern of water flow is from one of the major rivers--Jhelum, Cherab, Ravi, Sutlej, or Indus--to major and minor canals, through outlets (moghas) to watercourses (khals) to farmers' fields. The Irrigation Department provides a regulated discharge for each watercourse command area determined by water availability. Usually about one cubic foot of canal water per second (CUSEC) is provided for each 350 cultivated acres.

In contrast to the modern diversion facilities of the irrigation system, little attention has been given to the 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 watercourse 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 observations: (1) poorly constructed and maintained earthen delivery channels which are infrequently cleaned; (2) trees and phyraetophytes covering banks; (3) improper channel alignment and elevation; (4) excessive leaks and spills due to improper construction and lack of maintenance; (5) about one mile of field ditches per each 20 acres of land; and (6) unlevel small fields.[3] From the

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3/For more detailed descriptions of Pakistan watercourses see: Gilbert L. Corey and Wayne Clyma, Improving Farm Water Management in Pakistan. Water Management Technical Report No. 37. Fort Collins, Colo., Colorado State University, March 1975.

Wayne Clyma and Gilbert L. Corey, The Importance of Farm Water Management in Pakistan. Water Management Technical Report No. 38. Fort Collins, Colo., Colorado State University, March 1975.

canal outlet (mogha) to a typical farm field watercourse losses exceed 40 percent. In the fields, due to lack of water control and knowledge, farmers' application efficiencies are extremely low.

From the mogha outlet to the last farm on a watercourse, the Irrigation Department exercises little control or supervision except for collecting water assessments, levying fines for infractions of specified codes and settlement of major water disputes. The Irrigation Department, upon request of farmers, does establish a regulated (pucca) turn system for the distribution of water with a fixed turn system down the watercourse and its branches with specified weekly time periods for each farmer depending on his acreage.

Without such a request, farmers themselves devise their own informally regulated (katcha) rotation system. The maintenance, repairs, and cleaning of the watercourse main channels and field ditches are the sole responsibility of farmers.

THE WATER MANAGEMENT PROBLEM--SELECTED PHYSICAL DIMENSIONS

In essence, farmers in Pakistan can mismanage water in two domains:

1. The domain of the watercourse channel--to what extent is water lost to productive agricultural use by virtue losses in the delivery channel to the fields? Losses in the watercourse channels between the mogha outlet and farmers' fields are registered under the concept "delivery efficiency." Delivery efficiency, Ed, is defined as:

$$Ed = \frac{\text{(flow of water at farmer's field)}}{\text{(flow of water at mogha outlet)}} \times 100$$

2. The domain of field application--to what extent is water lost to productive agricultural use as a result of applying too much or too little water to crop root zones relative to crop needs. The measure, <u>field application efficiency</u>, Ea, is defined as:

$$Ea = \frac{\text{water stored in the root zone}}{\text{water applied to the field basin}} \times 100$$

Delivery losses in earthen channels are expected to be higher where the length of the run is longer, where soils are sandy, and where channels are lower than field elevations, creating "dead storage." If the main watercourse channel is too high in relation to the channel outlet, the pressure of water backing up against the mogha outlet will reduce the discharge. In earthen channels, losses are expected to increase in proportion to distance from mogha outlets to field outlets.

Where public and/or private tubewells discharge into ditches constructed only for traditional canal allotments substantial losses via spills can be expected. A total of 201 usable delivery efficiency evaluations were obtained on sixteen watercourses in ten villages located in five different agro-climatological zones, or cropping regions.

Behavioral factors affect delivery losses via patterns of watercourse construction, maintenance and repair. Poor maintenance results in silt deposits, excessive vegetation along channels, and rodent holes. Farmer's collective and individual actions are important factors in reducing such sources of loss.

As a result of such factors, farm delivery efficiencies for earthen channels around the world are quite low. A recent preliminary investigation in fifty irrigated areas of sixteen developing countries shows that farm delivery efficiencies of earthen channels constructed in sandy, sandy loam, silt and silty clay soils ranges from less than 50 to about 65 percent.[4]

The concept of application efficiency refers to the proportion of the water applied to the field basin relative to the water required as indicated by the amount of water stored in the plant root zone. The primary goal is to apply water as uniformly as possible over the field in order that the depth of application will approximate the soil moisture depletion on the crop root zone. The irrigation method used in Pakistan is the basin type, and factors that influence the application of irrigation water include the level of the field, length and width of basin, rate of discharge versus rate of infiltration, soil moisture depletion, temperature and evaporation, rooting depth of crop and leaching requirements. Two hundred and twendy-two usable field application evaluations were obtained from sample farmers representing 81 farm units.

Overall irrigation efficiency, a summary measure, can be computed from delivery and application efficiency data by multiplying the two sets of values.[5] Table I displays overall irrigation efficiency data for farm units by cropping regions, and reveals that from approximately 40 percent to over 75 percent of the water made available at the mogha outlet is not used productively due to losses in delivery and application.

In sum, then, large proportions of precious irrigation water are being lost in all sampled watercourses across all

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4/Bos, M. G., and J. Nugteren, On Irrigation Efficiencies. International Institute for Land Reclamation and Improvement. P. O. Box 45. Wageningen, The Netherlands, 1974. p. 25.

5/See Alan C. Early et al. Water Management Technical Report No. 45. Prepared under support of USAID Contract AID/ta-c-1100. Colorado State University. (Forthcoming, 1977)

cropping regions. Agricultural development will require watercourse improvement programs to reduce losses both as a result of deficiencies in watercourse channels and deficiencies in field application. Agricultural improvement programs must, as a minimum, be focused on watercourse realignment, compaction and/or lining, land leveling, and improving farmer access to sources of knowledge and credit.

Table 1. Irrigation efficiencies for all farm units by region.

Cropping regions	1 Ea Wt. mean	2 Ed Wt. mean	Irrigation efficiency 1 x 2
Lyallpur	77.4	68.2	52.8
Multan	92.6	53.5	49.5
Lahore	95.6	61.2	58.5
Sargodha	51.0	53.5	27.3
Gujranwala	44.7	55.5	24.8
Overall weighted means	76.1	56.6	43.1

Ea = Application efficiency

Ed = Delivery efficiency

THE WATER MANAGEMENT PROBLEM--SELECTED SOCIOLOGICAL DIMENSIONS

What is the sociological environment within which the physical problem of poor irrigation efficiencies is nested? The discussion begins with an examination of the central components of Punjabi village organization, and then proceeds to consider the existing system of farm water management--patterns of water purchasing, trading, stealing, and interactions with lower level irrigation officials. Building upon such bases, two questions are asked and tentatively explored:

1. Because watercourse improvements and land leveling represent "collective good" problems, how do farmers handle such problems with the existing village social structure? In particular, we inquire as to how farmers organize themselves to provide the "collective" goods represented by village mosques, and watercourse cleaning.

2. If improvement of irrigation efficiencies requires improved watercourses and land leveling among other things, and if the provision of such improvements represents a "collective goods" problem, the solution of which necessitates the organization of village farmers into associations which can supply watercourse improvements, land leveling, and other required inputs, what should be the criteria for selecting villages with social environments most conducive to the establishment and effective functioning of farmer water user associations?

I: COMPONENTS OF PUNJABI VILLAGE ORGANIZATION

Central building blocks of village social organization are biradari (brotherhood) networks which are combined into caste networks each faction of which--if there are petty factions--are linked to higher governmental authority through a numbardar (headman) (See Figure 1.) Villages are divided into two types of castes--agricultural and artisan. Artisan castes perform nonagricultural services for the village and members typically do not have access to cultivatable land. They will not be the focus of this study simply because they have little perceptible influence on water management as do the agricultural castes.

A. Biradari (Brotherhood) Groups

Biradari groups form the core of village social organization--obligations within this network typically carry more weight on individual farmer decision-makers than the obligations of any other social network. Headed by the eldest competent male who is answerable to higher village authorities for the conduct of his brotherhood associates, the biradari is

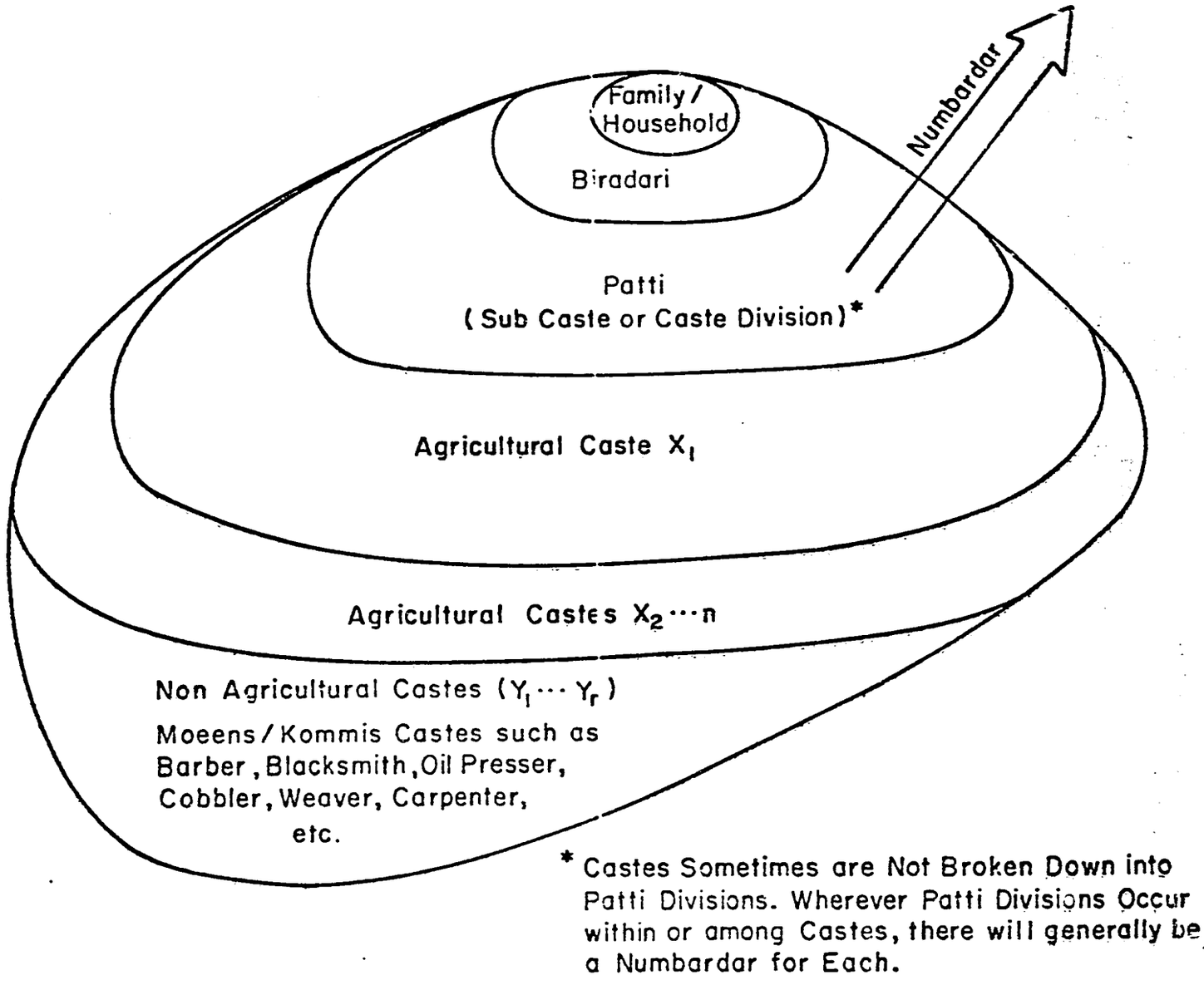

Figure 1 Village Social Organization

a political unit which can be expected to take common positions on issues and candidates for office, a social security unit which takes care of its own in the event of financial reverses, ill health and death, and it is a social unit affecting water management.

On the social side, almost three quarters of responding sample farmers maintain that they will not enter into a vangar relationship--a ceremonial relationship which implies more than acquaintanceship but a real rapport and willingness to ask for, and grant, favors--with people beyond their biradari group (See Table 2).

Participation in other ceremonies--circumcision, weddings, funerals--is also largely bounded by biradari lines as shown in Table 2. In intimate matters of selecting a marriage mate, less than 10 percent of responding farmers indicate that they would permit a marriage outside their biradari. A hypothesis, not established in this study, is that those who are less bounded by biradari lines are those who are either most or least influential. Those least influential are looking for opportunities to develop ties with more influential groups, and highly influential groups are looking for opportunities to cement alliances with other powerful biradaris.

General sociability, not requiring much commitment, is not bounded by biradari lines as evidenced by the fact that 90 percent of responding farmers (N=107) say they would smoke the hooka with others outside their biradari. However, willingness to jump biradari lines drops when matters involve a greater level of trust. Table 3. shows that almost half of responding farmers indicate that they would not borrow tools or implements from farmers not of their biradari group. Over three-quarters of the respondents say that they would cooperate to install a tubewell only within their biradari (See Table 3). As the required commitment in the social relationship increases, so it appears, does the propensity to stay within the biradari.

A 25 percent sample (N=167) of farmers on each watercourse was asked to rate each biradari group's influence in matters of watercourse cleaning and disputes relative to the other biradari groups on the same watercourse. (See Appendix B for details about the influence measure). Figure la displays the degree of influence attributed to the biradaris and reveals that the scores range from a low of 2 percent to a high of 100 percent of the potential influence score attainable if all respondents saw fit to give the highest possible influence score. What accounts for the variability of influence among biradaries? Because data was gathered only for a 25 percent sample of watercourse members--a strategy made necessary by limited time and resources--data about land holdings, number of members, and other factors

Table 2. Sample farmer indication of Biradari boundedness for vangar relationships, social ceremonies, and marriage relationships.

Would enter into Vangar Relationship only within Biradari				Would invite only Biradari members to social ceremonies of weddings, funerals, circumcision				Would enter into marriage relationship only within Biradari			
Yes		No		Yes		No		Yes		No	
%	N	%	N	%	N	%	N	%	N	%	N
73.6	95	26.4	34	60.9	56	39.1	36	90.1	82	9.9	9
N = 129				N = 92				N = 91			

Table 3. Sample farmer Biradari boundedness for tool/implement borrowing and cooperation in tubewell installation.

Would borrow tools/implements only within the Biradari				Would cooperate only with Biradari members in tubewell installation			
Yes		No		Yes		No	
%	N	%	N	%	N	%	N
48.9	66	51.1	69	77.8	42	22.2	12
N = 135				N = 54			

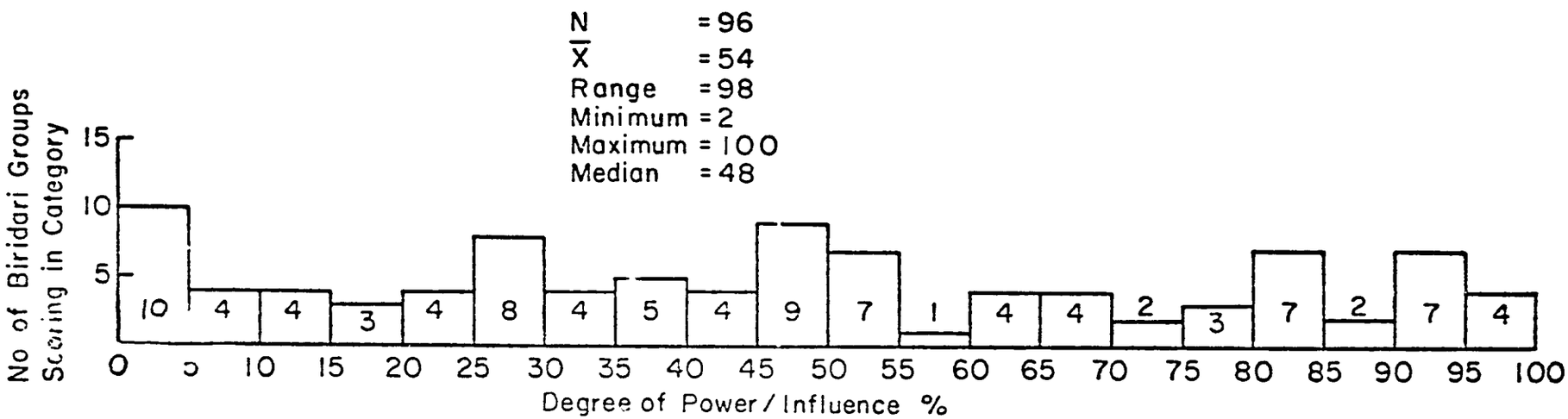

Figure 1a. Biridari Group Influence on Watercourse Cleaning and Disputes.

associated with biradaris is not available to analyze the factors which account for the variability of influence. However, the literature of village studies in Pakistan strongly suggests that there is a direct, strong, and positive association between amount of power/influence and the extent of land ownership. The more the land owned by a farmer or biradari group of farmers, the more the moeen (non-agricultural caste group) depends on the farmer, the more income and possessions, the greater the capacity to entertain important officials, and the more ability to make personal contacts with authorities which in turn increases influence, prestige, and power vis a vis others.[1]

In sum, then, biradari groups are basic units of social action and much decision-behavior is affected by biradari requirements and pressures. Biradaris vary widely in their power/influence as estimated by sample farmers.

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[1]See for discussions of power and influence in Punjabi villages: Inayat Ulah, Perspectives in the Rural Power Structure in West Pakistan. Development Research and Evaluation Group. United States A.I.D. Mission to Pakistan, April, 1963. Also, Muhammad Rafique Raza, Two Pakistani Villages: A Study in Social Stratification. Lahore, University of the Punjab, 1969. Much confusion still exists over precise meaning of concepts of power and influence. A variety of scholars have attempted to arrive at conceptually clear definitions. One of the most useful approaches, in our judgement, is that of Bachrach and Baratz who define power in terms of the ability to invoke the threat of sanctions upon another party in order to secure that party's compliance. Influence, on the other hand, has to do with securing compliance without employing the threat of sanctions, but through use of techniques of logical or moral persuasion. See, Peter Bachrach and Morton S. Baratz, Power and Poverty: Theory and Practice. London, Oxford, 1970, p. 17-38. Because the measures which were taken on the watercourse did not sort out to what a particular biradari or individual farmer's score was based on estimates of ability to control sanctions, this report consistently refers to power/influence. There is little doubt, however, that in the case of high scoring biradaris or individual farmers, that a major portion of the score probably can be attributed to control over sanctions--power--credit, contacts with officials, ability to withhold food or animal fodder in times of shortage, and ability to threaten armed force.

B. Caste Groups

Castes constitute a set of largely horizontal social strata, based on occupational specialization, which are ranked according to occupational prestige. Caste membership is inherited from one's family and is ascribed for life.[1]

Sample farmers represent seven major agricultural caste groups (See Figure 2). Non-agricultural castes, because members do not typically own farming land, exercise almost no influence in water management decision making. Moeen influence data were collected only on three watercourses in two villages and they uniformly obtained low scores from sample farmers (See Table 4).

Table 4. Non-agricultural Caste (moeen) power/influence in watercourse cleaning/disputes.

	Percent of Potential Score
Maximum Score	30
Minimum Score	0
Median Score	11
Modal Score	0
Mean Score	10.4
Range	0-30

N=24
Influence Scale from 0 to 100

Interviewers learned that those moeen groups which scored above zero on the influence scale owned some parcel of agricultural land with the exception of a religious leader (Pir) whose influence cannot be traced to landholding.

Agricultural caste groups of the same name receive highly variable power/influence scores across the sample of watercourses. Figures 3, 4, and 5 show the distribution of Arian, Jat, and Rajput scores across the watercourses where they are present. (It should also be stated that "other" in the graph may include a number of Jats or other agricultural castes. Some farmers reported subcastes which could not be identified even with the assistance of Punjabis.) Like the biradari groups, the existing sample data does not allow analysis of the sources of variability in caste power influence scores, but the hypothesis is that power/influence varies directly with land ownership.

C. The Numbardar

Numbardars are village headmen who represent the government to villagers. Usually the Numbardar position is occupied

[1]The most detailed treatment of caste in Pakistan is that of Sir Denzil Ibbetson, Punjab Castes. Lahore: Superintendent, Government Printing, Punjab, 1916. Reprinted by Mubarah Ali Publishers, 1974.

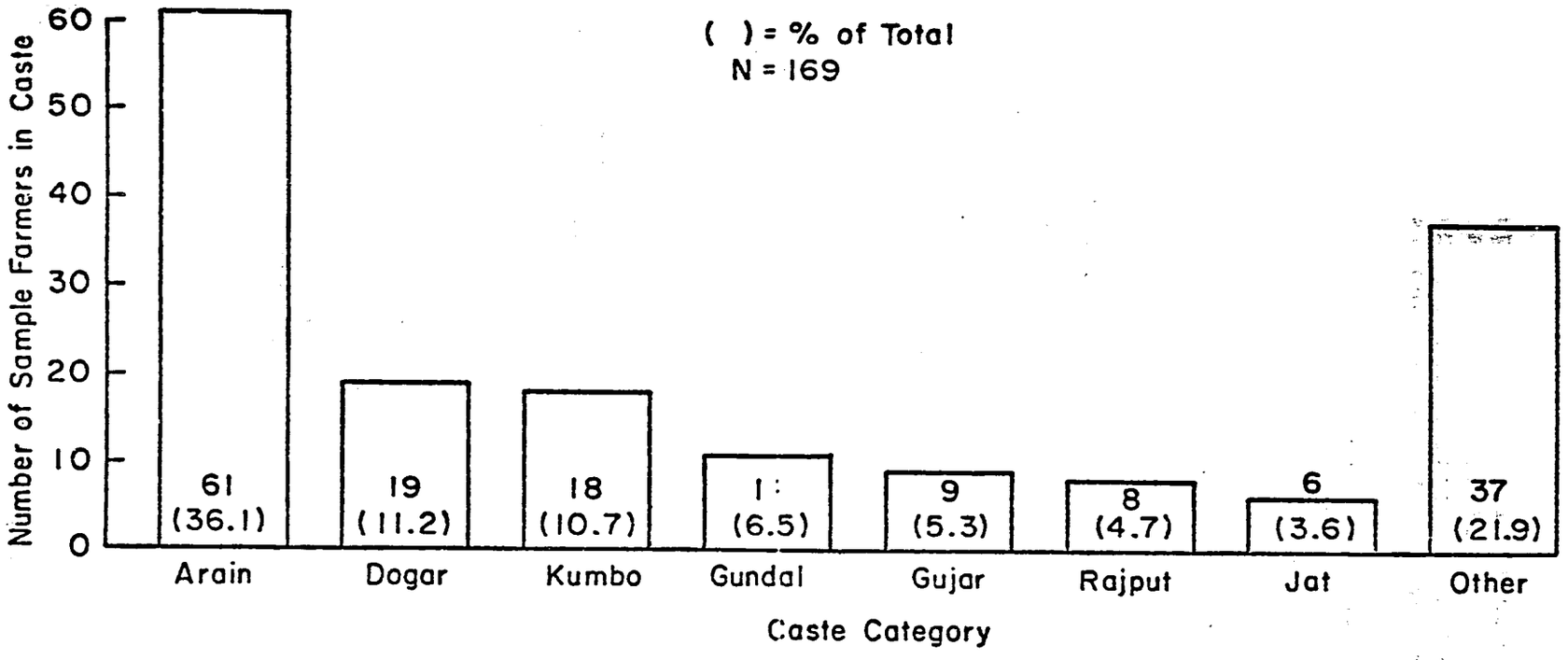


Figure 2. Sample Farmer Caste Group Distribution.

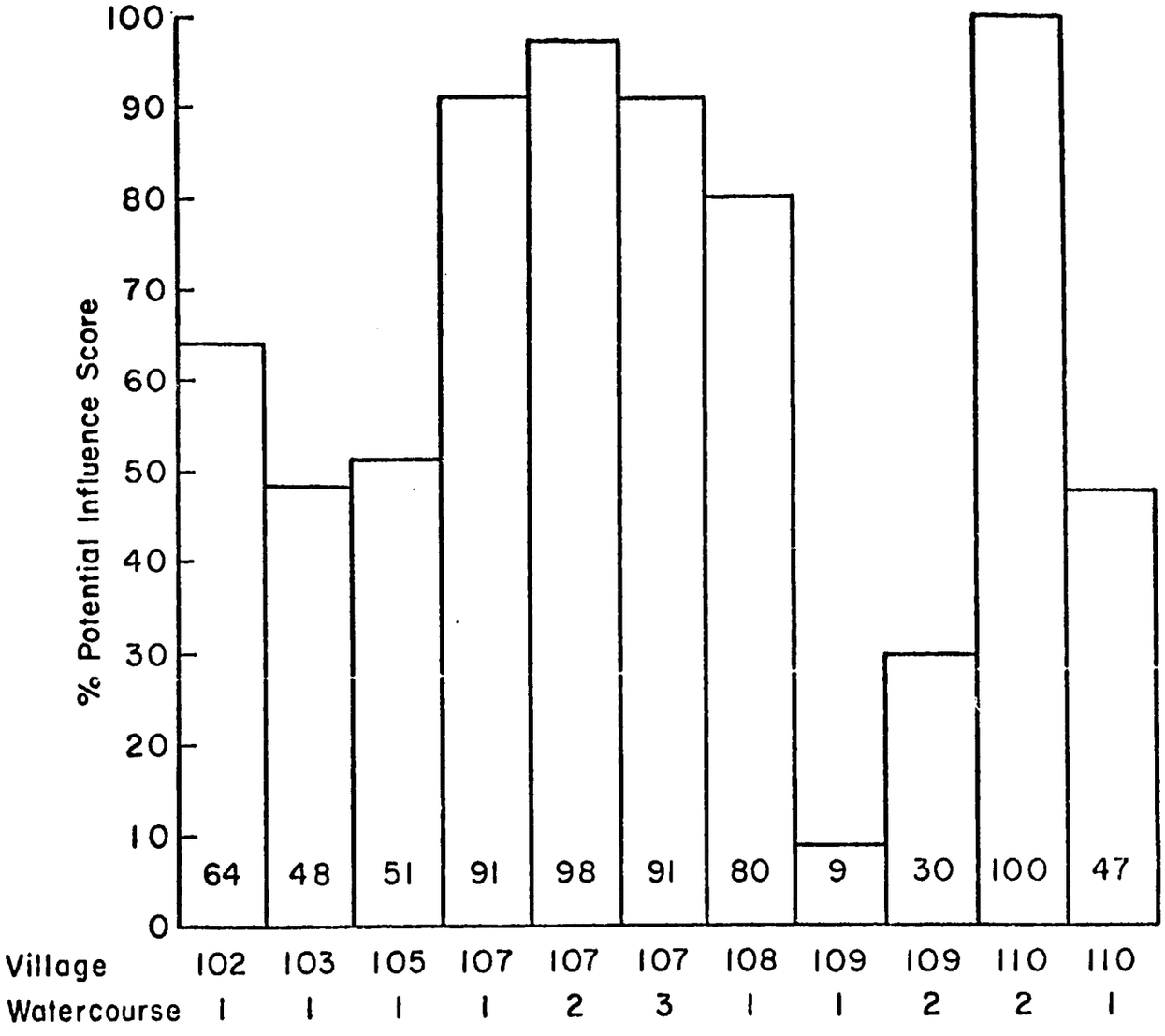


Figure 3. Distribution of Arain Caste Group Influence in Watercourse Cleaning/Disputes

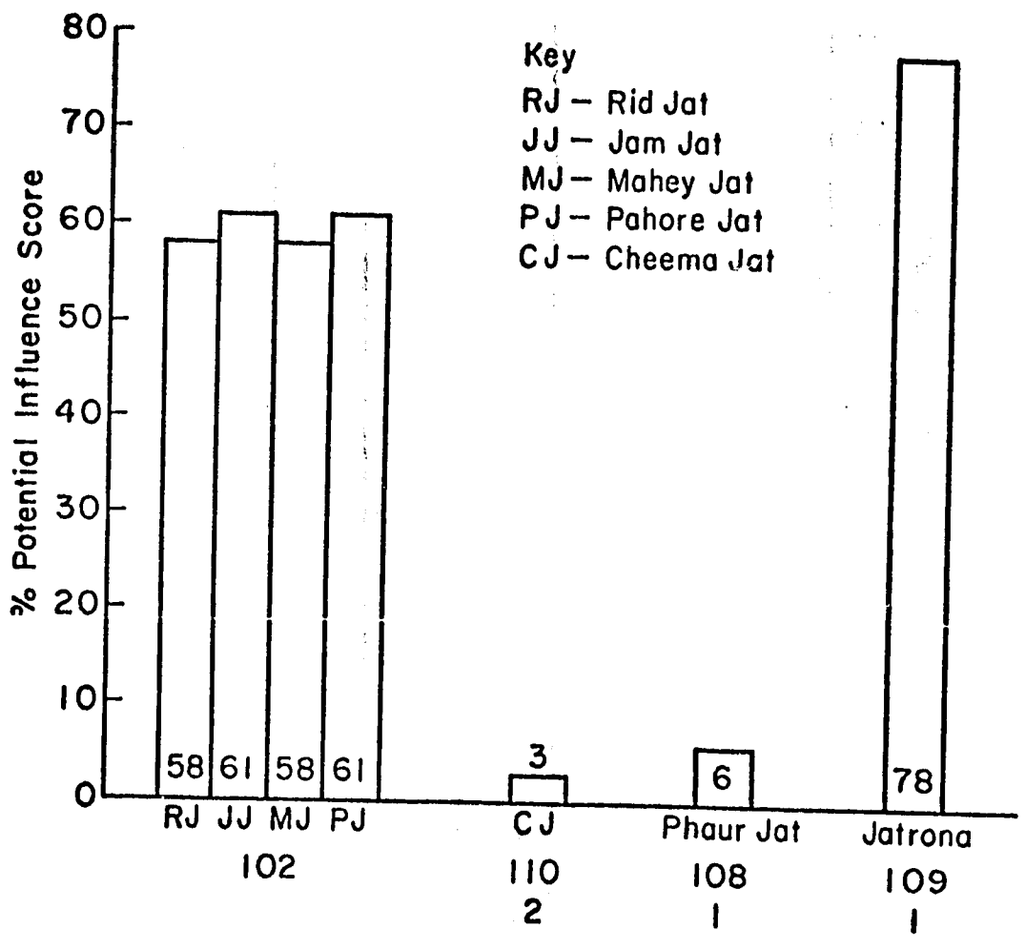


Figure 4. Distribution of Power/Influence Jat Caste/Biridary Groups.

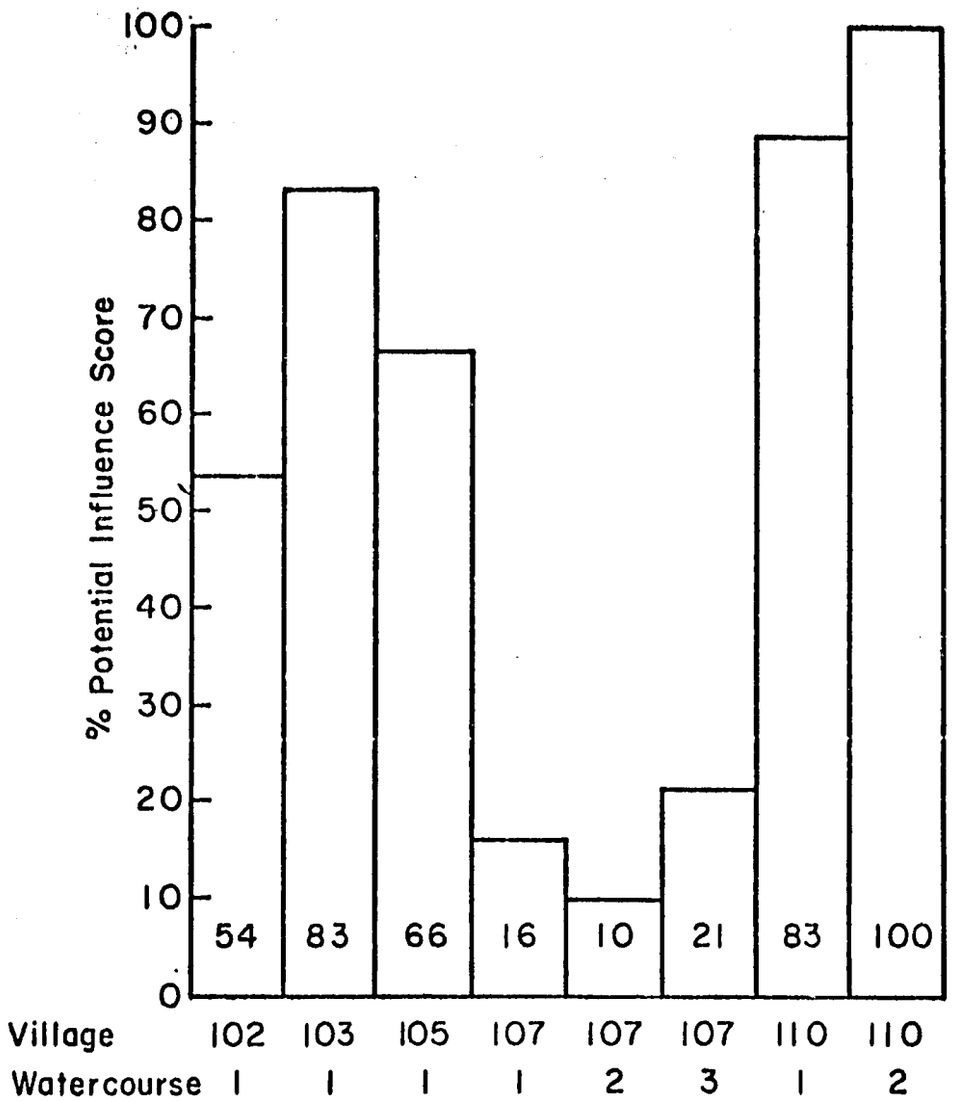


Figure 5. Distribution of Rajput Caste Group Influence in Watercourse Cleaning/Disputes

by a sizable landowner whose family, at some past time, was fortunate to be chosen by government authorities to serve, in effect, as a land tax collector. Unless the Numbardar commits gross violations of the norms, the position is passed on through hereditary affiliation. The primary duty of the Numbardar is to collect land revenue and canal assessments from farmers. For their service, Numbardars receive 5 percent of the gross amount of revenue collected. The Numbardar is well situated, therefore, to gain power and influence in village affairs by Virtue of his capacity to revise sanctions for non-payment, postponing payment, or loaning money to a defaulting farmer. The influence and obligations obtained in such matters is easily translated into other village dealings. Sample farmers consistently give high influence scores to Numbardars in response to the two part question: How much influence does the Numbardar have in matters of watercourse cleaning and settling disputes? (See Figure 6).

II. PATTERNS OF FARMER WATER MANAGEMENT--THE EXISTING SYSTEM

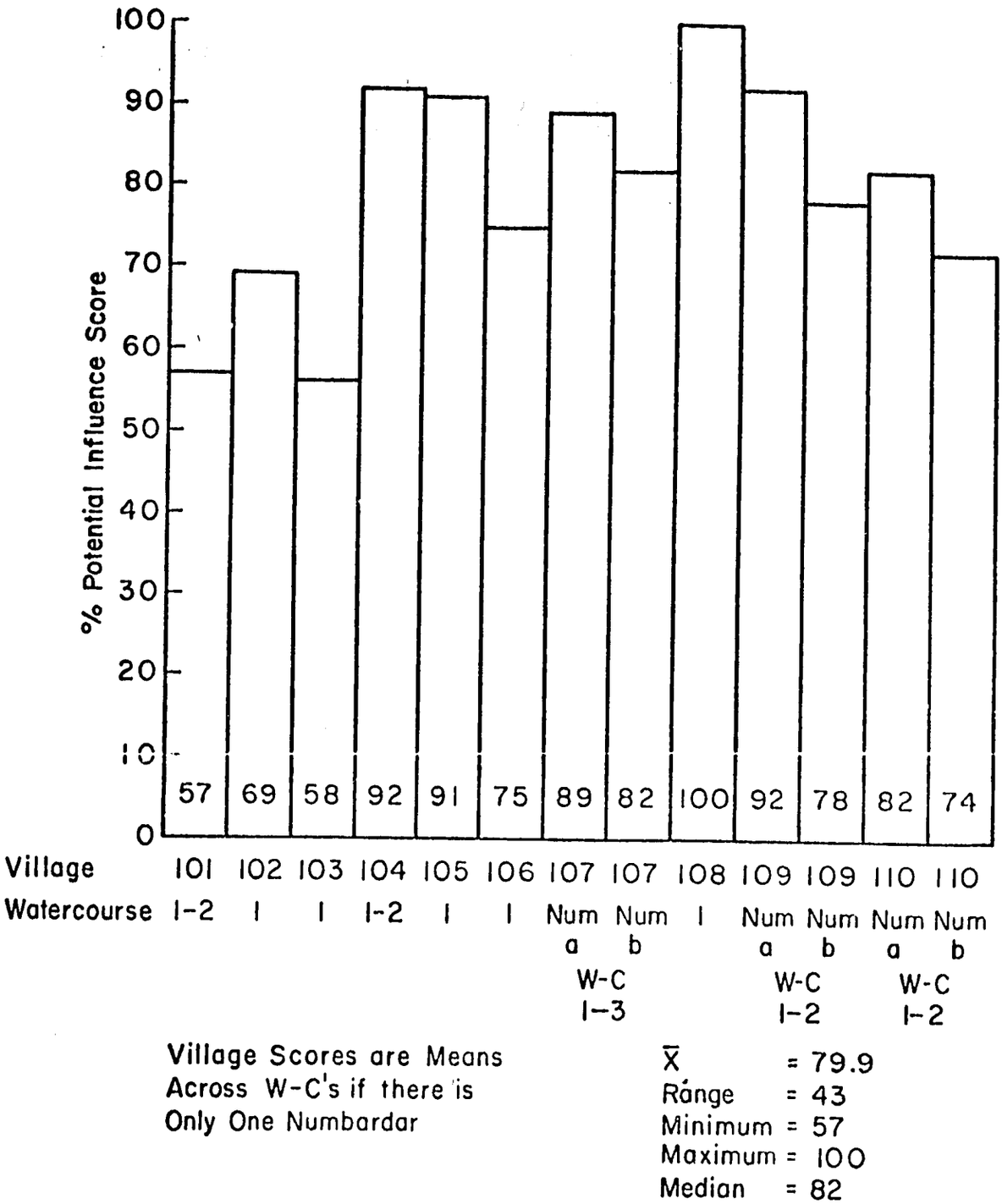
After having described central components of village social network, the task now is to examine selected aspects of the irrigation problem as experienced by the individual farmer. Those problems, and the farmers response to them, are a product of complex interactions between the social components of village organization described above and the larger physical irrigation system in which villages are nested.

The canal system in Pakistan was established in the last third of the nineteenth century on two fundamental premises:

1. That limited water supplies should be applied thinly over wide areas as insurance against famine. Although over-irrigation is found at selected points in the system, overall there is a shortage of water given the requirements of modern seeds, fertilizers and pesticides;

2. That there should be minimal local farmer control over water supplies--water is allocated to canals, and from canals to watercourses, in fixed proportions. Water is allocated to farmers in strict proportion to acreage.[1] The operating premise is that the less

[1]For a discussion of the problem of rigidity in water allocation see: Richard B. Reiginger, "Delivery of Canal Water in North India and West Pakistan," and West Pakistan, "Economic and Political Weekly, Vol. 6, No. 52, Review of Agriculture. Dec. 25, 1971, p. A157-A162.



Village Scores are Means Across W-C's if there is Only One Numbardar

$\bar{X}$ = 79.9
Range = 43
Minimum = 57
Maximum = 100
Median = 82

Figure 6. Distribution of Numbardar Influence Across Villages.

opportunity for petty officials to engage in corruption and extortion vis a vis farmers. In addition, large landlords would be prevented from taking advantage of small operators.

Generally, a cultivator has a weekly turn expressed in hours and minutes for each parcel of land. There are two ways of allocating turns to farmers during each irrigation period:

1. The kuchi warabandi system--an informal rotational arrangement worked out by watercourse members among themselves. This system provides for some flexibility in that rotations can be shifted among farmers according to individual needs. However, small farmers are vulnerable to the manipulations of more powerful larger operators; and,

2. The pacca warabandi system in which the Department of Irrigation sets a fixed turn for each farmer on the watercourse. This system poses the advantage of protecting each farmer's right to the water, but flexibility is lost as water trading becomes illegal. The pacca system will be established upon petition by any single farmer dissatisfied with the informal katcha system. Among sample watercourses, all have installed the pacca system with the single exception of Marracca, Village 103.

Sample farmers indicate an overwhelming preference for the pacca rotational system's security as contrasted with the pucca system and two other alternatives described by the interviewers.[1] The contract system would involve a watercourse farmer association contracting with the Irrigation Department for a specified amount of canal water to be delivered at a specified time for a specified amount of money. The demand system was explained to farmers as one which would give farmers control over the mogha outlet and make canal water available on demand just like private tubewell water is presently. Table 5 shows that sample farmers overwhelmingly prefer the pacca system.

While the organizational principles upon which the irrigation system is based were designed to serve the values of drought insurance and social equity, they are incompatible with the needs of modern agriculture, the technology of which demands water supplies to be concentrated and focused on root-zones of crops in precise amounts, at specific stages in plant growth. All of this means that the farmer must

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[1] Farmers have no experience with these two additional alternative systems and the researchers are doubtful that the interviewers were consistently successful in communicating these two alternatives in the interview situation.

Table 5. Sample farmer preference for water allocation systems.

Type of System	No. Farmers	Percent of Farmers
Kutcha	9	5.3
Pacca	153	90.5
Contract	1	0.6
Demand	6	3.6
N=169		

exercise control over the amounts and timing of his water supplies. Such control is minimized under the existing system, but there are four general ways by which farmers can attempt to expand their control over water supplies: 1) tubewells pumping groundwater can make limited amounts of water available upon demand to supplement canal water supplies, or 2) illicit water trading, buying and selling, can be used to dispose of unneeded supplies in return for informal commitments of return water shares from the trading or purchasing partner; 3) stealing water from a downstream farmer's turn; or 4) farmers can seek favors from irrigation officials. In effect, each of the four options listed is a way by which farmers can secure increased control over a system designed to exclude their participation. The section of the report which follows examines these four dimensions of the water management problem as we look at the struggle of farmers to obtain increments of control over a most critically important input into their farming operations. First, we stop to ask: Do farmers really see water as all that important?

A. Farmer Perceptions of the Importance of Water and Water Management problems as a Constraint Upon Their Production

Sample farmers were asked which item, among a list of farm problems, posed the most important constraint to increased agricultural production on their farms. Table 6 displays the overall results. Water problems are, by far, viewed as the most significant constraints to increased production--outranking problems with other inputs such as fertilizers, credit, machinery parts, labor, etc. Looking at farmer perceptions of constraints by cropping region, the same pattern holds up as seen in Table 7. Consistently, farmers report that water constraints constitute more significant limits to their increasing production than all other constraints combined. In all but two regions, sample farmers give water constraints majorities of greater than two to one. Sample farmers in the Sargodha region give water problems the smallest majority to be found among the regions--a response likely affected by the fact that theirs is a region distinguished by the presence of large public tubewells supplementing canal water supplies and alleviating water scarcity. Sample farmers from the Gujranwala village, while again giving water problems a large majority

Table 6 . Farmers perceptions of major farm problems which are constraints to increased production.

Reported Problem	Number Reporting	Percentage Reporting
Shortage of water	112	71.3
Lack of fertilizer, insecticides or credit	23	14.7
Lack of available spare parts for machinery or implements	15	9.6
Other*	7	4.4
Total Reporting	157	100.0

*Includes labor shortage (2 reports); need more land (4); lack of extension.

Table 7 . Farmers reports of major farm problems constraining increased agricultural production.

Cropping Region	Number Reporting	Water Constraints %	All Other Constraints Combined
Sargodha	39	56.4	43.6
Multan	58	72.4	27.6
Gujranwala	16	62.5	37.5
Lyallpur	15	80.0	20.9
Lahore	29	89.7	10.0
Total	157	71.3	28.7

over other constraints are doubtlessly affected by the fact that they have installed fifteen private tubewells to supplement water supplies on the two sample watercourses. Furthermore, the sample farmers from the Gujranwala region were interviewed shortly after the monsoon season began--a fact which might lead to understatement of the importance of water problems among respondent farmers.

The perception that water problems constitute the most important constraint to increased production holds up consistently across different farm size categories as shown in Table 8. But, as farm size increases, non-water problems tend to take on slightly more significance in the sample farmers rankings.

Pursuing farmer perceptions of the water problem, interviewers asked, "If water is your major farm constraint, what specific type of problem is it?" Over fifty percent of the respondents view insufficient canal supplies as the major problem (See Table 9). Slightly less than half as many identified "watercourse losses" as their major problem. If farmers are to be effectively mobilized to undertake the arduous tasks of watercourse reconstruction so as to improve the poor delivery efficiencies identified in earlier section of this report, farmers must be made more aware of the significance of their losses in poorly constructed watercourses.

The issue of canal closures, one item on Table 10, bears further scrutiny. The Department of Irrigation is required by law to provide advance notice to farmers about routine canal closures for repairs and cleaning, and about rationing of water to canals. A substantial proportion of sample farms indicate that they never receive information from the Irrigation Department regarding these crucial matters (Table 10). Information about seasonal availabilities of canal water is not required by law to be circulated to farmers, but this information could be disseminated at small cost. It is not received by over 90 percent of all sample farmers, as Table 10 indicates.

In sum, then, substantial majorities of sample farmers in all cropping regions and representing all size categories rank water problems as the foremost constraint to increased agricultural production. When queried further about the specific nature of the water problems, they indicate that insufficient supplies at the mogha concern them the most. The Irrigation Department fails to communicate, in any effective way, critical information about canal closures and other operating information. Do farmers view water problems as all that important in their hierarchy of farm problems? The available evidence indicates that the answer is "yes". Discussion now turns to the means by which farmers attempt to

Table 8. Major farm problems reported by farmers by farm class size.

Farm size (acres)	No.	Shortage of Canal Water (Percent)	Improved Implements or Farm Machinery Spare Parts (Percent)	Availability or Price of Fertilizer and Insecticides (Percent)	Other* (Percent)
Up to 7.49	46	78.3	13.0	4.3	4.3
7.50-12.49	42	76.2	4.8	14.1	9.6
12.50-24.99	45	64.4	4.4	22.2	8.9
25.0+	24	62.5	20.8	8.3	8.3
Totals	157	71.3	9.6	12.8	6.3

*Labor shortage 1.3; Lack land 9.1; Extension .6; and credit 1.9

Table 9. Sample farmer ranking of specific water problems.

Type of Water Problem	Number Choosing Item as Major Problem	Percentage Choosing Item as Major Problem
Insufficient canal water supply	62	53.9
Losses of water from watercourse	28	24.3
High price of diesel fuel or erratic supply of electricity for tubewells	12	10.4
Watercourse too low in relationship to field dead storage	7	6.1
Fields not level	3	2.0
Closures of canal	3	2.6
Farmers who did not report water as major problem in table or no response	42	26.7
N = 167		

Table 10 . Farmers' reports of Canal Department information received about closures and canal water availability.

Type of Information	No. of Farmers Reporting	Responses		
		Usually %	Sometimes %	Never %
Advance notice of canal closures for repairs	169	12.4	10.1	77.5
Advance notice of canal closures for cleaning	169	14.2	13.0	72.8
Advance notice about canal rationing of water	169	33.1	33.7	33.1
Information about seasonal availability of canal supplies	169	1.2	0.6	98.2

expand their control over that which they indicate is so important on their list of problems.

B. Control Option One--Patterns of Water Trading, Buying and Selling

Trading of water turns is not permitted under the law.[1] Yet, in their attempts to gain control over water timing and supplies, almost forty-five percent of the sample farmers indicate that they trade partial turns, and over one-fifth trade full turns, eleven or more times during one rabi and kharif cropping cycle (Table 11). Farmers engage in the practice of trading irrigation turns with remarkable consistency across cropping regions as indicated in Table 12 across all farm size categories as shown in Table 13, and across all watercourse positions as displayed on Table 14. The buying and selling of water without express permission of the Superintendent Canal Officer, is strictly prohibited under the law,[2] but Table 15 reveals that the selling of canal water is practiced by a substantial minority of sample farmers in all cropping regions with the exception of the Multan region where the majority of respondents engage in the practice, and Sargodha (the public tubewell region) where none claim to buy or sell canal water.

Table 16 reveals a slight positive relationship between the tendency to buy and sell canal waterand location away from the watercourse head.

Table 17 summarizes several sample farmer illegal transactions with canal water--transactions designed to expand the farmer's minimal control over his water supplies. Each of the transactions listed in the left hand column of Table 17 is expressly forbidden by law and farmers are uniformly aware of their illegality. Yet, when asked about the nature of their trading patterns, the majority of sample farmers (65 percent) indicate they will trade water with anyone who is topographically situated so as to make trades feasible without suffering substantial losses of water by spending it just to fill watercourse ditches. Nearly a third of the respondents indicate that they will limit their trading to other members of their biradari (Figure 7).

C. Water Control Option Two--Patterns of Using Tubewell Supplies

Only a minority of farmers own tubewells, but over fifty percent of the sample farmers report that, when needed, they

[1] Canal and Drainage Laws, As Amended Up to Date Revised Edition. Compiled by S. Masud-ul-Husson. Lahore, Khyber Law Publishers, Second edition, n.d., p. 22.

[2] Ibid, p. 22.

Table 11. Farmers' reports of degree of trading partial and full turns for Rabi and Kharif crops.

Times Traded	Partial Turns n	Partial Turns %	Full Turns n	Full Turns %
None	13	7.8	84	50.3
1 - 2 times	11	6.6	7	4.2
3 - 5 times	21	12.6	14	8.4
6 - 10 times	46	27.5	24	14.4
11 or more times	75	44.9	38	22.8
TOTALS	167	100.0	167	100.0

Table 12. Farmers' estimates of trading partial and full turns on Warabundi system for Rabi and Kharif cropping seasons 1974-75 by cropping regions.

Cropping Region	Number Reporting		Times Traded (Percent of Sample Farmers) None (0)	Little (1-5)	Some (6-10)	Much (11+)
Sargodha	43	Partial	0.0	18.7	39.2	37.2
		Full	58.1	4.7	14.0	23.3
Multan	63	Partial	9.5	17.4	12.2	60.3
		Full	33.3	14.2	20.6	31.7
Gujranwala	16	Partial	12.5	-	43.8	43.8
		Full	75.0	-	6.3	18.8
Lyallpur	14	Partial	14.3	28.6	28.5	28.6
		Full	57.1	28.6	-	14.3
Lahore	31	Partial	9.7	29.1	38.7	22.6
		Full	58.1	19.3	12.9	9.7
All areas	167	Partial	7.8	19.2	27.5	45.5
		Full	50.3	12.6	14.4	22.8

Table 13. Farmers' estimates of trading partial and full turns on Warabundi system for Rabi and Kharif cropping seasons 1974-75 by farm size classes.

Farm Size Acres	Number Reporting		Times Trading Reported None (0)	Little (1-5)	Some (6-10)	Much (11+)
up to 7.49	47	Partial	4.3(R)	23.4	25.5	46.8
		Full	40.4	14.9	6.4	38.3
7.5 - 12.49	47	Partial	14.9	14.9	27.7	42.0
		Full	55.3	10.6	17.0	17.0
12.5 - 24.99	47	Partial	4.3	17.1	34.0	44.6
		Full	48.9	14.9	21.3	14.9
25 and over	26	Partial	7.7	23.0	19.2	49.9
		Full	61.5	7.7	11.5	19.2
All sizes	167	Partial	7.8	19.2	27.5	45.5
		Full	50.3	12.6	14.4	22.8

x^2 NS

Table 14. Reported trading of partial and full turns and position on watercourse.

Position on Watercourse	Number Reporting		Times Trading Reported None (0)	Little (1-5)	Some (6-10)	Much (11+)
Head	57	Partial	7.0	21.0	22.8	49.1
		Full	43.9	15.8	17.5	22.8
Middle	52	Partial	7.7	15.3	30.8	46.2
		Full	50.0	5.8	19.2	25.0
Tail	58	Partial	8.6	20.7	29.3	41.4
		Full	56.9	15.5	6.9	20.7
Total	167	Partial	7.8	19.2	27.5	45.5
		Full	50.3	12.5	14.4	22.8

Table 15. Farmers' reports of buying and selling of canal water from other farmers by cropping region.

Cropping Regions	Number Reporting	Do NOT Buy - Sell Canal Water	DO Buy - Sell Canal Water
Sargodha (mixed)	43	100.0	-
Multan (wheat/cotton)	63	30.2	69.8
Gujranwala (rice/wheat)	16	93.8	6.3
Lyallpur (wheat/sugarcane)	14	85.7	14.1
Lahore (wheat/fodder)	31	80.6	19.6
All areas	167	63.0	37.0

Table 16. Sample farmers reporting buying and selling of canal water with other farmers by watercourse position.

Watercourse Position	Buy/Sell Canal Water Yes (Percent)	No (Percent)
Head	29.3	70.7
Middle	30.8	69.2
Tail	35.1	64.9
All positions	31.7	68.3

N = 167

Table 17 Summary of Farmers' reports of extra legal canal water transactions.

Type of Extra Legal Transactions	Number Reporting	Percentage Reporting Yes	Percentage Reporting No
1. Trading partial turns of canal water	167	92.2	7.8
2. Trading full turns of canal water	167	47.9	50.3
3. Buying or selling canal water with other farmers	167	31.7	68.3
4. Buying water allotted by Canal Department for village roads	166	12.0	88.0
5. Buying water allotted by Canal Department for village ponds	166	9.6	90.4
6. Trading canal water for tubewell water	165	20.6	79.4

Table 18 Sample farmer reports of tubewell water availability by position on watercourse.

Watercourse Position	No. at Position	Not Available (Percent)	Available with Difficulty (Percent)	Easily Available (Percent)
Head	58	21.4	14.3	64.3
Middle	52	23.1	28.0	51.9
Tail	57	24.1	32.8	43.1
All	167	22.9	24.1	53.0

N = 167

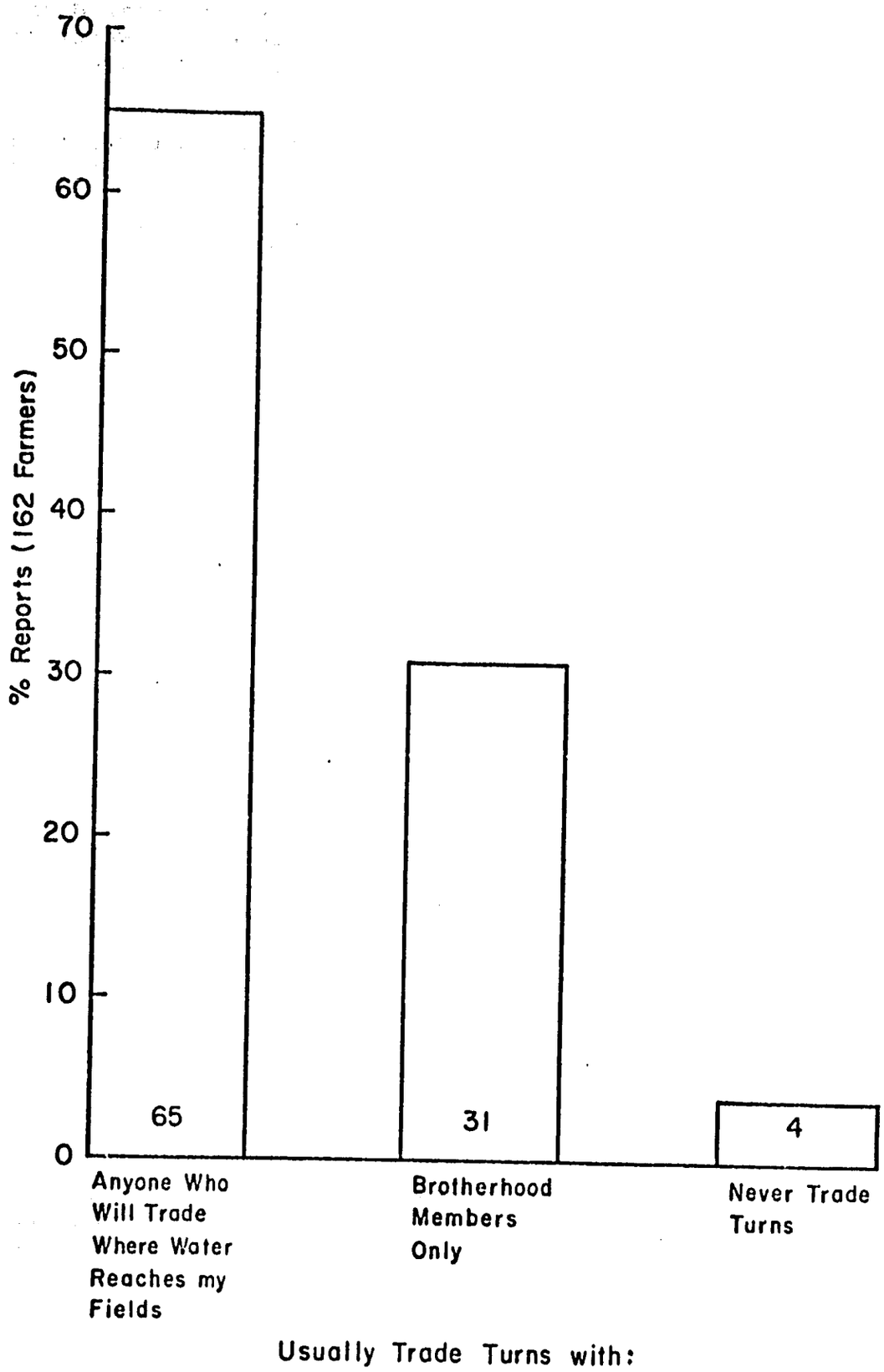

Figure 7. Farmer Reports about Whom They Usually Trade Turns on the Waribundi.

can easily obtain tubewell water via purchased or trades when there is necessity for supplementary water (Table 18). An additional 25 percent, almost, reports availability with difficulty.

In addition, tubewell water is sometimes traded for canal water, and vice versa. Since groundwater is often more saline than canal water, farmers in many areas do not like to exchange canal water for tubewell supplies. But, Table 19 shows that over one-fifth of sample farmers do periodically exchange the two kinds of water.

When asked a general question, "Can you obtain canal or tubewell water supplies beyond those fixed by the regular canal rotation, over 83 percent of the sample farmers report that such supplementary water is available from one or both sources (Figure 8).

One can conclude that sample farmer responses suggest that, within strict confines of a rigidly structured canal system over which farmers have little meaningful control beyond the mogha outlet, farmers have adapted by creating an informal, illegal, quasi-demand system so as to avoid having to accept obviously unwanted water deliveries at inappropriate times and to the best of their ability obtain water when required.

D. Water Control Option Three--Patterns of Water Stealing

Because farmers cannot be expected to reveal their stealing activities, interviews yield data only about the extent to which water theft is experienced and about the mechanisms employed to control it. At least some canal water theft is experienced by sample farmers in all cropping regions and by farmers of all size categories although the amount varies considerably. Looking at reported frequencies of water theft by region, the sample farmers in Gujranwala report the greatest number of thefts while those in Lahore report the least (Table 20). Small farmers tend to report somewhat lower numbers of thefts than do larger operators, but the difference is not statistically significant (Table 21). Location on the watercourse appears to make no difference with regard to frequency of stealing as seen in Table 22.

When a thief is caught in the act of stealing water, the most typical occurrance is to press charges against the offender with the biradari "influentials" who then handle any questioning, administer "oaths" at the village Mosque, and punish the guilty party with fines, social "shame" and "ostracism."

Table 19. Sample farmers' reports of trading tubewell water for canal water and vice versa by watercourse position.

Watercourse Position	No. at Position	Do Not Trade (Percent)	Do Trade (Percent)
Head	57	78.9	21.1
Middle	52	73.1	26.9
Tail	56	85.7	14.3
All	165	79.4	20.6

N = 165

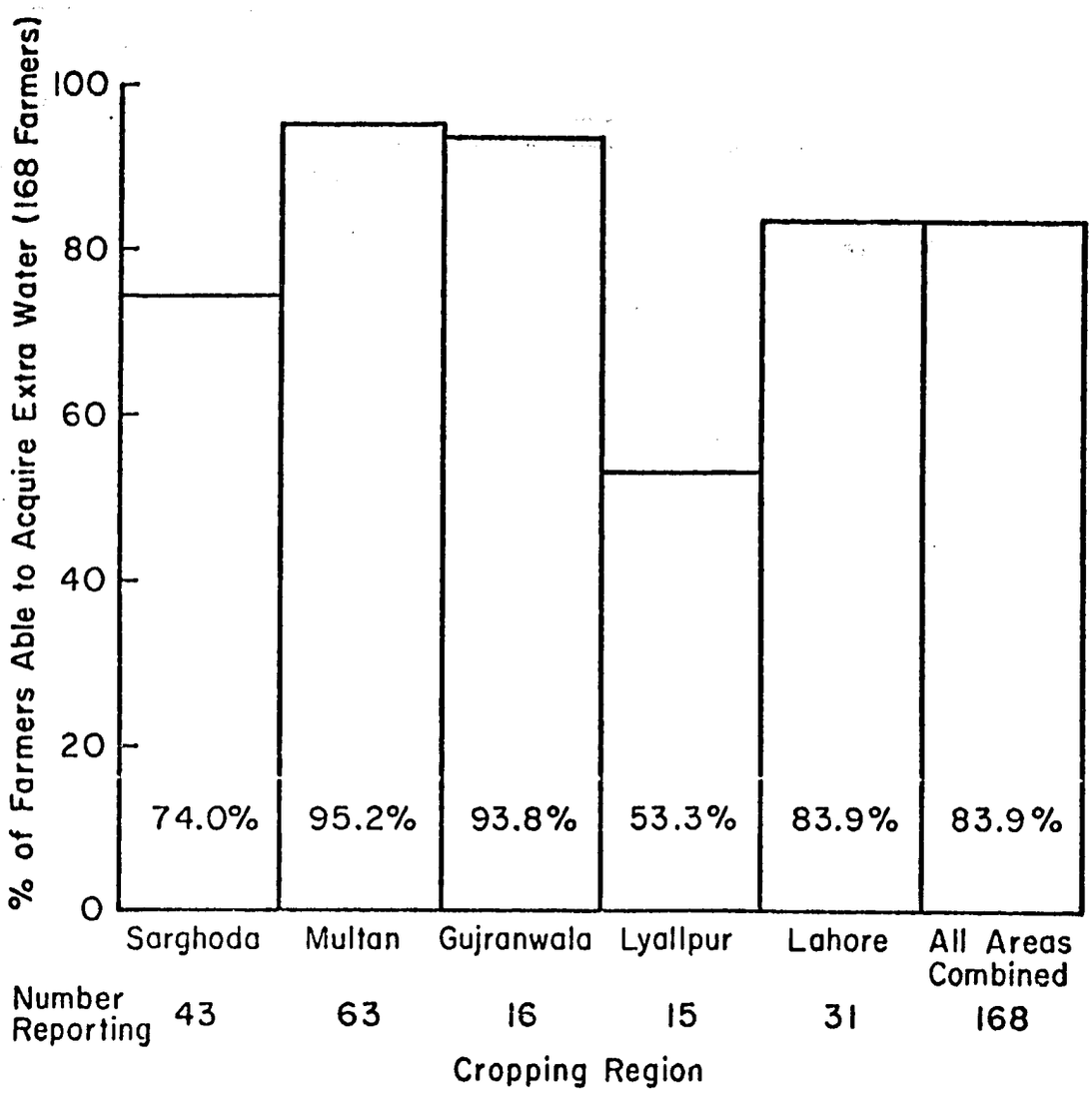

Figure 8. Farmers' Reports of Ability to Secure Canal or Tubewell Water from Others When There is Absolute Necessity.

Table 20 Farmers reports of frequency of stealing irrigation water during Rabi and Kharif seasons by cropping region.

Cropping Region	Number Reporting	Times Water Stolen			
		None (0)	Low (1-5)	Moderate (6-10)	High (11 or more)
Sargodha	43	55.2	14.0	14.0	20.9
Multan	64	68.8	14.1	6.3	10.3
Gujranwala	15	40.0	6.7	13.3	40.0
Lyallpur	15	73.3	20.0	6.7	-
Lahore	31	96.8	3.2	-	-
All Regions	168	67.3	11.9	7.7	13.1

Table 21. Reported degree of stealing water during last 12 months as reported by farmers shown by farm size.

Farm Size Acres	Number Reporting	None	Low (1-5)	Moderate (6-10)	High (11 or more)
up to 7.49	46	80.4	10.9	2.2	6.5
7.49 - 12.49	48	70.8	8.3	8.3	12.5
12.5 - 24.99	48	56.3	12.5	10.4	20.8
25.0+	26	57.7	19.2	11.5	11.5
All Sizes	168	67.3	11.9	7.7	13.1

Table 22. Reported stealing of respondent's canal water during Rabi and Kharif by position on watercourse.

Watercourse Position	Number Reporting	(Percent of Sample Farmers)			
		None	Low (1-5)	Moderate (6-10)	High (11 or more)
Head	59	72.9	15.3	6.8	5.1
Middle	52	72.5	9.8	3.9	13.7
Tail	58	56.9	10.3	12.1	20.7
All Positions	169	69.3	11.9	7.7	13.1

E. Water Control Option Four--Securing Concessions from Irrigation Officials

Farmers, in the course of their business, must deal with several lower level officials representing the Department of Irrigation. Chief among these are the Patwaris (who assess crop revenues), the Overseers (who allocate and repair Mogha outlets), the Pansals Nawees (gauge readers who send daily reports about the flow of water in major and minor canals). These officials take no responsibility for implementation of waribandi rotation turns, or for watercourse conditions, but they each possess capabilities to help or hurt the farmer.

It is the duty of Patwaris to check crops at times of crop failure and keep records of all crops cultivated on every acre of land on watercourses in his circle. The major work of the Patwaris is to make crop assessments for canal revenue. Since water, under Muslim law, is a gift of Allah and therefore cannot be justly taxed, revenue is collected to maintain the canal system by assessing each crop at a different schedule of rates per acre.[1] The Patwari makes assessments and the Numbardar collects the appropriate amount from each farmer. Not unexpectedly, farmers and Patwaris can make revenue arrangements to their mutual benefit and they typically do so.

Farmer informants in all sample villages reveal that Patwaris frequently "write off" a portion of the crop as having "failed." The Patwari and the farmer can then split the "savings"--both parties gaining at the expense of the government. The tax is "abiana," and to obtain a reduced "abiana" payment, farmers pay "fasalana", a traditional gift usually in kind to the Patwari in return for the concession. Only a third of sample farmers claim not to regularly pay "fasalana," (Table 23) and there is no difference by farmer position on the watercourse (Table 24). There are, however, significantly more larger farmers who claim to pay Fasalana than smaller operators (Table 25). Informants consistently agree that the amount of fasalana payment is graduated in accordance with size of farmer land holdings.

Patwaris have five optional ways to justify a reduction in farmer abiana payments: 1) cultivated land might be falsely declared fallow; 2) seeds can be falsely declared as not having germinated; 3) healthy plants can be falsely declared as having been decimated by disease; 4) hailstorm damage can be falsely claimed; and 5) an incorrect declaration of canal washout and flooding can be entered into the record. The Patwari's share of the concession is a matter negotiated on a case by case basis, generally falling in the range of a

[1] Recently a fixed flat rate per acre for canal water has been adopted in the Punjab.

Table 23. Proportion of sample farmers who pay fasalana to Patwari in cash, kind, or both.

	Number	Percent
Do not pay fasalana*	61	36.1
Do pay fasalana	101	59.8
No response	7	4.1

*"Fasalana" is a gift paid in kind at both harvests, usually the Patwari is paid in wheat, cotton, rice, fodder, or country sugar. The amount depends on the "type of relationship" the farmer wants or has with the Patwari.

Table 24. Sample farmers who reported payment of fasalana by position on watercourse.

Watercourse Position	Number Reporting	Do Not Pay Fasalana	Pay Fasalana
Head	57	33.3	66.7
Middle	50	38.0	62.0
Tail	55	41.8	58.0
All	162	37.7	62.3

Table 25. Payment of Fasalana reported by farmers shown by farm size.

Farm Size Acres	Number Reporting	Do Not Pay Fasalana	Pay Fasalana
Up to 7.49	45	51.1	48.9
7.5 - 12.49	46	41.3	58.7
12.5 - 24.99	47	23.4	76.6
25+	24	33.3	66.7
All sizes	162	37.7	62.3

fifty/fifty split in the case of smaller operators. Larger landlords seem to be able to retain more than a fifty percent share for themselves.

A major consideration for the Patwari is to keep the amount of his concessions within limits such that higher officials are not embarrassed by gross and clearly unjustified amounts, something that would make for investigations. Therefore, reductions in assessments generally fall within the twenty-five to fifty percent range and no more. If a Patwari were to give an especially generous concession to one party, he must cut back on his generosity with other farmers in that village or risk exceeding safe limits of revenue shortfall that can be justified to superiors for a particular village.

Only in two of the ten sample villages did informants indicate an awareness of village farmers attempting to secure concessions from Pansals Nawees. It would appear that villages located toward the head of a canal have little need to request extra amounts of water to be placed in the canal. In the two sample villages, representatives from which did reportedly approach a Pansal Nawees, informants speak of gifts--approximately 100-125 maunds of wheat collected from all watercourse members--presented to each official in return for which an unknown extra quantity of water was released into the canal during the night. One might hypothesize that the further a watercourse is located from the head of a canal, and the greater the number of moghas upstream which have been enlarged (see below), the greater the propensity of farmers to deal for "concessions" from a Pansal Nawees.

Overseers, officials in charge of the mogha (canal outlet to watercourse) attract much more attention from sample farmers than do Pansals Nawees. Because it is illegal for village farmers to alter the mogha in any way, the Overseer must be called upon to repair a mogha defect naturally caused or intentionally created by downstream farmers or the Overseer himself. Overseers are approached by farmers with requests for illegal mogha enlargements.

It is not uncommon for farmers in sample villages, wanting a Mogha "repaired", to collect from among themselves Rs. 1000 for "tipping" the Overseer as an incentive to get the jog accomplished. Bribes necessary to obtain a mogha enlargement are negotiated individually with representatives of each petitioning watercourse. The two major factors in calculating the size of the bribe appear to be the amount of cultivated acreage on the watercourse and the extent of the enlargement requested. Payments to the overseer for unauthorized mogha enlargement have ranged in sample villages from a minimum of Rs. 800 to Rs. 6,000. Such payments seem to be of considerable incentive as one informant reveals that an overseer of his acquaintance can enlarge up to ten moghas a night with assistance from the farmer clients.

In sum, then, sample farmers and key informants reveal that the majority of sample farmers reduce their abiana crop assessment by paying fasalana to Patwaris. Farmers in most of the sampled villages do not interact with Pansal Nawees, but most sampled watercourse units have organized contributions at one time or another to secure a mogha enlargement from the overseer. In addition, overseers are frequently bribed to make justifiable and needed mogha repairs. Bribing lower level officials to prevent officials from exploiting them, and to secure concessions is commonplace as shown in Table 26. Farmers were asked what they would do if faced with a commonly occuring problem situation. By large majorities, sample farmers indicate that they would resort to extra-legal bribes to resolve the situation. Use of regular channels of bureacratic authority to resolve the problem without resort to bribes, was endorsed by less than 25 percent of the respondents in all instances.

III. Village Organization and the Problem of Securing Collective Goods

A "collective" good is one in which significant benefit cannot be denied to those who do not help bear the costs of providing the good.[1] For example, an improved watercourse is a collective good because individual farmers will calculate as follows with regard to potential improvements. If one makes an investment of time, energy, and money to improve the section running through his land and many other farmers do not do so, then the payoff of his work is negligible. On the other hand, if many others for some reason undertake lining and straightening on their sections, he will still enjoy a share of the benefits if he does little or nothing. The "free rider" cannot be denied the additional amounts of water that would become available to him as a result of the work of others. Therefore, the rational calculating individual will choose to do nothing either way--even assuming that he has information about potential benefits, and the knowhow to make the improvements. This situation can only be mitigated by the presence of a social organization with the power to enforce sanctions upon all members such that each can be assured that his contributions will be matched by some acceptable proportion of contribution by others who benefit. Many aspects of irrigation systems represent collective good problems, but of particular interest to the researchers is the problem of watercourse improvement. Data reported in earlier sections of this study show that much valuable water is lost in poorly designed, constructed, and maintained watercourses. Delivery efficiencies are uniformly low across all sample watercourses

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[1]For a discussion of collective goods and social organization, see Mancur Olson, The Logic of Collective Action. New York, Schoeken Books, 1971.

Table 26. Farmers' means of dealing with problems related to canal officials.

Problem Situation	Total Number	Use of Extra Legal* Means (Bribery) %	Use of Legal Means (Not Employ Bribery) %	Will Do Nothing %
1. If Patwari makes an incorrect entry in his records of your water rate?	168	71.4	22.6	6.0
2. If Patwari requests you to increase your fasalana?	163	73.6	18.4	18.0
3. If overseer threatens to reduce your mogha outlet (i.e., canal supply)?	167	91.0	5.4	3.6
4. If you want to have your abania water assessment reduced?	157	80.3	13.4	6.4

without exception. Watercourse improvement becomes a major item on the agenda of water management improvement programs. But, how can village farmers be effectively organized to undertake watercourse reconstruction and to subsequently maintain the improved structures? Because this question was foremost in the minds of the researchers, a portion of the investigation was devoted to an examination of how villagers organize to provide the three kinds of collective goods already present in villages which farmers must buy and maintain themselves--mosques, and water course cleaning/ maintenance. This section of the report describes the mechanisms by which villages organize for these "collective goods" in order to reveal present patterns of problem solving and to inform further work on the problem of organizing farmers into effective farmer associations capable of undertaking watercourse improvement as well as other aspects of agricultural development.

A. Methods of Organizing to Build and Maintain Mosques

Punjabi villages typically are endowed with two kinds of mosques-- 1) private mosques erected by those who have both the required religious motivation and the financial resources; and 2) community (Jummah) mosques which are open for the use of at least major segments of the village if not all groups. The focus of the inquiry was on mosques of the latter kind--the type thought to require at least some minimal collective action to construct and to maintain. Table 27 displays the number and type of mosques found in sample villages.

What methods are employed to secure financial resources for initial construction and maintenance? In all sample villages, key informants revealed that biradary leaders did the actual collection of money, grain, fodder, animals, building materials and commitments of labor. Everywhere informal but intense social pressure is the device by which commitments are secured. Gossip to the effect that someone contributes less than a "fair share" relative to his community standing and resources is the major mechanism of social control. Whatever their devotion to Allah, donors give to avoid shame and loss of personal prestige. When repairs are needed in two villages, biradari influentials employ mosque loudspeakers to broadcast the amounts members of the respective brotherhoods have so far contributed thereby establishing a "friendly" rivalry and stimulating donations. In all villages, save three, key informants agreed that contributions were voluntary and no fixed tax was levied. However, in three sample villages, more formal arrangement has evolved. Key informants in two--101 and 107--note the existence of a "wash" system whereby a specified amount of money is axacted per acre of cultivated land--about Rs 5-7 per acre per cropping season. Additional voluntary donations are solicited beyond these amounts. Farmers of village 109 have had a long standing contract with the government to breed horses for the

Table 27. Distribution of mosques by sample village.

Village	Number Community (Jumah) Mosques		Number Private Mosques
	Sunni	Shia	
101	1	0	0
102	1	0	9
103	2	0	0
104	1	1	0
105	1	0	0
106	0	1	6*
107	1	0	0
108	1	1	0
109	1	0	11
110	1	0	4

*Each Sunni biradari has its own private mosque.

army. Each breeder is expected to donate Rs. 100 per mare per year to the village Mosque and School fund.

Informants were asked whether there were farmers who avoided contributing to the Mosque and what, if any sanctions were employed to punish holdouts. In no village are formal sanctions found, and only in a few instances do farmers refuse to give what is considered their "fair share."

B. Methods of Organizing to Construct and Maintain Schools

All sample villages support at least a primary boys school, and most support primary schooling for girls. One supports schools for both sexes all the way through the secondary level.

In some villages the government designated a parcel of land for locating a school, in other cases villagers must have provided land--usually a donation from a generous landowner was sought. In all cases villages must organize to obtain some resources to construct the school building--the government often contributes some construction costs and pays the teacher's salary.

As in the case of mosque construction, the biradary groups are the key mobilizing organizational unit supplemented in Village 102 by a Cooperative Farming Society which collects revenue from cooperative members through regular deductions from farmer payments. Some farmers in that village, however, have refused to join the cooperative society and they systematically refuse to contribute to the school fund or to a community mosque.

C. Organizing to Clean and Maintain Watercourses

Table 28 summarizes key facets of farmer watercourse maintenance behavior by village and watercourse. As in the case of organizing to support mosques, and schools, biradari groups in all sample villages are the social unit which is mobilized for watercourse cleaning and maintenance. Sanctions, where enforced, for refusal to participate in watercourse cleaning are almost invariably applied through the biradari group. Out-group individuals, even influential ones, will typically contact in-group biradari leaders for application of any sanction. Farmers clean those sections of the watercourse which pass through their fields, but biradari groups typically assume responsibility for particular sections of the main watercourse (sarkari khal) as illustrated by Figure 9. Each group's contribution is figured in proportion to their share of water which, in turn, is a function of size of land holdings. Practice varies, but the pattern in sample villages is that farmers are generally expected to clean approximately five feet (1 kharim) of main watercourse per three hours of water (1 par) received per irrigation turn.

Table 28

Village and Watercourse(s)	Times Watercourse Cleaned Per Year	Man/Days Employed Per Cleaning (Approx)	Median Satisfaction Expended by Informants	Type Sanction to Punish those who Refuse to Clean	Use of any Fine Money Collected
101 - 1/2	2-3	12-15	Moderate	Fine offender Rs.10, cut off one irrigation turn and give it to workers who clean section.	Purchase improved field outlets- nakkas
102 - 1	15.20	50-60	Low	Used fines and cut water off until fights erupted on 2 watercourse sections.	Fines collected on third watercourse section used to pay cleaning labor or to buy sweets.
103 - 1	24-26	10-16	High	Cut 2 hours of irrigation turn.	
104 - 1/2	6-12	15-20	Moderate	Fine offender Rs 10	
105 - 1*					
106 - 1	2	3-6	Moderate	Fine Rs 15-20 or cut irrigation turn.	Buy sweets for workers who clean.
107 - 1/2/3	6-8	20-22	Moderate	Pay rupees or sacrifice irrigation turn-See text.	Purchase improved field outlets- nakkas
108 - 1	12	10-25	Moderate-1st Branch Low - 2nd Branch	-- Social Pressure	
109 - 1	9	13-18	Moderate/ Low	Fine 5 Seer Gur (crude sugar)	Party
109 - 2	4-5	15-16	Moderate	Fine 5 seer Gur per de Fault	Party
110 - 1/2	1-3	7-8	Moderate	None	

*This watercourse was reconstructed and provided a concrete lining by the government. All arteries but one flush the sediment and informants indicated that farmers feel that the government should clean it since the government constructed the watercourse.

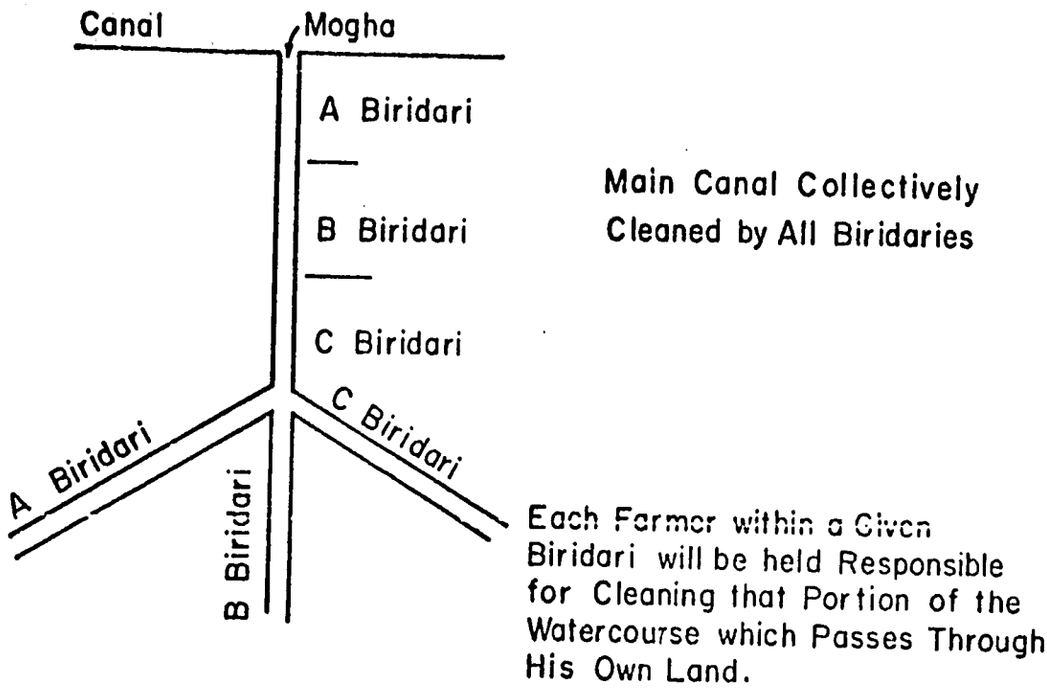


Figure 9. Generalized Pattern of Biradari Organization for Cleaning.

Village 107 informants revealed that a detailed system has evolved for estimating the monetary value of an hour's worth of irrigation water. A farmer not wanting to participage in cleaning on a given day can choose to pay the laborer who takes his place either two hours of water or the rupee equivalent. One hour's worth of water on each of the three watercourses is valued at Rs.16, 12, and 9 respectively. The variability is due to differences in mogha discharges. Therefore, a farmer on watercourse two who did not participate in cleaning would pay either two hours of water or Rs 24.

Informants indicate that watercourse cleaning might be initiated in one of two ways. A biradari leader may call upon his kin to clean their particular section of the watercourse with no cooperation from other village biradari units. Or, a farmer seeing a problem, can notify the watercourse committee--consisting of biradari representatives--which will mobilize the villagers for a cleaning effort. In villages endowed with a mosque loudspeaker, a village influential or chowkidar (watchman) may use the microphone to announce the need for cleaning.

C. Conclusion

Rudimentary informal forms of village cooperation exist for securing and maintaining collective goods--mosques, schools, and watercourse cleaning. No formal organizations with taxing power exist. Written contracts are nowhere employed to formalize agreements. Everywhere the social unit through which cooperation is mobilized is the biradari or brotherhood kinship group. Where biradaries are badly split one from another, serious problems of village cooperation emerge. Where biradaris split over an issue of enforcement of a sanction, the biradari leaders face the unpleasant choice of attempting to force application of the sanction at the risk of a serious biradari split or of withdrawing the sanction. In such circumstances, the sanction is likely to be compromised or withdrawn.

Some form of formal farmer organization must be constructed if farmers are to be able to contract, in a legally binding manner, with outside organizations technically competent to undertake major watercourse realignment and lining projects. Such projects will require that farmers enter into formal and enforceable contracts with each other and with contractors. Existing informal arrangements among influential biradari leaders are inadequate to the task of contracting with public or private contractors, for collecting revenue for payment, and to serve as a vehicle by which improved water management knowledge can be directed to farmers from the agricultural extension service. Whatever specific forms the formal farmer associations eventually assume, it is clear that they must adapt to the reality that the farmer acts primarily as an agent of a biradari group.

IV. ON THE PROBLEM OF SELECTING PREFERRED VILLAGES WITHIN WHICH TO CONDUCT ORGANIZATION BUILDING EFFORTS FOR IMPROVING WATER MANAGEMENT

It is far beyond the scope of this research report to come to grips with the problem of designing farmer organizations which will be effective vehicles of improved water management in the Pakistani setting. What this report now proceeds to do is to consider the question: Which villages should be selected as having social environments most conducive to establishment and effective functioning of farmer water associations? The research necessary to answer this question has yet to be done; answers which can be suggested at this point can only be highly tentative and only indicative of the direction we believe further research should follow. In essence, the argument which follows is that candidate villages for a water management improvement program be screened in the first stage, according to three sociological criteria:

1. The degree to which conflicts within the villages have polarized thereby making community cooperation difficult if not impossible;

2. The degree to which power and influence within the village is distributed equally, thereby making social organization along participant--as opposed to authoritarian--lines more likely; and,

3. The degree to which effective leadership is present around which the nucleus of an effective farmers association might be built.

In effect, it is contended that an initial set of candidate villages be successively sifted on each of the above criteria. Those which survive the three stage screening process might then be ranked according to technical and economic criteria such as topography, soils, existing watercourse problems, and estimated returns from watercourse improvement. Tightening or loosening the criteria will result in a smaller or larger set of villages surviving the screening process making it possible to match the number of candidate villages with the resources available to undertake water management improvement programs. It is suggested that a sample be chosen which violates the suggested criteria, and a third sample be randomly selected without regard to the screening process. Organizational efforts could then be attempted in all three samples of villages to test the null hypothesis that the selection criteria have no effect on village propensity to organize effective farmer water management organization. The working hypothesis is that organizations will be more effective in villages which are not polarized, which have more equal power distribution, and have stronger leadership than in villages in the other two samples, but it

will take systematic evaluative research to establish that the criteria suggested are appropriate guides for planned organizational change.

A. Criterion One--Degree of Conflict Polarization

It is assumed that conflict cleavages are omnipresent in social structure; they cannot be totally eliminated. The critical question is whether conflict is patterned so as to be negotiable, and conducted in a non-violent manner, or whether it is patterned such that it creates high propensity to commit violence and make cooperation between opponents impossible. The structure of cleavages is the key to whether farmer organizations will likely be undercut by hostile factors or effective agents of village programs and water management improvements. There are two polar types of conflict structures:

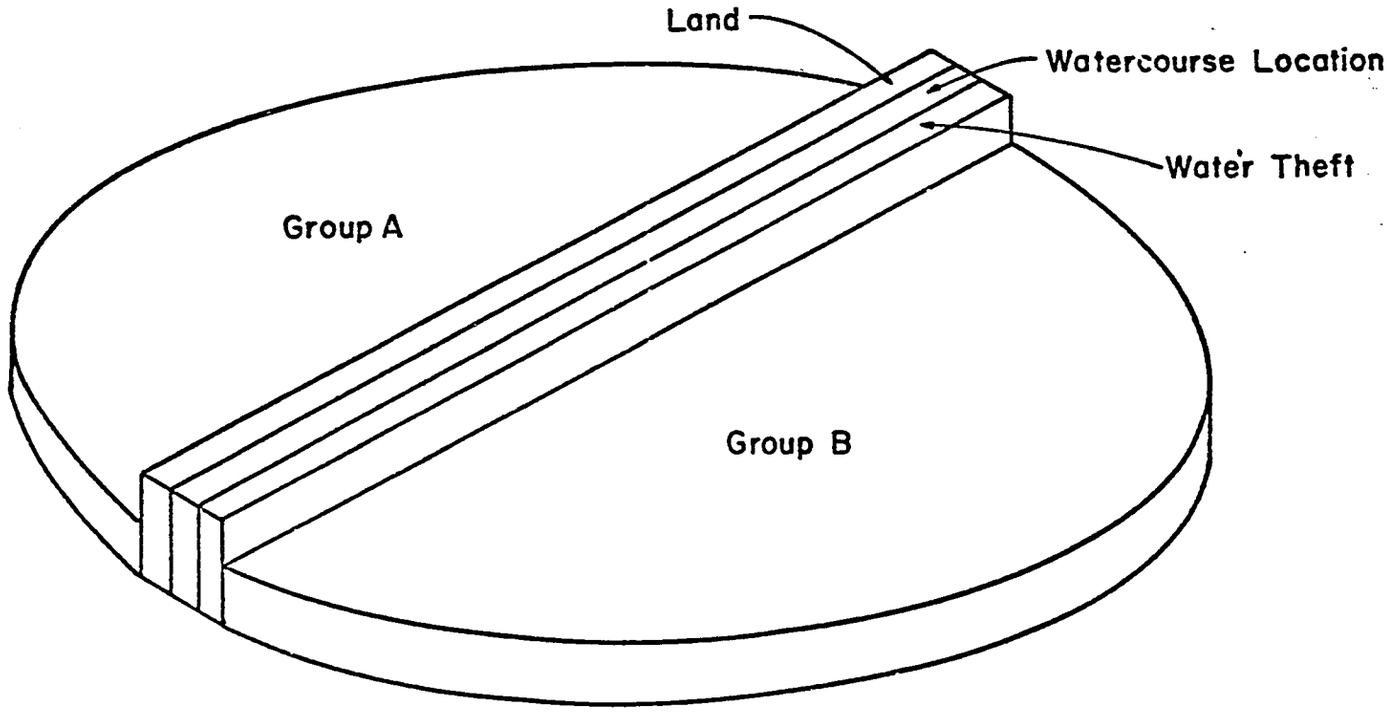
1. The overlapping--associated with limited capacity to absorb change, and with high propensity to commit violence. Change agents and planners should introduce programs in such a way as to reduce tendencies for this type of conflict pattern to develop.

2. The cross-cutting--associated with greater capacity to absorb change and with low propensity for violence. Change agents should introduce projects in such a manner as to facilitate growth of cross-cutting conflict structures among social groups.[1]

Overlapping conflict structures, creating high polarization, exist when opponent groups are cleaved apart by differences on all significant value fronts--economic, political, educational, religious, caste, tenancy status, etc. Adversaries on one issue are opponents on all. There are no cross-cutting attachments to common values. There is no common ground upon which to compromise, no incentive to negotiate. Opponents ascribe to each other less than human qualities reflecting their lack of shared values. Violence is condoned by both groups in order to protect against the extreme threat represented by the other (Figure 10).

Cross-cutting conflict structures exist when opponent groups are in opposition over a limited number of cleavage fronts, but are allied in common cause in other significant

[1] For a discussion of conflict theory upon which this text is based see Lewis Coser, The Functions of Social Conflict. New York: Free Press, 1967, Douglas Rae and Michael Taylor, The Analysis of Political Cleavages; and David M. Freeman, "Social Conflict, Violence, and Planned Change..." Coexistence: A Journal for the Comparative Study of Sociology, Anthropology, and Economics. Vol. 9, No. 2, p. 89-100.



Note: A's are Allied Against All B's on All Issues
Over which there are Cleavages.

Figure 10. Overlapping Cleavages - High Polarization.

conflicts. (See Figure 11). Actors in disagrement over one or more value preferences find shared attachments when they approach other issue areas. Here lay the roots of social cohesion. Cross-cutting cleavages over values stitch society together by facilitating constantly renewed willingness to negotiate disputes and seek grounds for compromise. Total involvement of an actor in any one conflict against any single opponent is precluded. Roles and statuses include interaction with a range of opponents on some issues who are allies on other conflict fronts. Multiple involvements in cross-cutting social cleavages precludes polarization on any one axis and keeps social groups open to ideas and innovations from each other. Cross-cutting cleavage patterns make for low propensities to engage in violence and for high propensities to tolerate change, deviance, innovation, and for cooperation in organizational efforts.

Sample farmers and key informants were asked about village conflict patterns. Specifically they were requested to talk about conflict cleavages between groups (who fights with whom) the dominant issues which make up the cleavage (what the opponents fight about) the dates started and terminated, mechanisms of resolution, degree of resolution, and the degree of hostility which was generated. Respondent statements about the degree of hostility were categorized along a dimension ranging from low to high hostility as follows: none, hostile verbal exchange, social exclusion (hooka Pawnee Bun), sporadic physical fighting, frequent physical fighting, killing/murder.

Sample farmer respondents and key informants identified 76 important village conflicts which have been important to villagers within the last five years on the 16 watercourses. (See Figure 12). To be counted, conflicts must represent a cleavage in the social network. The term, as used here, excludes personal dissatisfaction, jealousies, and pique which do not affect the social or community web. To be counted,[1] there must be issues which involve at least a small group of people who agree as to the nature of the issues, and there must be consequences for the group, not just for a particular individual. Of the 76 conflicts, almost 45 percent were directly related to water. Water and land conflicts clearly dominate patterns of sample village social life.

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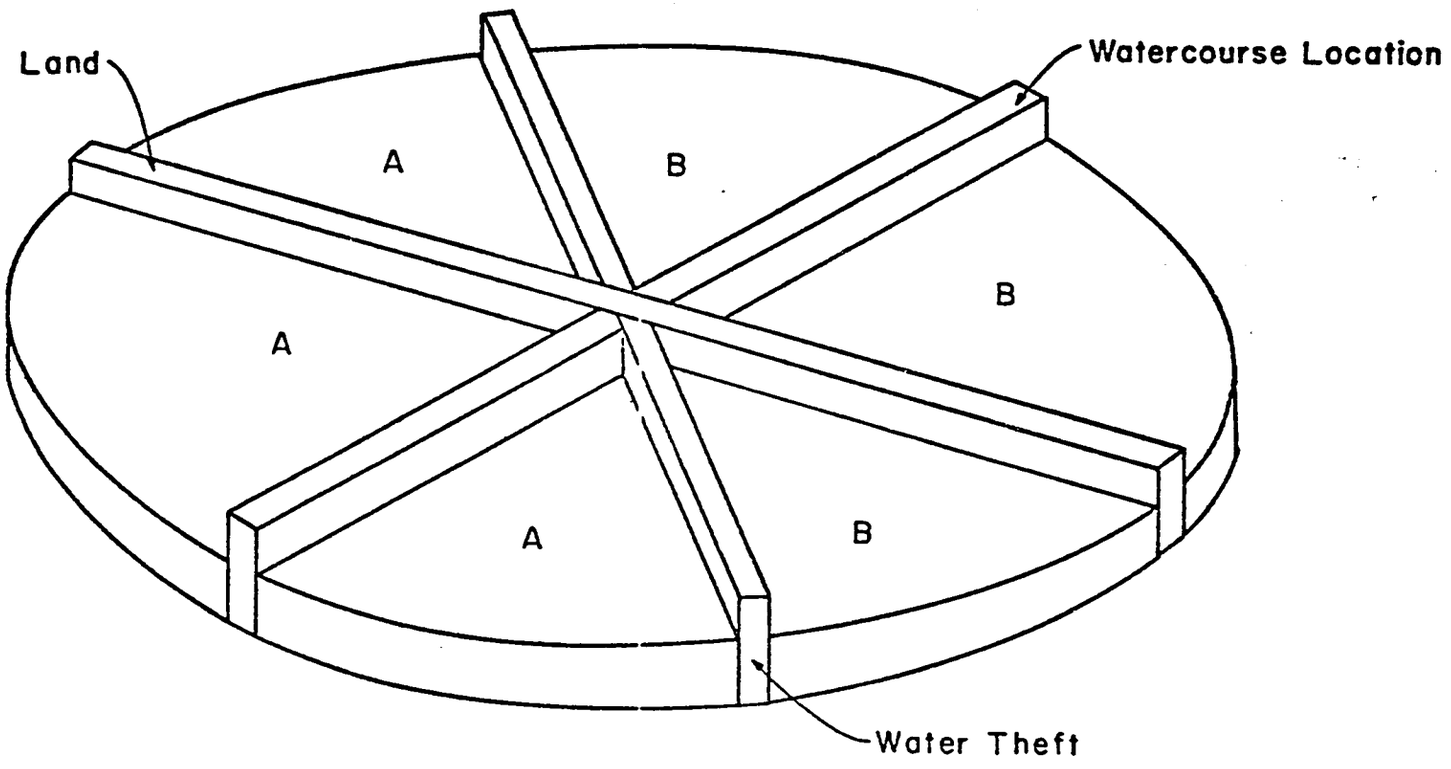
[1]Investigators have made an effort to avoid double counting of reported conflicts--something easy to do as respondents tend to mention the same cleavages over and over again. Information taken regarding the parties involved, the dates, the issues, allow one to avoid duplication in counting.



Note: Some A's are Allied with at Least Some B's on Each Issue Over which there are Cleavages.

Figure 11. Cross-Cutting Cleavages - Low Polarization.

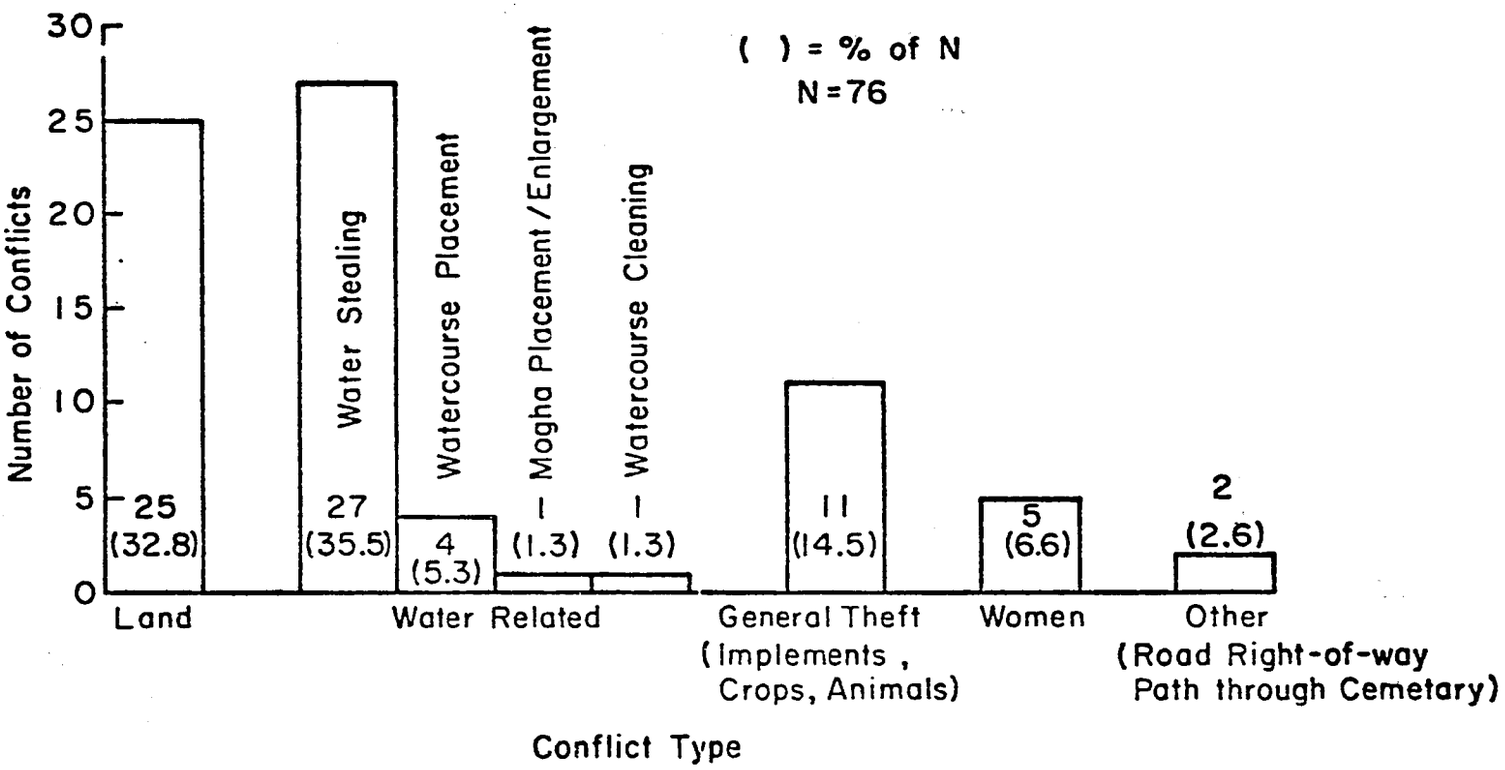


Figure 12. Distribution of Social Conflicts by Type, 1971-1975.

The most important thing about conflict cleavages, however, is not their number or the specific nature of the issues per se, but the manner in which cleavages are organized vis a vis each other. Are groups again and again divided by conflict cleavages such that they never ally together in common cause (high polarization) or are groups stitched in a web of cross-cutting attachments in which sometime enemies are sometimes allies (low polarization)? To obtain a crude view of village cleavage patterns (see Figures 13-15) the conflict patterns of the ten sample villages have been classified into three categories of polarization--high, moderate, low.

Time series data about water delivery efficiencies and watercourse cleaning activities are not available that would permit a useful analysis of the impacts of degree of polarization on village propensity to cooperate effectively to improve watercourse conditions. Delivery efficiencies vary so little among the sample watercourses that it is fruitless to make even a preliminary attempt at ferreting out association between village conflict polarization and watercourse delivery efficiency, but the general hypothesis can be formulated as follows: the greater the tendency toward polarization, the greater the difficulty in organizing farmers to take organized cooperative collective action to improve watercourse structures so as to achieve higher irrigation efficiencies.

1. Highly Polarized Villages

Villages are classified in this category when key informant and sample farmer information suggests that a set of major cleavage lines so dominates the village social life that few if any farmers can avoid entanglement in them and the opponents have few, if any, cross-cutting attachments.

Village 102 is highly polarized according to the available evidence. Jam Jats take a unanimous stand on one side versus Rid Jats, Pahore Jats and Arians. This cleavage has its roots in a bitter land dispute over which at least two antagonists have been killed in the last ten years and has overlapped a cleavage between cooperative society members vs. noncooperative farmers. Jam Jats, without a single exception have refused to participate in the cooperative farming effort which has been controlled by their antagonists.[1] Because the cooperative society has played a major role in financing the local school, the Jam Jats have refused to contribute to it--placing another cleavage right on top of the land, and cooperative fights. This tendency toward high polarization was exacerbated in 1974-75, when the engineers of the CSU

[1]At partition areas evacuated by fleeing Hindu farmers were allocated by the Cooperative Farming Society to incoming refugee farmers as well as to locals. The cooperative society retained title to the land.

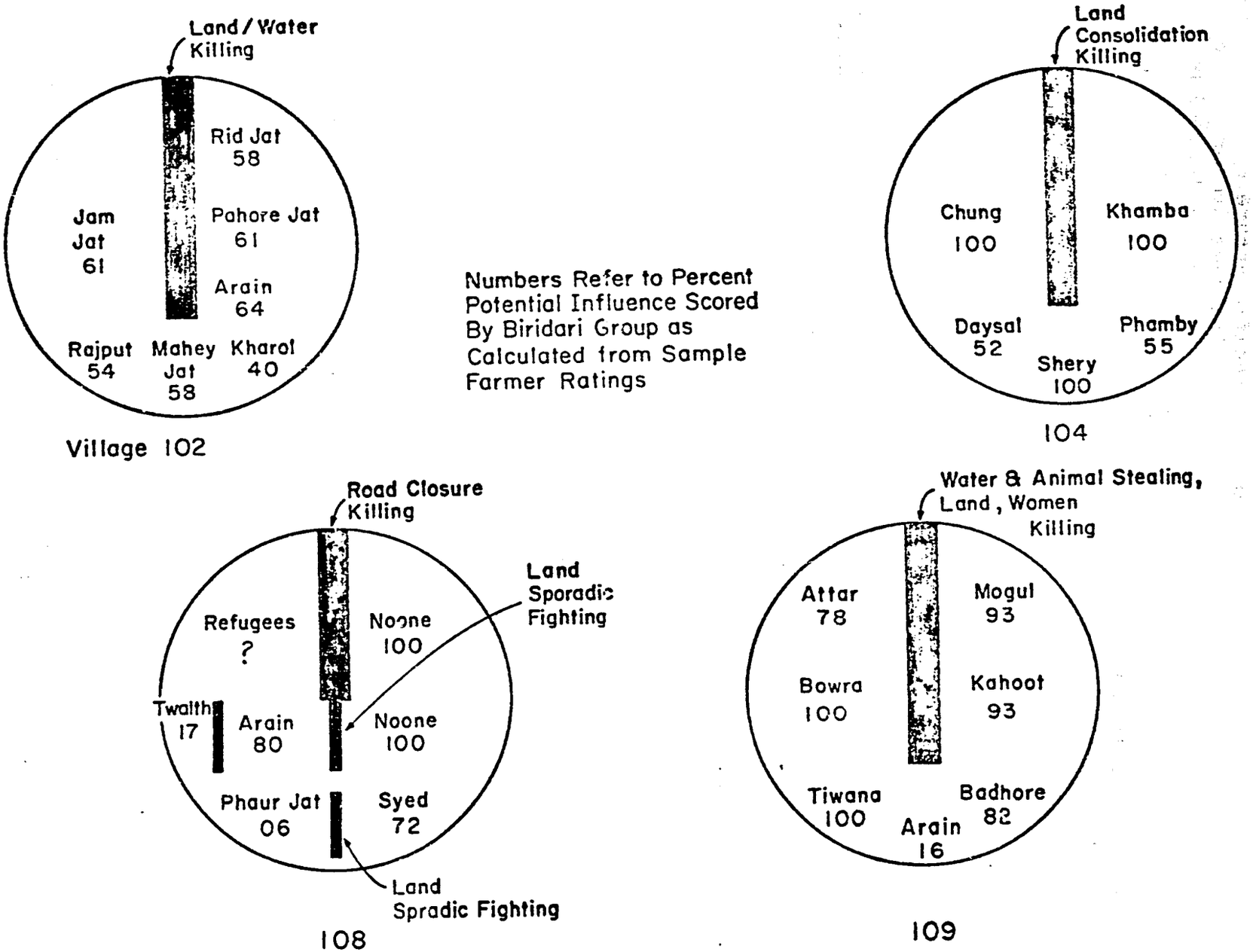
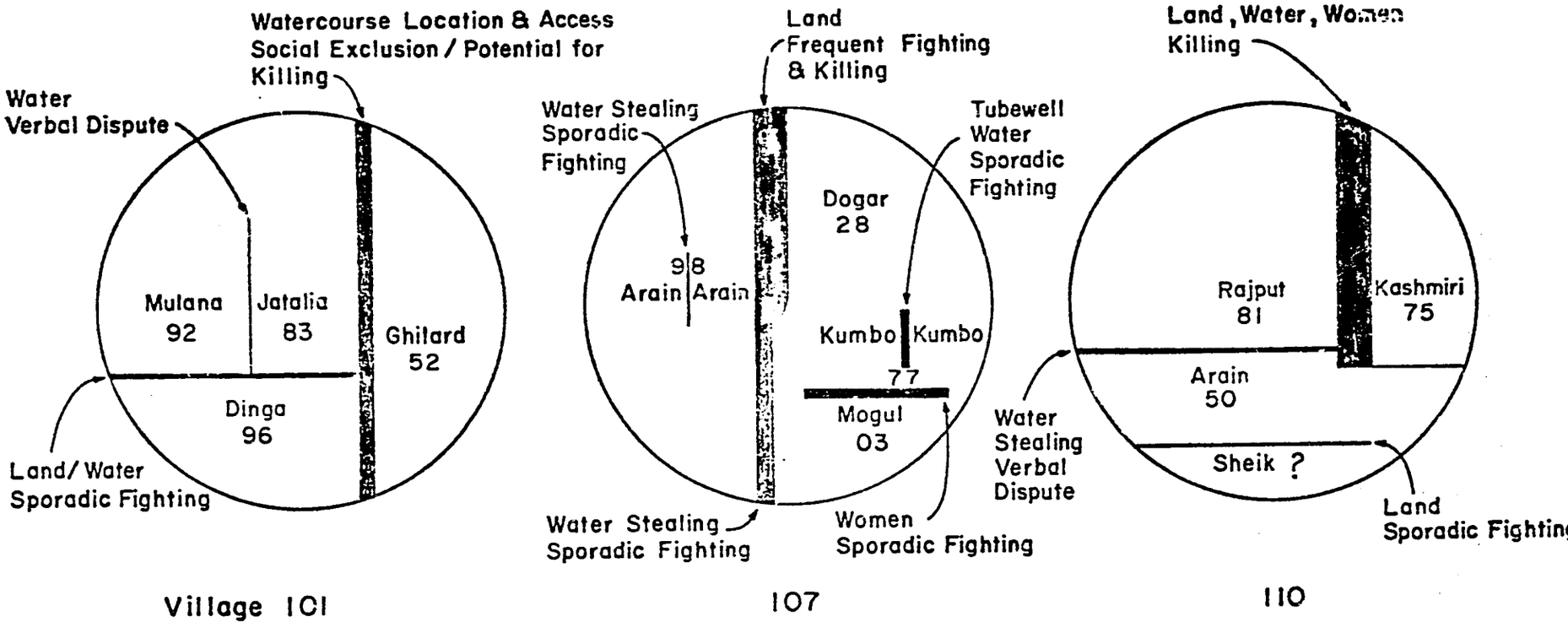
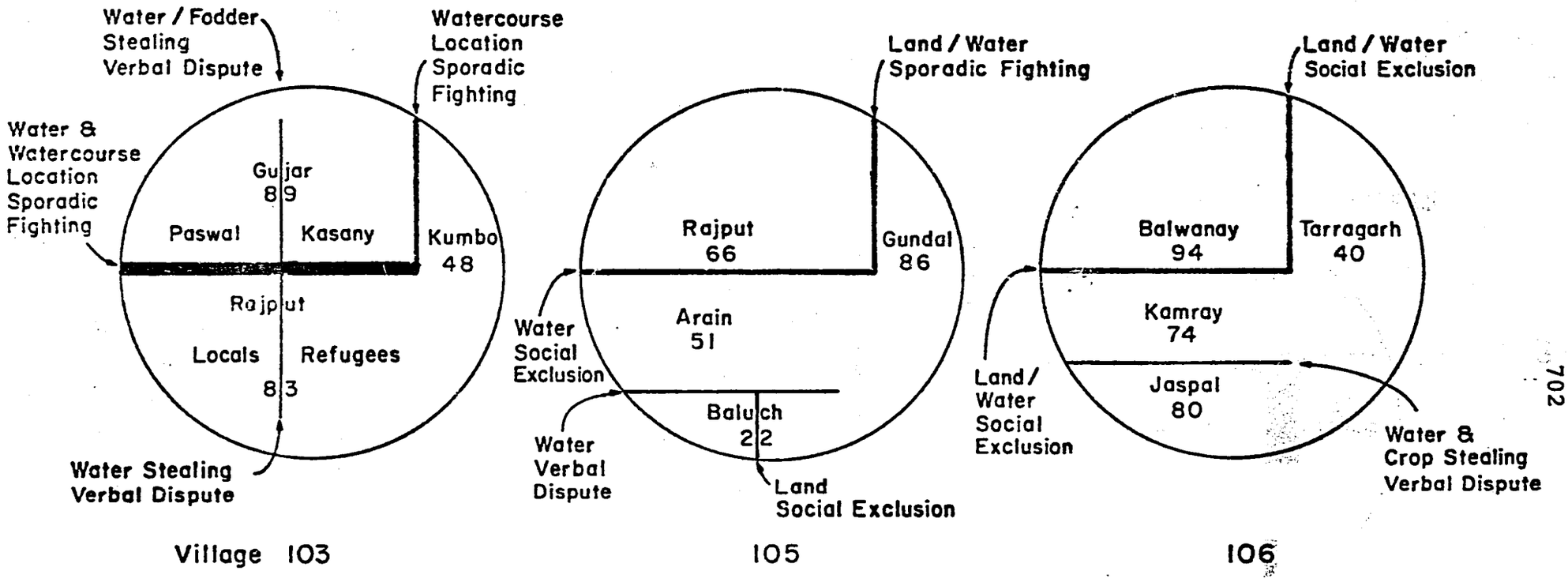


Figure 13. Village Cleavage Patterns - High Polarization.



Numbers Refer to Percent Potential Influence
Scored by Biridari Group as Calculated from
Sample Farmer Rating

Figure 14. Village Cleavage Patterns - Moderate Polarization.



Numbers Refer to Percent Potential Influence Scored by Biridari Group as Calculated from Sample Farmer Ratings

Figure 15. Fillage Ceavage Patterns - Low Polarization.

field party--attempting to initiate construction of an improved watercourse--dealt exclusively with the anti-Jam Jat leaders. Although a most innocent oversight, the direct consequence was that the watercourse improvement project was abruptly halted midway through the construction phase by Jam Jat resistence.

The most talked about event in Village 104 for years has been the attempted land consolidation scheme promoted by the Revenue Department in the mid-1960's. The village has one agricultural caste--Dogar--but has been deeply divided over land ownership questions between the Chung and Khamba biradaris. The Revenue Department's attempt to push ahead with the consolidation project resulted in physical combat, the killing of a Khamba man, and the jailing of two influential Chungs. The deep cleavage persists and continues to divide farmers.

In Village 108, a group of refugee farmers, for which no influence data was collected, found the access road to their fields closed by members of the Noone brotherhood--all of whom are locals. The refugees resisted and the resulting physical combat left two Noones dead and deep divisions within the village community. Arains oppose the Noone brotherhood on a less divisive land dispute which makes them to some unknown degree, allies with the refugees group. The Arains also engage in frequent fighting with the relatively weak Twalth brotherhood over allegations of water stealing. In what appears to be an unrelated conflict, Phaur Jats have in the past sporadically fought over land matters with the Syeds.

Village 109 is deeply split over a complex set of issues involving water stealing, land ownership disputes, and women. Attar and Mogul biradaris have been opposed since 1952 but things escalated to the level of killing in 1971 when Bowras allied with the Attars and Kahoots joined Moguls. Respondents agree that at least 22 men were directly involved in the fighting when violence peaked in that year.

2. Moderately Polarized Villages

Villages are classified in this category when key informant and sample farmer information suggests that, although major conflicts may be present and dividing important groups, the conflicts do not polarize the whole village, just a segment thereof, and some level of cross-cutting attachment appears to exist.

Village 101 is characterized by major cleavages dividing Mulana, from Jatalia, from Dinga over land and water conflicts but respondents indicate that those three groups will subordinate their differences in opposing the Ghilards quest to obtain water rights on a preferred watercourse. At the risk of over-simplifying, the Ghilard family owns land which

cannot for topographical reasons be effectively irrigated from its designated watercourse. The Ghilard leader has consistently, without success, attempted to secure water from a second watercourse which could potentially better serve his plots. Since 1960, the Ghilard's have spent over Rs. 10,000 to gain favor with government officials and other biradari leaders. A marriage of the Ghilard's daughter was arranged on the promise that rights on the preferred watercourse would be forthcoming. All such attempts, however, have failed. Violence has probably been contained only by the fact that the Mulanas, Jatalias, and Dingas present a united opposition to the Ghilards. The Ghilards' interest is clearly to drive a wedge between his opponents and should an act of planned or unplanned change allow him to do so opportunities for violence increase.

The dominant cleavage in Village 107 concerns a land dispute between the Arains and Dogars--a conflict which has witnessed sporadic fighting over the years leading to a killing in 1974. This village narrowly misses classification in the high polarization category because the Arains and Kumbos are divided among themselves and the Arain/Kumbo conflict appears, from informant responses, to be significantly less intense than the Arain/Doggar cleavage. The "side" cleavages prevent an exclusive pre-occupation with the dominant Arain/Dogar conflict.

The social landscape of Village 110 is dominated by a major cleavage between the Rajputs and a small group of Jammu Kashmir refugees. Involving both land and women the conflict led to a killing in 1975. The rajputs also conduct a low level conflict with the Arains over water and the Arains, in turn, are fighting at a slightly higher level of hostility with the Sheiks over land ownership matters. Therefore, the dominating Rajput/Kashmiri cleavage is major but does not appear to polarize entire village--only a segment.

3. Low Polarization

Villages classified in this category are those in which no major single cleavage so polarizes sub-groups that village social life is rendered apart--into even smaller segments. (See Figure 15). It is not a matter of determining that there are necessarily fewer conflicts present, but it is a matter of determining that whatever the quantity of conflict, cleavages are arranged in such a manner that they do not repeatedly over-lap to the point of making bargaining and negotiation difficult and violence probable. This is not to imply, however, that the conflicts are unimportant and can safely be ignored by agents of change. For example, the researchers learned that in Village 106, when invited to show a film on land owned by an influential Balwany, the Tarragarrah group would refuse to attend. The agent of planned change

cannot afford to ignore conflict when polarization is low--on the contrary, the objective must be to design and implement programs of change in such a manner as to undercut tendencies toward polarization. To achieve this, the change agent must be careful to 1) establish credibility with groups on all sides of the cleavages--something most difficult when cleavages are highly polarized, and 2) insure that both costs and benefits of planned programs are shared with relative equity by groups on all sides of the cleavages. To introduce a change program which places the benefits largely on one side of an existing cleavage and to direct the disadvantages or costs largely to the other side is to increase conflict polarization and flirt with social disruption, violence, and program paralysis no matter how technically feasible and/or economically justifiable the program.

In conclusion, the argument of this section is that it is possible to construct maps of important village conflict cleavages.[1] When villages are highly polarized, planned change programs to introduce farmer water management associations are likely to encounter more problems of resistance, subterfuge, lack of cooperation, and failure than are those same programs to organize farmers in non-polarized villages. No data is available to allow a useful analysis of the impact of successively higher levels of polarization on water management behavior, on responsiveness to planned change programs, or on identification of danger thresholds at which formerly "safe" cleavages become "explosive." But it is possible to suggest that a first criterion for selecting villages for programs of improved water management by that of screening out villages characterized by high polarization.

B. Criterion Two and Three--Equality of Power/Influence on the Watercourse and the Presence of Watercourse Leadership

Sample farmers were asked to rate each watercourse farmer, including himself, in response to the two part question:[2] How much influence/power does the farmer have in matters of 1) watercourse cleaning, and 2) settling watercourse disputes? The scores obtained yield a power/influence score for every individual farmer on the sample watercourses--even those not falling within the stratified random sample. The distribution

[1]The researchers are presently working on the development of methodologies by which conflict data can be gathered more easily, and with greater reliability and validity. The effort reported here can be viewed as no more than a highly tentative initial exploration.

[2]The same question posed to sample farmers about biradaris, castes, and Numbardars. Since responses to the two parts of the question turned out to be identical, values for the two parts have been collapsed into one for purposes of reporting results.

of influence scores for both the total population of farmers on the sample watercourses and for the study sample is displayed in Figure 16. Only in the case of sample farmers, could data be gathered about farming operations, farmer knowledge, farmer irrigation behavior, and other personal characteristics. But, by exploring some of the sample farmer data, it is possible to learn something about the characteristics of highly influential farmers.

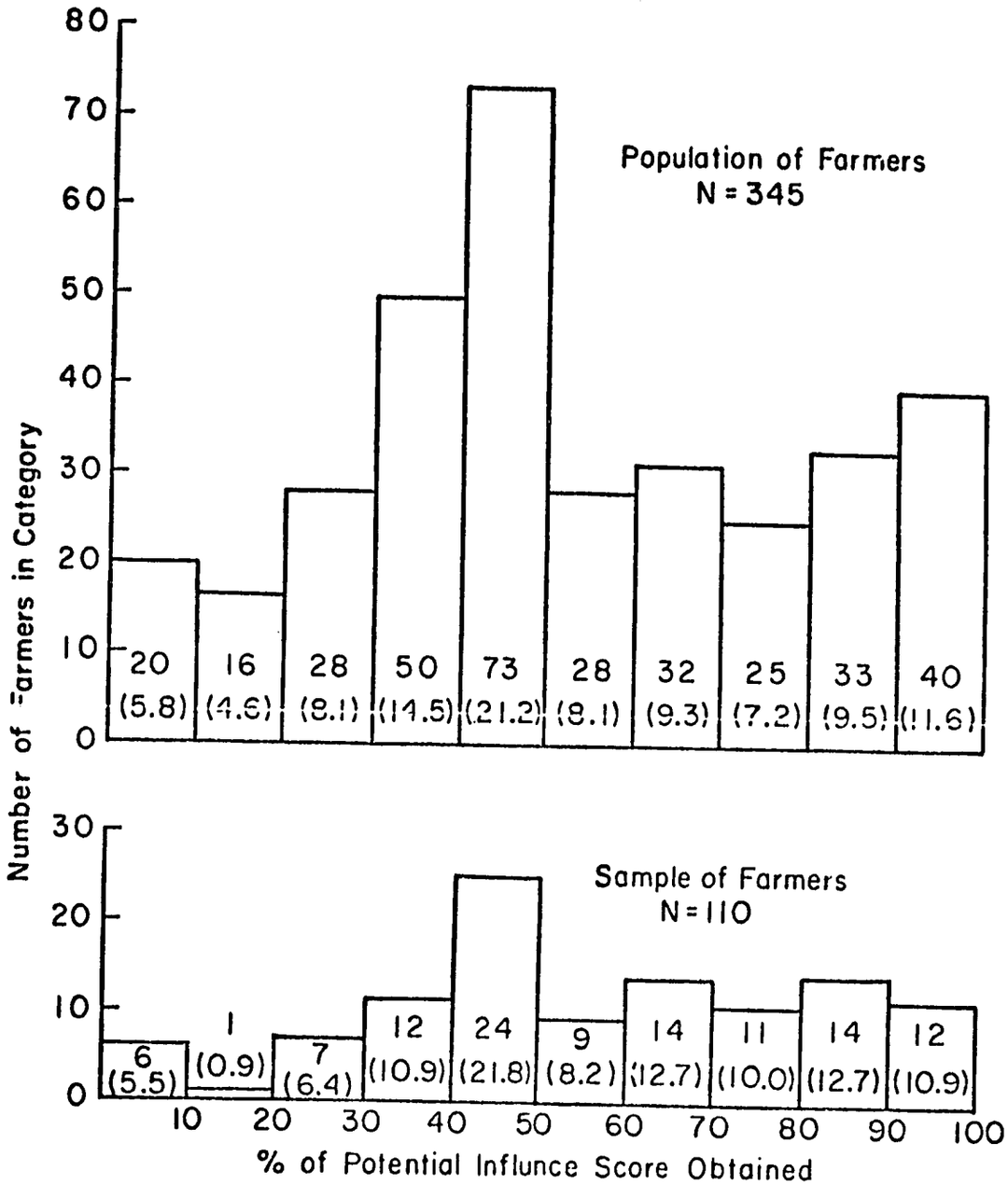
What, then, are some characteristics of the "influential/powerful" farmers? Are influentials better educated than non-influentials? No, they are not. See data in Table 29. There is no significant relationship between obtaining a high influential score and having completed higher levels of education.

Are sample influentials characterized by tending to be located toward the head of the watercourse--having fields located closer to the mogha? Table 30 shows that there is no relationship. However, there is a significant tendency for refugees to score higher on the power/influence scale than locals. See Table 31.

Table 32 shows that those with more power/influence tend to have more access to and make more use of, newspapers, radios, and magazines than do those with less power influence. In addition, those with more power/influence are significantly higher adopters of improved agricultural technology, have more knowledge of irrigation and agricultural services offered by local organizations, and own more land than do their less influential counterparts on the watercourse (Table 32).

Individual farmer power/influence analysis reveals something about the attributes of particular farmers, but now it is possible to proceed to an analysis of watercourse network characteristics. We approach the watercourse network, as distinguished from the individual farmer, armed with two concepts:

1. Centrality of power/influence--a dimension which tells one what percentage of farmers on a given watercourse score some specified amount of the potentially highest influence score--90%+, 80%+, 70%+, 60%+, 50%+. Obviously, farmers who score 90%+ of the potentially highest score that is possible to obtain are more "central" in the watercourse decision network than are farmers who score 30 percent of the potential. The centrality dimension reveals how many influentials at what levels are present in a watercourse network ranked cummulatively downward from 90%+ to 50%+. It is conceivable that everybody on a watercourse could score high or low on this measure.



Missing Village 107, W-C's 1-3

( ) = % of N

Figure 16. Distribution of Individual Farmer Influence/Power (Watercourse Population and Sample).

Table 29. Degree of Sample Farmer Influence by Level of Education Completed by Respondent.

Degree of Influence Score	Level of Education Completed							
	None		Primary		Middle		High+	
	No.	%	No.	%	No.	%	No.	%
0 - 40	20	(11.8)	2	(1.2)	1	(.6)	3	(1.8)
41 - 56	22	(13.0)	2	(1.2)	4	(2.4)	0	(0)
57 - 73	19	(11.2)	3	(1.8)	1	(.6)	3	(1.8)
74 - 100	66	(39.1)	6	(3.6)	7	(4.1)	10	(5.9)
	127	(75.1)	13	(7.7)	13	(7.7)	16	(9.5)

N = 169

X^2 = 6.46; 9 d.f; Not significant p > .10

Table 30. Degree of Sample Farmer Intuence by Watercoure Position.

Degree of Influence Score	Watercourse Position					
	Head		Middle		Tail	
	No.	%	No.	%	No.	%
0 - 40	9	(5.3)	7	(4.1)	10	(5.9)
41 - 56	9	(5.3)	10	(5.9)	9	(5.3)
57 - 73	12	(7.1)	6	(3.6)	8	(4.7)
74 - 100	29	(17.2)	29	(17.2)	31	(18.3)
	59	(34.9)	52	(30.8)	58	(34.3)

N = 169

X^2 = 2.36; 6 d.f.; Not significant p > .10

Table 31. Degree of Sample Farmer Influence by Local/Refugee Status.

Degree of Infuence Score	Refugee No.	Refugee Percent N	Local No.	Local Percent N
0 - 40	5	3.0	20	11.9
41 - 56	11	6.5	17	10.1
57 - 73	12	7.1	14	8.3
74 - 100	65	38.7	24	14.3
	93	55.4	75	44.6

$X^2 = 27.72$; 3 d.f.; $p < .001$

Table 32. Relationship Between Sample Farmers Influence/Power Scores and Selected Variables.

Degree of Farmer Influence is Associated with	Pearson's r	Spearman's rho	Kendalls tau
Farm management knowledge index	.0002	.0710	.0480
Farm management utilization index	-.0192	.1292*	.0868*
Index of access to canal information	.0301	.0138	.0160
Mass media access index	.2253*	.2072**	.1596***
Mass media exposure index	.2521	.1760**	.1316**
Adoption index	.2960****	.2846**	.2043****
Institutional services index	.2627**	.2487***	.1798***
Area owned	.3623****	.1744**	.1368**

* = significant at .10 level
** = significant at .05 level
*** = significant at .01 level
**** = significant at .001 level

For discussion of the several indexes, see Appendix B.

2. Equality (concentration) of power/influence--a dimension which defines the extent to which power/influence is distributed equally among farmers in the watercourse network. This score answers the following question: If one proceeds downward from the top of a ranked frequency distribution of farmer power/influence scores, how many farmer scores does it take, when summed, to equal or exceed 50 percent of the sum of all scores? A condition of greatest possible equality will be obtained if it takes exactly the top 50 percent of farmer scores to equal 50 percent of the sum of farmer scores. A condition of greatest possible inequality will occur if it only takes the top single farmer's score to equal or exceed fifty percent of the total scores--something which will occur when many farmers are given low or zero ratings.

Whereas an equality score may reveal equality when all farmers are equally weak or when all are equally powerful, it must be employed in conjunction with the centrality score which reveals the degree to which there is weakness or strength in the sample watercourse.

Data for power/influence centrality and equality are displayed in Figures 17-19 for all watercourses except the three in Village 107 for which no power/influence data were gathered. Bearing in mind that as equality scores approach the value of 50, the greater the equality of power/influence on the watercourse network, one finds that watercourse, Village 103, to be highly equal in the power distribution and nearly 70 percent of the farmers on that watercourse score 50 percent or more of their potential. In other words, the equality found on watercourse 1, Village 103, is the equality of influentials not of the powerless.

At the other extreme, Watercourse 1, Village 101, has only 25 percent of its farmers scoring 50%+ of the potential and half of the total power/influence score in the network can be accounted for by only the top 21 percent of the farmer scorers.

The working hypothesis is: the greater the percentage of farmers who score highly on the centrality dimension and the greater the equality of power/influence, the greater the probability of success in initiating and sustaining watercourse farmer associations. This hypothesis requires much further research for its verification and elaboration.

This exploratory inquiry could not focus intensively on the problem of securing data about quality of water management behavior and organization. For example, crop yields, delivery and application efficiencies would be appropriate

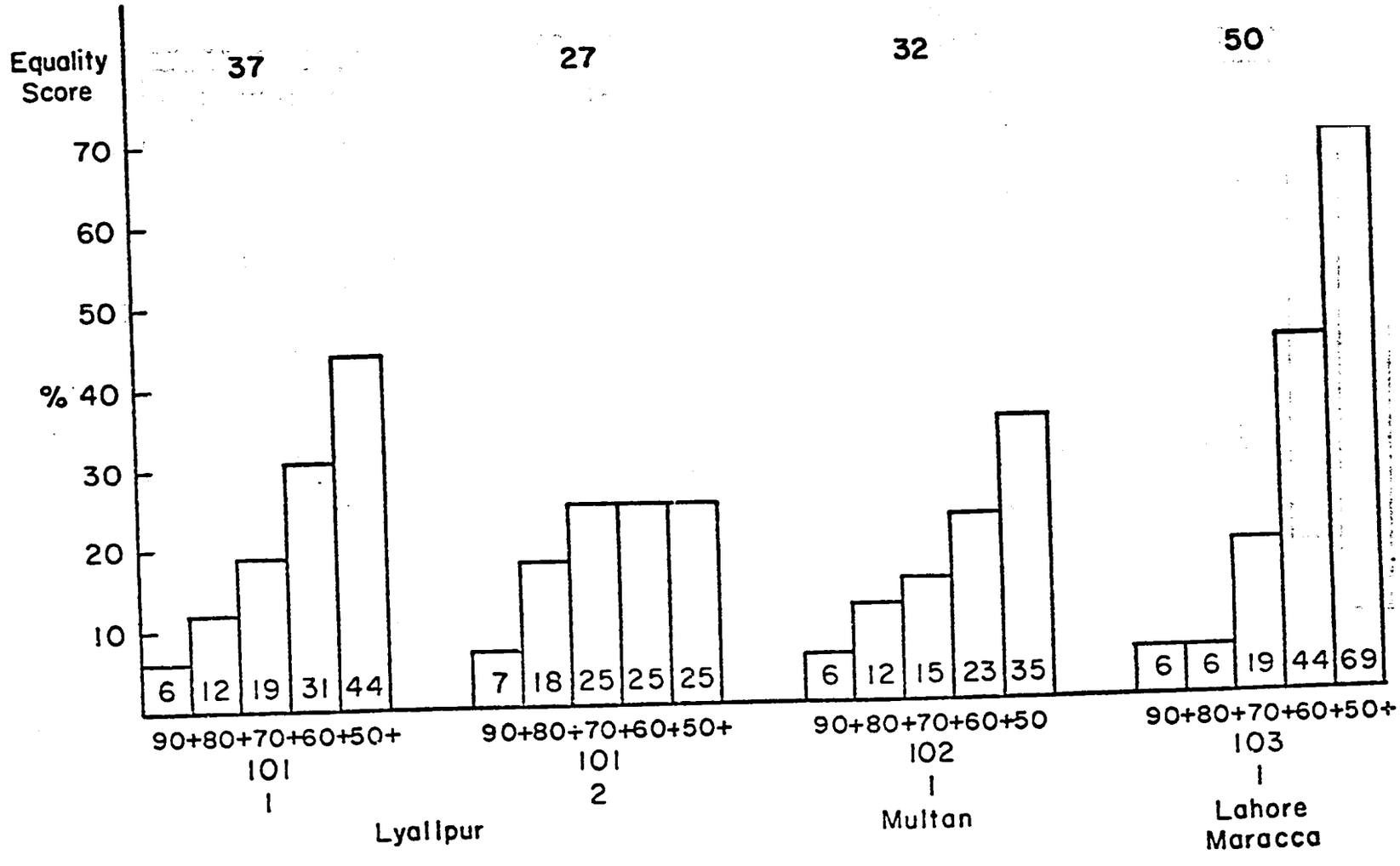


Figure 17. Centrality of Influence/Power (Leadership Strength).

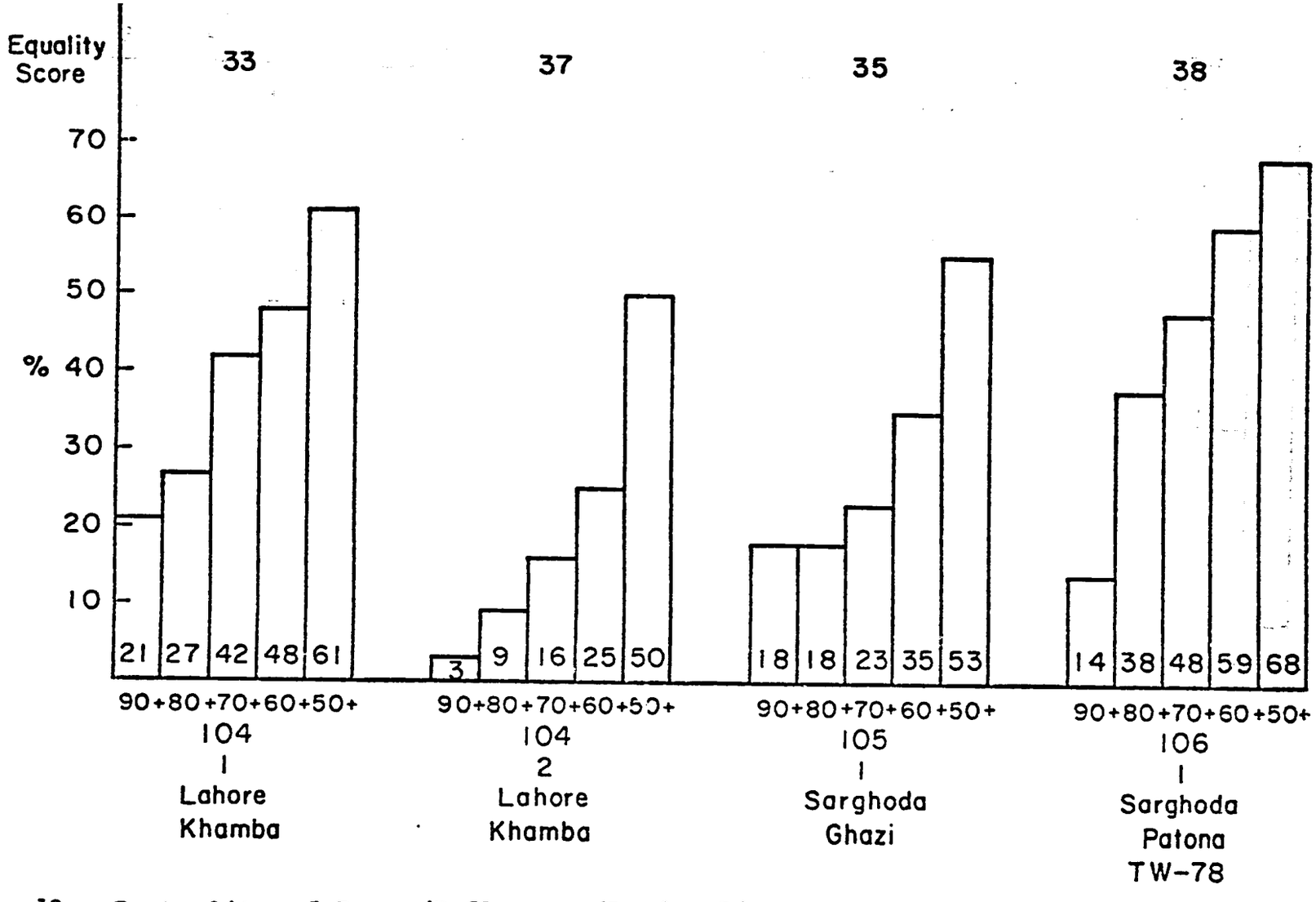


Figure 18. Centrality of Power/Influence (Leadership Strength).

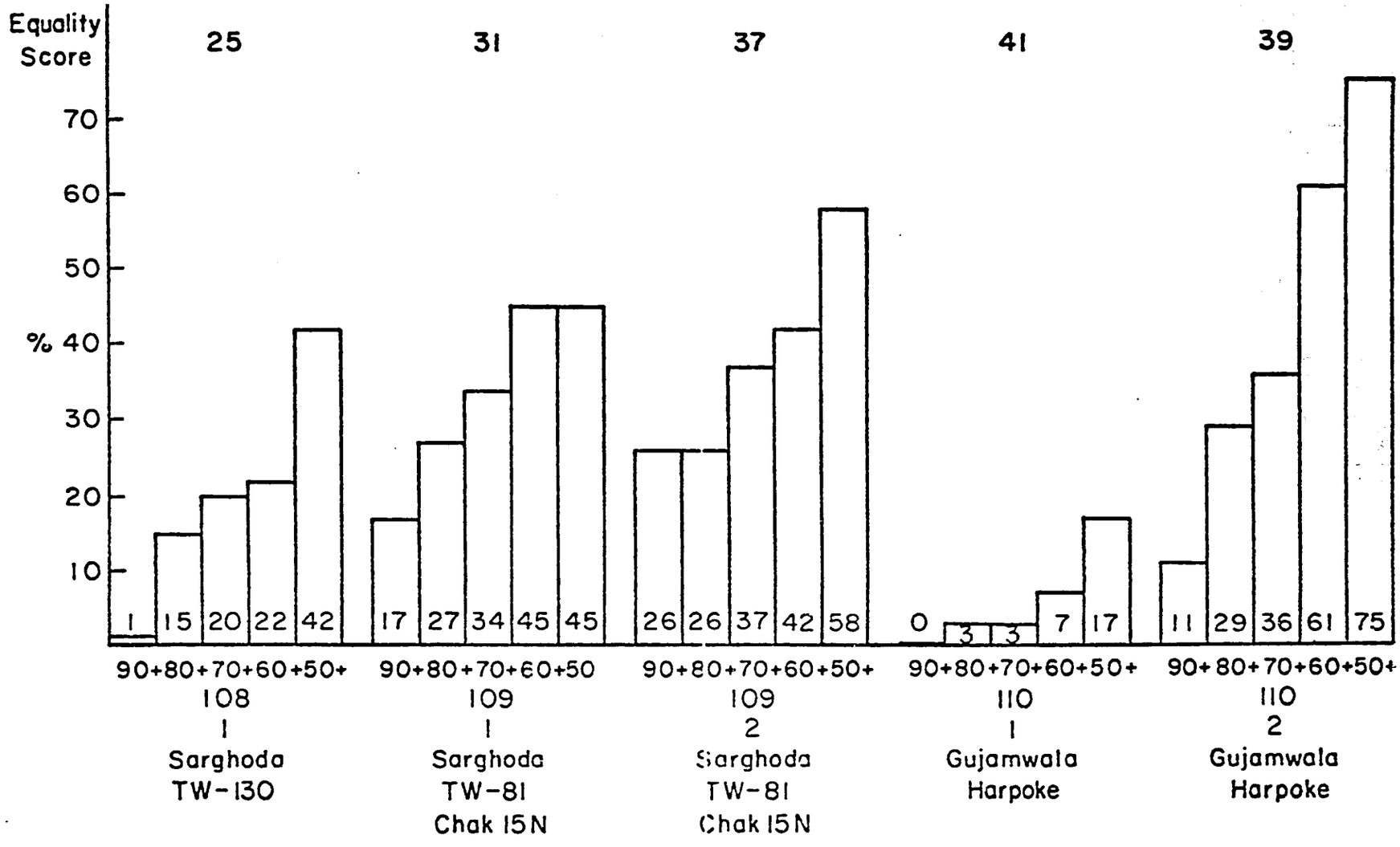


Figure 19. Centrality of Power/Influence (Leadership Strength).

variables on which to compare centrality and equality across watercourse social networks. Yet, there are many uncontrolled variables affecting the values of yields and efficiencies-- rainfall, soils, etc. -- such that there simply is no useful way to establish that a watercourse such as 106-1 with its characteristics of greater centrality and equality evidences higher delivery efficiencies than does a watercourse which has the least desirable social attributes that can be hypothesized.

What can be done, however, in a highly tentative way is to suggest that candidate villages for water management improvement programs which pass the non-polarization test, then be screened according to the criterion of power/influence equality. Those social networks which prove to be highly unequal can then be thrown out and the remainder be subjected to the test of power/influence centrality. It is suggested that those villages be chosen which give evidence of having a core of influential (central) leadership in the context of relative equality and non-polarization. Those are the villages, it is hypothesized, that are the best social candidates for water management improvement programs and for the organization of farmers into effective water users' associations. One can then choose from among this set of socially preferable villages according to technical and economic criteria.

If this method of reasoning were to be applied to the ten sample villages, and their sixteen sample watercourses, what would be the result? First, the criterion of conflict polarization would eliminate Villages 102, 104, 108, and 109 if moderately polarized villages are retained for consideration. Proceeding then to considerations of equality, one would eliminate at least village 101. (Village 108 also flunks the equality test, but was eliminated on the polarization criterion.) Of those which have survived the first two cuttings, "centrality" ranks watercourses in villages as follows: 106-1, 110-1/2, 105-1, and 103-1. The best candidates for watercourse improvement programs are these four sample villages. Villages/watercourses which are hypothesized as presenting social environments most conducive to the establishment and effective functioning of farmer water users associations are: (ranked by equality scores)

1. Village 103-1 -- Equality score - 50
   Centrality (80%+) - 6
   Polarization - Low

2. Village 110-1/2 -Equality Score - 41
   Centrality (80%+) - 29/3
   Polarization - Moderate

3. Village 106-1 -- Equality Score 38
Centrality Score (80%+) 38
Polarization - Low

4. Village 105-1 -- Equality Score - 35
Centrality (80%+) - 18
Polarization - Low

Village 106, has the best centrality configuration combined with the best equality scores. If we arbitrarily choose to look at the percent of farmers scoring 80%+ of the potential, Village 106 has a score of 38%, Village 110 scores at 29%, Village 105 (18%), and Village 103 (6%). In effect, for purposes of this example, we have in one case traded off a degree of conflict polarization for Village 110's reasonable centrality score. Village 110 is the only one of the four surviving watercourses which was checked as moderately polarized. This raises an important question. How much conflict polarization should one justifiably trade off for how much of a gain in centrality? This question cannot be usefully answered at this stage of the research. Because we do not know what trade-offs to make among the three criteria, at this stage, only tentative rankings can be made. We can conclude only that these four sample villages, in all probability, will present more favorable environments for organizational planned change efforts than those villages screened out on the basis of polarization and equality of power/influence.[1] We do not know at this stage how much centrality should be traded off for how much equality or polarization. But, it can be hypothesized, that conflict polarization should be the criterion of the first order and greatest weight. If polarized, village leadership will be constrained from employing its resources for constructive developmental purposes, no matter how great the equality and centrality. In sum, then:

1. Punjabi village farmers operate in a tight social network consisting of biridaris, castes, numbardars, Patwaris, and Overseers;

2. Farmers work within an irrigation system, established in the nineteenth century and unchanged in important respects to this day, designed to provide them with minimal control over the water supply;

3. Most farmers perceive water to be their most critical constraint to increasing agricultural production and they seek to enlarge their control over the rigid irrigation system in four major ways: 1) obtaining

[1]Note: There is a need to undertake examination of the relationship between the three suggested criteria and the degree to which villages have organized to provide themselves with local organizations such as mosques, schools, post offices, etc.

tubewell supplies which can be available on demand; 2) by extensive buying, selling, and trading water even though it is illegal; 3) by stealing water when it is needed; and 4) by bribing irrigation and revenue officials to secure "concessions."

4. Delivery and application efficiencies are low throughout the sample. A major component of improved water management, along with programs of extension, and credit, must be watercourse improvement. But if watercourses are to be improved, farmers must be organized into effective water users associations which will serve to obtain and maintain improved watercourses and provide for linkage of the farmer to sources of agricultural knowledge and to irrigation authorities so as to bring the flow of water under more precise farmer control.

5. The design and evaluation of farmer water users associations is a complex subject beyond the bounds of this study, but three sociological criteria have been suggested which, if employed to screen candidate villages for water management improvement programs, are hypothesized to identify those social networks most conducive to programs of planned organization building.

Appendix A

METHODOLOGICAL CONSIDERATIONS--
SAMPLE CHARACTERISTICS AND DATA COLLECTION

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 corpping or agro-climatic regions of the Punjabi; (2) watercourses in public tubewell areas and watercourses with private and no tubewells were to be represented; (3) watercourses were to be characterized by single and multiple caste villages; (4) sample watercourses were to be operated by indigenous local as well as 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 watercourses in ten villages.

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: (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.

Data Collection

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 wateroucrse deliveries are specified by Waryam et al.(1975).[1]

[1]Waryam Ali Mohsin, Wayne Clyma, and Alan Early, "The Installation and Use of Cutthroat Flumes for Water Management," CSU Water Management Research, Methodology Series No. 1. (Mimeograph).

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 field 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. 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 sociological data were administered to all the sample farmers. These were previously pretested and were written in simple Urdu. Interviewers received special training in administering the structured interviews and were closely supervised in the field. Two separate interviews were conducted with each farmer to assure better data given the relatively extended interviewing time required.

Types of Watercourses in the Sample

The major types of watercourses included in the sample are shown in Table A-1. Since the survey was conducted in the Kharif (summer) season on the two non-perennial watercourses, differences in irrigation behavior are not expected. They are both in Scarp or public tubewell areas with adequate water supplies for the full year. Only one watercourse had an unregulated or Kutchi warabundi where farmers themselves make decisions about the warabundi or turn system for the distribution of canal supplies.

The five major agro-climatological areas or cropping zones are presented in Table A-2, to show the District, type of cropping region and the months the data were collected in each area.

The months shown in Table A-2 are for each area included in the study and indicate periods when major data collection was completed.

Table A-1 Types of watercourses with number and percent of sample farmers.

Type watercourse	Number of watercourses	Number of farmers	Percent of farmers
Perennial	14	152	90.0
[a]Non-perennial	2	17	10.0
	16	169	100.0
Regulated-warabundi	15	153	90.5
Unregulated-warabundi	1	16	9.5
	16	169	100.0
Public tubewell	4	43	25.5
Private tubewell	9	104	61.5
No tubewell	3	22	13.0
	16	169	100.0
[b]Jalar waterlifts	1	16	9.5
Non Jalar	15	153	90.5
	16	169	100.0

[a]Non perennial water courses receive canal water only for the Kharif (summer) season.

[b]Jalar water lifts are traditional Persian animal powered chain-bucket lifts.

Table A-2 Major agro-climatological zones, sample villages, water courses and farms.

Area and Dates	Number of village sites	Number of sample watercourses	Number of sample farm	% of all farms
1. Lyallpur District (wheat-sugarcane) May and June	1	2	17	10.1
2. Multan District (wheat-cotton) (June)	2	4	64	37.8
3. Lahore District (wheat-fodder) (June-July)	2	3	31	18.3
4. Sargodha District (mixed crops) (July - August)	3	5	41	24.3
5. Gujranwala District (wheat-rice) (September)	1	2	16	9.6
Total	10	16	169	100.0

Table A-3.Farm and farmer characteristics of the sample.

Characteristic	Number of Farmers	Percent of Farmers
1. Tenure structure		
a. Owner operators	119	70.4
b. Owner-cum-tenants	25	14.8
c. Tenants	25	14.8
	169	100.0
2. Type of Farm		
a. Joint	61	36.1
b. Individual	108	63.9
	169	100.0
3. Farm size (acres)		
a. Less than 7.49 (very small)	47	27.8
b. 7.50 to 12.49 (small)	48	28.4
c. 12.50 to 24.99 (medium)	48	28.4
d. 25.0 and over (large)	26	15.4
	169	100.0

Appendix B

MEASUREMENT SCALES AND INDICES

1. Farm management knowledge index. This index includes eight recommended farm practices for a high yielding wheat variety, Chenab 70. Farmers were asked to give the recommended range of sowing dates, method of seedbed preparation, seeding method, seeding depth, seed rate, nitrogen inputs, phosphorus inputs, and split applications of fertilizer.

The following values were used for scores.

a. Recommended range of sowing date

Does not know	= 0
Knows within 4 days	= 2
Knows correct range	= 4

b. Recommended seedbed preparation

Local plow	= 1
Bullock mouldboard plow	= 2
Tractor mouldboard plow	= 3

c. Recommended seed depth

Does not kno2	= 0
Knows within one half inch	= 1
Knows correct depth	= 4

d. Recommended seeding method

Broadcast	= 1
Kera	= 2
Pora	= 3
Automatic drill	= 4

e. Recommended level of nitrogen when wheat crop follows cotton or rice with no green manure or organic fertilizer

Less than 75 lbs	= 1
75-99 lbs	= 2
100-114.5 lbs of N	= 3
115 lbs plus	= 4

f. Recommended level of phosphatic fertilizers (with conditions explained under e above).

Less than 24 lbs	= 1
25-49 lbs	= 3
50 lbs plus	= 4

g. Recommended split application of nitrogen fertilizer

No	= 0
Yes	= 2

h. Recommended seed rate for late sowing

Less than 40 seer/acre	= 1
40-49 seer/acre	= 2
50 seer/acre	= 4

A possible total score of 29 can be achieved by the respondent.

2. A farm management utilization index. It is composed of the same items as the above farm management knowledge index. Respondents were asked about the extent of use of each item. This index has a high value of 29.

3. Adoption of farm technology index. This index includes improved technologies and cultural practices which have been incorporated into the farm operation on a regular basis. The following innovations are given a score of one each: Two high yielding wheat varieties, a high yielding rice variety, use of pN fertilizers, wheat drill, mouldboard plow, bullock cultivator, bar harrow, line planting of rice seedlings, insecticides for rice, insecticides for cotton, split applications of nitrogen for wheat, rubber tire, bullock cart, fodder chopper, and use of tractor. The remaining innovations were given the following values: seedbed preparation with mouldboard plow, (1) and with tractor, (2) proper depth of seed placement for wheat (2) and with .5": (1) proper seed rate for wheat (2) and within 8 lbs; (1) proper level of nitrogen for dward wheat (2) and within 15 lbs. (1) for indivisible items such as regular hiring of a tractor for farm work was given on equal score as ownership. A total score of 23 is possible for adoption.

4. Access to canal information is a measure of the frequency with which farmers receive information from the irrigation department about canal closures for cleaning, repairs and rationing and about expected seasonal supplies of canal water. "Usually" receives information is weighted as 4; "sometimes" weighed as 2; and "never" is weighed as 0. A total score of 16 is possible.

5. Institutional services index. Farmers were asked to give the names, locations of office or residence and number of purposeful contacts with 10 local officials or agencies. A value of 2 was given for knowledge of the official's name; a value of 1 was given for knowledge of the official's location; values for contacts were assigned as: 2 for 1 to 2 contacts, 4 for 3 to 4 contacts and 6 for 5 to 6 contacts and 8 for more than 6 contacts over a three month period. Using the above values, a score of 110 is possible for a respondent.

6. Mass media exposure index. This index is composed of times listened to radio programs, television programs, times read newspapers or magazines for at least 30 minutes duration over the last week. For each of the types of media the following scores are given: none= 0; 1 to 2 times = 2; 3 to 5 times

= 4; and 6 or more times = 6. Another measure of listening to the regular farm radio program was combined with the above with the following values: none = 0; "yes" = 1; "yes" plus correct time of program = 2; "yes" plus time plus knowledge of station = 3; and "yes" plus time, station and knowledge of a program subject during last week = 4. A score of 22 is possible for a respondent.

7. Mass media access index. This index is combined from the following items: ownership or listening to the radio; ownership or listening to a TV; obtains newspapers or magazines or reads in village. A score of 7 is possible.

8. Degree of individual farmer influence on the watercourses. A score revealing each farmer's influence relative to that of every over farmer on the watercourse. The score is obtained by the following procedures:

a. A 25 percent sample of farmers on the watercourse ranked all farmers on the watercourse and assigned a value of 0 = no influence; 1 = little influence; 2 = some influence; and 4 = very much influence.

b. The highest score which a given farmer could potentially obtain is secured by multiplying the value of 4 (the highest score any single judge can give) by the number of respondent judges in the 25 percent sample.

c. The actual influence score obtained by a given farmer was computed simply by summing the judges' scores actually given to each farmer.

d. Each farmer influence score is then "normed" vis-a-vis all other scores by deriving its percentage value of the potential score.

This method of computing influence scores is also applied to biradari groups.

Example: For a farmer to obtain an influence score of zero, all farmer judges would have to grant zeros which would sum to zero and be zero percent of the potential score which could have been obtained if all judges had awarded the value of 4.

9. Centrality of farmer influence on the watercourse--a second dimension of influence/power relationships which reveals what percentage of all farmers on the watercourse obtained scores of 90+ percent, 80+ percent, 70+ percent, 60+ percent, and 50+ percent of their potentially highest score. This measure reveals something about the centralization or dispersion of influence/power among watercourse farmers. Conceivably many

farmers could be powerful or powerless. For example, a score of 31 in the 80+ percent category means that 31 percent of all the watercourse farmers obtained 80 percent or more of their potential influence score. This score is a statement about the power constellation of the watercourse as a whole and cannot be imputed as the property of any individual farmer.

10. Concentration of farmer influence on the watercourse--a third dimension of farmer power/influence relationships which reveals what percentage of watercourse farmers, proceeding downward from the top of an influence score, frequency distribution, it takes to account for 50 percent of all the influence/power scores attributed by the sample of judges to all farmers. The concentration ratio reveals the extent to which power/influence is distributed equally or unequally among watercourse farmers. If power/influence is exactly equal in distribution, then it will take 50 percent of all watercourse farmers to account for 50 percent of the total watercourse score which is nothing more than a sum of all farmer scores. For example, if the concentration score is 10 then it means that it only takes the top 10 percent of the influentials to account for 50 percent of the total influence--a highly unequal power distribution.

The concentration value is a statement about the power constellation of the network of farmers on the watercourse as a whole and cannot be imputed as the property of any individual farmer.

Appendix 41

LEGAL CONSIDERATIONS AND ALTERNATIVES TO ORGANIZING WATER USERS[1]

George E. Radosevich[2]

INTRODUCTION

This paper is a synthesis of information and experience based upon research and consulting in numerous countries on the subject of water law and water user associations and enlightenment on various water law systems as a result of organizing with several colleagues at Colorado State University, Utah State University and in Spain and directing the International Conference on Global Water Law Systems, Valencia, Spain, held in September 1975. The subject matter discussed is closely related and interdependent but falls within two distinct categories. First, the role of water law and a short description of several distinct allocation and control systems will be presented. This category concerns the substantive and procedural laws for government intervention into the use process of water resources. The second category surrounds the organizational potentialities and alternatives of the users to efficiently utilize the resources in the public and private interest and legal factors to consider when promoting the mobilization of the water users into collaborative associations.

The success of any agricultural development program with the objectives of enhancing the quality of rural life and meeting national food production requirements depends on a strong water policy to increase delivery and application efficiencies, to encourage conjunctive use of surface and groundwaters and to integrate water quantity and quality control. These objectives can best be achieved through the active and well-structured collaboration of local water users among themselves and with officials charged with administration, control and distribution of water.

The realization of these objectives also requires an awareness on the part of government officials and policymakers of the conditions and constraints to change which water users face within their localities. Conversely, the image of government officials and personnel in relation to the water users must be improved by their demonstrating an appreciation

[1]Presented at the Workshop on Implementing Public Irrigation Programs, East West Food Institute, Honolulu, Hawaii, August 18-31, 1976.

[2]Associate Professor of Water Law and Economics, Department of Economics, Colorado State University, Fort Collins, Colorado.

and understanding of the problems of local farmers and in providing the water users with timely information on water availabilities.

Formation of local water user associations can provide the infrastructure for improving irrigation efficiency and increasing agricultural production by:

(1) getting farmers directly involved in the local decision-making process;

(2) managing the water distribution system, thus improving the delivery, application, and removal of water throughout the system;

(3) resolving disputes between water users as individuals, and problems arising between water users collectively and the central government;

(4) serving as a communications link and forum for disseminating information and assistance on improved water use, agricultural practices and technologies, and methods for improving the quality of rural life;

(5) channeling the needs and desires of farmers and rural communities to those government agencies best equipped to meet them through that level of the association hierarchy which has access to the appropriate level of government organization;

(6) promoting the collective action of individual farmers by pooling their individual resources in actions which benefit the individual and the group;

(7) establishing a formal management mechanism for administering government aid with a higher level of accountability and permanence;

(8) taking advantage of the economies of scale in committing scarce financial and technological resources to programs which are better integrated with national or regional goals and which will benefit greater numbers of individuals.[1]

The recommended pattern for organizing water user associations is to examine both endogenous and exogenous entities and then structure and tailor the new entity to coincide with the religious, social, political, economic, and legal system for the country in question. Also, the water user

[1]Portions of this paper on water user associations are taken from the author's report to USAID, Legal Aspects of Water User Associations, in press, 1976.

association should commence with a simple, nonsophisticated organizational arrangement which is flexible enough to allow for institutional maturation as intra-water course demands and developments take place. It is also important to distinguish between improving an existing system and developing an entirely new program.

Other issues to be considered are: (1) the purposes of the organization, i.e., single purpose (irrigation) or multiple purpose (irrigation, conservation, drainage, reclamation, etc.); (2) jurisdictional or territorial limitations of operation; (3) financial operations, including assessments, public borrowing, and membership dues; (4) internal decision-making, including voting and selection of officers; (5) the interrelationship of the association with similar groups and with agencies of the central government; (6) possible incentives for individual participation; (7) how the water user association will function in relation to broader government policies for water and agricultural development; and (8) the method for resolving disputes which arise.

These issues must be viewed against the background of various influencing factors such as the trade-offs between the scarcity or abundance of labor and capital, the physical abundance of water resources and the environmental quality of that resource, and how the resource use is influenced by the seasonal aspects of surface runoff or aquifer recharge.

WATER LAW

Water is a fundamental natural resource with complex characteristics. The ability to apply water for beneficial uses is as much subject to natural laws of the physical universe as the laws of human institutions. The greatest benefit from water is derived when it is used in combination with other natural resources (soil, mineral, or vegetative) and economic resources (labor and capital). The more efficiently it can be used in combination with other resources, whether by technological or institutional innovation, the greater the benefit to the water user and society.

A quick review of water activities around the globe clearly indicates that this recourse has rapidly become one of the critical elements in determining local, national and regional growth. In the past three decades, particularly the last five years, the trend has been away from treating water as a free good, subject to near unrestricted control, to a recognition of the resource as a capital commodity whose spatial and temporal availability dictates policy formulation and new directions in macro and micro planning and development. Nations of all stages of development have accorded control and management of water resources a high priority.

Water laws are the expression of basic policy and substantive provisions dealing with the use of water and the development of water resources; they are the basis for establishing the administrative rules and regulations. The underlying philosophy of each particular system of water law has a direct connection to the surrounding physical factors of its origin. Where water is plentiful, regulation is aimed at ameliorating the harmful effects of water (floods, salinization, etc.), but, where water is scarce, regulation is aimed at ensuring an adequate supply, for example, by providing that water is not owned by one individual but, rather, collectively so that all may use what is available.

Over time distinct regional or national systems emerged which reflect particular physical conditions and social goals. Elaborate water laws and administrative systems evolved where the greatest needs and most serious natural constraints existed. Through adoption or imposition many of these systems have also influenced or directed water use and control in other countries or regions; and, although retaining many of the basic characteristics of the original system, have incorporated modifications to meet indigenous conditions.

The first objective of the Valencia Conference was to systematically describe a variety of these water law systems that have had a major contribution to the manner in which nations have managed and regulated their water resources or which exemplify unique features in response to specific water conditions or use goals. A uniform format was utilized by the experts reporting on these systems so that a comparison of features could be made between the systems. The second objective was to explore the social, economic and technical aspects of water resources use and management as these parameters related to functions and formulation of water laws. The final objective, and perhaps the most important, was to develop an approach to examining these legal alternatives in light of contemporary conditions and explicate a methodology for preparation of water laws that would bring about desired changes and maximization of water-related benefits.

Among the water law systems reviewed were the Spanish, French, British, Italian, Soviet, Hindu-Bali, Moslem, Latin American, Israeli, and the variations found in the United States and select Asiatic countries. The relationship of water law to the human and physical environment was discussed from the social, economic and technical perspectives concluding with presentations on national water planning, drafting water codes and multi- and bilateral assistance available to developing countries in preparing or revising water codes and administrative arrangements.

The following summary of selected systems of water law and administration is based upon the reports prepared for the ICGWLS.[1]

A classification has been made of the various systems into three categories: customary, traditional and modern water law systems. It is interesting to note the correlation between the classification and the reporting approach of the authors. A philosophical approach was used in describing the two customary systems--Moslem and Hindu-Bali. The traditional systems were descriptively portrayed reflecting the length and thoroughness of traditional codes. A variety of approaches were applied in delineating features of modern codes and laws. They ranged from defining the theme of the code as set out in policy with emphasis either on public interest or economic forces of the marketplace to analytical approach with emphasis upon the dynamic nature or failure of the law and the changes that have or ought to occur.

System of Religious Customary Base

These systems are represented by conceptualization of the Moselm systems of water law and the Subak system for water administration in Bali, Indonesia. Both systems have in common their religious origin. In both, water is treated as part of man's cosmogony, and in neither is water subject to private appropriation. Water is the object of a right to use, not ownership of the corpus, with the exception of the cases in which the Islamic law recognizes private rights on waters. This recognition is limited to small volumes of water contained in well-defined boundaries, like the water contained in a cistern.

The Islamic water law is not a national system of water law in the western style. Rather, it is a system of religious and traditional doctrines and uses. It goes beyond country boundaries pervading local customs. In turn, the religious element which gives commonality to the system is influenced by the particular uses of each place and locality. In this respect, it should be stressed that Islam did respect local practices, as long as they were not in opposition to the basic set of religious rules. The basic equalitarian concept of Islam prevails throughout all aspects of Moslem water law and is easily identified in the common water ownership and equitable proportionment principles of the law. In this way, for example, the policies of Yemen are to spread the water as much as possible, in order to irrigate the maximum possible

[1]For a thorough discussion on various water law systems, see Proceedings of the International Conference Global Water Law Systems, Vol. 1 to 4, Prepared by G. Radosevich, et. al., Colorado State University, Fort Collins, CO (1976). ICGWLS refers to the International Conference on Global Water Law Systems.

area of land. Another reason is that taxes are based on irrigated land. In Medina there is a policy of fair distribution of the waters, and water rights are attached to the land. With the spread of Islam, the appurtenancy principle spread to Spain and to regions of North and South America.

The trade centers of the desert developed notions about public uses of the waters. These notions were a requirement of the particular situation of these points of obligatory passage to all travelers. Also in these centers some concepts about wasteful use of the waters began to develop. The tribes of the desert also developed the notion of "harim," by which a territorial claim was made to land surrounding a water hole. Under the general conception that water should be freely available to all, each person had the right to use the waters for domestic and personal uses. Wells were declared free to use for all travelers, and endowments of water for public use were encouraged. Under the preaching of the Prophet, water was to be supplied also to beasts (domestic animals having preference).

Great rivers are absolutely common property. Small natural rivers are predominantly for the use of the riparian, and artificial rivers are for the common use of those who dig them. Surplus waters are to be always offered for the use of other persons.

Water for irrigation is to be allocated based on: (1) the crops; (2) the season; and (3) the local customs and the quality of the water.

It is allocated by time and volume and the order of preference is: (1) thirst; (2) domestic uses; (3) irrigation and commerce; and (4) industry.

Rules against abuse and waste pervade the use of the waters and any member of the community can claim judicial redress to establish or protect a water right on Subak water. River banks are protected through the harim and the use of public waters is supervised by the state.

Maktari points out that beyond and against the principles of the Islam there are problems for the rational uses of the water rights. Most constraints stem out of social inequities such as abuses on the side of the most prosperous farmers, in prejudice of the smaller water users.

The most rational use of wells is restricted because every person does have the right to drill a well on his land, even when it affects the rights of other water users.

Islamic principles on water administration are not very relevant; that is, the law says very little about high levels

of administration. The Islamic law, as a prevailing system of belief and tradition does not offer solutions for centralization of water management, but it has had a fundamental influence at local levels, where it results in a local authority controlling water rights.

Thus, administration and organization results from local and ancient customs. Local water masters carry out water administration. Maktari remarks that under the Islamic system there has been a breeding of conservatism and traditionalism even against technological change. Problems of abuses and corruption sometimes adversely affect the system. These problems, however, are not exclusive propriety of customary systems.

The other system of customary-religious based law that was presented at the Conference is the Subak. The Subak is the traditional water management technique of Bali in the Indonesian Archipelago. It is based on the Hinduism cosmogony. It survived the brief domination of Buddhist dynasties and was modified only slightly by Islamism, which reduced the unit for water administration to the level of the village. The Subak included not only one, but several villages for water administration.

The Subak is basically a community of farmers which irrigate. The common bond is irrigation and for this reason it encompasses several villages. The limits are not set by the village boundaries but by the irrigated lands. It is governed by rules of customary law.

Administration is through a Subak meeting (assembly) which has sovereign water jurisdiction and whose decisions are implemented by a chief water master. The latter is assisted by deputies, by assistants and by criers, which control respectively, each subunit of the water network, the end of the water network, and the distribution of water to individual users.

Water can never become an element of appropriation; it is only subject to rights of use. Water is distributed in proportion to crop needs.

The Latin American Systems and Their Problems

In Latin America there are two systems of water law. The first is the traditional system, influenced by the riparian system of France and by the system of the Spanish Water Law of 1879.

Second are the modern water laws, inspired by principles of comprehensive water management under the control of the state. These laws have attempted to translate principles of

water management into principles of water law. They are the laws of Mexico, Panama, Columbia, Peru, Ecuador and Chile.

There is a significant lack of effective channels of communication from the users to the highest levels of administration. In most of the countries there is a lack of general coherent policies which, translated to the water resources field, would give criteria for the guidance of the particular activities of each national water agency.

Significant attempts to overcome these constraints are represented by Mexico in which united decision making is combined with the maximum possible user participation. Also, in Cuba where there is an autonomous institute for water administration and Ecuador, which has implemented a comprehensive scheme for water administration.

Water administration can be carried out by federal and state agencies, like in Argentina or at a centralized center of autonomous decision, like in Mexico. Attempts of regional structures for water administration are carried out in Brazil, where the input of the central government is very significant. In Venezuela, an attempt for comprehensive planning and management is at present being carried out. Peru has most of the responsibillity for water management carried out by the General Directorate of Waters and Irrigation.

Examples of countries in which water administration is divided among several institutions are Uruguay, the Dominican Republic, Paraguay, Nicaragua, Guatemala and El Salvador. In Chile, there is a proposal for the creation of an Institute of Water Resources which would be charged with the coordination of all water resources activities.

In South America there is a growing awareness of the importance of water resources for the developmental process. There are serious attempts of implementation of new legal systems for the most correct management of the resource. There are, however, difficulties created by the particular socio-economic structures of the Latin American countries. The subject deserves special attention, for the new draft of new legal codes cannot be severed from the conditions of each country. If abstraction is made of the facts the seeds for failure will accompany any intent of legal change. The law is not only an instruement for the change of a particular socio-economic milieu; it is also a consequence of it.

Select Systems of Water Law in Eurpoe and the Mid-East

A brief summary follows of the system of water law in the United Kingdom, France, Spain, Italy, Soviet Union and Israel. These systems were selected for discussion at the ICGWLS due to their global influence or unique and potentially transferable features.

In the United Kingdom statutory regulations have been enacted in the public interest. England has placed a high premium on water and the resource needs have transformed the plentiful commodity to an item of scarcity.

For this reason, Common Law has been substituted by statutory law. The provisions which have evolved from traditional common to modern laws have been designed: (a) to secure an adequate supply of water both in quantity and quality; (b) to satisfy all needs and prevent waste; (c) to secure water quality and pollution control; (d) to promote flood control and land drainage; (e) to clean the rivers of the country; (f) to assure recreational and wildlife and fisheries opportunities; and (g) to protect the interests of affected water users.

Under common law the rivers are considered public juris which cannot be owned. Ownership is significant only in relation to waterbeds. The beds of tidal rivers are owned by the crown. The use of water in riparian land is an incident of the right of ownership. The quality and quantity of the water cannot be diminished, unless authorized by grant, statute or prescription. Rights regarding artificial water courses are always required by grant or arrangement. Underground water can be freely used, according to the English absolute ownership rule. Many changes were made in the common law after the enactment of the Water Resources Act of 1963 and its coming into operation on July 1, 1965. It is now necessary to obtain a license for the use of inland underground waters. Exceptions are given for small abstractions, riparian domestic or agricultural uses, and abstraction of underground water for household use. The Act has substituted for the common law rights of the riparians a system of compulsory licensing. Rights to the use of waters are legally protected and administered. Water authorities are given broad powers for the control of the use and abuse of water rights. Under the common law water was not to be impaired in quality. Water pollution control laws have been enacted which strengthen and further define the common law concept in the context of new and projected uses.

Administration of water in the United Kingdom is most interesting in terms of how a system evolves. From the 1945 and 1963 Water Resources ACts to the present 1973 and 1974 Acts, the concept of the river basin authorities have developed and been tested under centralized to decentralized control. All functions associated with the water cycle are under the control of a single authority in any one region which attempts to closely correlate to a natural hydraulic unit. This leads to an integrated system of water management combining water quantity and quality control and conjunctive use of ground and surface waters. The guidelines of these control and management activities are set by water policies elaborated by the Secretary of State and by the

Ministers of agriculture, Fisheries and Food. The intent is to jointly promote a water policy for water management in England and Wales. The regional authorities execute the policy.

There is a National Water Resources Council which consists of a chairman appointed by the Secretary of State, the Chairman of the water authorities and other members appointed by the Secretary of State, and the Minister of Agriculture, Fisheries and Food. The Council assists and gives advice in water-related matters to the Ministers requiring it, assists and controls in the effective performance of duties of the water authorities and must elaborate a scheme for training and education in water-related functions.

There are nine regional water authorities in England and one in Wales. The area of a water authority may be different for the performance of different functions, but the intent is to organize around natural watersheds where possible, with, however, alterations in the boundaries where social and economic reasons prevail. Water authorities are presided over by a chairman appointed by the Secretary of State, and consist of two or four members appointed by the Ministry of Agriculture, and a variable number of representatives of the local population. The Water Authorities provide an integrated control system for water within the confines of national policy laid down by the ministries and can take every necessary action to insure the best use and administration of the water.

In France the waters are considered a source of life and the legislature has admitted, with reluctance, the private appropriation. Common rights have been readily recognized in favor of the riparian owners of water courses. The need to legislate pollution control has produced a deep change in the system of water law as well as in the system for water administration. France has abandoned the old system of water classification which was based on the navigability or floatability of the waters. Waters were public that were navigable or floatable. At present, water resources can be declared public because of their utility of importance for uses considered vital by the state for the socioeconomic well being of the population. Waters can be declared public because of their relevance to agriculture, industry, domestic uses, and navigation as well as for their damaging potential, as when the waters can produce dangerous floodings (Act 1, Law of December 16, 1964). This new classification includes the waters that were considered public in the old system; and, at the same time, broadens the category to include waters that, even when nonnavigable or floatable, do have public importance, either for their utility or for their dangerous potential.

There are also "mixed" water courses in which the waters are public and the beds are private. Public and mixed water courses are part of the general category of public waters. Private waters are a residual category. They are what is left after the former two categories have been determined.

Private property rights are recognized over springs and underground waters, but with important limitations. These limitations derive from several facts. For example, a land-owner cannot make free use of spring water that, even when arising on his land, is used by towns or other domestic needs. The use of underground water is subject to health regulation. The right to underground water is only acquired in the abstracted water. The consequences are quite similar to the application of the English Rule. Flowing, nonpublic waters are common waters subject to common use. For the use of public waters authorization is required. Navigation does always have preference.

France has also developed an extensive system of water protection against pollution. Water administration at the national level is spread among several ministries due to the public or nonpublic nature of the waters because of the uses to which they are dedicated. For concrete management it is unified at basin level. The interministerial coordination is carried out by the Ministry of the Quality of the Human Life (Decrees of March 2, 1971, and June, 1975). The important decisions are taken by the "Interministerial Committee for the Action for Environment." Final decisions or arbitrations are taken up by the Prime Minister. At the basin level water administration is carried out by Basin Agencies in which local interests have representation.

Spanish water law proclaims all water flowing in natural beds are public property. The category of flowing waters is widely interpreted including large as well as small rivers and arroyos. Spring waters flowing in natural beds are also considered public. Also, classified as public waters, fluent or not, are waters located on lands of the public domain, or lands affected by public water works. The waters, which do not flow in natural water beds, and which are located in private lands are private property. The Spanish water law thus combines two criteria: (a) waters flowing in natural water beds are public; and (b) if the waters do not flow in natural water beds, their condition depends upon the legal conditions of the lands in which they are located.

The allocation of public waters for individual or private uses is by concession from the Ministry of Public Works. These concessions are not required for limited domestic or natural uses such as water for thirst and washing, but are a necessary prerequisite to uses of special developments." A priority in allocation is set out in Article 160 of the Water

Act of 1879, placing in the following order--towns, railways, irrigated agriculture, navigation channels, mills and other factories, and acquatic life and habitats. Public waters are totally administered by the Ministry of Public Works through the Directorate of Water Works. The country is divided into ten basin administration entities which provide logical management consistent with the natural flow regime.

The Agencies for Water Administration at basin level are: the Water Commissioner and the Hydrographic Confederation, integrated by the individual users, Communities of Irrigators and Central Syndicator of the Basin. It can be said that, through this system of organization, Spain has greatly harmonized the need of unified decision making at central level with the requirement of participation of the local water users. Central decisions are conveyed in each river basin through the Water Commissioner. User and local institutional inputs are furnished through the Hydrographic Confederation. The disputes on water can be solved by Special Administrative Courts, by the Civil Courts, or by the Criminal Courts, depending on the kind of issue.

In spite of a very workable system for water allocation and management, it is important to take note of changes in the Spanish law. Conditions and demands have so significantly developed in the country that, with the advances of technology, the law is required to evolve to a new plateau. Presently, a draft of a modern Spanish water code is being discussed which places emphasis upon the two major deficiencies under the old law--conjunctive use of ground and surface water and integration of water quantity and quality control. Thus, Spain is rapidly moving toward a more modern system of water law.

Italy defines as public all the waters which have or can have qualities useful for satisfaction of needs of public and the general interest. This classification is influenced by the magnitude, volume, flow or width of the waters, as well as for their relationship to the hydraulic system of which they form a part. The administrative authority determines the particular condition of each corpus of water, trying to assure adequate protection to pre-existing water rights.

The public waters are listed in registers of public waters. Nonpublic (private) waters are a residual category whose use is also regulated by the laws. These waters are springs or waters wholly within lands under private ownership. Public waters are allocated to use through a permit system which includes an elaborate review of the application to determine the appropriateness of the use and quantity requested.

Water administration is distributed throughout different levels: the nation, region, provinces, and municipalities.

The centralized administration of pre-war Italy gave way to a more fragmented system. Nevertheless, a resources approach has been retained in the juridical arena: Italy's water courts are composed of a Supreme Tribunal for Public Waters, and eight regional courts.

It was pointed out by Dr. Caponera that even though the Italian water law functions well, the lack of continuity between basins as physical units for water control and the political entities of water administration acts as a constraint for the best use of the water. This constraint remains even though the existence of a Ministry of Public Works offers a unitary center of decision.

The basic principles of Societ water law are contained in the Fundamentals of Water Legislation of the U.S.S.R. in force from September 1, 1971. They have the highest legal force. They contain the basic concepts and conditions for water use and control. In their elaboration, 15 water codes have been adopted by the Republic of the Union. There are, in addition, many subsidiary normative acts.

The law regulates state agencies, state and public enterprises, organizations, and individual citizens in connection with water ownership, management, use, conservation, control, and protection against the harmful effects of the waters. Thus, regulation refers only to water resources available as separate natural water bodies. When waters are no longer part of the environment they are regulated by other bodies of law.

The policies are to ensure the most rational and economical use of the waters; to preserve, maintain, and improve water bodies; and to prevent the harmful effects of the waters. The basic principles of the law are: (1) exclusive state ownership; (2) national and comprehensive use; (3) priority of domestic uses; (4) strict requirement of water pollution control; (5) development of technology for water conservation; (6) registration and control of water uses; (7) adoption of the basin as hydrologic unit for water administration; and (8) active participation of the population in water uses. It is considered fundamental that water resources, within basins, form a definitive and economical unit. Water administration is carried out through several levels of government, and through agencies of general state administration, agencies of special state administration, and agencies of branch administration.

An examination of the water laws and administrative organisms of Israel provides an excellent opportunity to observe the dynamic role and process of change served by a legal resources control system placed under extreme needs to optimize scarce water supplies. Many other examples exist in

national or subgovernmental jurisdiction in the case of federated systems, but the laboratory process of developing water laws found in Israel illustrates the ultimate role in extensive and intensive water control through formalized laws and regulations. All waters, regardless of their form or location, are under the strict control and jurisdiction of the State. The State holds the water in trust for the citizens of Israel and is duty bound to allocate and administer this limited resource in the most beneficial and efficient manner possible. This power and duty is placed with the Ministry of Agriculture and under the specific jurisdiction of the Water Commissioner.

The water being public property as a general proposition, entitles every citizen of the country to the right to use the resource. However, an important feature of this right is the conditions placed upon its exercise. Water is allocated for use by term and reviewable permit. The process of application and final actions for water use insure the proposed use is beneficial to the individual and country. The results of the use are within the range of maximum output and other users will not be unreasonable affected if the proposed use is approved. All water rights are registered which enables effective administration and the ability to prepare appropriate water plans and projections. The important feature of this modern code is the policy declaration which provides the basis for subsequent administrative operation. The policy reflects the national goals as water serves as an input to achieving them.

Administratively, the law enpowers the Water Commissioner or his agents the right of exclusive control over withdrawals as provided in the permits. The Commissioner can cancel, or amend any permit and permanently or temporarily alter or suspend uses under it. All water use is metered and water fees charged according to volumetric uses with rates varying throughout the country to reflect different uses and use conditions. The Water Commissioner also has full power to prevent degradation to the nation's water quality. Water pollution control is imperative and infractions are quickly dealt with.

In addition to the Water Commissioner, there are numerous boards and authorities to provide advice and assistance in water matters. Water users play an important role as members of many of the entities. Disputes are under the jurisdictions of a Special Tribunal for Water Affairs. Any person who feels aggrieved by the actions of a government official or other water user can bring his case before this Tribunal.

Water Law in the United States

Water law in the United States is a federated system of complex proportions. Federal (national) and state water laws exist in both the water quantity and quality aspects of this resource. At the federal level, jurisdiction over water originates with the Constitution. The Property, Commerce, General Welfare, Treaty and Compact Clauses provide the basis for federal involvement in navigation, pollution abatement and allocation and management of water resources. Particular laws have been enacted to provide the substantive control and organizational structures to carry out federal policies and programs.

State water laws are less cognizant of the hydrologic aspects of water resources. Each state, being an autonomous political entity has rights to develop policies, laws and organizations according to local and state needs. Thus, there are virtually 50 separate water law systems for quantity and quality control, often with the lack of uniformity between states causing interstate conflicts. The states are primarily concerned with methods of allocation, distribution and administration of ground and surface waters given the particular and wide range of geographical conditions in the country.

Ownership of water is either public as in the case of the federal government jurisdiction over certain classes of water, or public or state in the case of rights over water vested in state control. The use of water depends upon the state systems of water law and ranges from common law right in the riparian system to a permit, license or decree under the appropriation system. A form of contract water rights is becoming increasingly popular.

The past ten years have witnessed the emergence of federal involvement from water development to management in the national and regional interests. Population shifts in a mobile society, industrialization, energy development, increased needs for food and fiber, conflicts and complementarities of water use with the interface of economic sectors, and new technologies have brought about this involvement. States, faced with the same issues at a more concentrated and grass roots level, have likewise been experiencing a significant evolution in their quantity and quality control laws with an emphasis upon developing planning and management capabilities to make conscious decisions based upon an evaluation of alternatives, impacts and opportunity costs.

Water administration at the federal level is under the jurisdiction of the Water Resources Council and a multitude of ministerial land departments and departmental agencies, bureaus, and authorities. State administration is hierarchical from central control at the political jurisdictional level down

to such levels of hydrologic units within the state. Normally water quantity and quality control is vested in different agencies. The water law systems in the United States are in a dynamic and evolutional process brought about by changing conditions, and can constantly benefit by an awareness of experiences in any nation.

Asiatic Systems

Professor Clark, a well-known expert in water law systems of Oceania and Asiatic regions, has repeatedly proclaimed the difficulty of summarily discussing this topic due to the great diversity that exists between countries in the region. This topic was the subject of a meeting held in Bangkok in 1967, of experts in the field convened by ECAFE and under the formulation and direction of Dr. Caponera, FAO, Rome.

In a paper prepared for the ICGWLS, Mr. Clark prepared the following abstract of his report:

> Water legislation in Asia has been profoundly influenced by Common Law, Civilian and Roman-Dutch models. There is thus great diversity in the theoretical bases for water administration, but a common pattern of relying on administrative bodies to allocate and adjust private rights to use water. In this sense, systems of judicial apportionment of rights, through litigation, are most uncommon.
>
> There is remarkable similarity in the techniques used for granting and controlling rights to water, although the primary emphasis of the legislative schemes naturally differ with the hydrological problems encountered. There is increasing reliance on techniques of multi-objective planning, but care must be taken in adapting systems of environmental planning to the different economic and social goals of developing countries.

The range of features in the law extend ownership from state to public to private; acquisition of rights according to custom without administrative intervention to systems granting permits or concessions; allocations according to a nonpreference or to limited preference of user classes; and administration under centralized to decentralized systems. A major concern of many systems is with water removal as in flood and drainage programs rather than water allocation.

Summary

In summary, the water law systems illustrate a wide range of approaches in control of allocation, distribution and regulation of the resource under diverse conditions. Ownership of the resource extends from state ownership in the U.S.S.R., to public ownership in the vast majority of

of countries to some private ownership as found in Spain and other countries. Often a water policy is lacking which provides the orientation of control and management for the government agency administering the laws. It is recommended the "policy" should be given serious attention in any attempt to stimulate water use efficiency and promote formation of collaborative efforts among water users.

Allocation of water likewise varies considerably, extending from no evidence of a right, to customary rights, to government concessions, permits or titles to court decrees. The success of the public irrigation program will partly depend upon the assurance of continued water availability to the water users in order to elicit their willingness to invest time and money beyond the present practice. While the assurance or right or privilege should be definable and dependable, it must also be flexible to react to changing demands and technologies. Water laws, therefore, will play an important role in improving water use through public irrigation improvement projects.

WATER USER ORGANIZATIONS

A situation that exists in most every agricultural country, that is ignored or considered insignificant to the major efforts of improved water management, is the micro-structure organization or water user arrangements, Normally, technical solutions are offered to solve the problems of water users. Often, they do result in immediate and substantial benefits to him, provided he can afford the capital investment or is subsidized. But he must continually depend upon technical solutions; and as an individual has not really achieved the benefits of social interaction and cooperation in the utilization of his scarce resources, whether they are natural or acquired.

An alternative to a purely technical solution, and one which has attained substantial success and sophistication in many countries, is the formation of water users associations. The terms water user associations or water user organization are used here to refer to any of the patterns of farmer to farmer or farmer to governmental agency entities designed to facilitate water delivery, application and removal. These entities of various forms have enabled the farmer to optimize his efficiencies of water use by adding flexibility to his application scheduling, sharing costs of an improved delivery system, and preventing unnecessary water removal problems. As with the water law, though, not just any structural pattern should be adopted. There are a wide variety of associations with varying degrees of success. It is important that the organization be structured from withint the existing legal, social, economic and cultural framework, and not be a simple acoption of an association that has been successful elsewhere.

The discussion on water user associations is directed toward two topics. The first concerns certain legal aspects of such entities, and the second topic focuses upon suggested factors and guidelines to be included in the formation of water user associations.

Legal Aspects

This topic addresses four key features of water user organizations: legal status, organizational range, area of jurisdiction and government involvement and control.

The legal status of the water users associations depends on their conditions for formation. They can exist as either "de jure" or "de fact." In the former case they are allowed to contract, are vested with legal rights, and subject to legal duties. In the second case, "de facto" associations, the rights and the duties, legally at least, pertain to each particular member of the association. In this case, the association is more a scheme for cooperation, without "de jure" existence. It is important to note that where these "de facto" associations exist, they should be formally recognized by law.

Most "de facto" associations are based on old customary patterns developed as a result of man's efforts to control his environment. They are deeply rooted in the societies in which they exist and are more real and important than any legally created body. Often they can be used as bases for successive and successful institution building. In this respect two good examples are presented in the Paddy Lands Irrigation Ordinances that the British enacted for Sri Lanka (Ceylon) in the last century and by the Indonesian Laws which recognized the customary "Subak" system of Bali.

When the water users associations have a de jure existence, i.e., when they have a specific legal status, they can be private, civil, public, or administrative in nature. In Mendoza, Argentina, they are regulated by public law. The same solution applies in Chile, Peru, Mexico, and most of the European countries. In the United States, the range of associations has extreme variability; they can be private, quasi private, and quasi public and public. In Spain, water users associations are regulated by administrative, public law.

Water user organizations range from private to public, simple to complex, and single to multipurpose entities of either distinct existence or functioning at a particular level in a hierarchy of associations.

The first category pertains to the legal status of the organizations as either private, quasi private/public or public entities. The significance may be minimal in most countries where governments are actively involved in the

allocation and management of water resources, but usually, the private and quasi private entities have only a bare responsibility to the government water agency or the public, whereas, the public entity has a high degree of public responsibility in the use of public waters and thus is under more direct evaluation or control by the government.

Private organizations exist in only a few countries, most notably, the United States and Italy.

At the local level in the United States of America there are three distinct private organizational entities designed to accomplish water resources development and management within a system. Ranging in degree of private sponsorship from highest to lowest, they are the commercial irrigation or ditch company, the mutal irrigation company and the voluntary association.

Commercial irrigation companies are organized by entrepreneurs for profitable conveyance of right holders' water or for the conveyance and sale of water owned or controlled by the company. Mutual irrigation companies are operated by water users for their express benefit and can be incorporated or unincorporated. One of the most striking attributes of mutual irrigation companies is the ease with which they can be created. As private organizations, they need only follow the general corporation law of the state in which they wish to incorporate. Since this is private enterprise, as contrasted with the public, governmental nature of special districts, no public hearings, elections, or public reports of feasibility studies are required. Membership is on a voluntary basis.

Voluntary associations have similar objectives to mutual irrigation companies but their foundation is less on legislative enactments and more on custom. Such organizations are groups of water users informally associated under written or verbal agreements. They are not organized under state corporation laws and do not issue stock. Despite their lack of formal standing, their simplicity in structure and flexibility in operation make their use highly desirable in many countries.

The predominate form of water user associations are those which are governmental subdivisions and can exercise only those powers which they have been legislatively delegated by the central government. Collectively, publicly formed water user associations cover a broad range of functions for public water resources management. Because there are so many varieties of public water user associations, and so many of them have been given combinations of functions unique to their country of origin, it is impossible to define a specific role that they play in the management of water resources.

Suffice it to say that some are simple, small organizations servicing the water needs of only a few people within a highly localized area while others are as powerful and important as civil governmental units, affecting the living and working conditions of many people.

The best way to approach the role in water resources management is to note their typically dichotomous position within the structure of government as (1) independent units of local government, and (2) operating units for intergovernmental programs on the local level. In the first capacity, water user associations function as autonomous units of government, subject to whatever checks and balances the parent government has imposed on them, within a specific geographical area. In their second role, public water user associations give local people an opportunity for self-government while allowing varying degrees of supervision, control, and technological and financial assistance while managing water resources as local operating units for national programs. This example of intergovernmental cooperation is typical of the spectrum of public water user associations.

Organizational patterns of water user associations range from simple structures serving few users within a local area as is the case for the communities of water users of Mendoza, Argentina, to complex organizations which manage water use within a river basin or national water system and supply water across the spectrum of water uses for agriculture, municipal and industrial use as is the case in Taiwan, Mexico and West Germany.

The complexity of the structure is a function of geographical size, number and type of water users, size of individual holdings, physical availability of water supply, and the intricacy of the legal system within which the organization must operate.

Water user associations have been organized for a wide range of purposes. The most common purpose is for the delivery of water required for seasonal application in the production of crops. In some systems, the association is concerned with cultural practices related to the application of the water in methods which reduce soil erosion and salinization as well as cultural practices related to cultivation, selection of seed and other areas of close concern to agriculture.

Where the economic base of a country is more complex and the agricultural sector is not the major area of economic emphasis, water user associations are created for the purpose of protecting wildlife and fish habitat and distributing water to municipal and industrial users. In the main, the principal focus of these organizations is the provision of a stable

supply to irrigators. However, it is not uncommon to find that water user associations have a role to play in drainage, flood control and water quality areas too. The spectrum ranges from the complex commitments of the German water users associations to the very simple functions of the Commissions of Public Waters of Paraguay.

The position of the local water user association in a formal or informal hierarchy of water user associations will often depend whether the association has been formed voluntarily by the users in the area or if the central government has created the subdivision by decree and membership is compulsory. In the former situation, the local group may be autonomous in its freedom of operation and may have the ability to organize itself without regard of political boundaries. They may form a loose confederation at higher levels of government to see that their needs and interests are expressed to the appropriated entities of civil government.

In the latter case, organization and control of local associations will be according to stricter rules for operation and the structuring of the association will take place from the "top-down" and the hierarchy of associations will often parallel the divisions of civil government and operation will be more conscribed by the recognition of political boundaries and the interdependency between various levels of the association hierarchy. Although some flexibility is lost, communication, planning and implementation of government policy is improved. Also, this integration can facilitate the diffusion of technical and financial assistance throughout the system.

The general rule for jurisdictional control is that the association will have authority over those lands which are served or benefited by the activities of the association, i.e., lands irrigated by the canals and ditches of the association. Final governmental approval of the area of jurisdiction is used in most countries as a means to avoid an overlap in area controlled by two or more associations.

The common procedures for the determination of the spatial powers of the associations are: (1) the arbitrary establishment of an area of activity, or (2) a more flexible system in which the area of authority of a water user association varies with the area affected or benefited by irrigation works, or in accordance with the size of the areas in which the waters subject to the authority of the association are used.

Minimum size, rather than maximum, is a feature of the Philippine system and unless the association will service an area of 25 hectare, it cannot be formed. Other countries take the size of the area to be served into consideration as a method for determining the level of the association

in the total national hierarchy of water organization as is the case in France and Taiwan.

Government control of water user associations varies according to the stage of development of the association and the level of its operation, whether it be national, regional, or local. Control may be through statutory means or through initiative by government officials.

Government control is uniformly present during the process of organizing water user associations. Enabling acts provide for the method and form of organization. These procedures must be complied with in order to give the force and effect of law to the later efforts of the association. In the later operation of the association, legal requirements must still be met and a different type of government control may now extend to the regular activities of the association. Such a practice is most common in those countries which have recently undergone agricultural reform programs and where the association is promoted from the "top-down" rather than developing from the grass roots level. This control is typically applied to the budgetary operation of the association and to the annual repair work performed on the distribution system.

If the association, or hierarchy of associations, operates programs which have relevancy beyond the local level or in areas other than agricultural water supply, some control is exerted by that level of government which is affected by the program. This may require approval and coordination of efforts with national and regional governments as well as with municipalities.

The most common form of governmental control is found in specific statutes and governmental regulations. Under this system the actions of the association are presumed to be legitimate unless challenged by a party who feels he has been injured by association action. In other systems direct control is vested in an official of government who oversees the routine functions of water associations and can enforce compliance with the laws and policies of the central government.

Issues and Guidelines

Whether water user associations of some type are to be formed as a component to a national or provincial/state public irrigation improvement program or the concern of the government to provide irrigators with an opportunity and approach to mobilize for increased production and subsequently enhance the water use, there are several issues to be addressed. They are:

1. What are the related water and other resource development policies of the country?

2. What type of organizational structures currently exist, if any?

3. If organizations exist, are they institutionalized or coincidental, defacto or dejure?

4. What incentive exists for creating or improving water user association?

5. What are the land use and tenure systems?

A distinction must be made between improving upon an existing system or developing a new system of water user associations in an area where no institutionalized system exists. The former requires:

1. A state-of-the-arts assessment of existing institutions - not only local water user organizations, but all entities related to water control, use, and agricultural activities. The rationale for this assessment is to acquire an understanding of the pragmatic operation and to identify potential impediments or complexities to improving water user associations.

2. Evaluating the goals and problems of coordination of existing or proposed methods.

3. Determination of the degree of flexibility in formulating a complete system of administration consistent with national or regional policies and development programs, from the "bottom-up" grassroot form of organizational structure.

The latter requires:

1. Evaluation of national and subnational waterand related resources and socio-economic goals, policies and laws.

2. Determination of the degree of flexibility in formulating complete system of administration consistent with national or regional policies and development programs, from the "top-down" form of organizational structure.

The formation of water users associations is according to one of two methods. First, it is possible for water users to act on their own incentive to establish such an organization. Generally, this method is provided for under enabling legislation which creates the structure for, as well as the

method of organizing, the association. However, there are examples, such as that of voluntary association in the western United States, where collective action has developed, by necessity, without formal governmental approval. When an association is organized according to the provisions of an enabling act, the typical requirements are that at least a majority of the landowners or operators present a petition stating such things as the area of jurisdiction that the association will have, the membership roll, the purposes for which it is being organized, and the bylaws of the association for internal operation. The petition is submitted for approval to a court or administrative agency of the government. If approval is granted, the association begins operation and the information in the petition becomes binding on petitioners and nonpetitioners.

Secondly, it is possible that the central government may wish to establish water user associations according to a general plan for the nation or region or in an area where water shortage requires stricter controls on water use. In this case, the government may have authority to assume the initiative under the same enabling legislation which provided for individual action at the local level. However, the creation of water user associations, as management units in some countries, such as Mexico, is entirely the province of the federal executive. In such state-created systems, membership is compulsory on all operators in the jurisdiction of the association.

The majority of countries allow water user associations to organize according to the individual initiative of water users under provisions which are stated in enabling legislation. In this fashion, the method of formation and means of operation are controlled by the government. Furthermore, final approval of the association's establishment rests with the central government.

In those situations where action on the local level does not meet the requirements of the central government due to delay, watershortage, or other reasons, it is possible for the government to assume the leadership for establishing water user associations under the same enabling legislation.

Other examples can be found at either extreme--from the complete autonomy of voluntary associations in the western United States to the strict planning and control by the government in Mexico.

Water user associations can be formed either by individuals or legal entities. Membership can be voluntary or compulsory. Often, a minimum number of water users is required to forma a water users association. In some cases, special qualifications are required to be a member or officer of the executive

body of the association. Some countries require that membership be composed entirely of private land owners while others permit a mixture of non-landowners and government officials.

Upon formation of a water user association, membership in the association is generally compulsory on those individuals who will receive benefit from association efforts. A few systems, such as those in Mendoza, Argentina, and the United States, provide methods for the minority who do not wish to participate financially in the association to seek judicial review of the formation of the association. Membership entails certain responsibilities as well as rights. Full participation in activities beyond payment of dues and other financial support may be conditioned upon literacy, land ownership, or age.

Voting systems range from those countries such as Peru where votes are cast in proportion to the size of land holding within the association to the one-man one-vote system in most associations in the United States. Several systems permit municipalities, government personnel and agencies and private corporations to be members of water user associations also. The most important aspect of membership is whether to allow tenants and lessees to be voting members or to restrict such membership to landowners only. The general rule seems to be that membership in the association follows either title to the land or the right to the use of water. However, there is a growing trend, particularly in South American countries which have undergone recent land reform, to allow nonowners to participate fully in association decision-making.

Water users associations are conferred specific powers to carry out their commitments. The scope and class of powers is variable. In some countries, like Spain, or Germany, they can enact regulations which are legally binding on their members. In other parts of the world, like Mendoza, Argentina, they administer the distribution of the waters but do not enact regulations. In Spain they can be recipients of water concessions from the central government. Spanish water user associations also have judicial functions.

In most countries they can raise revenues, as we have already seen, and generally have the necessary powers to assure continuity and unity of control over water distribution and maintenance and repair of water owrks. They also might be given powers of eminent domain to condemn private property. They can also undertake the construction of new water works. In this respect their role is variable. In Mendoza, Argentina, they are limited to minor improvement works. In Germany they can even construct reservoirs and hydroelectric stations.

The powers which a water user association can exercise are granted to it by the central government, although some

examples exist in the western United States of associations exercising authority under contract and corporate law. Generally, associations are given the power to provide for the regulation of water delivery and the construction, repair and maintenance of the systems. Associations are given the authority to promulgate regulations for internal operation and to set tax or assessment rates for financial support of its activities. In both instances, approval by a higher level of government may be required before the association can enforce these actions upon its membership. Another standard feature is to empower the association to hire employees or other officials of the association to conduct the day-to-day business of the association.

The authority to resolve disputes between members has been granted to associations in some countries and this power may be exercised in some judicial capacity or by having the association arbitrate the dispute. Another interesting power is the right of the association to exercise the power of eminent domain to condemn private property in the form of land or water rights. Some countries provide that compensation must be paid for the property taken while other systems allow for expropriation without payment.

Where the authority of the association is derived from a grant of the central government's police powers, the association cannot go beyond those powers and those powers not given the association are reserved to the central government. In the exercise of its powers, the association is generally permitted to impose sanctions or penalties on its members who refuse to comply with association regulations. These sanctions can take the form of fines or other means such as loss of water service or water rights can be used to enforce compliance. Where such sanctions are allowed, a rational system gives the individual the recourse to appeal the ruling to a higher authority or court.

Exercise of the legal powers given to the association and other expressions of collectively made decisions require that a system for polling the association's membership be implemented. The most common form of collective decision-making is for members to express approval or disapproval of proposed actions by voting.

The numbers of votes which a member can cast vary from system to system. It is not uncommon for the number of votes to be a direct function of the number of acres or hectares which a member of the association has under irrigation or that voting be a direct function of the amount of water which a farmer has a right to. One system, Austria, equates voting with the amount of financial support contributed to the association.

In some countries voting power is directly proportional to water rights, or to irrigated acreage. In Spain, for example, a person has as many votes as units of water right. In other countries voting power has been regulated in order to avoid dominance by the big landowners. This regulation assumes different forms. In some countries everybody has one vote, regardless of the water rights; in others, a maximum number of votes per capita is set and, last, other systems try to balance by giving everybody a minimum number of votes to start with.

In Mendoza, Argentina, the law has tried to reduce the disparity in voting power between small and large landowners. Voting rights are proportional to the amount of irrigated land that each landowner has. There is a minimum amount and a maximum number of votes. The votes are determined in this form (Art. 42, Mendoz Water Law, 1884):

Votes	Ha
1	2000 m^2 to 2 ha
2	2 ha to 5 ha
4	5 ha to 10 ha
6	10 ha to 15 ha
7	15 ha to 20 ha
8	20 ha to 30 ha
9	30 ha to 50 ha
10	more than 50 ha

Members of the commissions of irrigation in San Juan, Argentina, vote on issues significant to the operation and management of the association. The number of votes each irrigator has is proportional to the number of hectares he has under irrigation on a graduated basis. The maximum amount of votes is ten.

Other nations such as Japan and parts of the United States apply a strict one-man one-vote rule.

Usually a majority vote is sufficient for most issues; however, issues which may require extraordinary action may require 2/3 or greater to gain approval. Such decisions may include construction of facilities, election of officers or decisions to use debt financing.

Certainly not all decisions need to be made by the collective action of the association. Purely administrative matter should be left to the discretion of officers or employees of the association with the opportunity to review them at the next regular meeting of the association.

The methods which water user associations can use to finance their operations is directly related to the sources from which revenue can be obtained. The most common practice

is to place the entire burden on the members of the association in the form of charges for the amount of water used or to levy taxes on the assessed valuation of the land owned by the irrigator. Payment is generally in monetary form; however, some countries allow farmers to make payment in-kind by working at a set rate for the association. Although rates or levies may be set by the local association, government approval is a common feature with many systems before revenue can be collected. Loss of water or other sanctions can be imposed against those who do not meet their obligations to the association.

Larger projects require amounts of capital which are usually beyond the resources of a local association. Therefore, cost-sharing with the central government in the form of loans or grants enable the assocaition to expand their financial base. If the government requires repayment of the loan with interest, the rate of interest will have a great effect on whether the project is undertaken. Even if the loan is interest free, repayment will be the responsibility of the individual users through assessments paid to their association. The central government may also perform the service of collecting and managing the money to repay the loan on behalf of the local association.

If capital is available in the private sector, it may be possible for associations to issue bonds which are retired by regular payments made by the association from assessments or charges required from individual water users. The requirement of repaying the debt with interest is a standard feature of private financing and here again the "cost" of money could be a limiting factor in using this method of financing.

CONCLUSION

The efficient and effective utilization of water resources is rapidly becoming a major topic in all nations due to increasing demands for food, fiber and energy. Agriculture, globally, is the largest diverter of water, and consequently a potential candidate for governmental action programs designed to improve the use of water and thereby either expand the irrigable acreages or reallocate the saved supplies to other sectors of the economy. To carry out such programs, however, requires the mobilization of the agricultural water users into some organizational entity through which the government can implement and assist the desired changes. These entities are best described as water user associations.

The prime objective is to enable the water users, individually and collectively, to improve themselves and provide the governing body with appropriate feedback so that realistic policies and programs can be formulated and implemented. Water user associations can function as the forum for farmers of any size land holding to realize and identify their role importance to their nation.

Appendix 42

ORGANIZING FARMERS TO IMPROVE IRRIGATION WATER DELIVERY--THE PROBLEM AND PROSPECTS FOR SOLUTIONS IN PAKISTAN

Max K. Lowdermilk, David M. Freeman,
Alan C. Early, George E. Radosevich and W. Doral Kemper[1]

I. The Problem

The kinds of organizations which people create and maintain for the social control of irrigation water intimately affect the productivity of its use. Attempting to comprehend physical and agronomic problems of irrigation without probing into underlying social organization for irrigation is like attempting to understand deficiencies in plant growth without reference to conditions of climate. When water moves efficiently from rivers, through a network of canals and associated watercourses to plant root zones, it is because people have effectively organized a decision system capable of enforcing technically sound rules for pursuing the collective interest. Defects in the delivery systems of irrigation water are typically associated with deficiencies in organizational relationships, or the lack of organizations.

Pakistan has one of the most extensive integrated irrigation water distribution systems in the world. However, Pakistani farmers are not adequately organized to obtain and apply irrigation water to meet the demands of a modernizing agriculture. The on-farm delivery of irrigation water is inefficient, due largely to inadequate farmer organizations, as evidenced by the following facts:

1. World Bank (1976) estimates suggest that, if the provisions for watercourse cleaning and maintenance stated in the Canal and Drainage Act (1873) were fulfilled, the farmers on 78,000 watercourses in Pakistan would "save" approximately five million acre feet of water by 1978 without capital inputs. If farmers were to engage in cleaning and maintenance of watercourses until 1982, about 10 MAF could be saved annually at no cost to government. This amount, valued at Rs. 360 ($36) per acre foot, would result in annual savings to Pakistan of approximately $360,000,000. Farmers

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do not provide mainimum levels of watercourse cleaning and maintenance because they do not know the magnitude of their water losses, they do not know how to do the most effective job of cleaning and maintenance, and they are not organized to do the job.

2. Watercourse delivery efficiencies are low--overall approximately forty to sixty percent of the water entering at the outlet mogha will be lost before reaching farmers' fields. Application field losses range up to about 75 percent and losses per 1000 feet go as high as 66 percent (see Table 1). Farmers need to organize to improve their watercourses; a few farmers working independently in an unorganized fashion cannot accomplish the necessary improvements.

3. One percent of water saved at all watercourse outlets would roughly equal a "savings" of about one million acre feet of water across the country. Each acre-inch of water saved has an approximate economic value to the farmer of about Rs. 30 (Eckert, et. al., 1975: 8-16). Organizing farmers to improve watercourses produces immediate and tangible benefits for both the farm and the nation.

4. The water "lost" through seepage and spills in poorly constructed and maintained watercourses also directly increases problems of waterlogging and salinity. While there is insufficient data to estimate how much on-farm delivery losses and over-irrigation during the year contribute to waterlogging and salinity, it is estimated to be substantial. Though return flow reuse is possible by tubewells, more tubewells alone do not provide a solution. Furthermore, increasing costs of fossil fuels make it more and more problematic to recirculate groundwater through tubewell pumping and over time the quality of water is degraded. Organizing farmers to improve watercourses produces both short and long term advantages by way of reducing seepage and spills.

5. The Government of Pakistan is aware of the need for organization of farmers at the grass roots level. A recent editorial (Pakistan Times, 1976) suggested that the lack of viable farmer organizations may be "one of the missing keys to improved agricultural development." A number of high government officials have recently expressed the need for some type of farmer organization for improvement of on-farm irrigation systems.

II. The Problem of Watercourse Improvement--A Case History

Some of the most significant evidence to support what farmers can do, given incentives, extension education, and engineering assistance, comes from a systematic research program which is culminating in selected and monitored

Table 1. Mean Delivery Efficiency and Percentage Loss Rate Summary by Watercourses and by Agro-Climatological Zones.*

District Location	No. Cases	Weighted Mean Percentage Delivery Efficiency Ed(m) 1/	Percentage Loss Rate/ 1000 ft. % LR	District Means Weighted by No. of Cases in Sample Ed	% LR
Muzaffargarh				47	27
WC 1	11	37	32		
WC 2	24	51	24		
Bahalwalpur				66	45
WC 1	13	82	36		
WC 2	19	65	63		
WC 3	11	59	35		
WC 4	11	58	37		
Dadu				60	14
WC 1	12	44	21		
WC 2	11	65	17		
WC 3	21	66	8		
Thar Parker				54	20
WC 1	17	59	10		
WC 2	16	63	22		
WC 3	14	40	63		
Thatta				30	48
WC 1	9	31	49		
WC 2	9	26	24		
WC 3	3	28	35		
WC 4	4	36	107		
Lyallpur				68.5	
WC 1&2	63	68.5	7.7		
Multan				57.9	
WC 1	7	64.2	14.4		
WC 2-4	70	57.3	15.2		
Lahore				61.7	
WC 1	10	61.7	19.9		
Sargodha				54.6	
WC 1	5	48.6	17.5		
WC 2	7	47.1	17.7		
WC 3	7	56.4	12.8		
WC 4	13	60.0	10.1		
Gujranwala				57.9	
WC 1-2	19	57.9	11.1		

TOTAL CASES 406

Mean Ed 53.26
Mean % Loss/1000 feet = 28.2

1/ Weighted Mean Efficiency of Delivery of Watercourse
*Data collection in progress; results incomplete.

improvements of watercourses by farmers under the direction of the Mona Reclamation Experimental Project and the Colorado State University Water Management Research Project in Pakistan.[1] Farmers referred to in the following case rebuilt over 33,000 feet of watercourse in 44 days. Later they individually improved over 10,000 feet of their private subbranches. Overall this improvement was accomplished at a cost of about Rs 2.0 per foot.[2]

The pilot watercourse improvement site was carefully chosen by the research team in conjunction with an extension advisor who knew the farmers and the area well, who had established credibility with them, and who remained with the project throughout the surveying, design, planning, motivation, construction and rebuilding stages. One important criterion which was weighed heavily in the selection of the site was the presence of leaders who formed a construction committee, who had credibility in the village, who had something to gain physically from increased water supplies due to improvement and who could enhance their prestige by working with advisors. The construction committee was able to motivate and keep farmer watercourse members working over the month-and-a-half period of watercourse renovation. The farmers provided all of the labor for reshaping and rebuilding the watercourse. Skilled masons were brought in to install the low cost concrete structures installed as outlets and at junctions in the watercourse. Eventually, local masons as available could be taught the techniques and given the concrete construction responsibility under the supervision of the young Pakistani agricultural engineers or subengineers assigned to the project to help maintain quality control on the work.

This initial pilot project had a larger input of foreign and local advisors time than could be the case in a large

[1]The Colorado State University Water Management Research Field Team in Pakistan is involved in testing various approaches to the problem of improving watercourses with farmer cooperation. These field experiments are expected to provide guidelines which can be incorporated in larger scale improvement programs.

[2]See: Colorado State University Field Party and Mona Reclamation and Experiment Project, "Helping Farmers Identify and Achieve Their Potential for Watercourse Improvement." Mimeographed report available at CSU Water Management Research Project Office, Islamabad, 1976. (The estimated cost includes farmers' labor, permanent structures, engineers' and extension workers' time plus about Rs. 10,000 in experiments by CSU. Therefore, the actual cost should be less than Rs. 2.0 per foot of improved watercourses.)

scale development program. However, it is expected that improvements in future programs resulting from the experience gained in these pilot studies will more than balance the decreased advisor input in terms of motivating the farmers.

News of this improvement has traveled to nearby watercourses and many groups representing farmers have requested that the research team take up their watercourse as the next to be improved. On one watercourse adjacent to the improved watercourse the farmers on their own initiative, with no technical assistance other than the demonstration "next door," cleaned and enlarged the channel and built up the banks on 13,000 of their 20,000 foot watercourse, so it had most of the obvious characteristics of the improved watercourse. Delivery efficiencies measured in their cleaned and enlarged sections were about 20 percent greater than in the unimproved section. These and other data on effects of cleaning show that rudimentary improvements can potentially save an important port on of the watercourse losses and can be accomplished by the farmers without direct engineering assistance. These documented farmer successes have inspired a program to determine how much farmers can be motivated to do on their own. This cleaning and maintenance program is being developed and tested in a newly instituted research subproject. It shows potential for introduction through the present extension program, or possibly through an intensive media campaign, and could save millions of acre feet of water and have a tremendous impact on water supplies and potential food production in the Indus Basin.

The lessons emerging from this case experience are:

1) Use local leadership potential;

2) Use self-help principle to employ farmers' labor so the farmers have a feeling of responsibility and will undertake future maintenance to protect their investment in time and labor;

3) Use low cost structures which can be locally manufactured and installed by local artisans;

4) Use people as advisors and motivators who have established local credibility; and

5) Follow through in a fixed time frame on all promises and commitments made to the farmers, thus helping to maintain program credibility.

III. Organizing Farmers for Water Management Improvement--Some Generalizations and Hypotheses.

The experience of the pilot watercourse improvement studies at the Mona Project indicate that:

1) Farmers can be motivated to organize for the purpose of watercourse improvements given an understanding of the magnitude of savings in water and optimum extension educational methods by workers with proven expertise and credibility.

2) Farmers must see for themselves the savings possible and be allowed to establish their own organizations.

3) Strong, disciplined leadership is essential for good cooperation by all farmers.

4) Incentives in the form of more water resulting from several "pucca" (or improved) junctions and nakkas are important, but it has not yet been determined that the "pucca" structures are a necessary condition for cooperation.

5) Improvement works or activities must be perceived by farmers as their own and for their mutual and individual benefits, rather than to fulfill a desire or mandate of the change agent or the Government.

6) The change agent (extension worker) must have a solid understanding of the farmers, and sufficient patience and skill to allow farmers to evolve their own decision rules and mechanisms when problems arise.

7) Once farmers are convinced about the usefulness of the innovation, they often outpace the change agents in both desire for other improvement and work accomplished.

8) Farmers from other watercourses come and see for themselves improvements, and are frequently convinced by this experience and in turn become active promoters of the new technology.

9) Farmers with no engineering assistance, when convinced of the need for watercourse improvement, can duplicate many of the improvements.

This experience and others in which the CSU program has participated indicates clearly that farmers can be motivated to improve their watercourses at low cost. There are many indications that a well conceived program can result in a "watercourse improvement revolution" in the 78,000 watercourse commands in the Indus Basin. However, this will require government incentives and minimum assistance that is not yet available. The major problem to date is that farmers have not, on a wide scale, been given necessary information or incentives to improve their on-farm irrigation system. The World Bank Report (World Bank, 1976) states that the

time has come for a national emphasis on programs to involve farmers in the improvement of their systems and the optimum utilization of irrigation water. To achieve this will require discipline and either formal or informal water user associations, which can provide the vehicle for wide spread improvejments over the Indus Basin.

What are some of the factors which can be expected to affect the ability of farmers to organize to provide themselves with improved watercourses? Selected factors, pulled from studies to date (Mirza, 1975; Lowdermilk, et al., 1975; Early, et al., 1976), can be presented in hypothesis form. Some are:

1) Leadership for collective action can more easily emerge in single agricultural caste villages where caste boundaries need not be crossed, or in multi-caste villages where no single caste group can successfully dominate and several groups must bargain in order to make trade-offs with each other. Single or multiple agricultural caste villages, as contrasted with double agricultural caste villages, will reveal a greater propensity to generate organized action and effective leadership in collective watercourse reconstruction, cleaning, and maintenance.

2) The greater the number of households sharing a watercourse command area, the greater the difficulty in mobilizing collective action to improve water management.

3) Farmers at the tail of the watercourse reveal a greater propensity to mobilize for action to reconstruct, clean, and maintain the watercourse than farmers whose land is located near the head of the watercourse.

4) The greater the number of large landlords toward the mogha (head of watercourse), the poorer the quality of collective watercourse activities.

5) The presence of public tubewells, providing supplemental water, on a watercourse leads to reduced efforts of farmers for reconstruction, cleaning and maintenance.

Such hypotheses can be further tested in the formal evaluation of water user associations to be established by a water management pilot project. Studies have revealed a number of useful insights and tentative criteria for selection of watercourse command areas where there is a high probability of developing successful water user associations. A brief summary of relevant findings can be constructed as follows:

1) Farmers do have experience with informal methods of collective cooperation for such activities as building and maintaining mosques and schools, employment of a village chowkidar, and cleaning and maintaining watercourses.

2) In all these informal tasks there are definite norms and sanctions which range from informal social pressure to explicit monetary fines. Identifiable leadership and decision making processes have evolved for applying and enforcing sanctions. Watercourse members on 14 of 16 watercourses in one sample report, sanctions for nonparticipation in watercourse cleaning which include cutting off the offender's water, monetary fines of Rs. 10 to Rs. 20 per offense, loss of irrigation turn, or payments of 5 Seers (10 lbs) of country sugar.

3) There are many variations between villages in the propensity to cooperate in all these collective tasks, as well as variations in the manner in which they engage in collective activities.

4) The Numbardar (village head) and other influentials provide the collective leadership which is usually divided among major caste or brotherhood kinship groups.

5) Influence, power and leadership in decision making are all significantly correlated with size of land holdings.

6) Watercourse cleanings, in terms of regularity, range from a low of once a year to a high of 24 times per year for 16 watercourses in the first survey phase.

7) Farmers typically report low to moderate satisfaction in the regularity and quality of watercourse cleaning. They are generally aware of some watercourse losses due to vegetation along the banks, siltation, nakka leaks, washouts at junctions, and spills from overtopping, but they are <u>not</u> aware of the extent of water losses. Nor do farmers have sufficient technical knowledge to adequately improve watercourses without outside intervention.

8) When farmers are made aware that 50 percent or more of their irrigation water is lost in conveyance due to poorly maintained watercourses, they become interested in improvements. Farmers usually judge the amount of water needed to irrigate a field basin by hours and minutes of their irrigation turn required. When farmers on improved watercourses see the shorter

period of time it takes to irrigate a field on a well maintained watercourse, they are motivated to improve watercourses on their own.

9) Watercourse users groups have their own methods of dividing work for cleaning the main watercourse (usually to the first major junction) which range from cleaning the whole designated reach to cleaning sections based on the number of Karams/Phar[1] of water received on the turn system.

10) Farmers in a sample of 37 watercourse command areas (Early, et al., 1976) report consistently that at no time has the Irrigation Department applied a fine or threatened a fine or sanction for lack of watercourse cleaning. (As stated earlier, specified irrigation officials [The Canal and Drainage Act of 1873 as amended, n.d.:21] have the authority to close the farm irrigation outlet (mogha) when farmers do not maintain the watercourse in proper customary repair.

11) Where there are villages or watercourse command areas which have two or three highly polarized groups which do not cooperate in any common tasks (repair and maintenance of mosques, schools, etc.), the probability that they can be successfully organized for collective action which water user associations require is lower than where such cooperation exists.

12) Where power and influence are more equally shared by all major brotherhood or caste groups on a watercourse command, there is hypothesized to be higher probability for successful organization of farmers.

13) Where there is evidence of strong leadership for community tasks, the probability is good for organizing farmers in water user associations.

Overall, findings are consistent across all areas of the Punjab and Sind Provinces that farmers do not maintain regulare schedules in the cleaning and maintenance of watercourses; that irrigation or other departments do not either encourage farmers to clean watercourses nor do they penalize farmers for not maintaining the on-farm irrigation system; that watercourse losses range from 20 to 80 percent with an average of 50 or 60 percent; farmers are not aware of the magnitude of these losses; and there is presently little

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[1] A Karam is two paces of about five feet and a Phar is a unit of three hours or 180 minutes.

incentive and no technical assistance, to enable them to improve their systems.

IV. Establishing Farmer Water User Associations--The Alternatives

There are many possible ways to introduce a systematically conceived framework of water user organizations in Pakistan. The objective is to make available to water users several selected organizational patterns and incentives to improve water use and let the users select the ones best adapted to their needs. This permits a stable organizational foundation with flexibility to incorporate local peculiarities. This approach will allow organizations to mature at a rate consistent with need and resources. It is critically important to not force an organizational pattern on farmers. It must be remembered that if full participation is desired by farmers, efforts must be found to make this a learning exdperience by organizers and farmers themselves. There are many values, norms, and sanctions in farmers' informal collective arrangements which may prove useful. In any pilot project for organizing farmers, efforts should be made to learn from the farmers themselves. Therefore, it is important that the staff either has, or that they be taught, an understanding and appreciation of village culture, farmers' views, and respect for and appreciation of farmers (Lowdermilk, 1964:30-69).

Investigations reveal no particular legal or structural obstacles to the formation of farmer water user associations (Radosevich and Stickley, 1976). Pakistan Islamic water law also provides ample precedents such as the importance of equitable water allocation among users. All waters are deemed to be the common entitlement of the community and are subject to public administration. Furthermore, the present law, under the Canal and Drainage Act, provides for collective action in the construction and maintenance of canals, as well as watercourses.

In order to accomplish and maintain improved watercourses, local farmer water users' associations would function to perform the following tasks:

1) Provide for watercourse operation and maintenance

   a. silt removal
   b. bund building - rebuilding
   c. vegetation removal
   d. alignment maintenance
   e. nakka patrol
   f. khal chowkidar

2) Perform construction/improvement of watercourse

   a. organizing construction
   b. scheduling labor
   c. supervising labor
   d. assessing money in lieu of labor

3) Manage augmented water supplies

   a. public tubewell - group ownership
   b. interface with private supply

4) Organize all farmers on the watercourse representing all biridaries on the watercourse and:

   a. establish a leadership committee
   b. provide necessary labor for rehabilitation of watercourse(s)
   c. settle any land encroachment disputes associated with watercourse reconstruction and realignment
   d. supervise the work of any local masons or other hired labor
   e. assume full responsibility for supplies and equipment
   f. participate in all phases of planning for watercourse improvement
   g. participate in the evaluation of the association's functioning and goal achievement.

Typically, a farmers' water association would serve a watercourse command area of about 400 acres and would be composed of about 40 farmers. Possible membership requirements would be attendance at meetings, contributions to interest-bearing savings account organized by the association, and purchase of shares in the association. Voting power would be allocated in a manner proportionate to water rights.

Sanctions for violating association rules might include utilization of a portion of the offender's share of water for one week for public purposes (extra filling of village ponds, etc.) or other fines. Farmers will probably devise many other specific forms of sanctions. There will be need for a procedure to grant recourse to an accused offender--one such rule could be to require a 2/3 vote of all members to sustain a sanction if challenged.

The question is, how might water users' associations be established in Pakistan? There appear to be three primary legal alternatives in the absence of specific legislation providing the purpose and guidelines for formation of such organizations.

Alternative 1 - Informal Water User Associations

The informal approach is conceived as a minimum solution. It is one that may be preparatory for becoming a formal organization when the membership has gained sufficient experience and maturity. Such an organization should be created with cognizance of future potentials, and attempts to introduce inflexible permanently constraining features should be resisted.

Guidelines which would facilitate the achievement of desired goals by informal water users associations in the context of Pakistan's present watercourse environment include:

1) All farmers on the watercourse should indicate willingness to become members;

2) Farmers should elect their watercourse executive committee, which becomes the supervisory committee for improvement activities;

3) All major caste, brotherhood, tribal and tenure classes should be represented in the association;

4) Farmers should participate in the planning, implementation and evaluation of all watercourse improvement activities;

5) Farmers should decide on the voting procedures--whether simple majority or a system of voting proportionate to water rights on the land they cultivate during a given period;

6) Farmers should assess themselves for provision of a ditch tender or watercourse chowkidar, or make some other arrangement which assures regular and constant surveillance for need of repairs and maintenance;

7) Farmers should adopt normative sanctions for violators of agreed upon rules and procedures. Farmers themselves should decide on (and formalize in writing) the sanctions to be used;

8) Regular meetings should be held for planning, settling disputes, extension education and evaluation; and,

9) The water management irrigation advisor and field assistants should be members of the association without vote.

Farmers should be allowed to work out their own organizational procedures which fit their particular situation. No

attempt must be made to pressure farmers to adopt a particular scheme that is foreign to their understanding. A variety of approaches will most likely evolve in informal associations and all should be carefully evaluated using objective criteria. Farmers can contribute greatly to the pragmatic creation of solutions to the water management problem.

Alternative 2 - Organizing Farmers Formally Under the Companies Act (1913)

A "company" is defined by its common usage as "an association of a number of individuals formed for some common purpose" (Radosevich and Kirkwood, 1975:92-93). Section 4(2) of the Companies Act provides that no company, association, or partnership consisting of more than twnety persons shall be formed for the purpose of carrying on any function (except banking) that has as its object the acquisition of gain unless it is registered as a company under the Companies Act or other act or charter. This provision does enable the voluntary formation of water user associations, since such entities are not created for gain or profit, but rather to help the users in optimizing their total resource capabilities. The effect of failing to incorporate is to exist as an informal company which may not be able to contract or sue to enforce a contract already entered into.

An association which has organized under the Act may issue shares representing ownership interest. The ownership interest can be represented by irrigated acreage within the canal delivery area, capital contributions, or other selected criteria. These shares are transferable and become, in effect, "movable property." Such provisions clearly encourage incorporation and facilitate the management of water resources delivered to the users.

Under this act, a form of water users association similar to the mutual irrigation company in the U.S.A., or the community of irrigators of Spain, could be organized. Although a system of water rights or concessions per se does not exist in Pakistan, the right to receive water from the mogha could be termed an equivalent for the association. Membership can be defined as all working landowners and tenants. Shares in the association can be appurtenant to the land, i.e. transfer from present owner to purchaser upon sales of land, or from landlord to tenant, or tenant to tenant upon change of working parties, but not permanently transferred from the parcel of land. This protects lands under a canal delivery system from being completely taken out of production due to the sale of rights to receive water where a landowner may make a significant profit from such sale. Reallocations of water in agrarian Pakistan from irrigated use to industrial or other uses through the private sector could defeat the national efforts to increase and stabilize food production.

Powers of the association can be broad enough to permit assumption of water rate and other assessment collections with failure to pay giving the association officers recourse to deny water delivery.

The flexibility in structure also permits the formation of various operational organs in the association for planning, management and dispute resolution. Organizing under the Company Act (in the absence of specific legislation on the topic) enables a high degree of self-management and operation by the water users.

There are advantages and disadvantages of incorporating. When dealing with companies, the property of the company belongs to the company (Radosevich and Kirkwood, 1975:92-93). This loss of control of ownership is offensive to a people who do not have much to begin with. However, creditors can proceed against only the company and not the individuals. Therefore, in organizing, the farmers will want to be informed of the implications so a conscious decision can be made on what properties, if any, will become company properties.

Alternative 3 - Organizing Farmers Formally Under the Cooperative Societies Act (1925)

The Cooperative Societies Act, 1925 (Radosevich and Kirkwood, 1975: 94-96), was enacted to facilitate the formation and working of cooperative societies for the promotion of thrift, self-help, and mutual aid among agriculturists and other persons with common economic needs so as to bring about better living, better business, and better methods of production. It was made applicable to the whole of Pakistan, except in Tribal Areas, by the Sind Cooperative Societies (West Pakistan Amendment) Ordinance, 1965.

The Act applies to "producers societies," which are groups formed with the object of producing and disposing of goods as the collective property of their members, and "consumers societies," which are societies formed with the object of obtaining and distributing goods to, or the performance of services for, their members and of dividing among their members the profits occurring from such supply and distribution.

Only societies registered as cooperatives may use the word "cooperative" in their titles. The Provincial Government may, by special order, exempt any society from registration requirements in an effort to save time and trouble. Provisions of the Companies Act do not apply to societies registered under the Cooperatives Societies Act, and this simplifies administration.[1]

[1]Legal experts should study Radosevich's work carefully. The Registered Societies Act and its provisions for formation of nonprofit associations should be examined as to its potential applicability for farmers organizations.

One important feature which distinguishes the formation of water user associations is the boundary of the association. Association boundaries must have a logical relationship to the water delivery, use and drainage area. Thus, they can be organized around a watercourse, one or more villages receiving water from a common canal, or some other configuration having a common source of supply (see Figure 1 for illustration). Social criteria to consider have been discussed above.

Quite often water users within an irrigation system find it not only beneficial to organize at the association level, but also to create a federation of associations along the minor and/or major canals (Radosevich, 1975:16-22). Figure 2 illustrates one possible arrangement depending upon the objectives of a federation of companies, a hierarchy could be formed with or without formal registration, if the federation is simply to improve water management through better timing of delivery or some other function not requiring contracting or assuming other legal responsibilities of liabilities, this may be done through informal unregistered association or associations.

V. Evaluating the Proposed Alternatives

Any pilot water management improvement program should include farmer water users associations organized applying the three above approaches--informal organizations, organizations under the Companies Act and organizations under the Cooperative Societies Act. Systematic longitudinal evaluation should be undertaken to obtain empirical data regarding the problems and successes of organizations operating under these three alternative conditions. Some key principles for conducting the evaluative research are as follows:

1) Principle One: Research should not evaluate specific administrators or village leaders--it should be primarily designed to evaluate the outcomes of alternative policies and organizational frameworks;

2) Principle Two: Researchers and associated administrators should emphasize the importance of the problem--obtaining and developing effective farmer water users associations--rather than emphasizing any specific method of obtaining effective farmer organizations. It is important not to advocate any specific organizational model at the outset, but to advocate the importance of the problem of developing farmer organizations by one method or another. Should any single model fail, it is essential to be in a position to shift to alternative models. The research posture must be to propose alternatives A, B, and C on an experimental basis; if, after subsequent evaluation, any or all of them should reveal serious

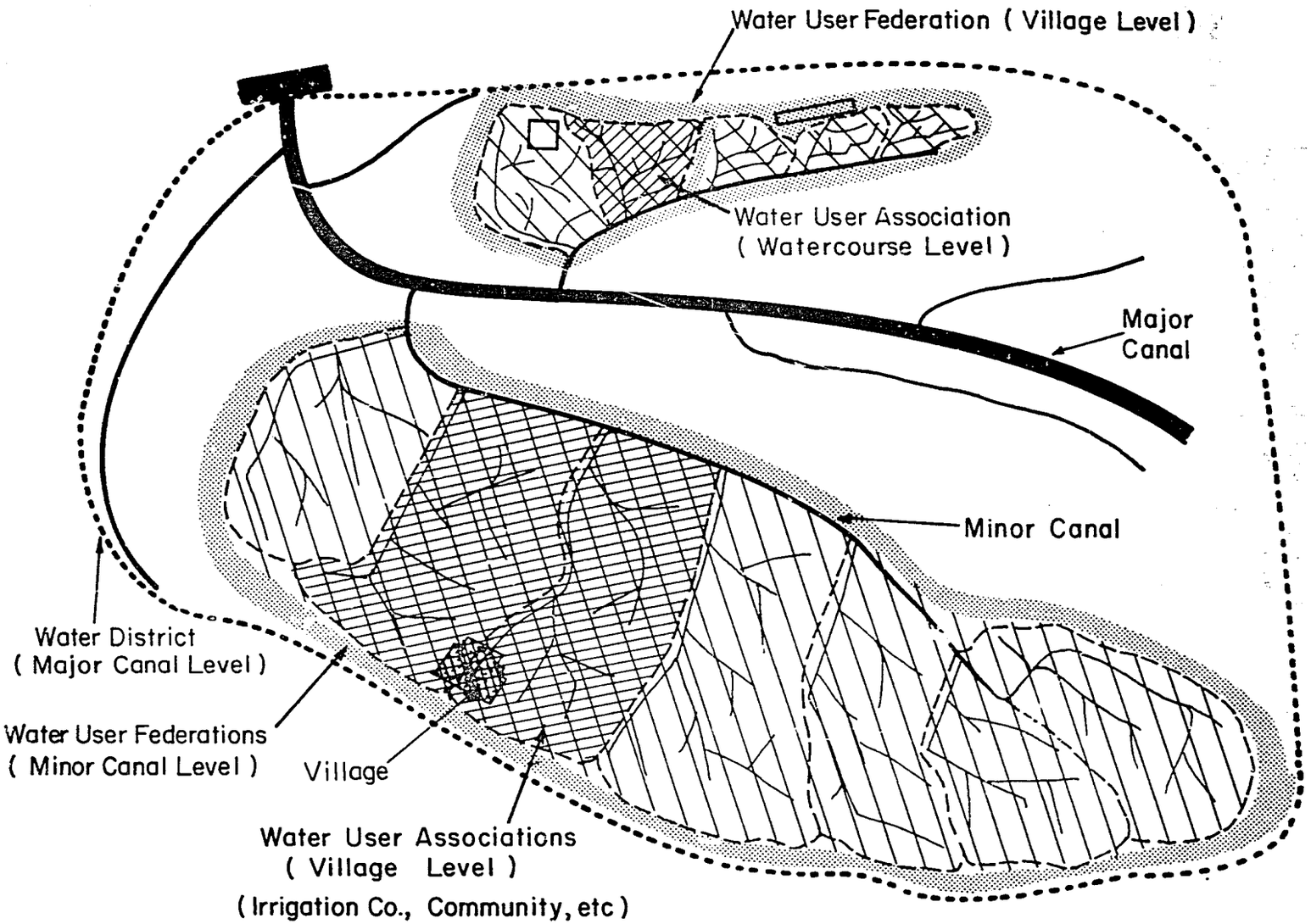

Figure 1. Water User Organizations for Pakistan: Development Scheme.

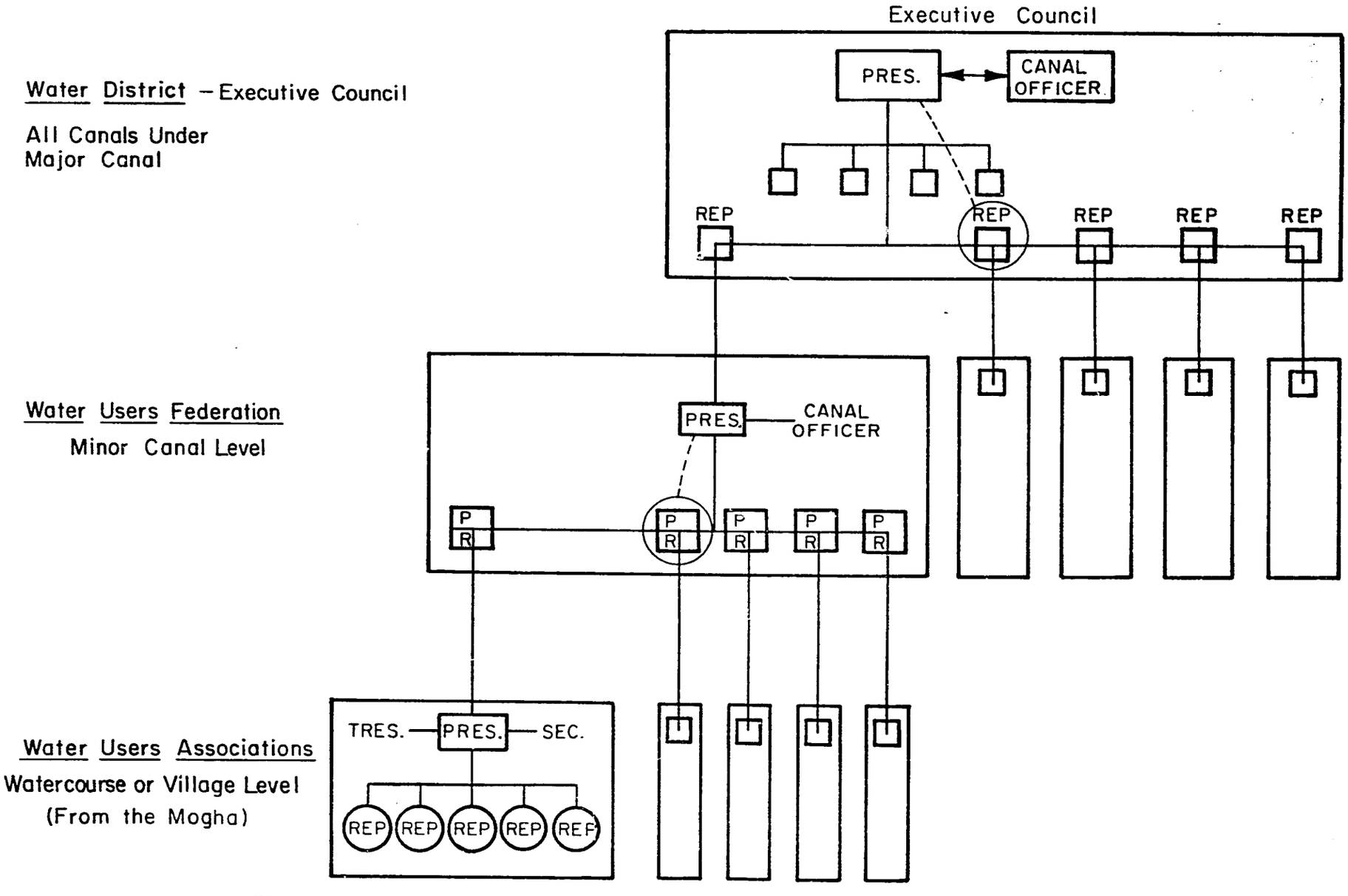

Figure 2. Water User Organization for Pakistan: Organization Scheme

deficiencies, models A_1, B_1 and C_1 can be reformulated based on previous learning experiences.

3) Principle Three: Affected administrators and villagers should be involved in the program evaluations as much as possible while still protecting the integrity of the assessment and evaluation;

4) Principle Four: Given that field conditions prohibit full implementation of tight experimental design in which all potentially confounding variables can be controlled, quasi-experimental designs will be employed. Lack of control over all potentially confounding variables is not cause for despair or paralysis, but researchers must generate, by informed criticism, as many plausible rival hypotheses as possible and do supplementary research which will determine whether the rival hypothesis can explain program "successes" or "failures" rather than planned program procedures and efforts.

5) Principle Five: Research should follow the principle of "staged innovation" in sample villages. Even though it will be the intent to create water users' associations in all villages selected for watercourse improvements, the logistics of the situation will prohibit exact simultaneous introduction of farmer water user associations. By "staged innovation", researchers should attempt as much as possible to "spread out" the introduction of the organizations so that by systematic means the last recipients can be treated as controls. This rotation can proceed by pre-planned phases in which the new villages representing an enlargement of the program can be brought into the study as control villages to be compared with "experimental" villages and then in turn serve as experimental villages in subsequent research phases.

VI. Summary and Conclusions

In sum, then, this paper has made a case that water losses of major magnitude are occurring due to poorly constructed watercourses, that such losses can be reduced in major ways at great savings to the national economy, and that to accomplish the objective of improving watercourses, farmers must be organized to effectively provide themselves with an important collective good--a well-designed, well constructed watercourse which will reduce seepage damage especially at the head of the channel, and which will increase needed water supplies at the tail. Recent research has been summarized, and it indicates that with appropriate technical assistance and information, farmers will be responsive to an opportunity to improve their watercourses.

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

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

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Appendix 43

MOTIVATING AND ORGANIZING FARMERS TO IMPROVE THEIR WATERCOURSE

Mohammad Mohsin Wahla, Sidney A. Bowers
and W.D. Kemper[1]

INTRODUCTION

To supply the Pakistani farmer's basic need for water, a canal system diverts almost 10 crore[2] acre feet of water from the rivers each year and another 30 million acre feet per year is pumped from the ground water. However, of the water delivered to heads of the watercourses, about half is lost during conveyance to farmers fields. With some exceptions, this condition is common throughout the 80,000 Pakistani watercourses.

The key to the economical reduction of this huge water loss is the spade and the force able to turn the key is the Pakistani farmer. When convinced of the magnitude of this loss and shown how to decrease it, these farmers can reduce the losses and improve the welfare of their villages. With this objective in mind, meetings were held with the farmers in several villages to convince them of the need, and their ability, to reduce their water losses.

In choosing the watercourse on which to initiate the first pilot program on reduction of water losses a priority list of required characteristics was developed as follows:

1. Farmer cooperation
2. Potential for improvements
3. Size of holdings
4. Accessibility

Based on the above, the watercourse serving Tubewell 56L (Village 10ML) was selected as the first watercourse to be improved in the pilot watercourse project.

METHOD

Prior to selection two or three meetings were held with each of the concerned villages. The first meeting with the farmers of 10ML was held at the dera of Malik Khan Mohammed. Only one day notice was given as to the time and place of the

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[1]Senior research officer, extension and training, Mona Reclamation Experimental Project, WAPDA; Agronomist, CSU Field Party; and Chief-of-Party, CSU Field Party, respectively.

[2]A crore is a unit of measure equal to ten million.

meeting. An extension field assistant helped spread the news and 15 farmers were present. When questioned about the absent farmers, those present replied that they were authorized to represent those who were absent.

The meeting was initiated by telling of the extent of water loss from their watercourse and how this could be reduced through improvement and maintenance. At the end of the meeting all farmers except two, Mohammad Saleem Shah and Malik Khan Mohammad, agreed to participate in an improvement program. Mr. Mohammad Saleem Shah expressed the thought that it "is no less than a lie that 50 percent of the water is lost from the watercourse." When asked how much land he could irrigate at the head and at the tail of the watercourse in one hour he replied one acre at the head and one-half acre at the tail. Convinced by his own answer, Mr. Shah agreed to participate. However, Mr. Khan remained negative. The extension agents appealed to him saying that, "If you do not cooperate there will be no improvement in the village, in the watercourse, and ultimately no improvement in the whole country and Mr. Khan we need your help in this improvement just as goats cannot graze without an old shepherd." At this moment he showed some willingness to cooperate and in the next moment was selected as a member of the watercourse improvement executive committee.

There are two major "biradaries" and two members from each were selected to serve on the watercourse committee. The farmers then agreed to provide 35 men per day for 40 days. Mona engineers would provide the design under the supervision of the CSU advisory team.

DUTIES AND RESPONSIBILITIES OF WATERCOURSE EXECUTIVE COMMITTEE

During this first meeting the following duties and responsibilities were assigned to the watercourse committee.

1. To assist in gathering and controlling laborers for watercourse construction.

2. To resolve land disputes caused by proposed watercourse realignment.

3. To help in site selection for installation of nakkas, check structures, culverts, buffalo baths, etc.

4. To supervise the labor and provide them the necessary equipment.

5. To make decisions concerning where the water normally used by the branch under construction would be used.

6. To censure workers who were late, absent, or whose work was substandard and develop in them a more positive work attitude.

7. To propose essential modifications of the warabundi to the proper authorities.

8. To determine the working hours and schedule for the watercourse inmprovement program.

9. To determine the labor assessment per holding.

10. To establish a watercourse maintenance program.

During a second meeting of the farmers the following decisions were made:

1. Watercourse improvements would start on branch G on December 17, 1975.

2. Farmers will provide labor at the rate of one man per square or two men per horse.[1]

3. Working hours are from 9 a.m. to 4 p.m. or until one completes his assigned share.

4. The water turn for a branch under construction will be used by the branches preceeding it in the warabundi schedule.

5. Three buffalo baths would be constructed.

6. Transportation of materials for nakkas and check structures would be the responsibility of those farmers served by the structures.

PRELIMINARY DATA AND DETERMINATION OF LOSSES

To facilitate watercourse improvement and its evaluation the following data and maps were collected and prepared:

1. Warabundi Schedule (Table 1)

2. Ownership Table (Table 2A-C)

3. Watercourse area map showing watercourse branches, the mogha, sanctioned nakkas, roads, drains, etc (Figure 1).

4. Map showing the main channel and main branches which were improved (Figure 2).

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[1]The land in this area was originally leased to farmer tenants in amounts of 50 acres by the government. The farmer was required to give the army one horse per year and thus 50 acres is commonly called a "horse."

Table 1. Warabundi Map of TW 56

Owner's Name	Sq.No.	Water Time Hrs.	Water Time Min.	Distance Time	Day	Starting Time	Finishing Time	Acres Held
Rehmat Ali s/o Fazal	32		34	-	Monday	6:00 p.m.	10:34 p.m.	25
Mehdi Shah & Salim Shah	31-46-47	10	57	-	Mon/Tues	10:34 p.m.	9:31 a.m.	
Khan Mohd.	31-33-47	8	21	-	Tuesday	9:31 a.m.	5:52 p.m.	42
Colony	30	1	33	-	Tuesday	5:52 p.m.	7:25 p.m.	
High School	30	1	00	-	Tuesday	7:25 p.m.	8:25 p.m.	
M.Mawaz, M. Aslam & Bros.	34-35	15	37	21	Tues/Wed	8:25 p.m.	12:23 p.m.	
M. Shah	35-36	7	15	21	Wednesday	12:23 p.m.	7:59 p.m.	
M. Arif & Bros.s/o M.Ashraf	37-43	6	52	15	Wed/Thur	7:59 p.m.	3:56 a.m.	
M. Aslam	37	2	18	-	Thursday	3:56 a.m.	5:24 a.m.	
Saleem & Nazir Shah	38-42-41	9	13	-	Thursday	5:24 a.m.	2:37 p.m.	
Fazal Ali & Bros.	38-39-40		49	-	Thursday	2:37 p.m.	11:26 p.m.	
Bhadar Khan s/o/Bhalwal	44-45-49	9	15	-	Thur/Fri	11:26 p.m.	8:41 a.m.	
Rehmat Khan	45-48-49	9	24	-	Friday	8:41 a.m.	6:05 p.m.	
Attaullah Shah	53-54	6	22	15	Friday	6:05 p.m.	12:42 p.m.	
Sardar Khan	50-51	8	25	15	Saturday	12:42 a.m.	9:22 a.m.	
Hayat Khan	51	0	43	-	Saturday	9:22 a.m.	10:05 a.m.	
Jumloy Shah	53	0	33	15	Saturday	10:05 a.m.	10:53 a.m.	
Nazir Ahmad	53-52	4	34	21	Saturday	10:53 a.m.	3:48 p.m.	
Feroz	52	2	14	-	Saturday	3:58 p.m.	6:02 p.m.	
Fatah Sher s/o/M.Khan	55	2	14	-	Saturday	6:02 p.m.	8:16 p.m.	
Doss Arain	55	1	09	-	Saturday	8:16 p.m.	9:25 p.m.	
WAPDA	55	0	06	-	Saturday	9:25 p.m.	9:31 p.m.	
M.Ashraf & M. Aslam	55-56	2	58	-	Saturday	9:31 p.m.	11:38 p.m.	
Hassan Shah	29-28	6	55	15	Sat/Sun	11:38 p.m.	6:48 a.m.	
Ehsan Elshi	27-28	7	05	15	Sunday	6:48 a.m.	2:08 p.m.	
Feroze	26	2	21	15	Sunday	2:00 p.m.	4:44 p.m.	
Sardar Khan	25-26	4	35	-	Sunday	4:44 p.m.	9:34 p.m.	
M. Nawaz Malik	25	6	11	15	Sun/Mon	9:34 p.m.	4:04 a.m.	
		G.Water						
Fateh Sher Khan	22	2	17	-	Monday	4:04 a.m.	6:17 a.m.	
Anyat Shah	22	2	17	-	Monday	6:17 a.m.	8:34 a.m.	
Khan Mohd.	24	4	04	15	Monday	8:34 a.m.	12:53 p.m.	
Sardar Khan		2	05	-	Monday	12:53 p.m.	2:58 p.m.	
Hassan Shah	23	2	21	-	Monday	2:58 p.m.	5:19 p.m.	
M. Sadaq	23	2	11	1-33	Monday	5:19 p.m.	6:00 p.m.	

Table 2-A. Hand Holding Record of TW #56

S.No.	Owner's Name	Type of Cultivation	Land Holding in Acres	Acres/ Square No.	Remarks
1.	Mohd Zaman	M.Akram(T)	5.5	5.5/32	
2.	Raja Anayat	Rehmat Khan(T)	11 1/2	11.5/32	
3.	Ghulam Haider	"	2/3	.67/32	
4.	Mohd Ali	"	2/3	.67/32	
5.	Ahmad Ali	"	2/3	.67/32	
6.	Raja Khan	"	2	2/32	
7.	Ashiq Hussain	"	2	2/32	
8.	Ghulam Hussain	Self	2	2/32	
9.	Mohdi Shah	Self	12	12/31	
10.	Khan Mohd	Self	55	5/31, 12.5/42, 25/33, 12.5/47	Tractor
	8 acres belong to Government for plot scheme in square No. 31				
11.	Rehman Khan	Self	62 1/2	12.5/47, 25/48, 12.5/45, 12.5/49	Tractor
12.	Saleem Shah	Self(T)	25	25/46	
13.	M. Nawaz Malik	Self)Joint	12 1/2	12.5/34	
14.	M. Aslam	Self)farming	12 1/2	12.5/34	
15.	M. Taj	Self)with	12 1/2	12.5/35	
16.	Abdul Ghani	Self)tractor	12 1/2	12.5/25	
17.	Ch. Badar Khan	Self	56	12.5/45, 12.5/49, 25/44	with tractor
18.	Shah Mohd.	Self	37 1/2	12.5/35, 25/36	
19.	M. Hussain Shah	G. Rasol & Khushi Mohd. (Ts) 3 M. Nawaz on rent sys.	25	12.5/29, 6/28, 6.5/23	
20.	Izas Hussain Shah	Self	11	8/29, 3/23	
21.	Mussefar H. Shah	Self	11	5/29, 3/28, 3/23	
22.	Zafar Hussain Shah	Mian Khan(T)	2 1/2	2.5/30	
23.	Mian Khzan Elahi Gujar	Self with Tractor	37 1/2	12.5/28, 25/27	
24.	Abaid Shah	Allah Ditta(T)	8 1/2	8.5/54	
25.	Mohd. Shah	Gh. Pasool(T)	8 1/2	8.5/54	
26.	Fazal Shah	Self	8	8/54	
27.	Aslam Shah	Self	12 1/2	12.5/53	
28.	Nazeer Sabonalo	Self	12 1/2	12.5/53	
			12 1/2	12.5/52	

(Table 2-A continued on following page)

Table 2-A. (Continued from previous page)

S.No.	Owner's Name	Type of Cultivation	Land Holding in Acres	Acres/ Square No.	Remarks
29.	M. Aslam	Self	6 1/2	12.5/52	
30.	Cardar Ali	Self	6 1/2	6.5/52	
31.	Hazal Khan	Self	12 1/2	12.5/50	
32.	Akbar Khan	Self	12 1/2	12.5/50	
33.	Sardar Khan	Self	12 1/2	12.5/50	
34.	Kadar Khan	Self	12 1/2	12.5/51	
35.	Mohd. Arif)	Joint Culti.	7 1/2		
36.	Khalid Masud	s/o M. Ashraf	7 1/2	15/43	
37.	Sajid Masud)		7 1/2	7.5/26	
38.	Abid Masud		6 1/4	12.5/37	
39.	Anjid Masud		6 1/4	12.5/37	
40.	M. Aslam Shah	Self	6 1/4		
41.	Attaullah Shah	Self	6 1/4	12.5/37	
42.	M. Ashraf	Self	6 1/	12.5/25	
43.	M. Peroz	Self	6 1/		
44.	M. Anghar	Self	12 1/2	12.5/25	
45.	M. Nasrullah	Self	12 1/2	12.5/26	
46.	Iman Shah	Self	4		
47.	Dhineb	Self	4	12.5/22	
48.	Shah	Self	4 1/2		
49.	Fateh Sher	Self	12 1/2	12.5/22	
50.	H. Hayat	Self	6	6/24	
51.	M. Khan	Self	6	6/24	
52.	Malik Sadiq	Self	12 1/2	12.5/23	
53.	Fazal Elahi	Self	15 1/2	12.5/38, 3/40	
54.	Saleem Shah	Self/Joint	16 1/2		
55.	Nazir Shah	farming	16 1/2	12.5/38, 25/41, 12.5/42	
56.	Rajid Hussain Shah		17		
57.	M. Anwar	Self	3)	3/56	
58.	M. Aslam	Self	3)	3/56	
59.	M. Ashraf	Self	3)	3/56	
60.	M. Aziz	Self	3)	3/56	
61.	Mohd.	Self	12 1/2	12.5/55	
62.	M. Anwar	Self	15 1/2	12.5/39, 3/40	
63.	Ghulan Sarwar	Self	15 1/2	12.5/39, 3/40	
64.	Fateh Shah	M. Anwar (T)	12 1/2	12.5/55	

Table 2-B. Land Ownership Map and Associated Information

Authorized T.W. #56 Discharge to 56 L (cusecs)	Mogha Discharge (cusecs)	Irrigable Acreage (acres)	Land Owners	Owner Cultivators	User Tenant	Tenants
2.7	2.75	814	64	51	1	10

Table 2-C. Size of Land Holdings in Acres

Acres holding	1-4	5-8	9-12	15-16	17-20	12-25	above 25
No. of holdings	13	17	20	3 1/2	3	3	5

Total = 64

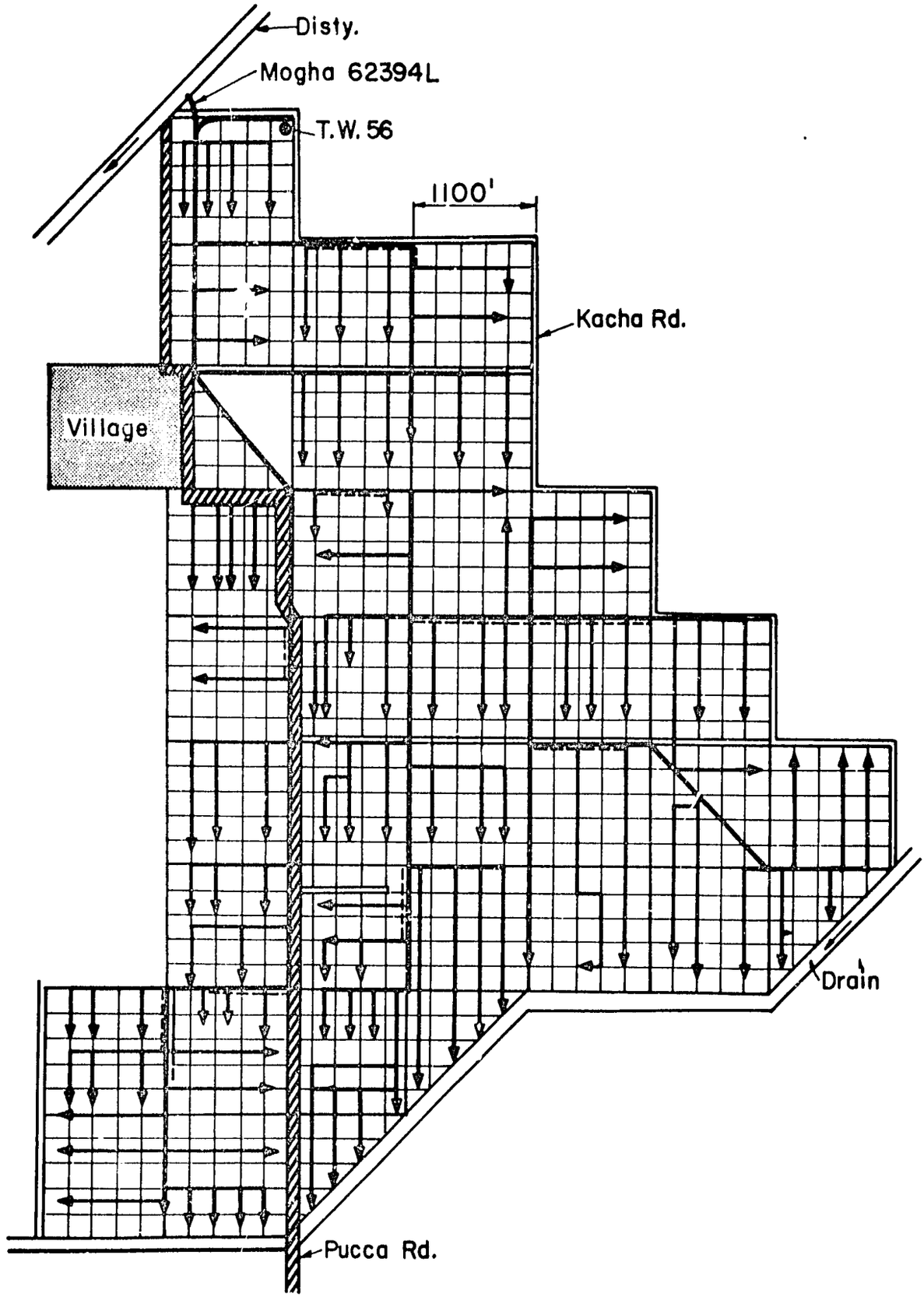

Figure 1. General plan of T.W. 56 watercourse. (Dark lines leading to arrows are watercourses. Dashed lines indicate parallel watercourses which were eliminated in the improved watercourse.)

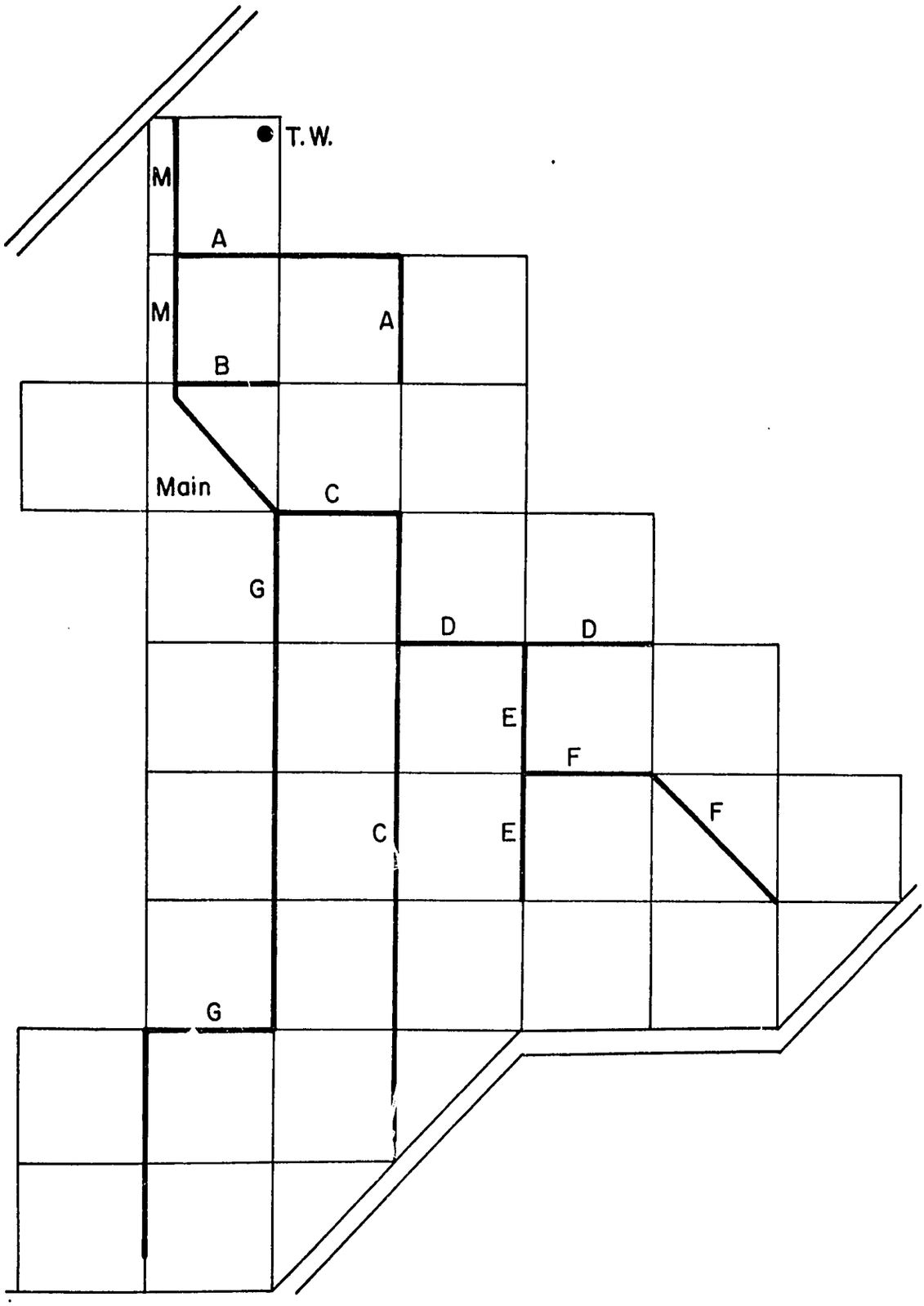

Figure 2. Main channel and main branches (authorized) which were improved. (Letters A through G designate branches discussed in text; heavy lines indicate watercourse channels.)

5. Cropping pattern (Table 3).

6. Water loss data (Tables 4A, 4B and 4C).

IMPROVEMENT WORK

Dr. Kemper, Colorado State University party chief, suggested starting the improvement on Branch G, one square down from its head, where techniques of reconstruction could be easily demonstrated. The farmers, however, insisted on starting the work at the head of G Branch. Old banks were dismantled down to the level of the surrounding land. Banks were then compacted with both hand compactors and by foot. Attempts to use tractor tires and sheep foot rollers proved unsuccessful.

On the first day all the labor worked randomly on a 660 foot section of Branch G. This proved unsatisfactory since the men did not know their assignment and consequently wasted much time in smoking hukkas and chatting. The next day Mohammed Feroz, a khal headman, was appointed to distribute specific sections to each of the farmers according to their holdings. With a definite work assignment each man took more pride in his work and tried to complete his assignment as soon as possible. Before leaving, however, each person was required to have his work inspected by the field assistant. The need for this inspection to achieve quality control was evident in sections done a day late by farmers who were called away on emergencies during the time appointed to work on that section. Since the regular work crew had moved away from that section, no inspection was made on these "late sections" and the quality was often definitely substandard.

When the improvement of Branch G was half completed, there was a closure of both the canal and tubewell, and improvement of the main channel was begun since during its improvement water could not be delivered to the main branches. The closure period was 3 weeks long, which allowed improvement of the main channel, completion of Branch G and improvement of about 1000 feet of Branch C. Improvement on the small branches A and B near the head of the watercourse was deliberately postponed because it was feared that if these two were finished first the farmers on these branches would not work actively on the larger branches.

As a result of the canal closure, doing the main channel during the closure, and using the water on other branches during the time the farmers were working on one branch, the farmers lost very little water due to construction. This was due to, in part, the main branch being relatively short (3600 ft). On a later pilot watercourse where the main channel was almost 10,000 feet long, the farmers lost over a week of water supply because of having to shut off water while working on this main branch.

Table 3. Area under Different Crops in each Square

Sq.No.	Garden	Garden + Crop	Sugar Cane	NC	Cotton	Rice	Bajra or Maize	Total
32	2				6.5	2	2.5	13
31			1	1	4.5	3		9.5
33	10		2		4.5	1		17.5
47					4	1	1.5 1.5	10.5
46	7		.5		5		4	15.5
38	24						1	25
30	Half square consists of school and grave yard					1		1
29	4.5		2		8	2.5	1	18
35	19	5			1			25
45	19.5	2			1		2.5 chill	25
48	3	2	2	2	6		2.5	18.5
28	14					.5		14.5
36			2.5					
44	6		3		4		4	17
49	10				3	5		18
54	5				3		5	13
27			.5	1	5		2	8.5
26	12.5		1		1	1	1	16.5
37	3		3.5	.5	3	3	2.5	15.5
38	8		1	.5		1	4.5	15
42	15		5		1.5		2.5	24
50	9		.5	3.5			1.5	14.5
51	3		2.5		2.5		1	16
52	2	10	2.5		5	.5		20
53	5		1	1	8		2.5	15
55					2		6	8
56/2			1	.5	2		2.5	6
41/2	5				4.5			9.5
40/2					4			4
39	1.5		1	.5	7.5		3.75	14.25
25	12.5		.5		2.5	.5	2.5	18.5
24	2.5				3		.5	6
23					5	.5	2	7.5
22			1.5		8		5.5	15
TOTAL	208	23	36.5	15	133.5	16.4	72	505

Total Irrigable acres = 814

Table 4-A. Watercourse Losses for TW 56 Before Improvement

No.	Date	Initial (cusecs)	Final (cusecs)	Loss (cusecs)	Distance (ft)	Loss (cusec/1000)	% Loss 1000ft	Delivery Efficiency %
1	19 Nov.75	4.40	3.90	0.5	3,640	0.14	3.12	89
2	20 Nov.75	4.80	4.20	0.6	3,860	0.16	3.24	88
	Main + A							
3	18 Nov.75	4.60	2.45	2.15	2,440	0.38	19.16	53
4	18 Nov.75	4.60	3.19	1.41	2,080	0.68	14.74	69
5	18 Nov.75	4.60	2.50	2.10	4,270	0.49	10.69	54
	Main + C							
6	15 Nov.75	4.48	2.24	2.24	9,340	0.24	5.35	50
7	15 Nov.75	4.49	1.40	3.08	9,840	0.31	6.99	31
	Branch C							
8	20 Nov.75	4.20	2.70	1.5	5,480	0.27	6.52	64
9	20 Nov.75	4.20	2.97	1.23	3,680	0.33	7.96	71
10	19 Nov.75	3.40	2.20	1.20	2,580	0.47	13.68	65
11	19 Nov.75	3.40	2.60	0.80	1,340	0.60	17.56	75
12	20 Nov.75	4.20	1.75	2.45	6,290	0.39	9.27	42
	Main + G							
13	17 Nov.75	1.88	0.64	1.24	11,300	0.11	5.84	34
	Main + C + D + E + F							
14	15 Nov.75	4.48	1.31	3.17	9,140	0.35	7.74	29
15	15 Nov.75	4.48	2.65	1.83	9,140	0.20	4.47	59
16	15 Nov.75	4.48	2.65	1.83	9,340	0.20	4.37	59
17	15 Nov.75	4.48	2.30	2.18	9,840	0.22	4.95	51
18	15 Nov.75	4.48	0.90	3.58	10,340	0.35	7.73	20

Table 4-B. After Renovation Water Loss Measurements on Tubewell 56

No.	Date	Initial (cusecs)	Final (cusecs)	Loss (cusecs)	Distance (ft)	Loss (cusec/1000)	%Loss 1000ft	Delivery Efficiency %
		Main						
1	2-6-76	2.55	2.25	0.25	2200	0.11	5.36	88.2
2	2-18-76	6.20	4.30	1.90	3980	0.48	7.69	69.4
3	2-19-76	2.92	2.80	0.12	3980	0.03	1.03	95.9
4	2-21-76	5.45	4.15	1.30	3980	0.33	6.01	76.1
5	2-23-76	5.30	4.50	0.80	3980	0.20	3.79	84.9
6	2-26-76	2.60	2.55	0.05	1100	0.05	1.73	98.1
7	3-4-76	6.15	5.59	0.56	3980	0.14	2.29	90.9
8	3-8-76	5.85	4.85	1.00	3980	0.25	4.30	82.9
9	3-10-76	5.30	4.28	1.02	3980	0.26	4.82	80.8
10	3-22-76	2.05	2.00	0.05	3980	0.01	0.60	97.6
11	3-24-76	5.00	4.50	0.50	3980	0.13	2.51	90.0
12	3-27-76	4.85	4.10	0.75	3980	0.19	3.89	84.5
		Main + A						
13	2-10-76	6.50	5.37	1.13	3300	0.34	5.27	82.6
14	2-24-76	5.70	4.60	1.10	3300	0.33	5.85	80.7
15	2-26-76	2.60	2.00	0.60	4400	0.14	5.25	76.9
		A						
16	2-26-76	2.55	2.00	0.55	3300	0.17	5.25	76.9
		Main + C						
17	2-4-76	2.97	1.95	1.02	6180	0.10	5.50	66.6
18	2-5-76	2.00	1.34	0.62	9480	0.07	3.27	67.0
19	2-20-76	5.73	4.95	0.78	6180	0.13	2.20	86.4
20	3-4-76	6.15	3.19	2.96	9480	0.31	5.07	51.9
21	3-8-76	5.85	3.15	2.70	9480	0.28	4.86	53.8
		C						
22	3-4-76	5.23	3.19	2.04	5500	0.37	7.09	61.0
23	3-8-76	4.85	3.15	1.70	-	-	-	64.9
24	3-18-76	4.76	4.09	0.66	-	-	-	86.1
		Main + C + D						
25	2-13-76	6.65	4.35	2.30	8380	0.27	4.13	65.4
26	2-20-76	5.73	4.10	1.63	6180	0.26	4.66	71.2
		D						
27	2-20-76	4.95	4.10	0.85	1100	0.77	15.6	82.8
		Main + C + C + E						
28	3-6-76	6.13	4.30	1.83	7480	0.24	4.00	70.1
		F						
29	3-6-76	4.30	3.25	1.05	-	-	-	75.6
		Main + G						
30	2-7-76	5.50	3.45	2.05	9480	0.22	3.93	02.7
31	2-16-76	6.60	4.15	2.45	9480	0.26	3.91	62.9
32	2-23-76	5.30	4.15	1.15	9480	0.12	2.29	78.3
		G						
33	2-23-76	4.50	4.15	0.35	2200	0.16	3.55	92.2

Table 4-C. Average supply to the watercourse, delivery to the field, and delivery efficiency before and after improvement at TW 56

	Supply to WC (cusecs)	Delivery to Fields (cusecs)	% Delivery Efficiency	Ave. Flow Measurement Distance
Before	4.36	2.07	47.5	8058
After	5.24	3.65	69.7	7306

On branches C and D there were numerous big trees along the watercourse which hindered the improvements. The owners of the trees were reluctant to cut them but two days after the watercourse committee condemned their selfish attitudes, the trees were uprooted.

It had earlier been decided that the watercourse would be kept straight. This led to two disputes over alignment. The first dispute was settled by the farmers after a few hot words were exchanged. The second, however, was much more serious and almost led to violence between two executive committee members, but the matter was settled, with the assistance of the extension agent, which allowed completion of the work.

At several places in the watercourse there were large ponds due both to water erosion and animal damage. To prevent future damage to the watercourse some of these ponds were developed into lined buffalo baths into which farmers agreed to concentrate their animal activities. At several other points in the watercourse there were subbranch watercourses which ran parallel to the main watercourse. Banks separating these two channels were often very thin and were an additional source of seepage. Throughout the watercourse all such parallel channels were eliminated by installing nakkas in addition to the one per square originally authorized. Leakage through the additional pakka nakkas was less than the extra loss through the thin banks, resulting in saving considerable water.

FINAL TOUCH UP

After completion of this watercourse, water was turned into the channels to locate points of leakage. A fifteen man team was organized to walk through the watercourse closing rodent holes, cracks, compacting seeping banks, adding additional freeboard where needed, etc. This final finishing required four days work, but since the water was only in about half of the watercourse during this time, many leaks were not stopped.

After improvement of the watercourse all farmers were pleased over the increased water supply. Availing of this opportunity a general meeting was called of all watercourse share holders for the purpose of hiring a Khal Chowkidar (watercourse watchman) whose primary duties would be to help maintain the watercourse and assure the continued benefit of increased water delivery over a longer period. Hiring of the Khal Chowkidar with a salary of 32 maunds of wheat per year was unanimously approved. Duties were assigned to the Khal Chowkidar as follows:

DUTIES OF THE KHAL CHOWKIDAR

1. To patrol the watercourse and stop all leakage, seepage, overtopping, etc.

2. To inform (under the direction of the executive committee) the farmers at least one day prior to watercourse cleaning and to assist in assembling them for the work.

3. To discourage and report to the committee any intentional damage to the watercourse.

4. To act as an intermediary between the committee and the farmers.

5. To report all breakage and damage to control structures and culverts.

6. To reduce the plant growth in the watercourse.

7. To remind the farmers about the need to maintain the watercourse.

TRAINING OF THE KHAL CHOWKIDAR

The hired khal chowkidar, Mr. Mohammad Manak, was instructed in the cause of watercourse losses. Areas of instruction included the following:

1. Leakage: to reduce leakage by plugging holes, cracks, rodent burrows, and using mud to seal nakka leaks.

2. Seepage: to reduce seepage by compacting cores in banks.

3. Overtopping: Provide 6 inches of freeboard.

4. Flow restrictions: to remove weeds, grasses, and other restrictions from watercourse channels.

5. Prohibit all watercourse damaging practices: persons continuing in such practices are to be reported to the committee.

6. Flow rise: when full supply water level rises to two inches above designed full supply level, the watercourse should be cleaned.

Improvement of Sub Branches

In one of the meetings the farmers were told that to get proper benefit they should either divide the supply between

two sub branches or clean and enlarge sub branches. While most farmers promised to do so after wheat harvest, Mr. Mohammed Shah improved his without delay. He not only received significantly more water from the improvement, but set an example for the other farmers. Mr. Shah's farm now looks like a model farm.

Transmission of Knowledge

To promote improvement of watercourses and to use the additional water beneficially, field assistants have been assigned a water management responsibility in their routine programs. These programs have created an interest among the various surrounding villages. Such interest was evident in a nearby village which set aside their usual quarrels and united together to improve about 60 percent of their watercourse by enlarging the channel and increasing the freeboard without any guidance other than seeing what had been done at TW 56 watercourse. They then approached the improvement project personnel wanting to know how much additional increase the project could give them. They believed they had already doubled their water supply without help! Measurements showed that improved sections delivered about 30 percent more water than their unimproved sections.

Sediment Trap

Near the mogha the channel was built one foot deeper and two feet wider than the rest of the watercourse for the purpose of trapping sediment to prevent its deposition in the sections of the watercourse channels from which it would be difficult to dispose.

SUMMARY

1. The confidence and spirit of the extension agents played a major role in organizing and inspiring the farmers to improve their watercourse.

2. Committee representatives were selected from all the biradaries.

3. Individuals with adverse opinions were won over prior to improvement.

4. The practical demonstration of the engineering and extension staffs on the site earned the admiration of the farm labor.

5. Important decisions made prior to improvement were:

   a. Where water allocated to the branches under improvement would be used.

b. Sequence of branches improved.

c. Alignment of the watercourse.

d. Location of culverts, buffalo baths, check structures, etc.

e. Schedule of working hours.

f. Which branches were to be improved.

g. From where soil to build the watercourse would be borrowed.

h. All trees on the banks of the watercourse would be cut prior to beginning the earth work on that section.

6. Politeness and tact were used in dealing with reluctant labor.

7. Watercourse work was distributed according to the size of holdings.

8. Three of the four committee members took full interest and were present throughout the improvement work.

9. Compaction and proper freeboard both decreased losses and increased the watercourse life.

10. Maintenance is essential to retain the increased water supply to farmers fields.

11. Maintenance and protection of channel are greatly improved through hiring a khal chowkidar.

Appendix 44

THE NEED FOR A WATER MANAGEMENT EXTENSION SERVICE IN PAKISTAN

by
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SIGNIFICANCE

The level of scientific irrigation management is extremely low in most LDC's. The farmers usually have no training in soil-plant-water relationships and the existing extension staff is also undertrained in this area. These circumstances result in a situation where water, even with its high scarcity value, is often wasted in overirrigation and mismanagement.

This paper documents the magnitude of losses in Pakistan's watercourses and the low level of scientific irrigation knowledge of most of Pakistan's farmers. The quality of available extension advice relating to farm-water management is also tested and found to be quite low. A proposal for developing a dedicated core of water management extension advisors is presented and details how such a group could be organized and trained. This type of service is essential for proper utilization of irrigation water not only in Pakistan but in most LDC's that practice irrigated agriculture.

Field studies by the Colorado State University Water Management Team (Lowdermilk, 1975a), WAPDA staff at Mona Reclamation Experimental Project (Clyma, 1975 and n.d.), and Colorado State University through the IRDP staff at Lar and Shadab (Ali, 1975), as well as studies undertaken by other governmental-consulting staffs (White House-Department of Interior Panel on Waterlogging and Salinity in West Pakistan, 1964), provide ample evidence that farmers are not efficiently utilizing the available water supply. This inefficiency results both from extensive losses in the watercourse system and from a low level of knowledge concerning the plant-water-soil relationships relevant to Pakistan agricultural conditions. A massive adult farmer education program is needed to overcome these problems of poor irrigation efficiencies and low level of knowledge about scientific irrigation. The suggested vehicle for conducting this education program is a Water Management Extension Service.

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The purpose of this paper is to first present a sample of recent survey data and engineering field measurements that documents the magnitude of the losses in the watercourse and the low level of scientific irrigation knowledge of most of Pakistan's farmers. The second section examines the factors relating to these problems, especially in terms of the quality of available extension advice relating to farm-water management. The final section presents a proposal for developing a dedicated core of water management extension advisors and details how such a group could be organized and trained.

Background

Pakistan's famous canal system was the end product of a long line of trial and error experiments by a highly trained and motivated group of engineers and physical scientists (Michel, 1967). Much of the research involved delivering the water through the canals to the distributaries and directly to the outlets (moghas). Little attention, however, was paid to the important social and economic questions relevant to the efficient utilization of the water at the farm level. In particular the training necessary to make the transition from rain fed or dryland agriculture to irrigated agriculture was not provided. This lack of knowledge and training has resulted in extensive mismanagement of the precious water which has led to additional problems of soil waterlogging and salinization.

To investigate the degree of water losses in Pakistan watercourses, Colorado State University Research Team has measured the field delivery efficiencies in over 300 watercourses. This work entails a comparison of the inflow at the mogha compared to the actual water delivered to the farmer's field (at the nakka). Tables 1 and 2 present a sample of results from this research from watercourses in Punjab and Sind (Lowdermilk, 1975).

From Table 1 the mean and median field deliveries for the 14 watercourses investigated were both 61 percent and from Table 2 the mean and median were both 55 percent for 22 watercourses. An additional 10 percent of the water is commonly lost in filling the watercourses, initial wetting of the banks and breakage of bunds. This indicates that about half of the water passing the mogha is lost before it reaches the farmers' nakkas. The corresponding loss rates per 1,000 feet of watercourse varied from a low of 11.1 percent per 1,000 feet at Gujranwala site to 30.9 percent per 1,000 feet at the one Lahore site. Additional research is currently underway to determine if these measurements are representative of watercourse losses in different zones of the irrigation system.

In order to determine the level of farmers' knowledge concerning plant-soil-water relationships, a series of surveys was designed and administered. These questionnaires investigated the farmer's conceptions about how plants remove water

Table 1. Mean delivery efficiency (E_d)* and summary statistics for fourteen watercourses in Northern and Central Punjab. (Early, 1975a)

District	Lyallpur	Multan		Lahore	Sargodha			Gujranwala	Overall sum or weighted mean
No. of watercourses	2	1	3	3	1	1	1	2	14
No. of measurements	57	7	69	10	5	7	4	19	178
E_d mean	68	65	57	62	49	47	67	58	61
E_d median	66	61	59	63	49	60	68	56	61

*Delivery efficiency (E_d) is defined as the weighted mean rate of water delivered to the nakka divided by the weighted mean rate of water delivered by the mogha.

$$(E_d = \frac{\text{NAKKA DISCHARGE}}{\text{MOGHA DISCHARGE}} \times 100)$$

Table 2. Mean delivery efficiency (E_d) and summary statistics for 22 watercourses in southern Punjab and Sind. (Early, 1976)

District	Muzaffargarh	Bahalawalpur	Sukkur	Dadu	Thar Parkar	Thatta	Overall sum or weighted mean
No. of WC's	2	4	6	3	3	4	22
No. of measurements	35	54	16	44	47	25	221
E_d mean	48	66	67	60	54	30	55
E_d median	53	66	69	61	54	20	55

from the soil and what is the effective range for this process. They also were designed to determine the farmer's ideas relating to soil infiltration characteristics and effective moisture holding capacity. The farmers were first requested to estimate the depth of root penetration for certain crops and were then asked to estimate the depth of water penetration for a given volume of water ponded on their field.[2] The results of these questions are summarized in Tables 3 and 4.

From these tables it is obvious farmers do not have any scientific knowledge either of the depth of effective rooting of a plant or of the effective wetting profile of a given volume of water. In certain seasons farmers are quite often observed to be overirrigating a crop by a factor of 2-3 times the actual water requirements. This may be a direct result of the fact that farmers have no idea of the concept of storage of moisture or the plant's ability to extract water from this moisture reservoir with its long and extensive root system.

In the same series of questions, farmers were also requested to describe how they determine when a crop needs to be irrigated. The results of this question are presented in Table 5. Forty percent of the farmers reported "by the appearance of the soil surface" while 31 percent reported "by the date of the last irrigation." Twenty-six percent reported "by the appearance of plants." No farmers reported checking the subsoil for moisture nor did they seem to really understand the significance of this technique. Farmers were also vague on describing what specific characteristics of plants actually indicate stress.

The above examples can be repeated on almost any watercourse in Pakistan. They are by no means unique events and simply serve to show the need for training farmers to be both better maintainers of their distribution systems and better managers of their irrigation water. The question that immediately arises is who will provide this training to the farmers? This is the topic of the next section.

Extension Personnel

The obvious source of advice and training for on-farm water management as well as all other farm activities should come from the existing agricultural extension services. In order to explore the effectiveness of the existing agencies established to assist farmers, a series of interviews was conducted with a sample of farmers. The object of the interviews was to determine how many farmers had knowledge of the Government officials and the number of contacts with them over the last three months. The results of this survey are summarized in Table 6. It is obvious from this information that farmers not only, for the most part, had no contacts with workers other than the canal

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2/In order to eliminate measurement communication problems the farmers were asked to illustrate depths with their hands and the interviewer converted this to inches.

Table 3. Farmers' estimates of depth of root penetration for selected crops. (Values in the columns indicate number of farmers selecting that given root depth. Values in brackets ( ) indicate the percentage of farmers selecting that root depth.)

Crops	2.5"	3"-4"	4.5"-6.5"	7"-12"	15"-18"	24"	36"	Actual[b]
Cotton	1(3%)	-( )	4(11%)	17(48%)	9(26%)	2(9%)	1(3%)	5'-6'
Berseem[a]	17(49%)	18(51%)	-( )	-( )	-( )	-( )	-( )	2'
Sugarcane	1(3%)	5(14%)	16(46%)	11(31%)	2(6%)	-( )	-( )	2'-3'
Wheat	13(37%)	16(46%)	6(17%)	-( )	-( )	-( )	-( )	5'-6'
Rice	7(20%)	18(51%)	10(29%)	1(3%)	-( )	-( )	-( )	9"-12"

a/Seven farmers (20%) reported 1-1.5 inches of root depth, eight farmers (23%) reported 2.0 inches for Berseem.
b/A properly irrigated crop in a deep, well drained sandy loam soil.

Table 4. Farmers' estimates of depth of penetration of water if five inches were ponded on their fields.

Depth (inches)	No. reporting	Percentage of total respondents
.5	1	3%
1.0	12	33%
1.25	1	3%
1.50	7	19%
2.0	6	17%
2.5	2	5.5%
3.0	2	14%
Don't know	5	14%

Table 5. Farmers' responses to "when water is available how do you decide what particular crop needs irrigation?"

Rank of importance	Date of last irrigation	Appearance of soil surface	Appearance of plants	Plant size	God's will don't know
Most important	11	14	9	1	-
Next important	2	15	14	0	4

Table 6. Farmers' knowledge of and contacts with agricultural personnel.

Official of department	Knows official's name or someone in Agency office (No. of farmers)	Number of contacts in period of last three months			
		0	1-2	3-4	5
Agr. Ass't.	1	34	3	-	-
Field Ass't.	2	34	1	-	-
Dev. Ass't.	8	27	5	2	1
Bank	4	31	3	-	1
Coop Dept.	1	34	1	-	-
Fertilizer Store	9	26	6	-	-
Canal Patwari	23	12	-	2	2
Canal Zelladar	-	35	-	-	-
Overseer	-	35	-	-	-
Sub Division Officer	-	35	-	-	-

Table 7. "Please list all of the later varieties of high yielding wheat recommended by the Research Station at Lyallpur for this area."

Variety	Number of Field Assts. to report this
SA42	19
Blue Silver	11
PARI 73	9
1372	5
CHENAB 70	3
MEXI PAK 65	5
SUNDALL	9

patwari, but that most farmers did not even know the names of the other appointed workers. The few contacts the field assistants or agricultural assistants had made in the last three month period were with large or influential farmers on the watercourse.

In order to examine the level of knowledge the current extension workers have about important practices in agriculture, a short examination was given to a selected group of extension workers (Early, 1975b). The following tables summarize some of the results.

The list in Table 7 illustrates that a number of the field assistants are confused about the proper late variety. Chenab 70 is not a late variety nor is Mexi Pak 65, although it does better than Chenab 70 when sown early or late. Every field assistant should be aware of the correct early and late varieties for their area.

The second question relates to fertilizer application rates for high yielding varieties. The results of these responses are summarized in Table 8.

From Table 8 it is again evident that there is quite a bit of confusion concerning both the amount of fertilizer to apply and the type that is best to apply. The field assistants were also asked a question concerning the rooting depths of the major crops for their area. Their responses are presented in Table 9.

It is evident that many field assistants did not know the answer to this question. It is also clear that they hold a concept of rooting depth similar to that of the farmers. They too like the farmers, have no training in this important aspects of irrigation water management.

Well trained farm level workers dedicated to agricultural improvements is perhaps one of the most critical needs in the agricultural sector today. Essentially this is an institutional problem with roots in the past and there are no short term solutions. To begin to provide the services which farmers desperately need will require institutional reorganization and intensive training programs for both field staff and their supervisors.

Farm Water Management Field Extension Services

A study of the Agricultural Department reveals that this old line department, established over 100 years ago as a result of the Indian Famine Commission Reports, has not been able to innovate to meet all the needs of today's farmers. To date, proper attention to the water management problems of the farmers has not come from this or any other government organization.

Table 8. "How much fertilizer and what types should you apply to obtain 50 maund/acre yields with the high yielding varieties of wheat?" (Early, 1975b)

Type of fertilizer	Responses*
Urea	11
Triple Super Phosphate	11
Potash	3

*Some field assistants gave no response.

Amounts of fertilizer to apply	No. of F.A.'s recommending
1 bag of nitrogen	4
1 bag of DAP	4
1 bags of nitrogen	12
2 bags of DAP	6
1 bag of Triple-Super Phosphate	8
1/2 bag of DAP	1
1/2 bag of Triple-Super Phosphate	1

When to apply nitrogen fertilizer	No. of F.A.'s recommending
Before sowing	11
After about 20 days	7
Second irrigation	6

Table 9. "Give your estimate of the rooting depths of the following crops." (Early, 1975b)

Inches/feet of root penetration	Maize	Wheat	Rice	Berseem	Cotton	Lucerne	Potatoes	Weeds along canal
0" - 3"	10	7	5	7	-	1	4	-
3" - 6"	7	10	7	6	1	4	8	-
6" - 12"	1	-	1	1	4	2	4	-
12"-18"	-	-	-	-	2	2	1	-
18"-24"	-	-	-	-	2	-	-	3
24"-36"	1	1	1	-	6	-	-	3
36"-42"	-	-	-	-	1	-	-	1
42"-48"	-	-	-	-	-	-	-	1
48" or more	-	1	1	1	3	3	-	5
Actual depth	3'-5'	4'-5'	9"-12	2'	5'-6'	5'-6'	1/5'-2.5'	3'-5'

The numbers in the columns indicate how many field assistants responded to that rooting depth for that crop.

Crop production could be markedly increased by improving the general level of extension training, providing specialized training in on-farm water management, and teaching extension workers the most effective techniques for presenting their knowledge to farmers.

In order to provide such training to the field staff of the Department of Agriculture it is necessary for a training center to be established that has both the necessary facilities and the dedicated trained staff. While it would be possible to create a new center or perhaps use the existing center in Sargohda, utilization of facilities and highly trained personnel of the Agricultural University at Lyallpur (at least for the Punjab) is one choice for such a training site. However, even here the staff, while having a high level of academic knowledge, does not have training applicable at the farm level in applied agricultural practices. Therefore, before a training program could be organized additional training of the staff would be required. This training could be provided by expatriate experts such as the Colorado State University Water Management Research Team, by USAID technical experts, by special training courses at such institutions as ILRI in the Netherlands, or by some combination of all these sources. The major requirement for training is a well organized, practical course that is concentrated at the field level aspects of farm water management and needs to include emphasis on social factors as well as technical factors.

A proposal to develop an intensive training program for on-farm water management has been presented in another document (Early, 1975b). It is not necessary to repeat this document but perhaps a brief outline of the proposal will be useful.

The proposal initially envisions a three-sided agreement between the Agriculture Department's Extension Service, the University of Agriculture, Lyallpur, and an outside organization of water management experts. The idea is to develop a program through the University of Agriculture, Lyallpur Short Course Institute. The University would contract with the Agriculture Department to provide this training. In the initial stages, expert advice would be provided by the outside water management experts. The major philosophy of the training course would be to make it 90 percent practical and conduct 75 percent of the training in the field. The object will be to train on-farm advisors under Pakistan field conditions. Villages around Lyallpur provide ample sites for training on how to ideas and solve farmers' problems. The program would be very tightly supervised by well trained, dedicated staff members. The focus is on problem conceptualization, identification, and solution; learning to think about on-farm water management problems and finding solutions under farmers' conditions. Such approaches will help the advisors to internalize systems approaches which are necessary for an understanding of solving complex on-farm water management problems.

Ultimately the optimal solution would be to create a federal or provincial water research center that is responsible for both the training of water management extension advisors and for on-farm water management research. This center could be affiliated with the University of Agriculture or it could be under the auspices of a group such as the Irrigation Drainage and Flood Control Research Council. The most important factor is to staff the center with competent men that are interested not in academic research exercises but in farmers' water management problems.

CONCLUSION

Water management between the mogha and the farmers' fields is one of the, if not the, weakest link in the entire water distribution system. The need for massive improvements both in distribution of the water and in utilization of the water is obvious and emphasizes the necessity for a massive farmer education program conducted by well trained active water management extension field staff. This document presents one proposal for developing such a staff but alternative methods exist that may be just as effective. The important fact to consider is the quality of the training provided to the field staff and the extension supervisory staff. Until such an on-farm water management extension staff is actively assisting farmers, increases in quantity of water delivered to the mogha from dams such as Tarbela will not provide the benefit to agriculture that their planners and designers envisioned and in some cases, may do as much harm in terms of waterlogging as they provide benefits in increased yields.

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