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# ANNUAL PROGRESS REPORT
# FOR WATER MANAGEMENT RESEARCH PROJECT
# FOR YEAR ENDING OCTOBER 31, 1970

Submitted to

The U. S. Agency for International Development
Contract AID/csd-2162

December 31, 1970

Colorado State University
Fort Collins, Colorado

## SUMMARY

### Significant Results and Utilization

The project is centrally funded by AID/Washington. Recommendations and advisory council are provided by CUSUSWASH in cooperation with AID's Research Advisory Committee. The Project Director, Dr. Maurice L. Albertson and staff of Colorado State University are shown on the Organizational Chart, Section I.

The general objective of this research project is to increase food production in West Pakistan through the improvement of water management practices to optimize economic returns from limited water resources.

Dr. Gilbert L. Corey, Chief of Party, reports encouraging contacts and planning results with GOP's Agriculture Research Council (ARC) and the Agriculture Research Coordination Board (ARCB) the responsible agencies for coordinating research programs throughout West Pakistan.

University personnel provided by CSU have made a good start through meaningful contacts with Pakistan officials resulting in coordinated planning and activation of some of the many research projects contemplated.

The University has successfully reached its objectives through research activities initiated in local GOP institutions. However, CSU's research specialists report some delays in project activation due to non-action or slow reaction of GOP personnel. Nevertheless, project research objectives will continue to be developed cooperatively with appropriate Pakistani personnel and CSU's policy will continue to be in an advisory, co-worker, or counterpart capacity rather than in planning and performing research activities themselves.

OUTLINE OF
ANNUAL PROGRESS REPORT FOR THE PAKISTAN
WATER MANAGEMENT RESEARCH PROJECT
FOR YEAR ENDING OCTOBER 31, 1970
(November 1969-October 1970)


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## SECTION I. INTRODUCTION

This report continues the reporting of progress, as requested by AID/Washington, for the period November 1, 1969 through October 31, 1970, for the Colorado State University project, "Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries," Contract Number AID/csd-2162 and Amendments 1 and 2.

The general objective of the CSU research effort is 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. Research is aimed at water management problems in the semi-arid lands of West Pakistan, but the results will be applicable in principle to similar conditions in other regions. This improvement of water management practices is necessary to obtain maximum economic returns from limited water resources and such inputs as improved seeds, increased use of fertilizers and pesticides, and supporting institutional structure.

During this reporting period CSU on-campus research projects, as outlined in Amendment 2 of the AID Contract, have been continued. On the basis of the on-campus research activities, research projects have been initiated in Pakistan to be performed by Pakistanis.

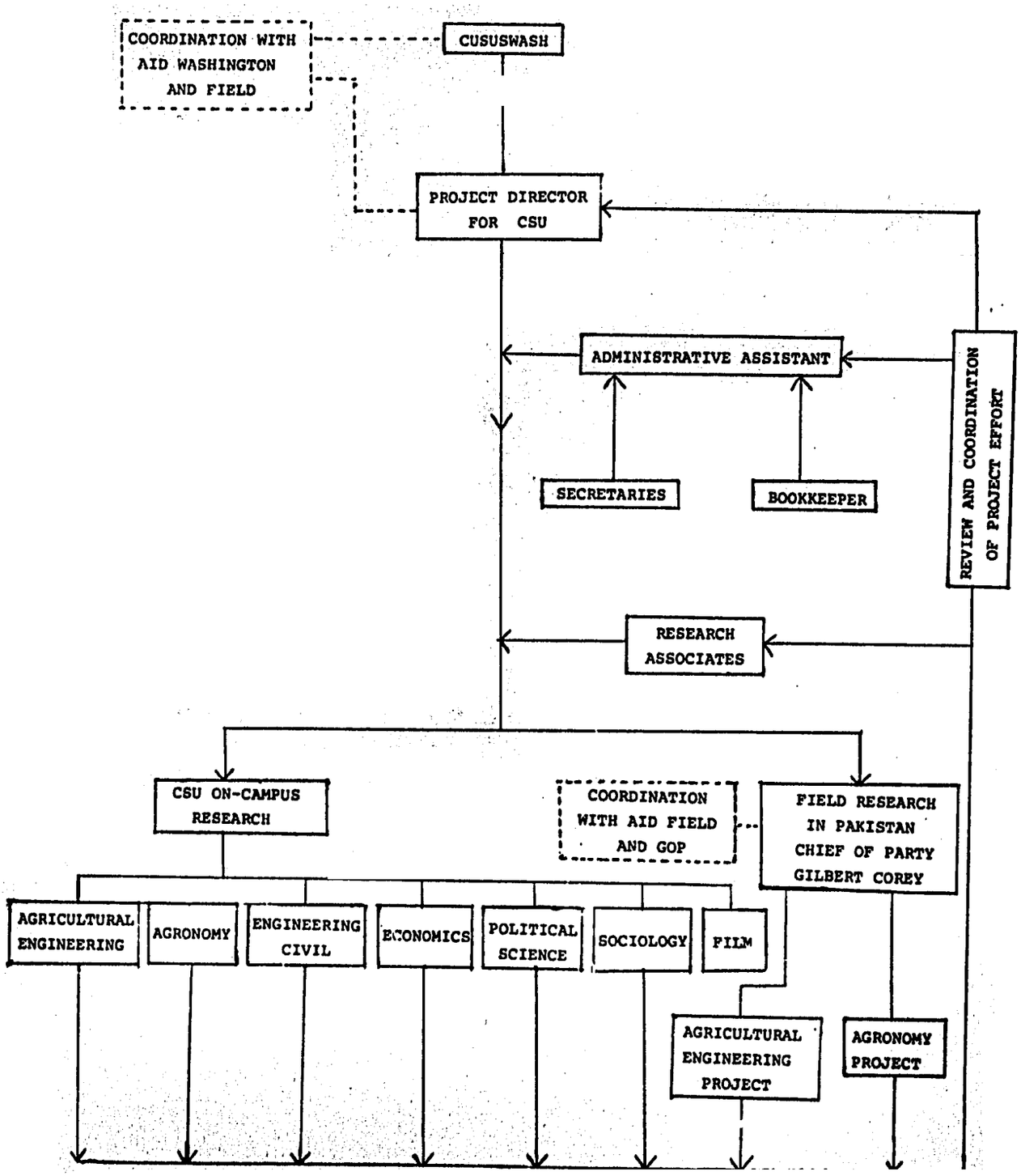
This report includes a general summary of activities in Pakistan, covering the following:

1. Progress made on the Film on Land Preparation for Level-Basin Irrigation,
2. CSU on-campus activities,
3. Water Management Project meetings,
4. Foreign travel,
5. List of project personnel, and
6. Project Contract.

Appendices A and B give the project plan for the two on-going research projects in Pakistan.

For lines of authority and responsibility please consult the Organizational Chart below.

# WATER MANAGEMENT RESEARCH PROJECT



## SECTION II. ACTIVITIES IN PAKISTAN

The CSU Chief of Party (Agricultural Engineering), Dr. Gilbert L. Corey, arrived in Pakistan on 27 August 1970. After a short period of orientation and getting "settled" in Lahore, a great deal of time was spent contacting Pakistani agencies and visiting agricultural areas to become acquainted with water management problems. By 1 November a total of 29 days had been spent in the field.

Previous contacts had been made by CSU specialists relative to initiation of research projects in Agricultural Engineering and Agronomy as established in the Project Agreement. Visits to Pakistan by CSU faculty and staff are summarized in Section VI. Foreign Travel. The Agricultural Engineering and Agronomy Department projects were initiated and presently are in progress. Details appear later in this section.

Discussions have been held with several GOP agencies relative to the possibility of working with them on water management research. A few of these plans may be slow in developing but most show good promise. These are summarized here:

1. Department of Agricultural Engineer - WPAU: A project involving village practices and interactions with water management practices and a project to study methods of irrigation including basin, border, furrow, and sprinkler. This department has the capability and equipment to pursue these studies.

2. Department of Rural Sociology - WPAU: A project involving social factors which explain on-farm water management decision making behavior. A project proposal has been developed by the CSU Sociology Department in cooperation with the Department of Rural Sociology and funds are being sought to initiate the first stage.

3. Water and Soils Investigation Division WAPDA (WASID): This agency is very receptive to technical assistance in water and soils which CSU can give. The Division is looking forward to the arrival of the soils scientist. WASID seeks advice on methods of monitoring the SCARP areas. This agency collects tremendous quantities of data on water quality, soil salinity, and agricultural production. However, the quality of data collection must be improved. Several discussions have already taken place regarding CSU's assistance to WASID.

4. Mona Project (WASID): This is a pilot project where WAPDA is attempting to develop methods and procedures of water management. Research and demonstration plots are located throughout the project area.

The scientists operating this project are also very receptive to advice from CSU specialists. Two visits to the area have been made.

5. Directorate of Agricultural Engineering: The CSU Agricultural Engineering Department project is presently working in cooperation with this agency. They are, however, interested in expanding this study into other areas of farm water control. Recently 60 additional acres of land was acquired primarily for this purpose.

An attempt is being made to combine most of these proposed projects into one water management project to facilitate fund requests from the GOP Agricultural Research Council (ARC). It is hoped that combining projects will also create closer working relationships between agencies doing similar research.

Two research projects are presently underway in the vicinity of Lyallpur. These are field experiments involving on-farm water control. In each, wheat is the present crop and plans include carrying each experiment through a sequence of crops for several years. Details are given below:

1. Water Control and Land Preparation: This project, involving hydraulics of border irrigation, is being carried out at the Machinery Demonstration Unit farm of the Directorate of Agricultural Engineering, Lyallpur, in cooperation with the Department of Agricultural Engineering at CSU. A detailed project proposal is included in Appendix A.

   Early in September 1970 a 20 acre field was selected for the experiment. It has since been leveled to zero grade, the

tillage treatments applied, wheat planted and fertilized, and the borders constructed. To date one irrigation treatment has been applied.

The Directorate of Agricultural Engineering (WPAU) has indicated a keen interest in water management research. This agency is an arm of the Agriculture Department and one of its functions is to provide engineering services to land owners desiring land leveling for better water management. Therefore, if this agency through its own research can demonstrate better design, the impact should be felt country-wide. The Director is presently considering use of plots to demonstrate better water management procedures.

2. Water Quality-Leaching Fraction Experiment: This project involves the management of irrigation waters of varying salinities and is being carried on by the Punjab Research Institute, Lyallpur, in cooperation with the Department of Agronomy - CSU. A detailed work plan is included in Appendix B.

In order to have a supply of saline water, it was necessary to construct a tube well at the site. Since the location is near the center of the doab it was felt that saline water would be available. To date the tube well has been drilled and tubing and pump are being installed. The water is very saline, but a detailed analysis is not yet available.

The wheat varieties have been planted, salinity sensors installed, and the plots have been laid out. Since the tube well was not finished the first irrigation was applied with canal water on all plots. It is expected to start the varying salinity water levels during the second irrigation treatment.

The location of this experiment is excellent in that hydraulic structures are available for mixing and metering water. It is expected that work of this type can greatly be expanded at this site because of this excellent facility.

## SECTION III. FILM ON LAND PREPARATION FOR LEVEL BASIN IRRIGATION

The general objective of the film as per Contract No. AID/csd-2162, Amendment No. 1, is as follows:

> The purpose is to produce a film based upon the results of research, that can be used by AID and other personnel to explain the basic principles of proper land preparation for irrigation to farmers, government officials, and students in foreign countries, particularly Pakistan and India, and the Middle-East countries.

More specifically the objectives are to:

1. Educate farmers and policy makers in South East Asia concerning the potential for improving on-farm water management by better land preparation methods
2. Show farmers and policy makers the need for providing agricultural engineering assistance to farmers (of the type provided by the SCS in the USA), and
3. Provide instruction for agricultural engineering students and equipment operators in regard to land-leveling engineering, equipment, and operational methods.

Messrs. Carlos Seegmiller and William Williamson (CSU camera team) completed filming in Pakistan during August and September 1970. They were also in Pakistan filming in November and December of 1969, but found it necessary to return to Pakistan because some important sequences filmed in West Pakistan in 1969 proved to be inferior in quality. Dr. Arthur T.

Corey, Film Project Director, was also in West Pakistan during November and December 1969 in connection with filming activities. Filming has taken place in Turkey, West Pakistan, Southern Rio Grande Valley in Colorado and the Salt River Project in Arizona.

Two separate films will be produced. The first is a general audience film concerning land forming for irrigation and will run for approximately thirty-five (35) minutes. The second film for which the script has not been written, is a specific training film on techniques of setting transits leveling etc. This film lenth will be about fifteen (15) minutes.

The first film is in the most advanced stage of completion and has been reviewed by Dr. O.J. Kelley, Deputy Associate Assistant Administrator, Research and University Relations, AID/Washington. The film was approved providing minor modifications were made. These changes have now been completed.

The next step will be to complete the script of the second film and then match the narration and background music with the pictures on both films. When this has been completed the films will receive a final review by AID/Washington before release of the films.

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## SUMMARY

The Water Management Research Project concerned with on-farm water management in Pakistan was continued during the calendar year 1971. Emphasis during the year has been placed on obtaining a more interdisciplinary approach to on-farm water management research in Pakistan. This emphasis has resulted in a number of formal and informal interactions among CSU project personnel. An attempt was made to determine how this interdisciplinary research can be effectively conducted. To emphasize the interdisciplinary nature of the on-farm water management research, this report has been organized so that activities are reported by subject matter with delineation of the interrelationships between the various research efforts.

A number of significant research findings, plans, and improvements in project coordination were achieved. These range from the development of a computer model of salt water coning under a tubewell and means for improving crop production in highly saline soils to plan for the initiation of research on technology implementation in Pakistan.

Three major subdivisions of our interdisciplinary research have been delineated. The first delineation is the development of new technologies or methods for improving on-farm water management. An example of the development of new technology is research directed toward the development of skimming wells which can be used to remove fresh water that overlies saline water in Pakistan. During the previous year studies

on a laboratory and physical model and a computer simulation model have resulted in a better understanding of the hydraulics of salt water coning when removing fresh water that overlies saline water by use of a tubewell. These studies and trips to Pakistan by CSU researchers have resulted in the development of several possible methods of skimming fresh water. Plans for the coming year will involve the testing of these theories in Pakistan.

Soils data, including physical and chemical properties, mineralogical properties, and fertility data, were developed during the past year. These data will facilitate the designing of pertinent experiments on irrigation water management in Pakistan. Studies have also shown that crop growth was especially responsive to phosphorous (P) applications in saline and/or sodic soils with an initially low P level. The results indicate that P fertilizer will indeed overcome some of the depressing effects of moderate salinity and sodium levels and that the P requirement is higher in saline soils than for normal soils.

Studies on the design of proper water application facilities for irrigation were conducted. The most significant finding to date is that there is a severe problem with low infiltration rates and poor root penetration in the soil that cannot be solved simply by improving cultivation techniques. Additional research will be directed toward the inclusion of treatments to determine how to improve infiltration and depth of rooting. Field experiments to determine data on soil salinity management were undertaken on experimental plots in Pakistan. However, because electrical power was not available for the

pump on the tubewell that was to supply saline water, this research data was not collected. Power has now been supplied to the well and this experiment will be conducted during the coming year.

The ability of Pakistani farmers to respond to economic incentives was evaluated based upon historical data. The conclusion was that the farmers are quite sensitive to economic policies and that they respond to positive incentives and react otherwise if the policies undertaken are incorrect. The study also suggested that risk and uncertainty and the desire to be self-sufficient are important factors to Pakistani farmers. Therefore, even though farmers are generally quite responsive to economic incentives, the responses are influenced by how risky the new change is and whether they will be able to feed themselves even if the crop is lost.

Implementation of new technology is the second area of effort. For example, procedures need to be developed for the introduction of new methods in such a manner that these methods will be adopted by the farmers in Pakistan. With proper delineation of the factors that control the adoption of new technology, including social constraints when new technology has been developed, then more rapid adoption of these procedures can be expected. A research proposal has been prepared by an interdisciplinary team of CSU and Pakistani personnel that is awaiting approval by the Agricultural Research Council. This interdisciplinary proposal has the objective of improving human and institutional capabilities for adopting technological changes that will improve on-farm water management in Pakistan. The sociological objectives of the project are to explain on-farm water management decision

making for a water course. The quality of water management decisions on farms will be identified by a number of dependent variables that will measure the quality of on-farm water management. This project will be instituted in Pakistan as soon as approved by the Agricultural Research Council.

To further aid in the implementation of new technology, a film entitled, "Land Forming For Irrigation," has been in production. Part I is designed to convince administrators in Pakistan that their agency should provide engineering assistance to farmers. Part I has now been completed and has been shown in Pakistan and elsewhere. Part II is designed mainly for classroom instruction of engineering students and is expected to be completed during the coming year.

The third area of interest is to evaluate the effect of new technology on water management and indicate its value or suggest new alternatives that may improve on-farm water management. An economic and social analysis of the effects of new technology can involve prior determination of the effectiveness of new technology and the evaluation of new technology being adopted or having been adopted by farmers. These methods of evaluation will be accomplished by interaction of CSU interdisciplinary research in order to assure that proper economic and social variables are measured both during the research and during the implementation phases.

The film on "Land Forming For Irrigation" will also be evaluated. The ability and effectiveness of the film to propagate new information about new technology of land leveling for improved water management and the ability

to transmit the professional role of the agricultural engineer to the authorities in the water management agencies will be tested.

Research efforts through the coming year will be directed more and more toward interdisciplinary approaches to priority needs in Pakistan. Some of this research will be conducted on the campus of Colorado State University directly related to, and in support of, research conducted in Pakistan.

# INTRODUCTION

In West Pakistan an extensive irrigated agriculture has existed for over a century. Dams and distribution systems have been built and are in operation. However, little effort has been made to develop on-farm water management systems for efficient use of water. Land leveling and proper location and design of farm ditches and irrigation structures are almost non-existent. Drainage for the most part has been neglected. Information on when to irrigate and how much water to apply has not received the attention that is necessary.

Crop production must be increased for the national interest. Gains to crop yields are possible through proper water management and other farming practices. However, in many instances, irrigation serves only as a measure of insurance against crop failure. Not enough effort has been made to capitalize on the tremendous production potential that is available through the proper use of irrigation water combined with good fertilizer and cultivation management practice combined with the use of high yielding varieties. In order to increase the effort to find practical solutions to the above problems, the government of Pakistan requested technical assistance from the United States. Colorado State University developed a project to assist Pakistan to improve on-farm water management and supply this technical assistance.

The general objectives of this research is to increase food production in the arid to sub-humid lands of the less developed countries through the improvement of water management practices and other farming practices. This improvement of water management practices is necessary to obtain maximum economic returns from limited water resources and other inputs such as improved seeds, increased use of fertilizers, and proper use of pesticides. Improvement is also needed in supporting institutional structures in order to fully capitalize on the potential for improved food production in the developing countries.

Program Objectives

The specific research studies will be selected to meet the high priority needs of West Pakistan through on-campus research and research in Pakistan. These studies will include but not be limited to:

1. The 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 a limited amount of irrigation water.
2. The development of knowledge and data that can be used for the economic design and construction of conveyance and delivery systems including structures for control and measurement of irrigation water on the farm.
3. The development of surface and subsurface drainage systems to eliminate the hazards resulting from surface flooding and high water tables.

4. The identification of important factors affecting the degree of leveling of the various soils in the major climatic zones and the relationships of these factors to erosion, water infiltration, and good land use from cropping practices.

5. The development 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. The integration of these water use factors into the productive cropping system consistent with farm size and available farming practices.

7. Where soil salinity and exchangeable sodium are problems, studies will include soil amendments, soil and water management procedures and use of salt tolerant crops.

Further objectives related to objective 6 above, but expanded by the Mission Program Agreement (PROAG), are:[1]

-- Organizational structure required for effective management and control of irrigation water; extent of participation of farmers.

-- Means to induce farmers and others associated with water management to make the changes necessary for most efficient use of irrigation water.

1 / With this inclusion, the specific objectives as stated in the Mission PROAG are fully covered by contract objectives 1-7 above.

Integration of the various components of the water system of West Pakistan for increased agricultural production.

On-campus research and research in Pakistan will be related to the above specific objectives as the results are reported.

# REPORT OF RESEARCH

Basic to the improvement of on-farm water management in Pakistan is an interdisciplinary approach to the problems of water management. The solution to on-farm water management problems depends upon three fundamental processes:

1. The development of new technology or new practices or data which is basic to the solution of a particular problem.
2. The implementation or application of this technology to the particular problem needing solution.
3. The evaluation of the success of this new technology to solving the particular problems of LDC's.

Since these problems are very complex, an interdisciplinary approach to each problem is essential to reach the most satisfactory solutions. Specific discipline oriented research is sometimes necessary in order to obtain specific data or develop a new technique in order to solve a particular problem within the context of the resources that are available in Pakistan. However, the definition of this problem, the formulation of the research procedures, and the interpretation of the results must be within the context of the interdisciplinary requirements of the solution. Fundamental to these solutions is the interaction of the various disciplines involved in an interdisciplinary planning and evaluation of the program at frequent intervals.

This program of research for on-farm water management has involved the disciplines of agronomy, agricultural engineering, economics, civil engineering, political science and sociology. The report of the results will be in terms of how these results impinge upon the various requirements for problem solution. No departmental designation of the results will be involved except in terms of the specific technical aspects of the research. These results are reported under one of the three fundamental headings described above with a discussion of the needs and requirements of the interdisciplinary solution of the problem

## I. New Technology or New Practices

Data concerning the natural resources of an area are necessary before an adequate approach to the area problems can be developed. Crops, soil and water are a part of the physical resources of any area. Human and institutional resources are the complementary restraints on the ability of the area to solve these problems. Data on the physical resources of the area are being developed through research by agronomy, agricultural engineering, and civil engineering.

### Soils and Crops

Soils data, for which little were available and few facilities or qualified personnel to obtained the data, are being obtained on campus a CSU. These include physical and chemical properties, mineralogical properties, and fertility status. These data will facilitate the designing of pertinent experiments in Pakistan.

Compacted, slowly permeable soils constitute a wide-spread problem for efficient irrigation and crop growth. In addition, data are necessary to generalize specific research relative to the variation of soil characteristics throughout Pakistan. Soils data are also necessary for delineating the criteria for proper fertility and irrigation practices including land modifications that may subsequently be developed. This research is directly related to Program Objectives 4, 5, and 7.

Mineralogical and moisture retention properties of these soils in Pakistan are necessary in order to develop recommendations for irrigation management on a variety of Pakistan soils. Without these data much research of an exploratory nature repeated over a number of geographic areas would be necessary to define procedures for solving the irrigation water management problem. Studies of soil mineralogical and moisture retention properties were conducted at CSU because of facilities at CSU which are not available in Pakistan.

The proper management of irrigation water depends also upon the proper management of fertility. Nitrogen and available phosphorous are very low in the soils of Pakistan. A proper fertility balance is helpful for reducing the adverse effects of soil salinity and exchangeable sodium. If poor quality groundwater is used for irrigation, it is probable that fertilizer requirements and recommendations would be different than those used for canal water.

A study of the relationships between fertility and salinity has been conducted at Colorado State University during 1971 to obtain precise data on crop fertility and growth requirements as related to salinity management. Important results have been developed for nitrogen and especially phosphorous for varying levels of salinity. These research results have indicated that proper levels of phosphorous in particular can substantially increase yields under high levels of salinity.

The studies also show that crop growth was especially responsive to phosphorous (P) applications in saline and/or sodic soils with an initially low P level. Sorghum yields were increased by P applications on a naturally saline-sodic Pakistan soil with a very high initial available P level also. Corn and sorghum yields were depressed by increasingly large applications on naturally or artificially salinized soils low in available P.

The results indicate that P fertilizer will indeed overcome some of the depressing effects of moderate salinity and sodium levels but the P requirement on saline soils is higher than for normal soils. The fertilizer balance appears to be much more critical in saline soils than in non-saline soils. Zinc and manganese improve crop yields to a small degree at moderate salinity and sodium levels. The fertility-salinity studies are directly related to Program Objectives 5 and 7.

Water Supply

With respect to the development of methods of water application and the study of soil salinity and exchangeable sodium defined in Program Objectives 5 and 7, a project to obtain data on all of these factors was considered. It was decided, however, that a plot study involving all the pertinent variables would be too cumbersome to be practical. Variables such as length of run and leveling techniques require longer plots than do such variables as timing and rate of water application, quality of water, etc. Instead, it was decided to install a set of plots to specifically study water application practices for various crops in Pakistan. In this particular study we wanted to determine the effect of more modern and deeper tillage on the infiltration rates of the local soils, because this would have an important bearing on such factors as the optimum length of the run, minimum size of stream, and other irrigation variables. The study is specifically related to Program Objectives 4, 5, 6, and 7.

Plots were installed in October, 1970 on the Machinery Demonstration Unit Farm near Lyallpur by personnel of the farm with the advice of the CSU chief of party, Dr. G. L. Corey. The details of the original plot layout have been described in the Annual Report for 1970.

Probably the most significant finding to date is that there is a severe problem with low infiltration rates and poor root penetration in the soil that cannot be solved simply by improving cultivation techniques. Consequently, the plot study as described in last year's report has been

modified to include treatments involving the use of both gypsum and green manure in an attempt to improve infiltration and depth of rooting.

With the data gathered from these experiments, it should be possible to make firm recommendations as to the optimum size of stream and length of border to use with each crop, depending, of course, on the tillage practice. These recommendations should prove useful to the farmers using mechanized practices as well as using traditional methods. This information will also be appropriate to a study of the optimum design of irrigation systems.

Field experiments to determine data on soil salinity managemer were also undertaken on experimental plots in Pakistan for Mexipak and Chenab wheat varieties. This experiment relates to Program Objectives 5 and 6. This experiment included plans for four water qualities and three leeching rates. However, electrical power was not connected to the pump on the tubewell dug to furnish saline water. The crop was grown and harvested but no information was obtained on the effects of water quality or leeching factions. A similar experiment was started again in November 1971, when electrical power was connected to the pump.

The economic implications of modifying the procedures for irrigation and the management of salinity for improved crop production will be evaulated from the field research. The experiments are planned in order that pertinent economic data be collected to indicate the economic feasibility of such practices. This is essential during the planning phase

and the experimental phase in order that implementation of these technological practices be evaluated before implementation actually occurs.

Conveyance channels are a vital component of large irrigation systems. As a rule, these channels have to transport a water-sedimen mixture. To change the existing irrigation conveyance systems in Pakistan, better knowledge will be needed about the hydraulic and sedin characteristics of sandbed channels. A dissertation entitled "Flow in Sandbed Channels" has been prepared at CSU. Design curves for computing the resistance to flow and bed material transport in sandbed channels has been derived in this study, which is based on the canal data in Pakistan, flume data collection at CSU, and some river data fro the Rio Grande.

In irrigation systems, as the channels divide to serve the project area, the bed material tranoport capacity of the flow decreases. Unlesi adequate quantities of sediment are removed along with the irrigation water (through the turnout structures), the conveyance system is likely to fill with sediment. As the channel fills, a decrease in the sediment transport capacity of the channels occurs. The problem of silt in water course channels is abundantly manifested in Pakistan and other areas of the world. This problem affects the total efficiency of the irrigation system.

A possible solution to channel silting is to route bed load material and irrigation water in such a way that sediment is equitably distributed

among the farms such that the transport capacity of the water course channels is uniformly decreased. The routing of sediment in large irrigation systems has been studied and a manuscript of the final report is complete. This report will provide means for solving the problem of water course sedimentation of the larger conveyance canals. So far, the study has been based on a computer simulation system. Its conclusions will be checked by a study of an existing canal in Pakistan. The sedimentation research is related to Program Objective 2.

Turnouts are the structures that control the amount of flow that passes from the Government-managed system to the farmer-managed water course. At present these structures in Pakistan have small capacities and are regulated so that they deliver water continuously whenever the distribution system is in operation. It is becoming more evident from research being conducted on optimal water management, that in the future there must be a design of turnouts to deliver large quantities of water for short periods. Turnouts can be designed for the proper delivery of water under present knowledge but information is not available for designs of turnouts for equitable delivery of the sediment contained in the water. Such designs are important to insure a proper sediment balance in the canal system and distribute the sediment equitably among the farms.

Accordingly, an experimental study is being conducted at CSU toward determining the design features of outlets that affect sediment delivery. A master's thesis has been prepared entitled "Sediment

Conduction Turnouts" and presents a review of previous work in this area, covers the data from the early tests of the study and presents the general trends that appear to be developing from the data. Ongoing tests are extending the range covered by the data and confirming the trends that have appeared so far. These additional studies are necessary because sedimentation data contain a large number of variables and the relationships are difficult to establish conclusively.

Field application of these results will be in the future. A great deal of study and preliminary tests will be required to document the superior effectiveness of the proposed change in the operation of the irrigation system. The Irrigation Department can then be persuaded to review the new procedures. This type of study is presently underway both in Pakistan and CSU. Program Objective 2 on the design of the conveyance system motivates this research.

Research on reuse of ever increasing saline water for irrigation in Pakistan is essential because current irrigation water used from many tubewells has high levels of salinity. In addition, as increasing amounts of groundwater are developed the water used will become more saline. Due to specific hydraulic conditions in the Indus Valley, a research program was developed to reduce the amount of saline water that would normally be pumped from tubewells. Because of the unique facilities and personnel that are located at CSU, this problem was most appropriately defined as an on-campus research project. Program Objective 2

relates to increasing the groundwater supplies that may be used for irrigation and also for deliberately using the groundwater reservoir as a storage basin.

The amount of surface water for irrigation in the Indus Valley is about half that needed for optimum production on the lands served by the present canal system. Optimum production, therefore, can be obtained only through the conjunctive use of groundwater and surface water. Unfortunately, the fresh water aquifer of the entire Indus Plain is underlain by saline water at varying depths. Wells used to remove fresh water overlying the saline water often produce water of poor quality because of contamination from underlying saline water. The reason for the contamination is that any drawdown of the water table causes an upward mounding (coning) of the saline water beneath the well. This severely limits the rate that water of good quality can be pumped from many wells in the Indus Valley.

A project has been underway for the past two years, the ultimate objective of which is to develop methods for reducing the amount of contamination from the underlying saline aquifer. As a first step, existing theory relating to salt water coning under wells has been evaluated. This theory comes primarily from three sources: The earliest theory on the subject was published in 1946 by Muskat writing on problems of water coning in oil wells. In 1965, Flora Chu Wang published a solution to the problem of optimum depth of penetration of skimming wells. Her theory was developed as a result of an investigation

of the design of skimming wells for application in the Indus Valley, where she worked as a member of the Water Resources Study Group of Harvard University. In 1968, Bennett, et. al., of the U. S. Geological Survey, published the results of an electric analog study of brine coning beneath fresh-water wells in the Punjab region of West Pakistan.

Both physical and mathematical models have been employed to evaluate existing theory. It has been found that existing theory is not adequate to provide a quantitative description of the coning process. A numerical model has been developed which requires fewer assumptions than existing theory.

Data from the numerical model employing a computer solution agree very closely with results from the physical model. These data, however, confirm a prediction by Muskat that the highest stable position of the apex of a brine cone is substantially lower than the bottom of the well screen. With the apex at its highest stable position, a higher well discharge causes saline water to flow into the well. Muskat's theory, however, overestimates the well discharge when the apex of the cone is at its highest stable position, whereas the numerical model developed as a result of this study correctly estimates the well discharge as observed for the physical model.

A preliminary analysis of several possible skimming well procedures has also been made. This includes the use of horizontal collectors, multiple shallow wells, and the sealing of a horizontal area of the aquifer at the base of the well. The feasibility of a conjunctive use procedure,

using surface water to depress the saline water cone during periods when the well is not in use is also being studied.

If an economical method of skimming fresh water with minimum saline water contamination can be perfected, it will have a very great impact on the improvement of the conjunctive use of ground and surface waters in the Indus Valley. This in turn should have a very beneficial effect on the agricultural production from the available water supply. This is particularly true in the large areas where saline water is relatively close to the surface. The area around Lyallpur is a good example.

The Ministry of Agriculture, through its Agricultural Engineering workshops located in several parts of Pakistan, has the responsibility and organizational capability of assisting farmers to construct relatively shallow wells. The problem is to find the right type to perform the skimming function.

A paper describing an analysis of the salt water coning problem is now being prepared and should be published in the spring of 1972.

Social Change

In addition to specific technological improvements of irrigation water management for improved food production in Pakistan, a number of broad, multi-faceted approaches are being developed. These approaches involve an evaluation of existing or already known technology as well as an interdisciplinary evaluation of their potential. One of the simplest procedures for introducing technological change is the economic incentive. To evaluate the usefulness of economic incentives, a study

of the economics of water use was made for Pakistan and was completed during the previous year as a Ph. D. dissertation at CSU.

This report concludes that "Farmers in West Pakistan are quite sensitive to economic policies. They respond readily to those which have positive incentives and react otherwise if the policies undertaken are incorrect." The same report found that changes in price and terms of trade were among the major causes of growth in output. As the price of crops increased, farmers adjusted their production accordingly. The study also argued that the tendencies to overwater or to underwater crops may be explained by the existing water pricing mechanism where acreage rather than the volume is the basis for water charges. Once paid the cost of water is fixed and water is no longer viewed as being a variable cost subject to the normal rules of economic allocation during the production period.

Two further points were stressed in the report. It was suggested that risk and uncertainty, and the desire to be self-sufficient are important factors to Pakistani farmers. Therefore, even though the farmers are generally quite responsive to economic incentives, the response is influenced by how risky the new change is and whether they will still be able to feed themselves even if the worst should actually happen.

The risk of adopting a new technology that results in improved water management may be great and the consequences of failure may also be more drastic. Not only is there a greater likelihood of a

complete loss in yield where high producing varieties and high fertility levels have been maintained, but there is the corresponding added cost of the technological inputs. When credit has been the means of developing the capital necessary for these inputs, failure can result in the loss of property. The evaluation of risk and uncertainty is an important aspect of the human and institutional resources in the area.

## II. Implementation of New Technology

Innumerable research reports have been prepared on the technological solution of food problems in the developing countries. These technological solutions have assumed that implementation of the technological procedures was feasible within the human and institutional resources available in the country. These reports are generally prepared citing previous research, mode of attack, experimental procedures, results and recommendations. Implied in the recommendations is the assumption that the farmers and responsible officials and individuals in a particular country will implement the recommendations.

The on-farm water management research project has assumed that technological solutions to problems of on-farm water management in Pakistan will require specific activities to implement the solutions. These implementation assumptions are embodied in an interdisciplinary approach to attempt to define the needed procedures for actually carrying out the technological solutions to the defined problems. The interdisciplinary capability to implement these technological solutions have been improved and developed under a current grant for this purpose from AID.

A number of implementation levels have been identified and are presently being investigated for implementation procedures. Within the definition of the technological adaptation of land-leveling practices for improved irrigation water management, a program of education fo institutional administrators has been formulated part of which consist of a film that provides educational concepts for the advantages of irrigation of land leveling to improved on-farm water management. Also anticipated is another film that would develop the capability of individuals for actually implementing the land-leveling practices on the farm. Extension services to help farmers to adapt to new practices are essential.

A number of constraints to the acceptance of new technology in the Indus Valley have been noted by the CSU contract team. One is that the Pakistani farmers and most of their advisors have seen only one way of irrigation, cultivation, land preparation, etc. These have been employed without substantial change for many generations. It is difficult for them to conceive and put into practice new methods.

Another is that Pakistani farmers have a substantial distrust of government representatives for historical reasons. They also have a distrust of collective enterprises whether of a cooperative, corporate or a governmental nature. However, some farmers are willing to accept new technology when it is within their resources as individuals to undertake it, but if the new technology requires collective inputs, it is harder to obtain acceptance.

Furthermore, neither the British Colonial Government nor the Pakistani Government have attempted to assist farmers with problems of managing water after it leaves the water course turnout. The irrigation distribution system is operated by hydraulic engineers who are not trained in the field of water management on farms. There is no government agency comparable to the United States Soil Conservation Service which is responsible for assisting farmers in regard to land preparation, irrigation system layout, etc. Only an extremely small number of people trained to help farmers with irrigation problems exist in Pakistan and even these few find it difficult to obtain jobs.

Film Project

An educational film entitled "Land Forming for Irrigation" has been in production. The film is in two parts. Part I is designed to convince administrators in Pakistan that their agencies should provide engineering assistance to farmers. The film explains the part engineers can play in improving on-farm water management. It also makes the points that there are a number of ways of irrigating and that the present farm irrigation layouts in Pakistan need to be modified for more efficient production. Part I has now been completed and has been shown in Pakistan and elsewhere.

Part II is designed mainly for classroom instruction of engineering students. It explains the techniques of land-leveling surveys and calculations. Part II is incomplete but is being completed as rapidly as possible. Most of the filming on both parts was done in Pakistan and Turkey with a lesser amount in the U.S.A.

## Human and Institutional Capabilities

This program is also directed toward the specific research objective of improving human and institutional capabilities for adopting technological changes that will improve on-farm water management in Pakistan. An interdisciplinary approach to this problem was defined by interaction of the various disciplines at CSU. The sociological objectives of this project explains on-farm water management decision-making behavior for a water course. In the context of what factors determine the quality of on-farm water management decisions a number of dependent variables have been defined which will measure the quality of on-farm water management. The measurement of these factors will require interdisciplinary interaction from a number of groups including agricultural engineering, agronomy, civil engineering, and economics. These factors as currently defined are:

1. Application of appropriate amounts of water in relation to crop requirements.
2. Appropriate timing of water and relation to crop requirements.
3. Constructing and maintaining quality water courses defined in terms of inlet design, lining, size, cleanliness, seepage, and directness of route.
4. Quality of tubewell water used, defined in terms of capacity of water course, and appropriate mixing of tubewell water and canal water.

5. Quality of land preparation including leveling, cultivation, and soil conditioning.

The above factors are indicative of the interdisciplinary interaction that will be required in order to conduct and evaluate this particular experiment. In addition, interaction will be needed in order to improve the experiment as the data is collected and the results interpreted.

After the first stage of the study has been completed, factors which determine the quality of water management practices will be investigated to determine the acceptance and rejection by farmers of innovations that have been introduced. The capacity of farmers to effectively employ these innovations in water management technology to increase farm production will also be evaluated.

The implementation of this research project depends upon the availability of funding in Pakistan and the availability of an interdisciplinary team to advise and evaluate the experiment while it is being conducted. These procedures require on-site long term personnel on assignment in Pakistan and the approval of the Agricultural Research Council at the provincial and central government level. The value of this research in terms of the specific research objectives listed earlier depends on the ability of Pakistani institutional and human resources to adopt new technology for on-farm water practices for improved food production.

A number of research reports and other types of materials have been prepared by personnel on the project. A list of these reports that have been prepared for the past year and a list of those in preparation are included below.

## PUBLICATIONS FOR WATER MANAGEMENT PROJECT

| TITLE | AUTHOR |
|---|---|
| Bibliography with Annotations on Water Diversion, Conveyance, and Application for Irrigation and Drainage, CER 69-70-KM3, September 1969 | K. Mahmood<br>A. G. Mercer<br>E. V. Richardson |
| Organization of Water Management for Agricultural Production in West Pakistan (a Progress Report), ID70-71-1, May 1970 | P. O. Foss<br>J. A. Straayer<br>R. Dildine<br>A. Dwyer<br>R. Schmidt |
| Dye Dilution Method of Discharge Measurement, CER70-71-WSL-EVR47, January 1971 | W. S. Liang<br>E. V. Richardson |
| Water Management in West Pakistan, MISC-T-70-71RFS43, May 1970 | R. F. Schmidt |
| The Economics of Water Use, An Inquiry into the Economic Behavior of Farmers in West Pakistan, MISC-D-70-71DW44, March 1971 | D. Worku |
| Pakistan Government and Administration: A Comprehensive Bibliography, ID70-71-GNJ17, March 1971 | G. N. Jones |
| The Problem of Under-Irrigation in West Pakistan: Research Studies and Needs, ID70-71GNJ-RLA19, June 1971 | G. N. Jones<br>R. L. Anderson |
| Maximum Water Delivery in Irrigation, CED70-71JHD45, August 1971 | J. H. Duke, Jr. |
| Flow in Sand-Bed Channels, CED70-71-KM30, February 1971 | K. Mahmood |
| The Problem of Water Scheduling in West Pakistan: Research Studies and Needs, ID71-72-GNJ8, November 1971 | G. N. Jones |
| Monastery Model of Development: Towards a Strategy of Large Scale Planned Change, ID71-72-GNJ9, November 1971 | G. N. Jones |

## Other Publications

| Title | Author |
|---|---|
| Planning, Development and Change | Garth Jones<br>Shaukat Ali<br>Richard Barber<br>James Chambers |
| A Study of the Contribution of Private Tubewells in the Development of Water Potential in Pakistan | West Pakistan Univ |
| A Comprehensive Bibliography: Pakistan Government and Administration | Garth Jones<br>Shaukat Ali |

## III. Evaluation of New Technology

An obvious and direct means for evaluating the effectiveness of new technology is through an economic analysis of the effects of new technology. This analysis can involve prior determination of the effectiveness of the new technology and can also involve the evaluation of new technology being adopted or having been adopted by farmers. The economic evaluation of new technology will involve these two aspects: (1) the evaluation of research results before introducing the new technology; and (2) the evaluation of on-farm introduced technology. This will be accomplished through interdisciplinary research in order to assure that proper economic variables are measured both during the research and during the implementation phases. These research projects do provide for this analysis and more thorough planning of the research and implementation will be provided in the future.

Work on the decision making and quality of on-farm water management in Pakistan will have a corresponding objective and interest in evaluating the effectiveness of new technology to improve on-farm water management. This measurement of the employment of new technology to improve on-farm water management will involve an evaluation of the propensity of farmers to adopt or reject the new technology and also the ability of the farmers to employ the innovation in order to effectively raise the quality of water management. This research will be directly applicable to planning future introductions of new technology and also to improve current methods of introduction in order to improve

on-farm water management. This process of evaluating the propensity of farmers to adopt new technology should be invaluable.

The film on "Land Formation for Irrigation" will be evaluated This will involve an interdisciplinary evaluation and will attempt to measure the ability or effectiveness of the film to propagate information about a new technology, land leveling, for improved water management and the ability to transmit the professional role of the agricultural engineer to authorities in the water management bureaucracies. This evaluation of the attempt to implement new technology should provide insight as to how additional new technologies can be introduced.

An evaluation by CSU project personnel of the achievements of interdisciplinary research will continue. This evaluation will result in the defining of new objectives and new research projects as priority needs are delineated. The process of evaluation of research while it is being conducted will be an integral part of the evaluation of new technology but within the context of the Project.

## PROPOSED PLAN OF WORK

The proposed plan of work for the coming year will involve further interdisciplinary planning of research projects and the improving of on-going research projects and their interactions. The presence of an interdisciplinary research team on long-term assignments in Pakistan will improve this capability to formulate research for on-farm water management in Pakistan. Basic to the interdisciplinary research requirement is the presence in Pakistan of an additional agricultural engineer, an agronomist, soil scientist, and economist. These individuals can then provide the capabilities for relating more directly the CSU on-campus research to problems of water management in Pakistan including research on additional aspects of the water management problems of Pakistan.

The experiments related to the objectives of practical methods of water application, integration of water use factors, and soil salinity problems will continue. Field experiments on the aspects of water quality and crops, including tillage, leaching requirements, soil amendments and other factors, will be conducted in Pakistan for the coming year. In addition, future plans for research on land leveling and modifications to improve soil infiltration rates as identified from previous research will continue. Progress in this area will depend upon the formal approval of research proposals by the Agricultural Research Council (ARC). The implementation of field tests of skimming well techniques are planned in Lyallpur and other areas of Pakistan. Proposals to conduct such tests have been prepared by WPAU staff with the advice of CSU consultants. These proposals will also have

to be approved by the ARC in order to obtain local currency to implement these studies.

A major effort requiring interdisciplinary procedures by CSU personnel on long-term assignment in Pakistan and the on-campus CSU faculty is interaction and cooperation with the Pakistani Mona Project personnel to improve research on on-farm water management problems. This includes the formal cooperation of agronomy, agricultural engineering, civil engineering, economics, sociology, and other disciplines as the interdisciplinary plans are formulated. Future progress will depend on assignment of long-term personnel to Pakistan.

More interaction of economics in the formulation of plans for technological innovations and the evaluation and interpretation of the results of the technological research will be developed during the coming year. These include techniques for evaluating the economics of various technological practices as well as the collection of data during the conduction of the research. The development of economic, social, legal, and administrative criteria for the evaluation of the implementation of technology in Pakistan will be further developed during the coming year. A report on Pakistani water law is in preparation. The success of this research will depend upon a number of factors but the assignment of an economist in Pakistan is necessary for the interdisciplinary planning of research and to provide data for on-campus research at CSU and guidance to the CSU resident faculty in the areas of relevant research for Pakistan. Thus, the assignment of an economist in Pakistan is crucial if the objectives of on-farm water management research are to be obtained.

Further refinement of the means for evaluating the sociological factors that affect on-farm water management is needed. This requires more

interdisciplinary planning with interaction by the various disciplines involved. Also, the improvement of the indexes or dependent variables indicating improved on-farm water management are needed. Guidance to the research program in terms of locating an interdisciplinary team in Pakistan is also needed. The development of further procedures for collecting the data on the evaluation of sociological factors will continue.

An evaluation of the effectiveness of the film "Land Formation For Irrigation" developed by the Project will be conducted in the coming year. The emphasis will be on the technologically induced social conflicts, land consolidation, and other technological impacts of the film.

The reordering of priorities to relate problems of on-farm water management in an interdisciplinary approach both at the Mona Project and for systems analysis of a water course will be developed in the coming year. A greater emphasis will be placed on the development of accurate data and criteria for the evaluation of irrigation. The study of turn-out structures will continue. The conjunctive use of surface water and ground water needs more thorough investigation as this area receives additional attention in future research plans during the coming year.

In the coming year there is a need for the definition of the role of research techniques on administration to the on-farm water management project. This area needs definition in terms of the administration of the lower levels of the on-farm water management decision process as well as implementation of improved technology at the higher levels of the bureaucracy in Pakistan. However, to properly formulate these research plans, more

interdisciplinary planning for the development of a research plan is needed. Future developments of priority research will be on the basis of interdisciplinary interaction and will be restricted to these types of statements of research needs in order to develop priority research for Pakistan. Also, bibliographic reports will be related to these identified priority research needs in order to complement the on-going research.

Most of the priority research needs planned for Pakistan were developed as a result of the experience of the CSU project personnel prior assignments in Pakistan and from CSU personnel on various trips that have been made to Pakistan. These trips have and are playing an important role in the formulation of priority research needs for on-farm water management in Pakistan. There are definite advantages that accrue in having CSU teams, formulated on an interdisciplinary basis, visit Pakista This prevents discipline oriented views of problems of on-farm water management in Pakistan. The technological disciplines and the social science disciplines benefit from such interdisciplinary interactions.

There is a need to involve all researchers at CSU working on on-farm water management problems in trips to Pakistan in order to provide the interdisciplinary interaction and first-hand impressions of these priority research needs. A number of statements can be quoted from trip reports which indicate the degree of importance of these trips to the formulation of research plans and the conducting of research on on-farm water management in Pakistan.

# APPENDIX

The Director of the Project is Dr. Maurice L. Albertson.

The following list of professors and graduate research assistants have actively participated in carrying out the objectives of the Water Management Research Project:

| PROFESSORS | DEPARTMENT |
|---|---|
| Biggs, H.H. | Economics |
| *Corey, A.T. | Agricultural Engineering |
| Ellenbogen, B.L. | Sociology |
| *Freeman, D.M. | Sociology |
| Franklin, W.T. | Agronomy |
| Hodgdon, L.L. | Sociology |
| *Jones, G.N. | Political Science |
| Longenbaugh, R.A. | Civil Engineering |
| Mahmood, K. | Civil Engineering |
| McWhorter, D.B. | Agricultural Engineering |
| *Mercer, A.G. | Civil Engineering |
| Nobe, K.C. | Economics |
| Richardson, E.V. | Civil Engineering |
| *Schmehl, W.R. | Agronomy |
| Straayer, J.A. | Political Science |
| Smith, G.L. | Civil Engineering |
| *Tinnermeier, R.L. | Economics |

POST DOCTORAL

Malik, M. Bashir . . . . . Agronomy

GRADUATE RESEARCH ASSISTANTS

Andrew, J.W.
Chaudhry, M.T.
Doddiah, S.
Duke, J.
Khan, M.J.
Lemma, W.A.
Monadjemi, M.
Nazar, A. M.

*Designated as CSU Department Leaders for the Project

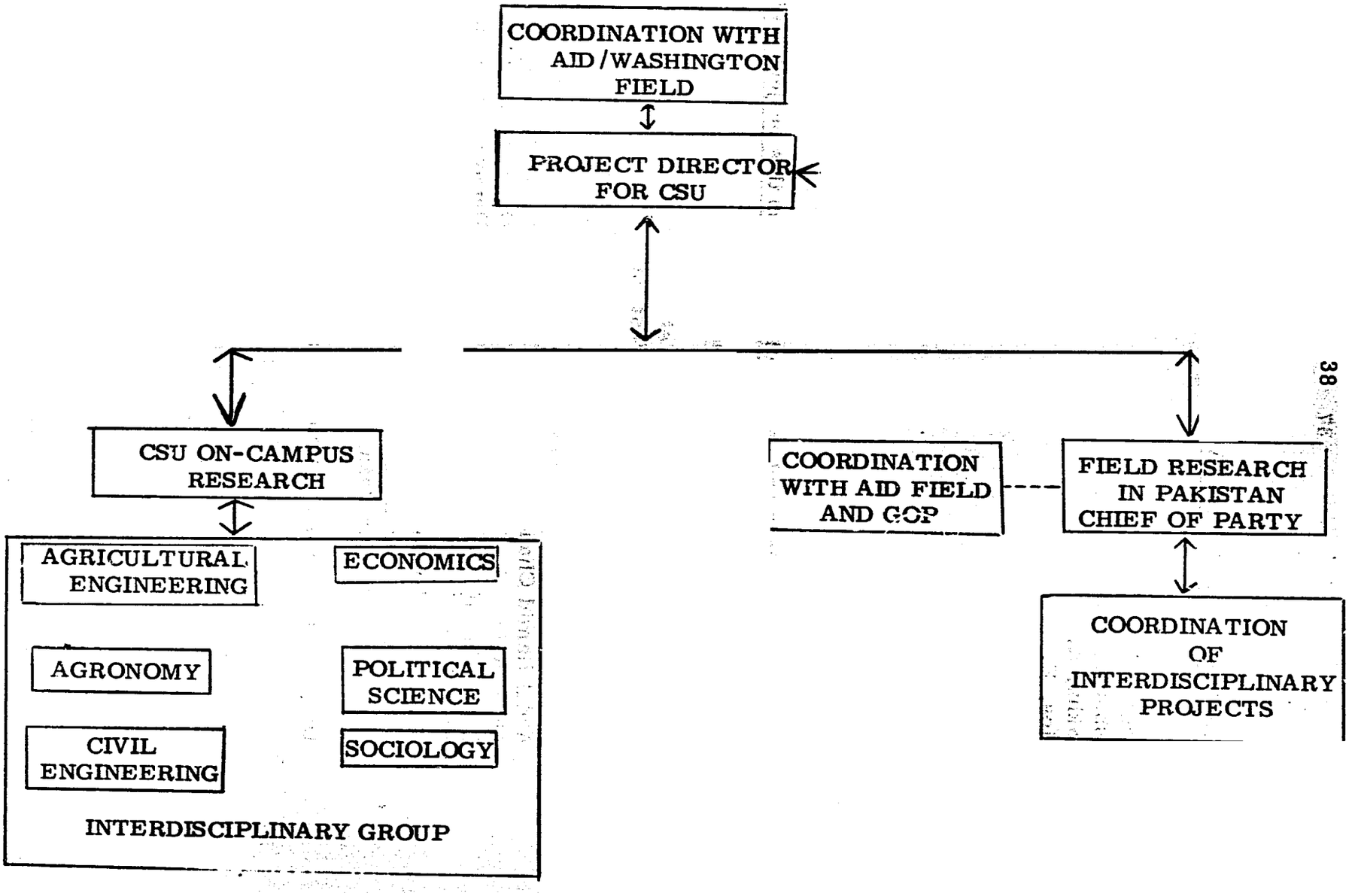
GRADUATE RESEARCH ASSISTANTS (con't)

Neghassi, H.M.
Osborne, P.S.
Rakha, A.
Rios, E.
Rizwani, A.R.
Schmidt, R.
Trautman, L.O.
Tuffour, S.
Worku, D.
Mirza, A.
MacDonald, K.
Kahn, Saeed

Pakistan institutions and personnel involved on this project are:

| Name | Institution |
|---|---|
| Dr. Inam-Ul-Haque | West Pakistan Agricultural University |
| Dr. Shah Muhammad | West Pakistan Agricultural University |
| Dr. Said Ahmed | Punjab Agricultural Research Institute |
| Hyatt M. Bhatti | Ayub Agricultural Research Institute |
| Ghulam Hussan | Ayub Agricultural Research Institute |
| Abdul Hamid Chaudary | Machinery Demonstration Unit Farm |
| Abdul Aziz | Machinery Demonstration Unit Farm |
| Khalid Sharif | Machinery Demonstration Unit Farm |
| Roshan Ali | Machinery Demonstration Unit Farm |
| Haider Ali Chaudhari | West Pakistan Agricultural University |
| Ali Muhammad Chaudhry | West Pakistan Agricultural University |
| Muhammad Rafique Raza | West Pakistan Agricultural University |

Dr. Gilbert L. Corey, Chief of Party, CSU

# WATER MANAGEMENT RESEARCH PROJECT

## FUNCTIONAL DIAGRAM