RESEARCH NEEDS
FOR
ON-FARM WATER MANAGEMENT

PROCEEDINGS

OF

AN INTERNATIONAL SYMPOSIUM

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HOW TO READ THIS REPORT

In order to serve a variety of readers having different interests and responsibilities, this report is organized at four levels of detail.

1. The Synopsis is a brief statement of the conclusions. It should be useful for top executive review. It contains 1½ pages.

2. For a somewhat more detailed summary review including a summary of how the conclusions were reached and by whom, and a brief note on the general rationale behind them one should review the Table of Contents and also read Chapters I and II, "Introduction" and "Summary and Recommendations," 10 pages.

3. Chapter III includes the summary reports of each of the five panels dealing with the five major questions addressed by the Symposium. In these, the arguments of the position papers and Panel and Symposium discussions are summarized and each recommendation or conclusion is discussed. This should be of interest to executives, staff specialists, and advisers with responsibility for planning and executing programs, 21 pages.

4. Part II, Chapters IV to VIII, contain the position and working papers in detail. These present the views of some of the world's most experienced scientists and administrators in the field of on-farm water management including experts from developing countries, FAO, Asian Development Bank, World Bank, and Organization of American States. A wealth of experience is contained in these papers. These should be of interest to executives, planning staff and advisers, scientific specialists, and administrators in the field of on-farm water management at all levels.

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SYNOPSIS

The following areas of knowledge deficiency in the field of on-farm water management were identified by the Symposium: 1) Physiological responses of crops to environmental stresses; 2) optimal crop productivity relationships of water and other inputs, 3) methods for systematically transferring crop productivity functions geographically; 4) improved on-farm systems, including drainage, and measuring and control structures; 5) improved production systems and understanding of climatic variables for rainfed agriculture; 6) improved prediction of quantity and quality of surface and subsurface water supplies and improved storage and distribution procedures for optimal on-farm water management; 7) methodology to identify critical technological innovations or systems; 8) improved "systems" to facilitate or deliver appropriate water management technology; 9) farmer motivation; 10) methods for involving farmers in the planning and management of water distribution systems; 11) approaches to needed water rights legislation; 12) prediction of economic consequences of alternatives; and 13) techniques for predicting socio-economic problems. This is not a complete list but the Symposium felt it defines the principal areas of deficiency.

All of the topics included in the foregoing paragraph are appropriate for AID central-funding support; however, certain aspects of Items 7, 8, 9, 10, and 13 might be handled by regional international centers because of political dimensions.

All of the topics mentioned are more or less generalizable, but all also have site-specific dimensions, particularly in implementation. Field research continues to be necessary, partly in order to delineate what the real problems are, but transferability could be improved substantially if data taken could be synthesized into more general "systems" concepts. Such an approach would also help identify the important controlled experiments that need to be made. It would require conceptualization. Once conceptualized, it could be used at any level of sophistication ranging from simply having available compatible sets of data to be applied "by hand," to sophisticated computer simulation models incorporating theory and wide spectra of empirical data. Item 3 suggests this approach to improving the transferability of crop production functions and relates especially to Items 1, 2, and 5. This research seems appropriate for AID central funding, but Mission-supported and country research could add to the store of transferable information if compatible measurements of the important variables identified were made.

Nearly every country has research or demonstration stations working on physical and biological aspects of water management at some level. Interactive experiments considering multiple variables seem more the exception than the rule. Pilot projects that identify project-level problems and attempt to integrate knowledge into viable production systems have been used quite widely with generally indifferent success. Prototype level programs (such as India's Command Area Development Programs) are just getting started in India, Southeast Asia, and elsewhere. Little progress has been made on generalizing results. A number of research stations, including some international ones, are working on various aspects of on-farm water management technology. As much as possible, these should be integrated into regional and international networks and efforts made to insure improved transferability of results.

Breakthroughs are possible, but cannot be predicted. In some areas, e.g., rainfed agriculture, systematic approaches to crop-production function transfer, the climate seems promising. As with most technology, the real payoff in on-farm water management is apt to come through continuing incremental improvements based on research under actual practice conditions.

There are difficult problems of implementing technological knowledge often related to political, cultural, and financial considerations. The Symposium outlined a strategic approach to research problems associated with implementation (Chapter III.4). A shortage of trained manpower at all levels is viewed as a serious handicap.

The present AID research contracts appear just now to be reaching the time period where real payoff can be expected. Colorado State University should emphasize research leading to acceptable physical and institutional water course systems providing adequate and equitable distribution of water, with consequent studies aimed at uniform distribution of water on fields; salinity and sodium control; improving summer crop stands; developing crop, water, fertilizer responses for major crops; and developing techniques to deliver management services to farmers. Utah State University should prepare research guides enabling Latin American countries to conduct their own essential experiments, adapt or develop existing predictive models for yield response under varying environmental and cultural conditions, identify water-law components that impair efficient water management and develop strategies for their correction. Both universities should focus their efforts toward components that can be completed within needed time-scales for implementation and should report scientific progress separately from administrative, logistic, and planning considerations. Substantial research progress whose implementation will increase food production in the study countries and throughout the world has been made. Prior to issuing additional *new* research contracts, however, AID should consider contracting for comprehensive "state-of-the-science" reviews in the specific area to be researched.

"Social" or mixed systems problems such as Items 8, 9, 10, and 13 are considered researchable although a more "clinical" or "case study" approach than presently used even in the social sciences may be necessary. These and similar areas would seem to be appropriate topics for an innovative high-quality interdisciplinary regional center or centers, in whose management the concerned countries participated. Support of such a center or centers through the World Consultative Group would be appropriate for AID; however, objectives and program of such a center or centers should be sharply focused and clearly defined.

PART I

RESEARCH NEEDS ON ON-FARM WATER MANAGEMENT

CHAPTER I

INTRODUCTION

The Symposium which generated this report was organized in response to several considerations. In general, water management at the farm level appears to many as the single most important constraint to increased food production in many developing countries. There is evidence that the Green Revolution has been most successful where conditions of good water management exist. Unfortunately, achieving improved on-farm water management appears to be one of the most intractable of development problems on both irrigated and rainfed areas.

Development and Purpose of the Symposium

AID's Technical Assistance Bureau (TAB) initiated research in on-farm water management in 1968-69 using central AID funds at a level of about $1,000,000 per year through contracts with Utah State University and Colorado State University. Institutional development grants were made to these two institutions in 1969 in the amount of $750,000 each and to University of Arizona at the level of $375,000. This program is summarized in Chapter III.5 and reported in considerable detail in Chapter VIII.

A meeting of AID's water management consultants, held at Rosslyn, Virginia, March 22-23, 1973, confirmed the need for an in-depth examination of the entire problem of on-farm water management globally and AID's response to it. The group recommended that an international Symposium be scheduled for Autumn 1973 and stated guidelines for the study to be made. Minutes of this meeting are contained in Appendix B of this report. Based on these recommendations AID's Technical Assistance Bureau staff developed additional program details and arranged with Utah State University, through its International Programs Division, to administer the Symposium at Park City, Utah, October 1-8, 1973.

Purpose and objectives

The purpose of the Symposium was identified as follows:

> Thoroughly evaluate the agricultural water management problems of the developing countries taking into account the present research information that is available not only in AID projects but to other projects and see how this fits into a world network to identify the gaps; and, secondly, to focus upon the inter-relationships of the Colorado and Utah water project and how these relate to supporting each other's objectives and how the findings are applicable to similar problems among the various LDCs.

Its principal objectives were to answer the following questions with regard to research on farm water management for both irrigated and rainfed agriculture:

1. What is the present status of knowledge throughout the world with respect to on-farm water management problems?

2. How is this knowledge being applied throughout the developing world and what are the major lacks of knowledge for its adoption?

3. Who is doing what to help solve the remaining problems?

4. Are there breakthroughs which can be general or are all water problems site specific?

5. If there are generalizable problems, how may these be approached in an interdisciplinary framework as needed?

Structure and Content of the Symposium

In order to serve its objectives, one day, beginning on Monday, October 1, was devoted to each of the following topics:

1. In what phases of water management are we adequate or deficient in knowledge?

2. What is the nature of research to be done and where and how to conduct it?

3. How can results be implemented in the less-developed countries?

4. What are the constraining problems?

The fifth day, Friday, considered AID's centrally-funded program. Over the weekend, panels with a chairman and a rapporteur appointed for each topic, prepared their reports. These were presented on Monday morning, October 8. During the afternoon a sixth panel outlined the content of the Symposium's summary and recommendations, Chapter II.

During each morning of the first week, prepared position or background papers were presented on the day's topic. Following this, the general session recessed until 3:00 p.m. to provide time for panel meetings, individual study, and informal discussions. During the first hour of the afternoon session the panel presented its views, which were then discussed by the entire symposium. Evenings were available for panel meetings and individual study and discussion. The pattern for the final day deviated in that the morning was devoted to reports of each of the five panels and the afternoon to general discussion. Several weeks prior to the symposium each participant was provided with an advance prospectus suggesting some of the major issues and questions, and outlining the proposed program. This was followed by a "Guidelines for Speakers and Panelists" (Appendix A).

Invitations to participate were issued to specialists from: 1) Developing countries, *5*; 2) international agencies, foundations, and development banks, *6*; 3) AID regions and TAB staff, *10*; 4) consultants, *15*; 5) university contractors, *14*; and 6) observers, *2*, from interested agencies. The number in italics in each case is the number (totaling *52*) who attended in each category. Because of close program ties, university representatives and the TAB program director concerned with AID's tropical soils program and with dryland crops (Hawaii and Oregon State) were also invited, presented background papers, and participated in the discussions.

Persons from developing countries did not *represent* their respective countries, but came as invited individual specialists.

Within the overall group were specialists whose present residencies include the following countries: Argentina, Bangladesh, India, Israel, Jordan, Pakistan, Peru, Philippines, Sudan, and Turkey as well as United States, so that fairly good geographical coverage was achieved. Also represented were FAO, World Bank, Asian Development Bank, Organization of American States, and Rockefeller Foundation; and AID's African, Latin American, and Asian Bureaus, and Office of Engineering as well as TAB. Three members of AID's Research Advisory Committee (RAC) also were present. A full list of participants appears in Appendix D.

Opening Session

Dr. Omer J. Kelley, General Chairman, called the Symposium to order. He stated that the reasons for the conference were as follows:

1. AID's interest in the Symposium is in order to optimize its own program of centrally-funded research. Dr. Kelley referred to the development grants (and research contracts) mentioned earlier and also stated that under the research program Utah State University is emphasizing work in Latin America; Colorado State University, principally in Pakistan, but also in Vietnam. AID would like to know whether or not they are pursuing reasonably optimum lines and how their efforts might be improved. Dr. Kelley referred participants to the guidelines for the Symposium (Appendix A) for more detailed information on the specific nature of the questions to be considered.

2. The World Consultative Group on Agriculture has had before it three successive reports on what should be done by them in terms of international agricultural water management efforts. So far they have not visualized a way to get a hold on the problems. Hopefully this Symposium may lead to some suggestions that would be useful to that group and to a valid and useful international effort.

3. Centrally-funded research in AID is subject to internal reviews, including review by its Research Advisory Committee of outside scientists. This Committee has raised various questions with regard to AID's centrally-funded program in agricultural water management. It is hoped that this Symposium will develop a background of information against which this program may be better evaluated by these reviewers.

Dr. Kelley pointed out that AID's centrally-funded research needed to be of general rather than country-specific interest. The important question, therefore, is the degree to which centrally-funded research results are transferable to other sites. All of AID's research is not done under its centrally-funded program. Research that is specific to countries may be funded by the AID missions.

Organization of the Report

The report is organized in two parts and an appendix. Chapter II provides an overall summary of recommendations and suggestions; Chapter III contains the reports of each of the five panels. Part II (Chapter IV to VIII) comprises the background or position papers, by chapters, prepared for each day's discussion.

CHAPTER II

SUMMARY AND RECOMMENDATIONS

This chapter contains a summary of recom- ıendations based principally on the five reports prepared y the discussion panels on the analytical questions and ›pics identified in the Introduction (Chapter I) as escribing the Symposium's stated "Purpose." The sum- ıary is organized in three parts; general recommendations 'e given first, followed by those relating to AID's rogram of centrally-funded research. The recom- ıendations are followed by a discussion of the five uestions describing the purpose and objectives of the ymposium, Chapter I.

General Recommendations

The five summary reports from which the following commendations are drawn are contained in Chapter III. ısically, the recommendations are problem-oriented and dged to be of importance to improve on-farm water anagement in both irrigated and rainfed agriculture. ıe research identified is, in general, of importance to ımerous of the developing countries and the results ould be generalizable. However, *implementation* of the sults will often be site-specific in which local conditions ıst be carefully considered. The reader should refer to e various panel reports (Chapter III) and the background pers (Part II) for more details.

The discussions brought out the important con- eration that on-farm water management options are bedded in large multi-dimensioned systems that limit e range and scope of decisions that the farmer can ıke for himself. Moreover, these systems in general, multi-objective in which improved water management even agricultural production may be missing or occupy condary, or at best, parallel positions in the objective Considering this embedment, some of the Panels' ommendations deal with the general system and thus y *appear* to have little to do with *on-farm water nagement*. This is not the case. Without relaxation of ne of the contextual constraints, efforts to improve ter management can be frustrating.

In what phases of water management are we adequate or deficient in knowledge? Priority research needs were identified as follows:

logical and physical framework

1. Improve the understanding of the physiological ›onses of plants to environmental stresses of water. salinity, temperature, and their interactions under field conditions. Particular emphasis should be given to methods of generalizing research data and to methods of transferring general information to field problems which are site-specific.

2. Obtain improved knowledge of the inter-relationships between water and other inputs in order to optimize crop production. This information is needed for both irrigated and rainfed agriculture.

3. Study methods for transferring crop productivity information geographically by systematically organizing or modeling the collection, storage, and retrieval of information and considering physiological theory on crop responses to stress and interrelationships between water and management inputs.

4. Develop improved design for on-farm irrigation systems and means for implementing them which are readily adaptable to countries with limited resources. This need includes improved design of simple and economic irrigation and drainage systems, economic structures for water control, and land forming.

5. Develop improved production systems, including appropriate technology and plant breeding, and a much better understanding of climatic risk and microclimate modification for *rainfed* agriculture.

6. Improve the predictability of quantity and quality of surface and subsurface water supplies, and evapo-transpiration. Develop better engineering procedures for water collection, storage and delivery systems, and general drainage systems that are responsive to optimal on-farm water management needs.

Social and institutional framework

7. Develop a systematic methodology to help iden-tify critical technological innovations or systems to promote the most rapid and efficient advances for a given set of conditions. Both comprehensive and simplified models are needed to predict the effects of environment, "inputs," and management factors, both under the farmer's control and external, at a given site under varying conditions or levels of husbandry.

8. Develop improved systems to "deliver" or facili-tate the adoption of appropriate new water management technology in developing countries. This need for better

"social delivery systems" for new water management technology is considered very important.

9. Evaluate factors which influence motivation for farmers to change to improved water management practices. Particular emphasis should be given to the various incentives and disincentives, including sociological and economic ones, to determine how these incentives can be used to facilitate a desired change and how incentive policy may be developed and implemented.

10. Determine effective ways to involve farmers in planning and management of water distribution systems. This relates to the need to make the farmer more aware that water is a manageable resource and for him to understand what he can do to facilitate better on-farm water management.

11. Develop approaches to modern water laws that consider unique needs under various cultures and other conditions in developing countries. These are needed in relation to water rights, water storage, delivery systems, watersheds with international boundaries, and related questions. Special attention should be given to effective methods of administration of water laws.

12. Improve predictive capability and criteria for assessing economic consequences of water management and utilization systems including costs and returns from alternative approaches and consideration of choices between building new or enlarged systems or improving existing ones.

13. Develop generalized information and predictive techniques for examining socio-economic problems associated with changing water management technology. In some respects this relates to "incentives," but is oriented toward collective rather than individual implications.

The Panel noted that water management involves a hierarchical system in which each level depends upon, but doesn't control, the sufficiency of the next higher level. It stressed the need for understanding and dealing with the entire system, but confined its recommendations to the specific topic of *on-farm* water management. The Panel expressed the strong need for better water measurement.

The Panel recognized that the above list is not complete but does define the principal limits of our knowledge.

2. *How can results be implemented in developing countries?* (Chapter III.2)

The general order for implementing an on-farm water management program consists of the following steps, according to the Panel:

1. Develop desire or demand for water management.
2. Set up institutions and training programs.
3. Set up and operate test and demonstration activities.
4. Initiate on-farm activities complete with technical and financial assistance.
5. Accelerate the application of programs and financial institutions.

The following are necessary elements implicit in a successful program of implementation:

1. Timely and adequate water deliveries to the headgate.
2. Appropriate on-farm irrigation, drainage, and road system installations.
3. Water applications made in an efficient and timely manner.
4. Drainage facilities to remove excess irrigation and/or rainwater.

Necessary national strategic factors that have to be present are: 1) Commitment, 2) mobilization, 3) trial areas, 4) installation of facilities, 5) finance, and 6) supplemental services. Details are described more fully in Chapter III.2.

The Panel recommends research on the following topics in order to develop the "know how" to improve and accelerate implementation of good on-farm water management programs:

1. Developing better means for gaining political and administrative support and popular demand.

2. Determining the most effective level and structure of the central control authority for generating the institutional development, including bridging the gap between agency activities dealing with project works and those dealing with agricultural activities.

3. Optimizing the selection process for choosing the initial trial area programs.

4. Estimating manpower and training needs for the design and implementation of the on-farm programs.

5. Gaining the farm community's acceptance of the proposed programs with particular attention to demonstration, educational needs, and incentives.

6. Evaluating "the response" beginning as near as possible to the embryo stages of all phases of development and guiding the course of activities accordingly. Without early evaluation, continued ineffective courses of action may greatly delay progress if not kill the entire program.

7. Reviewing the opportunities for forming custom operator enterprises to construct on-farm management works and determining their training, equipment, and financial requirements.

8. Investigating the need for forming representative bodies which provide links among the canal and tubewell operating and maintenance authorities and the water users, the agricultural advisory services, and possibly the farmers' credit institutions with the objective of obtaining the most effective distribution and profitable use of the available water resource within a canal command.

9. Reviewing the statutory regulations and laws available to insure that the implementing authority has all of the necessary powers for access to and acquisition of land where necessary for effective and economical construction of on-farm water management works as approved by the majority of beneficiaries.

10. Determining the irrigation and drainage techniques and inventing new ones which are best adapted along with suitable alternatives.

11. Identifying the most successful mechanism for financing (and organizing the social and physical structure of) on-farm works under varying host country conditions.

12. Developing appropriate environmental considerations and statements for developing countries having differing needs and viewpoints.

3. *What is the nature of the research to be done and where and how should it be conducted?* (Chapter III.3)

The Panel suggested four classes of research depending on level of control of the variables and empirical and fundamental nature of the problems. Generally, the more site-specific and empirical the research the less it is generalizable, although specific research at one site may be integrated into more general predictive models or concepts involving data at a number of sites. This research classification system is shown in Table 1, Chapter III.3. The Panel gave examples of research falling under each of the classes.

Dr. J. Montgomery suggested three sequential steps in decision making that need to be considered in defining research purposes: 1) Technological systems, 2) delivery systems, and 3) incentives.

Recommendations of the Panel are summarized[1] as follows:

1. AID needs to insure that the generalized research necessary for it to accomplish its mission of increasing food production is somehow accomplished. Thus centrally-funded AID research on on-farm water management should concentrate in areas having a medium or low level of empiricism including predictive systems models and delivery systems. Specialized advanced technological research could be done by specialized centers and strictly site-specific research left to Mission sponsorship. Centrally-funded research should also support research at specific sites in order to obtain information for generalizable systems; conversely, by advance definition of variables to be measured and their standardization, site-specific research could provide much information useful for generalization. AID central-funding should support research on advanced systems analysis including models for cultural and institutional processes, and incentives, either directly or through international centers as appropriate.

2. Scientists and engineers should provide a series of alternatives and consequences to the decision makers, and furnish well-designed, practical, and economically desirable alternative research solutions to the present practice of individual farmers.

3. Deficiency in research and needed research should be determined by a rational and systematic approach.

4. Models using systems analysis seem to provide hope for more rational understanding of complex research problems. However, care should be taken to insure the practicability and limitations of such models so that results obtained from systems analysis will not be misinterpreted.

5. A productive research effort is possible by coordinating university research centers with university extension services and field project offices, integrating all efforts and emphasizing problem oriented research.

6. Institutional and socio-political problems are complex and intangible. They are least understood, but often produce road blocks to implementation of water management programs. Research is much needed in this area

7. Regional water-management research centers with specific problem-oriented objectives should be estab-

[1]In order to avoid going into fairly lengthy discussion of research classes, these recommendations have been paraphrased somewhat from the way they are worded in Chapter III.3.

lished where common regional problems exist and where research can be conducted most effectively. Such centers would have the additional benefit that they will focus regional research activities and also serve as delivery systems for technological solutions to water management problems of developing countries.

8. All of the 13 topics identified by Panel I are appropriate for AID central funding. In some cases, Mission-funding would be appropriate, under the guidelines indicated in Recommendation 1. Items 8, 9, and 10 of Panel I can probably best be researched through regional institutional centers; Items 7, 11, 3, 5, 6, 12, and 13 either by centrally-funded AID projects or through such centers or both. Centrally-funded research on Items 1, 2, and 4 should lead to generation of data under a full spectrum of developing country environments (some of this also could be done by AID missions, countries, or international agencies), and should be responsive to needs for systematic transfer of this information.

4. What are the constraining problems in conducting and implementing research? (Chapter III.4)

The Panel gained the impression that constraints often were administrative, institutional, and economic resulting from traditional attitudes. It felt that some of these problems are researchable. *It identified the shortage of trained personnel as the major constraint to successful conduct and application of research* and stressed training in order to develop an appreciation of the need and opportunity for improvement, as well as for development of specific scientific fields and manual skills. AID appears to be in a good position to develop both third-country and host-country training efforts.

The recommendations made do not cover research in the traditional sense, but identify some of the problems that must be solved if new concepts of on-farm water management are to be implemented readily. They have been shortened and paraphrased from Chapter III.4 in the summary following.

Conduct of Research

Physical and biological framework

1. Continue the use of bilateral survey teams as a first step in evaluating the scientific aspects of specific development problems.

2. Use highly qualified scientists (donor and host nationals) for participation in all University and Mission field party programs.

3. Determine priorities for AID-supported research based on prior field evaluation of actual water management practices and of environmental constraints, and with the objective of increased production.

4. Encourage regularized climatological, resource, crop, and marketing data collection and reporting.

5. Develop and encourage the use of conceptual models for problem identification and interaction of crop and environmental factors as guides for research problem selection.

Economic and social framework

6. Recognize problems of logistic support at all levels and develop more responsive procedures.

7. Emphasize case studies and cross-cultural analysis of research management modes.

8. Motivation of research scientists and administrators in developing countries is in itself a proper subject for research.

9. Increase advance coordination of international and bilateral assistance relating to research.

Application of Research Results

Physical and biological framework

10. Attempt to combine research information and resource data into systems of cropping practices prior to initiation of extensive programs of application.

Economic and social framework

11. Involve the farmer, as appropriate, in determining the objectives of the development projects from which he is supposed to benefit, including the specific measures which directly affect his land.

12. Crop insurance, guarantees, credit, and other methods of providing "risk insurance" should be considered during the first years in order to encourage adoption of new agricultural methods.

13. Land consolidation policies should be clearly stated. When established, these should be implemented without delay in order to avoid uncertainties in the minds of the farmers.

14. Additional emphasis should be given to study of the means to overcome social and cultural constraints to cooperation and innovation.

15. Competence and skill at the governmental policy level to deal with problems of national planning priorities and administration of programs should be developed.

16. Particular attention should be given to the development of cadres with the *complete* set of skills

needed to implement agricultural and on-farm water management programs. Personnel at all levels of needed skill should be trained simultaneously for the needs of a particular project. This "horizontal" approach is recommended as an alternative to "vertical" training schemes in which only the highest levels are trained. Nationals who have not had the full range of experience nor developed all the skills needed in implementing a project cannot properly train the sub-professionals and skilled laborers.

General comments

There are many problems of on-farm water management or related ones that need research. Several of these problems are now being studied by various international research organizations and centers. These are not listed here. The research problems listed are not site-specific and the research suggested should be generalizable. However, the incorporation of research results into actual practices, implemented for improving on-farm water management will often be site-specific and/or culture-specific. Full cooperation of the individual farmer and all levels of government will be required for effective implementation of the results of the research.

AID's Centrally-funded Program of Research

The Colorado State University and Utah State University programs which constitute AID centrally-funded research program on on-farm water management, are described briefly in Chapter III.5, the Panel's report, and in more detail in Chapter VIII. In addition, institutional development grants, under Sec. 211(d) of the Foreign Assistance Act, have been made to Utah State University for on-farm water management; to Colorado State University for water delivery and removal systems and relevant institutional development, and to the University of Arizona for systems analysis of watershed management. The charge to the Panel was to consider the design, operation and coordination of the program; whether or not the priorities are correct; what changes in strategy, if any, might be desirable; and possible deficiencies in global research acquisition and knowledge delivery systems, and what might be appropriate for AID to do through Mission efforts and at the international level beyond its central-funding abilities.

1. Colorado State University (Pakistan and Vietnam)

Research efforts to date have delineated major irrigation water management problems. These are listed in Chapter III.5. Substantial progress has been made in identifying the real problems enabling CSU to sharpen and limit its research within important time-specific goals.

Recommendations

CSU should now concentrate on the development and testing of: a) Acceptable physical and institutional water course systems for adequate and equitable delivery of water, b) acceptable physical and institutional systems of scheduling irrigations, and c) the integration of good water management practices into workable, productive cropping systems. Concurrently, studies in Pakistan should be aimed at: a) Developing improved techniques for distributing water uniformly within fields while controlling salts and sodium, b) establishing better stands of summer crops, c) establishing irrigation-fertilizer responses for major crops, and d) developing techniques that will enable local specialists to deliver management services to farmers. Experiments that require economic and sociological interpretations should be coordinated with economists and sociologists during the planning stages.

General guidelines necessary to implement similar research/development programs elsewhere in other large irrigated areas, e.g., India, should be documented.

2. Utah State University (Latin America)

Accomplishments are listed in Chapter III.5. These include: Increasing yield by optimum combinations of water and other management practices; estimation of crop water requirements; water-table level and salinity control for fine-textured tropical soils; improvement of indigenous research institutions; effects of water rights laws; modeling physical results of water management changes; and optimizing economic alternatives. Experience has shown that each member of the USU field staff has had a major influence on the careers of two or three country nationals per year, that an additional one dozen or more receive significant profession development through face-to-face contacts and about one dozen more are influenced by occasional contacts.

Recommendations

USU should prepare research guides that will enable developing Latin American countries to delineate their own problems and conduct their own essential experiments. Existing mathematical models should be adopted, or developed, to enable predicting yield response functions for various crops under varying environmental and management practices. Guides for collecting the necessary field calibration data should be prepared to enable using the model in other areas of Latin America as well as in Pakistan and Southeast Asia. Components of water law structure that impair efficient water use should be identified and procedures suggested for their removal or change. USU should now concentrate on those objectives where it appears that greatest progress can be made, and particular emphasis should be given to generalizing results for use throughout Latin America.

3. Colorado State and Utah State Universities

Both institutions have made substantial progress on a number of components of soil and water management whose successful implementation will increase food production in the study countries and throughout the world based on further development of techniques and procedures having application to other areas.

Recommendations

In order not to cloud the issues with prospective plans, logistics, etc., progress reports by the contractors should contain a concise scientific progress section oriented toward the stated objectives, and showing and documenting scientific progress made during the reporting period.

4. Design, operation, and coordination of contracts

The Panel pointed out the importance of strong and experienced scientific leadership and of directing project components so that each reaches its attainable objective within the available-time framework, and recommended against starting related studies that could not be completed within the time framework for implementation. In addition to coordination at the project-leader level, research workers at the two institutions should discuss problems on a one to one basis, exchanging inputs as may be desirable.

5. Institutional development

Experience now gained should enable both USU and CSU to make a critical assessment of future deficiencies in on-farm water management competence. The University of Arizona watershed models may have transferable capabilities useful for on-farm water management.

6. Deficiencies in water management research acquisition and delivery systems

While encountering many difficulties in the early stages, both the CSU and USU contracts have gained sufficient momentum that they are just now reaching the period of potential payoff in terms of generalizable research, and identification of systems and procedures for increasing food production; although clarification of objectives, delineation of direction, and progress reporting need continuing improvement. The Panel believes the projects are moving in the right direction and their extension will increase the stature and ability of AID Missions and Bureaus to serve developing countries.

The Panel believes, that before initiating a comprehensive *new* research contract to solve a specific on-farm water management problem, AID should consider a contract to compile all pertinent available research and technology on the subject. Several examples, e.g., *Advances in Corn* and *Corn Production: Principles and Practices*, Iowa State University Press, are cited as models.

Another approach would be to contract with the best-qualified available contractor in terms of experience in the subject area, and possibly geographical area, to conduct such diagnostic research as may be needed to solve a specific problem. This could be followed by a Symposium to recommend follow-up research projects. Perhaps this approach might be considered as a first step toward increasing production in rainfed areas.

Objectives of the Symposium

In developing the prospectus for the Symposium the objective was defined by five questions. These questions were listed in Chapter I and are discussed in the material that follows.

1. What is the present status of knowledge throughout the world with respect to on-farm water management problems?

Considering that scientific on-farm water management 1) requires a synthesis of a number of interactive elements at the farm level in a reasonably optimal way, and 2) that farm level decision options are constrained by the contextural social delivery systems, the present status of knowledge is inadequate for developing countries. Systematic knowledge is largely related to conditions in the developed countries. There is a good central body of technical knowledge mainly pertinent to the temperate environments and crops. Some of this, but not all, is theoretically extendable to other soils and climates. Even this body of information is far from complete. There is much yet to be learned about water stress effects on plant physiology, for example, and the U.S. Salinity Laboratory is substantially revising concepts of salinity, leaching, and drainage that were accepted two decades ago. In actuality, methods of transferring physical and biological knowledge to other environments are generally in their infancy, although there are specific exceptions, e.g., evapotranspiration predictions, etc. In the western countries, particular technologies and social delivery systems have evolved under conditions of relatively great affluence. These systems have a too-little-recognized, but tremendous impact on what can be done on the farm. Little is known about how to adapt scientific knowledge and technology under different cultural conditions, or even how to insure that a viable context for change will exist.

2. How is this knowledge being applied throughout the world and what are the major lacks of knowledge for its adaption in the various parts of the world?

Scientific knowledge and technology is spread by many devices. An important one is through international education, another is through learned societies and their journals. FAO has utilized regional and country seminars to analyze problems and disseminate information on on-farm water management. (See Chapter V.2.) FAO also maintains literature files, provides bibliography, and recently has initiated a series of "Irrigation and Drainage Papers." A third device is through technical assistance in its various forms. Based on apparent results, application of knowledge of on-farm water management globally is generally poor and almost invariably very slow, but there are occasional bright spots, e.g., tubewell technology on the Asian Subcontinent.

Probably the major lack of knowledge for its adaptation is a failure to understand the complexity of the general systems in which improved water management must occur, if at all; and the lack of systematic and efficient methodologies for transferring knowledge to new physical and biological environments.

There is no methodology, nor little research on the transfer of institutional systems related to on-farm water management.

3. *Who is doing what to solve the remaining problem?*

Nearly every country has research stations working on physical and biological aspects of water management. Some of them, as India, are initiating pilot projects to integrate on-farm management into irrigation systems. Many organizations, some of them international: FAO, UNDP, the World Bank, and the Asian Development Bank, are sponsoring pilot or pioneer projects. There are a number of research stations, some of them international ones: U.S. Salinity Laboratory, IRRI, CIMMYT, etc., that are working on basic science and technology related to water management. On general systems and overall strategy, little is being done, but ADB is interested and has done some work in the Philippines. Some work is being done on farm delivery systems (watercourses) mostly in Pakistan through AID sponsorship. Ideas for transfer of crop production functions, vis-a-vis water management in a generalized sense are just now being conceptualized at USU, CSU, University of California and other universities mainly in the Western United States.

4. *Are there breakthroughs which can be general or are all water problems site specific?*

There can be general breakthroughs, but these cannot be predicted. The subject is not without promise. There certainly could be major breakthroughs in the systematic management of rainfed crops, or in the efficient transfer of crop production functions, for example. Invention of an inexpensive closed conduit for use in inter-farm distribution of water would help solve many difficult problems that severely limit productivity in the field. The general but essential elements of a hierarchical (individual, project, country) development and management system insuring good on-farm water management might be delineated.

Being mainly technological, the real payoff can probably be expected through incremental improvements under practice. The tubewell, for example, has had a significant impact in several developing countries during the past decade or so. In a sense, this is a breakthrough, but in implementation. The technology is centuries old, but continually being improved.

All water problems are, in part, site specific, but the knowledge to solve them is not. Trickle irrigation is a case in point. This now constitutes a reservoir of general technical knowledge and materials that has to be adapted to specific fields. But specific adaptation improves the general art. Much of water management knowledge has been, and will probably continue to be, inferred from, and quantized through, numbers of site-specific experiments, as well as from theory and sophisticated controlled experiments. Conceptual frameworks for generalizing physical and biological knowledge show promise.

5. *If there are generalizable problems, how may these be approached in an interdisciplinary framework as needed?*

Physical and biological framework

There is, of course, pertinent basic physical and biological research. There is no question about the generality of this.

There are arrays of knowledge around certain central ideas that are useful for problem solving, for example: *Evapotranspiration* in terms of climate and crop parameter; *crop productivity* in terms of soil, climate, moisture, etc., parameters.

The first example, evapotranspiration, involves representatives from many disciplines including at least physicists, plant physiologists, climatologists, meteorologists, agronomists, soil scientists, and engineers. Conceptual models have been developed based on certain physical and biological concepts and using empirical data. As these models have been tested under an expanding set of geographical conditions, their shortcomings have been noticed and the models refined until predictions of evapotranspiration can now be made with confidence. Temporal ranges of evapotranspiration at given sites and crops could have been determined by purely site-specific research for every site and crop. This would have been literally "exhaustive" and the experiments would not have led to understanding by themselves. On the other hand, experience in this field has shown that theory and centralized experimentation without extensive site testing gave predictions that were grossly in error.

These arrays of knowledge can be thought of as multi-dimensional response surfaces, they are mostly continuous and generally smooth. If the most influential parameters (dimensions) are known, the surface could be located simply by taking parametric data under widely varying conditions, but normally this blind empirical approach can be greatly improved by basic theory. In any case, extensive site testing cannot be avoided if the problem has substantial complexity. The approach to such systems would seem to have the following steps:

1. Defining what is the single thing to be predicted.

2. Thinking about and defining all of the variables that could influence the thing to be predicted and at the same time looking for theory that would help link the variables to the thing to be predicted.

3. Developing a conceptual model; i.e., postulate comprehensively how the various elements may be linked and in what sequence.

4. Refine the choice of variables and develop the linkages through theory insofar as possible and a series of experiments under widely varying conditions measuring *all* of the identified variables.

The paper by Keller et al., Chapter VII.5, is an attempt at doing the first three steps for a crop productivity model. While large conceptual models may appear overwhelming, parts of them can usually be disaggregated into simpler, more directly usable models.

In a very substantial way, the approach to the water laws problem is analogous but less formal. Here responses are qualitative and parameters include the substance and structure of the law.

Institutional and economic framework

At a different level some concepts of *social delivery systems,* i.e., the institutional array that embeds the farmer, or elements of them, ought to be generalizable. Most of the Panels identified serious constraints arising in this area (Chapter III.1, III.4, Chapter VII.5). Here however, the nature of the variables and their complexity is far less understood; moreover, the linkages are transient as people's values change under development or for other reasons. These problems, as they relate to on-farm water management, should be researchable, but the territory is quite unexplored. They probably will have to be approached on a case-history basis. Interdisciplinary teams could do this on a regional basis in which the countries whose interests are to be researched play leading roles. At least one regional international center ought to tackle research on these problems.

CHAPTER III

SUMMARY REPORTS

1.

DEFICIENCIES IN EXISTING KNOWLEDGE OF ON-FARM WATER MANAGEMENT PROGRAMS FOR DEVELOPING COUNTRIES

The following background papers were presented and provided the basis for discussions and some of the conclusions reached by the Panel:

In What Phases of Water Management Are We Adequate or Deficient in Knowledge? (Southeast Asia); Dr. Kunio Takase. Irrigation Project Manager, Asian Development Bank.

Deficiencies in Water Management Knowledge in Pakistan; Dr. J. B. Eckert, Agricultural Economist, CSU Field Party, Islamabad, Pakistan.

Comments on Irrigated Agriculture in Latin America; Eng. Augustin Merea, Coordinator of the Irrigation Program Istituto Interamericano de Ciencias. Agricolas OSA (IICA), Buenos Aires, Argentina.

Water Management in the Sudan; Osman Ahmed Ali Fadl and H. G. Farbrother, Senior Soil Physicist and Senior Plant Pathologist, respectively. Gezira Research Station, Wad Medani, Sudan.

General Knowledge Deficiencies; Amnon Golan and Cecil M. Bolt. World Bank, Washington, D.C.[1]

Discussion Panel:

- Ernest T. Smerdon, Chairman, University of Florida, Gainesville, Florida.
- M. L. Peterson, Rapporteur, University of California, Davis, California.
- A. Alvin Bishop, AID, Washington, D.C.
- G. L. Corey, Colorado State University, Islamabad Pakistan.
- Charles A. Breitenbach, AID, Washington, D.C.

Conclusions reached by the Panel were based on an excellent set of papers by specialists with first hand knowledge of problems in developing countries. The verbal presentation made by the Panel before the participants of the Symposium on Monday, October 1, has been modified as discussions through the week revealed further information. These discussions made clear that both lack of knowledge on technical agriculture and inadequacies in the delivery of information on water management are important deficiencies. The latter deficiency was cited by many speakers as a substantial reason for poor water management practices on the farm. Another limitation was motivation or incentives to accept new or transfer technology. In view of the importance of barriers to accepting new water management technology in developing countries, the Panel has added these problems to its list of knowledge deficiencies. It is apparent that techniques used for disseminating new agricultural technology in the United States is not necessarily effective in developing countries.

Deficiencies in knowledge as identified by the Panel have been organized under two categories: Physical and Biological, and Social and Institutional. It is recognized that research is in progress on nearly all problem areas indicated, either within AID's programs or elsewhere. Therefore, identification of a deficiency is relative, not absolute.

Deficiencies Within the Physical and Biological Framework

1. *Need for a better understanding of the physical responses of plants to stresses such as water, salinity, temperature, and the interaction of these factors.*

There has been much research at many locations on responses of different plants to stress. For this reason, some justification is needed for why we identify this as a knowledge deficient area. Only recently, have a few research workers attempted to collect data from numerous sources to derive generalizable formulas on plant responses. Much of the earlier collected data cannot be included because the workers were solving site-specific problems and failed to include in their publications all the information needed to develop general water response criteria. One aspect of water use that has received little attention is the optimization of water use in situations

[1] Presented orally only.

where land is more plentiful than water. Interactions of water with stage of plant development and with other stress factors or inputs such as fertilizer need further study. A thorough understanding of the physiological and physical forces in plant-water relations is fundamental to irrigation and to dry-land agriculture and should be a part of any comprehensive water management research program.

2. *A better knowledge of the interrelationships between water and other management factors to optimize production for both rainfed and irrigated crops.*

Water, whether applied as irrigation or as rainfall, interacts with numerous other production inputs. These include fertilizers, pest control, tillage practices, and any others which affect production. Earlier advances in agricultural production have come largely from single inputs. Future production increases will arise from the optimum combination of inputs for particular situations. Much is already known about optimizing inputs in irrigated agriculture.

Less is known about optimizing inputs in the more arid nonirrigated regions, and very little is known about the complex set of crop and resource interrelationships that constitute traditional farming systems. Because this represents so much of the world's agriculture the information need is considered very important.

3. *Study methods for transferring crop productivity information geographically by systematically organizing the collection, storage, and retrieval of information and consideration of physiological theory on crop responses to stress and interrelationships between water and management inputs.*

Presentation of research results at this Symposium indicated progress toward developing simulation models or information systems for productivity in terms of specific crops and environmental factors in nature or as modified by external inputs. Success will require obtaining data from many locations and different environments, and consideration of plant physiology. Data from the U.S. and other countries not within the target of AID's activities should be sought and included. These models should be very helpful in predicting water needs as well as identifying promising cropping and cultural systems. Additional basic data on plant responses to stress and management inputs are needed. Some of these answers reside in the disciplines of physics, biochemistry, etc., and research in these areas is apt to be both basic and long-range in nature.

4. *Need for improved on-farm irrigation systems including drainage, and means for developing them for countries with limited resources, including appropriate technology.*

Poor control of irrigation water on the farm has been mentioned repeatedly in this Symposium. Some participants have argued that the farmer is intelligent and has made rational decisions given the resources available to him. Resources which have limited him are knowledge of new technology, farm power, and equipment. Better information is needed on the design of irrigation, surface and subsurface drainage systems, particularly for small land holdings and simple inexpensive equipment adaptable to local power sources to level land, construct irrigation and drainage ditches, build levees, and to form planting beds for row crop agriculture. Flood irrigation is used in preference to furrow irrigation by many farmers who lack the means for making furrows and beds. The researchable problem in these situations is how to shape land for better water control. Participants at this Symposium have stated that nearly all farmers want to level their land for better water control. We need to devise methods applicable to their means. Other problems included under this category are on-farm structures for water control, canal linings, and the most efficient farm lay-outs. Advanced-country technology may not prove directly useful under indigenous economic and cultural conditions for handling the problems mentioned above. Such technology needs to be adapted carefully to these conditions, or new technology developed.

5. *Need for improved production systems, including appropriate technology and plant breeding, and for rainfed agriculture and a much better understanding of climatic risk and microclimate modification.*

While Topics 1, 2, and 3 apply equally to both irrigated and rainfed agriculture, considering relative areas of arable and potentially-arable land, increased emphasis should be given to those aspects of plant physiological stress and interrelationships between water and other management factors that apply to rainfed agriculture. Increased efforts toward characterizing climate and its time and space variability in relation to presently cultivated and potentially new crops and the use of climatic analogues for these areas are needed. Modification of microclimate utilizing physical barriers, windbreaks, and reflectants, etc., inter-row cropping of tall and short cultivars, etc., should be considered. Plant breeding or cultural techniques which could increase photosynthesis in relation to transpiration holds promise. Attention needs to be directed toward integrating crop, climate, and cultural factors into more efficient rainfed agricultural production systems.

6. *Need for improved predictability of quantity and quality of surface and subsurface water supplies, and evapotranspiration; including engineering procedures for water collection, storage and delivery systems, and general drainage systems that are responsive to optimal on-farm water management needs.*

Effective irrigation and surface and subsurface drainage requires an adequate basic water supply and a common physical system capable of delivering water as needed and removing it when it is in excess. On-farm water management requires a good understanding of the basic water supply and its variation as well as a knowledge of evapotranspiration requirements. Recent developments in hydrological and watershed modeling show great promise for predicting available water supplies, including both quantity and quality, taking into account complex climatic and cultural variations. Any water storage and distribution system is limited by the vagaries of supply and the physical laws of hydraulics; however, technology and procedures which could lead to designs that are more responsive to on-farm needs should be given increased interdisciplinary attention by agriculturists and engineers.

Deficiencies Within the Social and Institutional Framework

7. *Identification of the critical technological innovations or systems to promote the most rapid and efficient advances for a given set of conditions.*

The primary decision facing a research worker is identification of the critical problem. The wrong choice at this point can result in a serious loss of time and resources. One of the participants at the Symposium referred to this as "technological forecasting." Decisions must be made regarding which dimensions of a technological system to choose. Such decisions require observations and analyses of the problems, the available resources, and choosing among several options and sequences in solving component parts of the problem.

The informational deficiency is in devising a generalized method by which research workers in the field can systematically approach the problem of making technological choices in any given situation. Keller Peterson, and Peterson[2] have addressed this problem with a suggested computerized model to predict crop production functions for changing environmental conditions. The model should be perfected and tested. Under field situations, technological choices need to be made on-the-spot. Therefore, a more simplified method is needed for field identification of "husbandry programs" related to crop production. This can be described as a generalized approach to specific problems and therefore appropriate for AID central research funds.

8. *Improved systems for delivery of new technology on water management in developing countries.*

Frequent references in this Symposium to failures in gaining adoption of new irrigation and water management technology leads to the conclusion that we do not know how to do this job efficiently. The channels through which new technology is delivered were the subject of considerable discussion and differing opinions. An example is the problem of land leveling. Opinions differed as to whether land leveling should be done as a part of a development project and charged to the farmer or left for the farmer to do on his own with or without credit and technical advice. Choice of an appropriate technology delivery system is a researchable problem. Effectiveness of a delivery system may differ with the technology to be delivered and the culture within which the system operates. To this extent the solution is site-specific but the factors to take into consideration in this choice are generalized. The Panel believes this deficiency in our knowledge is very important and that research on delivery of new technology is urgent.

9. *Incentives or motivations for change.*

Additional knowledge is needed on what factors influence motivation for change within the system and from the viewpoint of the farmer. This problem is related to delivery systems for new technology. We identify it separately because of its importance. Motivations may relate to external factors such as economic considerations, legal or political influences, or to personal incentives. Included are economic, historical, cultural, and educational factors or religious beliefs and personality variables. Motivations or incentives may be culture-specific but an understanding of what motivates people to accept change can help to narrow the gap between knowledge and practice. This problem is obviously researchable and important.

10. *Involvement of farmers in planning and management of water distribution systems.*

Statements were frequently made in this Symposium that farmers do not realize that water is a manageable resource. The reason for this is that many options for management decisions have been eliminated by the time water reaches the farms. Those responsible for water delivery systems consider their responsibilities discharged if water is delivered to the farm on an equitable basis. Although water delivery may be equitable, it may not be in harmony with crop demands. In cases cited at this Symposium, the delivery systems are incapable of meeting peak demands and so compromises are required. Data are available to determine estimates of optimum productivity of water by crops. Even though this information is far from perfect, it can be used to derive formulas for optimization of land and water resources use, given the limitations of a delivery system.

Optimization procedures cannot be employed except through working with all the farmers receiving water from a delivery system. Research is needed in devising appropriate water-user organizations for purposes of formulating needs, communicating these needs to policy

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[2] "A strategy for optimizing research on agricultural systems involving water management." J. Keller, D. F. Peterson, and H. B. Peterson. Chapter VI.4.

makers in the delivery system and for striking the compromises to optimize water productivity for food production. Organizational structures may need to be different for various cultures but the principles can be generalized.

11. Water laws and regulations that are in harmony with modern water storage and delivery systems.

Water laws in nearly all countries including the United States need up-dating in relation to making optimum use of water for society as a whole. Water laws and traditions were devised at a time when equitability was viewed in a different framework than exists today. An example in the U.S. is the conflict in water rights between states when the watershed crosses state and national boundaries. Similar conflicts arise between individual users and between those adjacent and those not adjacent to stream channels. As water becomes increasingly scarce in relation to needs, justice in distribution takes on a new dimension.

Information presented in this Symposium indicated considerable research activity in collecting water laws from different countries and comparing their features. We believe this is a very important research activity that should be helpful to policy makers and politicians in modernizing water laws and also improving the effectiveness of administering these laws. We indicate this as a knowledge deficiency area because the work is not complete and, in fact, requires a continuous effort. It may be impractical to consider model water laws to fit different countries, but such models could point out the considerations involved in the maximum productivity of water for food production. Models also should give attention to water rights problems when a watershed crosses international boundaries.

12. Economic consequences of water management and utilization systems including costs and returns from alternative approaches.

Economic benefits at individual and national levels need to be assessed for various alternative approaches to water management. Included also should be choices between developing new or enlarged systems and improving efficiencies of existing water collection, storage, delivery, and farm water utilization techniques, including possibilities for reducing losses in existing systems.

13. Socio-economic problems associated with changing water management technology.

More knowledge is needed on the economic and social implications of developing new or improving existing water distribution and management systems. Governments and lending agencies require information on costs and returns from different water application methods, economic benefits from more precise land grading, and costs and returns from tubewells under different management situations. Improved water technology will not only increase food production but it is expected to improve rural income, increase demand for production inputs and employment on both farm and in service and supply industries. Information is needed to predict the effects of these technological inputs on income, income distribution, employment, and the overall social consequences of these economic factors.

General Comments

This Symposium is concerned with on-farm water management. The problems of water management are linked to a system in which there is a hierarchy of problem areas. Watershed management, water impoundment, power generation, water delivery, on-farm water management, and drainage all are part of an interlocking system. It was not within the scope of this Symposium to consider problems of the entire system but there are obvious constraints imposed on any segment by the one immediately above in the system. We believe that where these constraints are particularly serious, as they are with water delivery schedules to farmers, some attention must be given to management of that system. An analogy might be useful. Labor unions in the United States continuously research the management and profits of the industries they serve. This strengthens their bargaining position. Similarly, research of water delivery systems may reveal opportunities for adjustments to help solve on-farm water problems.

Farmers, if organized to express their collective needs, would indeed be in a weak position if the water currently delivered to them was not efficiently used. Consequently, it is in their own self-interest to know the efficiency of their own system. This requires measurements of water deliveries, percolation losses, drainage, etc. A need exists for making these measurements, probably confined to a section of a water system or by farm sampling procedures. Although this is not actually a research activity, it is information vital to identification and selection of high priority research.

The Panel does not believe the above list of knowledge deficiencies is complete. It does believe the principal limits of our knowledge have been identified and should be useful in designing a comprehensive program of research.

2.

IMPLEMENTATION OF NEW AND EXISTING KNOWLEDGE OF ON-FARM WATER MANAGEMENT PROGRAMS FOR DEVELOPING COUNTRIES

The strategy which is presented is basically a summary of the following presentations, floor discussions and the Panel's input:

Implementation of Water Management Programmes in Canal Irrigated Areas; B. B. Vohra, Joint Secretary, Ministry of Agriculture, India.

A Worldwide View of Implementation of Improved Water Management; Clyde Houston and Michel Grehan, Chief and Senior Officer respectively, Water Resources and Development Service, FAO, Rome, Italy.

Implementation of Water Management in Turkey; Kaya Bozkurt, Regional Director, TOPRAKSU, Izmir, Turkey.

Implementation of Water Management in Southeast Asia (Philippine Case); Kunio Takase, Irrigation Project Manager, Asian Development Bank, Philippines.

Discussion Panel:

Carl Anderson, Chairman, U.S. Soil Conservation Service, Washington, D.C.
Jack Keller, Rapporteur, Utah State University, Logan, Utah.
Leland Anderson, Agency for International Development, Pakistan.
Arturo Cornejo, Ministry of Agriculture, Peru.
C. M. Bolt, Senior Engineer, World Bank, Washington, D.C.
Osman Ahmed Ali Fadl, Senior Soil Physicist, Sudan.

Order of Implementation

The general order of implementation suggested was:

1. Development of desire or demand for water management.

2. Set up of institutions and training programs.

3. Test and demonstration activities.

4. Initiation of the on-farm activities complete with technical and financial assistance.

5. Accelerate the application of programs and financial institutions.

The authors of the papers presented the results of activities in their areas of experience. Many good suggestions were also received from Panel members and other Symposium participants. The following recommendations were developed from these varied experiences as being the most effective strategies of implementation. One should note that all projects and implementations of new programs do not start at the same stage of development. However, the areas of concern listed will have already been partly carried out or will have to be considered in the implementation of any program of on-farm water management. While the material that follows deals more specifically with irrigated agriculture, the same general processes apply to rainfed programs.

Elements of an Effective On-farm Water Management Program

The purpose of on-farm water management programs is to increase farm incomes and the agricultural productivity of water. The following items are implicit elements of an effective program:

1. Timely and adequate water deliveries to the headgate. A roster system (delivery schedule) for water distribution to individual farms should be provided.

2. Appropriate on-farm irrigation, drainage, and road system design and installation. This includes such items as land leveling and land shaping, on-farm ditch lining, sprinkler equipment, measurement, field distribution, and field application facilities.

3. Water applications made in an efficient and timely manner.

4. Drainage facilities (intermediate and main drains to connect with field drains) to remove excess irrigation and/or rainwater.

The synthesized strategy for implementing on-farm water management programs is laid out in the following six stages. As implementation passes through the stages there needs to be a continuous evaluation of "the response" complete with feedback and adjustments as needed. Other elements common to all stages are competent personnel and adequate financing.

Strategy for Implementing On-farm Water Management Programs

Commitment

First, the value of on-farm water management programs must be demonstrated in order to obtain acceptance. Often on-farm water management programs involve a major portion of the agricultural sector budget of the host country. Therefore, the groundwork must be carefully laid to obtain citizen support and a commitment from public officials. A crisis is often the triggering mechanism for initiating the on-farm water management program. However, the decision makers must be informed of the potentials of the program before a favorable response can be expected. This can be done through observation and consultation tours in developed countries, by means of suitably-devised literature, or by both. Part of the groundwork-laying process involves preliminary (technical, economic and social) feasibility studies. Once a favorable policy decision is near, a more complete feasibility study and the establishment of goals are necessary. Development of feasibility studies involves the search for and/or training of competent personnel. Sometimes demonstration activities are also needed to illustrate the possibilities of the proposed programs.

As soon as budgeting allocations have been made and the organization has been outlined, training facilities should be established and associated appointments made.

Mobilization

A coordinating central authority should be established at the irrigation command level to develop the "institutional" framework for establishing the on-farm water management program. This may involve drawing existing agencies together to operate in an integrated manner and/or the creation of new agencies. The program typically involves agencies dealing with public works, resource inventories, agriculture, marketing, finance, social services, and administration.

Important initial activities of the authority are:

1. Assessing the capabilities of existing (or proposed) irrigation and drainage work and outlining potential improvements.

2. Carrying out of adequate soil, topographic, cadastral, ownership, and resource surveys.

3. Collection of adequate climatic and crop data.

4. Preliminary development of the trial area programs including the above technical inputs as well as anticipated farmer response to incentives.

Trial areas

The purpose of trial areas is to develop and establish suitable design criteria for on-farm water management programs. The test areas can range from government-owned and operated pilot farms or experimental stations to field trials made in collaboration with local farmers. Technical assistance must be adequate to insure proper installation of such trials with follow-up programs.

Once the on-farm water management program criteria have been established, the existing (or proposed) irrigation and drainage works should be checked against the program requirements. Needed improvements or modifications must be scheduled in phase with the installation of on-farm water management practices. The initial staff required for installation of the practices may be trained at the trial areas. Major budgeting allocations become necessary at this stage and the strategy and schedule for installation must be established.

Installation

The installation phase of the on-farm water management program follows the construction of necessary major (project) irrigation and drainage works without delay and includes the design and installation of farm facilities and the successful application of improved practices. The success of the program depends upon its general acceptance by the farm community.

Improved on-farm water management practices must be observed by farmers before one can expect their acceptance. Therefore, "demonstration farms" must be set up. Typically these farms are the original trial areas with satellite units. The nature of the demonstration process will depend upon local circumstances. Such items as communications, farm size, land ownership, and previous irrigation or farming experience must be considered.

Adequate training programs for engineering and agricultural management advisory services are absolutely essential for success. Training of engineering aides and other sub-professional personnel must be included in the program. It has been frequently demonstrated that the installation of on-farm water management programs which are left to the farmers own devices and financial resources are unsatisfactory. Typically, such programs are excessively slow to develop, usually of marginal quality, and developed in a random manner. Therefore, it is essential that adequate numbers of competent personnel be assigned to the installation phase of the on-farm water management program. This includes the on-farm application of water after the irrigation facilities (such as land leveling) have been installed.

Finance

For the successful implementation of the on-farm water management program governmental financial resources are not only required for the major construction works, but contrary to common practice, also as advances for constructing on-farm works. Financing is also required for modification of existing delivery systems, outlets, and for the provision of intermediate and main drains. When institutional funds cannot be arranged for on-farm works, such funds must be provided through governmental financial resources Recovery of these advances would be through normal revenue channels or as betterment tax or water charges.

For new projects, it is suggested that on-farm works be included as part of the project works, subject to the criteria established in the trial areas. The unit of construction should include at least the entire area served by an outlet. For economy of scale, several outlets may be grouped together when this is possible.

On existing projects it is suggested that the farmers served by each outlet form "an association" by majority consent. A new irrigation and drainage plan (and when necessary, a land-leveling plan) should then be prepared for the outlet area by the authority and presented to the farmers for their comments or approval. After approval, work will be carried out by the authority and costs recovered through revenue channels.

The on-farm irrigation and drainage system designs, construction techniques, and the mix of equipment and labor employed will vary with the conditions and local resources available. There is a need here for investigating alternatives, developing new concepts, and determining the least cost approach.

Supplemental services

Implicit in the success of all development programs are the essential supplemental services for both the construction phase and the operational phase. Farm to market roads and access to irrigation and drainage works for operation and maintenance are essential Storage and handling of agricultural inputs and outputs and marketing facilities are also necessary. So also are the organization of credit and other inputs required by the farmers.

It has been recommended that the agency which is responsible for the irrigation and drainage system operation and maintenance should also be competent to provide the agricultural advisory service. Field personnel should be members of the community and have incentives which are compatible with the success of the on-farm water management program.

The authority should monitor "the response" and develop the needed tools for this endeavor. They should keep under review the beneficiaries' capacity to repay for water supplies as well as the operational and maintenance costs of the system.

Specific Areas for Research

Specific areas for research which are relevant to on-farm water management program development are:

1. Developing better means for gaining political and administrative support and popular demand.

2. Determining the most effective level and structure of the central control authority for the institutional development. Of prime importance here is the means for bridging the gap between agency activities dealing with project works and agricultural activities at and beyond the farm level.

3. Optimizing the selection process for choosing the initial trial area programs. This area of activity will no doubt be dealt with and expanded upon in other Panel reports.

4. Estimating manpower and training needs for the design and implementation of the on-farm programs giving specific attention to logistics, facilities, and equipment.

5. Gaining the farm communities' acceptance of the proposed programs with particular attention to demonstration and educational requirements coupled with a viable incentive package. The incentive package needs to induce group action by overcoming temporary losses due to construction activities, resistance to boundary realignment, and reluctance to change.

6. Evaluating "the response" beginning as near as possible to the embryo stages of all phases of development and guiding the course of activities accordingly. Early response evaluation is essential to efficient development; without it continued ineffective courses of action may greatly delay progress if not kill the entire program.

7. Reviewing the opportunities for forming custom operator enterprises to construct on-farm water management works where government authority forces require supplementary capacity; and determining the training, equipment, and financial requirements of such custom enterprises for their successful introduction.

8. Investigating the need for forming representative bodies to establish a link between the main (project) canal or tubewell operating and maintenance authorities and the water users, the agricultural advisory services, and possibly the farmers credit institutions, with the objective of obtaining the most effective distribution and profitable use of the available water resource within each canal command.

9. Reviewing the statutory regulations and laws available to insure that the implementing authority would have all of the necessary powers for collecting water charges and access to and acquisition of land where necessary for effective and economical construction of on-farm water management works as approved by the majority of beneficiaries.

10. Determining the irrigation and drainage techniques and developing new ones which are best adapted along with suitable alternatives. This could include: Possible deviation from standard concepts in design, structures, and equipment taking into account both initial and O&M costs and labor inputs; development of simple packages of instructions and guides for both design technicians and irrigators; and using the most advanced technology available to develop new techniques to better fit the environmental restraints of developing countries.

11. Identifying the most successful mechanism for financing (and organizing the social and physical structure of) on-farm works under varying host country conditions.

12. Developing appropriate environmental considerations and statements for developing countries having differing needs and viewpoints.

3.

NATURE OF RESEARCH AND WHERE AND HOW TO CONDUCT IT

The following background papers were presented under the theme question:

Dryland Farming in Jordan; Amin Abu Sha'er, Wheat Project Leader, Ministry of Agriculture, Jordan.

Research for Rainfed Agriculture; Norman Goetze, Extension Agronomist, Oregon State University.

Research for Irrigated Agriculture; Marvin E. Jensen, Director, Snake River Conservation Research Center.

Systems of Soil Classification and Their Relation to Water Management; L. D. Swindale, G. Y. Tsuji and H. Ikawa, Associate Director and Associate Soil Scientists, respectively, University of Hawaii.

A Strategy for Optimizing Research on Agricultural Systems Involving Water Management; Jack Keller, D. F. Peterson and H. B. Peterson, Professor of Agricultural and Irrigation Engineering, Vice President for Research, and Professor and Head of Agricultural and Irrigation Engineering, respectively, Utah State University.

Research on Climate and Agricultural Production; Norman J. Rosenberg, Professor of Agricultural Climatology. University of Nebraska.

The International Irrigation Information Center, (IIIC); Joseph Shalhevet, Director, Soils and Water Institute, Valcani Center, Israel.

Discussion Panel:

- Ven Te Chow, Chairman, University of Illinois, Urbana. Illinois.
- Phillip G. Hubbard, Rapporteur, University of Iowa, Iowa City. Iowa.
- William D. Kemper, Colorado State University Fort Collins. Colorado.
- John D. Montgomery, Harvard University. Cambridge. Massachusetts.
- H. B. Peterson, Utah State University, Logan, Utah.
- Stephen L. Rawlins, U.S. Salinity Laboratory, Riverside. California.
- Kunio Takase, Asian Development Bank, Manila. Philippines.
- Joseph Shalhevet. Valcani Institute, Israel.

This report summarizes the significant highlights of the papers and floor discussions. and those identified by the Panel. It covers questions and judgments regarding 1) the design. operation and coordination of the program, taking into account the past two days' discussion, 2) whether or not the priorities are correct, 3) what changes in objectives or strategy, if any, might be desirable considering in particular what might be AID's best role utilizing its centrally-funded resources, 4) any deficiencies in the global research acquisition and knowledge delivery system, and 5) what might be appropriate both through AID Mission efforts and at the international level beyond what can be done with central funding.

The discussions, necessarily, will overlap Question No. 1: *What is the present knowledge throughout the world with respect to on-farm water management problems?* The speakers were asked to prepare an advance paper. but also to respond to the past discussions as much as practical. They were requested to give particular attention to what must be site-specific and what can be generalized and to mention existing institutions and their capabilities in research.

The Panel was asked to amplify or supplement specific issues or points raised by the authors giving attention to possible organization, communication, and data systems. types of research institutions needed, etc., and to discuss all important points, especially the deficiencies, identified under Question No. 1.

Research needs in general, as well as in specific, areas were delineated by many of the speakers and panelists, and also by other Symposium participants. Major emphasis was placed on the *what, where,* and *how* to deal with the needed research. Special topics, based both on factual findings and experiences, included: Typical dryland farming practice, rainfed agriculture. irrigated agriculture. applicability of soil classification in soil water management, system optimization of water management research, agricultural climatology research, and international centers for water management research. Collection of basic information about microclimate. plant physiology. soils, and social factors was stressed.

Analysis of Research Questions

In order to facilitate systematic and orderly discussion of the theme question. a research activity matrix. Table 1. was drafted to serve as a framework for discussion. This matrix is, of necessity, highly over-

Table 1. Research activity matrix.

NATURE			HOW		WHERE			
Empiricism	No. of variables	Class	General	Site specific	Univ., gov. and private research inst. and centers	Governmental services; univ. extension services	Field project office and farm organizations	International regional
Low	Few	(A) Advanced, academic	1[a]	3	1	3	3	1
Medium	Medium	(B) Implementational, adaptive	2	2	2	1	2	2
High	Numerous	(C) Grass-rooted, practical	3	1	3	2	1	3
High	Numerous (mixed)	(D) Clinical,[b] integrative	2	2	2	3	3	1

[a]1, 2, 3 descending order of magnitude or frequency.

[b]Consideration of specific complex problems in real life-context in relation to generalized principles and, heuristically, refining or extending generalized principles.

Discussion Considerations:
(1) Objective of research
(2) Identification and coverage of research
(3) Optimization of research
(4) Conduct of research

simplified. Discussions were also directed toward four major items: Objectives of research, identification and coverage of research, optimization of research, and conduct of research.

Research Activity Matrix

A clear-cut classification of the *nature* of a particular category of research is extremely difficult if not impossible. Four classes were suggested. These are described from various points of view as follows.

Class A research is described as advanced and academic. Such research requires either basic theoretical knowledge or elaborate laboratory or field experimentation, or both. The problems actually dealt with in nature, or the "prototypes," of this class are often complex, involving numerous variables. All these variables cannot be taken into account at once in a theoretical and controlled situation, or "model." For a workable model, a few major variables governing the problem have to be considered and the nature of the model has to be exact and precise as much as possible in representing the prototype. Empiricism must be kept to a minimum, except for the determination of some model parameters.

From the papers and discussions of this Symposium, particularly relating to Questions Nos. 1, 2, and 5, examples of Class A research can be identified as follows:

Soil-water-plant-climate-fertility-cultural relationships, such as moisture tension and plant stresses, chemical weed control, control of phreatophytes, determination of effective precipitation and evapotranspiration or consumptive use, improvement of quality of irrigation water, improvement of fertility and seeds, salinity and sediment control, development of new crop varieties, suitable crop patterns, and efficient soil classification.

Hydraulic research, such as control of seepage and spillage losses, refinement of flow measurement and water distribution works, and physical and mathematical modeling for development of skimming wells.

Agroclimatic agricultural studies, such as theoretical and model investigations on use of windbreaks, reflectants, and other methods to improve water-use efficiency.

Hydrologic investigations such as development of watershed and groundwater models, and research on stochastic hydrology for understanding uncertainty and variability of precipitation, temperature, humidity, and drought.

Advanced systems analysis research including theoretical physical and physical-economic simulation and optimization models for irrigation and agricultural management, comprehensive systems models for on-farm water management, and conceptual models for cultural and institutional processes relating to on-farm water management.

Class B research is described as implementational and adaptive. Through such research, basic knowledge and advanced theoretical and experimental findings gained from Class A research are applied to solving more or less generalized, or common, on-farm water management problems. Empiricism is introduced wherever necessary in applying the results to complicated problems where more variables of significance must be considered. Typical examples of such research are as follows:

Development of general guides such as for irrigation systems design, construction, operation, and maintenance, for planning and evaluating irrigation projects, and for complying with and adjusting legal, cultural and institutional constraints.

Efficient collection and its improvement of design data.

Identification and search for financial resources for on-farm water management and development.

Research for tools to enhance consciousness on cost-benefit justifications and on-farm water and land resources.

Institutional and inter-organizational coordination and cooperation.

Research for adequate methods of training and educational programs including publication of textbooks, working manuals, and field guides.

Class C research is described as grass-rooted and practical. It is directed toward the farm level, the farmers and farm managers, for the solution of their day-to-day or immediate problems. Research therefore, must be expressible in layman's terms. The problems are complex and involve numerous variables which are often intangible and unquantifiable. Consequently, high empiricism depending essentially upon the past experience, sound judgment, and socio-cultural knowledge must be added to whatever rational methods that have been developed in Classes A and B research. Examples of Class C research are as follows:

Field trials for adapting Class A or B research to local situations.

Development of motivation and incentive of the farmers and farm managers, and also of their mutual understanding and cooperation under local economic and cultural coordinations.

Effective application of the results of Classes A and B research to solving farmers' daily problems.

Research to obtain local background information to enable applying generally available research results.

Class D was added to take into account various kinds of integrative research whose scope and location cuts across the other classes. It requires advanced and probably academic insight based on substantial data drawn from case histories or site-specific data from several or numerous places. On the other hand it often involves a high degree of empiricism. There are some important problems on which advanced research is badly needed, but where variables cannot possibly be controlled. Examples include:

National or regional institutional and policy development involving such things as delivery of technical services and advice, credit, marketing cooperatives, repayment, settlement, tenure, responsibility for interfarm infrastructure, etc., relating to incentives for on-farm water management.

Systems or models for geographical and cultural transfer of agricultural productivity, and water requirements under both unaltered and altered site conditions.

Development strategies to best achieve stated objectives where on-farm water management is involved.

"How" and "Where" to Conduct the Research

This question was examined primarily in terms of the "generalizable" or "site specific" nature of the research. A particular research area cannot always be classified sharply as being in one or the other mode, but may often have to be examined in terms of frequency or magnitude of the site-specificity or generalizability. The frequency of generalizable research decreases from Classes A to B and to C, and the reverse becomes the case for site-specific studies. Of course Class A research needs to be applied to site-specific problems, but most Class A research activities as such are directed to obtaining generalized results. Conversely, the results of site-specific research may be transferable utilizing interpolation and extrapolation, as well as theory, for applications to other site-specific problems.

With regard to *place* where the research should be conducted, Class A research requires specialists and facilities of highest quality which can be found generally in universities, governmental and research institutes and centers, and can be conducted most adequately in these locations. For implementational and adaptive research, Class B; governmental and university services are thought to be optimal. Class C research activities may be carried out through extension services of universities or government services, often through field or project offices, and occasionally through local farm organizations. Specialists must work hand in hand with local agents and farmers in such research.

Class D research could best be conducted by relatively sophisticated regional centers, university consortia, or intergovernmental agencies. If national policies are involved, as often will be the case, top technocratic officials in concerned countries should be involved in the research program design.

Physical and Biological, Institutional, and Economic System of Classification

The Panel also considered that the nature of research can be classified into the three frameworks outlined by Dr. Takase (Question No. 1): a) Physical and biological; b) institutional: and c) economic. These classifications are related to, but cut across, the four classes proposed in Table 1. The Panel considered suggestions that a unified list of priority research programs be compiled in accordance with this classification.

Objectives of Research

The concensus of the Panel was that the ultimate social objectives of research, be they for income distribution or foreign policy reasons, should be left with high-level policy makers. The Panel agreed that for its purpose the research to be discussed has the sole objective of alleviating the deficiency in knowledge as identified under Question No. 1.

Identification of Research in Terms of Decision-making Needs

There is a definite need to identify research needs including a systematic search for research "loopholes" or deficiencies and unfilled information gaps based on the utility of the research in the decision process at all levels. Dr. Montgomery suggested three orders of decision making in sequence useful for that purpose. 1) Technological systems: 2) delivery systems: and 3) incentives. Consideration of the decision order might be useful in narrowing the range of research issues that would be appropriate for support by development agencies. In each order, systematic gathering and interpretation of knowledge, and structuring and evaluating alternatives are needed to aid decision makers.

"Technological systems" comprise the application of technology assessments and forecasts. These techniques attempt to structure alternatives for the users of technology to achieve comparable goals. They constitute a type of "comparative research" that attempts to identify the best alternative. Most scientific research activities reported in this Symposium relate to first-order decision-making "technological systems."

The second-order, "delivery systems," refers to the channel through which the technology can be made available to the user; for example, research might be to determine whether a certain irrigation technology should be implemented by the farmer, by a government agency, or by a private corporation or by some combination of these. "Systems of delivery" were defined similarly by Dr. D. F. Peterson who described them as those "systems" that make available the wherewithal (e.g., know-how, resources inputs, markets, incentives, etc.) to modify water management policies or to optimally utilize moisture environment.

The third-order, "incentive," decisions relate to the motivation of farmers. This is least understood and should be given more research attention. For example, water pricing and regulations fall in this area of research. Mr. B. B. Vohra cited cases in which collective objectives require attention to individual incentives, e.g., a farmer may be expected to accept a change in the crop pattern in the overall interest of better water utilization, or he may be asked to sacrifice one winter crop in order to provide a longer working season for construction forces who can operate only during dry winter months.

Research relating to the three-order decision-making model can be related to the classes proposed in Table 1. Technological systems fall mainly in Class A and much of the second- and third-orders fall into Classes B and C; however, much, especially second- and third-order, may fall into Class D. In order to illustrate the applicability of the three decision orders to on-farm water management research, Dr. W. D. Kemper analyzed the projects in Pakistan as reported in his paper "Colorado State University - Water Management Research."

Optimization of Research

After the needed research is identified, optimizing the research effort is desirable. Optimal alternatives under given constraints need to be identified. Under Question

No. 4, various constraints to conducting and implementing research were recognized and discussed. The Panel believes that an effective approach to optimize research in the system model optimization as described by Dr. Jack Keller in his paper co-authored with D. F. Peterson and H. B. Peterson on "A Strategy for Optimizing Research on Agricultural Systems Involving Water Management." This paper presented the rationale for a model for optimizing agricultural systems through knowledge transfer The model attempts to disaggregate the environment into significant measurable components. Crop production is used as the overall integrator of the agricultural system response to the husbandry program imposed at a specific site. The model as presented is only at a conceptual stage. The real system is so complex, the variables and parameters are so numerous and many functional relationships of the system components are yet to be determined With the astronomical magnitude of computer capacity required, a comprehensive solution of the proposed systems model seems to be only next to impossible at the present stage of knowledge For practical solutions, the model probably can be disaggregated and simplified without loss of the essence of the prototype problem. The proposed model or other similar systems models not only should aid in organizing available data and investigations and provide a framework for data retrieval, but also should form a useful tool to assess deficiency in research and to optimize research effort.

Conduct of Research

Much consideration was given by the Panel to the conduct of research. The following discussion is based on the four problems defined within the biological and physical framework proposed by the Panel discussing Question No 1

Biological and physical framework

1 Better on-farm structures and better measuring devices. No research program can be formulated without knowing exactly the nature of the problems to be researched In research there is a need for direct application of existing knowledge, with modifications according to ingenuity and resourcefulness of the engineer. Test of proposed structures is necessary on site, but the problem to be dealt with should be viewed in a very generalizable manner.

2. Relationships between water and other inputs. The effect of a single input variable on crop production is, in many cases, well understood and transferable, on the basis of the existing production function or the findings of Class A research. However, interactions between several variables are complicated, particularly at the Class C research level, and no easy tool is generally available for generalizing local results from site-specific Class C research. Development of tools, such as those suggested by Keller, Peterson, and Peterson, should be encouraged.

Presently it is the *problem of interactions* which should be researched in less developed countries. Successful application of existing knowledge can be achieved many times by experienced personnel with relatively low academic background, such as farm managers and extension workers. Such people may find communication with the farmer easier than would a specialist, and, as pointed out in Dr. Jensen's paper, may also help the farmer and researcher to define field problems which require research. This approach has been successfully tried by Israel's cooperation with the developing countries.

3. Physiological responses to stresses. Two levels of research may be defined here, namely, field level and laboratory level.

At the *field level*, the time for irrigation for optimum crop production is highly important. Meteorological models for computing the total or daily evapotranspiration are available, but the determination of irrigation interval is more site-specific The latter ties in closely with the irrigation method employed and with salinity control. New ideas regarding frequency of irrigation are emerging and research should be attempted to develop and apply them, where practicable, in less developed countries. It does not seem necessary to go through all the steps of irrigation development and research, from the simplest to the more advanced, in developing countries as was done in the more developed countries.

At the *laboratory level*, more fundamental Class A research, such as on plant response to stress, must accompany the adaptive research of Class B and the grass-root research of Class C in each country, even if not locally essential. Two reasons can be mentioned. Be it field or laboratory, only trained and qualified personnel can conduct good research Fundamental research is necessary in order to encourage and stimulate such people locally Only then will they be able to apply results obtained from other countries or sources to their site-specific conditions. Another reason is that it is a mistake to completely neglect long-term development in favor of short-term objectives. Both long-term and short-term research, probably with relatively different emphasis, should run concurrently if ever the less developed countries are to pull out of their present difficult situation.

4. Measurements to understand losses from the irrigation system. Two types of controllable losses may be identified, namely, the channel losses and the field losses; both are difficult to assess accurately. Direct measurement of field losses may not be practical or even possible. By knowing evapotranspiration and leaching requirements, water may be applied in such a way that losses can be avoided or minimized. This requires good control over water application. Research is, therefore, needed for improving such controls. Channel losses may be measured or estimated, but this should be done by experienced personnel. Better flow measurement methods should be investigated particularly for variable discharges.

Institutional and economic framework, general comments

Several other comments on research are pertinent. Messrs. Leland Anderson, O. L. Corey, B. B. Vohra, and others have pointed out that major constraints to progress of more efficient on-farm use of water lie in the political and institutional arenas. Anderson and Corey commented that more money would not speed progress in Pakistan because of shortage of trained personnel. Possibly such comments might be misconstrued as meaning that scientists and engineers need not push research forward as rapidly as possible. We believe that we cannot afford this lag in effort if nations are to be fed satisfactorily in the future.

To see where the efforts of research might be directed, we need to come back to Dr. Montgomery's comment that the role of research is to provide alternative choices--and the consequences of these choices--to the decision makers. Our job should not be to develop a technical package and push it into the developing country, but rather to develop a set of alternative packages accompanied with information on their costs and payoffs, and let the country's administrators and/or even the farmer select the package to use. Perhaps we are trying too much to "sell" a specific technological fix to a country without understanding the consequences ourselves. Though undoubtedly there are political and institutional bottlenecks to implementation of a specific package, these are not likely to be "road blocks" to developing our understanding of the systems so that decision makers, when so motivated, can make rational choices.

International Centers

The International Irrigation Information Center (IIIC) was discussed. This center will be an international information analysis center dealing with all aspects of field irrigation and will be established at Valcani Center, Beit Dagan, Israel, under sponsorship of the International Development Research Council of Canada.

The World Consultative Group on Agriculture, in which AID is a participant, has eight international research centers. These are listed in Appendix C. Unfortunately, none of these deals with water management systems.

Dr. Dean F. Peterson suggested the need for regional centers and an international center to serve as the cutting edge for research on delivery systems necessary for implementing technological solutions of on-farm water management. Such research would have to be inferential based on case histories and would need active involvement of the participating countries.

The success of international and regional research centers, however, will not be great unless clearly defined, specific goals can be established for each. Certainly the successes of centers like the International Maize and Wheat Development Center in Mexico and the International Rice Research Center in the Philippines is partly attributable to their well focused objectives. Dr. Earl Heady suggested that such centers might develop a series of models, beginning with the plant and extending to regional economic systems. It may turn out that development of such models could serve to focus the activities of regional centers sufficiently that they could succeed.

With a wealth of information already available in many areas related to on-farm water management, a major attempt to catalog these data in quickly retrievable form suitable for research purposes appears to be in order. A computer-based system is the obvious answer, and its access should be keyed into a diagnostic system to be described below.

Perhaps the *greatest need* at this time is for a diagnostic system which will enable a trained outreach analyst to feed data about a local situation into a network, add information based upon the generalized results of completed research, and obtain a tentative diagnosis or solution as the output of the network. Eventually, of course, such a network of stored data and programmed inputs could be designed into a computer program. However, it need not be a computer program initially, any more than a physician needs a computer to diagnose a patient's problem.

From the farmer-customer's viewpoint, of course, a diagnosis is of doubtful value unless accompanied by a recommended cure. The need for a "package" output was mentioned by more than one speaker, and it is extremely important that alternative plans be presented to the farmer. This would include preliminary consultations and discussions, an indication of priorities from the farmer's perspective, land grading, equipment, chemicals, measuring devices, and irrigation water when required. The follow-up on actual implementation and the results should certainly not be neglected. This is an area where research would pay large dividends.

Recommendations

Keeping in mind the need for AID to address its efforts to the worldwide need for food and fiber (grain in the bin and fruit in the box) as well as upholding the dignity and recognizing the wisdom of the individual farmer and considering the institutional constraints of a particular country, the following recommendations are proposed:

1. As the scope for research on on-farm water management is broad and the funds available for research are limited, centrally-funded AID research on on-farm water management would be most cost-effective if it is

directed to programs with emphasis on Classes A or B research. For Mission-oriented site-specific problems, largely Class C, AID Mission funds should be used. AID should cooperate or separately support Class D research at the international or national level when clearly focused programs having high priority are identified.

2. The U.S. scientists and engineers can help considerably by encouraging research, providing a series of well-designed practical, and economically desirable alternatives and reliable information on consequences to the decision makers

3 Deficiency in research and needed research should be determined by a rational and systematic approach instead of a shotgun fashion or bull-session procedure which leads only to confusion.

4. Models using systems analysis seem to hold the promise of helping to provide rational understanding of the complex research problems. However, care should be taken of the practicability and limitations of such models so that the results obtained from systems analysis will not be misinterpreted.

5. A productive research program is possible by coordinating university research centers with university extension services and field project offices, integrating all efforts and emphasizing problem-oriented research.

6. Institutional and socio-political problems are complex and intangible. They are least understood but often produce road blocks to the implementation of water management programs. Research is much needed in this area.

7. Regional water management research centers with specific objectives should be established where problem-oriented research can be conducted most effectively. Such centers would have the additional benefit that they will focus regional research activities and also serve as delivery systems for research needed to implement technological solutions to water management problems in developing countries.

4.

CONSTRAINTS TO CONDUCTING AND IMPLEMENTING RESEARCH

The conclusions in this paper are drawn principally from the following presentations:

Water Management Research-Constraints in Conducting and Evaluating; H. B. Peterson, Professor of Agricultural and Irrigation Engineering, Utah State University.

Water Management Research in a Developing Nation-Concepts and Constraints; G. L. Corey, Chief of Party, Colorado State University, Islamabad, Pakistan.

Some Constraints in the Implementation of Water Management Programmes in Canal Irrigated Areas; B. B. Vohra, Joint Secretary, Ministry of Agriculture, Government of India.

Constraints to Project Development in Latin America; A Cornejo, Director General de Aguas, Ministry of Agriculture, Peru.

Constraints on the Transfer of Research Results; D. F Peterson. Professor of Engineering, Utah State University.

Additional thoughts were drawn from the floor discussion and from presentations by the following Panel members:

John T. Phelan, Soil Conservation Service, Chairman.
Norman J. Rosenberg, University of Nebraska, Rapporteur.
Kaya Bozkurt, TOPRAKSU, Turkey.
Jerry B. Eckert, Colorado State University Field Party, Pakistan.
Clyde Houston, FAO.
Earl O. Heady, Iowa State University.

Previous discussions have included a consideration of the adequacy of knowledge, how results of research can be implemented in developing countries, and what, where, and how additional research should be conducted. This report deals with an identification of the problems which constrain the conduct of research and implementation of research results in on-farm water management.

Included are two general topics: Constraints on the conduct of research and constraints on the application of research results. These are considered in the frameworks of the scientific problems, and the institutional, economic, social, and cultural problems.

The discussion of constraints necessarily contained many points related to Panel discussions held earlier in the week. The overwhelming impression received was that many constraints affecting both the conduct of research and the application of research results are not of a biological nor physical nature. Problems of an administrative, institutional, and economic nature resulting from traditional attitudes and cultural and religious backgrounds are very important. Some of these problems are researchable. Others must be resolved by the host country itself through its superior understanding of its specific culture and tradition. Perhaps the greatest challenge to conducting successful research and application programs is the determination of approaches and procedures that will be acceptable and productive within the cultural context. Cultural differences can create constraints on the part of both the donor and the host, thus retarding progress until constraints from both sides are removed or decreased.

The shortage of properly trained personnel seems the major current constraint to successful conduct and application of research. Training is needed to develop an appreciation of the need and opportunity for improvement, as well as for development of specific scientific fields and manual skills. USAID is in a unique position to promote United States and third country training programs when such training is needed. Insofar as possible, the host countries should be encouraged to develop internal training programs to provide the large number of trained personnel needed to conduct and apply research.

Constraints in the Conduct of Research

Physical and biological

Problem definition in the realm of on-farm water management is extremely complex, especially because of the interaction with a wide range of agronomic and ecological problems. Resource surveys of soils, topography, water supply and quality, and climatic conditions and their recurrence are frequently inadequate to permit satisfactory description of the environmental limitation in problem areas.

Recommendations

1. The use of interdisciplinary bilateral survey teams should be continued as a first step in evaluating the scientific aspects of specific development problems.

2. Highly qualified research scientists (donor and host nationals), with leadership ability, should be identified and encouraged to participate in all university center and Mission field party programs. This level of qualification is needed to develop programs of effective research and to avoid poor problem definition, poor planning, and repetitive research.

3. Field evaluation of actual on-farm water conveyance and application efficiency, and the field evaluation of soil, climate, and crop constraints to increased production should serve as the basis for determining priorities for AID supported research.

4. Host governments should be encouraged to regularize data gathering services with respect to climate, land, and water resources. Crop and market reporting activities should also be regularized.

5. The further development and application of conceptual models to identify and categorize problems; including the possible interactions of soil, water, and crops, should be encouraged as a guide to research problem selection.

The economic, institutional, cultural, and social problems

Political and administrative uncertainties cause difficulty in maintaining the necessary continuity of efforts in many research programs. Governmental goals, objectives, and priorities, as well as personnel, may change rapidly and derail research programs before solid results are achieved.

The policy changes which result in large fluctuations in the numbers of persons assigned to overseas research projects are counter-productive.

The diversion of personnel from research to temporary technical assistance assignments can cause serious difficulties in the conduct of research projects.

The problems of adequate logistical support for field parties and the inevitable weaknesses in communication and coordination between AID/W, the Missions, university centers and field parties make the conduct of research more difficult.

Ineffective liaison between concerned agencies and ministries in the host country may impede the conduct of research work.

The lack of effective systems of incentives and rewards for counterpart scientists, technicians and others may be the most critical constraint to the effective conduct and application of research and to the continuity and morale of technical cadres.

Recommendations

1. Problems of logistic support must be recognized at all levels, especially the host country, and more responsive procedures developed.

2. Emphasis should be given to the conduct of case studies and cross cultural analysis of research management modes in developing countries. Successful and unsuccessful experience should be considered in an effort to generalize constraints and opportunities in creating an effective working environment.

3. The motivation of research scientists and administrators in develop-countries to initiate and sustain effective research programs is itself a proper subject of research. The methodology of Ben David, cited in D. F. Peterson's paper, suggests a relatively rapid way to gather ideas and develop strategies for motivation. The so-called "clinical approach" can be used by capable social scientists and other scientists as well, especially those with experience in development work.

4. There has been an important increase in international and bilateral assistance. Efforts at coordination should be made prior to the inauguration of AID programs and during the conduct of AID programs already underway. Lack of coordination between donors and host countries can become a major constraint to conduction and application of research.

Constraints in the Application of Research

The physical and biological problems

Inadequacy of inventory data including basic information on geological conditions, soils, topography, weather and crops makes difficult the adaptation of research results to other locations.

Recommendations

1. Research information and resource data should be combined into systems of cropping practices for use by the farmer. This requires the input of knowledge and experience from many sources supplemented with in-country judgment to develop a "package of practices" for a specific crop and location. Such packages should be developed before extensive application programs are initiated.

The Panel endorses, in general, the concept of a "research to application" sequence where research moves from lab and field plot studies to pilot project establishment to development area. Feedback of information through evaluation at each stage should be incorporated into the system as soon as results permit. Refinements in the applications should be made as deemed necessary.

The economic, institutional, cultural, and social problems

Limited capital resources and existing land tenure systems mitigate against rapid adoption of new methods. The element of risk is often too great for the subsistence farmer to accept. Often the threat of land consolidation and uncertainty of land reorganization programs increases hesitation to proceed with the installation of permanent improvements.

How local social and cultural institutions determine the acceptable patterns for implementing appropriate cooperative efforts is not known.

The Symposium has identified the lack of an adequate cost/benefit consciousness and the lack of an adequate resource consciousness at policy levels as an important constraint to the application of research results. The principle of maximal returns on the national investment is not always recognized. Inadequate recognition of the manageability of the water resource also constrains effective action. Gaps in organizational structure further constrain the effective implementation of research results.

The lack of adequately trained and motivated personnel at all levels–scientific, administrative, technicians, craftsmen, and skilled labor–hampers the application of new methods and systems developed in research. Lacking also, are the appropriate economic and social indicators which can be used to demonstrate the effectiveness, or lack thereof, of proposed and existing water management and agricultural systems.

Recommendations

1. The farmer should be involved, at appropriate times, in determining the objectives of the development projects from which he is supposed to benefit. He should be consulted in determining certain of the specific measures which directly affect his land.

2. Crop insurance, guarantees, credit, and other methods of providing "risk insurance" should be considered during the first years to encourage adoption of new agricultural methods.

3. Land consolidation policies should be clearly stated. When established, these should be implemented without delay in order to avoid uncertainties in the mind of the farmer.

4. Additional emphasis should be given to study of the means to overcome social and cultural constraints to cooperation and innovation.

5. Competence and skill at the governmental policy level to deal with problems of national planning priorities and administration of programs should be developed. This can be effected through broad exposure to potential approaches. Study tours to nations where similar problems have been dealt with are very helpful. Often interactive arrangements with counterpart policy makers can aid in developing broadened perspectives and recognition of opportunities.

6. Specific attention should be given to the development of cadres with the *complete* set of skills needed to implement agricultural and on-farm water management programs. Personnel at all levels of needed skill should be trained simultaneously for the needs of a particular project. This "horizontal" approach is recommended as an alternative to "vertical" training schemes in which only its highest levels are trained. Nationals who have not had the full range of experience or developed all the skills needed in implementing a project cannot properly train the sub-professionals and skilled laborers.

Outlook

The above enumeration suggests that many of the constraints to the conduct and implementation of on-farm water management research are, themselves, the proper subject of research work. Development of methods to eliminate or minimize the impact of these constraints offers the prospect of major improvement in the worldwide agricultural productivity of water in agriculture.

The Panel emphasizes that some of the most serious constraints that must be overcome are social, institutional, cultural, and economic ones.

The Panel recognizes, of course, that long-standing traditions and institutions are not easily changed. Long-term strategies must consider these factors and development workers in on-farm water management must be prepared to adjust their thinking and their goals to that which is achievable.

5.

AID'S PROGRAM OF CENTRALLY-FUNDED RESEARCH AND INSTITUTIONAL DEVELOPMENT IN WATER MANAGEMENT

The following papers and Panel and Symposium discussions, combined with other source material (progress reports and project proposals), formed the basis for the recommendations made by this Panel.

Introduction and Background; S. H. Krashevski, A. A. Bishop, Senior Research and Grant Advisor and Program Analyst, TA/RIG; and Water Management Specialist, TA/AGR, AID/W, respectively.

Report on the University of Arizona's AID 211(d) program "Optimum Utilization of Water for Agriculture with Special Emphasis on Systems Analysis of Watershed Management Under Conditions Characteristic of Less-developed Countries"; D. B. Thorud and M. M. Fogel, Professors, Department of Watershed Management, University of Arizona.

Colorado State University 211(d) Institutional Development Grant; M. L Albertson, Professor of Civil Engineering, Colorado State University.

Colorado State University AID-supported Program in Water Management Research; W. D. Kemper, Professor of Agricultural Engineering, Colorado State University.

Utah State University 211(d) Grant–Institutional Development in Water Management; H. B. Peterson, Professor of Agricultural and Irrigation Engineering, Utah State University.

Utah State University AID-supported Program in Water Management Research in Arid and Sub-humid Lands of Less-developed Countries; B. C. Palmer. Field Director, Water Management Research Program, Utah State University.

CUSUSWASH: Council of United States Universities for Soil and Water Development in Arid and Sub-humid Areas; Bruce H. Anderson, Director, CUSUSWASH, Logan, Utah.

Tropical Soils Project: Inter-relationship to Water Management Projects; T. Gill, Tropical Soils Specialist, TA/AG, AID/W.

Discussion Panel·

M. E. Jensen, Agricultural Research Service, Chairman.
Ven Te Chow, University of Illinois.
E. O. Heady, Iowa State University.
S. H. Krashevski, AID/W.
J. J. Young, AID/W.
W. W. Donnan, Consultant, Rapporteur.

Background

Dr. Bishop briefly described AID's organizational structure consisting of Missions, Regional Bureaus, the Technical Assitance Bureau (TAB), and its Agricultural Division (TAB/AGR), and the Research and Institutional Grants Division which handles all AID Grants. AID has missions in most developing countries. These missions promote agricultural techniques and transfer of knowledge within their respective countries. Leland R. Anderson represented the Mission in Pakistan. Regional Bureau representatives in attendance at this Symposium were: Charles Brietenbach (South America); John Young (Asia); and Princeton Lyman (Africa).

The Director of TAB/AGR is Dr. Omer J. Kelley. The TAB is a staff operation and has a major responsibility for technical know-how in the various fields in which it functions.

Initially AID and TAB/AGR's program emphasized a "how to do it" approach by providing extension specialists. In addition there was a large impetus toward building institutions in the developing countries. Many good agricultural institutions resulted from this effort, but little or no attendant research effort was generated.

In the late 1960's AID's endeavors were focused on research and practical field trials. AID now has assumed a low profile in the developing countries and contracts with the various Land Grant Institutions in the USA to perform both research and the transfer of technology. AID's main thrust has been in the areas of soil and water, livestock, food legumes, food grains, and agricultural inputs such as fertilizers, insecticides, and herbicides. AID does not respond to needs concerning specific commercial crops such as coffee, sugar, etc., nor forestry because of the great emphasis FAO has placed in these areas. AID participates in and provides about 25 percent of the funds for the maintenance of six of the following international centers: Wheat and Corn (Mexico); Lowland Tropics (Columbia); Potatoes (Peru); Rice (Philippines); Slash-burn (Africa); Livestock diseases (Kenya); Livestock forage (Addis Ababa); Vegetables (Taiwan); and Tree crops (Costa Rica). From these countries there radiates a network of information, seeds, techniques, and training opportunities for scientists and technicians from the developing countries.

Dr. Krashevski indicated that AID's policy changed about one and a half years ago to help the poorest of the poor in a broad spectrum including health, nutrition, and education, but AID will not work in a country without a request or proposal from the country. He indicated that centrally-funded research, which began in 1966, has emphasized research contracts with existing organizations. Also, emphasis is placed on innovative impact-producing projects. An external research advisory committee (RAC) reviews all projects and proposals and considers the impact of the research on the developing countries. Dr. Krashevski stressed that 211(d) grants to universities for institutional development were not oriented only to developing on-campus capabilities, but for institutions to develop their international capabilities.

TAB/AGR negotiated two research contracts for water management research in arid and sub-humid lands of less developed countries in June, 1968. These contracts have joint general and specific objectives. Because of Utah State University's historical interest in Latin America, AID entered into a contract with USU for on-farm water management research using Latin America as the primary research area. The actual place of work and the priorities were to be negotiated between the contractor, USAID Missions, national irrigation research agencies, and TAB/AGR as opportunities for Mission and national priorities were identified. A similar agreement was entered into with Colorado State University for on-farm water management research in semi-arid lands of the Near East-South Asia region. Specific studies on high priority needs were to begin in Pakistan in cooperation with AID and appropriate agencies of the Government of Pakistan. Both contracts have been funded at an annual level of about $500,000. AID also provided three 211(d) grants in 1969 for institutional development in water management. These were: (1) $750,000 to Utah State University to increase its capability in the field of on-farm water management; (2) $750,000 to Colorado State University to increase its capability in the field of water conveyance; and (3) $375,000 to the University of Arizona to increase its capability in the field of watershed management.

Copies of the papers by Albertson, Kemper, H. B. Peterson. Palmer, and B. H. Anderson, which describe these programs and provide additional details, are included in the Proceedings.

Dr. Tejpal Gill presented a series of slides illustrating the interrelationships and linkage of the water management research with AID's on-going programs of research on tropical soils.

Panel Meeting

After the luncheon break, the discussion panel held a one-hour meeting to develop preliminary recommendations for deliberation by the Symposium. Chairman Jensen reviewed the charge to the Panel which was to raise questions and judgments regarding: (1) The design, operation, and coordination of the program in relation to discussion the past four days; (2) whether or not priorities are correct; (3) what changes in objectives or strategy, if any, might be desirable, especially AID's role in using its centrally-funded resources; and (4) possibly consider deficiencies in the global research acquisition and knowledge delivery system and what might be appropriate for AID to do through Mission efforts and at the international level beyond central-funding abilities.

After brief comments by each Panel member, the Panel agreed to present 5 or 6 recommendations for consideration by the Symposium. These recommendations were to be openly discussed and if necessary, revised through discussion and suggestions from the Symposium. The brief presentations and limited time for discussion left the impression that the scope of the coordinated program seemed to be too broad, the objectives seemed vague, much of the work seemed to be of a technical assistance nature, and more effort appeared to be needed in synthesizing the results of specific studies so that the results could be generalized for use in other regions. However, the Panel recognized that additional detail could be found in the reports and also recognized that the two research contracts were just reaching the payoff period.

Panel Discussion

At 3:00 p.m., when the Symposium reconvened and the Panel assembled, Dr. Jensen presented the preliminary recommendations of the panel and opened the discussion for the Symposium. The results of the vigorous discussion that lasted until 5:00 p.m. were considered by the Panel along with detailed reviews of the papers, discussions with project directors and researchers, and previous progress reports in the preparation of the following recommendations.

Panel Recommendations

Progress, scope, objectives, and priorities

Colorado State University Projects (Pakistan and Viet Nam)

Accomplishments. Research efforts to date have been directed to delineating major irrigation water management problems in Pakistan (Objectives 2, 5, 6, and 8, see Chapter VIII) and in developing related water management technology on the campus (Objectives 7 and 8). Problem definition, complete with identification and measurement of the variables involved in an existing irrigated farming system, is in itself research. On-farm water management problems are complex because of the numerous biological, physical, and social interactions involved. Accurate problem definition is essential to planning and conducting effective research programs to avoid disproportionate efforts on problems that are not limiting food production. Major problems limiting the production of food on the 30 million acres of land in Pakistan that have been delineated, in cooperation with the USAID Mission and agency cooperators in Pakistan, are:

1. Farmers do not accept technology until they have seen obvious demonstrations of its benefits and are reasonably assured of a return on the investment of their meager resources. These demonstrations are most effective if conducted on the farmers' fields.

2. Several million acre-feet of water do not reach the farmers' fields because of seepage, spillage, and dead storage losses in the water courses.

3. Group organizations for operation and maintenance of water courses and for participating in water delivery policies are nonexistent.

4. Even though total water supplies are scarce, field studies have shown that farmers may over-irrigate portions of fields by factors of two to five because excess water deliveries are not controlled, there are penalties if excess water is put on non-cropped acreage, and soil water holding capacity--consumptive use relationships are either not understood or cannot be implemented.

5. Basin irrigation methods that involve unleveled land result in nonuniform distribution of water. This condition over a period of time, has been aggravated because the infiltration rates in low-lying areas are higher than in the high areas. This difference appears to be due to sodium accumulations in the high areas which has decreased the intake rate.

6. Stands, especially summer crops, generally are very poor because of a combination of factors such as high salt concentrations, soil crusting, poor seed quality, method of planting, and possibly flood irrigation-disease interactions.

7. Limited supplies of nitrogen that farmers are able to purchase are being leached by over-irrigation.

8. Many wells are unnecessarily pumping underlying saline groundwater because the pumping rate and well depth are incorrectly designed and operated.

Recommendations. Substantial progress has been made in identifying the real on-farm water management problems limiting food production in Pakistan. This is adequate to enable CSU to sharpen and limit its research on existing objectives to attain time-specific goals. The research clearly has shown that large losses of water occur in the water courses, over-irrigation by a factor of two to five is common, and consumptive use-soil water-holding capacity principles are either not understood or cannot be implemented under existing systems. Discussions at this Symposium indicate that some of these problems are common to all of Southeast Asia. Therefore, CSU should now concentrate on the development and testing of: (1) Accpetable physical and institutional water course systems for adequate and equitable delivery of water, (2) acceptable physical and institutional systems of scheduling irrigations, and (3) the integration of good water management practices into workable, productive cropping systems (Objectives 2, 4, 5, and 6).

Concurrently, studies in Pakistan should be aimed at: (1) Developing improved practical and acceptable techniques for distributing the water uniformly within fields while controlling salts and sodium; (2) establishing better stands of summer crops involving both irrigation and cultural practices; (3) establishing irrigation-fertilizer responses for the major crops; and (4) developing techniques that will enable local specialists to deliver management services to farmers so that, as the new water delivery and distrubiton systems are installed, they will be operated so as to substantially increase food production. Experiments that require economic and sociological interpretations should be coordinated with economists and social scientists during the planning stages.

General guidelines necessary to implement a similar research/development program should be documented so that they could be applied in other similar large irrigated areas, e.g. India.

Utah State University (Latin America)

Accomplishments. Because of USU's prior experience in Latin America, field work that complemented and strengthened the high-priority objectives of the host country and USAID Missions got underway earlier than the CSU studies in Pakistan. Discussions with developing countries and Missions identified a number of high priority researchable components of Objectives 2, 3, 4, 5, 6, and 8 (see Chapter VIII). Research on these components has resulted in the following accomplishments to date:

1 Studies oriented to improving cultural practices on irrigated land by optimum combinations of water and other manageable variables have been underway for several years. Three years of data obtained in Chile show that the yield of corn can be increased from 3,800 to 7,600 Kg/ha with nitrogen fertilizer and improved water application techniques. These

techniques are quickly being adopted by the communal and family farms growing 7,200 hectares of corn in the Aconcagua Valley. In Colombia. the yield of soybeans can be increased from about 680 to 1,080 Kg/ha with 11 cm of water and to 1,780 Kg/ha with 22 cm of water.

2. Crop water requirements are needed for the design and construction of water conveyance and delivery systems in the tropics. Climatological data from Bolivia, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Venezuela, and Panama, collected and assembled in cooperation with officials from the concerned countries, have been analyzed and used to determine: (1) The amount of dependable precipitation, expressed by probability levels by region and month; (2) regional potential evapotranspiration standardized to a short well-watered vigorously growing crop; and, (3) estimated crop-water requirements by time of year and by region. Reports have been published for Venezuela, Colombia, Guatemala, and Panama.

3. Criteria for controlling water-table levels and salinity on fine-textured tropical soils are needed. A pilot drainage system based on the results of a hydrologic computer model, covering about six hectares and instrumented with observation wells and piezometers, has been installed in Colombia to test concrete tile drains, open drains, and imported perforated plastic drains. Changes in salinity as a result of leaching studies will be used to extend drainage practices to the 16,000 hectares of Atlantico-3 in Colombia and other similar areas Related studies on controlling aquatic weeds in open drains and economic alternatives to open drains are being investigated in El Salvador, and perforated plastic pipe is being tested as a collector drain in combination with mole drains. A report is available describing the developing and testing of mole plows at the USU Drainage Farm.

4. Improving the facilities and capabilities of indigenous research institutions to conduct effective on-farm water management research and the training of local scientists is a prerequisite to the implementation of generalized research to site-specific problems. In addition to training programs and establishment of a soils laboratory in Northern Colombia, the planning and development of irrigation research facilities at three locations in the Sao Francisco Valley of Brazil have been completed. These stations are now operative with irrigation systems, leveled land, seed storage facilities and plot layouts for field studies. Training sessions have been conducted for researchers as well as administrators of SUVALE.

5. Identifying institutional factors that are constraints to efficient on-farm water management and determining feasible alternatives is an essential component of this project. A study of water rights and water law centered in the Andean Pact countries with Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela providing the main source of the field data combined with nearly 30,000 pages of water law data collected from United States sources and taken to Quito, Ecuador, for analysis and comparison with the field data, has resulted in a detailed water law digest for the Andean Pact countries. Draft copies of the publication are available in both English and Spanish and have been distributed to the appropriate government agencies of the countries concerned. A seminar, to review the publication and identify the laws and/or water rights which tend to restrain or facilitate good on-farm water management practices, was planned for Quito, Ecuador, in January 1974.

6 A simulation model for forecasting the results that may follow a particular water management decision or sequence of decisions was developed to utilize the unique capability of the hybrid computer (analog-digital) at the Logan campus. Complex combinations of management options including timing, amount, and methods of application coupled with water supply, soils, water quality, and water table constraints can be considered using optimizing techniques of mathematical models to offer solutions to problems. The model has also been developed to optimize research work. Data inputs are now required to improve the resolution of the model. Once the models have sufficient resolution to appear to be valid they will have an impact on the gathering of data needed and how it is taken to be most useful.

7. Integration of water-use factors into productive cropping systems also requires optimizing economic alternatives. Water management economic data have been collected in Bolivia, Ecuador, and El Salvador to establish economic benchmarks in these countries. Various levels of technological management can now be subjected to economic comparisons.

8. The USU experience during the first five years of this contract has shown that each member of the USU field staff has a major influence on the professional careers of about two to three country nationals per year, that an additional dozen or so persons per year receive professional development through frequent meaningful face-to-face contacts, and perhaps an additional dozen are influenced by occasional contacts.

Recommendations. Substantial successful experience has been obtained to show that the application of general irrigation research technology will result in the essential site-specific information to implement improved practices to alleviate various critical irrigation water management problems. USU should now concentrate on the preparation of research guides that will enable developing countries in Latin America to delineate their own major problems and design and conduct their own essential experiments. Existing mathematical models should be adapted, or developed so as to utilize experimental data to predict yield response functions for various crops, water management, and cultural practices. Preferably a more basic simulation model utilizing physical-biological principles should be considered which will enable evaluating 1- to 5-day effects of water management The model components of crop, soil, fertilizer, and climate that have the highest interaction with water should be completed first. Guides for collecting the necessary field calibration data should be prepared to enable using the model in other areas of Latin America as well as in Pakistan and Southeast Asia. The components of water law structure that impair efficient water use should be identified and procedures suggested for their removal so that these can be considered in other developing regions. USU should also now restate its program and concentrate on those objectives in the contract where the greatest progress can be made considering problems solved and those that remain. Particular emphasis should be given to utilizing the results of on-going and completed studies so as to generalize the results for use throughout Latin America.

CSU and USU

Accomplishments

Both USU and CSU have identified and worked on a number of components of soil and water management problems and each has made substantial progress. Successful implementation of the findings to date will not only increase food production in Latin America and Southeast Asia. but throughout the world by further developing the techniques and procedures which have had application in other areas. These results have applicability to small- as well as medium- and large-sized farms.

Recommendations

One of the difficulties encountered particularly by project reviewers, but also by contract coordinators, AID Missions, and others is to readily determine the progress that has been made in achieving the project objectives. When the contractors summarize "research accomplishments" statements of work planned, underway, or work that the contractor hopes to do, should not be included because they tend to cloud the issue and raise doubts about the progress toward achieving time-specific and attainable goals. We recommend that the progress reports contain a consise scientific progress section that may include, but not be restricted to the following:

1. Objective--Number and description, or tie in the following sections to specific objectives.

2. Progress During the Reporting Period--Include only pertinent, meaningful results perhaps with meaningful summaries of data as they relate directly to the objective and the potential impact of the results if implemented. Cite specific publications that contain additional detail.

3. Documentation of Progress--List only those publications that are a direct result of this research contract.

    (a) Publication--technical publications in scientific and technical journals, technical bulletins, etc.

    (b) Other Documentation of Research--List theses, unpublished reports, papers that may or may not be published. Also include presentations of papers, etc.

4. Specific Goals and Objectives During the Coming Year–Next year's work should build on the progress to date. Time will not permit many interesting, but fragmented studies that will have only a minor impact on LDC's within the time period of this project.

Contracts–designs, operation, and coordination

Each of the two research contracts must have a strong director who is acquainted with the administrative requirements of his institution and experienced in water management and problem-solving or Mission-oriented research. Project Directors will be required to take positive actions to assure that the work continues on the highest priority problems. They must also direct the various components of the research projects so that each reaches its attainable objectives within the available time framework. New related studies should be carefully selected.

Only those objectives which can be reached within the available time framework to enable the recipient countries to begin implementing the solutions developed should be initiated. There should also be coordination at the Project Leader level. In addition, research workers with the two institutions, working on closely related problems should be given the opportunity to discuss mutual problems on a one-to-one basis in order to optimize the use of research results and experiences gained to date. In some cases, inputs can be exchanged. For example, a researcher at one institution may provide theoretical or simulation model results for the research in the field in exchange for field input data to test hypothesis and simulation models.

Institutional development in water management

Experience gained by the two institutions in developing on-farm water management research programs should now enable a critical assessment of current and anticipated future deficiencies in on-farm water management competence. This Symposium and the Proceedings will provide specific guidelines for this purpose. Though oriented toward watershed management it appears that the techniques being developed at Arizona may have direct applicability to the problems of on-farm water management. For example, the expected quantity and distribution of available water for irrigation and precipitation in both irrigated and rainfed areas represent essential inputs for the determination of cropping systems and the management of irrigated farms. There does not appear to be significant coordination of Arizona studies with the needs of the other two institutions. The Arizona hydrologic and decision-making models may have direct transferable capabilities to the modeling needed for on-farm water management.

Deficiencies in water management research acquisition and delivery systems

Existing research contracts. Though both institutions encountered many problems in the formulation, establishment, and implementation of their respective projects, both projects have now gained sufficient momentum so that they are just reaching the potential period of payoff in terms of research that can be generalized, and in implementing systems and procedures for increasing food production. We recommend concentrating on specific objectives as previously indicated. We also recommend improving the reporting of progress because confusion still exists within AID and review committees relative to attainable goals. AID project coordinators and reviewers still have difficulty in determining progress made toward the current objectives. We believe that the projects are moving in the right direction and therefore recommend that both projects be extended to enable receiving the full potential impact of the results. Extension also will increase the stature and ability of the Bureaus and Missions to serve LDC's.

New research contracts. Before initiating a comprehensive new research contract to solve a specific on-farm water management problem, AID should consider a contract to compile all pertinent available research and technology (published and unpublished) on the subject. A symposium similar to this with proceedings would be one approach. Another approach would be to contract for the preparation of a prospectus of a state-of-the-art text followed by a symposium and/or publication of the book. Several excellent examples of this effort are: Advances in Sugarbeet Production: Principles and Practices, Iowa State Univ. Press, 1971, and Advances in Corn and Corn Production: Principles and Practices, Iowa State Univ. Press, 1966 (both sponsored by Chevron Chemical Co.). Professional societies might be encouraged to take on this assignment such as that which produced Wheat and Wheat Improvement, Amer. Soc. Agron., 1967 and similar monographs. Individuals could also be contracted for this purpose. Examples of individual efforts are: Water Deficits and Plant Growth, Vol. I, 1968, Vol. II, 1968, and Vol. III, 1972, Ed., T. T. Kozlowski, Academic Press, New York and London; and Plant-Water Relationships, R. O. Slatyer, Academic Press, 1967, New York and London. Research needs would be a required part of each chapter. The material in the resulting publication would include the most pertinent and reliable compilation of global research, a comprehensive, unbiased, and in-depth analysis of the data, deficiencies in research, and specific recommendations for solving these problems for various site conditions based on existing research and technology. The individual(s) selected for such an assignment must be a highly trained researcher(s), but with demonstrated ability to "solve problems" by applying available research technology.

Another alternative would be to select the best available contractor in terms of experience in the subject area and perhaps in the geographical area to conduct such diagnostic research as needed to clearly delineate available technology and/or research needed to solve a specific problem. This type of contract could be completed in a one-year period which would be followed by a symposium to review and recommend follow-up research projects. Perhaps this approach might be considered as the first step for increasing production in rainfed areas of developing countries. The research deficiencies identified would form the foundation for future comprehensive research contracts.

PART II

BACKGROUND PAPERS

CHAPTER IV

DEFICIENCIES IN EXISTING KNOWLEDGE

1.

IN WHAT PHASES OF WATER MANAGEMENT ARE WE ADEQUATE OR DEFICIENT IN KNOWLEDGE? (SOUTHEAST ASIA)

Dr. Kunio Takase[1]

Introduction

To establish the adequacy or deficiencies in our knowledge of water management, it is necessary to identify the main problem areas encountered. The findings in this paper are based on 6 years of experience with irrigation water management projects in the Asian Development Bank. The Bank's irrigation water management projects, in turn, have been developed with two major purposes, namely, an increase in food production and farmers' income in Asia.

Major Factors Affecting Food Production

1. *Complete irrigation covers only 2 percent of rice-harvested areas in Asia.*

The rice-harvested areas in Asia, excluding the People's Republic of China and Japan, have been roughly estimated at 70 million hectares, of which about 35 percent is irrigated and the remaining 65 percent is rainfed. Most of the so-called "irrigated area," however, is not properly irrigated, mainly because of the absence of farm ditches. In fact, complete irrigation systems have been developed for less than 2 percent of the rice-harvested areas in Asia. Given the dependence of the rice-harvested areas on weather conditions for their water supply, it is natural that rice production should fluctuate heavily with the pattern of weather conditions each year, and it is not unusual for these fluctuations to be of the order of 20 to 30 percent. In addition, in the period since the end of World War II, fluctuations have occurred quite regularly, at 7-year intervals, mainly due to changing weather conditions (see Figure 1).

2. *Intensive irrigation is preferable to expansion of new areas.*

In Asia, engineers and economists both recognize that intensive water resources development is, in general, a much easier method than extensive land development for coping with the ever-increasing food demand brought about by the rapid expansion of the region's population. Their major reasons for this conclusion are:

- (i) Land resources are scarcer than water resources (see *Workshop Report*, paragraph 4[2]);
- (ii) It costs more to develop the land resources than the water resources needed to yield a given increment of rice production; and
- (iii) Land settlement involves complicated social problems.

3. *"Green Revolution" production would be consumed in five years.*

If high-yielding varieties were planted in the entire "irrigated area" of Asia, average paddy yield would rise to 2.11 ton/ha., against 1.74 ton/ha. in case of local varieties, which means a 21 percent increase in total production.

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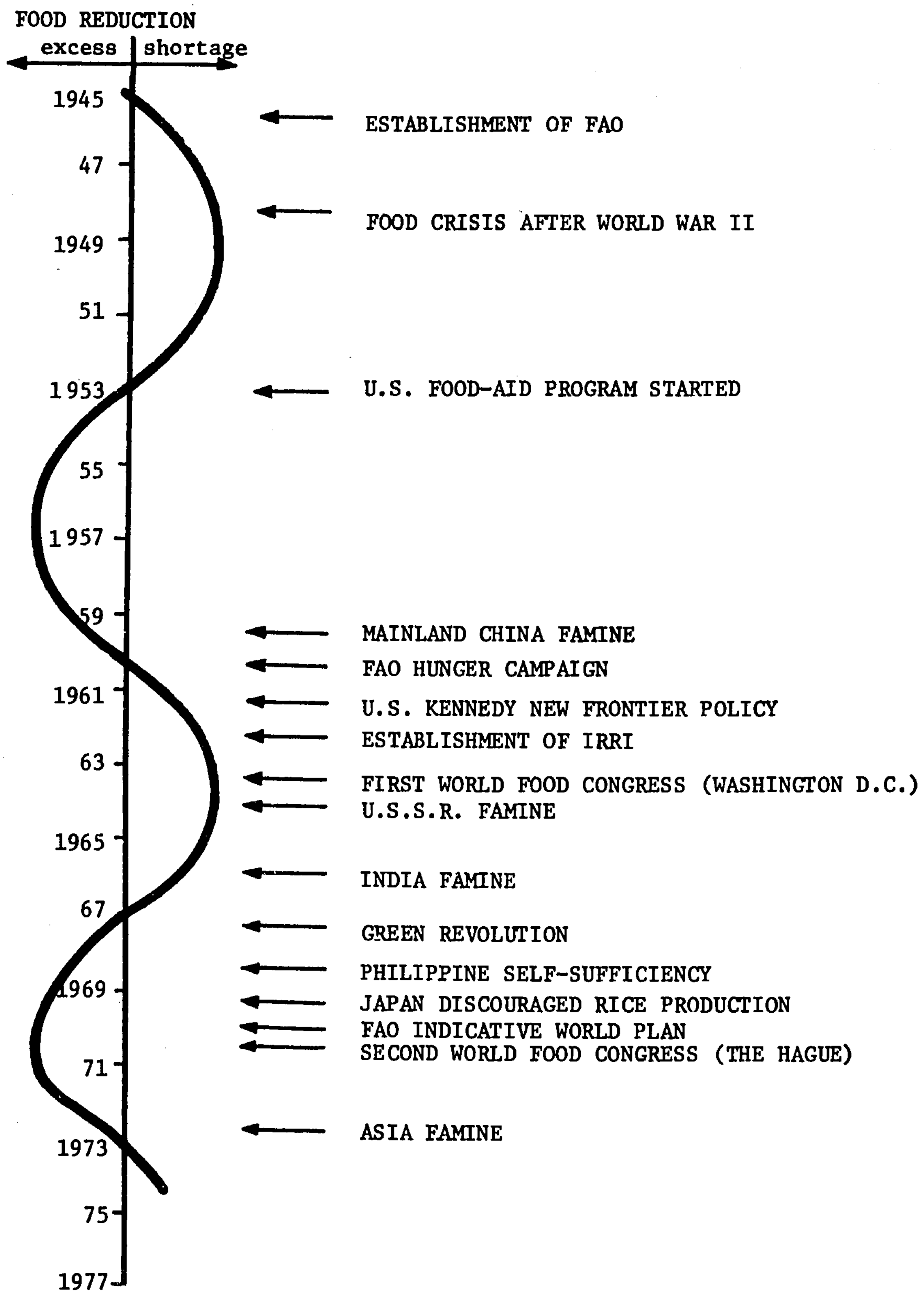
[1]Irrigation Project Manager, Asian Development Bank, Manila. Views expressed in this paper represent the personal views of the writer and do not necessarily reflect the policy of the Asian Development Bank.

[2]Regional Workshop on Irrigation Water Management, Asian Development Bank, Manila, Philippines. July 1973.



* This chart has been drawn by the writer based on discriptions in Prof. Torao Tamai's "World Agricultural Policy in Turning Point." 1972

Figure 1. Seven-year cycle of food production.

The annual increment in paddy production required to satisfy the demand of growing populations and higher living standards, however, is predicted to be 4.1 percent. The production increase to be expected from "green revolution," therefore, would be absorbed in 5 years, unless the "irrigated" land was substantially improved or its area expanded. Also, the high-yielding varieties and application of fertilizer and pesticide may not be effective without water control (see *Workshop Report*, paragraph 5).

4. *Farmer incentives are a pre-requisite to increased production.*

It is not desirable, socially and economically, to undertake irrigation projects in areas with a very high tenant ratio or a poor land tenure system, because the project benefits go to a few rich and absentee landowners. A land reform program undertaken in conjunction with other agricultural development activities, such as the provision of credit, cooperative and marketing facilities, encourages increased agricultural production and results in higher farm incomes.

Problem Areas

Bearing the above factors in mind, the Bank has extended its technical and financial assistance to developing member countries on the basis of two guidelines (*Workshop Report*, paragraphs 6 and 7):

(i) *Will the Project contribute an immediate production increase?* Smaller and shorter-term projects generating quick economic returns are preferable to large projects involving higher costs and longer maturity periods.

(ii) *Will the Project contribute to the betterment of farmers' lives?* Integrated area development concepts should be applied and include land reform, credit, farmer organizations, guaranteed input supplies, marketing feeder road, rural electrification, and other community developments.

A description of the procedures involved in formulating a project for Bank financing is given elsewhere (*Workshop Report*, paragraph 15). The feasibility study involved normally deals with five topics, namely:

(i) National Economic and Agricultural Background;

(ii) Present Status of the Project Area;

(iii) Proposed Project;

(iv) Project Implementation and Operation; and

(v) Economic and Financial Justification.

The Bank has found that four types of reasons can delay project implementation.

(i) The most common of these is procedural and relates to procurement of equipment, consultants and contractors.

(ii) The second major reason stems from physical, institutional, and economic problems.

(iii) Thirdly, legal matters such as delays in getting the parliamentary approval required for loan effectiveness or difficulties in carrying out the project to government reorganization, have caused delays.

(iv) The fourth type of reason involves either financial (nondisbursement of local currency) or security problems.

The first two types of delay, at least, can be minimized, and remedial actions should thus be focused on these two areas (*Workshop Report*, paragraph 16).

Excluding the procurement problem which is a problem for the Bank and those similarly situated, rather than for this Symposium, there remain the problems of a physical, institutional, and economic character. These can be broken down into 24 items for discussion in this Symposium (see Table 1 for details). They might not all seem to be directly related to on-farm water management, but they should be included if "our primary concern is research directed to how to increase the agricultural productivity of water," as mentioned in the "Guidelines for Speakers and Panelists." Regarding the state of knowledge on these items, it seems that:

(i) We are deficient in precise knowledge about most of the problem areas, except a few items where fragmental information exists (but without meaningful generalization and integration that can be employed to increase agricultural production); and

(ii) All ite[illegible] will be solved specifically, site-by-site, but they can, or should, also be generalized.

Proposed Research Program

Seven priority subjects are suggested for immediate research work:

(i) Typical layouts for irrigation, drainage and road networks in relation to various slope and soil conditions (*Workshop Report*, paragraphs 30-34).

(ii) Standardization of farm turnouts with a simple measuring device (*Workshop Report,* Appendix 8).

(iii) Criteria establishing experimental farm and pilot schemes (*Workshop Report,* paragraphs 11 and 42).

(iv) Typical operations and maintenance programs of farmer organization (*Workshop Report,* paragraphs 51-55).

(v) General policy considerations for determining irrigation water charges (*Workshop Report,* paragraph 56 and Appendix 16).

(vi) Social indicators that quantify social benefits (*Workshop Report,* paragraph 62).

(vii) Unification of the terminology and statistical bench marks employed (*Workshop Report,* paragraph 17).

Table 1. Problem areas for discussion.

	Knowledge		Research	
	Adequate	Deficient	Site-Specific	Generalization
A. Physical & Biological Framework				
1. Topographical map		x	x	
2. Climatological data	x		x	
3. Hydrological data		x	x	
4. Soil and land classification		x	x	
5. Water requirement (crop and diversion)	x		x	a
6. Layout of irrigation, drainage & road network		x	x	
7. Water management facilities		x	x	
8. Land preparation		x	x	
9. Cropping patterns and production technology		x	x	
B. Institutional Framework				
10. Land ownership		x	x	
11. Farm supplies		x	x	
12. Credit and marketing facilities		x	x	
13. Research and experiinent (experiment form)		x	x	b
14. Extension and training (pilot scheme)		x	x	
15. Farmers' organization		x	x	
16. Construction of farm ditches		x	x	
17. O&M program		x	x	
18. Water charges		x	x	
C. Economic Framework				
19. Agricultural commodity prices		x	x	
20. Crop yields	x		x	
21. Production costs		x	x	c
22. Farm budget		x	x	
23. Social indicators		x	x	
24. Post evaluation (statistical framework)		x	x	

[a]Standardization of procedures and establishment of technical criteria are necessary.

[b]General guidelines should be established.

[c]International research work should be organized.

2.

DEFICIENCIES IN WATER MANAGEMENT KNOWLEDGE IN PAKISTAN

Jerry B. Eckert[1]

The first question assigned to this Symposium is, "in what phases of water management are we adequate or deficient in knowledge?" This paper focuses on the deficiencies that have become apparent as Colorado State University has sought to develop a water management research program in Pakistan. Since we have not yet explored all possible facets of the topic, it is probable that we have not confronted all of the existing gaps in knowledge. The list presented is therefore incomplete, and one cannot infer that knowledge is adequate on topics that are not listed.

In the following discussion, the specific questions on which more knowledge is needed in Pakistan are highlighted. While this emphasis may seem to have a rather narrow geographic focus, it is felt that the 15 broad subject areas represent subjects on which knowledge is generally deficient in much of the developing world. Some indication of the degree to which further research on these subjects will find general applicability multinationally is given in each section.

Deficient Phases of Knowledge

1. Physiological responses of plants to stress

Two sources of stress are important in Pakistan; moisture deficiency and salinity. Salinity can affect germination emergence, nutrient and water uptake, and other factors. Moisture stress affects cell differentiation, cell elongation, vascular system efficiency, photosynthetic and enzymatic activity, nutrient uptake and movement within the plant, and other factors. The severity and incidence of these stresses on different stages of plant growth determine their effects on the various components of yield.

Understanding these factors has become more important with the spread of high yielding varieties which seem to have more than one period of high sensitivity to stress. For example three stages are important in dwarf rice grown in Pakistan: maximum tillering, panicle initiation, and flowering. In dwarf wheat the most important period is not flowering as often supposed, but rather the stage of crown root initiation, tillering, and spikelet differentiation, all of which occur some three weeks after planting.

There is a considerable amount of basic research already completed or underway on this topic. The universities of developed countries and the international crop research centers have led the way. However, much basic research remains to be done that should have general relevance.

Site-specific dimensions applicable to individual countries center around integrating the basic physiological growth parameters with details of local climates, soils, water availabilities, and farming systems. Only then can the farmer adjust both his crops and cropping practices for maximum productivity.

2. Farm management environment of irrigated cropping

Systematic irrigation has been practiced in the Indo-Pakistan sub-continent for more than a century. Beginning in the 1880s, diversion structures were placed on the major rivers and irrigation water was delivered to previously unirrigated land. Under the British administration, as each new area was opened up it was colonized with good farmers from more densely settled areas. In most instances this meant moving people south from the ancient Khyber Pass-Delhi axis where rains were adequate for cropping (as much as 40 inches annually in some areas) to new lands where rainfall was generally less than 20 inches. The new irrigation systems provided as much as 2 acre feet of supplemental water per commanded acre annually.

Throughout this period there was essentially no research or extension in Pakistan on water management at the farm level, very little research on water control in channels below the minor distributaries, and even little appreciation of the losses and inefficiencies that might be involved. As a result, the current mix of "traditional" cultural practices was developed essentially through trial and error by transplanted rainfed farmers with no external infusion of water management concepts or techniques.

For this reason the soil-crop-water matrix of relationships is unknown to farmers at the *conceptual* level, and it is understood at the *practical* level only to the

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extent that manifestations of stress or imbalance result in visible changes in plant morphology or yield. Furthermore, since this subject has never been researched, water use planners do not really know what the farmers know and what they don't.

Plant-soil-water relationships are a highly generalizable research area as long as the basic dimensions of each component are adequately specified. There is also a need for some verification within the climatic and cropping environments of specific countries. The question of just how many water management principles particular farmer populations have derived by trial and error and what flexibility their cropping systems have to accept modifications in this respect is a highly site-specific but important issue.

3. Sources of water loss in the watercourse system

Historically almost all research effort has been concentrated on the efficiency of the delivery system above the turnouts from minor distributaries. Little attention has been given either to design or evaluation of watercourses under village and farmer control. We know that serious losses result from seepage, spills and breaks, over irrigation, and evaporation from water left standing in channels. But we do not know the quantities of water lost from each source. This site-specific information is urgently needed to determine priorities in research as well as in applied programs of watercourse improvement.

4. Inequality of water distribution

A closely related issue stems from the fact that we are unable to characterize precisely what the above watercourse losses do to the equity of distribution of the water resource. We feel (but are hesitant to admit) that lands on the watercourse tail are less adequately served than those at the head. But the extent of the difference is not known. Nor is the impact of this difference on cultural practices, cropping intensity, employment and income understood. Some evidence indicates that high-yielding varieties have been adopted less completely at the tail. Other evidence suggests that cropping intensity remains below 100 percent at the tail while it may be quite a bit higher at the head. More accurate information is needed before the water resource can be more equitably distributed. This issue is, again, site-specific.

5. Principles of water application

Recent research shows that application efficiencies in Pakistan are particularly low. The nuances of border design, border level, surface texture, rates of flow, turn out structures, and infiltration rate modification, while common knowledge elsewhere, are not understood by Pakistan's agricultural scientists, much less the farmers. Again, trial and error has wrought the use of an approximately level system of border flooding where water is applied without regard to the rates of advance and recession. Other cultural practices remove the above ground organic matter, increase nutrient leaching, and in several other ways contribute to diminished application efficiencies.

Much of the generic research on this issue has already been done. Some work remains possible on the hydraulics of surface flow related to surface texture and crop. Som what more localized issues include developing the influ ces of particular soils or soil salt problems on applicat n dynamics. A completely site-specific problem is the integration of means to control these hydraulic principles into local farming systems. In Pakistan this means we must find ways of improving the level and structure of borders in an agriculture characterized by the lack of mechanical power. We must find ways of altering the soils infiltration characteristics where rural society uses all above ground plant residues for fuel or fodder.

6. Salinity management

It is well known that salinity is an important historic problem in Pakistan. It has become even more critical in recent years as some of the many tubewells installed since 1960 have drawn up highly saline water. This problem has become so acute in some areas that wells have been closed as a result of farmer's requests.

Some of the specific issues on which our knowledge is presently deficient include:

(a) Crop tolerances to salt and how these can be enhanced by varying the irrigation or cropping techniques.

(b) A good specification of the chronology of changes in the soil chemical and physical properties as irrigation with saline water is initiated and continued.

(c) Our irrigation water quality standards are not adequate.

(d) Movement and management of salts. While this may be understood fairly well by a few it is not understood by farmers. Yet farmers are currently groping for solutions as salt accumulation occurs on their land.

Much of the above research has probably already been done and is transferable. What Pakistan needs is for the process of transfer to be enhanced, both into the country for field verification and from the scientist to the farmer for widespread adoption.

7. Experience in water measurement techniques

Water measurement techniques are an "on-the-shelf" technology in the form of handbooks, specifications, etc., throughout Pakistan. Yet it is a very dusty shelf indeed. Only one research station has any experience in measuring water and that was achieved by use of a calibrated tank. A few permanent wiers exist at other locations but these are largely unused. And since these techniques rely on immobile equipment, research specialists have no experience in water measurement on farmers' fields. Farmers characterize the flow of their tubewells by the size of the discharge pipe and judge the amount of irrigation by evaluating the depth of standing water with a more or less experienced eye.

This problem is not a deficiency in knowledge since measurement techniques are well developed and available in-country. Rather it reflects a deficiency in experience resulting from a lack of appreciation of the importance of precise water application.

8. Interaction of irrigation and fertilization techniques

Pakistan's farmers as well as most of her crop scientists do not understand the several ways in which irrigation techniques can affect the availability, uptake, and efficiency of nutrient use. In part this is because chemical fertilizers have been an important farm input only since 1960. There has been little or no research in Pakistan since then on fertilizer-water interactions either by the soil scientists, agricultural engineers or by economists estimating response surfaces.

If recent evidence on over-irrigation is correct, as I believe it to be, then nutrient leaching must be an important though inadequately perceived problem to the country's farmers. Several avenues for further research have been suggested which would have general, multinational applications. Among them are nutrient problems associated with the build-up of air pressure and the temporary loss of aeration under flooded borders as well as the particular nutrient retention problems associated with crop rotations where paddy rice alternates with upland crops.

Additional areas in which the knowledge or data base of Pakistan, at least, is deficient include the following.

9. Soil survey data

Although much has been done, especially in the irrigated areas, the key issue of infiltration rates remains untouched. We are unable today to generalize accurately the infiltration characteristics of important Pakistan soils, a situation which impedes water management research planning.

10. Consumptive use data

Existing results from Pakistan have been obtained with traditional varieties grown in low yield regimes and with an inadequate specification of the full range of climatic and soil environmental variables that pertained. Research is currently under way in-country to correct these deficiencies.

11. Water-nutrient response surfaces

A closely related problem is that no data exists to portray crop response surfaces where water is explicitly treated as a variable input and tne irrigation technique is precisely controlled. Some response surfaces do exist but, again, they reflect the varieties and cultural practices of 20 years ago and the method by which water was applied is unspecified. Research planning, and indeed national commodity planning and policy, suffers as a result.

Deficiencies in knowledge or data exist that are particularly relevant to rainfed agriculture. Rainfed cropping has the overriding factor of variability in moisture receipt and hence is subjected to much higher degrees of risk than is farming using irrigation. Many of the points made above could be restated in terms of farming systems dominated by risk and they would then hold for rainfed agriculture as well.

12. Rainfall intensity and runoff

Weather stations are scattered only infrequently throughout the rainfed farming zone and they are usually poorly instrumented and attended. As a result very little data exist that would characterize the intensity of rainfall or the amount of runoff. Both research and applied programs of agricultural development suffer from the lack of knowledge of just how much additional water could be captured on fields or in the watershed.

13. Land forming techniques compatible with the resources of rainfed farmers

Rainfed farming in Pakistan occurs largely on the areas above (northerly of) the Indus Plain; locations that are characterized by greater topographic variation than is the irrigated basin. For this reason, leveling, terracing and other water capturing and control mechanisms can require the movement of substantial amounts of earth. Pakistan has not adequately conceptualized or researched the various methods of achieving this where their rainfed farmers almost invariably have no access to mechanical power.

14. Soils characteristics

The Soil Survey of Pakistan has so far confined their attention to the irrigated regions. Hence the basic parameters of soils in the rainfed zones remain unknown.

15. Crop management under risk

Much of Pakistan's and India's rainfed crop land is also cropped at barely subsistence levels. The combination of uncontrolled and variable water receipts with the absolute necessity to eat renders the farming systems and management modes of the irrigated areas irrelevant. Instead farm management principles stress the insurance of a sufficient food supply at the expense of high yield. Risk minimization characterizes the cultural practices applied. Water is treated more as an insurance policy rather than a variable input into a market responsive production process.

In order to research and develop improved water management techniques for this type of environment, we need a much fuller understanding of the full range of motivations, values, and technical relationships between crops, inputs, and cultural practices that constitute rainfed farming systems.

Postscript

These 15 subject areas on which knowledge or experience is deficient in Pakistan may well be biased toward site-specific research topics. If so this reflects the author's point of view, that being one of an expatriot researcher trying to establish a program in a specific foreign country; Pakistan.

3.

COMMENTS ON IRRIGATED AGRICULTURE IN LATIN AMERICA

Engineer Agustin Merea C.[1]

Introduction

The sole purpose of this work document is to serve as a basis for discussion by the specialists met in this important Symposium and has been prepared in accordance with the request of the organizers.

Focus of the Theme

Having in mind the concern of the Symposium participants who have responsibilities in one way or another for agricultural irrigation development in the sense that this should contribute significantly to the harmonious and integral development of the various countries, we have felt it advisable, insofar as Latin America is concerned, to focus on the subject matter from a broad point of view, indicating some of the actions which may be valid in reaching the primary objective of the Symposium.

A discussion of this subject within the terms given, even circumscribing it within the area of Latin American irrigation development, is not easy. We must not ignore the fact that development priorities are different in each one of the countries, and that each one requires its own solution. In spite of this, it is hoped that the ideas presented in this work document, the situation and, within the limitations resulting from some generalization, will be useful in assisting in a fruitful interchange of ideas and experiences among the distinguished participants at this event.

Also, before beginning the discussion of the subject, we believe it would be helpful to review the agreement which established the Interamerican Institute of Agricultural Science and try to adjust our discussion to its philosophical perspective. In order to do this we would like to quote from some comments made in this regard by Dr. Jose Emilio Araujo, Director General of IICA:

> The humanist projection is based on the premise that the institutions of the agricultural section strengthen themselves sufficiently so that their programs reflect the idea that the ultimate users of the technological actions are not things but persons. In other words we must place the human being in his proper position of intrinsic dignity as the ultimate goal. This objective must supersede all technical activities. Let us after all establish a human development in our countries.

Conclusions Related to Some Development Studies and the Role of Agriculture in Latin America

We support the idea that irrigation development in the Latin American countries on various scales is intimately tied with its agriculture. This premise will facilitate the analysis and discussion of the comments made in this work document. The following are some of the conclusions that relate to various studies made, not only by national agencies, but also by regional and world agricultural development agencies in these countries.

In a general way the various studies agree that agriculture in Latin America is not carrying out the basic role that it ought to in the development of a region. Consequently, since we are not providing the proper nutrition necessary to insure a good diet, nor to provide for the export which is indispensable in order to bring in external resources which our countries need in their integral development, we are not obtaining the minimum development goals established in the Letter of Punta del Este, Uruguay, i.e., 5 percent economic growth rate.

One factor that underlines this conclusion is the population increase which is taking place throughout Latin America at a level very close to 3 percent a year. In accordance with this growth rate, the 244 million who lived in this region in 1965 grew to 280 million in 1970 and it is estimated that in 1980 they will reach 364 million. This very significant increase is better appreciated if one considers that in 1900 the United States had a greater population than Latin America; that between 1950 and 1960 this reversed and, that by the end of this century, in accordance with the various demograph projections, the population of Latin America will be about double that of the United States.

Studies carried out by CEPAL and FAO in 1970 in which the Latin American countries were grouped according to total agricultural development, show that in most cases the population increase is greater than the agricultural development and that few have a rate of agricultural development equal to population growth.

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These studies also show that the majority of the Latin American countries have had to increase their importation of food significantly recently, thus slowing down their own process of development through diverting important financial resources necessary for capital development of essential industries and other sectors. Thus, originated the vicious circle which makes it impossible to absorb the excess population which is moving from the country into the urban centers, resulting in unemployment and a higher cost of living.

FAO studies for the World Indicative Plan of 1970 estimate that the internal demand for agricultural and livestock products in Latin America in 1980 will be about 80 percent greater than in 1965 or almost 100 percent greater if we consider the need for an effective redistribution of income in favor of the poorer groups among our populations. An idea of the gravity of the problem can be secured by considering the figures of ALALC which indicate that in 1966 the Latin American countries invested 1,200 million dollars in the importation of agricultural products. It takes little effort to visualize the tremendous investments that will be necessary in the immediate future if we do not drastically increase agricultural production.

To further emphasize the trend, the volume of agricultural exports from Latin America between the period of 1948 to 1952 and 1965 increased by 39 percent, while imports increased by 70 percent. Unfortunately, in many cases this very significant difference has been further accentuated since 1965.

Also, a conclusion resulting from various studies and with negative repercussions in Latin American development, is the high cost of middle men, both in the provision of goods and services and in world marketing of agricultural products.

Finally, let us review some conclusions made a little over a year ago by Dr. Addekeh Boerma, Director General of the FAO, in his annual report to the Economic and Social Council of the United Nations.

In this report he expresses extreme concern over the situation created by the notable decrease in agricultural production, emphasizing that while the provisions of the U.N. for the second development decade targetted an annual increase of 4 percent, in 1970 it reached only 3 percent and in 1971 did not exceed 1.5 percent. He cited as the reason that little attention is given to agricultural development and is justified by the increasing devaluation of basic export materials when compared with the increasing importation of manufactured goods from the industrialized countries. A trend was also noted in structural reform, the development of agriculture, especially the Green Revolution, which had to some degree slowed this trend.

It cannot be denied that the various conclusions that we have cited are markedly pessimistic, since they apply to all of the Latin American countries. In spite of this, there is the conviction that these countries have the capability of overcoming them and that within them, according to their capacity, there will be an important role played by the present and future irrigated areas and with an appropriate interplay of policies, socio-economic activities, and technology there can be developed a significant comparative advantage over dryland areas which should result in spectacular increases in agricultural production.

In spite of the possibilities of increasing dryland agriculture by using more advanced technologies, these will never develop production levels that can be reached in areas provided with irrigation, whether total or supplementary, even in areas with normally adequate precipitation. In addition, an appreciable part of the dryland areas of the Latin American countries are marginal as are their productive capacities, often because of an excess or lack of rain. We are all familiar with the frequency with which various governments have had to declare these zones as disaster areas.

Differences Between Latin American Countries Related to Their Areas of Agricultural Development

Based on the data cited, we can conclude that among the Latin American countries with several exceptions, there is an appreciable similarity in the percentage of contribution to the internal gross product by the agricultural sector. This averaged 16.2 percent for 1969. With these general similarities in mind, let us now turn to some of the differences which exist between the Latin American countries as related to the theme of this Symposium.

An appreciable number of the countries depend fundamentally on dryland production in their agricultural sector. In Table 1 the differences will be noted. Also one may note that all of the Latin American countries have some areas under irrigation. The total of these areas is in excess of 9,526,000 hectares which represents 6 percent of the total cultivated area of the region.

Some of the differences among countries that can be noted in Latin American statistics related to agriculture are: Rural population and rate of growth; percent of the value of agricultural products compared with total export; percent of the value of imported agricultural products over total imports; relative percentages of dryland and agricultural production influencing respective national economies, etc. We should also mention that political institutions have an important influence on the adoption of policies or lines of action which favor the development of irrigated areas. The current federal system found in various countries which recognize in its provinces or

Table 1. Lands cultivated and under irrigation in the Latin American countries.

	Thousands of hectares		
	Cultivated[a]	Irrigated[b]	Percentage[c]
Northern Zone			
Costa Rica	622	26	4.2
El Salvador	648	21	3.2
Guatemala	1,498	32	2.1
Honduras	823	66	8.0
Mexico	23,817	3,515	14.8
Nicaragua	873	29	3.3
Panama	564	14	2.5
Total	28,845	3,703	12.8
Andean Zone			
Bolivia	3,091	64	2.1
Colombia	5,047	270	5.4
Ecuador	2,596	463	17.8
Peru	2,814	1,091	38.8
Venezuela	5,214	218	4.2
Total	18,762	2,106	11.2
Southern Zone			
Argentina	33,450	1,300	3.9
Brazil	67,976	550	0.8
Chile	4,511	1,170	25.9
Paraguay	947	9	1.0
Uruguay	2,252	43	1.9
Total	109,136	3,072	2.8
Antilles			
Haiti	370	42	11.4
Dominican Republic	1,067	110	10.3
Cuba	2,044	493	24.1
Total	3,481	645	18.5
General Totals	160,224	9,526	6.0

[a]Includes annual and perennial cultivated pastures and fallow lands according to the census made in the various years.

[b]This includes lands irrigated by canals, wells, and sprinkler irrigation, whether throughout the year or only in the dry season.

[c]Of irrigated lands over cultivated lands.

Source: Annual Report of Production, FAO, 1969, brought up to date, in part, with data obtained from recent national reports.

states, the fundamental attribute of administration and development of its water and land resources, contrasts with the "united" regime found in other countries, whereby executive power for resources is at the national level. Consequently, in countries having a "federal" regime there coexists an appreciable number of organisms or entities at the national, provincial, or state level with common responsibilities related to the various activities of irrigation development, but without having in general, a level of coordination essential for these areas to develop. On the other hand, the areas with a "unified" regime, even though they have the advantage of having a fewer number of institutions, still do not escape the limitations of a lack of coordination between agencies.

Another fundamental difference between the countries in the region is that some of them are not actively applying integral agrarian reform and farmer organization processes. This is in spite of the fact that in the 1961 Conference at Punta del Este it was agreed that these processes were needed to effect a transformation in the structures of unjust land holding systems and land exploitation. Latifundio and minifundia was to be substituted for more just systems of land ownership which would include among other things, adequate amounts of credit given at the right time, technical assistance, commercialization and distribution of produce, and the economic stability which is fundamental for the welfare of the farmer and which would guarantee his liberty and dignity.

In noting these discrepancies, which the participants of this Symposium could undoubtedly add to, the purpose has been to reinforce that which was previously said. Having in mind the characteristics of the various Latin American countries, it is not likely that the ideas which we have suggested as lines of action in favor of a better and more rational development of irrigation areas will result in an adequate application of each and everyone of them. In addition we recognize beforehand that such problems of a general nature which have undoubtedly been already discussed by other speakers may have been overcome to some degree. At any rate, many of the factors constraining our development have their origins in sectors other than those which are represented here.

Courses of Action Favoring Irrigation Development in Latin America

With these things in mind, we have some courses of action or policies which in our opinion can contribute to the development of this area.

Agricultural planning

We believe that it is the undoubted obligation of the state to carry out short, medium, and long-range agricultural planning on a permanent basis.

This planning should harmonize dryland and irrigation production at the national level, it should be formulated by the agricultural planning sector in close collaboration with the commercial, financial, and industrial organization operating in the interior and the exterior and be related directly to the capabilities of the country. It should have priority for the majority population groups, substituting local production for importations and permitting competitive export.

Agricultural planning in the irrigated areas should be done, we believe, by the executives who are directly responsible for the operation, conservation, and development of these areas. These executives should, with the legal backing and in conjunction with other criteria such as consideration for the ecology of the pertinent areas, the availability of hydraulic resources and the preferences of the farmers, develop and put into practice irrigation and other cultural practices in accordance with their plans.

To a great extent the success of agricultural planning lies in serious and careful studies of the various realities and in their appropriate evaluation and control with the assistance of a two-way flow of information between those responsible for its formulation and those who have to apply it.

Putting into operation the legal and regulatory norms related to the use of water

In order to facilitate the desired development, it is imperative that both the surface and subsurface waters be used in the best interest of the countries.

Legislation which has already been passed in some of the Latin American countries should be developed. This permits, among other things, the following:

(1) Reorganize zones, watershed basins, or irrigation areas with the objective of a better and more adequate use of the water.

(2) Declare zones of protection in which activities that can affect water resources can be limited, controlled, or prohibited.

(3) Be able to divert water from one watershed to another one which requires development.

(4) Replace a water supply source of one or more users by another of similar quantity and quality in order to obtain better use of the available resources.

(5) Establish as the general rule, the volumetric measuring of the distribution and use of water in its various utilities.

(6) Recover the economic costs which are charged against water users and for its various uses by volume utilized.

(7) Distribute water for agricultural use, normally in accordance with semiannual or annual irrigation plans.

(8) Take into consideration, in the planning for water use, available subterranean waters in irrigation project areas.

(9) Define the criteria under which water will be distributed in irrigation project areas for the best social good where there is likely to be an eventual water deficiency.

(10) Create a system of social indemnification in which the water users participate in an irrigation project or appropriately compensate those, who after application of the previous principles, are unable to use the water.

(11) Reaffirm the authority of those responsible for operation of the projects within the appropriate laws and regulations.

(12) Simplify, to the utmost, administrative red tape which tends to tie up necessary adjudications essential for the better use of the water and land.

(13) Permit the maximum involvement possible by the water users at various levels in the irrigation project in decision making, including, among other things, the adoption of cultivation and irrigation plans, conservation works, and improvement of the pertinent infrastructure.

(14) Incorporate as advisors to the irrigation project authorities, authorized representatives of the regional credit authorities, technical assistants, and agricultural researchers in farmer training and organization, agrarian reform marketing, planning, etc. to assist in the making of decisions.

(15) Create a court of adjudication of lands and waters to facilitate the appropriate consideration of water user complaints against administrative resolutions and decisions by various project authorities.

(16) Charge the owners and/or users of improved land, totally or partially, the monies invested by the state in the construction, improvement, or rehabilitation of irrigation projects fixing the obligations and the payment period by appropriate consideration of such factors as agricultural capability, size of farms, economic condition of the farmers, and cost per hectare of the works.

Application of agrarian reform of rural readjustment action

We suggest that for Latin American irrigation areas, the following criteria for development would be in our interest:

(1) Maintain by means of adjudication to campesinos under the associated farms, better adoption of the physical unity of the areas that can be affected in order to permit greater efficiency in the distribution of water and agricultural activities.

(2) Integrate minifundio zones so that they become efficient irrigation areas.

(3) Promote, with the support of the various campesino organizations that are established, cooperatives to provide agricultural materials, machinery, storage, marketing, and processing of agricultural products.

(4) Secure land from absentee owners who have without justification, not developed agricultural activities and put their water to better use.

(5) Declare for public use and expropriate before construction of new irrigation projects, all of the land that is within the project area in order to permit that those responsible for the design can properly develop efficient irrigation units.

Priorities for the investment of public funds

Having in mind the amount of investment necessary for the planning, construction, improvement, rehabilitation, and development of irrigated areas and the scarcity of resources, we suggest the following order of investment priorities:

(1) Improvement and additions to the collection, distribution, control, and measurement of existing works.

(2) Regulation of irrigation.

(3) Flood control.

(4) Drainage of areas which, because of the water table level or the presence of salt, have lost their productivity or are threatened.

(5) Conservation of hydrologic basins and flood control.

(6) New irrigation projects.

Agricultural research and technical assistance

For these important activities which are so closely related to irrigation area development and which, through the support of experimental stations and other collaborating agricultural lands within representative areas, the following activities are indicated:

(1) Adopt or discover improved crop varieties that can be developed within the ecology of the area and in accordance with agricultural planning.

(2) Research and adopt irrigation methods which will be the most appropriate for the various crops having in mind crop characteristics, existing soils, application efficiency, and the capabilities of the farmers.

(3) Conjointly with the above, discover the best planting dates, cultural practices, and depths and frequencies of irrigation most appropriate for the various crops during the growth period.

(4) Develop specification and insure their compliance in practices that relate to crop and animal hygiene.

(5) Develop and publicize methodologies which will be the most economic and rational for the systematic development of lands for irrigation, drainage, and leaching.

(6) Give special assistance to farmers with scarce resources.

In spite of the obviousness of the above described activities, we believe we do not err in affirming that in many of the Latin American irrigated areas these things are not being carried out on a scale that is needed in order to favor their development, since there is not available sufficient technical personnel, nor sufficient research and demonstration areas.

Agricultural credit

Without doubt this service is one of those which is most frequently involved in development. We have the following recommendations:

(1) Increase to the maximum possible limit the financial resources of the official credit institutions that are responsible for the different types of credit needed for agricultural and livestock activities.

(2) Create, where they do not exist, official entities which have the distribution of agricultural credit as their only responsibility.

(3) Include in the Boards of Directors of these official agricultural credit entities, not only representa-

tives of the official sector, but others involved in various agricultural developments, such as the users of the credit.

(4) Establish regulations which require, as is already done in some countries, that private banking dedicate a percentage of its capital to agricultural credit.

(5) Reduce interest rates to the lowest possible level and fix differential scales in accordance with socio-economic criteria and at national and regional agricultural planning imperatives.

(6) Include sufficient resources so that farmers in the agricultural credit can handle properly their obligations of administration, operation, conservation, and improvement of irrigation projects.

(7) Provide credit for technical assistance from the professional private sector.

(8) Provide for the establishment of agricultural processing industries.

Agricultural marketing

This process is complex and difficult to carry out not only at the national level, but at the international level. It is, if not the principal, certainly one of the major components in the agricultural development of both irrigated and dryland agriculture.

In spite of its complexity and the fact that appropriate treatment of agricultural marketing is beyond the range of this document, permit us to make a few observations on this topic. We suggest that the Latin American governments should support activities which tend to:

(1) Within the limits of agricultural plans, guarantee to the farmers fixed prices for their products.

(2) In the production center establish facilities for storage required for the various products.

(3) Support the creation of commercial cooperatives and purchasing centers near the major centers of consumption.

(4) Fix the major food prices.

(5) Stimulate the export of agricultural products that can compete advantageously in world markets.

(6) Control the sale of products used in agricultural production.

(7) Establish a permanent system of evaluating for future planning fluctuations occurring in internal and external markets.

(8) Study and fix quality standards for agricultural products destined both for internal and external use.

(9) Control the importation of agricultural products.

Education and training

Undoubtedly, the correct application of the different policies and lines of action that are involved in the integral development of Latin American agriculture in general and in irrigation in particular requires of its directors a high grade of training.

Limiting ourselves to those who are directly involved in administration, operation, and conservation on irrigation projects, we would like to point out the desirability of establishing in every country at a pilot project a well equipped training center designed to help all of the staff at various levels who are involved in irrigation projects to become trained in the various disciplines and methodologies of their professions. This also should be extended to water users on these projects who should be made familiar with the methodologies and technology that is most appropriate for their agricultural activities. This training capability already exists in some Latin American countries (Brazil, Colombia, and Peru among others).

Institutional organization

Institutions are already set up in Latin American countries, having in mind the political processes, to operate within the various systems. Consequently, we do not suggest a fixed organization model. I am sure that the participants of the Symposium will agree that we should limit ourselves in underlining the urgency of reinforcing as quickly as possible the coordination that is essential for the administration, operation, and conservation of the Latin American irrigated areas and integrate these with all of the other actions that would contribute to their development.

We believe that there is much left to do in this regard. The distribution of water in many of the irrigated areas in Latin America is not supported by the results obtained in the experimental stations in regard to appropriate planting dates and frequency and depth of water. A part of the crops are planted on lands that are not well suited to them, credit is not extended at the proper time and in sufficient amounts, and cropping patterns are poorly planned often resulting in an excess of products in their areas. Routine conservation works frequently interfere with the normal distribution of water to the crops and stations do not dispose and apply cultural practices which are best for crop development and for conservation of land and water.

Without doubt there have been some very favorable changes made in recent years in many Latin American countries by institutions involved in the development of irrigation. Limiting ourselves to national institutions which are related to the process of adminsitration, operation and conservation of irrigation projects, there have been recently developed or reorganized: In Argentina, the Subsecretariate of National Hydraulic Resources; in Brazil, the Irrigation Executive Group for Agricultural Development and (GEIDAS); in Chile, the National Irrigation Company; in Peru, the General Directorate of Waters and Irrigation Districts; and in Mexico, the Subsecretariate of Hydraulic Resources. Finally, at the regional level in the countries with "federal" regimes there is the important work that has been conducted by autonomous development corporations of which there are several excellent examples in Mexico, Venezuela, Argentina, and Brazil.

Final Comments

We are certain that the thoughts expressed in this working document have not covered all of the activities that the Latin American countries are developing or can adopt in order to speed up the development of their agriculture, and, of course, their irrigation waters.

In spite of this deficiency we would like to express our confidence and hope that these comments have been useful in an interchange of ideas, that, supported by the great experience of the distinguished professionals present in this meeting, might enable us to draw useful conclusions, not only for the program of technical assistance to irrigation of AID, but also other organizations and international agencies that are represented here.

I will mention one of these international organizations, the Interamerican Institute of Agricultural Sciences of the OAS (IICA) in relation to its fulfillment of its general objective of helping Latin American countries to stimulate and encourage rural development as a means for general development and the welfare of its population, recognizing the fundamental role that irrigation can play in the reaching of general objectives.

IICA has established among its different programs a specific one to assist in the development of irrigation. This program for the moment, is limited to the temperate South American region–Argentina, Brazil, Chile, Peru, and Uruguay–but will shortly be extended in accordance with the recent resolution of the Board of Directors to the rest of the Latin American countries. In order to assist the participants of this Symposium, I have attached, as Appendix I, of this working document a statement describing various aspects of that program

Appendix I
Activities of the Irrigation Program of IICA

Program I

Agricultural education

Postgraduate level. Support the carrying out of courses for graduates in irrigation in the Latin American centers of superior training that are already teaching in this specialty.

Provide scholarships to graduate students interested in irrigation.

Program and partially finance the interchange of professors.

Participate in the programming and presentation of courses by IICA specialists.

Stimulate and support technically and financially theses which deal with hydraulic resources. Program technicians can function as professors and advisors and thesis advisors to graduates in irrigation and agricultural economics.

Study the possibility of developing through IICA interrelationships between graduate training institutions and advanced centers such as the University of California at Davis.

Faculty level. Analyze the training programs in irrigation in the advanced institutions of agricultural education.

Collaborate with various faculties so that they might develop what would be considered a minimum amount of knowledge necessary for professional functioning of agricultural technicians.

Carry out meetings for professors of irrigation in which study programs are prepared for the situations of each region.

Prepare material for publication of a basic text of irrigation courses in universities with illustrations related to technical and economic aspects of the use of water, principally in Latin America.

Program II

Agricultural research

Develop agreements to establish a uniform methodology for collecting, analyzing, and publishing basic irrigation information. Carry out international seminars for specialists to obtain climatic and hydrologic data necessary for irrigation.

Promote the coordination of technical and institutional work related to irrigation.

Establish regional research projects in areas representative of the various zones—humid, arid, and semi-arid. The determination of levels of use appears to be of particular urgency.

Propose experimental designs for research in irrigation which will assist in the economic evaluation of its results.

Promote and partially finance the exchange of researchers in irrigation between the principal institutions of the area.

Support the following types of research:

Agronomic research. Identification and quantification of the effect and interrelation of limiting factors in irrigation.

Study of the climatic and hydrologic resources in order to identify regions with a humidity deficit, principally in the normally humid zones.

Study the quality of water available and water distribution systems, especially in arid and semi-arid zones.

Determine crop water requirements.

Analyze the critical crop periods with respect to rainfall deficiencies.

Determine interrelationships among soil moisture, fertilizers, and other inputs.

Analyze crop rotation and diversification in irrigated areas.

Reclaim soils affected by problems of salinity and drainage.

Engineering research. Study of distribution, measuring and control structures for irrigation water.

Design of irrigation systems in order to achieve a greater water use efficiency.

Reduction of conduction and storage water losses.

Economic research. Supply and demand potential for crops in irrigated areas.

Analysis of groups of representative lands with emphasis on calculations of the structures of costs and incomes and in planning of irrigation at the farm level.

Study of the minimum economic size of irrigated farms.

Analysis of the problems of planning and the joint use of surface and subsurface water.

Feasibility of systems and irrigation practices.

Determination of cost-benefit relations in alternative uses of water.

Legal and organization research. Model laws for distribution and control of irrigation waters.

Organizational models for irrigation districts.

Disposition alternatives of the major value generated by irrigation projects.

Program III

Rural development and agrarian reform

Collect and systematically distribute information on the data related to hydraulic resources and its rational application for development. Study the possibility of establishing a documentation center on hydraulic resources.

Identify specific projects that can serve as a basis for activities of evaluation and operation methods based on research and in-service training.

Contribute to the determination of methodology for the elaboration, analysis, and evaluation of multiple-use water projects, including irrigation.

Provide assistance in the development of irrigation projects that require international financing, principally through the International Development Bank.

Publish a manual of evaluation and operation of irrigation projects.

Promote interdisciplinary work by technicians and various professionals with emphasis on collaboration between agricultural and civil engineers and economists.

Offer training and advice for the development of national irrigation courses by official training institutions for rural technical personnel.

Collaborate in the establishment of a development area based in an irrigation project, possibly in Buenos Aires Province with the Argentine Secretariate of Hydraulic Resources.

Initiate a program of short courses on specific aspects of the application of soils for irrigation; obtaining of water for small irrigation works; irrigation planning at the farm level; and irrigation of selected crops.

4.

WATER MANAGEMENT IN THE SUDAN: WITH SPECIAL REFERENCE TO IRRIGATED AGRICULTURE ON THE CENTRAL CLAY PLAINS

Osman Ahmed Ali Fadl and H. G. Farbrother[1]

Introduction

After more than 60 years of highly successful production of irrigated crops, mainly long-staple cotton, with sorghum and fodders; and more-recently introduced wheat, groundnuts, and sugarcane, on heavy montmorillonitic clay, it is clear that the major problems of soil and water management must have been satisfactorily resolved. Wherever adequate supplies of water have been made available there have been no recorded cases of failure due to intrinsic soil or water defects.

By 1934, the research workers of the Ministry of Agriculture and the engineers of the Department of Irrigation had confirmed the broad guidelines for use of water and the operation of the canalization system to meet those requirements. The 1934 recommendations have remained in force since then as the basis of the irrigation practices. Over the years, however, there has been a great deal of rationalization in the field implementation of those recommendations; mainly in the direction of reducing the extremely high labor inputs originally demanded of the tenants of the Gezira Scheme. It is important to note that although the details of some of the field operations have changed almost beyond recognition, the basic rates of water utilization have remained unchanged. (Farbrother, Ann. Rept. '70/71.)

There were very rapid increases in the gross area commanded on the central clay plains during the years following Independence in 1956. The new irrigation schemes ranged in size from Managil Extension of 800,000 feddans[2] (336,000 ha), to hundreds of small privately owned pump schemes, varying between 12,000 feddans and 40 feddans. On these newly developed areas, the same recommendations were adopted, together with all the expertise in water management that had accumulated from experience over the years on the original 1,000,000 feddans (420,000 ha) of the main Gezira Scheme. Again a remarkable record of freedom from major problems of field watering was achieved: except, perhaps, where water availability, for various technical reasons, was the limiting factor.

Salinization: Is It a Threat?

1. Measurement of salt status

The question of salt accumulation in the Gezira soil after being brought under irrigation has apparently occupied the attention of research workers since the inception of the scheme. Beam, for example, claimed in 1911 that if gypsum was to be used in the Gezira it might improve soil fertility and tilth. Joseph (1925) concluded that the 6.5 ppm sodium in the irrigation water from the Blue Nile replaced the exchangeable calcium in the clay, hence resulting in the apparent waterlogging of irrigated soils. This was assumed to be the reason for low productivity. Balls (1935) strongly advocated a sub-soil drainage system in the Gezira, comparable with what had been done in Egypt, as a precaution against the development of a perched water table. These arguments, it should be noted, were presented in years of very low cotton yields, when the lack of a drainage system was presumed (quite wrongly in today's view) to be the main factor involved. At the time, these arguments initiated a long and heated controversy with Greene and Bailey (1935) who did not find any strong evidence of inevitable soil deterioration under irrigated cultivation, as would have been necessary to justify such an expensive project. In their opinion, the lateral and the downward movement of water into this soil was so slight that, in any case, a drainage system would have been ineffective.

It was estimated by early research workers that the amount of total salts added by irrigation to land on the then standard 6 course Gezira rotation was 2.4 tons per hectare every three years.

More recent work, however, has indicated that there has, in fact, been a net downwards movement of salts over the years since irrigation was first introduced. Osman Ali Fadl (1964) for example, worked on samples collected from the top 10 cm of soil of the "Permanent Fallow Plot," and from a "Continuous Cotton Plot," (the latter irrigated seasonally since 1918) at the Gezira Research Station (GRS). He reported the data shown in Table 1.

[1]Senior soil physicists and senior plant pathologist, Gezira Research Station, respectively.

[2](1 feddan = 0.42 ha = 1.038 acres).

Table 1. Salinity of Gezira Soils.

	Saturation Extract Analysis				
	ECe	mequiv/litre			
	mmhos/cm	Na	Ca	Mg	Σ cations
Cotton	0.56	2.80	1.98	0.30	5.08
Fallow	1.01	8.32	1.00	0.66	9.98

	Exchangeable Cations mequiv/100 g soil					
	Na	K	Ca	Mg	Σ cation	ESP
Cotton	1.23	0.84	37.26	5.41	44.74	2.75
Fallow	4.30	0.64	29.31	2.73	36.98	11.63

The plots referred to are only 2 kilometers apart at the Gezira Research Station, and it is evident that ECe and soluble sodium are very low in the Continuous Cotton Plot, in spite of it having received very large quantities of Blue Nile irrigation water over the previous 45 years.

Later on, Fadl (1971) reported that the total water content of the soil profile under the Continuous Cotton Plot at the end of the cotton season was 874.7 mm to 2 meters depth. This was higher than that generally encountered under rotational cotton at the Gezira Research Station, where at least two dry fallow years are included in the eight year rotation. The difference was also due in part to the shallow depth of rooting of the cotton plants grown continuously on this plot without added fertilizers. More important, perhaps, is the fact that there was no indication whatever of a perched "water table" in this profile.

The ECe in this profile was less than 1 mmhos/cm down to 100 cm depth, thereafter the conductivity increased slightly with depth until it reached 5 mmhos/cm at 185 cm. These figures showed that salts under this plot were extremely low in comparison with other sites at Gezira Research Station or for the typical Gezira soil. Although this does not indicate that the soil has reached equilibrium with the salts as found, yet it can safely be concluded that, even after watering for more than 50 years, there has been no accumulation of salts, in the rooting zone. There has certainly been transport of salts down the profile and any zone of accumulation must be below the 2 meter depth of sampling.

In a research project on the periphery of the eastern boundary of the Gezira Scheme, Osman Ali Fadl and Mohamed A. Ali[3], investigated a highly saline-sodic site which was planned for development as a fruit and vegetable garden. Samples from the top 40 cm of soil before irrigation gave mean ECe 15 mmhos/cm, and ESP in excess of 60. Following two inundations totalling 705.3 mm, the ECe was reduced to 1 mmhos/cm in the top 10 centimeters, and to 6 mmhos/cm in the 30-40 cm zone. Recommendations for the development of the site were based on the observed movement of water down the profile. The measurement of water was by a neutron probe, and the supplementary information on salt movement by physical sampling. Now, at the time of writing, after ten months of irrigation, the site carries a good crop of lucrene (*Medicago sativum*) and other fodder crops.

2. **The evidence of rising commercial yields**

Yields of cotton, groundnuts, and wheat in the Gezira have increased over the past decade mainly as a result of improved husbandry, crop protection, fertilizer policy, and varietal introductions. The field management of irrigation water in the commercial areas of the Sudan has never been noticeably influenced by the theoretical considerations of salinity and permeability; although, as we have seen, a great deal of classical research has been carried out over a long period, and reported in the world's literature. The merits of any proposed changes in the irrigation schedules have been judged solely on the responses obtained in the yield of seed cotton. The quantities of water actually used in these field schedules will be discussed at greater length in a later section of this report; *but it is relevant here to interpret the encouraging upward trend in yields of all the main crops of the Gezira as evidence that (a) the supplies have approached the optimum requirements, and (b) that at that level of water utilization the basic soil conditions have not become a limiting factor to yields.* The intensification of the standard eight-course rotation of the Main Gezira over the last decade, from only 45 percent cropping to 62 percent or more, has resulted in a very large increase in water used on the land. The fact that yields of cotton, wheat, and groundnuts have risen appreciably over the same decade, gives additional cause for optimism that salinity is unlikely to become a limiting factor to the further intensification of the rotations.

It is relevant at this point to present some examples of the advances in both the techniques and the basic knowledge of the bahavior of Gezira clay under irrigation.

Soil Moisture Measurement in Studies on Salinity

The scientific evidence now available in support of the views on salinity which have been given above, has been obtained primarily from recent advances in the physical understanding of the role of water in the soil.

[3]In preparation for publication.

The use of neutron probes and gamma probes in obtaining moisture and density profiles, before, during, and after watering, has provided a new and comprehensive insight into the behavior of both soil and water in the typical Gezira clay profile.

(a) The role of cracks. In 1972, for the first time on Gezira clay, the IAEA neutron probe (made by Troxler, North Carolina) was used to follow the minute-by-minute progress of the initial stages of watering. The exceptionally rapid completion of the intake of water confirms that the first stage of wetting is confined to free flow down the cracks, being quantitatively related to their volume and depth. Previous research has suggested that the latter are inversely proportional to soil moisture content. This was clearly demonstrated on a moist profile when an irrigation of about 73 mm was taken up by the 0-60 cm depth, in as little as 5 minutes. (Fadl, Ann. Rept. 1972/73.) This suggests a rate of uptake of 88 cm per hour—some 1000 times greater than the highest hydraulic conductivity quoted for Gezira clay elsewhere. As soon as the 0-60 cm profile reached its full capacity, the rate of water intake declined to almost zero.

(b) Moisture profiles in depth. The neutron probe results have also shown that later stages of wetting depended on the difference between the water uptake "capacity" of the soil, and the initial soil moisture content in the upper layers. However, at an extremely dry site, which was irrigated for the first time, the neutron probe has shown that water uptake decreased exponentially with time, approaching zero after 6 hours.

Whether this slow redistribution of irrigation water is by slow saturated flow, or by unsaturated flow in response to the tension gradient set up by the invariably dry subsoil, is still an unresolved question.

The seasonal limit of detectable change in soil moisture content, using gravimetric methods, was shown by Farbrother (1970) to average 1.3 meter depth under long-staple cotton crops. For paddy rice, on the other hand, Fadl (1973) using the neutron probe, has reported detectable accretions at 2.0 meter depth after continuous flooding for the three months growing season.

The weight of the overburden, even at 50 cm depth, is now suggested as the main reason for the low hydraulic conductivities at that depth. Abdine (1971), working in the laboratory on disturbed samples under a stress comparable with 50 cm overburden, reported hydraulic conductivities varying from 0.009 to 0.0009 cm per hour as the ESP increased from 3.8 to 28.8.

At these levels of hydraulic conductivity, however, the amount of water moving to depth will obviously be very limited under the normal irrigation regime of the Gezira.

Conclusions

These detailed studies of the principles of downwards movement of water in the Gezira clay profile, explain many of the questions relating to the transport of sodium salts to relative safety below the cyclic depth of wetting.

Clearly, these examples of the advances that have been made in recent years on the physical behavior of water in typical Gezira clay profiles have introduced a new dimension into the hitherto controversial questions of salinity and water management under long-term irrigation. So rewarding has this particular research already proved, that the saline-sodic site mentioned earlier, formerly classified as unirrigable, is now being brought successfully into production by following the appropriate advice on water management.

In this particular aspect of water management, considerable advances in knowledge have been made under these difficult, and almost unique, soil and water conditions. Much remains to be done, however, and the present limitations of trained staff and facilities (not to mention the high dollar costs of spare parts for the Troxler gages and scalers), are severely hindering the progress in this field.

Crop Water Requirements

1. Design water use assumptions

Over the 60 years of irrigation in the Sudan there have naturally been great changes in the attitudes adopted by the various official organizations responsible for the administration of water. In general, these changes have reflected the tremendous advances that have been made elsewhere in the subject over the past 25 years, since Dr. H. L. Penman of Rothamsted, England, first began to apply the principles of pure physics to the questions of natural evaporation to the atmosphere. In retrospect, however, it is not unfair to comment that the scientific contributions to the practice of irrigation in the Sudan have often in the past lagged behind academic achievements. But it will be readily appreciated by all scientists and engineers who have their feet on the ground, that it is far more difficult to inject science into an already well established and successful scheme, than into a new project not off the drawing-board stage.

In spite of many difficulties with traditional and conservative attitudes, great progress has been made over the past few years in fitting sound scientific explanations to the current practices of field watering. A great deal of research effort has been put into the scientific basis of prediction of water requirements and it is with a considerable sense of pride that we can now claim that the *"Penman Eo x Crop-Factor"* method of forecasting crop requirements for the central clay plains area of the Sudan, is at least as good as, and possibly better than, any other method in use elsewhere.

It is relevant at this point, to trace out the sequence of steps over the lifetime of the Gezira Scheme that have led up to the present satisfactory methods of forecasting crop water requirements.

The earliest irrigation engineers of the Gezira, for example, assumed a rational peak requirement for a "cropped feddan," irrespective of crop and season. The original assumption used in the design of the Gezira canalization system was a peak requirement of *"34 cubic meters per cropped feddan per day"* (8.1 mm per day), but for gross supply calculations, this was reduced (by "Scale-of-size" assumptions too complex to be explained here) to *28 cubic meters per cropped feddan per day* (6.7 mm per day) inclusive of conveyance losses. (Ref: Original Data Design Sheets S.I.D.)

Irrigation engineers eventually avoided the complications of "Scale-of-size" by adopting a uniform *30 cubic meters per cropped feddan per day* (7.1 mm per day) exclusive of conveyance losses, for all planning purposes in both design and supply.

This figure of 30 cubic meters per cropped feddan per day was fully compatible with the traditional Gezira field schedule of *"420 cubic meters water duty per feddan at 14-day intervals,"* and it remained virtually unchallenged until 1970.

In 1964, however, Hunting-MacDonald as consultants to the Ministry of Irrigation, submitted their pre-investment study of the new Rahad Scheme, in which they introduced to the Sudan for the first time a form of the Penman Eo x Crop-Factor method of predicting crop water use. It did not then constitute a challenge to the universally accepted traditional schedule, as it was not widely circulated, and was in any case, very difficult to understand.

2. The tradition research approach

Contemporary with the long period during which both engineers and agriculturists accepted the arbitrary assumptions on consumptive use, the research workers of the Ministry of Agriculture were actively committed to the policy of testing likely variations of irrigation schedules. They covered as wide a range of nominal water treatments as could be devised, using the yield of cotton as the criterion in fully factorial field layouts. A typical example would have had all 12 combinations of 7, 14, 21, and 28 days interval, with "Light," "Medium," and "Heavy" rates of water duty (nominally, 71, 100, and 143 mm respectively).

More than 135 field trials were conducted, mainly with cotton as the indicator crop, and on average, the 14-day interval at "Medium" rate gave the best chance of obtaining consistently good yields. The response curves, however, were always very broad and flat; individual treatments rarely reached significant differences from the overall mean, except occasionally at the factorial extremes. In no trial did the best combination of rate and interval outyield the neighboring trials on the research farm in the same year. Moreover, these field comparisons of schedules failed to give the quantitative evidence that was so badly needed on the daily water consumption of crops; even though some soil moisture measurements on a limited scale had been incorporated into the trials after 1957.

3. Methods of prediction

Predictions of consumptive use, derived by the various methods published by research workers elsewhere, were calculated using Sudan climatic parameters, following the impetus given to this approach by the establishment of the Agro-Climatological Section of the Sudan Meteorological Service in 1957. Thornethwaite, Blaney and Criddle, Turc, Ollivier, and Penman Eo (in this first instance without its later Crop-Factor adjustment) were all soon considered unsatisfactory, in that they appeared to be quite incompatible with the "420 cubic meters at 14 days" of the traditional schedule; at that time considered by all the interested authorities in the Sudan to be above dispute.

Other estimates of consumptive use were also attempted from a variety of evaporation pans, the Piche, and close cut turf lysimeters; but these were even less satisfactory because of the exceptionally high levels of advective energy throughout the year except during the rainy periods of July, August, and September.

4. The new approach to crop water use

By 1963 the standing of consumptive use studies in the Sudan had fallen so low that there appeared to be no scientific alternative to the engineers' arbitrary assumption of "30 cubic meters per cropped feddan per day." Indeed, this figure, and the 14-day interval, were in almost universal use for all water accounting purposes; including such detailed agricultural applications as the calibration of metering devices for liquid nitrogen, as well as for the overall planning of water resources at highest level.

However, following the lead given in 1964 by Hunting-MacDonald, the agricultural research programs on water use were suddenly reoriented towards intensive measurement of actual field water use by the main rotational crops. This reorientation was achieved over the next few years by an unprecedented expansion of the traditional gravimetric soil moisture facilities at the Gezira Research Station; these were devoted to the determination of as many patterns of daily soil moisture depletion vurbes as was possible, using only the periods between successive irrigations as the basis of each independent curve.

By 1970 sufficient information had been accumulated on cotton, and other arable crops, to establish "norms" for the seasonal patterns of water use. The *prevailing weather*, in terms of Penman Eo, from planting to harvest: and the *stage-of-development* of the crop, have become the two basic inputs in the current "Penman Eo x Crop-Factor" method of predicting water requirements. Crop-factors have been derived for each crop, and in cases where the range in growth habit within crops is appreciable (such as the varietal differences between medium and long-staple cotton), each crop factor is tailored to the characteristic form of growth under Gezira conditions. The crop-factors are derived from the ratio of *measured water use* to the *Penman calculated value* of evaporation as from an open water surface; in our terminology expressed as:

$$\frac{\text{Evapotranspiration}}{\text{Penman's estimate of evaporation}}$$

–abbreviated to ET/Eo.

Following the very pronounced seasonal pattern of change in the value of the ET/Eo ratio, crop-factors rise from about 0.50 for the month after planting, through the mid-season peak, which always appears to coincide with attainment by the crop of the peak Leaf Area Index (LAI) to very much lower values again as senescence sets in before harvest. Peak values of the crop factor in mid-season vary between 1.2 and 1.4, which may be held for only a short period, as in the case of wheat, or maintained there for several weeks, as is typical of long-staple cotton.

The overall ET/Eo ratio, when expressed as the arithmetic average over the whole of the growing season of the crop is considerably below 1.0 and is therefore best avoided in irrigation studies in the Sudan, where the provision of adequate water is considered of particular importance at the time of highest demand in mid-season.

Means over successive 10-day periods (1/3 months) are normally adequate for changes in the crop factor, and for changes in the value of Penman Eo. But for forward planning of water utilization, such as in joint studies with the Projects Division of the Ministry of Irrigation, the mean monthly calculations of the Penman Eo x Crop-Factor predictions have been frequently adopted for the sake of simplicity.

Fortunately, the numerous factorial field experiments at the Gezira Research Station have provided every opportunity to derive ET/Eo ratios for most standards of vegetative vigor of cotton crops; ranging from the poor, nitrogen starved controls of fertilizer trials, up to the very excellent standards of growth of the Cotton Breeding Section's bulks.

The crop-factors derived from all available ET/Eo ratios for cotton of average vegetative vigor, together with the apparent upper and lower limits, are given in Table 2. The planting date is assumed to be during the recommended period--late July to early August.

For most practical purposes, when a forward prediction of water needs to be made for cotton on the large commercial scale of the Gezira, it is not, in fact, realistic to use either the "Excellent" or the "Average" crop-factors as given above. About mid-way between them, however, is the special series of crop-factors, known as the "Upper Median," which have been recommended for prediction of water use for *"Well grown cotton on an extensive Gezira-wide scale."*

This "Upper Median" crop-factor has been particularly useful as the planning "norm" when information has been requested for design capacity work, or for forecasts of *maximum* discharge requirements. "Average" crop-factors, on the other hand, have sometimes been useful for comparing discharges with cropped area requirements in particular past years. Even "Poor" crop-factors have their uses; notably one involving the analysis of the various reasons for under-utilization of canal capacity.

Table 2. Crop-factors: Long-staple cotton.

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
"Excellent" growth:	0.50	0.70	1 30	1.40	1.35	1.10	0.75	0.75 [a]
"Average" growth:	0.50	0.60	1.00	1 10	1.05	0.90	0.90	1.00
"Poor" growth:	0.50	0.55	0.75	0.80	0.80	0.70	0.50	0.65

[a]The apparent anomaly of "average" crop-factors exceeding those for "excellent" towards the end of the season, is a reflection of the late vegetative regrowth that practically always results from earlier set-backs in growth and development. Note also that the March crop-factor is not applicable to a "short" season, when last water is likely to be indented for in February.

Given that the choice of crop-factor has been made to suit the particular purpose of the intended prediction, the next step is to select the most appropriate Penman Eo value from the data for the area as supplied by the Agro-Climatological Section of the Sudan Meteorological Service. For central areas of the Main Gezira Scheme the following table has been widely used (based on the 1957/1968 averages for GRS, Wad Medani).

In Table 4, evaporation is given in mm per day, as is required for international publication, but for all irrigation purposes within the Sudan, the daily evaporation losses, and daily use by crops, are very much more conveniently expressed in cubic meters of water per feddan.

1 mm = 4.2 cubic meters per feddan.
1 feddan == 4200 square meters.

If the calculation of water requirements applied to past seasons, the actual Penman Eo data should obviously be used if available for that year. For forward planning, the choice from Table 4 will clearly depend on the purpose of the forward prediction. Design of canal capacity will invariably require the upper confidence limit, while supply norms can usually be best calculated on the average, providing that the likely limits around the average are borne in mind. Even the "lowest expected Eo once in 10 years" has its uses; notably one particular use involving the analysis of the various reasons for underutilization of canal capacity. (Past generations of Gezira irrigation engineers have always commented, sometimes most critically, on the fact that the actual take-off has so frequently been well below the maximum capacity to which they had designed the system.)

Only the crop-factors for cotton have been quoted here as an example of the method, but other crop-factors are available for all the rotational crops of the Gezira, though in some cases with a less certain background of ET/Eo ratios than for cotton. Crop-factors for sugarcane, and other perennial crops of importance to the Sudan have also been derived from the relevant ET/Eo ratios.

Recapitulating for a moment on the derivation of the crop-factors, in order to make a comment on the order of accuracy to be expected from the *Penman Eo x Crop-Factor* method in the Sudan, it should be remembered that because the crop-factor is essentially a measured parameter, derived from a number of actual soil moisture depletion curves, it can be assumed to compensate for any small systematic error that may be involved in the local routine calculations of Eo.

Indeed, the crop-factor buffers the method against possible criticism that we continue to use the original coefficients and formula of Dr. Penman's 1948 paper. Several academic contributions to this subject have become available in recent years; Rijks. D., formerly a micro-meteorologist with the Cotton Research Corporation, has three papers in the "Journal of Applied Ecology" reporting his detailed studies in "The water use

Table 3. "Upper Median" crop-factor: Long-staple cotton.

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
"Upper Median" crop-factor:	0.50	0.65	1.10	1.20	1.15	0.95	0.70	0.70[a]

[a]Not in a "short" season.

Table 4. Penman Eo evaporation losses in mm per day.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High:	6.3	7.6	8.6	9.5	9.6	10.6	9.8	8.5	7.9	7.5	6.7	6.0
Av.:	5.6	6.8	7.6	8.6	9.0	9.6	7.9	6.5	6.9	6.5	6.0	5.4
Low:	5.2	6.1	7.1	7.6	8.2	8.6	6.2	5.8	6.1	5.6	5.4	5.0

High = Highest expected Eo once in ten years.
Av. = Long-term mean, 1957-1968.
Low = Lowest expected Eo once in ten years.

by irrigated cotton in Sudan," I, II, and III. Dr. Hussein Adam, now Head of Agro-Climatological Section, Sudan Meteorological Service, worked on various aspects of net-radiation above Gezira field crops, as part of a Ph.D. thesis submitted to the University of Reading, England.

It should also be noted that the nuclear probes, made by Troxler, and introduced to the Gezira by Dr. F. Cope on behalf of IAEA in 1970/71, have already contributed much to our knowledge of the seasonal patterns of water use. Dr. Osman Ali Fadl is currently reporting daily rates of water consumption measured with the neutron probe which appear to be in very good agreement with the earlier findings based on gravimetric sampling. The great advantages of the nuclear techniques are seen at their best in the current work with sugar cane and paddy rice; both crops having previously presented difficulties under Sudan conditions.

5. Field checks of the Penman Eo x Crop-Factor method

The Gezira offers unique opportunities for checking the practical applications of any method of prediction. The Ministry of Irrigation records the daily discharge data for all the important gates and weirs of the system for the headworks at the Sennar Dam down to the final points of supply to the "minor" canals. The control of water then passes to the Sudan Gezira Board.

It is reasonable to accept the assumption that supplies in past years have not been far short, if at all, of the optimum field requirements of the cropped areas. Therefore, the Ministry's discharge data, and the Sudan Gezira Board's cropping statistics (again, very well documented and available for many years past), can be used for field checks of the *Penman Eo x Crop-Factor* method now used exclusively in GRS studies of water requirements. This is possible on any scale, from a few thousand feddans comprising each "Minor" canal area, up to the total gross area exceeding 2,000,000 feddans as served by the headworks at the Sennar Dam.

For field checks of water supply to individual fields of crops in the Gezira, or on experiment stations, the problems of measurement of flow are particularly difficult. Weirs, notches, submerged-gates and flumes are all unsatisfactory because no loss of head across the device is permissible if rates of watering are to continue unaffected. The heads of water available under current methods of operation of the "Minors" are already so low that the loss of even a further few centimeters is critical.

Some flow meters which do not reduce the supply level have been used experimentally, but the extreme variability in hour to hour rates of discharge in the ultimate field channels is liable to introduce large errors. The most recent flow meter to be tested by us under Gezira conditions, and by far the most successful, is the standard *"Braystoke" Current Meter,* made by Valeport Developments, Devonport, England. The Braystoke flow meter is exceptionally free from fouling by the high silt content and organic trash load of the typical Gezira irrigation water from the Blue Nile. It is also sufficiently linear in response over its exceptionally wide range to permit its use as an integrating meter over convenient periods of watering.

6. Penman Eo x Crop-Factor prediction on the scale of the gross area served by the Sennar Dam

Following is an example of the application of the method to a current problem, comparing the predicted crop requirements against the actual discharges month by month, for the total area served from the Sennar headworks. The special purpose of this particular exercise was to prepare the best estimates of each component of water use contributing to the run down of "stored" water during the months after December, when the low river flow is insufficient to meet the demands of the crops. This information was needed for an examination of the relative merits of the alternative uses to which the stored water could be put.

(1) The predicted requirements during the rainy months of August and September do not allow for rain. The cut back in discharges has been shown to be closely related to the rainfall pattern of the season. (Ref: IBRD Gezira Study Report 1966.)

(2) The cotton pre-water requirements are related to the feddans scheduled for planting in the following year.

(3) The dura and groundnut pre-water requirements for the following year, are essentially "Land preparation" items, the crops being sown the following month, July 1972.

(4) The big discrepancy for January 1972 cannot be fully explained. Some part of it may be due to the undesirable recent practice of withholding water to cotton in January to enforce a higher standard of picking of the early part of the crop; but it is certainly to be hoped that the 234 million cu m shortfall in discharge is not a reflection of the extent of this practice.

(5) The transit losses given in Table 5 are as calculated at GRS on the basis of the expected losses by evaporation from the area of open water surface exposed by the canals assuming seepage and escape to be nil. Transit losses as a percentage of the discharge appear to vary between 6 percent and more than 30 percent according to the month.

Table 5. Estimates of the components of consumption of water for the total area irrigated in the Gezira and Managil rotational areas.

(In millions of cubic meters per month)

Crop:	Feddans	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
					1971					1972			
Cotton	(589387)	-	252	334	554	530	475	407	330	198	-	-	-
Cotton	Pre-water:	-	-	-	-	-	-	-	-	201	195	-	-
Wheat:	(153120)	-	-	-	61	98	119	121	69	-	-	-	-
Lubia:	(99956)	-	-	-	69	45	64	81	36	-	-	-	-
Dura:	(295693)	167	278	284	105	-	-	-	-	-	-	-	-
Dura	Pre-water:	-	-	-	-	-	-	-	-	-	-	-	177
G. Nuts	(179960)	92	109	173	170	81	-	-	-	-	-	-	-
G. Nuts	Pre-water:	-	-	-	-	-	-	-	-	-	-	-	108
Gardens	(46595)	-	-	-	40	35	32	34	37	46	2	-	-
Transit	Losses	63	38	42	57	63	61	64	78	96	80	79	70
Total calc. req's		322	677	833	1,056	852	751	707	550	541	277	79	355
Total discharges		508	314	508	931	804	636	473	518	561	247	128	354

"Stored" water period. (Jan–May)

On the enormous scale of the Gezira and Managil there are many opportunities for errors in calculations of water requirements. Nevertheless, the use of the Penman Eo x Crop-Factor method in this case has given a remarkable demonstration of its capability to solve the most complex situations in water management.

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CHAPTER V

IMPLEMENTATION OF NEW AND EXISTING KNOWLEDGE

1.

IMPLEMENTATION OF WATER MANAGEMENT PROGRAMS IN CANAL IRRIGATED AREAS

B. B. Vohra[1]

The Indian experience indicates that the following distinct steps need to be taken to improve water management in the commands of big irrigation projects.[2] Many of these steps can and should be attempted simultaneously in order to save valuable time.

1. Creation of an informed official opinion

It has been estimated that the minimum requirements of a program to achieve optimum water management in the 18-odd million hectares of land which are commanded by our big surface irrigation projects will be of the order of Rs. 3000 crores ($4000 million). Obviously, even a beginning cannot be made with such a far-reaching program unless policy makers in the States as well as at the Centre are convinced that something needs to be done urgently about this matter. Since the subject of water management was almost completely new even to irrigation engineers (who thought that their duty was done once the reservoir was built and irrigation system completed up to the outlet level) not to speak of officers belonging to other disciplines, it was decided, towards the beginning of the Fourth Plan, to adopt a three-point strategy to sell the idea to the people who mattered.

(a) In the Fourth Plan a modest (Rs. 15 crore or $20 million) but 100 percent centrally funded program was taken up in 10 command areas (later increased to 19) for the construction of market centers and market roads in newly irrigated areas on the condition that the State Government created special new administrations for the improvement of water utilization and the provision of certain essential infrastructural services in these commands. The implementation of this program automatically involved the exposure of high level State officers to the new ideas.

(b) Selected senior officers drawn from Irrigation as well as Agricultural Departments were sent on brief observation tours to the United States and other developed countries under an arrangement with the USAID and later with the FAO/UNDP. As many as 22 senior officers have availed of such tours already and have come back convinced of the urgent need to improve water management in our own country.

(c) The relevance of good water management to Indian conditions was explained by the Department of Agriculture in a number of rather frankly worded papers which were circulated to key officials both at the Centre and in the States. Although in the beginning there was some resistance to the new ideas particularly on the part of some irrigation engineers who feared that investment in water management would effect the availability of funds for taking up new projects, a significant change in official opinion took place within a short time. The Irrigation Commission which was then in existence supported the need for improved water management in its report submitted in the summer of 1972. This was followed by an endorsement of the new ideas by the Task Force of the Planning Commission in its report of November, 1972. The National Commission on Agriculture has also stressed the need for improved water manage-

[1]Joint Secretary to the Government of India, Ministry of Agriculture, New Dehli, India.

[2]The problems of water management in the commands of privately-owned tubewells and wells and of small surface irrigation schemes which together account for nearly 60 percent of the total area under irrigation are much easier of solution and are not touched in this paper.

ment in its interim report of March, 1973. Finally, a Group of State Irrigation Ministers set up to inquire into the reasons for the under-utilization of irrigation potential–to the extent of over 16 percent for the country as a whole, even in the extremely liberal sense in which the word "utilization" is used by the Irrigation Departments–has recommended in a report submitted in June, 1973, that special measures need to be taken to improve water management in command areas.

Here it must be noted that a significant role was played by a number of experts from the USA and, in particular, by Mr. Don Williams during the last 10 years or so in repeatedly stressing upon the Government of India the need for improved water management. It was largely as a result of such efforts that a small Water Management Unit was first created in the Union Department of Agriculture in 1966-67, and which began to play an increasingly important leadership role in this new field of activity.

2. Creation of an informed public opinion

Water management is, however, too important a matter to be left to the bureaucracy alone. If it is to be implemented on a sustained basis and on the requisite scale, it is necessary that the program should have a powerful public backing. It is felt that not only should recourse be had to the mass media to inform the public about the over-riding importance of this program in the Indian context but that important leaders of public opinion should also be taken on conducted tours to areas–both within and outside the country–where good management practices have yielded perceptible results. Ministers (both of Central and State Governments and not necessarily those alone who deal with irrigation and agriculture), members of Parliament and of State Legislatures, newspaper editors, and other people whose opinions matter should be included in such an exposure to the program

It must however be noted that it has not yet been possible to implement these ideas on any significant scale.

3. Introducing the subject at the technical level

In a situation where there had been some talk of better water management but so far no actual attempt to achieve it, it was suggested by USAID that work should be taken up on a pilot basis with the assistance of trained personnel of the U.S. Soil Conservation Service. This recommendation was accepted by the Government of India and three pilot projects were set up with USAID technical assistance in the commands of three different irrigation projects in 1967-68.

Almost simultaneously, an FAO/UNDP project for the improvement of land and water management was established in the Chambal command in the Rajasthan State, where canal irrigation had given rise to serious waterlogging and salinization. All these four projects proved to be extremely useful in bringing together technicians and specialists of various disciplines to work under actual field conditions. By providing workers with the self-confidence which can come only from tackling actual problems and by serving as demonstration and extension centers in an important new field of activity, these projects justified the hopes placed in them.

As a result, it was decided by the Government of India to expand this program and to give 100 percent Central assistance for the establishment of a total of 25 such projects during the Fourth Plan. During the Fifth Plan, it is proposed to double this number so that at least one pilot project is located in the command of each of the 50 irrigation projects in which water management programs are due to be taken up.

It would be difficult to over-emphasize the role which such projects–if they are executed effectively–can play in making a success of water management programs. During the Fifth Plan, it is proposed to spend Rs. 10 crores ($13 million approx.) on such projects.

4. Creation of an adequate technical infrastructure

Water management is a complex subject and ideally calls for a great deal of accurate information (in matters, such as, the nature of local soils, the topography of the land, the water requirements of various crops in given climatic conditions, and feasibility of supplemental irrigation from groundwater sources) before the designing and execution of the rational water delivery, water removal and land shaping works can be attempted. Such information is not yet available for all the commands, and special efforts will have to be made to obtain it through surveys, investigations, and observations. Large numbers of technicians in the concerned disciplines will accordingly have to be recruited and trained before water management programs of a sophisticated nature can be taken up on an extensive scale. The requirements of agricultural and earth-moving machinery will also need to be assessed so that arrangements may be made for procuring it in time, as well as of placing trained operators in position.

The magnitude of this task would naturally depend upon the size of the program proposed to be undertaken. During the Fifth Plan period (1974-79), it is proposed to invest at least Rs. 600 crores ($800 million) on water management programs in 50 selected commands. Of this amount, Rs. 300 crores ($400 million) are proposed to be spent by Irrigation Departments on the improvement (including lining) of delivery systems up to the outlet and on the construction of intermediate and major drains in order to combat waterlogging. Since irrigation departments already possess the necessary trained personnel, this program should present no particular difficulty in implementation. As far as the balance amount of Rs. 300 crores ($400 million) is concerned, this will be spent mainly on on-farm works and will require the participation of large numbers of soil scientists, agronomists, agricultural, irrigation and drainage engineers. The additional requirements of personnel and machinery for the implementation of this part of the program are being currently worked out.

5. The phasing of implementation

Realizing that the best is the enemy of the good and that the creation of the technical infrastructure needed for the implementation of water management programs on an ideal basis is going to be difficult and will take time, it is felt that priority should be given to the minimum requirements of the command areas. Such requirements include the construction of unlined water courses beyond the outlet over vast areas for which irrigation waters are available but cannot presently be properly utilized, the distribution of water to farmers on a fixed turn basis and the provision of minimum drainage facilities. It is proposed to cover as much as 12 million hectares by such a program during the Fifth Plan. During the same period, it is proposed to execute sophisticated water management programs over an area of 0.5 million hecares only.

6. Creation of the necessary administrative infrastructure

In view of the multiplicity of the disciplines involved and the number of agencies which are responsible for planning and executing various aspects of water utilization and command area development programs, it is absolutely necessary that strong and well-integrated administrative structures should be created at the command levels so that such programs may be designed and executed in an efficient manner. It is also necessary to create adequate coordinating arrangements at the State and Central levels.

After a careful consideration of the problem, in consultation with State Governments and other concerned interests, it has been recommended that each command area should be constituted into a special development area and should form the charge of a Command Area Development Authority. Such an Authority will be chaired by a senior coordinating officer and will have as its members senior whole-time officers of all the technical departments concerned- such as, irrigation, agriculture, and cooperation—as well as the representatives of farmers, the local administration and office-bearers of the land development and commercial banks in the area. This Authority will be responsible for the designing as well as execution of water management works in all parts of the command and will be given ample administrative, financial, and legal powers by Government to enable it to discharge this responsibility.

Since on-farm works have to be financed on a loan basis, and since such works have to be necessarily executed on the basis of an entire outlet catchment (and not on the basis of individual holdings), it is necessary that some special arrangements should be made for obtaining loan finance in bulk and placing the same at the disposal of the executing agencies (which will normally be the relevant departments of the State Government). The cost of such works to be borne by individual farmers will be worked out and recoveries made in due course through the normal channels. It has been recommended that in order to achieve these objectives a Land Development Corporation should be created in each command and that it should be manned and controlled by the same officers who constitute the Command Area Development Authority.

It has been recommended that at *the State level* a special new organization should be created to take care of the water management and command area development programs which will be taken up by the State during the Fifth Plan. There will also be a high-powered committee under the chairmanship of the Chief Minister of the State to effect the necessary coordination between the various departments involved in the implementation of such programs.

At the Centre, responsibility for water utilization and command area development has been placed on the Department of Agriculture. However, in order to review the progress of these programs and to effect the necessary coordination between the Ministry of Agriculture and the Ministry of Irrigation, a high level committee has been set up under the chairmanship of the concerned Member of the Planning Commission.

7. Financial arrangements

As already mentioned, water management programs are going to figure in the Fifth Plan in a very big way indeed. Out of the total proposed investment of Rs. 600 crores ($800 million) as much as Rs. 300 crores ($400 million) will be found from Irrigation Department budgets, Rs. 150 crores ($200 million) from Agriculture Department budgets and the remaining Rs. 150 crores ($200 million) from institutional sources, such as the Agricultural Refinance Corporation and Commercial and Land Mortgage Banks.

The tapping of institutional sources for water management programs is a welcome development because it not only represents an additionality to Government budgets but ensures that the works undertaken with loan assistance satisfy minimum cost-benefit requirements. The increasing interest which is being taken by the World Bank in these programs is to be welcomed for similar reasons. In this connection, it may be noted that the World Bank is expected to assist as many as 10 such programs in as many commands during the Fifth Plan period.

2.

A WORLDWIDE VIEW OF IMPLEMENTATION OF IMPROVED WATER MANAGEMENT

Clyde E. Houston and Michel Grehan[1]

Introduction

Improved water management is as equal in importance to successful irrigation as water development. In fact, irrigation and drainage workers in developing countries generally agree that improved water management probably can do more towards increasing food supplies and agricultural income in irrigated areas than any other agricultural practice. Experience has shown that if a country took the money to be used for a new irrigation scheme and used it to train irrigation technicians in water management, who in turn would train the farmer, the returns from increased production and income would be several times the return to be gained from the new scheme. The following tabulation indicates the difference in knowledge and practice in a developing country and the tremendous potential for increasing production. Similar differences can also be found in developed countries.

Approximate Yields (units per acre)			
Crop	Research Station	Farm Demonstration Plots	Average Farm
Rice (paddy)	50	40	15
Cotton	35	28	8
Maize	100	80	11
Wheat	60	40	9

In most developing countries, very little is known as to the amount of water to apply at an irrigation or the frequency of irrigations for maximum crop returns. Usually only by the appearance of the crops is it indicated as to where too much or too little water is applied.

Under traditional irrigation practices water use usually is high whereas yields are low. The water-use/crop-yield ratio can be as unfavorable as 5,000 tons water/1 ton yield for wheat and 5,000 to 12,000 tons water/1 ton yield for rice.

Land and water resources which easily can be developed for agriculture are becoming short. New irrigation and drainage require higher investments which can be economically made only with high crop returns. In addition, water shortage in many areas calls for a better water/yield ratio. It has been proved that ratios as low as 1,000 tons water for 1 ton of wheat and 2,000 tons water for 1 ton of rice are possible under well managed irrigated conditions.

Better water management, use of fertilizers, better seeds and application of improved cultivation techniques are the main elements for better yields and improvement of the water-use/crop-yield ratio. The advantages of proper fertilizer application and use of high yielding varieties can easily be demonstrated to the farmers and in most cases are readily accepted by them. In contrast to this, measures to improve water management are often opposed by tradition, be it traditional irrigation practices which have been developed over centuries, or be it traditional rainfed agriculture. However, the introduction of high yielding varieties, which can only be grown successfully with abundant fertilizer inputs, makes farmers realize the importance of an assured and controlled water regime without which such inputs are wasted. The limitation of expanding high yielding varieties and crop failures in recent years, due mainly to flood and drought, highlight the basic role to be played by proper water management.

The introduction of improved water management in agriculture is a complex problem involving the whole of rural society and agricultural administration and often has consequences which reach as far as the national legislative bodies who have to effect the required changes in land and water laws. The main problem, however, will be to educate farmers to use water properly.

It is clear that measures to accelerate benefits from water development projects for agriculture must necessarily be grouped around the farmer's field, as the success of investments depends ultimately on the effectiveness with which the water is used by the farmers. If water is to be used effectively by the farmer he must have adequate means to do so and he must know how to do it. Finally, there must be sufficient incentive in material terms for him to be productive and sustain his effort, and all of the necessary inputs to successful irrigation must be available.

[1]Chief and Senior Officer, Water Resources and Development Service, Land and Water Development Division, Food and Agriculture Organization of the United Nations, Rome, Italy, October 1973.

Apart from increasing crop yield and ensuring economic use of water, good water management also has a significant effect on the economy of a project. This is because low irrigation efficiencies result in demands for a larger quantity of water which calls for greater storage capacity, larger structures and larger canals and, therefore, heavier capital investment. Furthermore, water so wasted may considerably reduce the area that can be irrigated with a given amount of water, thus raising the construction cost per unit area and reducing the overall project returns. Also wasted water usually results in waterlogging and drainage problems which in turn reduce production and increase costs.

World-Wide On-Farm Water Management Problems in Developing Countries

Inefficient water distribution and use

Many developing countries still lack experience in drawing up agricultural development programs with adequate provision for water management and control at the farm level. Very few farmers are able to handle water as well as they can handle other inputs, such as fertilizer.

One of the main problems in developing countries is the low efficiency of water use. Information available indicates that in many gravity irrigation projects less than 50 percent of water developed at the source finally reaches the field. Taking into account the low application efficiency on the farm due to plot-to-plot irrigation in the absence of field distribution systems, overall project efficiency as low as 20 to 30 percent is common in developed as well as in the less developed countries where management of water is virtually neglected.

Lack of adequate water distribution works

The farmer, as a rule, is good at improvising out of sheer necessity, but this seldom produces orderly and precise solutions. Consequently, he is often without the facilities for effective water control. Lack of appropriate farm irrigation distribution facilities such as ditches and ancillary regulatory structures and measuring devices, plus proper land preparation, has resulted in uneven water distribution, while the absence of drainage systems has caused waterlogging. The long time-lag between the start of water delivery and the arrival of water in the farthest field has led to over-irrigation in some fields and a shortage of water in others, and it is not uncommon that stagnant water prevails while large tracts of fields remain unirrigated.

Necessity for proper operation and maintenance facilities

In the past, many irrigation projects devaluated rapidly due to lack of proper operation and maintenance and, as a consequence, farmers were unable to obtain the expected benefits from them. Poor irrigation and drainage conditions frustrate the farmer's labor, and consequently adversely affect his livelihood. If conditions do not improve, he loses interest in his farm and may even be compelled to abandon it.

Necessity for advisory services

Adequate advisory services are essential to effect the transfer of knowledge of water management and irrigated agriculture to the farmer's field. The farmer must know how to use the water, that is, how to apply water in time and quantity; he must know how to combine water with agricultural inputs, such as how to manage an irrigated farm in order to obtain high crop returns; he must know how to prepare his fields for the application of water and how to remove excess water; and, finally, he must know how to conserve water and soil, which are his most valuable resources.

The provision of this knowledge to the farmer necessitates that the information be made available to him in a form which he can understand and accept. The dissemination of such information will involve millions of farmers. It represents a tremendous task which calls for the use of considerable skills and techniques by the extension worker.

More education and training required

At present there is a shortage of trained personnel in the field of irrigated agriculture, and if an expanded program on this subject is to be undertaken the lack of manpower will be a major constraint.

Education and training for improved water management involve three levels: The professional, the technician, and the field worker.

Planners, designers, or those responsible for the management of irrigation projects in addition to the researcher, extension worker, and farm manager, need to be knowledgable in the principles and practices of good water management. Similarly, personnel of the intermediate level, the technician employed in engineering and agricultural sectors, must receive training in this subject to enable them to do their work competently. Last but not least, is the training of irrigation workers and progressive farmers who provide leadership and training to other farmers.

Tackling the Problems

General irrigation practices

Most farmers in developing countries work on a subsistence basis. In the absence of modern irrigation facilities, they have developed their own cultural practices, sometimes representing a near optimum combination of prevailing "production factors" such as crudely constructed irrigation facilities and low yielding varieties of cereal adapted to grow in adverse conditions. Consequently such farmers have traditional beliefs and cultural habits. Some of these beliefs or habits have a scientific basis, others have not. The problem is to determine which practices are best and concentrate on extending them while at the same time decreasing the use of those less valuable. To provide assistance in this endeavor, strong research and extension services are required.

Water distribution

Irrigation and drainage facilities at the farm level should be given appropriate attention and treatment by the organization responsible for planning and designing new water development projects for agriculture. This would ensure that the necessary facilities are adequately provided at that level. Meanwhile, many attractive opportunities exist in the re-development or further development of existing irrigated areas through modification and renovation of irrigation and drainage works. The inclusion of adequate farm irrigation and drainage facilities should form an integral part of the modernization plans of such schemes. This is one of the decisive steps that can be taken to bridge the gap between the old way of farming and modern irrigation farming.

Operation and maintenance facilities

To prevent deterioration of irrigation projects, adequate operation and maintenance of the irrigation and drainage systems must be assured by an appropriate organization established for such purposes.

Such an organization can be in one of many forms ranging from a 100 percent government-operated scheme to an informally organized farmers' association. A formally organized and government-controlled irrigation authority is desirable for large irrigation projects, or an irrigation association with legal status and appropriate rights regarding financial responsibility and work.

When it comes to farm level facilities, the maximum involvement of the farmer with proper advice and assistance from the responsible authorities is indispensable. Incentives for the farmer to participate in the operation and maintenance of irrigation systems are prerequisites for successful irrigation.

Extension services

Strong extension services for farmers are indispensable for successful irrigated farming. Although traditional farmers may be ignorant of modern farming technology, they are not unreceptive to such knowledge; they can be motivated, but the eventual acceptance of new practices can only be brought about when they are convinced of the material benefits to be gained and realize that such a change will not involve risk of losses.

The ingrained and traditional beliefs and methods of farming cannot be changed overnight. Extension workers must understand such beliefs in order to determine successful means of persuading farmers to accept and adopt modern agricultural technology. Farmers can be convinced only through influence, persuasion, demonstration and, above all, benefits that can be derived from the new practices. The qualities of leadership of an extension worker, in addition to his skill and knowledge, are essential in this work. Success in the first attempt to introduce new techniques and practices is crucial in bringing about a desired change, for this is a great step towards establishing the farmer's confidence. It follows that a failure can be very costly as it will be some time before the farmer concerned can be persuaded to deviate again from his traditional beliefs.

Education and training

Subjects for irrigation engineers and scientists directly responsible for irrigation development should include planning, design, and construction of irrigation and drainage networks at the farm level; operation and maintenance of farm irrigation systems; improvement of irrigation efficiency, the effect of proper water management on crop yields and water management for crop diversification. Most of this knowledge can only be acquired through the development of practices and techniques adapted to local conditions. In-service training tailored to meet the needs is one of the most suitable ways of doing this. Training seminars and symposia can be of considerable value. These should be designed to meet the requirements of professional personnel and be relevant to local conditions. In the long run, universities and research institutes will have to play an important role in rapidly developing the required expertise, particularly in the field of applied research.

At the technician level, the teaching of similar subject matter is considered necessary but with less theory and more emphasis on the practical and operational aspects. In-service training, particularly in the form of "on-the-job" training, is a suitable way to meet immediate requirements.

The training of the great number of field workers and farmers is the most difficult task of all. This training should be simple, direct, and practical as the main objective at this level is to provide the farmers with knowledge which will enable them to produce high crop yields through proper water management. A suitable approach is to carry out training in representative pilot areas where basic data for project operations and maintenance have been obtained and where the response of farmers to improved irrigation and drainage practices has been tested and assured. Such demonstration farms are one of the more effective ways of disseminating information.

Experience in developed and developing countries has shown that probably the best method of demonstrating and teaching improved farm irrigation system design and operation is by the method of evaluating irrigation systems as outlined in USDA, SCS, Agricultural Handbook No. 82 "Methods for Evaluating Irrigation Systems." This is especially impressive when the students, whether they are farmers or academics, participate in the measurements and interpretation of the data collected. Although this method is time-consuming and physically strenuous, the results are so worthwhile that it should be extended to all irrigation workers who are in contact with farmers. It will be necessary to determine the availability and the requirements of workers in this field in order to properly plan intensification.

Research

A prerequisite for the practice of good water management is information concerning water requirements and the application of water in quantity and time.

A considerable amount of research has been carried out in a number of developing countries on the water requirement and timing and amount of irrigation. However, much of the available data and results are not utilized and are not correlated or readily available for practical and large scale application. The results remain to be tested under local conditions so as to be of practical value for water management by the farmer.

Applied research should also be carried out to identify the relationship between field water requirements and scheme water requirements so as to find the bottleneck of low irrigation efficiency as well as a practical method to improve it. Research should also include various water saving measures including the restriction of deep percolation, adoption of intermittent irrigation, and reuse of drainage water.

One of the problem areas which requires intensive research is soil and water conditions for the introduction of diversified agriculture in rice monoculture zones. Crop diversification has called attention to the need for drainage for upland crops grown in rotation with rice on lands so far used only for rice cultivation. However, on heavy soils such as those encountered on flood plains and in coastal areas, which have slow drainage properties, difficulties have been experienced since most upland crops cannot tolerate submergence for any length of time. A number of possible measures to overcome this have been considered. They include the rapid removal of water ponded on the soil surface by land grading; deep plowing to break up the relatively impervious hardpan formed under conditions of repeated puddling operations; the use of mole drains and by introducing tile drains. No completely satisfactory solution has yet been reported and much work remains to be done on this problem.

Case Studies of Water Management Implementation in Several Developing Countries

Greater Chao Phraya and Phetchaburi-Kang Kracharn Projects, Thailand

In this project, substantial additions to the quantity of irrigation water available for the project have made it possible for about 800,000 acres out of the total of 2,100,000 acres to be equipped for perennial irrigation and thus enable second crops of rice or other economically worthwhile plants to be produced in the dry season. The main objective is to educate the farmers in the new agricultural technology so that the increased resources can be fully utilized all the year around.

The existing extension services have been considerably reinforced to cope with the additional training programs involved. In addition, farmers are assisted by loans for seeds and fertilizers to be repaid at cost. The main methods used by the extension services include demonstration plots at on-farm levels where crop rotations can be established in direct contact with the farmer and the usual mass media activities provided by broadcasts, meetings, and simple descriptive literature.

During the period 1964-71, 165,000 acres were brought under full production with year-around multiple cropping and by 1976 it is planned to increase this area to 600,000 acres The main problems met with during the progress of the project so far have included the following:

(a) Trained manpower deficiencies.

(b) Rental increases due to enhanced value of irrigated land. This decreases incentives to farmers.

(c) Liability of second crop to increased attack by pests.

(d) Water control and apportionment difficulties in dry periods.

(e) Inadequate supply of the necessary additional farm equipment and implements.

(f) Loss of additional crops by thieving.

These problems are all being dealt with by strengthening the extension services and the administration of the project and by tightening up the farmers' legal protection and security.

Demonstration plots at Xylophagon, Larnaca District, Cyprus

These plots are situated in the main potato growing area of Cyprus and have been established to show the farmers how improved water management and irrigation practices will help them to achieve an increase in the potato yield per unit of water. The method employed is to establish two plots—the demonstration plot and the "witness" or "datum" plot—under exactly the same conditions of planting, fertilizer application, pest control, harvesting, etc., and to vary only the water application. The demonstration plot benefits, in this respect, from having carefully measured water quantities applied at the right time, the quantities being determined with the aid of soil-water measurements at various depths after each irrigation. Advanced water management techniques are employed to ensure the constant availability of water and its effective application.

The autumn and spring crops take about 3½ months to grow fully and require, during a 2½ months irrigation period, an average of 12 irrigations for the autumn crop and 7 irrigations for the spring crop. Increases in yield obtained in the demonstration plot range from 3 percent to 50 percent with an average of about 15 percent. Maximum yields obtained on the experimental plot amount to about 16 long tons per acre. The increase in productivity per unit volume of water averaged 30 percent.

The demonstrations have proved that good water management will help the farmers to increase potato yields and—just as important—to economize in the use of water in an area with very limited resources. The demonstrations also show that spring potatoes, which require less water, yield nearly twice as much as autumn crops and therefore have the highest productivity per unit of water.

Project for tile drainage provision in Egypt

The project area extends along the upper Nile from about 100 kilometers south of Cairo to Aswan immediately to the north of Lake Nasser. In this strip of the Nile, which is nearly 800 kilometers in length, 125,000 hectares of irrigated land provide the main support for about 88,000 families and it has been estimated that nearly one-third of the area could become barren in 35 years because of inadequate drainage. Good water management being impossible without efficient drainage to eradicate waterlogging and salinity, the Egyptian Government has planned to spend $115 million over the next 6 years on the installation of a comprehensive system of tile drainage.

This is the country's second major drainage scheme. In 1970 the Egyptian Government launched an 8-year project to install tile drainage in 400,000 irrigated hectares of Nile Delta land and the venture is already proving its worth. The improvements in irrigation techniques have become increasingly necessary since the completion of the Aswan High Dam made it possible to provide facilities for perennial irrigation in the 3 million hectares of cultivable land previously irrigated by seasonal flooding. The resulting increased cropping has been a direct cause of a decline in water management standards because of the existing poor drainage facilities and underground tile drainage provides the only satisfactory permanent means of rectifying the situation.

The 250,000 hectares equipped with tile drainage have already shown substantial increases in yield of the principal crops—rice, cotton, wheat, and maize—and the integrated planning involved in establishing such a comprehensive drainage network will also simplify the task of controlling the breeding of bilharzia-carrying snails and hence of diminishing the incidence of bilharziasis.

A 5-year project completed by FAO in 1964 and financed by the United Nations Development Programme demonstrated that mechanically laid tile drains were half as costly as hand laid drains. Since then the Government has been using mechanical equipment for its program of 30,000 kilometers of buried field drains and about 4,000 kilometers of collector drains. The work program also includes the deepening and widening of existing open drains, the construction of four new pumping stations and the reclamation of nearly 10,000 hectares of severely salinated land.

The Chapula Irrigated Horticulture Project, Zambia

This project was established, in connection with the development of the Kafue River basin, in January 1969 under the title of "A small scale irrigation development and training project" with the aid of funds provided by the United National Development Programme. FAO was the designated executing agency.

The original objectives for the project were mainly concerned with the construction of a 100 - 200 acre irrigation project for demonstration and training and, particularly, with the need to evolve efficient methods of water management for the production of fruit and vegetables. A second phase of the project, now under way, has had its objectives enlarged to include the evolution of efficient water application techniques and the collection and analysis of data relating to the economic aspects of water use.

An important element in the water management investigations undertaken by the project was a detailed comparison of the various irrigation methods—basin, furrow, border, and sprinkler—which could be utilized in the area. Operational rules and standards have been evolved for each type of irrigation method and labor requirements have been worked out.

A detailed economic appraisal was prepared and it was shown that under the conditions existing at Chapula, the water application costs for sprinkler irrigation are about 85 percent of the corresponding costs for surface irrigation. Also, because of the high cost of water in the area the conclusion has been reached that the objective should be to maximize the economic return per unit of water quantity used for irrigation rather than per unit of land area cultivated. As a corollary this means that, whenever possible, higher priority should be given to crops making the best use of water, requiring the least quantity for full production and having a relatively short growing cycle.

The results of the project are that satisfactory irrigated horticultural techniques, suitable under the ruling conditions, have been evolved and that a firm basis now exists in the area for expanding production on a commercial scale and for training both extension workers and farmers.

The Varamin and Garmsar Plains Irrigation Project, Iran

This UNDP/FAO project was launched to assess the water, land and human resources in the two project areas and, particularly, to examine the present agricultural and irrigation practices and to draw up a plan for increasing production in the area by developing improved irrigation methods and techniques. This entailed a very comprehensive program of work, including the preparation of a water resources inventory, the planning and design of improved irrigation networks, the evolution of cropping patterns suited to the soil conditions, the establishment of rural improvement programs, economic appraisals, and other activities. A most important aspect concerned the need for improved water management and some far-reaching recommendations were evolved in this respect.

One of the main conclusions reached by the project stressed the necessity to integrate surface water and groundwater resources to enable effective control of the limited water supplies available. Other important conclusions were that the existing irrigation practices suffered from water being supplied at long intervals (every 12 to 14 days only) which led to the system of irrigating in small basins so as to store as much water as possible in them whenever irrigation was possible. This led to very heavy percolation losses.

The major recommendations included the following with respect to water use and management:

(a) Adequate development would not be possible without the substantial importation of external supplies of water.

(b) A development authority should be set up to prepare a development plan and to design and construct a fully modernized integrated irrigation system.

(c) Operation and maintenance should be strictly controlled by the authority.

(d) The existing extension services should be expanded particularly to deal with training, farm productivity improvement, land consolidation and agricultural credit.

(e) Irrigation practices should be improved, not only by the utilization of the new canal system, but also by a complete revision in the method of water application. Water should be supplied more frequently, even during the late summer by the judicious admixture of groundwater. Furthermore, as the frequency of application rises, irrigation efficiency would be increased with a consequent lowering of costs.

Since the above recommendations were formulated in 1970, the Government has made good progress on the implementation of those relating to the modernization of the irrigation scheme network and the introduction of more efficient water application techniques. Construction of the irrigation system is shortly to commence and land grading in the project area is being systematically pursued. It can confidently be expected that within another five years fully adequate water management arrangements will be operating satisfactorily in this area of about 70,000 hectares.

Pilot project for irrigated agriculture at Battambang, Cambodia (Khmer Republic)

This pilot project was commenced in 1966 by the FAO in collaboration with the Government of Khmer and with the assistance of funds provided by the United Nations Development Programme. The project is in a preponderantly rice-producing area in which one crop each year is grown during and immediately after the wet season by traditional irrigation methods. A certain amount of dry season irrigated cultivation is practiced by farmers who pump water from the river by means of small, temporarily installed, motor pumps.

The main objectives for the pilot project are to equip an area of 300 hectares (later to be increased by 500 hectares) with full perennial irrigation facilities and to develop sound irrigation techniques at farm level by training farmers already in the project area to utilize efficiently the new irrigation and drainage network provided. The water necessary for irrigation is supplied by a substantial, permanent pumping station constructed on the right bank of the Stung (River) Sangker and although dry-weather flows are adequate for the pilot project as it stands now, new water sources will be necessary to effect the Government's intention of developing large-scale perennial irrigation in the area as soon as possible. These additional supplies will ultimately become available from a water storage in the upper basin of the river, the dam for which is at present in the planning and design stage.

The progress of the project has inevitably been hampered by the political perturbations in the country and by the security restrictions which have been imposed in the project area. Nevertheless, the full irrigation and drainage system of pumps, canals, and channels has now been completed and the planned 300 hectares of the pilot project are rapidly being made fully operational on a perennially irrigated footing. The future program not only envisages the expansion of rice cultivation by obtaining two crops each year but also the diversification of production by the introduction of suitable crop rotations which would include groundnuts, beans, maize, and horticultural crops as well as the basic crop of rice in the wet season.

The project is now at the stage at which it is possible to make permanent arrangements for farmer-training, extension services and the formation of farmers' association on cooperative lines. Individual farmers are being introduced to the principles of efficient and economical water management and are already ridding themselves of the engrained habit of over-utilization of irrigation water when this is available. One symptom of the success of the pilot project is the recent proliferation of small pumping units installed in the locality, the inspiration for which has clearly emanated from the new irrigation facilities established by the project.

Assisting the Spread of Improved Water Management

For better water management to be achieved on a worldwide scale, certain essential requirements will need, in the future, to be written into irrigation schemes at the very beginning of their preliminary and planning stages. These basic needs may be summarized as follows:

(a) New projects to be designed and constructed to satisfy the full water requirements of all individual farmers' fields so as to allow sufficient flexibility for changes in cropping pattern and to permit the efficient operation of the scheme as a whole.

(b) Projects for the rehabilitation of old irrigation schemes or for the modernization of traditional irrigation systems to be provided with all necessary water control structures, improved distribution networks and to be redesigned, if necessary, with regard to field layout.

(c) Effectual organizations for project administration and for scheme operation and maintenance to be established.

(d) Farmers to be educated in proper water management at field level through the intermediary of competent extension services or similar organizations.

Of the above requirements, the most important for developing countries is almost certainly the need to educate farmers to use irrigation water efficiently. Clearly, all help possible should be given to developing countries to further this aim and FAO is giving a high priority to such work as part of a comprehensive program of technical assistance and advice. The objective must be, on a worldwide scale and as a first step, to create awareness by governments and experts of the problems of water management in agriculture.

Apart from field activities such as the launching of new projects, the rehabilitation of old schemes and the establishment of pilot projects, examples of all of which were given in the previous chapter, the promotion of improved water management can be effected by direct contacts and discussions with national adminstrators and technicians who are themselves responsible for the construction and operation of irrigation works in their own countries. A United Nations Specialized Agency, such as FAO, is particularly suited for this type of technical assistance and a considerable proportion of the Water Resources and Development Service's operations is devoted to the organization of discussion groups, seminars, and training courses.

In promoting seminars and training courses the following three major lines of action have been taken:

(a) *Regional or interregional seminars:* To create an awareness among senior government officials of the need for and importance of water management and to stimulate regional or interregional cooperation and exchange of experience.

(b) *National seminars:* To discuss technical and institutional matters with government officials directly responsible for irrigation and agricultural development, placing emphasis on particular conditions and requirements prevailing in the country. Lectures and reports are prepared or translated into the local language for wide and immediate use by national staff.

(c) *Field training program:* To train national working staff, field workers, extension advisors and rural leaders through the application of scientific knowledge to practical use via pilot demonstration schemes, farm demonstrations and on-the-job training.

In the Asia and Far East Region, for example, two regional seminars have been organized in Manila and Tokyo in 1970 and 1972 and one is planned for 1974. National seminars were organized in Thailand and Korea in 1972; Sri Lanka and Malaysia in 1973; and there is a plan to organize similar ones in the rest of the countries from 1974 onwards. Noteworthy is the close cooperation with other agencies in conducting these seminars, including USAID. The AID provided lecturers and discussion leaders who made a vital contribution to the success of the meetings and it is strongly hoped that such cooperation will continue in the future.

The following short summaries of a few examples of the meetings held during the last three years may prove of assistance in giving an indication of the scope and influence of this type of activity.

(a) *Seminar on Farm Water Management held at Quezon City, Manila, The Philippines, in October 1970:* The purpose of this seminar was "to bring together experts in the field of irrigation and drainage, holding senior government posts to discuss policies, technical methods and institutional aspects which could help Member Governments (i.e. member countries of FAO) to obtain accelerated returns from capital invested in water development through improved water use and management at the farm level." A total of 86 national representatives and observers attended the meeting from 13 countries in the Asia and Far East Regions and from 8 international organizations or agencies. The final, unanimous report of the seminar re-asserted the need for better water management and stressed that this could only be obtained by more applied research, preferably supported by a Regional Water Management Centre, by better education and training at all levels, by the creation of more effective organizations for the operation and maintenance of irrigation schemes, and by intensifying regional cooperation.

(b) *Seminar on Water Use held at Damascus, Syria, in December 1971:* This seminar concerned itself with the "effective use of irrigation water at the farm level" and particularly with "the determination of water requirements, water application and drainage, water control and management, scheme operation and farmers' education and comprehension." Those attending the seminar were, as for the Manila seminar described above, senior government officials and experts, all coming from countries of the Near East Region. The 90 participants represented 19 countries as well as various international organizations and agencies. The findings of the seminar emphasized the high cost of water in the Region and therefore the urgency of improving water management techniques. The need for regional cooperation, as at Manila, was fully agreed particularly for the creation of adequate training and extension services and a Regional Training Centre for Water Management was proposed.

(c) *National Seminar on Water Management at the Farm Level held at Bangkok, Thailand, in March 1972:* This was a national seminar, organized in Thailand by the Royal Irrigation Department and FAO. The value of such a meeting can be judged by the fact that 75 Thai Government key officials from several ministries and departments attended and a total of 13 papers were presented by national participants for discussion. The seminar terminated with recommending that similar meetings should be held regularly in the future and that a permanent pilot or demonstration irrigated farm should be established in Thailand. As previously mentioned, similar national seminars were held in Korea, Sri Lanka, and Malaysia.

(d) *Seminar on Water Management and Control for Agriculture held at Tokyo, Japan, in October 1972:* This seminar was organized by the Government of Japan, in cooperation with FAO, as part of its technical cooperation schemes for developing countries. The aim of the meeting was to "contribute to the promotion of water management and control for agriculture in developing countries and at strengthening technical cooperation and mutual understanding between those countries and Japan." The report of the seminar stated that "the wise use and careful conservation of land and water resources should be as important to developing countries as pollution and environmental problems are to developed countries." With regard to FAO activities it is interesting to note that "it was unanimously proposed" that FAO should extend its technical assistance in the fields of water management, flood control and the prevention of crop damage, terminal irrigation and drainage networks, and project operation and maintenance.

In addition to the direct assistance provided by seminars and other similar meetings, the preparation and distribution of technical publications plays an important part in the promotion of better water management. The Water Resources and Development Service of FAO produces a wide variety of papers and reports on irrigation and drainage but, over the past two years, several concerned particularly with water management have been printed and sent to interested governments and technical organizations. The titles of the publications are:

- Irrigation and Drainage Paper No. 1: Irrigation Practice and Water Management.
- Irrigation and Drainage Paper No. 5: Automated Irrigation.
- Irrigation and Drainage Paper No. 10: Integrated Farm Water Management.
- Irrigation and Drainage Paper No. 11: Planning Methodology Seminar, Bucharest.
- Irrigation and Drainage Paper No. 12: Farm Water Management Seminar, Manila.
- Irrigation and Drainage Paper No. 13: Water Use Seminar, Damascus.
- Irrigation and Drainage Paper No. 14: Trickle Irrigation.

In conclusion, it is clear that, with the exception of relatively few well run irrigation schemes, the general level of water management in developing countries is low and that a rapid improvement in standards is not likely to be achieved in the near future. Sustained and increasing effort will need to be provided by technical assistance agencies, either national or international, to ensure a positive advance and it has to be remembered that, in this respect, time is not on our side. The scarcity value of water is increasing year by year as demand outstrips readily available resources and, at the same time, the intensity of agricultural production requires to be continuously raised–particularly in developing countries–to feed growing populations and improve feeding standards. The vital need, then, is more efficient use and therefore better water management techniques. The developed countries have shown that the upper limit of crop yield per unit area can be pushed to levels that a few years back would have seemed unrealizable, by carefully controlled irrigation coupled with other essential inputs. But the efficient application of these other inputs relies heavily on the basic adequacy of irrigation facilities. If water management is good, it means that the whole irrigation and drainage network is in first class working order, that the project is well conceived and that it is well run. Under those conditions the problems posed by the necessity for inputs such as good seeds, fertilizer application and pest control become immeasurably simplified. Good water management is the key to productive irrigated agriculture and no project, least of all in the developing countries, will succeed without it.

3.

IMPLEMENTATION OF WATER MANAGEMENT IN TURKEY

Kaya Bozkurt[1]

Introduction

Turkey's population is increasing at the rate of about 2.7 percent per annum. That is just under one million new Turks each year, or about 2,600 new Turks every morning at the breakfast table. The continuing increase in population poses a new problem of food supply each day. It seems imperative that new and improved methods of agriculture be applied in order to increase the amount of food per person and to provide sufficient food for the coming generations. Since the land base cannot be expanded this requires an increase in unit yields which in turn depends on development of sound irrigation water distribution systems and the efficient utilization of irrigation water.

Since the majority of the population in Turkey earns its livelihood through agriculture, irrigation is of vital importance to it. However, natural precipitation is not enough for irrigation throughout the country. Accordingly, the Turkish farmer has understood the benefits of irrigation and has been continuing his efforts to improve.

According to the reconnaissance and semi-detailed land classification surveys completed to date, of the 27.7 million hectares of land presently cultivated, 12.5 million hectares are suitable for irrigation. Available data shows that annual potential of surface water is 166 billion cubic meters. Of the amount, 80 billion cubic meters can feasibly be developed and may be used in irrigation. Groundwater reserves are estimated at 8 billion meters. Overall potential in the country reaches 88 billion cubic meters. With this potential 8.5 million hectares can be irrigated. At present, the total irrigated area in Turkey is around 2 million hectares, less than 1/4 of the total irrigable area. 1.2 million hectares–more than half of this area–is privately irrigated and the rest by state owned irrigation systems.

Since 1955 the Government of Turkey has established a large number of small and large irrigation systems, with the main objective of supplying water for the areas to be irrigated, but unfortunately land development services and on-farm water management implementation which would help irrigation to be more efficient has been neglected. Accordingly, the areas of land utilizing the irrigation water supplies within the boundaries of irrigation systems were only 45 percent of the total irrigable land within the projects. In further complication, the 45 percent of land that was irrigated was being done using irrigation methods that, at best, were only achieving an estimated 25 percent efficiency. Because of the apparent low return on public investment this situation attracted the attention of the authorities concerned and the Land Development Services were started.

During the second half of the 1960's, Land Development Services have been started in the State (Federal) irrigation systems with the funds obtained from the governmental budget. However, due to limited governmental budget and because farmers were not interested in the government-financed services, which they would have realized themselves otherwise, these services have not reached the desired level. It is imperative that these services be accelerated, widespread, and taken over by the farmers, and that their weight on the national budget be reduced.

Two different strategies have developed for the implementation of on-farm water management in Turkey. The one in use with state irrigation project areas features government financing and government execution. The other, which was developed primarily outside state project areas, features farmer financing and private-contractor execution. In the four years, 1968-1971, 80 percent of all government investment went to two state irrigation projects, Seyhan and Gediz. During the period 1971-73, an additional six more state projects were included in the government financed on-farm water development program.

The first stragety has proved effective in bringing rapid on-farm development to the selected project areas. This approach depends completely on the amount of money which is acquired from the general budget of the government for this purpose.

It has been demonstrated in the pilot "426 USAID/GOT" project in the Izmir Region, where the second strategy is employed, that proper land leveling, along with the follow-on cultural practices, have resulted in a two-fold or more increase in crop production with a corresponding sharp increase in profits to farmers.

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Implementation of On-farm Water Management

1. Land preparation

The preparation of the land for efficient use of irrigation water is the first measure to be taken. Reshaping the surface of the land to the suitable grade using precision land leveling, leads to economies in irrigation water use, as well as increased yields and more intensive use of land.

In Turkey, the possibilities for on-farm development have been very much restricted except on a few large project areas where government equipment, operating budget and personnel resources were concentrated. In these project areas, large heavy machines and equipment are employed for land leveling. The projects are financed, managed, and executed using government resources.

Outside the major state project areas, GOT and USAID in 1968, set out using a sharply differing strategy for on-farm water management development. This approach, presently confined to the Izmir Region, was for the government to provide technical assistance to farmers for planning the improvement of their lands. The farmers themselves would then finance the actual land improvement. A small team of Turkish engineers and AID technicians were assigned to implement this strategy.

Many problems confronted the team. First, there were no available machines, equipment or trained technicians to implement land leveling. Second, standards and irrigation guides for planning and designing did not exist. Third, private contractors for the purpose were generally not available. Lastly, the local manufacturers were not producing types of equipment for doing this kind of work; namely scrapers, land planes, listers, ridgers, subsoilers, and two-way plows.

The team was able to start the manufacturing of the necessary equipment and to capitalize on the power presently available in the form of the farm tractors, some of which have idle capacity. Studies are being made on credit program proposals which, when applied, should remove one of the chief constraints.

2. Water use

Nearly 100 percent of the on-farm irrigation in Turkey is by gravity flow. There is very little sprinkler irrigation practiced except on nurseries, state farms and research stations. All methods of gravity-flow irrigation are used. In areas where no on-farm development has been implemented, the wild flooding method is used with some control ridges and furrows being employed; but uneven distribution in these areas is common. Some areas have effected a slightly higher application efficiency with the use of small basin checks, but here the labor costs are very high.

In areas where on-farm development has been implemented, irrigation is either by furrows or by border irrigation or by a combination of both, depending upon the crop grown. The design of land leveling is usually quite uniform varying with respect to slope or gradient according to the soil texture and length of run. In the areas where soil is heavy, the gradients vary from .01 to .03 and in other areas .02 to .05. Cross slope usually varies from 0.0 to 0.2 percent.

One serious problem which confounds the engineering design of water application methods in Turkey is the parcelization of land under one ownership. Everywhere in Turkey, where small and medium sized farms are predominant, Turkey is faced with the problem of land fragmentation. Due to the fact that the land of one owner is distributed after his death among his children, each farmstead consists of a large number of different parcels scattered all over the village areas. Farms containing more than 20 or 30 different parcels are not an exception. The average number of land parcels under one ownership is 6.7. The average size is one hectare. A limited land consolidation program is being carried out to partially correct this situation, but progress is slow.

Farmers are more and more aware of the relationship of good irrigation practices to increased production. Head ditches, check dams and siphon tubes are used to achieve nearly equal distribution of water to each furrow or to each border strip.

In an effort to improve on-farm water management as well as attendant crop-culturing techniques and soil management practices, the Government of Turkey has initiated a type of farmer training program which has, as its key element, the employment of "Irrigation Foremen." There Irrigation Foremen are usually selected and employed on the basis of certain criteria, minimum educational achievement (eighth grade equivalent) and an acknowledged reputation as one of the more progressive farmers of a village.

After selection, Irrigation Foremen are given concentrated training for 6 weeks in practical fundamentals of irrigation farming. They then return to their villages as advisers, but, more importantly, serve as links between the village farmers and the technicians of the government technical agencies. One day each week they come from their villages to a central meeting place, usually county headquarters, where they receive a day of indoctrination training on a single subject by the particular subject matter specialist of the extension service, farm irrigation, plant protection, or irrigation project agency who is scheduled for that day. This program has proved rewarding so far and it is planned to expand it.

A program of farm planning has been found to be the most effective of all. However, there is a shortage of farm planners with strong backgrounds in soil and agronomy. But incorporating the cross disciplinary skills of agronomist, soil scientist, and engineer through a farm planner has resulted in maximum response from the farmers and at the same time gained their confidence.

Most of this type of planning has been carried out in areas where the farmers have their own independent water supply and distribution systems so that they arrange their own volume and rate of flow, scheduling, timeliness and payment schedules. On the state project areas it is necessary to rely on the irrigation foremen to assist the farmers in understanding these matters as well as advising on irrigation methods, cropping techniques, soil management, and fertilizer programs.

3. Cropping

As mentioned above, planning assistance includes agronomic aspects of land development and associated cultural practices as well as the engineering features. Without adequate attention to cropping and cultural practices the returns for the high investment in engineering improvements do not materialize.

The crop pattern in irrigated agriculture has been greatly influenced by marketing conditions. Traditionally, farmers prefer to raise crops which have dependable markets or crops that are suitable for storing, such as cotton, sugarbeets, corn, and small grains. In recent years exportation of fresh vegetables and fruits to the European market has had an influence on the expanding of vegetable and fruit growing areas.

Increased crop production from the unit area, due to better on-farm water management, encourages the farmers to improve their lands and to invest in optimum fertilizers, costly weed control and other inputs. Farmers who improve their land by leveling also search for additional technical aid toward better on-farm water management and cultural practices.

Identifying Problems

1. Institutional

In Turkey, on-farm water management is under the supervision of TOPRAKSU-Soil and Water Conservation Authority–which has the responsibility for assistance to farmers in developing their land for irrigation. This responsibility includes land leveling, drainage, irrigation water conveyance and control structures, water management techniques, land improvement, and land consolidation.

Increasing the speed of land improvement and on-farm water management implementation requires additional personnel, but hiring new personnel is forbidden by the new personnel law. On the other hand, training of the personnel is a must for better land improvement and on-farm water management. Training of professionals and subprofessionals was a great help in starting on-farm development activities; but the interest of the persons who are in the position of making decisions, is one of the more important factors for generating a development atmosphere in the new areas.

Irrigation Guides are prepared by TOPRAKSU research stations. They are in use only where the stations are located. The irrigation guides which are in use in the pilot 426 project area in Izmir, were patterned after those developed by the SCS. They were not tailor made to fit Turkey's climate, soil, crops, farming methods or equipment, but were modified to fit Turkish needs. At present there are not sufficient irrigation guides modified to local conditions, nor developed for the new on-farm water development project areas.

2. Infrastructure

In the state irrigation project areas where mechanization and irrigation are introduced, land fragmentation proves to be one of the biggest obstacles in the efficient utilization of equipment and irrigation installations. Only 50 percent of the surface equipped with state irrigation networks is in fact irrigated. This is mainly due to land fragmentation which prevents installation of adequately spaced tertiary irrigation canals. Most of the state irrigation projects require rehabilitation work, such as canal lining, additional tertiary canal installations and control structures.

In the cooperative projects, where water is pumped from underground, the high cost of electric power may prevent farmers from applying adequate irrigation water; on the other hand, in some cases, high prices help to increase water application efficiencies.

Shortage of irrigation water forces the authorities to deliver water to the farms for 24 hours a day, thus the farmers have to apply irrigation water during nighttime. The utilization of irrigation water day and night increases the efficiency of irrigation delivery systems, but at the same time results in very low irrigation application efficiencies.

3. Land development resources

Most of the government-owned land improvement machinery and equipment have been employed in the selected state irrigation project areas. This is mostly big earthmoving equipment, imported caterpillar, D6, D7, or equivalents. The amount of equipment which the Government owns is relatively small when it is compared with the amount of land improvement works to be done and a target of 60,000 hectares a year.

Outside of the state project areas, small earth moving equipment, locally manufactured and operated by small farm tractors is used. The labor skill needed for the manufacture of this equipment is quite adequate in

Turkey. But the manufacturers of equipment indicate they would benefit greatly if import restrictions were relaxed to allow them to import hydraulic pumps and control valves and hydromatic transmissions.

The number of private land-improvement contractors is very small. Most of them are farmer types, equipped with three or more 50-60 horsepower tractors, with attachments of mechanical scrapers, small levelers and chisels. There are a few contractors equipped with big earth-moving equipment. Since the land improvement construction depends on the season and the type of the crop grown, contractors tend to shift to other businesses during the off season and prefer to stay in those that are considerably more dependable.

For better on-farm water management, Turkey must level the lands and prepare the farms for efficient utilization of irrigation water. Land improvement construction is costly and it is difficult to accomplish these services using the limited governmental budget. There is no repayment for additional much-needed land development.

Outside of the state irrigation projects, only a very limited number of farmers can afford to invest money for land development purposes. Private banks in Turkey generally do not direct investments to agriculture at the farm level. Turkey's Agricultural Bank directs 80 percent of its loan funds to annual operation. A great number of farmers are ready to improve their land if the banks would give a credit with long-term repayment and medium interest rate.

Engineering services for land improvement are rendered by TOPRAKSU, both for government investments within state project areas, and for private projects outside state project areas. Most of the trained engineers and technicians are assigned to government-investment projects, but the intensity of land improvement has increased outside of the state project areas. A resulting shortage in engineering services has come about and farmers who are eager and want to participate in the program have to wait for these services. Private contractors need the same service and, most of the time, their equipment and operators stay idle.

How Turkey's On-farm Water Management Problems Can Be Best Solved

The establishment of irrigation projects, sometimes at proportionately large investment costs, is only marginally effective unless there is a local infrastructural base for supplying necessary services, materials, marketing facilities and credit resources to the farmers. It is rare that government alone can provide such a complete base of infrastructure in a balanced and timely manner.

However we have learned some lessons through our experience in Turkey with the on-farm water special project. We found that government can act as a catalyst in mobilizing private interest in the local community. For instance we guaranteed the purchase of a few pieces of equipment which were not being manufactured in Turkey but were needed for improving irrigation farming methods. We purposely stayed away from the large government-sponsored machinery workshops that merely fabricated machinery and take complete payment through transfer of government funds. It was proved that small, local machine shops would follow up with after-sales service, would go and market their product in neighboring communities, and would give some training to farmers in the use and maintenance of their equipment product. We are now finding that these small manufacturers are selling equipment to farmers on modified time-payment plans.

The same procedure was used for encouraging local entrepreneurs to become private contractors and go into neighboring areas to market their custom services. A recent example found a group of contractors from our area moving out over 500 miles away to take a land-leveling contract for a group of farmers. The size of this contract was about 500 hectares. The same is proving true for suppliers of seeds, fertilizers, pipes, siphon tubes, and other material inputs. For marketing facilities and product contracts, it is seen that processing and storage interests are investing in plant facilities where production potential is large enough to guarantee their investment.

Each of the private sector interests acts as a highly effective extension service for motivating an atmosphere at the local level for land improvement and more productive farming methods. Both of these factors lead the farmer to adopt more efficient methods of water use.

Credit resources have traditionally been given on an annual basis and at a very low level (average T.L. 100 per farmer) in Turkey. We are presently developing a credit plan whereby credits will be available to farmers for land development on a medium- to long-term basis and for annual farming operations at a higher level (average T.L. 250 per farmer), to private contracting firms for acquiring sufficient equipment for carrying out a successful private contracting business, and to manufacturers for improving their manufacturing base as well as their technology base.

By inviting private interests into the mainstream of the agricultural development effort, by restructuring the credit process, and by offering the farmers a more secure market for their produce, interest in more efficient utilization of water and other cropping practices has almost magically expanded over one thousand times during the past five years. This leaves us with the other problem previously identified, shortage of technical personnel.

It is customary to have all survey, design, and planning work done by government technicians in Turkey.

But in our region we have reached the saturation point and, with the implementation of the new credit program, demand for services will increase even more. We are considering an arrangement whereby technical services, especially survey and design, will be done by the private sector and TOPRAKSU will control the inspection of work to see that TOPRAKSU national standards are complied with.

TOPRAKSU's newly organized Research Division with seven research stations and two institutions are working on 290 projects and 765 field trials which are closely related to on-farm water management. Forty percent of research projects are directed to water use on irrigated land; 30 percent to moisture conservation; 15 percent to fertilizer research; and 15 percent to non-arable erosion control, dune control and flood control. Research stations work closely with the farmers and conduct demonstrations on water management on the farmers' fields.

Conclusions

On-farm development services in Turkey are a most important means of speeding up agricultural production and closing the gap between the number of hectares for which irrigation water is available and those actually irrigated. This gap totals 400,000 hectares.

The size of the land-development services for large-scale irrigation projects should be determined considering both governmental and private sector resources. Forwarding the private sector capacity to provide these services increases the speed of on-farm development and the private sector's contracting capacity. To acquire these services the credit system should be improved, manufacturing of equipment for land development should be encouraged, bidding conditions should be re-organized and permit conditions for importing the necessary equipment should be relaxed. To close the gap in land development services and enhance the promotion of these services. programs should be prepared for contractors to work directly with farmers. The private sector should be supported if Turkey is to realize land development services completely. To help farmers on this subject credit allocations should include the following areas:

1. Credits for farmers to realize land development services,
2. Credits for private contractors to buy equipment,
3. On-farm operation credits, and
4. Credits for local manufacturers producing land leveling and agricultural equipment.

The capacity for technical help by government agencies should be increased and private contractors should be encouraged on a wider scale.

In areas where land fragmentation is an obstacle to efficient irrigation and land development, consolidation should be carried out and attempts made to provide each farmer with direct access to irrigation, drainage, and roads.

4.

IMPLEMENTATION OF WATER MANAGEMENT IN SOUTHEAST ASIA (PHILIPPINE CASE)

Dr. Kunio Takase[1]

Three-stage Approach

In order to achieve production targets in a fully-fledged irrigation project most effectively, the Bank considers a three-stage approach essential and has applied it in most of the projects it has assisted. The three stages are: (1) The Experimental Farm; (2) the Pilot Scheme; and (3) the Pioneer Project.

1. *The Experimental Farm* deals with basic field investigations of agronomy, soil, crop, and water relationships. It aims at solving location-specific problems through research, and usually covers an area of about 5 to 10 hectares.

2. *The Pilot Scheme* is essentially a trial demonstration of, and training in, water management and modern farming techniques on a practical scale. Usually undertaken by pilot farmers, this approach aims at solving mainly technical problems. It is on a limited scale, of between 100 and 200 hectares, but the physical layout has the same degree of complexity as that of a pioneer project.

3. *The Pioneer Project* is a model of a fully-fledged irrigation project under actual farm management. It should be large enough to be an economic unit of agricultural production and includes credit, processing, marketing and institutional arrangements. Such projects aim to solve not only technical problems, but also marketing, economic, and organizational problems associated with a larger-scale operation. An area of from 1,000 to 30,000 hectares is involved depending on the purpose of the pioneer project.

NIA-ADB Water Management Project

This was a typical example of a pilot scheme implemented by the Bank (i.e. the second stage of the above three-stage approach). A description is given in the *Workshop Report.*[2]

Angat-Magat Integrated Agricultural Development Project

Out of eight pilot schemes formulated under the NIA-ADB Water Management Project, the two largest irrigation systems (Angat and Magat) were selected as pioneer projects (the third stage of the three-stage approach) and are now being implemented with financial assistance from the Bank.

The Angat-Magat Integrated Agricultural Development Project covers about 70,000 hectares. The objectives of the project are to contribute to the Philippine Government's goal of self-sufficiency in rice, to promote crop diversification, to create more employment opportunities, to generate foreign exchange savings, and to raise the income of the farmers. The Project involves:

- (i) Improvement and expansion of the irrigation, drainage, and road networks;
- (ii) Increasing agricultural productivity through diversification of cropping patterns (four rice and one soybean in two years), appropriate inputs and modern techniques;
- (iii) Transferring the land to the tenant-farmers that till it;
- (iv) Providing agricultural credit to those farmers who become owner-farmers; and
- (v) Creating compact farm units, each of which consists of a group of adjoining farms that share on-farm ditch, the whole to cover 30-50 hectares and serve as a single production unit.

The investment cost of the Project is estimated at $17.7 million, including a foreign exchange component of $8.8 million, which the Bank is financing, and a local currency component of $8.9 million.

Our experience indicated that service roads are equally as important as irrigation and drainage ditches for effective water management, because watermasters have to move quickly along canals from gate to gate by jeeps or motorcycles. One watermaster supervises an average of 10 ditchtenders over 30 kilometers of canals servicing about 1,500 hectares; without mobility, therefore, water management facilities cannot be operated effectively. Also,

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[1] Irrigation Project Manager, Asian Development Bank. Views expressed in the paper are the personal views of the writer and do not necessarily reflect the policy of the Asian Development Bank.

[2] ADB, *Regional Workshop on Irrigation Water Management,* July 1973, pages 63-70 (Appendix 1) and pages 248-252 (Case 2, Part IV, Section II).

these service roads are needed by farmers to make the more frequent visits to their farms that modern farming techniques require and to enable larger agricultural production to go out to markets.

The NIA Water Management Training Center, which was established as a result of the NIA-ADB Water Management Project, will be responsible for training NIA staff and pilot farmers not only on water management but also in the agricultural and institutional aspects mentioned above. In addition, six demonstration farms will be established in representative areas to experiment with and to demonstrate new site-specific cropping patterns and cultivation techniques.

In order to ensure the success of the Project, a Project Committee will be organized through an interagency agreement involving the following eight agencies:

- (i) Department of Agricultural and Natural Resources (DANR);
- (ii) National Food and Agricultural Council (NFAC);
- (iii) Department of Local Government and Community Development (DLGCD);
- (iv) Department of Agrarian Reform (DAR);
- (v) Agricultural Credit Administration (ACA);
- (vi) Central Bank of the Philippines (CBP);
- (vii) Rural Bankers' Association of the Philippines (RBAP); and
- (viii) National Irrigation Administration (NIA).

The Project Committee will be responsible for major policy matters, budgetary and personnel requirements, and for formulating operational guidelines for the Project, while NIA is responsib'. ior implementation of the Project as Executing Agei.., .

Pilot-Evaluation

Past experience has shown that one of the basic problems commonly encountered in the appraisal of projects in most Asian countries is the scarcity or non-availability of good statistics, particularly for the project area. A possible solution to this problem involves devising a statistical framework that would systematically provide information for measuring or charting the development that actually occurs in the project area. Establishment of such a framework is essential for the meaningful post-evaluation of projects and this, in turn, contributes to the qualitative improvement of the Bank's appraisal techniques. To this end, the Bank recently initiated a pilot statistical framework for the Cotabato Irrigation Project, in cooperation with the Philippine Government.

CHAPTER VI

NATURE OF RESEARCH AND WHERE AND HOW TO CONDUCT IT

1.

DRYLAND FARMING IN JORDAN

Amin Abu Sha'er [1]

Introduction

Jordan is situated just off the Levant of the Mediterranean between latitude 29°17' and 33°23'N. It is bounded on the north by Syria, on the south by Saudi Arabia, on the east by Iraq and Saudi Arabia, and on the west by the International Armistice Line.

The total area of Jordan is estimated at about 96,000 square kilometers,[2] 90,000 sq km on the east bank, and 6,000 sq km on the west bank (now the occupied part of Jordan). Of the total area, only about 1.3 million hectares[3] are cultivable, 1.08 million ha are cropped every year and of this 0.82 million ha are in field crops, vegetables, and fruit trees. The rest is in range and forest. Only 75,000 ha are under irrigation. Most irrigation is located in the Jordan Valley (about 396 meters below sea level). The rest of the area (about 87 percent) is in the eastern part of the country and consists of hills and flat lands with prevailing desert conditions of low rainfall (100-150 mm),[4] high wind velocities and Mediterranean type climatic conditions. Hilly and coastal climatic areas have higher rainfall (350-600 mm).

Regions

Jordan is divided into four distinct regions:[5]

1. The Uplands. Estimated area, 11,500 sq km.
2. The Steppe Region. Estimated area, 10,000 sq km.
3. The Rift Valley complex. Estimated area, 5,500 sq km.
4. The Desert Region. Estimated area, 69,000 sq km.

Climate and Its Effects on Agriculture

Temperature

Winters are cool and summers are warm. Average minimum temperatures in the coldest month (January) vary from 2°C in the cold arid desert regions to 10°C in the very warm desert areas. Average maximum temperatures in the warmest month (July or August) range from 30°C in the Mediterranean sub-humid zones to 42°C in the very warm desert areas and the valley.

Rainfall

The pattern of rainfall is markedly changeable. Precipitation is highly seasonal, being virtually confined to the winter months (November - April), and extremely variable in amount.

The following illustrates the distribution of annual rainfall averages by area.

Rainfall in mm	Area receiving such rainfall sq km	percent
Over 600	300	0.3
500 - 600	2,000	2.1
400 - 500	2,000	2.1
300 - 400	1,200	1.2
200 - 300	6,000	6.2
Under 200	84,500	88.1
	96,000	100.0

[1]Wheat Project Leader, Ministry of Agriculture, Amman, Jordan.

[2]2.56 sq km = 1 sq mile.

[3]1 hectare (ha) = 2.5 acres.

[4]25 millimeters = 1 inch.

[5]FAO, Country Report 1967, Jordan.

About 12 percent of the country's area receives rainfall exceeding 200 mm and only about 6 percent receives over 300 mm. Only this small portion can support sustained crop production. Extreme annual variations of rainfall greatly affect the area and the production of rainfed crops, as the following figures illustrate for the three main rainfed crops: Wheat, barley, and lentils during 1964-1971.

Season	Rainfall average of 17 (mm)	Area (000) ha	Production[a] (000) M Tons
1963/1964	462	414.0	409.0
1964/1965	475	393.5	392.7
1965/1966	293	297.8	131.7
1966/1967[b]	489	307.2	275.5
1967/1968	322	312.4	123.8
1968/1969	374	244.2	223.8
1969/1970	251	284.3	65.6
1970/1971	317	312.3	197.0

[a]Statistical yearbook 1971, Jordan.

[b]East Bank only with effect from 1967.

The effect of rain is not determined entirely by the annual average precipitation, but also depends on distribution through the winter months (November - April). Generally speaking, the amount of rain necessary to have a good crop of wheat in Jordan is about 300-400 mm. It has been observed that the average yield of wheat per hectare did not increase much when the rain exceeded 400 mm. Yield decreased when the rainfall was under 300 mm. The rains through December - February have the greatest effect on increasing the yield of wheat. Conversely, low December - February rains decreased yields.

Crop Production Conditions

About 35 percent of the cultivable area or 378,000 ha is given to the cultivation of field crops, and wheat occupying about 225,000 ha is the most important staple food crop contributing about 60 percent of the area under field crops. Vegetables and fruit trees, mostly citrus and banana, are raised under irrigation in the Jordan Valley. The wheat crop is grown mostly under highly erratic rainfall conditions. The wheat-growing area contains land which must be regarded as sub-marginal because of rainfall conditions and soil poverty Part of this sub-marginal land yields a crop once or twice in ten years and is planted only in years having favorable early rains. Other parts yield a crop perhaps once in three or four years and are more regularly planted. The extent of such sub-marginal land is not known with any certainty, and judging by various estimates which have been made, it may be something of the order of 125,000 to 200,000 ha.

On an average, the country produces about 150,000 tons of wheat every year, which is only about half of its annual consumption of grain. The deficit is met through foreign imports, mainly from the United States. Due to the highly erratic nature of the rainfall in both amount and distribution, the yields as well as the total production are subject to considerable annual fluctuations.

Whereas, a crop of wheat or barley may be raised every year in the areas with a rainfall of over 300 mm/year, only one crop every other year is possible in a fallow system in areas with rainfall less than 250 mm/year. The overall average yield of wheat for the period (1951-1972) is about 660 kg/ha. Jordan is among the lowest countries of the world as far as the average yield per hectare is concerned, compared with Syria, 1450 kg/ha; Egypt, 2670 kg/ha; Lebanon, 4000 kg/ha; Holland, 4490 kg/ha; U.S., 2180 kg/ha.

Increasing wheat production in the country is made more urgent due to the rate of population increase estimated at about three percent annually. The Government has, during the last 10 years or more, been exerting efforts in this direction through the Wheat Production Improvement Programme and also through the wheat project started in 1967 and implemented in cooperation with USAID and Oregon State University. Moisture supply has been found to be the major limiting factor for increasing yields of rainfed crops. More recently, however, favorable results have been obtained by applying a package of improved practices including summer fallow techniques, tillage, weed control, fertilizer and improved varieties. These practices which have been carried out, since the 1967/68 crop season, on demonstration plots supervised by the wheat project personnel have proved that wheat yields can be increased by 60 percent over those now realized on farmers' fields.

Causes for Low Yields

In addition to the planting of sub-marginal land, a number of factors tend to maintain the cereal yields at low levels:

1. Late planting of much of the crop, owing to shortage of farm power and equipment.
2. Neglect of soil and water conservation.
3. Reduction of fallow without compensating improvement of production techniques

4. Weed competition, particularly for water; and inadequate weed, pest, and disease control.

5. Lack of manure and fertilizer.

The Wheat Project [6]

Due to the low yields of wheat and to the increasing rate of population and high per capita consumption of wheat, the Government of Jordan, through the Ministry of Agriculture and program-related agencies from the United States Government, has been involved in a program to increase domestic wheat production in Jordan.

In the 1967/1968 season the Wheat Project was started. Through this project the package of improved practices mentioned would be demonstrated in various parts of the country. The first strategy of the project was to demonstrate the applicability of these improved practices to Jordanian conditions and to win support from both the private and public sectors affecting the local wheat industry. Combinations of various tillage practices which would most efficiently conserve two years annual rainfall for one wheat crop through a clean tilled summer fallow system were planned for field evaluation. Results of these demonstrations involving improved seed, weed control, seeding with a grain drill, and the use of fertilizers are summarized as follows:

The use of chemical weed control is being accepted by Jordanian wheat farmers. Use of this practice has gone from zero to 5700 ha since the start of the project. As a result of this, some commercial spraying is going on now.

The value of the grain drill has been demonstrated. Lower seeding rates are used and more uniform stands of wheat are obtained. Use of the chisel plow and sweeps in place of the disk plow is growing satisfactorily where ample power is available. This type of adaptive research needs to be expanded and continued over a period of years in order to determine the most practical combination of tillage procedures which will most efficiently conserve moisture for maximum wheat production under summer fallow conditions in each of the dry and medium rainfall areas. A detailed study of soil moisture levels should be incorporated with the tillage practices.

More uniform stands and less competition from weeds should make more efficient use of the limiting resource, water, and improved soil fertility should give an economic response. Results of simple rate of nitrogen study at an experiment station in the Jordan Valley with a variety of local wheat grown under full irrigation is summarized below:

N(kg/ha)	Yield (kg/ha)
0	1880
50	2430
100	4320
200	5760

Harvest year	No. of Demonstrations	Wheat Yield kg/ha Demonstr. Plots	Farmers Plots	Yield Increase	Percent Increase
1968	40	1480	770	710	92
1969	63	2080	1350	730	54
1970	30	1450	740	710	95
1971	46	1470	870	600	60
1972	64	1740	1250	490	39
1973	80	1770	1150	620	71
Average	--	1670	1020	650	--

[6] Evaluation of wheat project, 1971. Dr. Norman Goetze.

This shows clearly that yield potentials in irrigated regions of Jordan are comparable to other areas of the world and that yield increases are still occurring at even the highest increments of nitrogen. This type of work needs to be expanded by trying higher rates of nitrogen and by varieties which are more tolerant to lodging or which have the physiological potential for maximum yield. Similar work must also be done on various rainfall locations in the dryland areas.

The use of fertilizers for wheat production has been accepted by farmers. Some 2700 ha were fertilized last season (1972-1973) on farmers' land in spite of the low over the farmer's fields of about 650 kg/ha as an average. expected to increase in the coming years.

Plant breeding and variety testing on wheat has been done for years using various international spring wheat collections. Some of the dryland nurseries are not yet receiving enough fertilizer to show maximum yield potentials of many of the varieties. In 1972 all of the dryland sites received only 40 kg of N per ha. Data show that most of the vulgare types are out-yielding the durum types, and that the highest yielding local check variety produced only 64 percent as much as the highest yielding semi-dwarf in the international collection.

Since Jordan faces a continual wheat deficit, potential foreign exchange requirements could be decreased by maximizing wheat production using highest yielding varieties.

The wheat demonstrations show an increase in yield over the farmer's fields about 650 kg/ha as an average. Assuming that the average area planted to wheat every year is about 200,000 ha by application of the same methods used in the demonstration plots, Jordan could produce about 130,000 metric tons more annually than at present. At a price per ton of wheat of about 40 Jordanian Dinars,[7] the potential foreign exchange requirements could be decreased by 5.2 million Jordan Dinars.

There is no doubt that the wheat project has made some really significant early progress, and if the long-term goals of the project are obtained, satisfaction of wheat production goals can be reached and wheat imports reduced.

[7] One Jordan Dinar = 3.12 U.S. dollars.

2.

RESEARCH FOR RAINFED AGRICULTURE

Norman Goetze[1]

Major attention is being given at this Symposium to water management on farms within existing or potential new irrigation systems. This is the natural result of the interests of the majority of those in attendance.

Dramatic improvements have been made in increased efficiency of production of many irrigated crops through both in-country developmental projects and by multi-national and multi-agency commodity and regional programs. In some cases short-term gains have been made by shifting crops to irrigated rotations. The consequence of the successes of these programs has been to ignore the long-term potential of increased productivity of crops which have sole competitive advantages on large areas of agricultural land deemed marginal because of low rainfall. Potential increases in yield per unit area are proportionately as great as those in irrigated regions. The total cultivatable areas of such marginal lands are much larger than those of irrigated or potentially irrigated lands, hence the opportunities for increasing total world production of crops is greater in rainfed areas than in irrigated regions.

Unfortunately the limiting factors are much more complicated on rainfed marginal lands. The research programs necessary for developing improved production practices are more involved and take longer to do. Consequently these problem areas have gone largely ignored by agencies and institutions, which have had to gain their support by short-term successes. Yet in the long run, significant increases in world food supplies would result from research and developmental programs in the rainfed areas. Time is running out in initiating some of these programs.

Actually, many of the basic plant, soil, and water interrelationships are similar between natural rainfall and artificially applied irrigation water. The following differences between sources of water, however, have caused a general lack of transferability of information between dryland and irrigated crops agronomists: 1. Within limits, man has been unable to control the natural rainfall and has instead gained experience in adjusting his farming operations to match the rainfall patterns. 2. Rainfall occurs in certain cyclical and rhythmical patterns, but varying moisture stresses develop during most cropping sequences. 3. There are seemingly random erratic variations in the normal rainfall cycles which wreck the most carefully designed research programs and farming operations. 4. Within most irrigation projects and even within individual irrigated farm operations, there are crops that are grown more like rainfed crops than like well managed irrigated crops.

[1] Extension Agronomist, Oregon State University, Corvallis, Oregon

Basic Rainfed Moisture Research Problems

1. Moisture interception

Rainfall is characterized by erratic rates and timing. During low intensity rain, evaporative losses are excessively high and during high intensity rain, runoff results whenever the rate exceeds the effective infiltration rates. Only in rare cases does the normal rainfall come at a time and rate to match the infiltration rate of the soil and the consumptive use requirement of the crop.

2. Soil moisture storage

The water holding capacity of the soil and the depth of the soil profile are the major limiting factors of how much moisture can be held in reserve for later plant use. Microclimatic influences on evaporation rates, cropping practices to shorten the shortage period, improved summer-fallow techniques, and elimination of weed growth can all help to increase the efficiency of soil moisture storage.

3. Maximizing crop response within limits of available soil moisture

Vast agricultural areas of the world will always receive only limited quantities of natural rainfall. Additional quantities of water can be intercepted and stored as mentioned, but the major research breakthroughs will be developed in making more efficient use of the present water supplies. Traditional agricultural habits, lack of appreciation of the potential for these areas, and fear of tackling difficult and risky research problems have delayed initiation of programs to improve water use efficiency under marginal conditions.

Specific Research Suggestions

1. Improvement of moisture interception

Many agencies have developed designs for useful structures for minimizing soil erosion and for efficient water conservation. Some experiences have been gained in making use of crop residues for encouraging moisture interception. Tillage practices have also been developed as an integral part of many given sets of cropping patterns. Limited work has been done recently on zero or minimum tillage.

Adoption of these practices is dependent upon their suitability to local environmental conditions. Therefore, site-specific or adaptive research will be required for all of these problems Some practices may be directly transferable but experience usually shows that local alteration of practices is helpful. Such modifications can be most efficiently investigated by host institutions with assistance by AID Missions or conventional contract projects.

2. Soil moisture storage

a. Chemical weed control is an effective method of improving soil moisture storage This relatively new field of agricultural science has received major contributions from American scientists and corporations. The "environmental" concern of the American public has throttled the U.S. leadership in this field. European based chemical industries are now most active in field development of herbicides. AID-sponsored projects have been summarizing world information and have also been supporting regional adaptive research. This work should be continued and strengthened. Perhaps its efficiency could be improved by its closer support and integration with Mission-sponsored commodity projects. There are future benefits to be derived from continual cataloging of world literature of herbicide uses. but adaptive research must be done before adoption of practices in specific local conditions

b. Tillage practices both to control weeds and to minimize soil moisture losses must be developed locally to suit local environmental conditions and to make best uses of locally available power and equipment. Some practices are transferable but their acceptance is dependent upon local adaptations and demonstration.

c. The additive effect of soils, climate, and time on soil moisture losses in a given location could eventually be defined through appropriate models based on "basic" research. The effect of individual factors could be determined through a systems analysis and then verified for local conditions through adaptive research and demonstrations. There are many gaps in our existing knowledge but some agencies and institutions are now attempting to develop models to incorporate the individual variables. Perhaps a close liaison by AID with possible central support of these projects would be most effective.

3. Maximizing crop response within limits of available soil moisture

a. Weed control is certainly a major opportunity for improvement of yields in relation to water use efficiency. The general principles would be equally applicable to both soil moisture storage and maximizing crop response. The general recommendations outlined in the above section would be applicable here.

b Individual crop varieties have been developed for drought resistance. Little attention has been given to crop production per unit of water under dryland conditions. Regional, institutional, and commodity breeding programs have extensive germ plasm collections and some also have the technical competence to study the physiological and morphological modes of water use efficiency on important crops. Contract research with these agencies would probably be most effective in developing more water efficient crop varieties.

c Whenever an improvement is made in any one of the many inputs in rainfed agriculture, the maximum response curve for each of the complementary inputs must be determined. The complete package of practices for rainfed agriculture must be developed into an integrated cropping system based on basic fundamentals and adapted to local conditions. Some "basic" research at regional, international, or commodity centers needs to be stimulated on the basis of maximum water use efficiency. Contract research would probably be most effective. Certainly, though, the adoption of these packages would ultimately be dependent upon local in-country adaptive research or demonstration.

How Can AID Best Organize Its Efforts?

1 A core staffing of highly trained and experienced agronomists, soil scientists, climatologists, and agricultural engineers dedicated solely to the objective of improving efficiency of crop production in rainfed agricultural areas would be singularly most important in focusing the agency's attention to this opportunity area. This staff in itself would not be expected to do the tasks outlined in earlier sections of this paper. It would instead be expected to review the research needs of its Missions and internal divisions in relation to availability of results from other organizations. It would also be expected to coordinate the other suggested program items to follow

2. Carefully defined grants for strengthening existing programs at commoditiy institutes, universities, and international centers could be used to stimulate meaningful basic research whose results would be mutually beneficial to both the grantor and grantee.

3. Regional centers of excellence at existing institutions or centers would benefit AID's program of research in rainfed agriculture in several ways. First of all there are professional gains to be made by nesting staff who have similar or complementary professional interests. These centers could also serve to give better field coordination than could be expected from the core staff. In terms of commodity or regional orientation, staff located at centers would become the specialists. These centers would also become focal points for individual Mission assistance for adaptive research by either host county or Mission contract personnel. Eventually the centers could also be an efficient location for both participant training and staff orientation.

Summary

Management of rainfed moisture in the various agriculture systems in relation to other inputs needs to be improved. Some of the problems are very complex. The sooner that a coordinated research program can be initiated, the sooner AID can make some real contributions in this most important field of international agricultural development.

3.

RESEARCH FOR IRRIGATED AGRICULTURE

Marvin E. Jensen[2]

Introduction

On-farm water management problems often are not recognized, but are very common on most irrigated projects. Crop production reduced by disease or insect damage is recognized and describable. Consequently, and understandably, research on disease or pest control is often given a higher priority than research on water management problems. Similarly, research results that produce distinct and obvious benefits under existing farming practices, such as new crop varieties, are easy to transfer as are research techniques necessary to adapt a new variety to a new environment or to change its resistance to local diseases or pests over a few years. Production limited by water management problems is often more difficult to comprehend and describe. Water affects the entire crop-soil-climate system, and water-related problems are not always readily discernable. Problems that seem too complex, or cannot be visualized, generally are not given a high priority by policy makers and funding organizations. A large amount of water management research exists, which, if applied, could increase food production substantially. These research results seem to go unused because we apparently have not developed adequate adaptive research techniques necessary to produce site-specific information, and we have not developed acceptable techniques to apply new technology. This situation is not unique to developing countries but is commonplace even in highly developed countries. Why? There are several key reasons. General solutions to problems will not be applied if the problems are not apparent, and site-specific solutions will not be applied if they are not economical and practical. There must be an incentive to apply a new practice. These are some of the specific major issues addressed in this paper as part of the assignment related to the overall goal, purpose, and objectives of this Symposium.

The ultimate goal of this Symposium is to develop guidelines and recommendations for on-farm water management research which, when implemented, will lead to increased agricultural production and income in less developed countries. The specific purpose of this Symposium is to thoroughly evaluate water management problems in developing countries, available research information, and research completed or underway in a world network so that gaps in research can be identified. We are also to assess the interrelationships of the Colorado and Utah State Universities' water research projects sponsored by AID and to determine whether these projects support each other's objectives and whether their findings are generally applicable in developing countries.

I am also to respond to related discussions on the question of the phases of water management of which we have adequate, and those of which we have deficient, knowledge as viewed from various geographical areas. Since these papers were not available before the Symposium, I will not provide a detailed listing of research needs. I will attempt to describe those characteristics of water management problems and research that are often overlooked in developing and implementing research programs and in applying solutions to water management problems.

Specific objectives to be considered during the Symposium are to find answers to five questions concerning The present status of knowledge; how this knowledge is being applied throughout the developing world and major factors limiting its application; who is doing research related to unsolved problems; the breakthroughs which can be applied generally through the various countries; and how general problems may be approached in an interdisciplinary framework. My discussion will concern irrigated agriculture, but many of the principles apply to rainfed agriculture where food production is normally limited by precipitation

Before we can intelligently discuss research for irrigated agriculture, we must recognize and describe water management problems, especially their uniqueness which makes additional research necessary. At the risk of repeating some of the statements made by those addressing the first question of our objectives, I will describe some of the more critical problems that I see associated with improving on-farm water management and food production. I will emphasize particularly those aspects of water management which limit the production of food to a greater extent than necessary under the existing circumstances.

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Characteristics of On-farm Water Management Problems

Most on-farm water management problems that limit food production are not unique to developing countries. There is much similarity between the problems in the developing countries and the developed countries where managing the complex crop-soil-climate system requires regulating the water component. Many of these problems begin when those who develop water resources do not consider the entire crop-soil-climate system which includes salt control and drainage, but are concerned only with delivering the water—the easy part of the job. Such developers tend to forget that the real purpose of irrigation is to produce crops.

There are many similarities in the techniques necessary to adapt available research and to apply irrigation technology to enhance food production. The major difference is in the alternative approaches available to improve water management. Farmers in the developed countries, for example, may invest in large capital improvements to attain a greater degree of water control that will improve or simplify the management of irrigation water. Farmers in developing countries must use alternative practices such as greater labor input to achieve better management. The principal similarity between the two circumstances is that managing irrigation water implies, first of all, an understanding of the available water status and the mechanisms controlling the loss of water from the soil root zone. Drainage and salinity control requirements are similar in the two types of countries but the options for control may be more restrictive in developing areas. Also, drainage and salinity control generally require control of areas used by many farmers.

Recognizing and delineating water management problems

The *foremost* water management problem is recognizing and delineating any water problem that is directly responsible for limited food production, such as the mismanagement of water, or the reluctance to implement better water management practices. A crop seriously stressed because of a severe shortage of soil water and a crop ruined by flooding are examples of obvious water problems. In most situations, however, numerous instances exist where excess water, or lack of water, and water-related factors significantly reduce crop yields, but are not recognized. Such scientists conducting research in other aspects of irrigated agriculture often do not recognize the adverse effects of poor water management. Obviously, policy makers and the administrators of agriculture programs in both the developed and developing countries will not be as aware of these more subtle water management problems that limit agricultural production unless these problems are carefully delineated and the effects documented. The natural result is to direct their limited financial and technical agricultural research resources towards studies that may in themselves advance scientific knowledge, but may not contribute to the solution of real problems limiting food production.

The *second* major problem that must be recognized at an early stage is that improved irrigation water management requires a continual application of new technology regardless of the capability of the irrigation system except, perhaps, for fully automated systems. Fully automated systems, however, usually require large capital outlays and an extremely high level of on-site technical skills to keep the systems operating. Improving on-farm water management is not like changing crop varieties, which may require a decision only once during a 5-year period or at most annually. Similarly, decisions concerning application of fertilizer are made only once or twice a year. In contrast, improvements of on-farm water management require the application of available irrigation science and technology on a daily or weekly basis, with the exception of improvements such as major land leveling or a change in the irrigation system which may occur only once in a 5- to 10-year period. A communication linkage is needed between those who control water supplies and delivery and the water user to keep the delivery system responsive to the needs.

To understand the necessity of continual application of science and technology to improve crop production, we must recognize the role that water plays in the complex crop-soil-climate system. Slatyer (1967), indicates that water is essential for the structural integrity of biological molecules, cells, tissues, and of the organisms as a whole. Water plays a vital role in the transport of mineral nutrients and the translocation of materials in solution throughout the plant body. He also indicates that in all actively growing plants there is a liquid phase continuity from the water in the soil through the plant to the liquid-gas interface at the evaporation sites in the leaves. The root system provides an extensive absorbing surface across which pass virtually all of the water and mineral nutrients utilized by plants. When the vital roles that water plays are recognized, it is not too difficult to comprehend the importance of water management. The operator of an irrigated farm must control the level of available soil water—a reservoir he cannot see and of which he cannot regulate the rate of outflow, but one whose level directly affects plant water stress and plant growth. In addition, since leaching is the only practical mechanism for controlling the salt concentration and the toxic levels of certain elements in the root zone, he must apply sufficient excess water for this purpose. Salt and sodium control in irrigated agriculture is probably the second and the oldest problem in irrigated agriculture. Applying water for salt control is especially critical where water supplies are limited, but it is also important when supplies are plentiful because excess application may cause drainage problems and leach valuable nitrogen from the root zone.

The crop-soil-climate system is difficult to manage effectively. How often have we assumed that the farmer, who may have the least understanding of the various mechanisms that control the system, will automatically achieve full benefits of water if we merely deliver some water to his land?

Common on-farm irrigation water management problems

On-farm water management requires daily or weekly decisions regardless of the irrigation system involved. The opportunities for mismanagement may be less with systems that are not flexible in their operation. For example, problems of excess water application are not nearly as common with sprinkler irrigation systems because the rate at which water can be applied is low and limited by the system. As a result, many hours of operation are required to apply a normal irrigation. With this method of irrigation it is much easier to prescribe and control the amounts of water applied but the timing is still subject to wide variations. In contrast, surface systems may allow little opportunity to control water applied because there may be no adjustable structures, water measurement devices, and lined channels. Under these conditions there are much greater opportunities and much more frequent occurrences of mismanagement.

Regardless of the system involved, on-farm water management still has a significant effect on food production from irrigated land. One important factor that is not often recognized is that irrigation scientists and technologists do *not* make the daily or weekly on-farm irrigation decisions though this is often implied by the scientific and technical agricultural communities. The decisions are being made by people with limited background and training, people who have not had formal training in the management of a complex crop-soil-climate system. In addition the needed decision-making data are generally not available to those who must make these decisions. The kinds of necessary decision-making data are: (1) The estimated available soil water status for each field and crop at all times; (2) the projected irrigation dates by fields that will avoid or minimize the effects of water stress or over irrigation; (3) the amounts of water that should be applied for each crop and field if the irrigator can control the amount applied; and (4) some knowledge about the adverse effects of early, delayed, or terminating irrigations. If a program is developed to improve the on-farm decision process through research and application of research results, it can be used initially to improve the management of existing systems without a significant investment of capital. As farms and irrigation systems are improved, the same program would become more essential to realize the full benefits of the improvements.

Problems of water shortages. The most obvious water management problem is a shortage of irrigation water for crop needs. In many areas the average annual supply of water to the farms may be only one-half to two-thirds of the consumptive use requirement. In general, it is automatically assumed that this shortage is the primary factor limiting crop production. It is not obvious that with poor facilities and management practices these limited water supplies may be used inefficiently. It is not uncommon, for example, to find excess water applications with limited supplies because the available soil moisture has not been depleted sufficiently to hold the minimum amount necessary to cover the area. Why would an irrigation be applied at this time? Water may be available only at preset time intervals and, in many cases, the farmer or farm manager, not knowing the rate at which soil water is depleted by evapotranspiration, is not aware of the quantity of soil water depletion that has taken place. Most surface irrigation systems in developing countries probably require a minimum depth of application of at least 4 to perhaps 6 inches (10 to 15 cm). A shallow-rooted crop may need to be irrigated when only 1 inch (2.5 cm) has been depleted, or irrigation water may be available when only 1 inch has been depleted. This is also a common problem but often unrecognized in the developed countries. Under these conditions scarce water supplies are wasted, valuable nitrogen is leached, and groundwater levels may be raised to water-logging levels. Thus, drainage problems may be created under scarce water supply conditions because of poor irrigation water management.

Another serious problem that is often not recognized is the nonuniform distribution of limited water supplies. Such nonuniform applications result in excessive applications to portions of fields, causing groundwater problems and aggravating the water deficiency in other parts of the field. This situation enhances the accumulation of salts due to the evapotranspiration and lack of leaching in the high places. This is particularly a problem with "level basins," regardless of their size.

Another aspect often not considered in water-short areas is the effective use of the limited precipitation or managing the irrigation water to optimize or maximize the effectiveness of what little precipitation is received. Many of these irrigation water management problems are also common in rainfed areas.

Problems with adequate water supplies. When water supplies are adequate many of the same problems mentioned above, such as irrigating when there is inadequate capacity to hold an irrigation and nonuniform distribution of water, are encountered. With adequate water supplies, it is not uncommon to find irrigations delayed unnecessarily, which may result in severe crop stress and decreased crop yield potentials, followed by excessive water applications with their adverse affects. These conditions are common in both the developed and developing countries. Another problem often associated with adequate water supplies is the availability of these supplies for crop water needs. This may be particularly serious where there are no or limited water storage facilities. On the other hand, in many of these areas groundwater supplies can be utilized to supplement surface flows during peak water use periods, and if water quality problems are not severe, pumping may accomplish needed drainage for many decades.

Problems of water quality. The most obvious problem associated with water quality is the accumulation of soluble salts as evaporation from the soil surface and transpiration remove pure water and leave the salts behind. Closely associated with soluble salts is the more troublesome accumulation of sodium. Presumably these problems will be discussed at a later time, but irrigation water management is the only practical method of maintaining a favorable salt concentration in the root zone. This is accomplished by uniformly applying slightly more irrigation water than necessary for evapotranspiration. Irrigation to bring the soil to field capacity before rainy periods will enable or enhance salt leaching by rainfall.

Problems with the main delivery system. There may be many problems with the main water supply-delivery system such as limited storage, seepage, sediment, etc. However, some on-farm water management problems are associated with how the system is managed. The farmers may not be able to attain maximum crop production with existing water supplies because the delivery system is rigidly controlled to deliver water on a rotation basis that may not be related to consumptive use and available soil water capacities. Water is often delivered when it becomes available in the system, which means that the irrigation distribution system is first a disposal system for water and second a transportation system to deliver water as needed for crop production. Without storage facilities, significant changes in irrigation scheduling may not be feasible, but generally delivery intervals could be modified to meet crop water requirements rather than optimize the operational efficiency of the system. A canal system is not efficient if it efficiently conveys the wrong quantity of water at a particular time or throughout the season (Henry Olivier, 1972). Often the managers of irrigation systems controlling water delivery do not understand the crop-soil-climate system or the farmers' problems. The water user and agricultural specialist need to have some input to the management of the main system. The user also needs to be involved in the operation of tube wells used to supplement canal flows. Also, financial resources for structures needed to improve the management and delivery of water may be limited.

Problems with on-farm delivery systems. Unlined ditches overgrown with trees, brush, and clogged with sediment greatly reduce the quantity of water that can be delivered to the fields as well as hamper the manipulation of water from one field to the next. Lack of capital to improve delivery systems is probably the greatest single factor retarding improvements of on-farm delivery systems. The formation of districts for "self improvement" or delegating to the management of the canal system the responsibility to maintain the delivery system to each main field may improve the management of irrigation water on the farm.

Legal problems affecting water delivery. Legal problems that regulate the quantity, timing, and mode of water delivery essentially independent of crop water needs may be a significant factor in both the developed and developing countries. Changing the legal structure to enable improving on-farm water management will be a slow process, but this should not deter efforts to improve on-farm water management within the constraints of the existing system.

Water management problems caused by soil problems

The more common problems that affect the management of irrigation water are low rates of infiltration caused by either fine-textured soils or the accumulation of sodium, low available water holding capacities on coarse sandy soils, and limited rooting depths which reduce the potential available water holding capacity. Rooting depths may be limited by chemical or mechanical conditions, or by a combination of these conditions. The most common chemical problem related to water management is the accumulation of soluble salts because of evapotranspiration. The accumulation of salts may directly reduce plant growth, and the accumulation of sodium may severely affect both the plant growth and infiltration rates and further complicate on-farm water management.

Available Research and How it is Being Applied

Soil-water-plant relationships

Sufficient knowledge is available to enable prescribing good or improved water management guidelines under most existing water supply and delivery systems for essentially all crops. This includes projecting the optimum irrigation dates, taking into account expected precipitation and the amounts of water that should be applied where water is not limiting. General knowledge also enables us to optimize the application of water where water is known to be the limiting factor. This knowledge includes predicting rates of evapotranspiration by growth stage and the probable levels of soil moisture tension where stress adversely affects growth of various crops. These research results are being applied to individual farms and fields by irrigation management service groups in developed countries. These groups are operated either privately or by irrigation districts and canal companies. Many of these service groups also provide plant nutrition and pest control services (Jensen, 1972, Lord and Jensen, 1973). Availability of these services is limited by a shortage of trained personnel who understand the whole system and recognize the farmers' ability to respond to needed changes.

Irrigation systems and management

There is sufficient general knowledge of irrigation water management to enable a thorough analysis of representative existing systems. Such an analysis would indicate where (1) Modifications or improvements should be made, and if made, (2) where substantial increases in crop production would automatically result, or, (3) where improved water management would become much easier to accomplish The U.S. Bureau of Reclamation recently completed such a comprehensive study on several areas of the Western United States.

General knowledge is sufficient, concerning the hydraulics of on farm irrigation systems including overland flow distribution of water over the field, and distribution within the soil, to enable describing the current operating characteristics of representative systems if site-specific data can be provided Members of a Western Regional Research Project in the United States are nearing completion of a comprehensive publication on Hydraulics of Surface Irrigation

The limitation of the available research mentioned above is the technical capability of applying functional relationships to new circumstances In many cases, it may be easier to obtain site-specific water management guide lines by conducting general irrigation water management experiments with local crops. However, there is no need to conduct these studies to reestablish general principles of scientific irrigation water management, but rather adaptive research is needed to verify and to obtain local calibrations of general fundamental relationships

Gaps in Research and Research Underway

The greatest gap in on-farm water management research is in the ability to clearly delineate the factors limiting crop production as a result of irrigation water management In most areas these factors are unique and require local input parameters to apply the general available research Brief cursory reviews by "experts" seldom pinpoint the real problems Similarly, application of complicated multiple correlation computer models that are not based on physical biological principles seldom pinpoint problems

Major constraints for example, to increasing food production may be attributed to the lack of adequate water delivered to the farm or group of farms. However, thorough assessment may reveal that only 15 to 30 percent of the water delivered is actually used by crops The balance of the water may be lost by seepage from on-farm ditches, by runoff or deep percolation caused by applications that exceed the amount the soil can hold or that are nonuniformly distributed because of soil surface topography, and by the nonbeneficial use of water by nonproductive vegetation such as trees and brush growing along waterways Local scientists and technicians must thoroughly understand the local system to recognize these deficiencies Understanding the entire system will require detailed studies which thoroughly evaluate representative existing systems. These cannot be conducted in the laboratories or on computers They need to be conducted by using field experiments which rely on the general available research in their design, but basically integrate the many functional relationships under local climatological, crop, and soil conditions Sometimes minor problems such as poor germination may play a major role in determining the potential production capability This problem may be overlooked in a laboratory analysis but would become obvious in a field experiment Computer models that simulate daily crop growth, evapotranspiration root growth soil water extraction, drainage, and leaching may pinpoint some of the problems. Local field experiments are needed, however, to provide input data.

Application of general available research knowledge requires site-specific input parameters which usually are not known These may include soil water characteristics, crop-soil characteristics such as rooting depth and various crop-soil-climate interactions. In most cases, it is probably easier to obtain this information from a few well-designed and carefully conducted field experiments than from extensive laboratory studies.

Moseman (1970) indicates that in developing nations "an especially neglected area is research on soils and water management, including the conservation and use of rainfall " Extensive water management research is underway at many field stations within irrigated areas of developed countries In contrast, the necessary training, opportunity for research experience in field plot techniques, and the practical aspects of conducting irrigation field experiments seem to be lacking in developing countries It appears that too many research trainees and graduate students from developing countries when sent to developed countries for training are assigned to work on theoretical problems and laboratory experiments requiring complex instruments and controlled environmental chambers The greatest gap is not in general water management research, but in the adaptive research necessary to apply available water management research in developing countries Facilities for adaptive research are also lacking. Moseman (1970) indicates that "perhaps the most common deficiency in agronomic research is the lack of precision in field experimentation because of plot lands poorly suited to exact and reproducible trials, with inadequate control of irrigation or moisture management and ineffective weed, disease or pest control "

Implementing a Water Management Research Program

Type of research needed

I have referred to applied and adaptive research in this paper as have many other authors The following statement by Moseman (1970) adequately describes the various categories of research:

> There is rather general agreement that fundamental or *basic research* is designed to deepen insights and understanding into biological and physical forces, or the economic and social conditions with which we are concerned. *Applied research* is the direction or utilization of such basic and background knowledge to the improvement or change of specific materials or conditions. *Adaptive research* .. involves adjustments, modifications, or changes, brought about through systematic research or "the methods of science."
>
> In distinguishing between *applied research* and *adaptive research*, the former represents the initial direction or application of fundamental knowledge to a practical end use, while adaptive research is concerned with the further modification or adjustment of that applied result....
>
> We have had considerable experience with *adaptive research* in crop breeding and improvement programs, in suiting crops to new environments, in changing resistance or tolerance to diseases and pests, and in modifying product quality The cooperative federal-state program of adaptive resarch successfully transferred the benefits of hybrid corn from the midwest to the southern states through the development of the "Dixie Hybrids." Similarly, soybean production has expanded in the United States largely because of the breeding and selection of varieties adapted to the different environments, especially to length of day, from the Mississippi Delta to the North Central states. (Moseman, 1970)

Adaptive water management research generally has not been clearly defined. One specific example would be a 3- to 5-year field experiment involving depletion of soil water to different levels before irrigating. This study would be conducted with the best local crop varieties and cultural practices under controlled conditions. Irrigations would be given at specific degrees of soil water depletion or at specific levels of soil water tension in some portion of the root zone. The levels of depletion for the treatments can be provided from studies already conducted in developed countries. The approximate general results would be predictable from previous studies, but not the exact response of the local crop variety under local soil and climate conditions. Complete supporting data on soil water depletion, amounts of water applied, and climate would be obtained to enable developing practical recommendations for other soils in the same climatic region. One or more types of fertilizers could be superimposed on each of the soil water treatments.

Studies like the one mentioned require enthusiastic, well-trained scientists, preferably at the Ph.D. level, who are dedicated to solving a problem which may require many years to complete. Suitable organizational and technical support is needed. Also, institutions in developing countries must recognize the potential for training their own scientists. This can be done to solve critical food production problems under the leadership of water management scientists who have demonstrated abilities and perhaps have the insight and desire to see that the best practices are applied.

Research direction and leadership

Most scientists are competitive. They want prestige and recognition. In the developing countries, the greatest need is to obtain local background information to enable applying general available research results. But often the scientists in these areas want to conduct basic research because, to the local scientific community and nontechnical administrators, basic research appears more attractive than applying available research results. Another significant factor in many areas is the attitude toward conducting field experiments under uncontrolled environmental conditions. These experiments require practical know-how and have a greater risk of failure in one season because of unforeseeable events. Fear of failure in adaptive research may play a significant role in the resistance of scientists to become involved in such studies. Actually, conducting productive applied or adaptive research under normal environmental conditions requires a broad range in technical capability and practical know-how Often more skill is needed than that required to conduct simple experiments under controlled conditions in a laboratory. On the other hand, with experience, scientists and field technicians can show very productive results from research conducted under field conditions — results that become readily apparent to nontechnical administrators, policy makers, and farmers in the immediate locale.

Most developing countries have limited financial and scientific resources available for research. Much of the scientific effort is often wasted by re-proving the wheel is round instead of applying the wheel to solve problems, re-proving Darcy's law before applying it to solve soil water flow problems, or overlooking basic scientific principles such as the conservation of mass and conservation of energy. Much effort also is wasted in deriving new correlations to show relationships shown many times before. The probable reason for this effort is the lack of qualified guidance in conducting research, and fear of failure if a new concept is considered since previous publications from other areas indicate that repeating an experiment will produce predictable results. This raises the question as to who should do basic research and who should do applied or adaptive research. In general, the more mature the scientist, the more qualified he is to conduct productive applied research, but he also must have technical training comparable to those conducting basic research. In a developing country where on-farm water management research is urgently needed and many of the basic principles are known, the research managers and policy makers should direct about 80 to 90 percent of the research into applied or adaptive areas and only 10 to 20 percent in the basic areas. Those conducting basic research should also have demonstrated a creative ability.

Moseman (1970) suggests the following elements of a research organization:

(1) A strong national center for background research and for conceptual and coordinating leadership for national and regional projects. The former Beltsville Research Center provided this resource in the United States. Similar national headquarters at Chapingo, Mexico; Tibaitata, Columbia; La Molina, Peru; La Platina (Santiago), Chile; and the Indian Agricultural Research Institute near New Delhi furnish similar "national headquarters" services in those countries.

(2) Regional centers for adaptive research and specialized attention to the agricultural requirements of the major cropping regions of the country. In the United States the federal field stations, together with selected state agricultural experiment stations serve as regional headquarters for specific research projects.

(3) Localized research and/or verification and testing stations designed to fit innovations to specific soil and climatic conditions. In the United States this component is represented primarily by the branch stations of state agricultural experiment stations.

> ...The level of competence at the regional stations should be similar or about equal to that of the central headquarters, but with the mix of scientific disciplines determined by the nature and complexity of the problems of the region. The competence at the localized field stations should be of the B.S. degree level of training at the beginning, with upgrading to the M.S. and Ph.D. level in time, as has occurred in the branch experiment stations in many of the states of the U.S. (Moseman, 1970)

In general, I agree with this proposal, but I have also observed that over a period of time replacements for vacancies that occur at the national level may not have the same broad and outstanding traits of the initial staff. Concurrently, as the training of the staff and the quality of facilities and technical services at regional centers improve, the role of the national center may change in time. This must be recognized to sustain a viable research program. There are many factors that contribute to this change. Many productive scientists at regional centers or field stations thoroughly enjoy their work and are reluctant to relinquish direct involvement in research for an assignment with semi-administrative duties that appear less productive and rewarding. These duties may involve preparing broad and long-range project proposals, budget statements, technical reports, etc. Living conditions and schools may be as good or better at regional centers. On the other hand, some more qualified scientists may prefer to avoid assuming additional responsibilities associated with accepting a new challenge for fear of failure, or may prefer the more comfortable routine of their present assignment. The net effect, if not recognized and corrected, may be a lack of communication with regional and field staffs resulting in an unrealistic appraisal of high priority research needs. The problem may become more serious when scientists at the national center begin to believe that only the national staff is qualified to conduct background research, and only the national staff has the ability to determine the direction of research programs. In practice, competent scientists that work day to day with current problems of food production often are aware of critical deficiencies in research and often are as qualified as scientists at the national center to conduct some of the needed background research. New ideas are scarce and should be solicited from all scientists.

Of prime importance is the technical direction and support provided to qualified scientists conducting research on all related aspects of water management that will lead to increased food production. The specific example of adaptive water management research would also be applicable to related aspects of irrigation water management. For example, knowledge about the hydraulics of surface irrigation is well known, but local intake rates, soil surface roughness parameters, etc., are not known. These data, obtained under local conditions, are needed to apply hydraulic principles. Closely related to water management research is the management of nitrogen which because of its solubility is subject to leaching. General research knowledge is adequate to enable local scientists to prescribe general nitrogen requirements and predict specific requirements. But local data needed for these predictions such as the mineralization capacity of soils are often not available.

Research direction also has the responsibility of avoiding the inefficient use of limited scientific resources for research by preventing too much of the research effort to go into nonproductive, or less productive activities such as constructing research equipment when it can be purchased and put to use.

General and Site-specific Research

A few examples of needed water management research or applied technology that can be generalized are given as follows:

1. Expected consumptive use (evapotranspiration) curves beginning with major food crops. The curves would show expected daily ET by growth stage under typical climatic regions and would serve as a guide to both the water user and manager of the irrigation distribution system.

2. General experimental guides to calibrate or adapt general crop-soil-climate interations, including probable levels of allowable soil water depletion, tentative crop growth-soil water stress relationships, and tentative levels of plant nutrients essential to sustain the productivity of new high-yielding varieties.

3. Experimental guides for calibrating or verifying ET-salt control-production relationships.

4. Experimental guides to evaluate and clearly show the limitations of existing irrigation systems and water management practices. The results of these studies would show the need to develop alternative methods of managing the crops and existing water delivery systems to meet crop water needs.

5. Experimental guides to provide continuous and effective water management services to each farm and farm operator. This also would require trained personnel working directly with the farmer.

6. Experimental guides to demonstrate the benefits of better water management and determine what incentives will result in the application of better water management practices.

7. Low cost, easy-to-maintain systems to control the quantity of water delivered to individual fields.

The results from site-specific experiments conducted by well-trained scientists following these general guides will lead to practices that can be applied economically to each irrigated field to increase and sustain the production of food.

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4.

SYSTEMS OF SOIL CLASSIFICATION AND THEIR RELATION TO WATER MANAGEMENT

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Introduction

Soils are classified for several reasons. One of the reasons is to learn or to understand the relationships of the different soils as they apply to agriculture. Presumably, under a given set of environmental conditions, soils which are similarly classified should have similar properties and behavior and should respond nearly alike to management practices. Man has been classifying soils from early times and much has been written on this subject. For example, some of the later works on the basic principles of soil classification are covered by Baldwin et al. (1938), Cline (1949), Soil Survey Staff (1970), Kellogg (1963), and Smith (1968).

Several systems of soil classification are used throughout the world and these systems are described in a recently published book by Buol, Hole, and McCracken (1973). These classification systems or schemes are those of USSR, France, Belgium, the United Kingdom, Australia, Canada, and Brazil.

Although the different systems emphasize different bias, they nevertheless convey the importance of climate, availability of soil water, and/or soil management as influenced by soil water.

The purpose of this paper is to describe how the U.S. System of soil classification, one of the more highly developed systems, can be used to convey the idea of soil water behavior and the availability of such water for crop production.

Soil Classification System of the U.S.

The latest U.S. system of soil classification is known by several names but more commonly as the U.S. Comprehensive Soil Classification System or the U.S. Soil Taxonomy. Various members of the Soil Survey staff of the U.S. Department of Agriculture as well as other soil scientists are responsible for this system, which was developed over a period of about 30 to 35 years, but Dr. Guy D. Smith deserves much of the credit in taking the leadership in finalizing the system.

The U.S. System consists of six categories. The highest category, which is made up of 10 so-called Orders, are differentiated one from the other by some soil forming processes as indicated by the occurrence of one or more diagnostic horizons. These Orders in turn form the Suborders based on properties which are influenced by wetness, soil moisture regimes, parent material, and vegetation in the mineral soils and by the degree of organic fiber decomposition in organic soils. The Suborder, then, is when the classification system first shows some relationship to water characteristics in soils. In the Great Group, which represents the third category, are soils of the Suborders possessing similar diagnostic horizons and layers, base status, and soil moisture and temperature regimes. The Subgroup constitutes the fourth category which indicates whether or not a particular Great Group represents a central concept taxa or whether or not that group shows close relation to other Great Groups, Suborders, or Orders. Then, there is the Family category, probably one of the most important categories. Characteristics such as soil texture, mineralogy, and temperature regimes which are important for agricultural and nonagricultural interpretations and uses are stressed. Finally, the Series represents the sixth category which includes soils with horizons possessing similar morphological, chemical, and mineralogical properties.

This paper will describe in the next few sections how certain categories of the U.S. System show relevance to moisture characteristics in soils and finally to water management.

The U.S. System and Its Relation to Moisture Characteristics

As described in Soil Taxonomy (Soil Survey Staff, 1970), there are three soil moisture regimes–the saturated, leaching and nonleaching regimes. The moisture regime is influenced by groundwater, moisture retention at different tensions, and period of wet condition. For a comprehensive review, the Soil Taxonomy should be consulted. The review will also be essential to learn the classes of moisture regimes–the aquic, udic, ustic, xeric, and aridic, or torric regimes. The definitions will reveal that the aquic regime represents soil moisture conditions which are quite saturated, whereas the aridic or torric regime is one in which soil moisture is usually a limiting factor. Soil utilization for crops under these

[1] University of Hawaii, Honolulu, Hawaii, October, 1973.

extreme conditions requires either removal or application of water.

Influence of the Moisture Regime on the Taxa of the U.S. System

As mentioned previously, the suborder is the category when some relationship to water characteristics in soils is first known. Examples are presented in Table 1 to show this relationship.

There are actually 47 Suborders but Table 1 lists only 22 of them which have properties showing association with wetness and soil moisture regimes. Where applicable, the Great Groups also show these influences, and examples will be presented in succeeding sections.

Except for the Suborder Folists, the Order Histosols by definition indicates a wet or saturated regime. No Subgroups of Histosols are, therefore, presented in Table 1. Aridisols by definition similarly denote a very dry condition in which there is insufficient water for normal plant growth unless irrigated. Table 1 lists, therefore, those Subgroups that show special significance to water characteristics in the different soils.

Examples of relationship between moisture regime and the taxa at the lower categories are, for example, the Subgroup Ustoxic Humitropepts for a soil series called Kolekole or the Subgroup Aridic Haplustolls for a soil series called Mahukona.

Influence of Soil Water Characteristics on Water Management

Water management in agriculture involves (1) protecting or reclaiming land from excess precipitation or flooding, (2) husbanding and managing soil moisture, (3) optimizing cropping practice to the moisture regime, (4) impoundment, distribution, and application of irrigation water supplies, and (5) coordinated management of watershed areas (CUSUSWASH Annual Report, 1973). All of the topics are wholly or partially dependent on the water release or water holding characteristics of a soil.

For most soils found in the temperate zones, the water release characteristics of a soil can be predicted from its texture or particle size distribution. That is, in most instances, coarse-textured soils would likely have high water infiltration rates and low water holding capacities while a clay-textured soil would have low infiltration rates and high water holding capacity. Either type of soil would therefore require vastly different water management practices.

Prediction of water release characteristics based on soil texture may not be valid for some of the agriculturally important soils in Hawaii and, in all probability, for similarly classified soils in other tropical areas of the world. For Hawaiian soils, particularly those classed as Oxisols and Ultisols, the water release characteristic curves are similar to those of sand at low suctions (Figures 1 and 2). Unlike sand, however, these soils retain as much as 30 percent water by volume at 15 bars of suction. The large water holding capacity of these four soils at high suctions were attributed to the presence of intra-aggregate pores (Sharma and Uehara, 1968; Tsuji, Watanabe, and Sakai, 1973). Since all four soils, the Wahiawa (Tropeptic Eutrustox), Molokai (Typic Torrox), Manana (Orthoxic Tropohumult) and Paaloa (Humoxic Tropohumult), have textures of a clay soil, soil structure rather than soil texture was considered to be more influential in determining the pore size distribution and the water release characteristics of these soils.

Examples of water release characteristic curves for soils of the Inceptisols and Vertisols Orders are presented in Figures 3 and 4. The Akaka (Typic Hydrandept) and the Lualualei (Typic Chromusterts) soils both shrink on drying. The former dries irreversibly because of its amorphous mineralogical constituents while the latter, predominantly montmorillonitic, shrinks and swells reversibly on drying and wetting.

Except for the Akaka and Lualualei soils, field capacity for the soils of Figures 1, 2, and 3 occurs at suctions less than the "standard 1/3 bar." In terms of water management practices, this is of utmost importance. If knowledge of the water characteristics of say an Oxisol were not available a farmer who samples a soil which is at 1/3 to 15 bars suction under field conditions will find little difference in water content. He may then incorrectly conclude that the amount of available water is sufficient. Similarly, if an irrigationist finds that tensiometer readings have not exceeded 1/3 bar, irrigation may be delayed and

Table 1. Influence of the moisture regime on the Suborder names.

ORDERS:	Entisols	Inceptisols	Spodosols	Histosols	Mollisols	Ultisols	Alfisols	Oxisols	Vertisols	Aridisols
SUBORDERS:	Aquents	Aquepts	Aquods		Aquolls	Aquults	Aqualfs	Aquox		
					Udolls	Udults	Udalfs		Uderts	
					Ustolls	Ustults	Ustalfs	Ustox	Usterts	
					Xerolls	Xerults	Xeralfs		Xererts	
								Torrox	Torrerts	

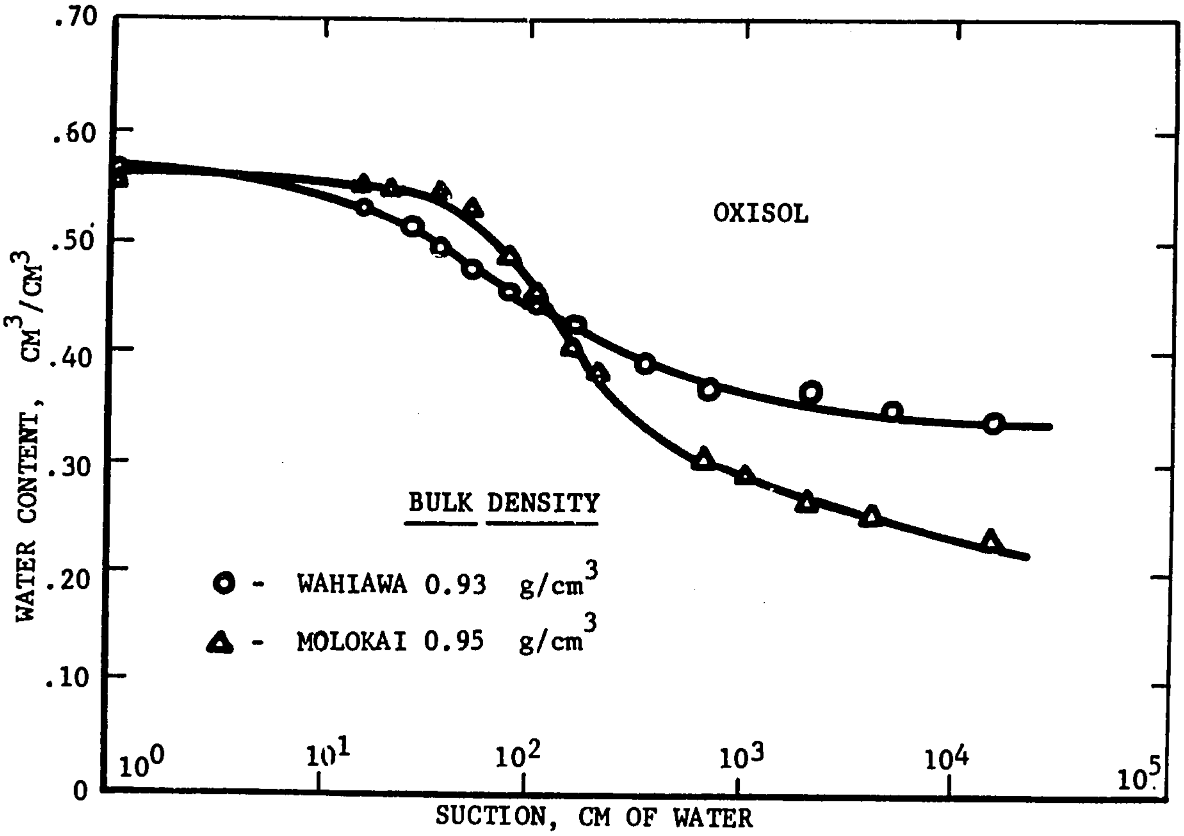

Figure 1. Soil water release characteristic curves for Wahiawa (Tropeptic Eutrustox) and Molokai (Typic Torrox) soils. (After Tsuji, Watanabe, and Sakai, 1973).

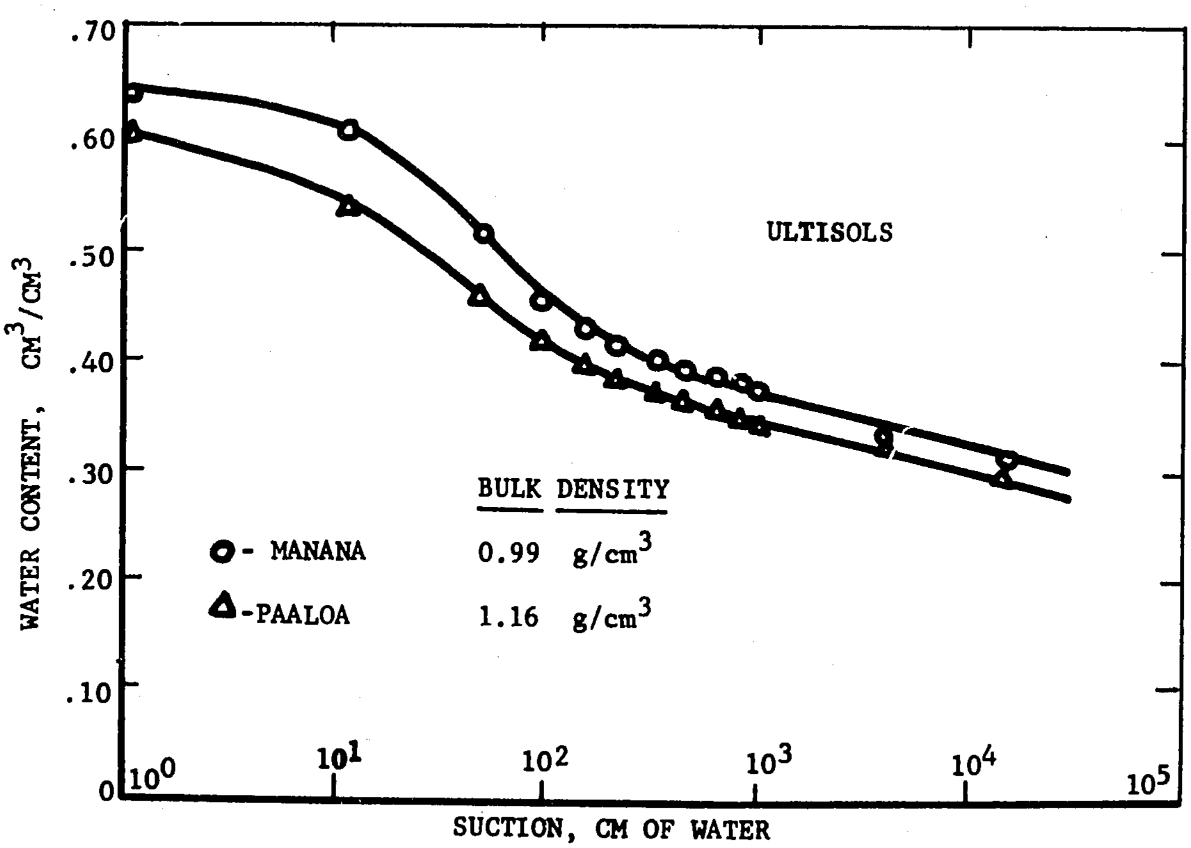

Figure 2. Soil water release characteristic curves for Manana (Orthoxic Tropohumult) and Paaloa (Humoxic Tropohumult) soils. (After Tsuji, Watanabe, and Sakai, 1973.)

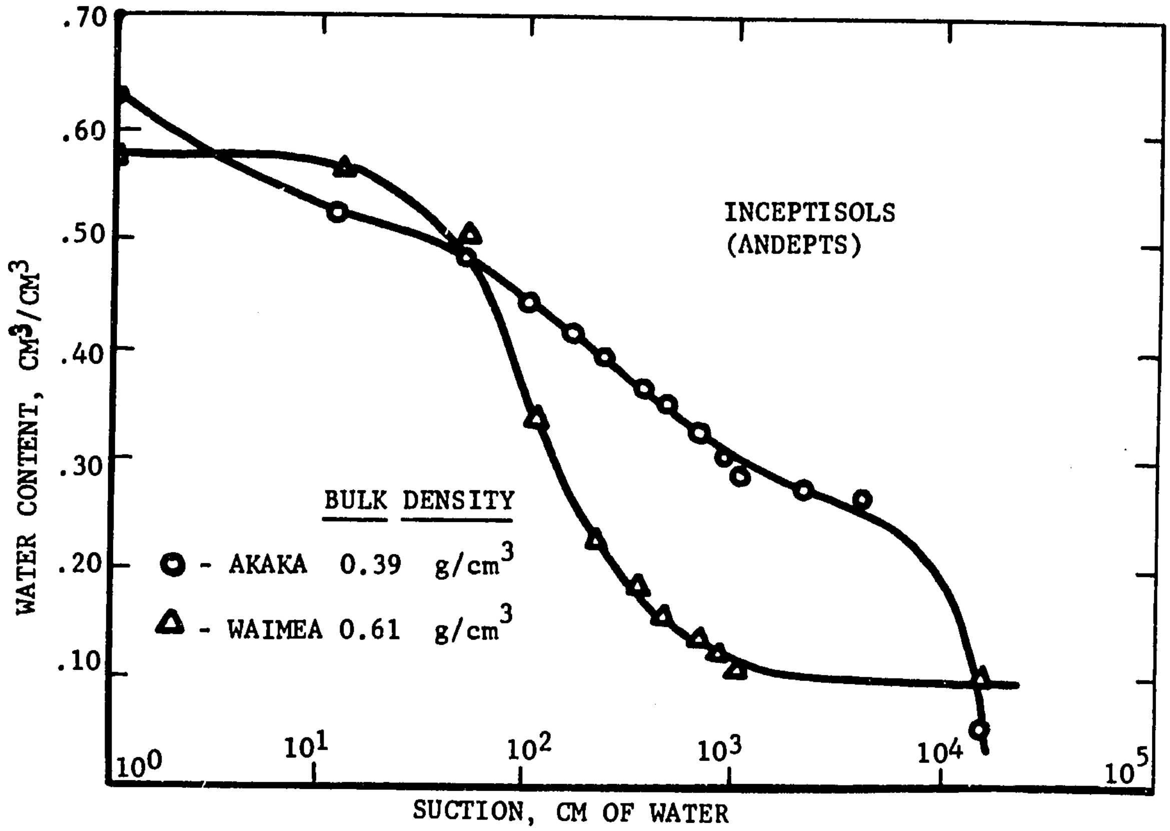

Figure 3. Soil water release characteristic curves for Akaka (Typic Hydrandept) and Waimea (Typic Eutrandept) soils. (After Tsuji, Watanabe, and Sakai, 1973.)

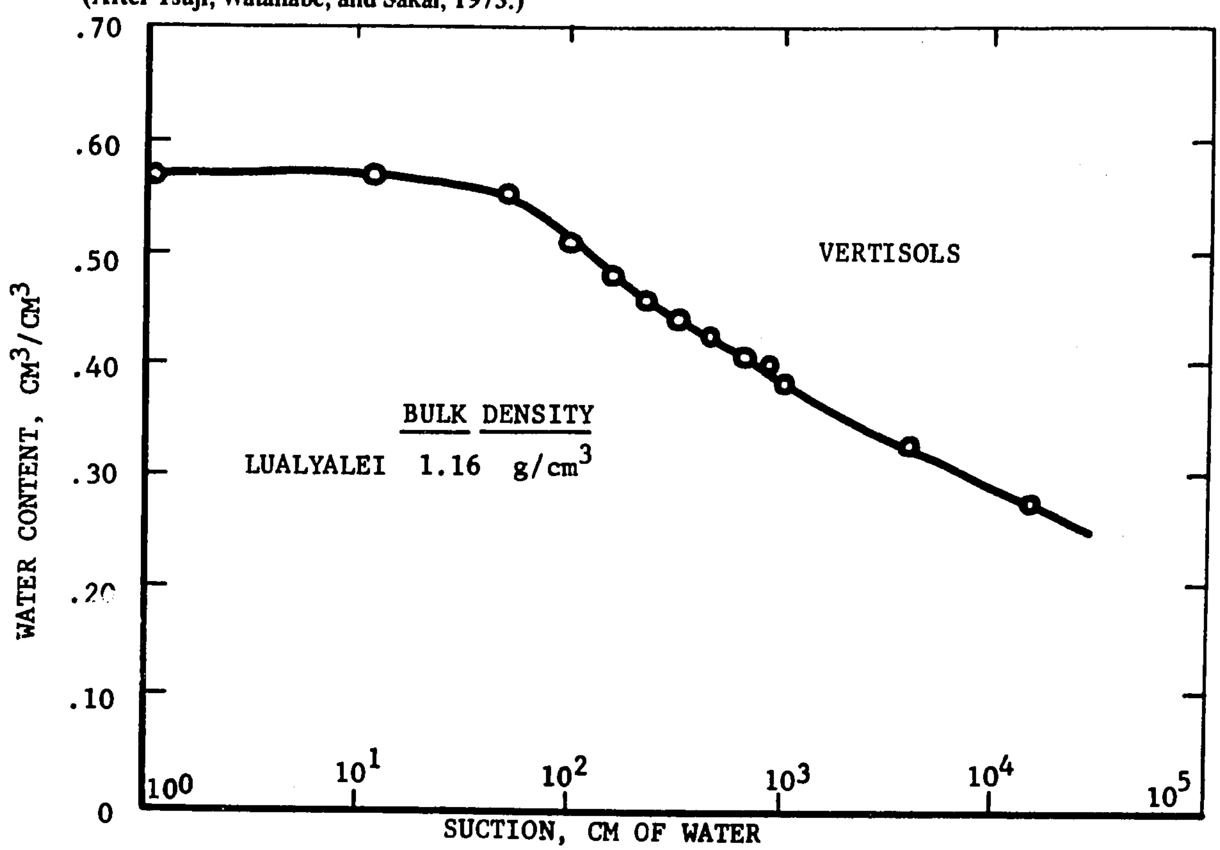

Figure 4. Soil water release characteristic curve for Lualualei (Typic Chromusterts) soil. (After Tsuji, Watanabe, and Sakai, 1973.)

10^4 105

subsequently result in irreparable damage to crops under cultivation.

Soil Water Characteristics and Soil Classification

Water characteristics of soils can also be related to soil properties other than the soil moisture regimes. There are three major factors that influence the retention of water in soils. They are texture (pore size distribution), composition (inorganic and organic constituents), and temperature. Coincidentally or not, all three factors are diagnostic in determining the classification of soils at the Family category However, as pointed out in the previous section, textural class alone cannot be used to predict the pore size distribution of strongly aggregated clay soils such as the Wahiawa, Molokai, Manana, and Paaloa. At the Family category level, the soil classification parameter that can most likely be used in predicting the water release characteristics of a soil is soil composition, or more precisely, the mineralogy. That is, soils of similar mineralogical composition should have nearly identical water release characteristics. Consider, for example, soils of the Oxisols and Ultisols Order in Figures 1 and 2. Under the Family category, the Wahiawa and Molokai are described as clayey, *kaolinitic*, isothermic and clayey, *kaolinitic*, isohyperthermic, respectively, while the Manana and Paaloa are both described as clayey, *oxidic*, isothermic.

In Figure 1, the curves show that water is more easily extracted from the Wahiawa than the Molokai at low suctions. The opposite is true at higher suctions. Such behavior has been attributed to stronger aggregation in the Wahiawa than in the Molokai by Sharma and Uehara (1968). This difference in water release characteristics may also be related to mineralogy. The Wahiawa, although classified as kaolinitic, may in fact contain more oxides or hydrous oxides than the Molokai but less than the Manana and Paaloa. Juang and Uehara (1968) have also shown that mica is present in the Paaloa, Manana, and Wahiawa but absent in the Molokai. If differences or similarities in mineralogy can be used to predict the degree of soil structural development, then the water release characteristics of the Wahiawa, Manana, and Paaloa should be similar. This assertion appears to be borne out when curves in Figures 1 and 2 are compared.

Summary and Conclusions

A system of soil classification will be useful to agriculture only if the system can show relationship to behavior and eventually to management. The U.S. System of soil classification has this attribute more than the other systems to date. The Suborder category and some of the lower categories show relation to wetness and the soil moisture regimes. The Family category indicates parameters such as texture, mineralogy, and temperature regimes; parameters which are all important to agriculture and nonagricultural interpretations of soils. Soil water release characteristic curves of selected soils have been presented to show soil-water behavior in soils of Hawaii. Because there is high correlation between soil water release or retention and properties such as soil structure and because the latter is closely related to mineralogy, especially in the Tropics, the Family category of the U.S. System has special significance. That is, if the Family category of a soil is recognized, much of the behavior of related soils can be predicted. Relationship between the mineralogy and behavior of tropical soils has already been presented by Uehara, Swindale, and Jones (1972) in another Symposium sponsored by the AID.

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5.

A STRATEGY FOR OPTIMIZING RESEARCH ON AGRICULTURAL SYSTEMS INVOLVING WATER MANAGEMENT[1]

Jack Keller, Dean F. Peterson, and H. B. Peterson[2]

Introduction

ptimal cropping systems are highly site-specific. iis has been recognized is demonstrated by the nce of extensive field trials as a basis for project ind for providing the extension-type information in initial developments or in changing agricultural s, both in advanced and developing countries. r, a consideration of transferable information systematic model should permit greater efficiency election of both applied and basic research as well he design of agricultural development programs g water management.

esently, both the design of programs of research agricultural development are based primarily on judgment. In forming their judgments, experts ı a reservoir of physical, biological, and economic tion gained by study and experience. The quality judgment made depends on the accessibility of tion stored in the literature or in an expert's brain, the skill with which he weighs and synthesizes that tion. The writers advance the suggestion that a erized model which could predict crop production ıs for changing environmental conditions could enhance the efficiency of the expert. Such a model ave both information storage and processing as optimization characteristics. The model could also ide the processes of characterizing the agricultural ment.

he model might be regarded as a sophisticated e of a hypothetical expert possessing all or most of vant information. Certain thought processes are / engineers and scientists in characterizing the ment, selecting research, and choosing potential action programs in the water management field. However, little attention has been given to verbalizing these thought processes. Without being verbalized, these are somewhat obscure and, perhaps, even the investigators who possess certain capabilities for making decisions in this area would be at a loss if called upon to describe the rationales for their actions. Verbalization of these thought processes is the first step in formulating the desired model.

The Model Rationale

Agriculture requires the superposition of biological production resources (culturable genetic materials, both plant and animal) upon an *existing* or *to be modified* set of environmental components. Biological production resources may be subdivided into various crops (or animals); these can further be subdivided into various plant varieties (or breeds). Each crop system will have varying physical and biological environmental conditions necessary for acceptable levels of production.

The model attempts to disaggregate the environment into significant components which are also measurable. Crop growth is viewed as having a number of intermediate production stages or indicators which will show a given response to each of the environmental components and a compounded response to combinations of them with the ultimate production being the overall integrator of crop growth.

Many of the environmental components are not fixed. They can be altered by various potential action programs or crop husbandry practices. Among the most important husbandry programs are irrigation and drainage. In turn, the selection of and success with crop programs is dependent upon the knowledge and ability to transfer information. The transfer process involves relating known environmental components and expected responses as affected by achievable husbandry programs to new environmental situations. The transfer process must also involve the techniques of categorizing the agricultural environment and optimizing the action programs needed to improve it. Biological production resources are not fixed either, but may be altered by plant and animal breeding programs both to improve quantity and quality of crops and to adapt to differing environmental components.

The model may thus be thought of as the interaction of two variable multi-dimensional vectors: *Agri-*

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cultural environment, $\overline{E}$, and *production materials*, $\overline{M}$. The output vector is the response, $\overline{R}$; i.e., $\overline{R} = \overline{E} \times \overline{M}$. In the general model, $\overline{R}$ may be any designated objective. In the crop production model $\overline{R}$ becomes the crop response $\overline{R}c$. The agricultural environment $\overline{E}$ reduces to $\overline{E}_i$, the intimate plant environment and $\overline{M}$ is the plant material.

Environmental disaggregation

The single overreaching factor relevant to transfer of information and technology can be described as *agricultural environment*. Agricultural environment may be disaggregated into four general frameworks which are subdivided into various relevant descriptors, each with a number of measurable components as presented in Table 1.

The concept of the framework was taken from Barlowe[3] who suggested a threefold framework in which land economics could be encompassed. The three frameworks suggested by Barlowe are the physical and biological framework, the institutional framework and the economic framework, These he defined as follows:

> Briefly stated, the *physical and biological* framework is concerned with the natural environment in which man finds himself and with the nature and characteristics of the various resources with which he must work. The physical and biological factors involved in this framework provide the physical support, the site, and the raw materials for various activities. At the same time they provide not only the inanimate resources of the earth but also the vegetative, bacterial, insect, fish, animal and human resources that both help and hinder man in his use of land.
>
> The *institutional framework* is concerned with the role man's cultural environment and the forces social and collective action play in influencing his behavior as an individual and as a member of his family, his various groups, and his community. It is concerned with the impact of cultural attitudes, custom and tradition, habitual ways of thinking and doing things, legal arrangements, government programs, religious beliefs, and other similar factors upon man-to-man and man-to-land behavior. Among its many facets, it also involves the effect of personal and household considerations–an individual's non-monetary goals or his family obligations–upon one's decisions as a business operator.
>
> The *economic framework* is concerned with the operation of our price system as it affects each individual in his attempt to make profitable use of his land-resource base. This framework deals with man's tendency to maximize his returns. It is concerned with the effect that economic concepts such as value costs, returns, and profits have upon his allocation and distribution of land resources and upon his use of these resources for production and consumption purposes.

[3]Raleigh Barlowe, Land Resource Economics, Prentice Hall Publishing Company, Inc., Englewood Cliffs, New Jersey, 1958.

In dealing with crop systems, the physical and biological framework must be divided into two groups of factors: *The intimate physical and biological site conditions* which form the immediate environment surrounding the plants in the field and the *external physical and biological resources* upon which the plant husbandry practices must depend. The successful application of these resources and the procurement of additional necessary resources for the husbandry of the crop system is dependent on the institutional and economic frameworks. As shown in Table 1, a second level of disaggregation identifies the *major descriptors* which are significant to the information transfer process related to crop husbandry and productivity. At a third level of disaggregation, the pertinent *measurable components* of each descriptor are listed (as will be presented later).

Crop response

Crop production is the overall integrator of the agricultural system response to the husbandry program imposed at a specific site. Transfer must be made in terms of specific crop varieties or crop systems. For each site-related environmental vector, there are large numbers of potential crop systems utilizing various plant materials. The failure or success of each plant material and the necessary husbandry programs can best be described at various production stages or indicator points which are related to the intimate plant environment.

Once the intimate plant environment has been defined, each measurable component of the environment can be looked upon in terms of its effect on various production indicator points related to the crop. The *crop production indicator points* selected are *planting opportunity, germination, early and rapid growth, flowering, fruiting, ripening, and harvest opportunity*, as shown in Table 1. Each intimate environmental component has some effect at one or more of these indicator points.

In order to optimize, one needs to know the existing plant environment, the quality of transfer, the *potential husbandry* program which might be taken in order to modify the environment and the quality of the *expected response*, i.e., whether it is *optimal, good, fair, poor, failure, or unknown*, as shown in Table 1.

Various qualities of knowledge *transfer exist*, as indicated in Table 1. This column is not necessary to the model, but is included to give some qualification as to the nature of transfer. Sometimes *explicit* relationships or formulas which allow definite predictions are available. More often the expert is confined to *objective* reasoning where only some data points or a mix of data and theory are available to provide a basis for information transfer. Simple interpolations or functions such as the empirical consumptive-use equations are examples. Often knowledge transfer capability is completely *subjective* and dependent totally upon experience and judgment. There

Table 1. Condensed summary model for optimizing comprehensive agricultural systems involving water management.

INTIMATE PLANT ENVIRONMENTAL VECTOR				PLANT MATERIAL VECTOR		
FRAMEWORK	DESCRIPTOR	MEASURABLE COMPONENTS	HUSBANDRY PROGRAMS	PRODUCTION INDICATOR	KNOWLEDGE TRANSFER	EXPECTED RESPONSE
I PHYSICAL AND BIOLOGICAL SITE CONDITIONS	CLIMATE SOIL SOIL MOISTURE FERTILITY PESTS		CULTURAL PRACTICES SCHEDULING IRRIGATION DRAINAGE FERTILIZE PESTICIDES ⋮ PLANT MATERIAL	PLANTING GERMINATION EARLY GROWTH RAPID GROWTH FLOWERING FRUITING RIPENING HARVEST	EXPLICIT OBJECTIVE SUBJECTIVE UNKNOWN NONE ⋮ INADEQUATE	OPTIMUM GOOD FAIR POOR FAIL UNKNOWN
ALTERED AND INTEGRATED PLANT ENVIRONMENT				PRODUCTION		UNITS

EXTERNAL ENVIRONMENTAL VECTOR				HUSBANDRY PROGRAM VECTOR		
FRAMEWORK	DESCRIPTOR	MEASURABLE COMPONENTS	ACTION PROGRAMS	HUSBANDRY INDICATOR	EXPERIENCE TRANSFER	EXPECTED QUALITY
II PHYSICAL AND BIOLOGICAL RESOURCES	HUMAN WATER ENERGY CHEMICAL		ENGINEERING DEVELOPMENT EDUCATION EXTENSION ENFORCEMENT ENLIGHTENMENT INFRASTRUCTURE INCENTIVES SUPPORTS ETC.	CULTURAL PRACTICES IRRIGATION DRAINAGE FERTILITY PROGRAM PEST CONTROL LOGGING AND SCHEDULING PLANT MATERIAL	EXPLICIT OBJECTIVE SUBJECTIVE UNKNOWN NONE ⋮ INADEQUATE	OPTIMUM GOOD FAIR POOR FAIL UNKNOWN
III INSTITUTIONAL	LEGAL EDUCATIONAL RESEARCH FINANCIAL					
IV ECONOMIC	INCENTIVES FACTOR MARKETS PRODUCT MARKETS			PROGRAM PRODUCTION		COSTS RETURNS

are also classes of knowledge transfer which could be considered as *unknown*, where it is not known if one exists and the explicit case of *none*, where it is known that no transfer is possible.

The class of transfer considered as *inadequate* may be used as a qualifier to the above transfer qualifiers. It may also be used to depict an inadequate categorization of the environment due to either insufficient data or insufficient knowledge of methods of categorization.

Husbandry programs

As far as the *external environment* is concerned the meaningful *response* is the ability to develop the physical and biological *resources* necessary for the *husbandry programs* directly related to crop production. For example, irrigation is a potential husbandry program which may affect the total crop environment of almost every crop at each growth indicator point. On the other hand, the ability to effectively irrigate can be greatly affected by the resources available and the institutional or economic environmental components dealing with water resources, water law, and water costs. Obviously, certain *action programs* are available which can modify the external environment to enhance the possibility of achieving the desired husbandry program. Water resources can be developed, laws changed or enforced, and economic incentives altered. The above process is outlined in the lower portion of Table 1.

Formulation and Use of the Model

Crop production is directly responsive only to the *intimate physical and biological site conditions.* The external environmental subvectors are relevant only as they impact on this one, through husbandry; i.e., $\overline{E}_i = f(\overline{E}_N, \overline{E}_R, \overline{E}_E, \overline{E}_S, \overline{H})$ where $\overline{E}_i$ represents the intimate plant environment which is linked to the natural existing site biological and physical environment $\overline{E}_N$, the external physical and biological resources $\overline{E}_R$, the economic component $\overline{E}_E$, the institutional component $\overline{E}_S$, and the husbandry programs $\overline{H}$. It is through $\overline{H}$ that $\overline{E}_N$ is altered to $\overline{E}_i$, i.e., $\overline{E}_i = \overline{E}_N \times \overline{H}$. This relationship is pictorially depicted in Figure 1.

At this point the intimate physical-biological-crop response components of an overall model can be partitioned off from the social and husbandry components. Table 1 has been expanded to give finer resolution to the important environmental descriptors and action programs associated with optimizing agricultural systems involving water management. Furthermore, the important measurable components of these environmental descriptors have been delineated. A portion of this expanded submodel is presented in Table 2. In its simplest form, the submodel would simply be a data bank partitioned by crops and capable of making interpolations or extrapolations as environmental factors are varied. To take this first step, crop production data under different environmental conditions should be collected in standardized form. *All* of the pertinent environmental factors should be measured. As a beginning, this could be done to develop data banks for major crops such as wheat, maize, and rice.

One advantage of the disaggregation of Table 2 is that it represents an attempt to be comprehensive. All of the significant environmental factors should be accounted for or categorized at both experimental sites and contemplated development sites. Neglect of any single factor could prevent transferability of information from the research side and unanticipated difficulties and perhaps even failure on the development side. It is important to have at least a few experimental data points for which each of the environmental descriptors was measured.

The writers developed this paper in the context of discussions of water management programs for developing countries, thus worldwide data are contemplated. As the model is developed, basic physical and biological relationships may be utilized to simplify and refine the response surface in lieu of simple interpolations.

Plant breeding

The possibility of developing new plant materials always presents the opportunity to improve production over that which might be expected using different varieties—existing or to be created. How to build this factor into the predictive model is troublesome. At first, within any one basic crop, productivity data might focus on the optimal variety at the test site with the thought that breeding or varietal selection could result in similar optimization at a new site. This approach would need to be used with caution. There would still probably have to be manual review or screening of variety limitations and potentials by crop geneticists for each prediction.

Interaction

This is implied in the model where various indicators or potential action programs or environmental components are cross referenced. For example, interaction is implied between soil moisture and fertility, since it is given as a potential husbandry program for each of these.

Knowledge transfer

The need for the transfer of knowledge is implicit in the model. Without such an ability, the desired environmental site conditions obtainable through husbandry programs, the selection and application of these husbandry programs, and the expected production indicator responses could not be predicted.

Table 2. Intimate physical and biological site conditions portion of model for optimizing comprehensive research and action programs on agricultural systems involving water management.

INTIMATE PLANT ENVIRONMENTAL VECTOR			PLANT MATERIAL VECTOR		
DESCRIPTOR	MEASURABLE COMPONENTS	POTENTIAL HUSBANDRY PROGRAMS	PRODUCTION INDICATOR	KNOWLEDGE TRANSFER FUNCTION	EXPECTED RESPONSE
CLIMATE	TEMPERATURE Daily High Daily Low Frost Free Period Degree Days Hourly Variation Monthly Average HUMIDITY Daily High Daily Low Monthly Average RAIN Daily History Monthly Average Intensity Probability LIGHT Daily Intensity Day Length WIND, HAIL, SNOW History Probability	CULTURAL PRACTICES PLANTING DATE IRRIGATION SHADING Cover Crop Inter-plant CULTIVATION TRANSPLANTING SPECIAL HARVEST WIND BREAKS SUPPORT HOUSING LIGHTING NEW PLANT MATERIAL	PLANTING GERMINATION EARLY GROWTH RAPID GROWTH FLOWERING FRUITING RIPENING HARVEST	EXPLICIT OBJECTIVE SUBJECTIVE INADEQUATE UNKNOWN NONE	OPTIMUM GOOD FAIR POOR FAIL UNKNOWN
SOIL	TEXTURE PROFILE Surface Sub-surface Profile STRUCTURE PROFILE Surface Profile INFILTRATION CAPACITY PERMEABILITY SALINITY pH CHEMISTRY ORGANIC CONTENT BACTERIA TEMPERATURE TOPOGRAPHY	CULTURAL PRACTICES PLOWING SUB SOILING CULTIVATION RECLAMATION AMENDMENTS PLANTING DATE IRRIGATION DRAINAGE COVER CROP CROP ROTATION MANURING NEW PLANT MATERIAL			
SOILMOISTURE	QUANTITY PROFILE Surface 0 - 30 cm 30 - 60 cm 60 - 90 cm 90 + cm POTENTIAL PROFILE SALINITY PROFILE	CULTURAL PRACTICES IRRIGATION DRAINAGE CULTIVATION MULCHING COVER CROP AMENDMENTS PLANTING DATE CLIMATE MODIFICATION NEW PLANT MATERIAL			
FERTILITY	NATURAL PROFILE Nitrogen Phosphorus Potassium Trace EXCHANGE ION TIE-UP RESIDUAL HOLDING CAPACITY	CULTURAL PRACTICES FERTILIZE MANURING CROP ROTATION ADDITIVES CULTIVATION IRRIGATION DRAINAGE COVER CROPS NEW PLANT MATERIAL			
PESTS	FUNGUS INSECTS NEMATODES WORMS & SNAILS POLLUTANTS BIRDS ANIMALS RODENTS WEEDS	CULTURAL PRACTICES PLANTING DATE PESTICIDES MECHANICAL IRRIGATION DRAINAGE CULTIVATION NEW PLANT MATERIAL			
ALTERED AND INTEGRATED			PRODUCTION		UNITS

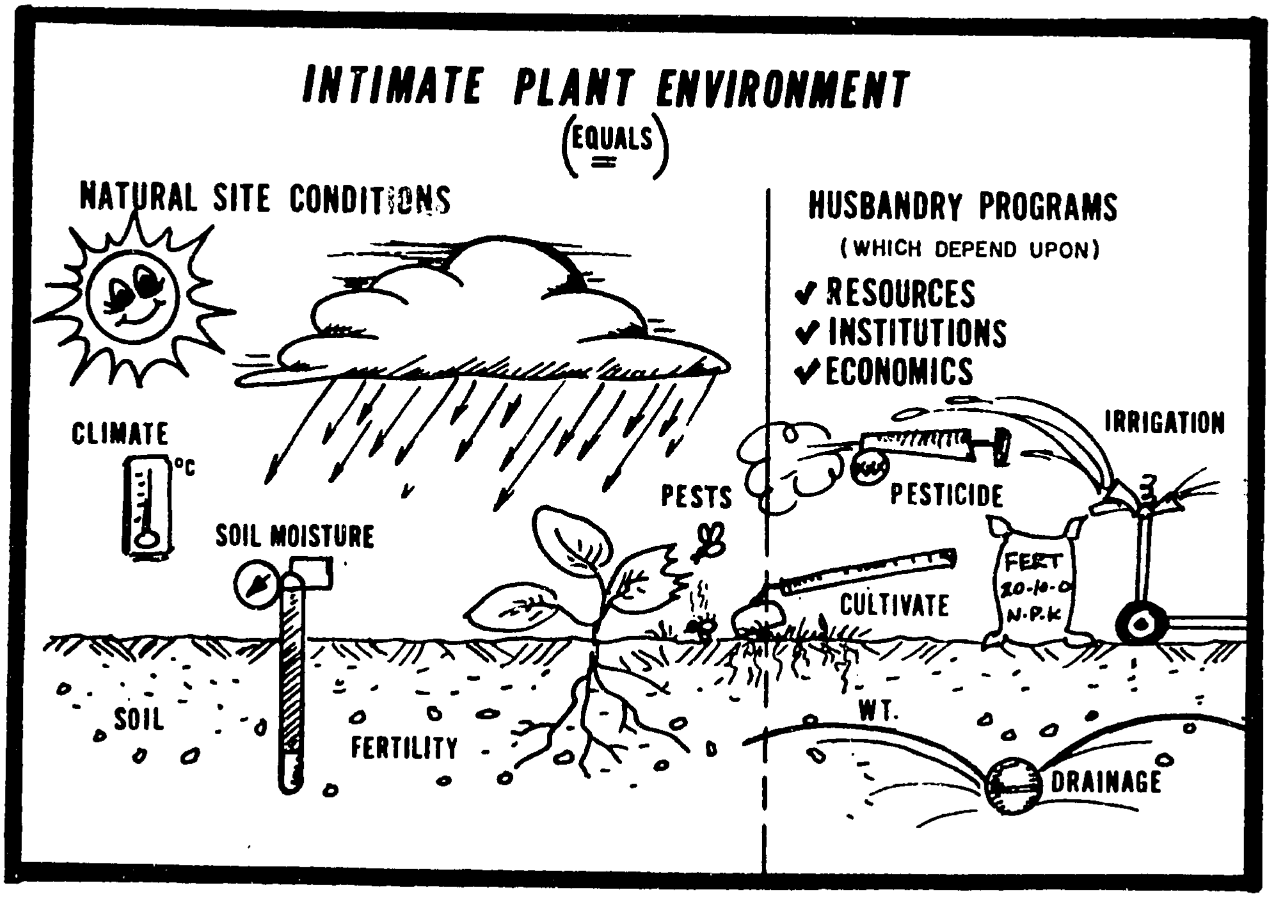

Figure 1. The intimate plant environment vector.

Comprehensive Evaluation

The submodel would provide predicted production functions for alternative choices of crop systems and husbandry as prerequisites to economic and social evaluation. The resource, institutional, and economic frameworks provide the qualitative and quantitative measures of the costs of inputs and the values of the expected responses. A summary of the total evaluation of the agricultural system is presented in Table 3. However, the only quantitative evaluation contemplated is economic, wherein the cost of the husbandry and action programs can be compared to the total economic value of the crop production and action programs to the farm unit or the region. Several operation-research type techniques have been devised for optimizing economic returns given certain levels of resource and marketing constraints. See, for example, Windsor and Chow.[4]

The "social" and "environmental" statements dealing with costs and benefits are, for the most part, qualitative, but some consideration of these categories may be imposed *quantitatively* on the evaluation in the form of constraints. Social and environmental consequences are important, however, in providing policy makers with the information necessary to make comprehensive decisions.

Application of the Model

The two important vectors operative at the production level are thus the intimate plant environmental vector depicted by the disaggregated measurable components as altered by husbandry programs and its interaction with the biological production (plant) material vector. The action is two-fold: A husbandry program is imposed on the site environment to make it more hospitable, and this modified intimate environment is imposed upon the plant material.

The availability and quality of the husbandary program depends upon the external environment which may, in turn, have been modified by some action program. Figure 2 shows a flow diagram of the model process and points out the importance of knowledge transfer.

[4]Windsor, J. S., and V. T. Chow. Model for farm irrigation in humid areas. Journal of the Irrigation and Drainage Division, ASCE, Vol. 97, No. IR3, September 1971.

Table 3. **Comprehensive evaluation of agricultural systems as a basis for the decision process.**

Aspect	Costs to Region	Benefits to Region
Economic Balance	Monetary cost of action and husbandry programs.	Monetary value of production and support programs.
Social Statement	Social cost of action programs to the region.	Social benefits of action programs and production.
Environmental Statement	Environmental cost of development programs.	Environmental value of the action programs.
Total	Comprehensive political decision by policy makers.	

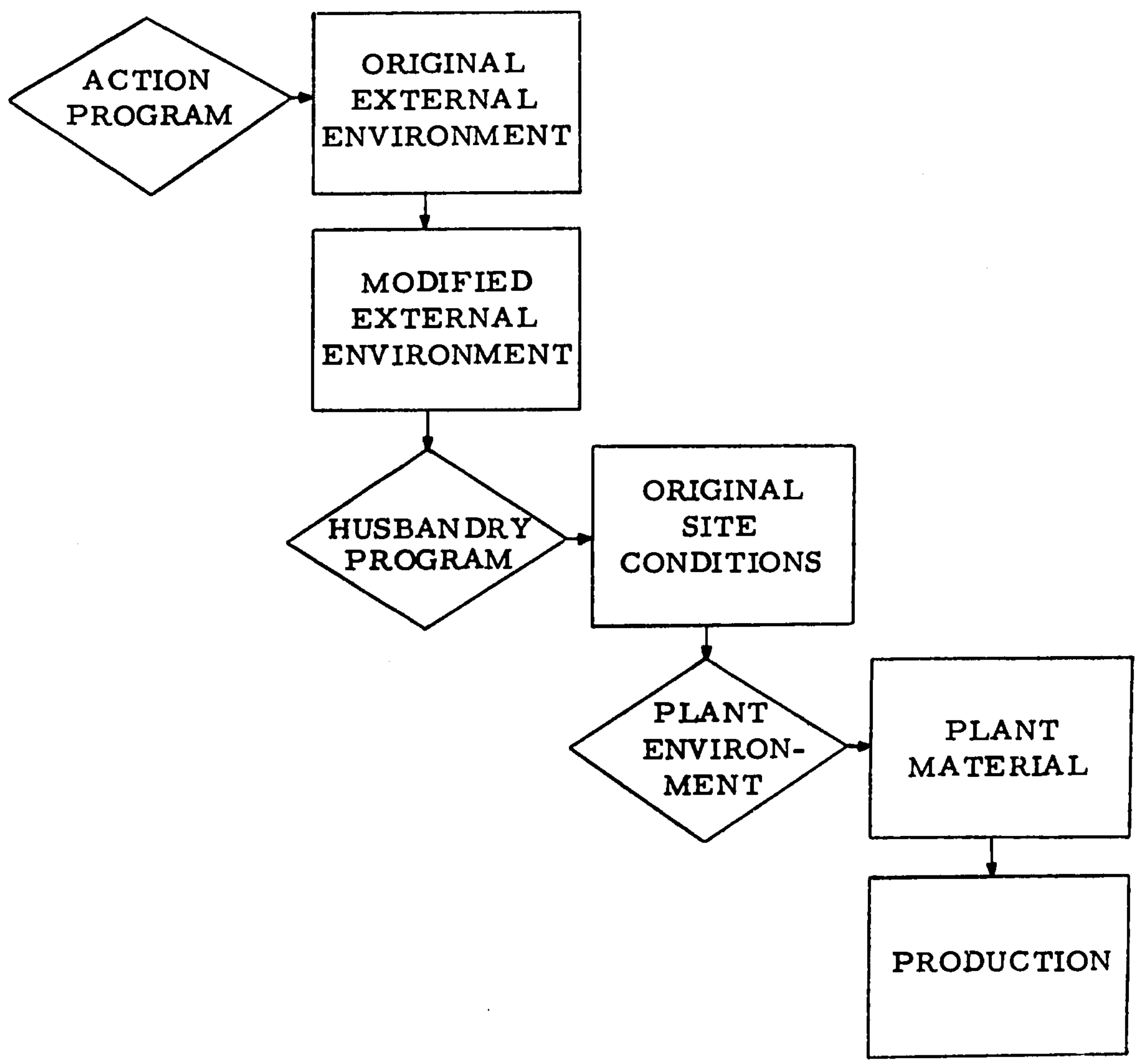

Figure 2. Flow diagram of model–knowledge transfer is implicit at all arrows.

The response of the plant material to this modified site environment is checked at a number of production indicator stages, and ultimately the expected productivity is estimated. The disaggregation of production into a number of production indicator points or stages is important in systematically selecting potential modifications to the husbandry program and estimating productivity.

Plant materials which have low production expectations at the given environmental site under reasonable husbandry programs are discarded in favor of more promising plant materials. The selection process is continued to the conclusion of the optimization process. This process implies that there is a data bank, the environment is characterized, and knowledge of applying husbandry programs and crop response expectations are transferable from one to another environment.

Agricultural engineering

In general, agricultural engineering technology is transferable. For example, irrigation system design parameters including details such as the expected sprinkler performance in wind can be estimated if the environment has been adequately characterized and sufficient sprinkler performance data are available. The reason for inadequate estimates results either from insufficient wind records or insufficient sprinkler performance data. Sprinklers should not be tested at the project site if it is more convenient or economical to adequately characterize the wind and use sprinkler test data which are already available.

The effective application of engineering technology to achieve practical husbandry programs implies that the desired alteration of the natural site environment is known. The technological processes required in the husbandry program which are best suited within a given set of external environmental restraints can be selected from the technological data bank. Thus test site operations are only needed for the final onsite fine-tuning and demonstration of the operating programs. For example, within various environmental restraint circumstances the following technology is transferable: Irrigation, drainage, and cultivation methods; fertilizer and pesticide application methods; and planting, thinning, and harvesting processes.

Plant requirements and responses

Much of the information regarding the intimate environmental requirements of specific crops and varieties and expected responses to site conditions is transferable. Two sets of data are required before this information can be applied, however.

1) The existing site environment must be categorized.

2) The achievable husbandry programs and resulting plant environment conditions must be estimated.

The information transfer process breaks down if either the "categorization" of the expected plant environment or the "data bank" of plant needs is inadequate.

An obvious example of applying the model as a check list for crop and varietal selection is:

a) Bananas fail in freezing climates—the temperatures in Alaska are well below freezing much of the year - no reasonable husbandry program other than green houses could alter the temperature sufficiently to create a hospitable environment for bananas in Alaska—failure of bananas can be expected.

A more subtle application is:

b) In parts of South America it would be desirable to grow corn under irrigation during the dry season. (Since there is little cloud cover, dry season corn should do better than wet season corn.) Many say corn doesn't do well during the dry season because of experience with planting the wet season varieties for a dry season crop. The problem results from temperatures being too high during the dry season for pollinization of wet season varieties. If the model had been applied, more suitable dry season varieties which would pollinate at higher temperatures might have been selected and been successful.

Characterizing the environment

The detailed study of many aspects which characterize the environment does not need to be carried out on or near the site. It is often most efficient to bring the component under study to an established laboratory rather than bring the laboratory to the site. This is especially true when highly sophisticated techniques are involved. The model will help pinpoint the most efficient strategy for characterizing the environment.

Optimizing research

Much of the basic information necessary for optimizing agricultural systems can be obtained from data already available in the literature. This is possible since much of the information required is transferable.

If adequate measurements are made in site-specific field trials under different environmental conditions, specific points in the model space can be delineated. With even a few such points the geometry of the model space can begin to be understood with the result that more valid transfer interpolations can be made. As additional data are collected, the resolution of the model can be improved as well as its geographical scope.

The application of this model should be most useful in organizing research efforts to minimize the number of site-specific studies necessary. The potential for optimizing research efforts to fill in the model space by utilizing transferable information, using the more sophisticated research facilities effectively, and conducting site-specific field trials only to bridge critical areas would be perhaps the most important contribution of the model. Furthermore, the model should afford a useful framework for the cataloging and retrieval of research information from a data bank.

Much information dealing with soil-water-plant-climate relationships is transferable. However, it is not unusual to find field research being conducted to determine crop response where it could easily have been predicted if the environment had been adequately characterized. For example, is it unnecessary to grow: (a) Cotton to find that the growing season is too short, (b) rice to find that the temperatures are too cool, (c) orange trees to find out it freezes, (d) alfalfa to determine optimum moisture requirements, etc., (e) wheat to find it is too wet to harvest at the proper time, etc. On the other hand, site-specific research is necessary to determine: (a) Varietal disease susceptabiliby, (b) interactions between climate-moisture-pest controls for various plant materials, etc.

Conclusions

Hopefully, this model will aid in setting up and guiding the activities of investigating teams. Too often proposed projects are viewed by "teams of experts" who go no further than measuring a number of environmental components. This may be a worthy and necessary effort, however, the ultimate success of projects depends on the level of knowledge transfer capability. The real and most unique experts are not technicians who measure the environmental parameters, but the few engineers and scientists who are capable of optimizing the agricultural system through knowledge transfer. The model discussed herein should help in organizing and defining the necessary processes.

In addition to forming a useful outline to guide the thought processes involved in research program development and project analysis, the model could form the framework for a data retrieval system. It is being proposed that the work be extended in an effort to make the model more complete and to form a world data bank for at least one important grain or fiber crop.

6.

RESEARCH ON CLIMATE AND AGRICULTURAL PRODUCTION IN THE CONTEXT OF ON-FARM WATER MANAGEMENT

Norman J. Rosenberg[1]

Introduction

On-farm water management in developed and less loped countries can be made more efficient if the :iples and methods of agricultural climatology and ometeorology are incorporated in the total plan of n.

Climate determines which agricultural enterprises possible in any given region. The availability of ble soils and the availability of water determine her the climatically suited practice can be adopted ly.

As a first step in regional development planning, climatic *surveys* should be undertaken. This is particu- essential where new crops or other new agricultural tices are considered for introduction. As part of such eys the agricultural practices in regions with *analogous* atic conditions should be studied as a guide to ntially useful innovations. The nature of agroclimatic eys and the use of climatic analogues will be described e following.

Agricultural climatology has, aside from its descrip- role, other important contributions to make to the :iency of on-farm water development. Optimization of *water use efficiency* (WUE) should be a major goal in development activities. For the purpose of this entation WUE is defined as:

$$WUE = \quad . . . . \quad (1)$$

The practices which can lead to improved water use :iency are many. Photosynthetic production (the nerator) can be increased by use of improved varieties, optimization of plant population, by optimization of area through proper use of fertilizers, and through per tillage practices.

Crop water consumption (the denominator) can be uced by judicious scheduling of irrigation to minimize ect evaporation from the soil. Windbreaks may be used to minimize the passage of dry, warm air into irrigated fields. Antitranspirant materials to close leaf stomates have also been suggested as a means of reducing transpiration. Reflectant materials can, possibly, be used to dissipate some of the radiant energy of sunlight which for some crops exceeds the optimum required for photosynthesis.

Some of the latter methods aimed at decreasing the denominator term by modification of the microclimate may, in fact, beneficially affect the numerator term (the photosynthetic production) as well.

These methods are discussed below and an analytical model to determine the influence of such measures as windbreaks, antitranspirents, and reflectants on the water use efficiency under a wide range of climatic conditions is described. Some results of the model calculations are also given.

Agroclimatic Surveys

Today it would be unthinkable, in view of our experience and sophistication, to undertake the development of new agricultural enterprises or the renovation or redesign of existing systems without first consulting soil survey data. Should we come upon an area which had not yet been surveyed–surely the investment in soil survey would be easily justified. We are less conscious of the need, it appears, for basic agroclimatic survey in advance of development efforts.

Large quantities of climatic data are available in the archives of national meteorological services, universities, experiment stations, and, occasionally, in the files of private agricultural companies and food processors. In certain of the less developed countries national airline associations maintain quite detailed records of weather conditions at major airports. Thus the basic information on solar radiation intensity, temperature, wind speed and direction, humidity, and rainfall, albeit on a widely scattered network, can often be met by reference to these national meteorological services and airline maintained services. Usually additional stations can be found where rainfall and temperature measurements have been kept for varying periods of time.

The availability of some basic data is fairly certain. The quality of these data, especially from outlying areas, is not always uniformly good, however, and the records

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must be scrutinized for evidence of systematic error or carelessness.

Available climatological data can be rapidly summarized with high speed computers and mean conditions calculated. For the purpose of agroclimatic surveys all data should be treated with some suitable form of probability analysis so that development planning can proceed with a realistic knowledge of weather related risks and hazards. For example:

- It is more useful to know the *probability* that 1 inch of rain will fall during the first week of the growing season (or 2, 3, ..., n inches in the first 2, 3, ..., n weeks of the growing season) than to know that the average rainfall in that period is 1 inch.

- It is more useful to know that the *probability* of 3 (or 4, 5, ..., n) consecutive days with maximum temperature greater than 100°F is 50 percent in July and 70 percent in August, than to know that the mean maximum temperatures are 90° and 95°F during those months.

Many other types of information should be included in agroclimatic surveys. We have at least two useful examples of agroclimatic surveys for guidance (de Brichambaut and Wallen, 1963, and Cocheme and Franquin, 1967). These describe conditions in the Near East and the Sahelian zone of Africa, respectively, and were produced under the auspices of United Nations Agencies.

Both surveys give valuable information on the general characteristics of the survey area including discussion of the hydrology, relief, meteorology and climate, vegetation, soils, and current agriculture. The predominant synoptic systems which govern the weather of the regions are described. Availability and probability of rainfall is treated in detail in the Sahel report as is evapotranspiration and hydrologic balance. Temperature conditions are described in both reports. Radiation and light regime are discussed in the Sahel report. Both reports give considerable detail concerning the main crops of the region–their climatic needs and tolerances. Both reports make some recommendations on how to develop adequate networks for collecting climatic and other data. Suggestions for the further agricultural development of these regions are also made.

Climatic Analogues

'Climatic analogues' are defined by M. Y. Nuttonson of the American Institute of Crop Ecology, Silver Spring, Md., as areas where precipitation, humidity, and thermal conditions are similar. He defines thermal analogues as areas that are alike in the length of day and temperature conditions only.[2] The excellent surveys of the Near East and the Sahel referred to above make some use of the concept of 'climatic analogues.' For example, a number of locations within and external to the Near East region are compared in terms of:

a) Number of days above certain temperature thresholds.

b) Amount of rain, duration of rainy season and extent of interannual variability.

c) Estimated potential evapotranspiration (ETP) in the winter and summer seasons and the ratio of precipitation to ETP during winter.

d) Phenology of the wheat crop.

On the basis of these comparisons it was established, for example, that the semi-arid zones with dryland farming in east Jordan and south Syria are analogous to certain other areas in the Negev Desert of Israel, certain sub-littoral areas in north Africa and Cyprus, areas in south and southwest Australia and in western Morocco. The arid zone of the western part of the high plateau of Iran (Teheran region) was found to be analogous in climate to Aleppo, Syria, and to the southern San Joaquin Valley of California.

The survey of the Sahelian zone points out that the basic tropical circulation responsible for its semi-arid climate exists elsewhere in the world as well. Although there is no region so large which is unaffected by the influence of high ground and of the sea, analogous regions can, nonetheless, be identified. One of these is in northwest India and adjacent areas of Pakistan and another in northern Australia.

The idea of the climatic-analogue is not new. Azzi (1956) treats the subject extensively. Nuttonson (1962) has done considerable work in categorizing climatic conditions of many of the Mediterranean countries and has identified many analogues to these climates worldwide. The files of many food processing companies undoubtedly contain data and studies of climatic analogues which have been developed to identify potential new sources of produce.

The concept of climatic analogues can be extremely useful where development efforts in selected regions require the introduction of new crop species or varieties (or animal breeds) and if new or alternative technologies are sought. Careful study of practices in the analogous region regardless of its stage of development may offer useful insights to the potentiality for change.

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[2]See for example Nuttonson (1962).

TA/AGR may be well advised to commission the collection and interpretation of existing climatic information, the preparation of agroclimatic surveys and the identification of climatic analogues for those regions in which development activities are planned.

Increasing the Water Use Efficiency

Some background of photosynthesis and evapotranspiration

The ultimate objective of agriculture and forestry is to fix solar energy in the form of usable vegetative or animal products.

Green plants provide, by photosynthesis, the first production step in the food-chain on earth. Photosynthesis is the process in which chlorophyll-containing plants produce primary sugars by the light-intermediated reaction:

$$6CO_2 + 12H_2O \xrightarrow[\text{chlorophyll}]{\text{light (112 kcal/mole } CO_2)} C_6H_{12}O_6 + 6H_2O + 6O_2 \quad \ldots\ldots\ldots (2)$$

As an energy conversion process photosynthesis is extremely inefficient. Table 1 (after Lemon, 1969) shows that even under the best current farming methods no more than 1 percent of the solar energy impinging on our lands is captured in crop production. The efficiency in subsistance farming is far lower. It is theoretically possible, however, to reach an energy capture of 8-10 percent. The table also shows that increased photosynthesis accomplished with no increased use of water can lead to major improvements in the water use efficiency since increased production need not involve increased water use.

Evapotranspiration is the vaporization and transport of water directly from soil or water bodies (evaporation) or at the surface of plant leaves after passage through the plant from the soil (transpiration). Evapotranspiration (ET) is an energy consuming process. Approximately 580 calories are required to vaporize one gram of water at 30°C. Where water is available most of the available net radiant energy is consumed in its vaporization.

Because of the large quantities of energy involved, ET is the major mechanism for cooling plant surfaces. The passage of water through the plant is also necessary for translocation of nutrients and chemical products to and from sites of absorption, reaction, and storage. However, more water than necessary is generally transpired in agricultural situations. If transpiration can be reduced, water can be conserved to support crop growth for a longer period in the field or to irrigate more lands. Transpiration reduction must be accomplished in a way which does not impede photosynthesis.

Table 1. Range of achievement and possibilities after Lemon (1969).

System of Source	Photosynthesis efficiency	Water use efficiency
		kg/ton H_2O
Subsistence farming		
Average	0.04-0.1 %	.04- .12
Best	0.08-0.2 %	.10- .24
Ranch farming		
Average	0.10-0.2 %	.12- .24
Best	0.20-0.4 %	.24- .48
Intensive farming		
Average	0.25-0.35%	.30- .42
Best	0.6 -1.0 %	.72-1.4
Experimental		
Season	0.8 -1.5 %	.96-1.8
Weeks	1.5%	1.8
Days	2 -10 %	9.6 -12.0

[a]Incident total solar energy base.

[b]Assume 60 percent conversion of solar energy to latent heat.

A resistance concept of photosynthesis and evapotranspiration

Ohm's law states that $I = E/R$ . . . . (3)

in which

- I is current flow
- E is voltage (the driving force)
- R is resistance

We can treat evapotranspiration and photosynthesis as resistance phenomena. For ET we write:

$$ET = C \cdot \frac{e_l - e_a}{r_s + r_a} \quad \ldots\ldots\ldots\ldots (4)$$

in which

- e_l is the vapor pressure in the substomatal cavity of the leaf.
- e_a is the vapor pressure at some point in the air above the leaf.

r_s is the resistance imposed to the passage of vapor out of the stomates (pores) in the leaf.

r_a is the resistance imposed by the air above the leaf to the diffusion of vapor away from the leaf.

$\vdots$ indicates that certain other constants are required for a physically balanced equation.

Photosynthesis can also be considered as an analogue of Ohm's law

$$P = C \cdot \frac{CO_2\ air - CO_2\ chl.}{r_a + r_s + r_m} \quad \ldots\ldots \quad (5)$$

in which the numerator is the gradient of CO_2 concentration between air above the leaf and at the chloroplast–the intercellular site at which photosynthesis takes place.

The same aerial and stomatal resistances to diffusion of water vapor (r_a and r_s) apply to CO_2 as well. In photosynthesis, however, the CO_2 molecule must diffuse not only through the air and through the stomate, but into the mesophyll cells where the reaction takes place. The resistance to diffusion into the mesophyll of the cell is r_m. Thus the diffusion pathway is longer for CO_2 in photosynthesis than for water vapor in evapotranspiration.

Under normal daylight conditions for a crop such as soybeans the orders of magnitude of the resistances are typically 0.2; 2.0; 5-10 sec cm^{-1} for r_a, r_s, r_m, respectively.

The rates of evapotranspiration and photosynthesis may be altered by manipulating the resistances. Any method or technique which will lower one or more of the resistances will increase photosynthesis--a beneficial effect. Increased evapotranspiration through reduced resistance is however, normally detrimental.

A resistance model for predicting evapotranspiration

Brown and Rosenberg (1973) developed a model for predicting evapotranspiration rate in stands of growing crops. The model is developed from the well known energy balance relationship:

$$Rn - S = LE + A \quad \ldots\ldots\ldots\ldots \quad (6)^3$$

in which Rn is the net radiation, S the soil heat flux, LE and A the latent and sensible heat fluxes at the earth's surface and from basic physical principles. The model is given without derivation here as:

$$LE = \frac{\left[f\left(\frac{(Rn - S - LE) r_a \vdots}{C_p \rho} + T_a \right) - e_a \right] \frac{M_w / M_a}{P} L\rho}{r_a + r_c} \quad \ldots\ldots\ldots\ldots \quad (7)$$

Solution of this equation requires iteration. A first approximation of LE is achieved using:

$$LE = \frac{M_w / M_a \left(L\rho \left[\Delta (T_s - T_a) + \delta \right] \right)}{P (r_a + r_c)} \quad \ldots\ldots \quad (8)$$

and iteration proceeds until resulting values of LE in Equation 7 do not differ by more than 1 percent.

With this background we may now proceed to evaluate certain techniques which may be applied to improve the water use efficiency. These particular methods are chosen for discussion since they may be especially useful in small holdings and where labor intensive methods are acceptable.

Methods to Increase Water Use Efficiency

Windbreaks

General comments. Use of windbreaks probably goes far back in the history of pastoral and agricultural civilizations. Wind problems have been of major importance in determining the characteristic agriculture in many regions.

We observe that grazing animals seek shelter from strong winds. This is a response, no doubt, to physical discomfort caused either by the chilling in cold wind, desiccation in hot wind, or simply by the mechanical pressure on the animal. Plants, too, are subject to damage caused by excessive chilling, high temperatures, desiccation or direct mechanical injury. Windbreaks (any structure which reduces windspeed) and shelterbelts (rows of trees planted for wind protection) can, by reducing these stresses, be profoundly beneficial to the growth of plants in their lee.

The drought years of the 1930's in North America and the serious wind erosion problems which followed prompted extensive planting of shelterbelts, particularly in the Great Plains. The Federal "Shelterbelt Project" of the 1930's and early 40's led to the planting of thousands of miles of 6-8 row shelterbelts in the Great Plains states. These shelterbelts were composed of a number of different tree species. It was prophesized by some at the time that a beneficial climatic change might follow.

[3] The notation used in this model and in previous equations is given in Appendix I.

As these shelterbelts grew to maturity in an era of rising land values and more moderate weather conditions, criticism arose as to the effectiveness and economy of the plantings. It became evident, too, that the tree shelterbelts compete with adjacent crops for soil nutrients and water and that the belts may shade the nearby crops sufficiently as to affect their production. Considerable followup research (Read, 1954; Stoeckeler, 1962) has shown that, despite the reduction of yield near the windbreaks, the net yield per unit land area of sheltered crops (even excluding the value of wood products from the shelterbelt) exceeds that in unsheltered adjacent fields.

Interrelations of wind shelter, moisture, conservation and plant growth. We think that the major influence of windbreaks on plant growth, particularly under dryland conditions, is due to the redistribution and conservation of soil water. In northern latitudes the windbreak will, if properly designed, aid in uniformly distributing snow and will thus improve the supply of soil moisture for spring grown crops. By reducing windspeed, the direct evaporation of moisture from the soil is also reduced since evaporation is a direct function of windspeed.

In shelter, the same type of soil, initially wetted to the same degree, will be subjected to lower evaporation demand than in the open. The slower evaporation rate in sheltered soil may provide an important advantage in maintaining better conditions for seed germination (Rosenberg, 1966a). On dry land, for example, seeds which germinate rapidly because of beneficial shelter effect, grow into larger plants and ramify roots more quickly into the soil. As these soils dry, crop cover decreases the relative importance of direct evaporation from the soil. Transpiration, then, becomes the major mechanism of water withdrawal. In time, and assuming transpiration is a function of leaf area alone, water depletion will induce soil moisture stress in shelter. The development of the sheltered plants will be checked while the unsheltered plants grow in a less inhibited way.

Microclimate in shelter and plant response. As a result of decreased windspeed in shelter a unique microclimate develops there. Its characteristics are as follows:

- nighttime temperatures are lower since temperature inversions are less likely to be disrupted by turbulence in shelter.
- daytime temperatures are higher over sheltered plants since the transport of sensible heat away from the crop is reduced.
- day and nighttime absolute humidity is greater in shelter—the air is more humid.

Decreased nighttime temperature increases frost hazard in late spring and early fall. Nocturnal respiration rates are reduced in response to the lower temperature so that storage of carbohydrates is more efficient in sheltered plants.

Increased daytime temperature increases the capacity of the air to hold water vapor and thus, in a sense, increases the drying power of the air. However, since vapor pressure is greater in shelter this effect of increased temperature is generally negated.

Windspeed has a direct influence on evaporation and thus the drying of bare soil in shelter is slowed. Plants, however, exert some resistance to the passage of water from the leaves to the air and frequently we find this resistance lowered in sheltered plants. The stomates remain more widely open in shelter because the moisture stress on the plants is less severe.

Under these circumstances sheltered plants may actually use more water than plants exposed to wind. During such times, however, photosynthesis proceeds more vigorously in the sheltered plants because the stomatal resistance is low.

Carbon dioxide concentration is barely affected by the presence of wind shelter.

These findings are documented in Rosenberg (1966b) and Brown and Rosenberg (1972).

Shelter effect on photosynthesis. Plant growth and yield are usually greater in shelter. Therefore, the net assimilation of carbon dioxide must somehow be increased. Greater net assimilation may result from a number of possible causes. The mechanisms which appear most likely are a) longer duration of photosynthetic activity because of reduced wilting with its concomitant stomatal closure and b) lower nocturnal respiration due to lower nighttime temperatures.

Shelter effect on evapotranspiration. Two factors apparently interact in determining the actual water use by crops grown in shelter. As noted the reduction of water stress on shelter grown plants often results in a reduced stomatal resistance. Consequently water use may actually be greater in shelter than in the open at certain times. Such a condition is shown in Figure 1 from Brown and Rosenberg (1971). Sugar beets were grown in the open and in the shelter of corn plants at Scottsbluff, Nebraska. During the morning hours latent heat flux was less than the net radiant energy available at the surface in both cases although water use in shelter was slightly greater than in the open. By mid-afternoon, however, the advection of sensible heat supplied additional energy for consumption in evapotranspiration. While water use rose markedly in the open field at this time the rate of latent heat flux remained moderate in shelter, apparently because less warm dry air reached the sheltered crop.

A more striking example of this 'blocking' of sensible heat advection is shown in Figure 2 from Miller et al. (1973). A portion of a soybean field at Mead, Nebraska, was sheltered with a slat fence barrier 2 meters tall. The fence was of 50 percent porosity with 10.8 cm slats on 10.8 cm centers. The fence made a semi-circle around one of two precision weighing lysimeters in the field. Figure 2 shows the net radiation pattern (top) and the windspeed in shelter and open sites in the field and the wind direction (bottom). Water use in terms of latent heat consumption LE was greatly reduced in the shelter. Evapotranspiration was reduced in the sheltered soybeans by 140 cal cm^{-2} (equivalent to about 2.5 mm). This effect was due to the sharp reduction in advection of sensible heat into the sheltered zone as a result of the mechanical reduction in the passage of warm dry air into the protected area.

Shelter effect on water use efficiency. The literature of shelter effect identifies a great many experiments and observations in which water conservation is demonstrated. When plant growth is markedly altered because of shelter, more water may actually be consumed, however. Yields are generally superior in shelter. Generally, then, shelter leads to improved water use efficiency [dry matter produced (harvestable yield)/water evaporated or transpired].

It is possible to make direct measurement of changes in soil-water content and of plant growth over periods of a week or longer so that the long-term effects of shelter on water use efficiency are demonstrable. To learn the mechanisms by which shelter affects photosynthesis and evapotranspiration it is necessary, however, to conduct micrometeorological experiments.

Micrometeorological measurements have generally demonstrated that evapotranspiration is reduced in shelter. The data on CO_2 flux obtained by micrometeorological methods suggest that photosynthetic flux rates are not greatly affected. Thus the micrometeorological methods support and refine the conclusions of the far more extensive agronomic experimentation which show that wind shelter does, generally, result in improved water use efficiency.

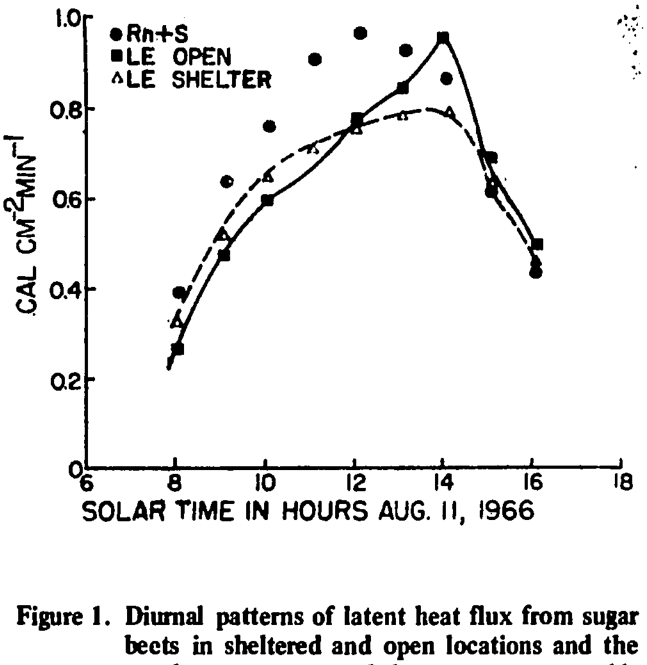

Figure 1. Diurnal patterns of latent heat flux from sugar beets in sheltered and open locations and the synchronous energy balance on August 11, 1966 at Scottsbluff, Nebraska.

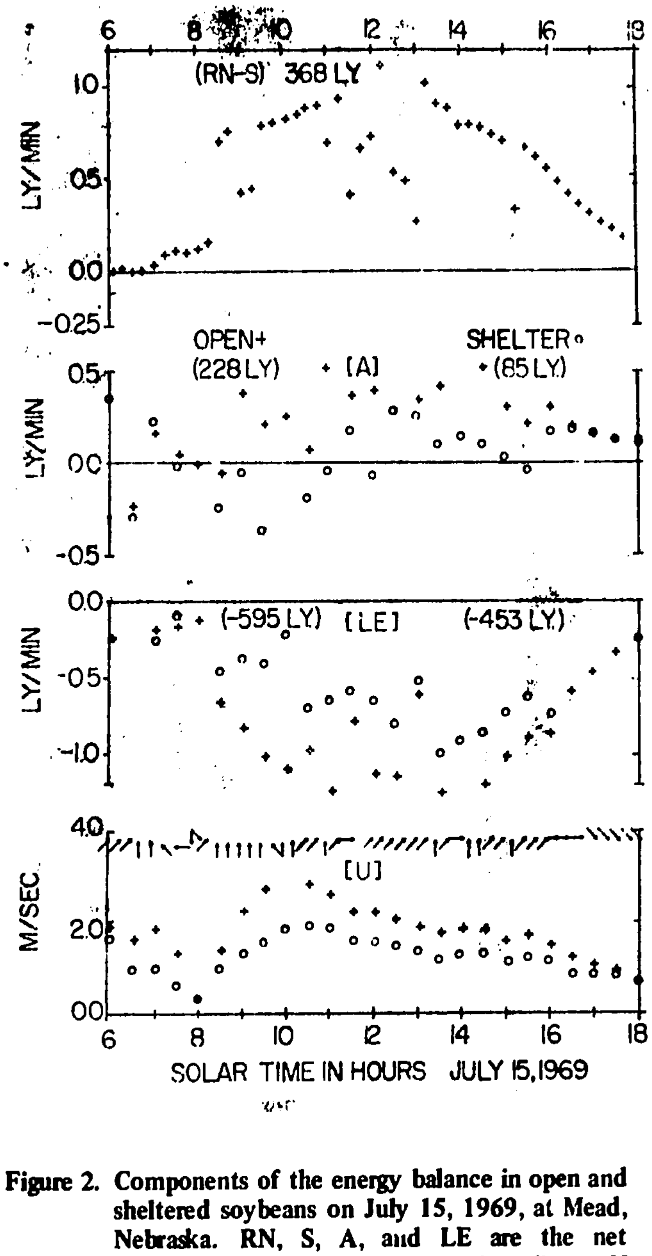

Figure 2. Components of the energy balance in open and sheltered soybeans on July 15, 1969, at Mead, Nebraska. RN, S, A, and LE are the net radiation, soil, sensible and latent heat fluxes. U is wind speed at 175 cm above the surface.

The resistance model predictions of evapotranspiration in shelter. On the basis of data already presented we may assume the following situations to prevail in a sheltered field as compared to an open one:

- r_a the air resistance, is greater in shelter because of reduced windspeed.
- r_s the stomatal (or r_c the crop) resistance, is lower in shelter because of reduced moisture stress on the plants.
- T_a the air temperature, is greater in shelter (during the daytime).
- e_a the vapor pressure, is greater in shelter.
- R_n the net radiation, is identical in shelter and exposed sites.

Table 2 shows the results of the resistance-model calculations of the influence of a hypothetical windbreak. The upper part of the table shows the change from latent heat flux (LE) in the open which follows from a one factor change in shelter. For example, the decrease in canopy resistance r_s in shelter leads to a predicted increase in LE from 0.89 in the open to 0.97 Ly/min in shelter. Increased air resistance r_a decreases LE. Higher air temperature alone increases LE while higher vapor pressure alone decreases LE. When all changes in shelter have been considered the model predicts no change in LE from that in the open.

The lower part of Table 2 deals with changing weather influences superimposed upon an already existing shelter-effect. For example, in cloudy conditions R_n is uniformly decreased in shelter and open sites. The resultant decrease in LE is greater in shelter. Greater stomatal resistance caused, for example, by moisture shortage in the soil reduces LE, especially in shelter. Similarly, greater windiness and increased air temperature as well as decreased humidity cause an increase in LE, but in each case the increase is greater in the open than in shelter. The input data are those developed in an area

Table 2. Resistance model estimates of the influence of a windbreak on evapotranspiration rate (latent heat flux).

Parameter		Net Radiation (Rn) cal cm^{-2}min^{-1}	Crop Resistance (r_c) sec cm^{-1}	Aerial Resistance (r_a) sec cm^{-1}	Air Temperature (T_a) deg. C	Air Vapor Pressure (e_a) mb	Latent Heat Flux (LE) cal cm^{-2}min^{-1}
A	Open	1.00	0.20	0.10	23.0	18.0	0.89
	r_c changes	1.00	0.15	0.10	23.0	18.0	0.97
	r_a changes	1.00	0.20	0.20	23.0	18.0	0.85
	T_a changes	1.00	0.20	0.10	25.0	18.0	1.03
	e_a changes	1.00	0.20	0.10	23.0	22.0	0.74
	Shelter	1.00	0.15	0.20	25.0	22.0	0.88
Cloudy	Open	0.50	0.20	0.10	23.0	18.0	0.65
	Shelter	0.50	0.15	0.20	25.0	22.0	0.55
Increased r	Open	1.00	0.30	0.10	23.0	18.0	0.77
	Shelter	1.00	0.25	0.20	25.0	22.0	0.74
Increased wind	Open	1.00	0.20	0.05	23.0	18.0	0.96
	Shelter	1.00	0.15	0.15	25.0	22.0	0.91
Increased T_a	Open	1.00	0.20	0.10	33.0	18.0	1.62
	Shelter	1.00	0.15	0.20	35.0	22.0	1.35
Dry Air	Open	1.00	0.20	0.10	23.0	8.0	1.30
	Shelter	1.00	0.15	0.20	25.0	12.0	1.11

where corn was used as a windbreak for sugar beets in western Nebraska. The model predicted influence on the windbreak and the measured effects were in close agreement.

Antitranspirants

General comments. The 'resistance-type' equations for evapotranspiration and photosynthesis were given as:

$$ET = f \cdot \frac{e_l - e_a}{r_a + r_s} \quad \ldots\ldots\ldots\ldots (4)$$

and

$$P = f \cdot \frac{CO_2\,\text{air} - CO_2\,\text{chl.}}{r_a + r_s + r_m} \quad \ldots\ldots\ldots (5)$$

The normal magnitudes of these resistances were also previously discussed. Generally, when plants are photosynthesizing effectively and stomates are widely open the mesophyll resistance may be considerably greater than the stomatal resistance. If, by some means, the stomates can be made to close partially, stomatal resistance will increase. The total impact of such an increase in r on evapotranspiration rate will be greater than on the rate of photosynthesis. Antitranspirants which cause partial stomatal closure will, of course, cause some reduction in transpiration. Thus water use efficiency can be increased. This concept was first elaborated by Zelitch and Waggoner (1962).

There are three types of antitranspirant materials. These are (a) film-forming substances which block the escape of water vapor from the leaf; (b) chemical materials which induce stomatal closure; and (c) reflectant materials which reduce the energy load on the leaf. Reflectants will be discussed as a separate case.

a) Film-forming materials include long chain alcohols such as hexadecanol which form monomolecular layers and are used more frequently to reduce evaporation from open bodies of water. Gale and Hagan (1966) found such materials unsatisfactory for use on plant leaves. Low viscosity silicone materials were tested by Angus and Bielorai (1965) who found the water use by potted sunflowers reduced with no detrimental effects on growth.

Thick film antitranspirants include latex, waxes, and plastics. To be effective such materials must be more permeable to CO_2 than to water vapor. Gale and Poljakoff-Mayber (1967) tested a number of such materials and found them, unhappily, considerably more permeable to water vapor.

b) Stomate-closing materials were classified by Waggoner and Zelitch (1965) according to their modes of operation. One type acts as a 'pump' by affecting turgor of the stomate guard cells. Atrazine, a commonly used herbicide, and hydroxsulfonates are in this group. A second type of material is believed to affect the permeability of cell membranes, acting as a 'check-valve.' Phenol mercuric acetate (PMA) and alkenylsuccinic acids are thought to work in this way. Zelitch and Waggoner (1962) found PMA effective on tobacco leaves in the greenhouse. Slatyer and Bierhuizen (1964a,b) with cotton and Shimshi (1963) with corn found under greenhouse and growth chamber conditions, that PMA did indeed effect a proportionately greater decrease in transpiration than in photosynthesis. Cole et al. (1971) tested PMA and dodecenyl succinic acid (DSA) (among other materials) on greenhouse and growth chamber grown alfalfa. Neither material had an effect on water requirement and DSA caused foliar damage.

Results of field studies with these chemicals have not been particularly encouraging. Generally the water savings have been small, of very short duration, and often the materials have caused foliar damage.

There is one case, at least, where an antitranspirant material has been effectively used in a natural situation. Waggoner and Hewlett (1965) applied the glyceryl half-ester of decenylsuccinic acid (GLOSA) to the undersides of broadleafed trees in small watershed of a southern forest. A 12 percent reduction of transpiration was detected by a significant increase in stream flow out of the watershed.

Although field studies with antitranspirant materials have generally been disappointing, there may nevertheless be situations where the use of antitranspirants can be helpful. In situations where the effects of drought can be avoided, even for a few days, by a reduction in transpiration the survival of a crop or vegetated community until the next rainfall may be accomplished.

Resistance model predictions of antitranspirant effectiveness. The resistance model was used by Rosenberg and Brown (1973) to estimate the influence of an antitranspirant material on evapotranspiration. Results are given in Table 3. The calculation assumed a 33 percent increase in r_c which is probably as much as can be expected under field conditions.

Under a net radiation of 1 cal $cm^{-2}min^{-1}$ and in cool, windy and dry air (Set 1) a 13 percent reduction in LE is predicted. The following five sets of calculations illustrate the influence of decreased windiness, increased temperature, increased vapor pressure, and combinations of these under the same net radiation. Two further examples are given under low net radiation, such as might occur in cloudy weather or at the beginning and end of the daylight period. Water savings are proportionately greatest when LE flux is low. During periods of strong sensible heat delivery, as in Set 3, a 10 percent water

Table 3. **Resistance model estimates of the influence of an antitranspirant material on evapotranspiration rate (latent heat flux).**

Parameter	Net Radiation (Rn) cal $cm^{-2} min^{-1}$	Crop Resistance (r_c) sec cm^{-1}	Aerial Resistance (r_a) sec cm^{-1}	Air Temperature (T_a) deg. C	Air Vapor Pressure (e_a) mb	Latent Heat Flux (LE) cal $cm^{-2} min^{-1}$
Set						
1	1.0	0.15	0.10	10	10	0.53
	1.0	0.20	0.10	10	10	0.46
2	1.0	0.15	0.40	10	10	0.62
	1.0	0.20	0.40	10	10	0.61
3	1.0	0.15	0.10	30	10	1.84
	1.0	0.20	0.10	30	10	0.68
4	1.0	0.15	0.40	30	10	1.10
	1.0	0.20	0.40	30	10	1.07
5	1.0	0.15	0.10	30	30	1.06
	1.0	0.20	0.10	30	30	0.99
6	1.0	0.15	0.40	30	30	0.89
	1.0	0.20	0.40	30	30	0.87
7	0.5	0.15	0.10	10	10	0.32
	0.5	0.20	0.10	10	10	0.28
8	0.5	0.15	0.40	30	30	0.51
	0.5	0.20	0.40	30	30	0.50

saving is predicted. During hot, dry, but calm periods the effect is small.

Reflectants

Physical considerations. Reflectant materials may be considered to be antitranspirants. However the mechanism involved is somewhat different than that of the film-forming or stomate-closing materials discussed above. If net radiation is reduced over a plant community less energy will be available for consumption in soil heat flux, sensible heat flux, and evapotranspriation. Since most of the radiant energy is consumed in evapotranspiration when water is available, reflectants should significantly reduce water use.

Net radiation can be decreased significantly by increasing albedo of the underlying surface. Ramdas and Dravid (Geiger, 1965) successfully reduced temperature of a dark Indian cotton soil by application of lime to the surface. Stanhill (1965) noted reduced evaporation as well as reduced soil temperature following application of whitening materials to a light colored loessial soil in the Negev Desert of Israel.

In the case where leaves or canopies are treated the effect of increased reflectivity should be a decrease in net radiation. Evapotranspiration and sensible heat flux generation should be reduced but photosynthesis should not be directly affected unless the availability of photosynthetically active radiation becomes critical. Baring this effect, the net result of reflectant application should be an improvement in water use efficiency.

Doraiswamy and Rosenberg (1973) applied kaolinite in a mixture containing plant gum and a surfactant to a 30 x 30 m plot of soybeans during 1969 at Mead, Nebraska. The kaolinite was applied at a rate of 196 kg/ha. During ten days of detailed observation which followed the reflectant coating persisted with no apparent sign of being washed away despite occasional light rains. Additional plots were prepared in 1970.

A comparison of the reflection spectra from the coated and uncoated crop canopies was obtained with a spectro-radiometer inverted over the crops. Results of such a comparison are given in Figure 3.

Reflection was increased in the visible wave band (corresponding approximately to 380-750 nm). No major difference in near infrared (corresponding approximately to 750-1550 nm) reflection was found to occur.

In these studies the reflection of visible radiation was increased by 80-300 percent depending on crop condition, cloud cover (intensity of shortwave radiation), and time of day.

The overall effect of the reflectant on radiation balance components, solar radiation, shortwave reflection, and net radiation is shown in Figure 4. The figure shows that shortwave reflection was increased by about 0.08 Ly

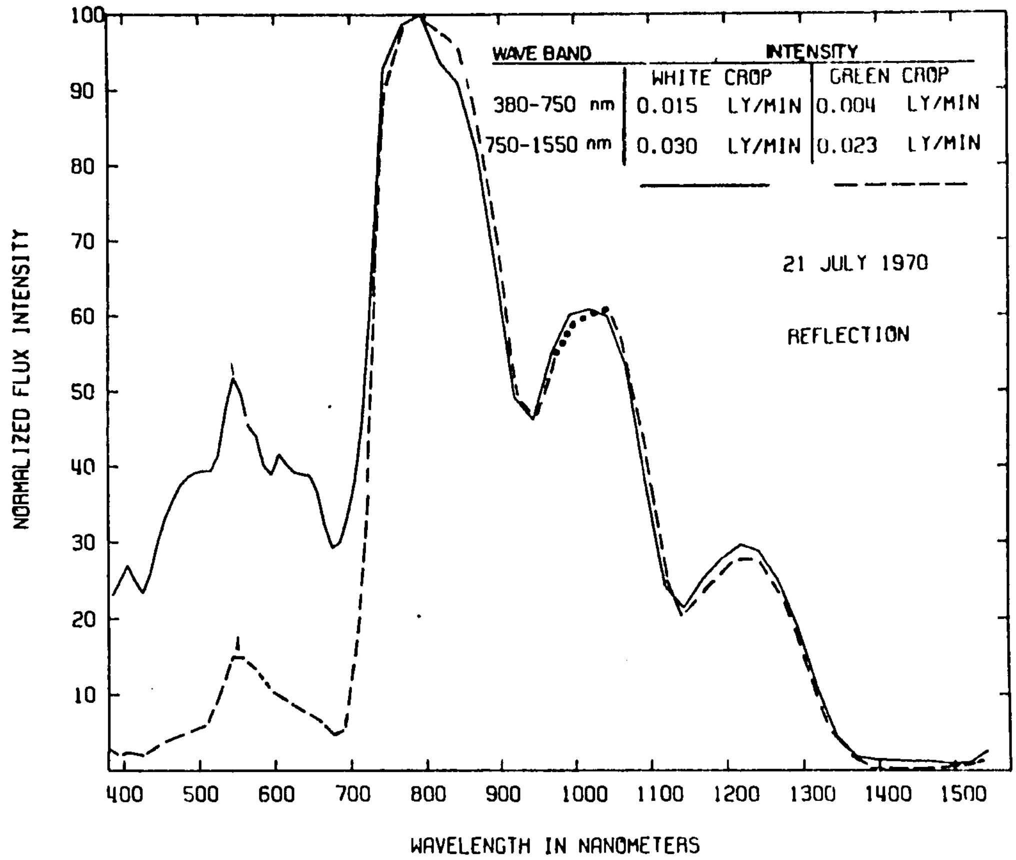

Figure 3. Reflection spectra for kaolinite coated and untreated soybeans normalized with respect to incident solar radiation. Mead, Nebraska, 1970.

min^{-1} under clear skies at midday and net radiation was reduced by about the same amount. Longwave balance was not affected by treatment.

Plant physiological factors. In crops which are light-unsaturated under their normal growing conditions—corn, sorghum, sugar cane, for example—the application of materials which reflect away visible radiation may reduce photosynthesis as well as evapotranspiration. Since most available reflectant materials which can be applied directly to plants (kaolinite, diatomaceous earth, aluminum silicates) reflect most effectively in the visible waveband the practice seems most applicable to those crops which are light-saturated in their regions of adaptation.

One obvious candidate for reflectant applications is the soybean which has been shown in agronomic and botanical studies to be light-saturated in the field until the leaf area index exceeds about 4 (midgrowth stage). Some reflectant induced reduction in photosynthesis might occur with this crop when it is light-unsaturated early and late in the day when solar radiation intensity is low. Experimentation to test the suitability of reflectants on soybean growth is underway in Nebraska (Doraiswamy and Rosenberg, 1973). Elam (1971) reports studies on sugar beets and alfalfa in California.

There are a number of ways in which reflectants may, in the future, be made more widely applicable. If cheap means of delivery can be developed, reflectants may be applied even to light-unsaturated crops as a drought avoidance technique so as to ensure crop survival over a short period through transpiration reduction. Reflectants applied to light-saturated (or perhaps even to light-unsaturated) crops may result in greater penetration of visible radiation into the lower canopy. If so the effect on photosynthesis will be beneficial. If reflectants can be developed which are more effective in the near infrared a greater reduction in energy load of the crop can result with less direct interference in photosynthesis. Although these advances await research and development, reflectant materials in use thus far already offer one important advantage over most of the film-forming and stomate-closing types of antitranspirants. These are inert materials and pose no danger to the health of man or animals.

Resistance model predictions of reflectant effect on evapotranspiration. The resistance model calculations of

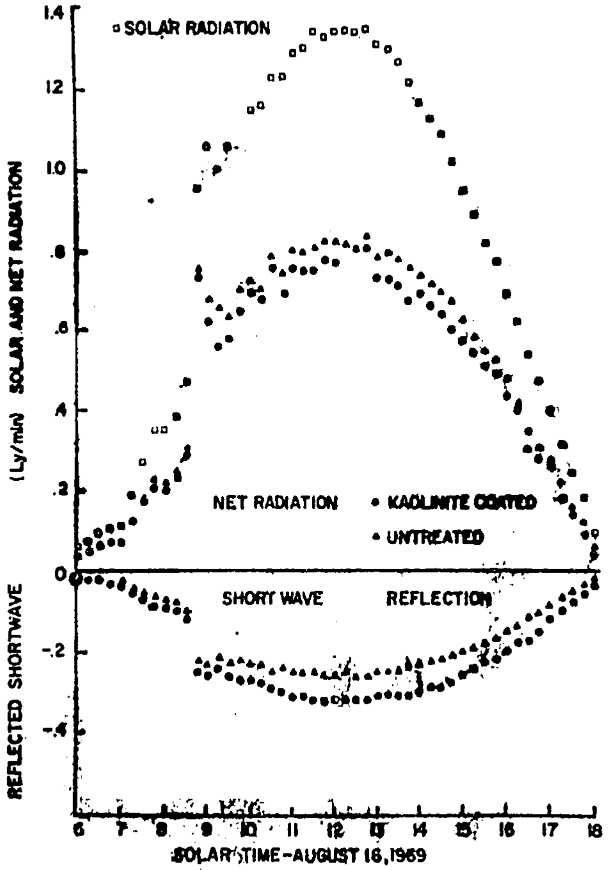

Figure 4. Daytime patterns of solar radiation and of shortwave reflection and net radiation over kaolinite coated and uncoated soybeans at Mead, Nebraska, 1969.

the influence of an hypothetical reflectant material are given in Table 4. Reduction in net radiation such as might occur as a result of cloudiness or the use of reflectants with no other physiological or climatic change is shown in Set 1 of the calculations. Sets 2-4 assume a 20 percent decrease in net radiation over the treated plants and evaluate the effect on LE caused by changes in the air resistance, the ambient temperature and humidity. Set 5 considers the possibility that the applied material may 'plug' or induce a slight closure of stomates. All of the cases tested with the resistance model suggest that reflectant materials will reduce evapotranspiration.

Small ponds–a special case for applied micrometeorology: Although not strictly a matter of water use efficiency in crop production I would like to note briefly how the principles illustrated above can be applied to another important aspect of on-farm water management.[4]

[4]See Rosenberg, N. J. (1969).

The principles of shelter effect and of increased reflectance can be combined and applied to the serious problem of reducing evaporation in impoundments. In western Rajasthan, for example, many small shallow ponds have been constructed and these supply an important share of all the water available to the human and animal populations of the region. In Rajasthan annual evaporation from free water can be 250 cm. This may be 50-75 percent or more of the pond storage capacity. Floating mats or rafts of jute or other local materials would, by reducing the extent of exposed water surface reduce the evaporation therefrom. These mats can be painted white and treated to maintain that color. Reflection would reduce the total energy incident upon the water.

Mat fences bordering the ponds would reduce the inward transport of air heated in passage over dry land and further tend to decrease evaporation.

Summary

The disciplines of agroclimatology and agrometeorology have contributions to make to the improvement of on-farm water management in both the less and more developed countries. Agroclimatology should be enlisted as early as possible to provide the basic climatic information and survey material needed for planning total agricultural systems. Light intensity and duration, the temperature and precipitation regimes, crop consumptive water use, and other critical climatic parameters need description. Whenever possible, climatic conditions should be characterized in probability terms.

When new varieties of crops or breeds of animals, or when irrigation and other production practices are sought for development areas, regions of analogous climatic conditions should be studied first. The identification of these climatic-analogues can be accomplished effectively by trained agricultural climatologists.

Agrometeorology offers techniques for improvement of the efficiency with which the water which reaches the field, by precipitation or by irrigation, is used in crop production. Windbreaks are effective for this purpose. Windbreaks composed of trees, of tall crops sheltering shorter ones, or windbreaks constructed of reeds, stalks, or other available materials should be tested extensively as an aid to improved on-farm water management. The effectiveness of the windbreak in increasing water use efficiency should increase with increasing windiness, aridity of the atmospheric environment, and dryness of the soil.

Evidence of reduced evapotranspiration due to windbreaks was presented in this report. A theoretical 'resistance' model of evapotranspiration mimicked the experimental findings very well. That same model suggests that antitranspirant chemicals which either coat the leaf

Table 4. **Resistance model estimates of the influence of a reflectant material on the evapotranspiration rate (latent heat flux).**

Parameter	Net Radiation (Rn) cal $cm^{-2}min^{-1}$	Crop Resistance (r_c) sec cm^{-1}	Aerial Resistance (r_a) sec cm^{-1}	Air Temperature (T_a) deg. C	Air Vapor Pressure (e_a) mb	Latent Heat Flux (LE) cal $cm^{-2}min^{-1}$
Set						
	1.00	0.15	0.10	10	10	0.52
1	0.80	0.15	0.10	10	10	0.44
	0.50	0.15	0.10	10	10	0.32
2	1.00	0.15	0.40	10	10	0.62
	0.80	0.15	0.40	10	10	0.50
3	1.00	0.15	0.10	30	10	0.84
	0.80	0.15	0.10	30	10	0.73
4	1.00	0.15	0.10	30	30	1.06
	0.80	0.15	0.10	30	30	0.94
5	1.00	0.15	0.10	30	30	0.06
	0.80	0.20	0.10	30	30	0.87

or induce stomatal closure are not likely to be effective in reducing actual transpiration. The model also predicts that a significant reduction in transpiration should result from the application of reflectant materials to certain crops.

Theoretical models of the photosynthetic and transpirational processes should be developed further These models can be used to predict which of the extremely large number of potential management techniques applicable to on-farm management problems are most likely to succeed. Thus with the guidance of these model calculations the limited manpower and funds for field experimentation can be used most effectively in testing the most promising methods first.

Acknowledgments

Much of the research work reported here was sponsored by agencies of the Federal Government. U.S. Department of Commerce, NOAA under Environmental Data Service Grant WBG-54 and the U.S. Department of the Interior, Office of Water Resources Research under the Public Law 88-379 program sponsored the windbreak related research. The Public Law 88-379 program also sponsored development of the 'resistance model' and some of the preliminary work on reflectants. The National Science Foundation now supports, under Grant GA-24137, a major research program on the use of reflectants to increase water use efficiency.

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Appendix I. List of Symbols

Symbols		Dimensions
A	= sensible heat flux	(cal cm^{-2}min^{-1})
C	= constant	
Cp	= specific heat of sir at constant pressure	(cal g^{-1}deg^{-1})
e	= water vapor pressure	(mb)
f	= functional notation	
LE	= latent heat flux	(cal cm^{-2}min^{-1})
Ma	= mole weight of air	(29 g mole^{-1})
Mw	= mole weight of water	(18 g mole^{-1})
P	= atmospheric pressure	(mb)
Rn	= net radiation	(cal cm^{-2}min^{-1})
r	= resistance to diffusion	(sec cm^{-1})
s	= soil heat flux	(cal cm^{-2}min^{-1})
t	= temperature	(deg C)
ρ	= air density	(g cm^{-3})
δ	= saturation vapor pressure deficit	(mb)
Δ	= $\frac{de_s}{dT}$ = slope of saturation water vapor pressure curve	(mb deg^{-1})

Subscripts

T_a, T_s, T_ℓ	= temperature of air, surface, leaf	(deg C)
e_a, e_ℓ, e_s	= vapor pressure of air, leaf, saturation vapor pressure	(mb)
r_a, r_m, r_s or r_c	= aerial, mesophyll, stomatal or crop resistance	(sec cm^{-1})

7.

THE INTERNATIONAL IRRIGATION INFORMATION CENTER

Joseph Shalhevet[1]

Establishment

An international information analysis center (IIIC) dealing with all aspects of field irrigation is to be established. It will operate as such and serve as a base for evolving an international training center in irrigation technology.

Location

The Institute of Soils and Water of the Agricultural Research Organization, Israel.

Longterm Aims

The longterm aims of IIIC will be to act as a data bank in all matters pertaining to field irrigation and, by all forms of extension from the data bank, to raise the level of irrigation efficiency throughout the world.

Initial Outputs

Initial outputs will comprise international inventories of sprinkler irrigation equipment and of its manufacturers and suppliers; international directories to irrigation research, extension, practices and information; abstracts of current irrigation research and news of irrigation R&D.

Research reviews on the water requirements of crops and on the extension methods suitable in developed and underdeveloped agriculture will be undertaken, as will clearing-house and referal services in basic and applied aspects of irrigation.

Availability of Services

Information and services will be available to all.

[1]Director, Soils and Water Institute, Agricultural Research Organization, Valcani Center, Beit Dagan, Israel.

CHAPTER VII

CONSTRAINTS TO CONDUCTING AND IMPLEMENTING RESEARCH

1.

WATER MANAGEMENT RESEARCH CONSTRAINTS IN CONDUCTING AND EVALUATING

H. B. Peterson[1]

In this discussion we are considering the constraining problems that we have encountered while attempting on-farm water management research in developing countries. This assignment more or less delegates us to look at the adversities we encounter. We find that the very nature of the subject has some constraining components. It places us in the position of appearing negative, which is not intended.

Nature of the Subject

1. Water functions in crops in a diffused and interacting capacity. In crop production we find multiple order interactions:

Water x Crop x Variety x Climate x Soil

2. For water *per se* there are few large knowledge voids which we can identify. (However, in our research proposal we identified a need to greatly expand our knowledge on water management of heavy soils. Suitable site conditions and country cooperation was located in Venezuela. A professional staff member was sent to the country to initiate the studies. AID decided to reduce its effort in the country so we were required to discontinue the study.)

3. Knowledge about water is transferable but the interacting components of production make much of the information largely site-specific unless the knowledge is well characterized and placed where it is available in an information bank. We have developed our production model to help systematize our research, utilize existing knowledge, and identify priority research needs.

Measuring Success

It is difficult to evaluate the success of water research. We are usually obligated to express our accomplishments in terms of utilization. The success of any water management venture (utilization of information) is dependent on economic, social, political, educational, as well as technological components.

Personnel

1. We lack experienced researchers who also have adequate language capability.

2. There are too few trained scientists in the countries that can be assigned as counterparts. Where the Host country has qualified people, they are badly needed elsewhere.

3. Our research personnel and country counterparts are used in part for technical assistance rather than research. It is not very reasonable in the eyes of the Host or the Mission for us not to provide professional assistance when present in a country and needed. They can hardly see logic in obtaining more new knowledge at the expense of not using what we have.

4. Most of the people in AID, the Mission, and country, through which we work, are not research oriented. In Brazil we found ourselves assigned to work with SUVALE, a development agency not research oriented.

Administrative Changes

This constitutes what is probably our greatest difficulty. There is a constant change of key persons in AID/Washington, Missions, and Host agencies. In order to obtain clearances for programs, in-country staff, back-up

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staff, all travel, etc., there must be approval at all levels. Our research program must be in harmony and of high priority with the Mission and Host. With each change in key personnel there is a delay while the new people make their evaluation to determine how our research fits into their plans. I can relay many specific examples of major delays encountered in the countries in which we work. In one country specific research was given top priority by the Mission. However, change in the agricultural officer assignment resulted in the research becoming a project of lowest priority. In Chile, we have had what was probably our greatest overall success, but a change in politics by election resulted in our departure. Another drastic change could find us once more involved! How do we anticipate and project for such changes in our work plans?

Logistic Problems

Considerable loss of time and resources are realized when trying to obtain clearances for purchasing and obtaining delivery of equipment. In El Salvador, we have two competent scientists and utilize considerable staff support from Logan. They are engaged in research of the nature suggested by a team reviewing our project. A change of cooperating agencies of the host country found our team working with an agency that could not provide any travel assistance. A request was made February 22, 1973, for permission to purchase a truck. As of October 4, we still do not have concrete evidence that this equipment is even on order.

Miscellaneous Frustrations

1. Signals we receive from Washington are often not very clear and/or frequently changed.

2. In Colombia our research team found the crop production to be highly variable or "spotty" within the fields. This made it nearly impossible to measure the effects of any of the irrigation treatments. The reason for these "bad spots" was not evident but likely associated with the soil. An attempt was made to get some assistance from North Carolina. (North Carolina has a soil test program in Latin America.) We found that they could not obtain clearance to work in the country. Our staff tried to use the in-country laboratories but found them unsatisfactory. Now, by using a remote route, the problem has been identified as one of minor-element toxicities.

3. The first request we had for research was to work on drought problems in Chile. At that time we could send scientists into the country for a period not to exceed 6 months. We had two people there for periods of 3 to 6 months and started studies. When nearing harvest there was a labor strike and the rains came. Soon thereafter there was no more interest in the project.

4. We have also experiences with the "numbers game" within the Missions. The ambassadors found there were too many U.S. people in Ecuador so we were requested to have Dr. Daines officially leave the country about 4 months before completing his assignment. (He was able to return on TDY.)

5. Early in the project life we were asked to provide an engineer and an agronomist to work in Northeast Brazil. USU was fortunate in having in the person of Professor Richard E. Griffin, an irrigation engineer with a number of years of practical experience, who had already spent several years in Brazil and who was willing to return there on our contract for two years. His ability to speak Portuguese made his nomination for the position an excellent choice. He was therefore cleared for relocation to Brazil, took a refresher course in Portuguese, leased his house, made a number of arrangements for handling his personal affairs while in Brazil, and was on the point of leaving when word came from USAID/Brazil that pending a 90-day appraisal of SUVALE's ability to provide needed manpower and logistic support to a USBR team then working with them, to hold up on plans to place a USU team in the country. There was some pessimism expressed on the likely capability of SUVALE to upgrade its support of the USBR team to the point where in USAID/Brazil's opinion they could be expected to function effectively with the USU team This left us with Professor Griffin all dressed up and no place to go.

At the same time as the Brazil negotiations, details were being worked out with several other countries to place USU researchers in the field. El Salvador asked for an irrigation and drainage specialist. An agreement was drafted but its ratification was delayed for several months while the USAID Mission carried out an Agricultural Sector Analysis. This, they felt, should precede commencement of any research to ensure that it fit within the priorities established by the sector analysis. The ultimate ratification of the agreement coincided with the suspension of negotiations to place Professor Griffin in Brazil. It was therefore decided to send him to El Salvador rather than wait for 90 days to find out whether or not we were going to be able to work at all in Brazil.

This shift was the best alternative available but imposed an extra language handicap on Professor Griffin.

Later when we were again cleared to have our engineer sent to Brazil we used one trained in Spanish.

6. We lack a firm base on which to formulate our plans. With the political uncertainties and high government staff turnover in developing countries, flexibility of program and contractor staff in accepting assignments must be designed into the contractor's method of opera-

tion and accepted by the financing agency as part of the cost of doing business. Some have called ours a strategy of opportunism. However, this term has taken on some negative connotations by its being associated with poor or inadequate planning or without proper regard to the consequences. On the contrary, in the context used here it represents the ability to react quickly to new, unforseeable conditions, making appropriate modifications in details and methods without losing momentum or sense of direction toward the primary objectives of the contract. We prefer to refer to the strategy which works best within these constraints as one of timely, appropriate adjustment to new realities.

Summary

We are seriously dedicated to water management research in developing countries, particularly in Latin America. But the logistics and strategy of doing that work are somewhat more complicated than doing it on the North Logan Farm. These are realities which may be eased somewhat by AID and contractor efforts, but probably not very much. They are doubtless inherent in the task of doing research for international development. Consideration of how to get the most out of our program led us to the production model concept reported in Chapter VI by Keller, Peterson, and Peterson.

2.

WATER MANAGEMENT RESEARCH IN A DEVELOPING NATION–CONCEPTS AND CONSTRAINTS

G. L. Corey[1]

My qualifications for identification of contraints to water management research in developing nations other than the United States are severely limited. I am familiar with only one nation's problems during a rather short period. This paper reflects what I perceive to be the serious constraints impinging on progress there at the present time. Some of the constraints we ourselves seem to perpetuate; so a few ideas on how to facilitate our own programs are also presented.

Pakistan's water management research programs, during the past few years, can be characterized as having many deficiencies. Some of those surely are applicable to other nations and in that respect are worth noting. Deficiencies include: poor definition of goals, objectives, and priorities; poor communication among professionals; generally undertrained professionals; lack of incentives to scientists due to failure to reward merit; failure to delegate authority; elaborate procurement procedures; time consuming procedures; lack of effective liaison among concerned governmental agencies; and, indeed, a lack of adequate research in the soil and water field.

To build research emphasis in this field at least some of these deficiencies must be removed. There must be change, procedures must be short-circuited, funds provided; and, most importantly, the farmer, the researcher, the extension specialist, the bureaucrat, and the politician must be aware that this is important and must take part in the "revolution."

Agriculture the world over is characterized by its extreme variability. Irrigated agriculture itself is a life style and in any one nation its development has been affected by the nation's history, culture law, public administration, area specific problems, and a host of other factors. National and regional research programs are greatly conditioned by the same factors.

The management of water in an irrigated agriculture represents a rather broad area of the production process, and research programs in developing nations take various approaches. Whatever "developing nation" denotes, we know that each has a unique set of problems and each is at a different stage of development in water management.

Perhaps the topic is so broad and so complicated that we are not sure where we are or where we want to go. One is reminded of Abraham Lincoln's cogent statement "if we only knew where we needed to go then we might be able to find our way." When we study any one nation's water management problems, we must first recognize our own limitations over a whole set of impinging factors over which we have little or no control. These include exogenous factors–war, flood, drought, famine, and endogenous conditions–political processes that control policy decisions, political instability, and a rapidly expanding population.

In Pakistan, for example, during the three years just past there have been many conditions which have frustrated our efforts to establish research activity. Political instability, the emotional shock of losing a significant portion of the country in a war, a soaring population which may be increasing at over 3.5 percent annually, labor unrest, prisoner-of-war problems, and finally a devastating flood have all contributed to development slow-down. Other problems such as a frozen bureaucratic system, a new administration inexperienced in planning and somewhat unaware of the importance of agricultural research, and our own bureaucratic sluggishness have not been conducive to a great amount of production in research.

A joint USDA-Land Grant University study in 1966[2] defined agricultural research as follows:

> Research in any field is the asking of carefully structured questions and the answering of those questions by precise methods of science. – In large measure (national and state) research agencies are in business to help achieve specific goals or targets that have been set by public agreement. To achieve such goals, we must know the factors and relationships that govern changes in the targets. To ask and answer the questions for each of our goals is in fact what research really is.

The environment of the developing nation does not completely fit this pattern because, at best, goals are

[1]Chief of Party. Colorado State University, Pakistan. The writer is indebted to Dr. Clyma, Agricultural Engineer, CSU Pakistan Project and Dr. Max Lowdermilk, Director, Agricultural Extension and Farmers Training Center; Mian Channu, Pakistan for their careful review and many suggestions in the preparation of this paper.

[2]A National Program of Research for Agriculture; Report of a study sponsored jointly by: Association of State Universities and Land Grant Colleges and U.S. Department of Agriculture, October 1966.

hazily defined. Research programs flounder because purposes are not clear. If we transplant our usual style and approach to research on this pattern we may also flounder. The "carefully structured questions" are missing. We see lots of problems and start answering our own questions; but, without care, the questions we answer may prove to be irrelevant questions. We seek solutions when we don't know the real problems. This trial and error process is mostly unfruitful because the solution is not usable unless it strikes at the real source of the underlying constraint causing poor management.

Problem Orientation and Identification

Regardless of how much we may know about water management, however much pressure there is to hurry and research a question–any question–and regardless of the constraints in our way; problem identification itself is a long term task. And far more time is needed to properly research the problem, record the results, and teach good technique along the way. Problem identification in water management requires that we can conceive the problems as the farmer sees them at the farm level. We must know what his problems are and also the particular constraints which confront the man who handles the water.

Inadequate cultivation, improper varieties, insufficient fertilizer, unleveled land, unimproved water channels all represent highly visible "malpractices." Yet, in general the farmer is aware that he is inadequate in these aspects and he has many valid reasons for managing the way he does. There is little opportunity to "experiment" when one operates at a subsistence level. In some cases he knows what to do but is financially unable. But in most cases he does not know how to proceed and at least feels he has no one to turn to for technical or financial help.

When one goes abroad for research he carries with him much knowledge perhaps but also some prejudice, prepossession, predilection, and even bias which have been created and conditioned by his own cultural and experience background. On any farmer's field he observes at least 20 things done wrong while producing one crop. These evaluations are correct but only in terms of his own criteria of what is right or what is wrong. If he would spend 6 months living with the farmer and observing how he does things from day to day he would undoubtedly find that 15 of the 20 things were in fact being done correctly in the sense that the farmer had no other reasonable choice given his particular constraints.

We must do research to identify key problems and certainly, in the broad field of water management, we must take the problem oriented approach to the research. This approach in general is totally unfamiliar to our counterparts as we ourselves have only recently given it proper perspective. We have little experience in problem identification research as such. Advisors present problems to students, industry presents problems to scientists, SCS presents problems to ARS, and more importantly the researcher can go to the field and receive information well articulated by the educated farmer who really knows the problem These sources and communicative channels are largely undeveloped in the developing country situation.

Water management practices are of poor quality over most of the world and every nation can improve; yet do we know why? There are many reasons and perhaps these are area and site-specific. A farmer in Colorado does not waste water for the same reasons that the farmer in the Punjab does, yet they both do.

In spite of the fact that on-farm water management is considered to be important to increased food production, there is little hard evidence that this is true. Where are the data from anywhere in the developing world which detail the effectiveness of farmer utilization of water–how much is actually available, when is it available, and how is it applied in relation to actual needs?

If problem identification is a constraining factor there must be reasons. Farmers themselves are rather independent and do not readily divulge information. This is true anywhere and when we go out of our own environment to study such problems we are, in the beginning, at a total loss. So we embark on a program of finding answers. It is a serious detriment if we continue to seek answers and forget to continue to search for the problems. I believe many, if not most, foreign assistance programs fall into this trap. There is a natural desire to produce something and be successful on a short-term basis. There is a reluctance to admit ignorance of the problem and the funding agency desires solutions which readily can be identified and hopefully programmed into a magic world-wide formula. What we are doing is worthwhile and interesting, but to be successful must be long range. There are no simple solutions. If it were easy to increase yields the farmer would do it without help. He makes intelligent decisions and when opportunity is there he takes advantage of it.

We need good information in order to identify farmer constraints and know his problems. Totally different cultural backgrounds form a wide chasm between those we seek information from and ourselves. Superstitions and religions play an important role. Being foreigners, we are buffered from the cold hard realities by our local friends; not to keep information from us but to make us comfortable. As one gathers data he also collects a great deal of non-data and misinformation. This aggravates the problem since some of this is retained and it becomes a point of misunderstanding in planning. Each expert gathers his information and misinformation and mixes it with his background experience to form his "mindset" on the problem. He is astonished, as he develops a solution, to learn that his colleagues with the apparent same information have developed different "mindsets" and different solutions.

If we research a problem which is not really a farmer problem he will not use the solution. Without good communication among farmers, between farmers and government, between farmer and researcher, and among researchers, no one is really conversant with any problem other than the overriding one of low yields. So, local committees, short-term consultants and high level official committees make recommendations on how to increase yields. No one follows through with implementation and the reports lie idle except for use as ready references for the next generation of committees and consultants.

For example, many detailed problem descriptive reports have been published in Pakistan using the same basic assumption that the farmers are doing a relatively good job of irrigating on a field by field basis and that the real problem lies in some other area. I see otherwise. Shultz's[3] "poor but efficient" theory may be correct but is only valid in a static or slowly developing situation and, in this particular case, needs challenging. All data gathered by Dr. Clyma to date in Pakistan indicate that the farmer is very inefficient with his scarce water resource. These data were collected by actual field and flow measurements.

Research on problem identification would appear, at best, to be an indirect attack and could be considered uninteresting and unattractive. However, I believe that until we spend a great deal of effort researching the problem we will do a great deal of wheel spinning and learning technologies which will not get adopted. It is natural to want to develop new technology. This is good but in many cases it does not answer the problem. The wrong problem was researched if the results are not adopted by the farmer, especially the smaller less privileged ones.

Technology Transfer and Adoption

Another constraining problem involves getting the so-called proven technology adopted or transferred. I consider a technology as unproven until it is adopted on some significant scale. With this definition, the research job in increasing food production does not end in the laboratory or at the experiment station.

Many technologies have been utilized to increase production in many areas. But, it does not follow that they can be proven and utilized everywhere. Quanats and persian wheels are proven water sources for thousands of acres yet we do not see many in use in the Western world. A technology which is not suited to a given area or a suitable one which is not adopted is of no value to that area. Yet, if we aren't careful we tend to associate technologies familiar to us with success even though they aren't being adopted.

Western society is imbued with the availability of a complicated communications system that permits ideas to go from conception to utilization, sometimes without research. An off-hand suggestion on a farmer's problem may become the basis for a new technology for that farmer. However, in most developing situations the transfer is not self-made. Some technologies transfer more readily than others but some are impossible with the constraints the farmer perceives. Some seemingly good simple practices could take years to transfer into a given situation.

Then, if some research should be in the problem identification area some also should take a form which allows ready adoption of treatments that prove themselves. This is not an easy assignment. The usual methods of research with which we are most familiar do not fit this style. Developing the technology of an experiment station and passing it to farmers through an extension service is generally the least desirable method. The research must sell itself. This can be facilitated by involving the farmer in the process, utilizing tools he is familiar with or that are available to him, and doing it in a manner which he can duplicate. If done properly with the right treatments, success can be measured in increased production because the farmers themselves will readily adopt any practice which makes them money without undue risk. When the farmer assists with the conduct of the experiments he experiences the procedures and results. This is one way to breach the communication gap, which may be very wide, between the researcher and the farmer. Sometimes it may be desirable to also involve non-research governmental agencies in the project.

This aspect cannot be over-emphasized. We are wasting our time if the technology itself is dependent on implements, institutions, systems, and procedures which are physically, economically, legally, or culturally unavailable. It is true that conditions change and at some point in time the technology may be acceptable but such esoteric adventures are not justifiable in the short run and may even be detrimental.

There is the possibility, however, of letting the research itself point the way to avoid, remove, or replace the bottlenecks so that the technology can be adopted. Proven practices being utilized in the developed world were discovered, refined, and implemented by some process. It is incorrect to assume that the same process will lead to success in other situations. The practice must be researched to define its degree of acceptability and discover its path to acceptance. There is no assurance that

[3]Theodore W. Schultz, **Transforming Traditional Agriculture.**

it can be utilized to its full potential and, through adaptation research, a less attractive version bent to fit the local condition may emerge.

The Local System and Implementation

The difficulty of the job begins to take proportion as we bring it into the local situation. Some of the research must be problem diagnostic and some of it needs to be problem oriented and accomplished in a manner which self-extends. This part of the work, then, tends to be site or country specific and it follows that it must be done in country.

The local system offers its own set of constraints. Some of these are peculiar to most developing situations and some are undoubtedly site-specific but the important thing is to learn to work within them.

Our own USAID and other technical assistance agencies have not had a good record in supporting research until recent years. Research that was undertaken tended to involve short duration projects. Most emphasis was placed on such things as community development or extension in agriculture. The technical assistance philosophy that technology could easily be transferred from the west and that research was not important has proved inaccurate. Effective research, the institutionalization of research, and the extension of results requires long-range plans and support.

Then, as we embark on research programs in farm water management, we are operating with institutions that have no experience in problem identification, interdisciplinary research, no concept of the team approach to research, and no concept that agriculture itself and research for agriculture requires a systems approach. Little is understood about the interrelated factors necessary for plant production. Problem oriented research is virtually unknown.

Institutionally, water management programs are frequently administered through agencies not having authority for other aspects of agricultural production. Often one administrative unit is responsible for water delivery, another for the agricultural production and extension phases and in some cases yet another responsible for the research. The usual lack of communication between such departments creates a void not easily breached. The lack of a participatory democracy makes it next to impossible for the farmer to get his problems before administrators, much less research institutes.

Generally there is no broad national policy of research or an awareness that problem oriented research is fruitful. Such systems leave vast areas of agricultural research neglected, including water management and soil and water conservation. Often in their place crop-specific programs have been developed to the point where a plant breeder is charged with the entire research program for a particular crop. In the sub-continent, the British interest in developing a few crops for export resulted in their research program developing along such lines. This vested interest approach to agricultural research has influenced today's priorities, since objectives have not greatly changed. Most technical assistance programs, even today, continue to foster this crop oriented attack. Regardless of its merits, such an approach affects programs like water management since they are neglected in such a system.

There is a paucity of protective, adaptive, problem oriented research in most developing countries. Few researchers even know what these types of research are, or why they are important. In general, applied research is not given the same status as basic research because it is not considered sophisticated. As one travels through the agricultural areas he notices the lack of attention to the practical field management of water. Even research workers have no idea of the amount of water applied to their research plots, of the moisture fluctuations within the root zone or, for that matter, the extent of the root zone. Many have scant working knowledge of plant-water-soil relationships. Apparently water is not looked upon as a manageable factor of production and yet one finds rather basic research being pursued. Educational systems which place supreme importance on memory and give almost no emphasis to problem conceptualization and solving are not conducive to development of technicians qualified in research problem definition and research methodology.

The researcher, just as the farmer, makes his decisions and does his work in a manner dictated by his constraints. He makes rational decisions and in general is doing his job properly given those constraints. If we are to use his talents and I believe we must, then we have to learn his constraints and help him within that framework. In general money and equipment alone will not increase his production because generally this is not his most serious constraint. His concepts for defining the most important problems and the procedures he uses to conduct his research must be improved to result in viable, relevant research programs.

Lack of professionalism and low quality of research and research reporting can usually be traced to lack of incentives, poor salaries, and political instability. This discouraging constraint requires that we work closely, in the field, with counterparts so they learn to appreciate the necessity of good quality data. I believe there is no other way and here again the process is frought with disappointment and delays. There has been evidence, however, that this approach can be successful. High quality, energetic, productive research teams can be organized, educated, and implemented.

These factors represent only some of the constraints one faces in developing integrated research programs on a problem oriented basis. They are not insurmountable, but must be considered and carefully programmed into every phase of the work.

Summary

The constraining problems are great. The job is not easy. Programs must be long-ranged. The probability of success in every phase is almost zero. But the pay-off is high. There is little doubt that a successful program of soil and water management could relieve food shortages throughout the world. Though not the only input to crop production, soil and water management must be improved before satisfactory results can be achieved from improvement of the others. Research combining all inputs is worthy of consideration.

The work must be accomplished within a system which is not familiar with integrated, interdisciplinary, problem oriented programs and one in which the very subject matter of the effort has been neglected. And yet, the programs must be wholeheartedly accepted locally or failure is inevitable.

The promotion of the program carries its own constraints and can be a frustrating, time consuming, discouraging yet thrilling experience. Techniques of such promotion are beyond the scope of this paper but I believe it to be a highly personalized endeavor which requires time, patience, and a degree of unselfishness. Researchers must be encouraged and assisted in the field conduct of experiments. Administrators must be educated to the farmer's problems.

Disappointments occur after the program is launched. If promotion is difficult, implementation is next to impossible. It is relatively easy to discuss procedures and project details in the comforts of the office. Agreement on responsibilities can readily be sorted and an apparently successful program is launched. During implementation the frustrating constraints surface. These are associated with the cultural, bureaucratic, political, human, and personality differences between ourselves and the local system. The frustrations are almost all on our side and therefore great patience is called for. One would hope the work could proceed smoothly since careful planning has paved the way. The simplest of detail will cause apparently uncalled for delays and patiences are strained. Since most frustrations are caused by schedule delays, the planning was incorrect. Most time schedules, when initiating a new program, need to be extended by a factor of at least two. The Eastern culture places little importance on the time factor. People in that culture are more interested in development of human relationships. We value time—they value people. This is a constraint which we alone must remove.

Any need for immediate answers places a restriction which cannot be successfully met. And if we devote full time to this constraint the end product is not increased production but verbiage; reports, papers, reviews, plans, and specifications written for each other. One is in a dilemma—planning and coordinating a world-wide research program which develops readily adaptable technology could be the wrong emphasis. Research results are of no value unless adopted. Adoption of new technology by a substantial number of farmers is a highly site-specific, personalized, time consuming, human adventure.

3.

SOME CONSTRAINTS IN THE IMPLEMENTATION OF WATER MANAGEMENT PROGRAMS IN CANAL IRRIGATED AREAS

B. B. Vohra[1]

1. Lack of adequate cost-benefit consciousness

Very large sums of money--amounting to nearly Rs. 3000 crores ($4000 million)--have been invested in big surface irrigation projects in India during the last 22 years. It is, however, being realized that the community is not obtaining the full benefits which these projects were expected to yield.

A hard-headed look at the performance of our irrigation projects leads to the inescapable conclusion that the main reason why additional production has not been achieved to the expected extent is the poor level of water management in their commands. The improvement of water mangement would however require large additional investments in existing command areas and these would, to a certain extent at least, have to be met at the cost of investments in new projects. If there was sufficient consciousness of the need to obtain early and adequate returns from investments in irrigation, water management programs would receive high priority. It is a heartening development that such consciousness has not only emerged but has begun to assert itself in India. Thus the Fifth Plan provides for as much as Rs. 300 crores ($400 million) for being spent on water management programs *out of Irrigation Department budgets alone.* In addition, provision is being made for at least Rs. 300 crores ($400 million) to be spent on such programs out of Agricultural Department budgets and institutional funds.

2. Lack of adequate resource consciousness

Poor water management practices involve a considerable loss of our basic resources of both land and water. The absence of drainage, coupled with heavy seepage losses from unlined distribution systems and the excess application of irrigation water can result in serious damage to the land by waterlogging and salinization. At the same time, the absence of proper delivery systems (which should be capable of reducing seepage losses to the minimum and delivering water to each field in the quantity in which it is required and at the time at which it is required) and the failure to level and shape irrigated lands in a proper manner results in the wastage of a great deal of water which has been impounded at a high cost to the community.

If there was a greater concern for the optimum utilization of our limited resources of both land and water, there would be an automatic demand for improved water management. It is a gratifying development that such concern is beginning to be felt not only by policy-makers within the government but also by many leaders of public opinion in the country.

3. Gaps in organization

For historical reasons, there has been up till now no organization specifically charged with the responsibility for the proper management of irrigation waters. The responsibility of State Irrigation Departments has traditionally ended with the construction of the reservoirs and the main distribution systems up to the "outlet" which may command a block of between 40 to 200 hectares in area. The construction of water courses beyond the outlet, as well as of field drains, where necessary, and the shaping of land for irrigation has, by implication, been the responsibility of farmers with such assistance as the State Agriculture Departments may be able to give them. However, not all State Agriculture Departments are fully equipped to undertake this work. Field drainage can, in any case, not be attempted unless it forms part of a total drainage plan which would involve the construction of main and intermediate drains by State Irrigation Departments.

This organizational gap is being sought to be filled by the creation of appropriate new organizations at the Central as well as State and Command Area levels as has been described in my other paper (Chapter V). Such organizations however take time to build and cannot be created overnight.

The creation of the proposed new organizations which are necessarily multi-disciplinary in nature will bring the irrigation and agriculture departments into a close working relationship This development is bound to create its own dynamic and will certainly lead to the end of the comparative isolation in which irrigation departments have tended to work in the past. Already the planning of new irrigation projects is being done in close consultation with agriculture departments which supply information with regard to soils and desirable cropping patterns in the areas which will be brought under

[1]Joint Secretary to the Ministry of Agriculture Government of India, New Delhi.

irrigation. It is not difficult to visualize a stage when the departments of agriculture and irrigation will form part of the same Ministry both at the Centre and in the States.

4. Inadequacy of design data

Improved water management requires that reliable and sufficiently detailed information should be available with regard to such matters as the nature of local soils, the topography of the land, the water requirements of various crops in the given climatic conditions and the feasibility of supplemental irrigation from groundwater sources. Without such information being available, it is not possible to undertake the designing of rational water delivery and water removal systems or to determine the manner in which the land should be levelled and shaped.

The collection of such data through surveys and investigations naturally takes time to organize.

5. Lack of trained personnel

Very large numbers of technicians belonging to various disciplines such as soils, topographical surveys, agronomy, agricultural engineering, irrigation and drainage engineering, and extension are needed to take up water management programs on a large scale It takes time to recruit and train such people, particularly under field conditions.

On-farm and drainage works also require a great deal of machinery which has to be obtained and entrusted to trained operators in accordance with carefully planned and time-bound programs. This also takes time to organize.

6. Enlisting the cooperation of the farmer

In the ultimate analysis, water management programs can succeed only when they have the full backing of the farmer who must be convinced that he will obtain adequate benefits in return for the money that he is being asked to spend on on-farm works. The farmer may also be expected to accept a change in the cropping pattern–e.g., from paddy to dry crops–in the overall interests of better water utilization in the command. Again, he may be required to sacrifice one winter crop in order to provide a longer working season to construction engineers who can operate only during the dry winter months.

This underlines the need for setting up pilot projects and demonstrations so that the farmer may see for himself the benefits of the works and practices which are being recommended to him. The organization of an efficient extension service is also necessary for obvious reasons.

It is envizaged that it may be ultimately possible to entrust a great deal of responsibility for improved water management including the execution of on-farm works to associations of farmers on a distributary basis once they are sold to the idea.

7. Lack of financial resources

It has been estimated that an amount at least equal to what has been invested in the construction of reservoirs and the main distribution systems of our irrigation projects will be needed to carry out the drainage, improved delivery, and on-farm works required for improved water management in our command areas. However, since it is difficult to organize water management programs and to spend money on them at anything like the same pace at which it can be spent on major engineering works, such programs will necessarily have to be phased out over a fairly long period of time. Accordingly the lack of financial resources is not likely to prove as important a constraint in actual fact as it might appear to be at first sight.

One way of overcoming normal budgetary constraints is to utilize loan funds to the maximum extent possible. However, not only is there a limit to what the farmer can afford to pay for water management works but there is also the question whether there can be any justification for asking him to pay for anything except on-farm works. In view of these considerations, it is felt that while the maximum advantage should be taken of institutional finance for on-farm works in the Fifth Plan, the Departments concerned should be expected to bear the cost of works and services for which they are traditionally responsible. According to this view, the irrigation departments should foot the bill for improved water management above the "outlet" and for intermediate and main drains, while agriculture departments should bear the cost of surveys, investigations, pilot projects, extension and research, etc.

In this connection, the great interest that the World Bank has begun to take in water management and command area development programs needs to be noted as a most welcome development.

4.

CONSTRAINTS TO PROJECT DEVELOPMENT IN LATIN AMERICA

WHAT ARE THE CONSTRAINING PROBLEMS?

Arturo Cornejo [1]

The points of view that I am going to present are personal ones and reflect my experience which mainly has been gained in Peru and other countries of Latin America.

To identify the constraints problems, I will use the three framework categories recommended by the organizers of the symposium, but in a different order.

A. The institutional framework.

B. The economic framework.

C. The physical and biological framework.

Before discussing the constraints let me state two facts:

1. The poorest farmers in Latin America are not in the irrigated areas. They are living or surviving in rainfed agricultural areas.

2. In irrigated agriculture we distinguish three categories of problem areas:

a. Lands that are going to be irrigated and for which we have good facilities available for the design, construction, selection, and organization of the farmers so that the system will operate properly;
b. Lands that are already irrigated by old systems with rather low efficiency and that need to be reorganized;
c. Irrigated areas with very small holdings which need concentration or aggregation of the holdings and organization of the farmers before anything can be done to improve the water-use efficiency. The most difficult problems are within this group. The small holdings means that there is already population pressure on the land and, many times, transplanting of families to other areas is needed to improve the standard of living for all of them.

Institutional Constraints

In a society like Peru, where in 1960 about 55 percent of the population lived in rural areas and 5 percent of the farmers owned 70 percent of the best land and almost all water rights, no significant changes can be made without revising these structural constraints. To remove the structural constraints two laws have been passed:

a. To reorganize the tenency of the land, and

b. A water law.

The water law states that all water is owned by the nation and the nation grants the use of the water on condition that it will be used properly.

Reorganization of the Public Administration

All institutions that deal with agriculture are organized under the command of the Ministry of Agriculture. The design, construction and operation of irrigation systems were placed under the Ministry of Agriculture. For Peru this is good because 85 percent of the water which we can control is used in agricultural production.

Clear Lines of Policy Have to be Stated

We have a National Institute of Planning and we are in the midst of a second five-year plan that will terminate in 1975. The government budget covers two-year periods. The policy in agriculture, besides completing the structural changes by 1975, is to increase food production. Our statistics show that in 1950, 60 percent of our foreign exchange came from exporting agricultural products and that we imported about 10 percent of the food we needed. Therefore, in 1950, agriculture was our main source of foreign exchange. In 1971 the agricultural exports amounted to 30 percent of our foreign income and we expended 28 percent of this income in importing foods. Therefore, the decision was taken to improve food production and we have worked a national crops plan that includes 18 food crops to which special incentives in credits, prices and so on, are given so farmers will produce more. With respect to water management, the following lines of policies and priorities have been set:

a. Organization of irrigation districts.

b. Organization of water users within the irrigation districts and incorporation of them into the decision-making process of improving the operation and maintenance of the irrigation district.

[1] Director General de Aguas, Ministry of Agriculture. Lima, Peru

c. Organizing irrigation water charges so all users have to pay for the water they use. We have organized a Department of Water Economic Studies and AID is helping by providing one expert in this area.

d. Training of personnel to operate the irrigation districts. We are using all facilities we can identify to train personnel. Our own experts, university professors, foreign aid, and so on are being drawn upon. AID is helping us in this effort by paying the expenses of eight engineers. Over a two-year period these are being sent for three months of "on-the-job-training" in the irrigation districts of North-west Mexico.

In relation to the training of personnel, I agree with Jack Keller that developing countries need to train personnel at all levels, scientists (to be trained mainly in the universities and research stations), engineers, technicians, and farmers. If we don't do that, constraints will be created all along the line. The only thing that needs to be specified is how to do the training, where to do it, and in what university, research center, or irrigation district. My impression is that every effort should be given to do most of the training in the home country.

International Cooperation

In the Ministry of Agriculture we have organized an Office of International Cooperation to get some order in this matter and to obtain the international assistance we need according to our priorities rather than what is offered to us. This may have increased the red tape a little, but is proving to be useful.

The Economic Constraints

From the above presentation you can conclude that our present goal is to improve the existing conditions in the irrigation districts as much as we can by removing structural constraints and setting up an organization where the farmers are represented before going into the big expenses of construction of new irrigation schemes. The rehabilitation of old irrigation schemes and especially the construction of new ones is a very costly undertaking under Peruvian conditions. The average estimated investment in four new irrigation schemes for which we have prepared feasibility studies is U.S. $3,000/ha, for construction and development with a five-year construction period. The composition of the investment is 50 to 60 percent foreign exchange which we must borrow from international lending institutions or from the private or state credit institutions of other countries.

We also are developing small and medium irrigation schemes (500 to 5,000 ha) in the highlands of Peru. The money was provided by the Inter-American Bank and we were able to include as part of the project the training of personnel. The Inter-American Bank loaned money to Mexico in 1971 to develop a plan to improve on-farm water management that included setting up facilities for training engineers, technicians, and farmers, setting up demonstration fields on the lands of different farmers having low efficiency of irrigation application; and to develop an organization for irrigation extension in the irrigation districts. The program so far has proven to be very successful. This is a practical means of helping to improve on-farm water management.

Another point I want to stress under "economic constraints" is the need to find economic indicators so that a proper value is given to items that are hard to evaluate in monetary terms; for example, the training of personnel. In 1960 we obtained a loan from the World Bank to develop a new irrigation scheme of 40,000 ha, called San Lorenzo. Finally, we developed 30,000 ha and the actual benefit/cost ratio of the project is around 1.0. This indicator doesn't consider the fact that almost all of the staff of the Ministry of Agriculture, that directs the new organization, did work for several years in San Lorenzo or received their practical training there.

In the economic framework, the policy of our government is to provide the main works for irrigation schemes, including the drainage systems, part of which will be paid for by the users via water charges. The on-farm development is totally paid by the farmer and the government provides the credit and the technical assistance. Only last August, after five years of negotiations, we obtained a $20 million loan from the World Bank for credit to farmers.

The Physical and Biological Constraints

My impression is that the condition of the developing countries in part is because of geophysical (physical) constraints. That is the case in Peru and other Latin American countries where the Andes form a formidable barrier and all projects especially irrigation projects are very costly.

Lack of good basic information, poor studies, designs, and construction cause many physical constraints to be built into the irrigation projects. These need to be removed, after proper evaluation, in order to increase the possibilities for improving on-farm water management. Irrigation, in simple words, is to control water in order to use it in agricultural production. When we have better control of the water we can use it better, with greater efficiency. To control water we need water structures that are simple, and easy to design and operate. I think these are some of the main constraints that have to be removed to improve on-farm water management. The farmers then will have to make their own decisions and we have to assist them as much as we can. My personal experience is that they are independent people and can really "raise hell" and have the power to change the things they feel are not good for them.

The thing I have been trying to point out is that when we put together the three main frameworks that we have been talking about--the physical and biological, the economic, and the institutional framework--the whole matter becomes site-specific, and I believe that a good starting point to help solve the problems is to listen carefully to the persons that have lived with them and then use the basic and general knowledge gained in basic research to help solve the problems.

5.

CONSTRAINTS ON THE TRANSFER OF RESEARCH RESULTS

D. F. Peterson[1]

Introduction

As Dr. Kelley has mentioned, AID has a program of centrally-funded research. This is not AID's total research program, because research is also supported with funds allocated to country missions. A criterion for centrally-funded research eligibility is that the research be generalizable, i.e., be capable of extension to applications regionally or globally. Thus, an important item of concern to those conducting centrally-funded research is its *transferability*. A second question is what kinds of research AID, principally a bi-lateral donor, can best undertake in contrast to that which might be done by other agencies. A stated objective of AID's program is to help increase the world's supply of food, and this is a major consideration in its research program.

At the risk of being simplistic, I would like to divide research in on-farm water management into two great classes. These classes apply equally to rainfed and irrigation agriculture. I define research very broadly as study which leads to new knowledge, whether it is site-specific or general. The two classes proposed are:

I. Research on crop production and resource conservation as related to intimate crop environments and on the development of technology to modify or optimize those environments.

II. Research on *systems of delivery* that make available the wherewithal (e.g., resources, know how, inputs, markets, incentives, etc.) to modify water management practices or to optimally utilize moisture environments.

Research of the first class is quite common. Except for hydraulics and economics, the second class is frequently regarded as not researchable. This is unfortunate, because it seems like this is the area where a substantial share of the immediate problems lie.

Class I. Crop Production and Conservation

A systematic approach is needed

Crop production depends upon the genetic material used and the characteristics of the intimate environment in which the crop grows. Transferability of research for a particular genetic material depends upon how well the intimate crop environment involved is identified and characterized. If we have this information for several environmental regimes and we can measure these same variables at some other place or predict how they might be modified, then we should be able to predict crop productivity, water use, and other optimal inputs at the new site. Transferability could be increased by taking into account basic scientific principles of climatology, plant physiology, and soil science. We need to know the variance of the intimate environment in the time dimension as well as in space. Probably thousands of experiments are being conducted on crop productivity. Probably relatively few of the results are very transferable except by subjective expertise because adequate measurements of environmental and genetic characteristics are not made or recorded. What we are probably really doing is running productivity experiments as integrated indicators of local environments.

Is not now the time to think about a more systematic and formal approach to the matter of transferability of production research information? Would it not be desirable to run a smaller number of comprehensive experiments formulated to fit into a designed information transfer system? Besides reducing the number of field trials there could be other advantages. Generalized information, systematically arranged, could more likely point the way to substantial breakthroughs in plant breeding, water management technology, etc. Basic principles of plant physiology as well as multi-dimensional interpolation could be utilized to make predictions for new sites. Such a system could lead to better project planning and policy formulations because more accurate predictions could be made in advance of field trials, etc., which take time. Also, resource inventories would be less likely to overlook important resource considerations. The question is whether or not a reasonably complete and relevant set of standardized environmental indicators can be identified or if the matter would be so complex that it would be incomprehensible.

I understand that FAO, USDA, and others have cooperated on a computerized information system for animal nutrition that is effective. A crop productivity system would be much more complex, but we should be encouraged by the success of the one on animal nutrition.

Need for resource conservation research

Similar considerations might also be given to systematic transfer of information relating to insuring resource conservation such as preventing soil erosion,

[1] Vice President for Research and Professor of Engineering, Utah State University, Logan, Utah.

water logging, salinity etc. At some point it may be worthwhile to hold a symposium oriented to the conservation of agricultural water and land resources.

Transfer of technology

Transfer of technology may be a rather different matter than information on productivity and conservation. Probably our problem now is that technology transfer is not given *enough* site-specific consideration.

AID's role

AID centrally-funded research ought to have a significant role in Class I research. Relevant information *can* be obtained under bi-lateral arrangements. I think that the United States has expertise and resources that can be extremely useful in the general arena of on-farm water management throughout the world. However, the notion of systematic transferability does imply the development of global and regional networks of experimental stations and generalized systems of information transfer that are also basically global, although these might have regional subsystems based on regional ecological differences. AID should be able to join with other nations and international agencies toward a program having such an objective.

Class II. Delivery Systems

Quite clearly a farmer is not going to change without change in the social context in which he lives. In other words, society must deliver[2] something new to him if he is to change. What is delivered may not necessarily be physical. It could be information or incentives. The system could be informal, for example, simply obtaining information in the market place about prices or from neighbors about new practices. Under the heading "delivery systems" are included the whole spectrum of transfer processes that impinge on the farmer. They include what has commonly been called "infrastructure." The spectrum ranges from passing of information by word-of mouth to sophisticated physical systems of dams and canals delivering water to formulation and implementation of policy at project, national, and, even, international levels. These systems are bound to be somewhat "culture-specific" although some may be less so than others. Those delivery systems that are "software"[3] oriented rather thar physical are apt to be the most culture-specific. Because these are "systems" does not mean they are not researchable. But, because they are culture-specific it is necessary that responsible leaders of the concerned cultures or countries be involved in the planning and formulation of research techniques and plans.

A great part of the discussion of this Symposium has centered around the problem of getting delivery systems to function adequately. It is doubtful if problems of this kind, which seem to be constraining, will be solved by research on crop productivity and technology alone.

Need for international centers

There are good arguments that lead to the conclusion that "delivery systems" research needs a strong international dimension. It must, usually, have status beyond that which a single country can give it. My own experience with the NESA seminars[4] also convinces me that there is indeed transferability of delivery systems concepts, especially among developing countries. The argument that country leaders need to be involved in the planning, and that a supra-national institution is needed, support the argument that the cutting edge for research oriented to "delivery systems" needs to be the international center. In the field of "on-farm water management" there are large regions having general ecological or climatic similarity that provide a rather logical basis for regionalization. Regional centers should be supported by a global center providing general information and support, but this global center might be relatively less formally organized than the regional ones and the elements of it may already be partly in existence. Such a regional center probably would not directly do Class I research at all. It could serve an important auxiliary function in the transfer of Class I information, it could help coordinate the region's Class I research and it could help identify the most logical and competent existing institutions to do such needed Class I research at the level of generality needed.

A different research approach is needed

One of the apparent obstacles to the concept of regional "on-farm water management" centers along the lines outlined above is the classicist approach to research which has, properly, dominated agronomic research and, apparently, but maybe not so properly, the social sciences. Present experts, mostly biologists, cannot visualize how the classicist methodology founded on physics is going to work. I don't see how it will either. But I don't think this is a good reason to decide against doing research on delivery systems. Perhaps a better methodological approach may lie in a direction pointed by Joseph Ben David.[5] Ben David's article contains a number of fairly complicated ideas, but its general theme is that the

[2] I include "going and getting it" as part of "delivery." This requires that "it" be available.

[3] That is those that evolve policy, develop institutions, etc., in contrast to transferring physical things such as water

[4] NESA Irrigation Practices Seminars 1956-1970. An evaluation. USAID. Washington, D.C. 1973

[5] How to Organize Research in the Social Sciences. *Daedelus*, February 1973.

"physics" model has not been particularly productive in social science and that research techniques used in "clinical medicine and engineering" would be more appropriate; that is, "emphasis should be placed on explaining particular events with the aid of general principles in contrast to establishing generally valid rules or principles." This implies a case history approach and the use of "more or less empirically grounded and partly intuitive explanatory models constantly checked and refined against empirical evidence."

So much for Ben David. I think that at least one regional center, with a small carefully-selected staff, working with country leaders in developing the center's research program, should be tried. If properly staffed and managed such a center could possibly prove very useful in unraveling the complexities involved in the "delivery systems" aspects of on-farm water management. Whether or not the World Consultative Group will find an appeal in this, I don't know. If they do, AID could play an important donor and leadership role in such an activity.

CHAPTER VIII

AID'S PROGRAM OF CENTRALLY FUNDED RESEARCH

I.

INTRODUCTION

S. H. Krashevski [1]

About one and a half years ago the direction of U.S. foreign assistance underwent considerable reorientation. At that time AID administrator. Dr. John Hanna, issued a policy declaring that the central theme of AID's program is emphasis on humanitarian assistance to the developing countries. This, of course, means that assistance to the developing countries will concentrate on improving the quality of life of the broadest spectrum of population, i.e., emphasis must be given to the poorest of the poor.

The so-called "new look of AID" indicates that U.S. humanitarian assistance will concentrate on health delivery systems, nutrition and food production, and education.

Another direction of the AID administrator's policy with respect to humanitarian assistance is the concept of a "collaborative style of operation." This indicates that AID assistance to LDC's will be based upon consideration and evaluation of proposals from the developing countries themselves. The developing country's requests for assistance will be evaluated and determination made if AID or U.S. contractors have the capability to deliver and if the priorities of global assistance will permit funding.

AID's Central Research

In 1966 AID received the authority from the U.S. Congress to conduct research on development problems facing more than one developing country. Since the funds allocated for those activities are rather meager, AID decided to support, with its central funds, research that is innovative, transferable, and impact-producing.

The centrally-funded research is administered by the Technical Assistance Bureau (TAB). Presently TAB supports research in the following fields. Agriculture, health, education, science and technology, nutrition, social science, and economics.

The Congressional ceiling for centrally-funded research is set at $9 million per year.

It is interesting to note that the significance of agriculture is recognized by AID. This is evidenced by the fact that agriculture is receiving about 60 percent of the total funds allocated to central research.

Grants to Increase Competency of U.S. Institutions

The Foreign Assistance Act of 1966, section 211(d), authorizes AID to grant funds to U.S. institutions to develop, or increase the institution's competency in a field in which AID determines that it may need help in implementing its assistance to the developing countries. The majority of these 211(d) grants have been in various fields of agriculture, although in recent years other areas are receiving increased attention and consequently more grants are being made outside of agriculture.

In agricultural water management. AID's program of centrally-funded research includes research contracts with Colorado State University, emphasizing work in Pakistan, and with Utah State University covering Latin America. Development grants have been awarded to University of Arizona, Colorado State University, and Utah State University. Today's session will examine this program of work.

[1] Senior Research and Grant Advisor, and Program Analyst. U.S. Agency for International Development, Technical Assistance Bureau Washington, D.C.

2.

THE UNIVERSITY OF ARIZONA'S AID 211(d) PROGRAM

Martin M. Fogel and David B. Thorud

In determining the optimum utilization of water resources for agriculture, watershed management represents the link in the overall natural resource system between the agricultural sector and the water source area. Development, assessment, and management of the land and water resources to obtain an optimal solution must consider the entire system. Water, which touches all bases, from its source to its use and to its eventual disposal is the medium that links the system together. Working on one aspect of this transient resource without consideration of possible effects on other components of the system can lead to serious consequences. The current concern for the environment in countries at all stages of development is testimony to this statement. The University of Arizona, under the leadership of the Department of Watershed Management, recognizes this worldwide concern and has addressed its activities towards providing solutions to the physical, economic, and social problems which characterize man's battle against drought, flood, and pollution.

The use of systems analysis presents the planners and designers of water resources systems with techniques for obtaining optimal solutions. These techniques with their inherent computer-based methods are employed as an aid in the decision-making process as it combines quantitative analysis and economic concepts into system design and evaluation. With the 211(d) grant, the University of Arizona has expanded its program of applied research and teaching in the area of systems analysis in watershed management.

General Background and Purpose of Grant

A firmly established concept states that improved water management is an essential element for increasing the agricultural productivity throughout the world. Reports have shown that 60 percent of the world's arable lands are deficient in soil moisture during all or some part of the growing season. A large share of the remainder suffer from floods and lack of drainage.

Water management in agriculture can be viewed as the development, processing, storage, transportation, and utilization of a raw material, namely water, for increasing food production. Producing a lasting and efficient system for accomplishing this overall objective requires that *all* segments of water-based activities be integrated into a common plan. Thus, CUSUSWASH has developed a coordinated program in water management for agricultural production. While Utah State University looks at the practices involving the utilization of water, Colorado State University delves into the problems relating to the storage and transportation of water. At the same time, the University of Arizona is concerned with the development, processing and storage of this vital resource, or the *watershed management* phase of the system.

Watershed management is generally defined as the management of the natural resources of a drainage basin primarily for the production and protection of water supplies and water-based resources, including the control of erosion and floods, and the protection of esthetic values associated with water. The University of Arizona is one of only a few institutions in the orld that has attempted to develop a coordinated effort in the management of this important natural resource. A little more than a decade ago, the Department of Watershed Management was established to bring together programs with a common interest in the management of water on the non-cultivated areas, the lands which supply the adjacent agricultural lands with a major portion of its water. Watershed management is a complex art that is decidedly interdisciplinary in nature. It involves the development and use of hydrologic simulation models, establishing functional relationships between land management methods and hydrologic processes, and also the techniques of systems analysis which seek to integrate the power of quantitative analysis with the concepts of economic theory. With water management systems becoming increasingly complex, so are the procedures which address themselves to the fundamental issue of design and management, that of specifying how men, money, and material should be combined to achieve a larger purpose. This is an area where the grant is having a large impact, that is, in the area of watershed management with special emphasis on the science and methodology of applying systems analyses techniques to problems of less developed countries.

Specific Objectives of the Grant

The University of Arizona through the Department of Watershed Management, in cooperation with supporting departments in the Colleges of Agriculture, Earth Sciences and Engineering contain a nucleus upon which to build an increased competency in research, education,

[1]Professor and Head of the Department of Watershed Management, University of Arizona, Tucson, Arizona.

and consultation within its area of responsibility, namely, watershed systems. Specifically, the objectives of the University of Arizona program are:

1. Expand its professional staff in Watershed Management with faculty members who are specifically involved in hydrologic modeling and the utilization of systems analysis techniques in watershed management activities.

2. Expand the graduate student research training program and activities related to the needs of developing countries.

3. Expand and modify course offerings concerned with water management in agriculture especially as related to emerging nations.

4. Expand and initiate special activities such as seminars, exchange programs, institutes, conferences, publications and other programs of interaction which will help establish continuous and effective lines of communication between the University of Arizona and the less developed countries.

5. Strengthen its capability to serve in advisory and consulting capacity through foreign travel and study by faculty members.

6. Improve its understanding of the type of problems encountered in the less developed countries, including the socio-politico aspects relating to the development and management of watershed systems.

Review of Objectives

While the objectives of the grant have, in general, remained as stated above, certain activities have been emphasized. These activities are listed under the objectives which have been regrouped as follows:

Improvement of research capability

The objectives included are:

a. *Hydrologic model building:* The development, modification, and quantification of relationships that describe the hydrologic processes occurring on watersheds and predict the effects of land management practices on the watershed system.

b. *Decision-making models:* The adaptation of relevant management techniques to actual problems encountered in the management of natural resources.

Improvement of teaching capability

a. *Computer assisted resource education system (CARES):* To instruct in the area of watershed management utilizing systems analysis techniques, computer based methods are essential not only to reduce the computational burdens, but also to provide the manager with freedom to exercise his creative abilities. The development of a computer-assisted instruction (CAI) program is a logical extension of the University of Arizona's effort to increase its research and teaching capability.

b. *Electric analog watershed model:* Another training aid that is being developed to assist in the instruction of resource management is a Passive Electronic Watershed Model.

c. *Course development:* New courses have been added and existing ones have been restructured to incorporate the aims of the grant.

Increase consulting competence

Foreign travel and study is the principal activity in which the University of Arizona improves its consulting capability.

Expansion of special activities

These activities may include the organization of seminars, institutes, conferences, exchange program or other programs that stimulate interaction between the University of Arizona and developing nations. The development of a library which will include bibliographies and abstracts as well as the acquisition of pertinent publications will be a major activity reported in this section.

Accomplishments

To meet the objectives of the grant, the University of Arizona has expanded its program of applied research and teaching in the subject matter area of systems analysis in watershed management. With the grant supporting additional faculty members, an enhanced capability for performing consulting services to developing countries has resulted. Criteria for measuring the effectiveness of the University's program are difficult to come by as numbers (additional faculty, graduate students supported, consulting trips, etc.) are often meaningless. Suffice to say, the University of Arizona has met every known request for technical assistance with professional expertise, is in the process of training competent professionals with an eye towards foreign service, is actively engaged in increasing its circle of influence, and stands ready to meet future challenges. The statements that follow are a presentation of the University's accomplishments during the last year.

and we suggest that these efforts represent a solid contribution.

Improvement of research capability

As pointed out previously, research efforts have centered around two broad categories, e.g., modeling of hydrologic systems and the development of management techniques applicable to water and other natural resources.

1. *Modeling hydrologic systems.* A total of six faculty members in three College of Agriculture Departments (Watershed Management, Soils, Water and Engineering; Agronomy and Plant Genetics) and in the Departments of Hydrology and Water Resources, and Systems and Industrial Engineering have been involved in related projects One subject matter area receiving considerable attention is the development of probablistic or stochastic models of precipitation and streamflow A goal here is to improve on methods for extrapolating point source data to areas where data are limited or unavailable. Managing an irrigation project or similar hydrologic system requires the best estimates of an available water supply and associated risks if the demands are not met.

Another subject area includes projects concerned with maximizing efficiency of water use in both irrigated and rainfed agriculture. Specific topics included determination of consumptive water-use efficiency for selected crops and development of a rainfall multiplication process for dryland farming in semi-arid regions.

Out of a total of five graduate students working in this subject matter area and supported by the 211(d) Grant during the past year, two have completed their objectives. Their efforts have resulted in a Ph.D. dissertation entitled, "Analysis and Application of a Passive Electronic Analog Model to the Hydrologic Regime of a Watershed," and a Master's thesis "Parameter Optimization for Simulating Semi-arid Watershed Hydrology."

Publications completed during the past year are listed at the end of this report.

2. *Management techniques.* Fundamental to the development and management of a region's land and water resources is a means for identifying, appraising and monitoring these resources and associated environmental processes. It is usually accepted that remote sensing has a great potential for becoming an important tool of the resource manager. As a consequence, the Watershed Management Department has initiated the development of a Remote Sensing Laboratory which will be equipped to handle a wide range of activities from routine aerial photo work to automatic data processing for analyzing satellite imagery in a digital format at a much higher resolution than possible with photos.

In progress this past year are two doctoral dissertations that are concerned with the decision-making process in the management of natural resources. One is investigating the use of systems analysis to arrive at the optimal investment for watershed development considering ecological and social constraints. Another is looking at the various uncertainties in meteorologic inputs, in input-output relations, and in parameter estimation, to develop a technique that will provide a meaningful transition from inventories to decisions. Decisions developed in this manner will enable the resource manager to base his programs on a quantified interpretation of inventory data. Two research papers on the use of Bayesian decision analysis were presented during the past year. This effort has implications for the design of water control structures especially those confronted with inadequate hydrologic data, which is often the case in developing nations. Another paper was prepared that concerned itself with the use of cost-effectiveness methodology to evaluate water resources systems in developing countries. The use of interactive multi-objective decision making under uncertainty was explored in still another research effort.

Improvement of teaching capability

Increasing the instructional competency of the University of Arizona has been directed towards two activities, developing a computer-oriented instruction program in resource management and in the development of applicable courses.

1 *Computer assisted instruction (CAI).* Partially supported by the 211(d) program, a doctoral candidate completed his work this past year and will be added to the Watershed Management faculty to direct the new Remote Sensing Laboratory. The title of his dissertation is "A CAI Language for Mini-Computers with Sample Dialogue and Problems Relating to Physics and Wildland Hydrology." CAI is ideally suited for training in the use of systems analysis in watershed management since most of these techniques requires the use of computers. Thus, training is accomplished using a tool that will also be used as an operational device which allows students to gain experience and confidence in the use of computers. Mini-computers are relatively inexpensive and can be used for both research and teaching. Another advantage of CAI is that it is a relatively simple matter to convert from English to a foreign language. To illustrate, the doctoral dissertation completed this year contains a CAI program in Spanish.

2. *Course development.* A new course concerned with land rehabilitation is in the process of being prepared. The course deals with water and wind erosion, sedimentation, revegetation, and site stabilization. A new graduate student, a Peace Corps volunteer returned from Iran, is assisting with the preparation of an extensive bibliography on the subject. About 1200 documents are presently in hand. Topics covered by this course are of

material interest to developing countries as erosion is a continuous problem, particularly where pressure exists to use marginal land for agriculture. Reducing the sediment load carried by streams is a primary objective of watershed management in many regions of the world.

Development of increased consulting competency

The University of Arizona's consulting capability is increased by extending faculty member contacts with counterparts in countries in need of technical assistance and in the actual performance of consulting functions.

A prime example of the former is the five-week trip made to eight Latin American countries by Dr. John L. Thames in the company of Dr. Richard E. Saunier, Environmental Programs Specialist for Latin America with the Peace Corps. Topics discussed with individuals from local agencies, AID Missions, universities, etc., included watershed rehabilitation, water harvesting, ecological impact of urbanization, forestry and fisheries management, and natural resources inventory. Countries visited were Argentina, Chile, Brazil, Columbia, Ecuador, Paraquay, Peru, and Costa Rica.

In addition to the above, contacts have been made with officials in Bolivia, Pakistan, Iran, and Ethiopia. Attempts are being made to involve the Watershed Management Department in a seminar or workshop on East African watershed and range programs. It is understood that a recent Ph.D. graduate from Ethiopia and now returned, Gebre H. Zere, will be coordinating these efforts. Under the guidance of the Director General of Soil Conservation and Watershed Management of the Ministry of Agriculture and Natural Resources, Iran, a program has been started to train Iranian students in watershed management and hydrology at the University of Arizona.

As a member of a three-man team of consultants from CUSUSWASH universities, Dr. Martin M. Fogel visited Nigeria to assist in the preparation of guidelines for a pre-feasibility study of a proposed irrigation project. The team visited the Do-Anambra Rivers area, the site of the proposed development, in August, 1972, and prepared a report for TAB/AGR in November. The report was transmitted to USAID/Nigeria who received the original request for assistance from the Commissioner of Agriculture and Natural Resources of the East Central State of the GON.

As a member of another three-man team of consultants from CUSUSWASH universities, Professor Sol D. Resnick visited the Philippines in August, 1973, to help develop plans for on-farm water management programs for the Bico River Basin, an area beset by both floods and drought.

Expansion of special activities

1. *Library development.* To implement plans for locating a library within the Department of Watershed Management that will contain reference material pertinent to developing countries, a professionally-trained librarian was recently added to the staff. She is establishing the library and will aid in the dissemination of information. She is full-time with support being drawn from three sources, the 211(d) Grant, a new Peace Corps program (described below) and the University of Arizona Water Resources Research Center. An important objective of this activity is to develop a computerized reference retrieval system in the subject matter area of watershed management that will be interfaced with the Office of Arid Land Studies Information System.

2. *International symposium.* As a cooperative effort, the Departments of Hydrology and Water Resources, Systems and Industrial Engineering, Watershed Management and Mathematics sponsored a symposium endorsed by four international societies. Topics centered around uncertainties in hydrologic and water resource systems. Attendance numbered 150 internationally recognized professionals with a good representation from developing countries.

Impact of Grant in Developing Institutional Capabilities

The 211(d) Institutional Grant has provided the necessary foundation from which it has been possible to entrain other resources into the University of Arizona's watershed management program. A direct outgrowth of the AID grant is the involvement of the Watershed Management Department with the Peace Corps' Environmental Program in Latin America. Six U.S. universities, including the University of Arizona, will provide technical assistance to at least ten Latin American countries in watershed management and related environmental programs. Specific topics to be emphasized include air and water pollution; watershed, forest, fisheries, and wildlife management; and regional planning. The objectives of the program include: 1) Assisting Peace Corps Country Directors, their staffs and host institutions in defining specific program objectives for volunteers, 2) providing technical support services for in-country staff in charge of Peace Corps Volunteer environmental programs, and 3) reviewing and assessing current technical achievements of Peace Corps watershed and associated environmental programs. At least six faculty members from the Department of Watershed Management and possibly others will be involved in making trips to Brazil and Ecuador, the countries assigned to the University of Arizona.

To meet the objectives of the 211(d) Grant in developing the use of system analysis techniques in watershed management, a multi-disciplinary team involving the Departments of Watershed Management, Hydrology and Water Resources, and Systems and Industrial Engineering has been brought together. This relationship has resulted in obtaining additional support for related activities. To illustrate, the 1972-73 period was the initial year of operation under a three year grant from the Office of Water Resources Research of the U.S. Department of Interior entitled "Decision Analysis for Watershed Management Alternatives." Another such activity is a National Science Foundation sponsored cooperative research program between the University of Arizona and the Water Resources Center, VIKOZ, of Hungary. The title of the project, a three year program, is "Cooperative Research on Decision-Making Under Uncertainty in Hydrologic and Other Resource Systems."

The increased competency in watershed modeling of hydrologic systems generated by the 211(d) Grant has resulted in the Watershed Management Department receiving additional support from such diverse sources as the USDA Forest Service, the Arizona Water Resources Research Center, the Salt River Water Users' Association, the Arizona Water Commission, and Peabody Coal Company.

In general, the grant has been highly instrumental in putting together a group of scientists, engineers, and students that is making an impact in the management of natural resources. Not only will the results of these efforts be applicable to developing countries, but to the state of Arizona's problems as well. A rapidly expanding population is placing a continuing strain on Arizona's resources. Solutions to these problems (water shortages, pollution, etc.) can utilize the same techniques being applied to developing countries. The models being developed to describe the hydrologic and decision making processes have as their goal the optimum utilization of water resources for agriculture. These models are of the universal type and require an estimate of the parameters based on appraisal of local conditions, be they in a developing country or elsewhere. The development of special instructional techniques for training and the dissemination of information on complex water management systems is also relevant to countries at all stages of development.

Utilization of Institutional Resources in Development

The University of Arizona has made a concrete effort in providing faculty time, office space, library facilities, equipment, materials, etc., to meet the objectives of the grant. Most of the faculty associated with the program are state-supported. The Watershed Management Department now has additional space for a Remote Sensing Laboratory, for a library, and for other uses.

A total of 18 foreign students, coming mostly from Africa and Latin America, have completed graduate work in the Department of Watershed Management since the beginning of the grant. Three former Peace Corps volunteers have returned to the University campus and are doing graduate work in watershed management. A nearly-completed Ph.D. student in watershed hydrology has accepted employment with a private consulting firm and will be working in developing countries.

Future Plans

It is anticipated that future efforts will involve a continued shift in emphasis to activities that will increase the University of Arizona's competency to perform consulting service and training in the field. With additional foreign travel expected as a result of the new Peace Corps program and the cooperative research project with Hungary, opportunities for consulting activities are correspondingly increased. Previous contacts in such countries as Ethiopia, Iran, and Pakistan will be utilized in an expanded effort to produce linkages with developing nations.

A new major research activity already begun is in connection with remote sensing. According to a recent AID report (TA/OST 73-17), "Remote sensing now offers a capability for approaching water-resources development and management on a more rational and integrated basis, and also on a regional scale." The report then describes a number of possibilities for its use such as in surveys of water resources, in watershed management and in monitoring surface water resources. In summary, remote sensing presents what may be an efficient and effective means for assessing and monitoring the water resources of developing countries.

List of Recent Publications Having Significant 211(d) Input

1. Chaemsaithong, K., L. Duckstein, and C. Kisiel. 1972. Cost effectiveness of water resources systems in developing countries: Case of the Lower Mekong. Proc. Intl. Symp. on the Planning of Water Resources. Mexico City. December 1972.

2. Davis, D., L. Duckstein, C. Kisiel, and M. Fogel. 1972. Uncertainty in the return period of maximum events: A Bayesian approach. Proc. Intl. Symp. on Uncertainties in Hydrologic and Water Resource Systems. Univ. of Ariz., Tucson. December 1972.

3. Davis, D., L. Duckstein, C. Kisiel, and M. Fogel. 1973. A decision-theoretic approach to uncertainty in the return period of maximum flow volumes using rainfall data. Proc. UNESCO Symp. on Design of Water Resource Projects with Inadequate Data. Madrid, Spain June 1973.

4. Duckstein, L., D. Monarchi, and C. Kisiel. 1973. Interactive multi-objective decision making under uncertainty. Proc. NATO Conf. on the Role and Effectiveness of Decision Theories in Practice. Luxemburg. August 1973.

5. Fogel, M. M., L. Duckstein, and C. C. Kisiel. 1973. A stochastic snow model to evaluate reservoir operation. Paper presented at AGU Natl. Meeting. Washington, D.C. April 1973.

6. Fogel, M. M., L. Duckstein, and C. C. Kisiel 1973 Predicting the hydrologic effect on land modifications. Paper presented at ASAE Natl. Meeting. Lexington. Ky. June 1973

7. Fogel, M M., L. Duckstein, and C C. Kisiel 1973 Optimum control of irrigation water application Proc. IFAC Symp. on Automatic Control of Water Resources Systems. Haifa. Israel. September 1973.

8. Morin, G. C. A. 1973. Desert strip farming A way to make the desert green. Prog. Agric. in Arizona. (In press.)

9. Morin, G. C. A., and A. W. Warrick. 1973 Steady-stage seepage in a hillside. SSSA Proc. 37:346-351 May-June 1973.

10. O'Hayre, A. H. 1972. Parameter optimization for simulating semiarid watershed hydrology Unpublished Master's Thesis. University of Arizona 74 p

11. Rasmussen. W. O. 1973. A CAI language for mini computers with sample dialogue and problems relating to physics and wildland hydrology. Unpublished Ph.D. Dissertation. University of Arizona. 151 p.

12. Tinlin, R. M. 1972. Analysis and application of a passive electronic analog model to the hydrologic regime of a watershed. Unpublished Ph.D Dissertation. University of Arizona. 109 p.

3.

COLORADO STATE UNIVERSITY

INSTITUTIONAL DEVELOPMENT GRANT

Maurice L. Albertson[1]

Introduction

The area of research assigned to Colorado State University under the 211(d) Grant is entitled, *"Optimum Utilization of Water Resources: With Emphasis on Water Delivery and Removal Systems and Relevant Institutional Development."* This program involves participation by six departments: Agricultural Engineering, Agronomy, Civil Engineering, Economics, Political Science, and Sociology. Traditionally, engineers and agriculturists working in the areas of water delivery and removal systems have only a limited understanding of the related institutional structure which is required for the successful operation of water systems. Therefore, a primary purpose of this 211(d) Grant program is to develop knowledge, understanding, and ability to overcome these shortcomings by recognizing and understanding the concomitant need to analyze prevailing social systems as they affect water delivery and removal--including the kinds of institutional changes necessary, the sources of resistance to change, and effective ways of dealing with various forms of social resistance to innovative forms of water delivery and removal. Thus, one of the chief characteristics of the University's participation in the 211(d) Grant program is its inclusion of social, economic, and cultural factors along with engineering, agricultural and other technological considerations--thereby increasing the capabilities, dimensions of understanding, and competence of the University in this assigned area of research.

Because of the complex nature of the physical, financial, and technological constraints placed upon the optimal use of water delivery and removal systems, including relevant institutional structures, the participating disciplines feel that solutions may best be found through a comprehensive interdisciplinary approach. The various departments involved in the grant program have strengthened and improved their activities with regard to and in support of the grant objectives through:

1. Adding faculty members who have expertise in water delivery and removal.
2. Teaching courses involving water delivery and removal systems and related institutional development to students in engineering, agriculture, economics, and the social sciences.
3. Guiding the research activities of faculty and research assistants in the area of optimum utilization of water resources.
4. Supporting and guiding the research assistants who are interested in optimum utilization of water resources.
5. Publication of technical reports.
6. Developing linkages throughout the world on common areas of concern.

In general, the six participating departments are increasingly able to meet the requirements of the 211(d) Grant through.

1. Close cooperation and coordination of their 211(d) activities with each other.
2. A deeper understanding of the role of each department for the theme of the grant program
3. Establishment by each department of benchmark data and literature applicable to the grant objectives.
4. Developing capabilities within each department to respond to water delivery and removal problems through orienting and training students and faculty to the issues of development, study of the larger questions of utilizing water and other natural resources for the achievement of planned change.

The Colorado State University accomplishments over the past four years of the grant program have generated far greater entrainment effects and other benefits than was realized when looking at the program annually in a piece-meal fashion. As a consequence, the net accrued benefits have made Colorado State University a better institution for foreign and national students to

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take up advanced and specialized studies in water delivery and removal systems including relevant institutional development.

Purpose

The stated purpose of the CSU 211(d) Grant is to improve CSU s level of excellence with respect to planning, development, management, and utilization of water resources with special emphasis on water delivery and removal systems and relevant institutional development related to the needs of the developing countries. Specifically, the *objectives and scope* are paraphrased as

1. Improving and expanding professional staff
2. Expanding the number of graduate students.
3. Expanding research programs.
4. Expanding and improving course offerings.
5. Expanding special activities such as seminars, exchange programs, institutes, conferences, and publications.
6. Helping to alleviate the shortage of qualified professional personnel.
7. Expanding staff and institutional capability to serve in advisory and consulting capacities.
8. Improving understanding of the nature of the less developed societies.
9. Exchange of personnel and publications.
10. Programs of interaction with other groups and individuals.
11. Establishing linkages and lines of communication between CSU and the less developed countries.

Specifically, CSU was assigned the following subject areas in which to work:

1. Water supply and development.
2. Water storage
3. Water conveyance and control structures
4. Water delivery structures.
5. Water measurement.
6. Control of erosion and sedimentation.
7. Development and use of wells.
8. Drainage components and systems.
9. Social, political, and cultural aspects of institutional development
10. Processes of change
11. Economic analyses of water systems.
12. Systems approach to analysis of water development and utilization.
13. Develop and analyze case studies of water systems.

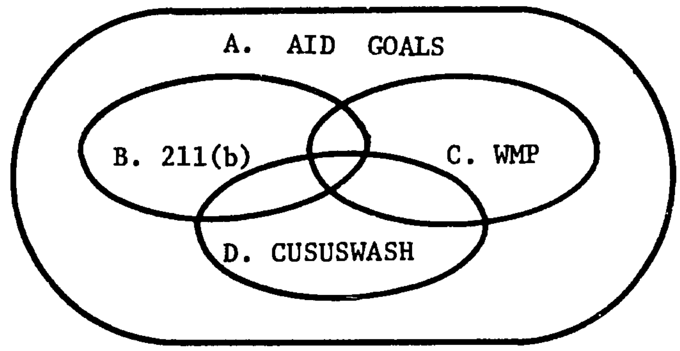
These objectives and areas of study for CSU do not stand by themselves, but they are part of an interlocking effort coordinating equally broad goals of the Water Management Research program and a variety of CUSUS-WASH activities. In the schematic illustration, Figure 1, is shown a general summary of the overlapping goals and objectives of the interrelated programs.

The lists in Figure 1 do indicate not only the interrelationship of goals in the variety of programs associated with the 211(d) Grant, but also serve as a framework for a better evaluation of specific objectives pursued, and of activities undertaken for their implementation.

..e Development Process

Underlying the entire scope and thrust of the 211(d) Grant program are key assumptions concerning the role of water management as a vital element in the total developmental process which is a sequential system Whenever development takes place - whether it is planned and deliberate or unplanned there are certain steps which tend to follow. Such steps, and their sequential nature, are illustrated compactly by the Development Wheel in Figure 2 From this diagram it can be seen that development involves various types of resources, broadly classified as physical resources and human resources.

Figure 2 shows that the manpower resource is motivated by his values and attitudes to take the action and provide the thrust which drives the development wheel. Development is accomplished by his effort and for his benefit. Briefly, the manpower resource acquires and uses information, process and systems by working through the institutional resources as vehicles to conserve and utilize the natural resources in order to expand the supporting infrastructure, within certain constraints, to produce additional goods and services for his own use and benefit, and to provide greater impetus for driving the development wheel still faster



Partial List of Goals

A. **Broad Goals of Aid**
1. Increased number and level of competence of manpower
2. Interdisciplinary approaches to research
3. Information and knowledge
4. To assist the developing countries

B. **211(d) Grant Goals**

(In-house)
1. Expand professional staff
2. Expand graduate students
3. Expand research programs
4. Expand course offerings
5. Expand special activities
6. Expand qualified personnel in international matters
7. Expand advising and consulting
8. Understand nature of LDC's
9. Establish lines of communication between LDC and CSU

(Subject areas)
1. Development of water supplies
2. Conveyance, delivery, and drainage
3. Storage and use
4. Control and measurement
5. Control of erosion
6. Use of wells as source
7. Systems engineering
8. Understand socio-economics factors
9. Analysis of social systems
10. Analysis of organization and administration structure
11. Economic analysis
12. Use of groundwater as storage reservoir

C. **Water Management Research Program Goals**

(On-campus)
1. Methods of skimming
2. Mineralogical analysis
3. Conjunctive use of groundwater and surface water
4. Farm turnouts
5. Use of saline water
6. Organization and administration of water management
7. Acceptance and use of water innovations

(Pakistan)
1. Land preparation
2. Use of saline groundwater
3. Classification of irrigation waters
4. Data limitations
5. Economic analyses

D. **CUSUSWASH**

(Universities activities)
1. Determine technical needs of LDC's
2. Determine methods of meeting technical needs
3. Determine areas of interest
4. Conduct joint activities

(Council objectives)
1. Mobilize capabilities of members
2. Exchange and communication
3. Provide professional staff
4. Uniform procedures and coordination
5. Exchange of personnel
6. Represent common interests

Figure 1. Interrelation of goals.

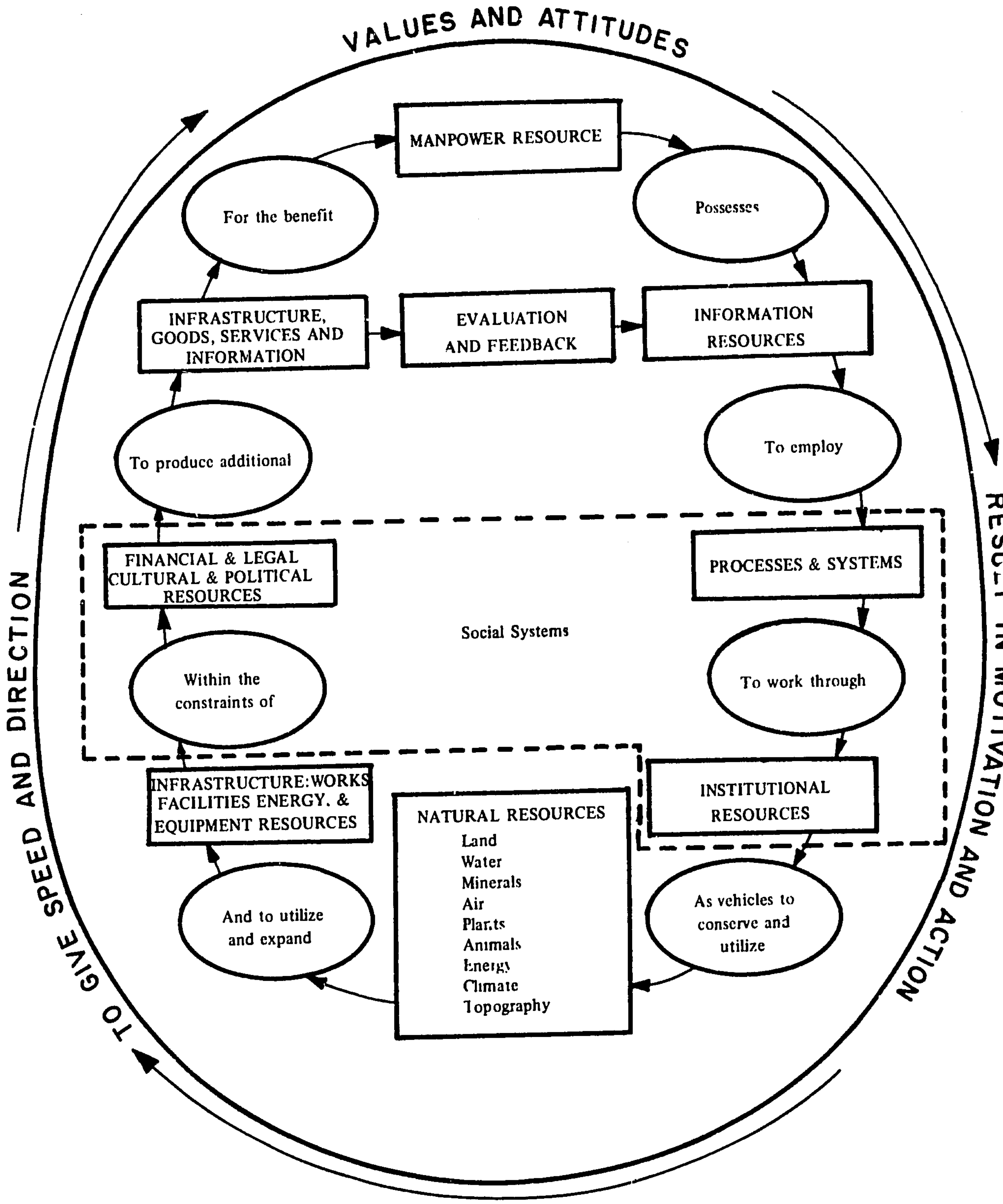


Figure 2. The development wheel, illustrating the development process (adapted from Albertson, 1972).

Note that there is a variety of linkage mechanisms between various stages or phases of the developmental process, and that this process is a dynamic one with feed back loops among the various subsystems. For a more complete presentation of the development process, and the role of research and education for development, see "Research and Education for Development" by Maurice L. Albertson and M. T. Chaudhry, from "Transfer of Water Resources Knowledge" edited by Evan Vlachos, Water Resources Publications, Ft. Collins, Colo., 1973.

Systems Approach

As part of the introduction and overview of the program and in order to present and assess project performance and objectives in a more cogent fashion, it is important to dwell briefly on its overall structuring and operation. We have adopted a systems approach to the study and analysis of development. The general orientation with the systems approach is part of the effort to integrate physical and nonphysical dimensions of irrigation systems, provide common vocabulary, and delineate appropriate parameters for interdisciplinary studies. In adopting a systems analysis we view water management as a system operating in a given environment where *inputs* (physical and nonphysical) processed through the "organization" (the input) result in outputs or goals achieved (either as goods or services). Two parts of Figure 3 summarize these ideas and provide an abbreviated format of the connecting concepts and dimensions guiding project assessment.

There is another way of summarizing the argument running through this brief report. Our aim is to generate the kinds of activities that may fulfill the objectives of the contract, but in such a way as to be able, through appropriate indicators, to evaluate how efficiently and effectively such goals have been reached. Or, in the following succinct summary:

- We are providing a *systems* model
- In order to construct a framework for *evaluation*
- Which, through the use of appropriate *indicators*
- Will make possible the measurement and *assessment* of

  1. Program performance
  2. Specific achievements

  As they relate to general project and development *goals*

In completing this brief introduction we would like to emphasize that three key concepts (systems analysis, indicators, evaluation) are not only parts of a concerted approach of all disciplines in the project, but also methodological milestones for identifying causes and corresponding effects and alternative options for more effective water delivery and removal systems.

Accomplishments

We have attempted to look at water delivery and removal as a system, with the various activities described under *Purpose* integrated into a total program aimed at a balanced understanding of both the phenomena involved and the planning, design, and operational features which are necessary for success. This is within the framework of the established assignment of CSU - a Land Grant Institution to provide programs and activities of education, research, and service.

The criteria we use for measuring successful accomplishment include: willingness of faculty to serve short or long terms abroad as advisors or consultants; attendance of all personnel at seminars and conferences; number and relevance of new courses developed, old courses revised and improved, and all courses taught; amount of student advising on water resource development; participation in research activities; service and consulting activities in and/or for developing countries; number and relevance of publications completed; linkages established; entrainment accomplished; and CUSUSWASH activities.

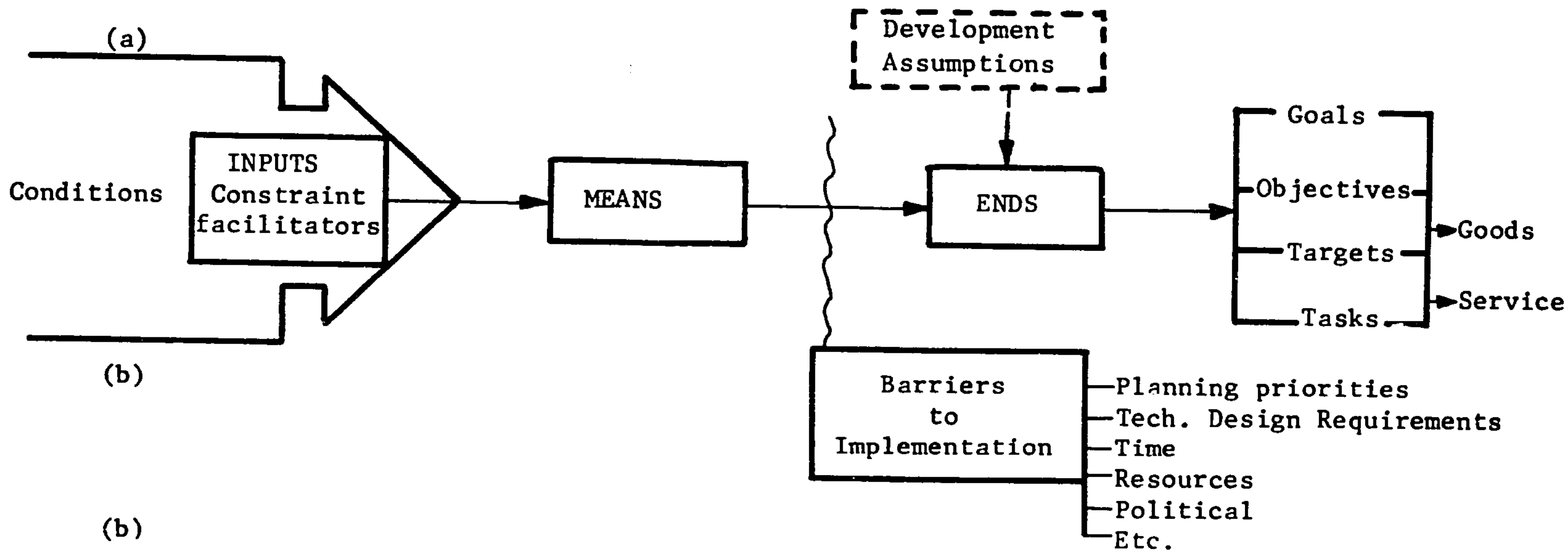
A primary thrust of the CSU program has been the improvement of the manpower resources, in the information resources, and the institutional resources which are needed for better and more efficient and effective development and utilization of the water resource within the constraints of other natural resources, and the financial, legal, cultural and political resources. (See the Development Wheel, Figure 2.) To this end, we have concentrated our efforts on: Improvement of faculty and staff, curriculum improvement, technical publication, library improvement, seminars, graduate students, meetings and travel, service, linkages, entrainment, and CUSUSWASH activities.

Improvement of Faculty and Staff

We have taken the position that improvement can result from either adding new personnel, who already have most or all of the qualifications desired; or improving the knowledge, experience, and ability of existing staff. To this end, 23 new staff members have been added and more than 40 existing staff members have improved their capability as a result of the 211(d) activities. Appendix A is a tabulation of these faculty and staff members.

Curriculum Improvement

To improve the capability of CSU in water resources management, eleven new courses have been added, and



(b)

INPUTS (Constraints/ Facilitators)	THRUPUT (Means)	OUTPUT (Ends, Goals, Objectives)	Significance (Consequences)
Physical Ecological Physical layout Socio-Political Demographic Cultural Legal Administrative Economics Capital Manpower	Personal campus — field Infrastructure Physical — Organizational Rules of Operation	Increased productivity Collective betterment Quality product Increased income Goods Services (see Fig.1)	Components of Development

Figure 3. A simplified version of systems dimensions.

significant improvements have been made in eighteen existing courses. Included among the new courses are the following:

1. *Irrigation Structures*—with special emphasis on water delivery and removal structures.

2. *Farm Irrigation Systems*—including international considerations.

3. *Water Resource Systems*—which looks at the total water delivery and removal system and its relationship to specific uses such as irrigation.

4. *Institutions and Economic Development*—which includes water resources institutions.

5. *Economic Analysis and Water Resource Development*—which studies the economic interrelationship of the various aspects of water resource development, including delivery and removal systems.

6. *Geography of Native Farming Systems*—which includes various irrigation systems and the problems of water delivery and removal.

7. *Irrigation Practices in Developing Countries*—which includes the way that water is delivered, applied, and removed at present, and how this could be improved.

8. *Interdisciplinary Seminar in Water Resources Management*—which is a credit course and involves students and faculty from five different colleges studying new concepts, research, existing projects, and projects which are now being planned or built.

9. *Planning Engineering Projects in Developing Countries*—which applies benefit-cost techniques to water resource project analysis in the setting of the developing countries.

Because of the increased activity across the campus in water delivery and removal systems caused by the 211(d) Grant, there has been much entrainment resulting in other courses being improved or added in fields directly or indirectly related to the grant, but without grant financial support

Publications

Reporting on activities related to the 211(d) activities has been in the form of special reports, theses, dissertations, and papers published in professional journals. These are tabulated in Appendix C which shows there have been 10 Master's theses and Ph.D. dissertations, 10 reports, and 8 papers.

Library Improvement

Although the CSU Library has historically been strong in its collection related to water resources in general and water management in particular, several thousand additional volumes have been added during the period of the grant through grant funds and from various other sources. The collection has now been set apart so that students and faculty have easy access to all materials.

Seminars

The International Interdisciplinary Seminar was initiated early in the grant period to serve as a focal point for interdisciplinary consideration of various water resources projects throughout the world and various other topics which have a bearing on the subject of the grant. This has now been formalized as a regular course for credit. The total attendance for a year is between 800 and 1000, and the average attendance for a single seminar is approximately 30. Appendix C lists the purposes of the seminar and the program topics.

Graduate Students

A large number of graduate students have been supported in the participating departments during the period of the grant. The following is a tabulation of numbers for the various departments.

Agricultural Engineering	6
Agronomy	3
Civil Engineering	31½
Economics	9
Political Science	13
Sociology	7

By having these students working on grant-related research, the major professor and other committee members move more completely into the area of on-farm water management. Several of the students either have gone, or will go, to a developing country to collect data for their research and their thesis or dissertation.

Meetings and Travel

A very important part of the 211(d) activities is attendance of staff members and students at meetings. This helps to generate contacts, communications and linkages among CSU personnel and others interested in the same or similar subjects. Such meetings are also stimulating to those in attendance and new ideas, approaches, and analysis result from them. Frequently, the staff member delivers a paper at a meeting so that the new knowledge which has been developed at CSU is transmitted to the profession at large.

Travel may also be for consulting or advising in which funding is borne by some outside source. If such funding is not available, however, then 211(d) funds are used if the activity is considered to be sufficiently important for meeting grant objectives. A specific example is the help CSU gave the IITA with its irrigation seminar in October 1972.

Several graduate students have travelled abroad to collect data for their research.

Service

We have taken the position that a primary purpose of the 211(d) Grant is to prepare the CSU faculty to be of service when called upon to do so. In this connection, most of the new faculty have been either assigned overseas or have served as consultants since joining CSU, and most of the existing staff have served on one or more assignments overseas since the beginning of the grant. Appendix D is a list of 30 services which have been performed

Linkages

Throughout the period of the grant, the faculty members have been diligent about establishing linkages with various individuals, with private organizations, with government agencies, and with other groups in order to maintain connections, to carry on correspondence; to exchange publications, and to discuss research activities and field problems. Many of the service opportunities reported were initiated through these linkages.

Entrainment

Because of the increased activity across the campus in water delivery and removal systems caused by the 211(d) Grant, there has been much entrainment resulting in other courses being added or improved in fields directly or indirectly related to the grant, but without financial support from the grant.

In part because of the stimulation provided by the grant, additional projects have been funded by other sources throughout the CSU campus. Appendix E is a list of 64 projects totalling $2,200,000 which are related to the grant topic that have been funded from other sources since July 1969.

Interdisciplinary Activity

At the beginning of the 211(d) Grant period, CSU had a few instances of limited interdisciplinary research activity Since the grant, however, the interdisciplinary team approach has developed in at least a half dozen major research contracts that involve as many as 4 or 5 different colleges and many more departments Without the 211(d) Grant it would not have been possible to develop these new programs.

CUSUSWASH Activities

CSU has considered cooperation in CUSUSWASH activities a major responsibility For this reason, many CSU staff members have attended the twice-yearly meetings of CUSUSWASH; a great amount of time has been spent serving as Trustees, and we have spent many man-days in meetings and developing material for such activities as the Integrated Approaches Committee, the Irrigation Management Program, and the Saltillo, Mexico, project.

Monitoring and Evaluation

Throughout all previous discussion a key underlying component has been the recognition of monitoring and evaluation as vital parts of the overall 211(d) program. Essentially, evaluation is viewed as a means for increasing the rationality of decision making, as a mechanism for better program planning, and as a device for assessing project accomplishments. Thus, in the context of the systems approach adopted for the overall program, it becomes possible to evaluate component parts and/or subsystems in a fashion summarized in Figure 4.

This diagram exemplifies four key distinctions we make in the 211(d) Grant evaluation

1. *Accomplishments*, i.e. the achievement of certain outputs as specified in the contract agreement.

2. *Performance*, or the meeting of organizational goals, or the effectiveness of various subsystems in meeting project goals.

3. *Efficiency*, or primarily an economic benefit-cost analysis relating given resources (inputs) to proposed goals or attempted targets (output).

4. *Efficacy*, or the attempt to incorporate "social benefit-cost" considerations, aspects of social policy, and all those intangible benefits that cannot easily be quantified in traditional input-output analysis. Indeed, efficacy considerations become more pertinent when examined in the context of AID's program dimension, *significance* or the extent to which the achievement of targets contribute to general development or other broader goals.

Plan of Work for 1973-74

The fiscal year 1973-74 is intended to consolidate and bring together all of the progress that has been made through the grant thus far Specifically, special emphasis is to be placed on publications which bring out the new information that has been gained during the Grant and to summarize certain existing information which needs to be made readily available, to establish ways for continuing the team activities which are already underway even beyond the end of the grant, to try to find ways of supporting (beyond the grant period) the new staff members which have been brought to Colorado State University as a result of the grant, and to round out the research and study activities.

Specific publications which are expected to be produced during this Grant period are:

1. *The Ultimate Irrigation Water Supply Potential of the Indus Basin, Pakistan* – An analysis of the present water delivery system and a projection, using systems analysis, of the ultimate potential using all sources and conveyance systems optimally.

2. *Water Resource Management of Small Farms in Developing Countries* – A collection of 10 papers giving an interdisciplinary approach to the subject.

3. *Water Resources Management Institutions in Pakistan* – A summary of existing institutional arrangements, examination of available models, and showing how a combination of models might be used to improve the institutional structure in Pakistan.

4. *Optimal Conjunctive Use Model for the Indus Basin* – A consideration of the optimal combined use of groundwater and surface water to maximize agricultural production.

5. *Sediment Problems in Rivers, Canals, and Watercourses in the Punjab* – An examination of the existing situation and measures which might be taken to improve it.

6. *Water Delivery and Removal Systems in the Developing Countries* – A volume containing a series of papers relating to water supply and conveyance, conjunctive use of groundwater and surface water, reuse of excess water, sediment problems, quality control, seepage, and water resource institutions, to improve delivery and removal systems—all aimed at reducing the cost of irrigation water to the farmer and making it available to him at the time and place and in the quantities that he needs with as little maintenance and operational expense and difficulty as possible.

7. *Aquifer Recharge for Optimal Conjunctive Use of Surface and Groundwater Resources* To consider seepage and the lining of canals as well as salinity control and general management of the underground reservoir which has been shown to be much less expensive than reservoirs above ground.

8. *Flood Control Measures in Pakistan* – To examine the recent floods, the damage they have caused to water delivery and removal systems, and measures which might be taken to prevent or minimize such damage in the future.

9. *Control of Sediment at Farm Turnouts* – A report of the results of laboratory and field experiments on methods and designs for controlling the sediment which enters a farm turnout and is deposited in the farmer's ditch or field.

10. *Development Planning* A book which presents a model on input-output techniques, which can be used to analyze such development problems as forecasting, optimization, international trade, and technology (this is not supported by 211(d)).

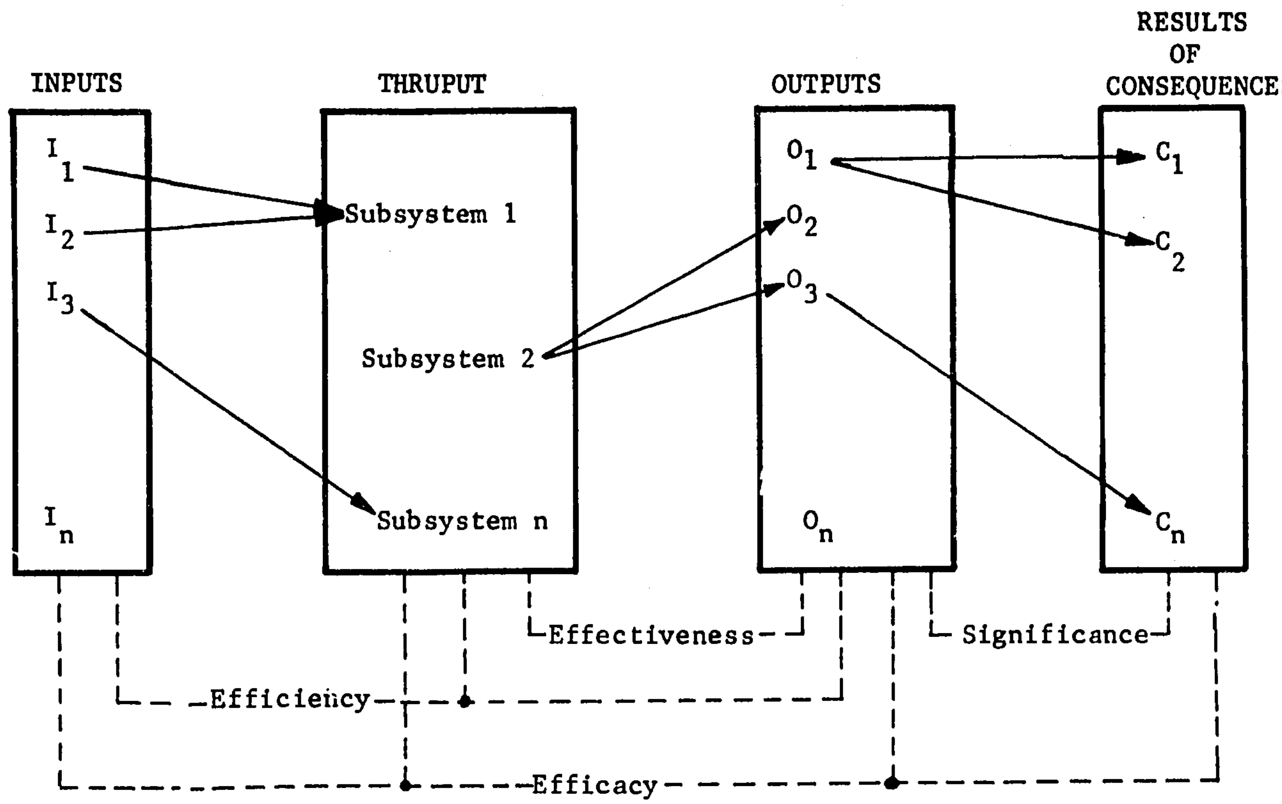
11. *Incorporation of Working Capital in Project Analysis* – Would include such factors as water application and fertilizers.

12. *Underlying Assumptions for the Rate of Return Analysis* – This would apply to water resources analysis as used by the World Bank.

13. *Prospects for Irrigation in West Africa* – Would include the socio-economic aspects of institutional development for water delivery systems and on-farm irrigation systems.

During the coming year new courses will be added, such as "Fundamentals of Irrigation and Drainage" which will be taught in the Agricultural Engineering Department for non-engineers such as economists, lawyers, sociologists, agronomist, and political scientists. The primary emphasis during the coming year, however, will be for the expansion and upgrading of existing courses—especially those which have been added through the help of the 211(d) Grant.

Research will continue on water conveyance layouts; design and management of water removal and delivery systems for small irrigated farms; pumping groundwater underlaid by saline aquifers, small irrigation structures for water delivery and removal; movement, accumulation and removal of salt in the soil; institutional arrangements for water delivery and removal systems; conjunctive use of surface water and groundwater; and techniques for reducing the cost of water to the farmer.



We need indicators in order to measure and/or assess:

1)	Accomplishments	(Output)
2)	Effectiveness	(Performance)
3)	Efficiency	(I/O ratio)
4)	Efficacy	(Questions of social cost, ultimate significance)

Figure 4. A scheme for evaluation.

Appendix A

Faculty Involved

New staff members who have been added:

1. Henry **Caulfield**, Political Science, is formerly Executive Director of the United States Water Resources Council and has many years experience in water resource development both in the United States and abroad where he has served as a consultant.

2. George **Radosevich**, Economics and Law, has a law degree and is specializing in international water law. He has repeatedly served as a consultant in the developing countries, and is now on leave to work in water resource development with the United Nations.

3. Huntley **Biggs**, Economics, specializes in theories of economic development, planning, and policies for economic development.

4. Garth **Jones**, Political Science, has had many years experience in developing countries and has recently resigned from CSU to work with the United Nations.

5. Ronald **Tinnermeier**, Economics, specializes in agrarian reform, water management, farm management, and production economics.

6. Evan **Vlachos**, Sociology and Civil Engineering, also has a law degree. He specializes in water resource development models, institutional structure water user organizations, research methodology, and demographic factors. He is serving as a consultant to various developing countries and U.S. agencies.

7. Arnold Klute, Agronomy, specializes in soil-water relations and the chemical composition of drainage water.

8. Wayne Clyma, Agricultural Engineering, has specialized in on-farm water management and is presently serving with the CSU research team in Pakistan.

9. William Hart, Agricultural Engineering, specializes in design of irrigation systems, hydrology, and irrigation engineering. He has served as a consultant in several developing countries in Africa.

10. David McWhorter, Agricultural Engineering, specializes in flow through porous media, and design and operation of wells. He has served as a consultant in developing countries on tube well layout, design, and operation.

11. Alan Early, Agricultural Engineering, has had experience in the Philippines and specializes in soil and water management, and the use of remote sensing for water resource investigations.

12. Doral Kemper, Agronomy and Agricultural Engineering, specializes in soil chemistry, soil physics, multiphase flow through porous media, and on-farm water management. He is the Director of the CSU Water Management Research projects in Pakistan and Vietnam.

13. Michael White, Agricultural Engineering, specializes in water law, both surface water and groundwater.

14. Judson Harper, Agricultural Engineering, is head of the department, and because of his strong interest in water resources, irrigation, drainage, and salinity control, is providing the leadership necessary to develop a strong department in this area.

15. Willis Shaner, Mechanical Engineering, specializes in the economics of water resources development. He has had many years experience in economic analysis in developing countries.

16. Neil Grigg, Civil Engineering, specializes in water systems, water management, optimization hydraulics, and hydrology. His experience abroad is in South America.

17. Khalid Mahmood, Civil Engineering, specializes in water conveyance and erosion and sedimentation problems. He was formerly with the Irrigation Department in Pakistan.

18. Talib Chaudhry, Civil Engineering, specializes in water resources systems, optimization, conjunctive use of surface water and groundwater, salinity, and seepage. He was formerly with WAPDA in Pakistan.

19. John Labadie, Civil Engineering, is a specialist in water systems analysis, operations research, optimization, environmental dynamics, and conjunctive uses of surface and groundwater.

20. Warren Hall, Civil Engineering, is the father of modern water resources systems engineering–having produced many of the world leaders in the field today and having co-authored the first textbook on the subject. He is presently on leave to serve as Director of the Office of Water Resources Research.

21 Cornelius DeMooy, Agronomy, specializes in soil-water relations and is presently posted with the CSU Water Management Research Team in Pakistan.

22. Jerry Eckart, Economics, specializes in agricultural economics and the economics of water resources development and management. He is presently located with the CSU Water Management Research Team in Pakistan.

Improvement of existing faculty

The following individuals have been involved in various types of Grant activities and have consequently improved their ability in the subject areas of the Grant to do research, teaching, consulting, and other service activities:

1. Willard Schmehl, Agronomy
2. John Reuss, Agronomy
3. Everett Richardson, Civil Engineering
4. Daryl Simons, Civil Engineering
5. Maurice Albertson, Civil Engineering
6. Albert Mercer, Civil Engineering
7. Hubert Morel-Seytoux, Civil Engineering
8. Morris Skinner, Civil Engineering
9. Robert Danielson, Agronomy
10. William Thomas, Agriculture
11. Gene Wilken, Geography
12. Leo Teller, Watershed Science
13. Gaylord Skogerboe, Agricultural Engineering
14. Wynn Walker, Agricultural Engineering
15 Robert Longenbaugh, Civil Engineering
16. Robert Whitney, Agronomy
17. William Franklin, Agronomy
18. Arthur Corey, Agricultural Engineering
19. Albert Barnes, Civil Engineering
20. David Hendricks, Civil Engineering
21 George Olson, Civil Engineering

22. Edmund Schulz, Civil Engineering
23. Hsieh Shen, Civil Engineering
24. George Smith, Civil Engineering
25 Charles Thomas, Civil Engineering
26. Vujica Yevjevich, Civil Engineering
27. Kenneth Nobe, Economics
28 Lee Gray, Economics
29. Loyal Hartman, Economics
30. Terultoma Ozawa, Economics
31. Rex Rehnberg, Economics
32 David Seckler, Economics
33. Robert Young, Economics
34 William Marlatt, Watershed Science
35. Linwood Hodgdon, Sociology
36. David Freeman, Sociology
37. John Straayer, Political Science
38. Norman Wengert, Political Science
39. Phillip Foss, Political Science
40. Duane Hill, Political Science

Appendix B

Publications

Publication of technical reports and papers and developing design manuals supported in part or fully by grant funds concerning water delivery and removal systems and related institutional development and considered to be of high priority by developing countries for the past four (4) years include (1) A total of 10 CUSUSWASH publications with 8 more underway; (2) eight technical papers published in scientific journals, and (3) ten Ph.D. dissertations and/or M.S. theses completed.

1969-70

Dissertation:

"Water Management in West Pakistan," by Robert F. Schmidt June 1970.

1970-71

CUSUSWASH Publications:

1 "Check-drop Energy Dissipator Structures in Irrigation Systems," by Gaylord V. Skogerboe, Venus T. Somarau, and Wynn R. Walker, May 1971.

2. "The Effect of Data Limitations on the Application of Systems Analysis to Water Resources Planning in Developing Countries," by Luis Ernesto Garcia-Martinez, May 1971.

Technical Papers:

1. Bibliography, by Garth N. Jones, Shaukat Ali, Richard Barber, and Jim Chambers. Published in *Planning, Development and Change: Bibliography on Development Administration*, 1970.

2. Accounting and Budgeting Reform in Pakistan for National Development; Reconsideration of Fundamentals, by Saiyid M. Hamid, Co-author. Published in National Institute of Public Administration Journal, 1970.

3. Public Problems and Non-Decision Making, by John A. Straayer. Published in *Natural Resources Journal*, July 1970.

1971-72

CUSUSWASH Publications:

1. Effect of Settlement on Flume Ratings, by Tsu-Yang Wu, August 1971

2. Width Constriction in Open Channels, by J. W. Hugh Barrett, November 1971

3. Cutthroat Flume Discharge Relations, by Ray S. Bennett, March 1972.

4. Culverts as Flow Measuring Devices, by Va-son Boonkird, February 1972.

5. Installation and Field Use of Cutthroat Flumes for Water Management, by G. V. Skogerboe, Ray S. Bennett, and Wynn R. Walker, March 1972.

6. Dualism in Mexican Agricultural Development; Irrigation Development and the Puebla Project, by Huntley H. Biggs, June 1972.

7. The Puebla Project Progress and Problems, by Huntley H. Biggs, July 1972.

8. Maximum Water Delivery in Irrigation, by James Henry Duke, Jr., August 1971 (Partial support of 211(d) Grant funds.)

Dissertations and/or M.S. Theses.

1. Effect of Settlement on Flume Ratings, by Tsu-Yang Wu, August 1971

2. Width Constriction in Open Channels, by J. W. Hugh Barrett, November 1971.

3. Culverts as Flow Measuring Devices, by Va-son Boonkird, February 1972.

4. Cutthroat Flume Discharge Relations, by Ray S. Bennett March 1972.

5. A Systematic Approach to the Water Supply of a Large Area, by Alain Deredec, 1972

1972-73

CUSUSWASH Publications:

1. The Puebla Project: Progress and Problems, by Huntley H. Biggs, July 1972.

2. Index for the Eight Near East-South Asia Irrigation Practices Seminars, by William L. Neal and Clifford Stockmyer, August 1972.

Technical Papers:

1. Culverts for Flow Measurement in Irrigation Systems, by Gaylord V. Skogerboe, Wynn R. Walker and Va-son Boonkird. Published in *Soil and Water Division of ASAE Journal*, October 1972.

2. Generalized Discharge Relations for Cutthroat Flumes, by Gaylord V. Skogerboe, Ray S. Bennett, and Wynn R. Walker. Published in *Journal of the Irrigation and Drainage Division*, December 1972.

3. The Green Revolution and Economic Development, by Huntley H. Biggs. Published in *The Rocky Mountain Social Science Journal*, June 1973.

4. Comparison of Bridge Backwater Relations, by Gaylord V. Skogerboe, J. W. Hugh Barrett, Wynn R. Walker, Lloyd H. Austin. Published in *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers*.

5. Slope-Discharge Ratings for Cutthroat Flumes, by Gaylord V. Skogerboe, Wynn R. Walker, Tsu-Yang Wu, and Ray S. Bennett. Published in *Soil and Water Division of ASAE*.

Dissertations and/or M.S. Theses:

1. The Organization of Thai Irrigators, by Michael C. Schiefer, May 1973.

2. A Laboratory Study of Bed Material Withdrawal in Farm Turnouts, by Ata Mohammad Nazar, May 1973.

3. Optimal Parameter Identification of Nonlinear, Time-Variant Hydrologic System Models, by Samuel Tuffuor, June 1973.

4. The Problem of Rural-Urban Water Competition, by Everett Meyers, June 1973.

Appendix C

International Interdisciplinary Seminar On Water Resource Management

Purposes of seminar

A. To develop appreciation among participants—faculty and graduate students—of the diversity of factors—including engineering, cultural, biological, economic, social and political—and thus, of the multidisciplinary nature of water resources management.

B. To gain basic intellectual understanding among all participants of the concerns, concepts, methods, and contribution of each academic discipline concerned with water resources management.

C. To foster construction of interdisciplinary models for the solution of water management problems through the joint efforts of faculty and graduate students representing the disciplines relevant for the solution of such problems.

D. To evaluate interdisciplinary models for the solution of water management problems from all points of view including those of experienced practitioners and observers of water resources management.

E. To appraise the successes and failures of water management efforts throughout the world, especially in less developed countries, in meeting human needs.

F. To enable participants from all academic departments to gain, in successive terms and years of their participation, greater and greater resolution in their knowledge of water resources management; and thus

G. To contribute to the achievement of increased levels of competence in water resources management among faculty and graduate students of Colorado State University.

Academic credit

As of the fall term 1972, the seminar is offered as a credit course, No. GS 797; and it is open to any interested graduate student.

Academic credit for attendance and participation in the weekly seminar is one credit per term. Satisfactory participation in a field trip of ten days or longer, such as that to the Lower Balsas River Basin, Mexico, in 1971, would also entitle a graduate student to one credit. In addition, one to three credits would be granted for making a major contribution to the seminar through preparation alone, or in a group, of a seminar paper requiring a substantial amount of work.

Place and time

The seminar is held regularly once each week on Wednesday from 3:00 p.m to 5:00 p.m in a room in the Student Center. Notices of meetings are sent each week to all faculty members and graduate students (i.e., whether they are taking the course for credit or not) who are on the seminar mailing list

Seminar administration

The seminar is a function of the Graduate School. A program committee composed of a chairman and faculty representatives of academic departments interested in having their faculty and graduate students involved in the seminar program establish seminar policy and develop the seminar's annual program within established guidelines. One or more graduate students from each participating academic department participate in the deliberations of the program committee as advisory members.

The current faculty members of the program committee are:

Henry P. Caulfield, Jr.	Chairman
Maurice L. Albertson	Ex-Officio
Huntley H. Biggs	Economics
Clarence Carlson	Fishery and Wildlife Biology
Linwood L. Hodgdon	Sociology
John Straayer	Political Science
David B. McWhorter	Agricultural Engineering
Albert G. Mercer	Civil Engineering
John O. Reuss	Agronomy

Appendix D

Services Performed

Linkages are developed by faculty, staff, and research assistants at CSU with faculty and staff of other universities, government officials, officials of private companies, institutions, and individuals in developing countries. The responses for technical assistance abroad that have been made by members of the faculty the past four years supported in part or fully under the Grant are as follows:

1. David Freeman, Sociology Department
West Pakistan
22 August to 21 September 1969

The purpose of Dr. Freeman's trip was to determine research capabilities and interests in selected universities in Pakistan pertaining to social factors relevant for maximizing the effectiveness of water and agricultural projects designed to increase agricultural production Discussions were held with university social science personnel in the following universities: a) West Pakistan Agricultural College, Lyallpur, West Pakistan; b) University of the Punjab, Lahore, West Pakistan; c) University of Peshawar, Peshawar, West Pakistan; and d) University of East Pakistan, Dacca, East Pakistan.

2. W. R. Schmehl, Agronomy Department
West Pakistan and Iran
9 September to 4 October 1969

Iran: Dr. Schmehl reviewed sugar beet production in a developing area comparable to West Pakistan. Sugar beets are being considered as an alternative winter crop in West Pakistan since higher wheat yields will release land for additional crops. Dr. Iraj Poostchi, Agronomist, Pahlavi University, was his guide to show the sugar beet production in Iran. Dr. Poostchi was on sabbatical leave at Colorado State University in 1968-69 to study sugar beet production in the United States. Preliminary arrangements were made with the Ministry of Agriculture for a cooperative Ph.D. training program.

Pakistan: Dr. Schmehl made initial contacts for the establishment of adaptive water management research projects with cooperative Pakistani Institutions. Among the people in West Pakistan visited were:

Dr. Leon Hesser, Agricultural Officer, USAID, Rawalpindi

Dr. Stefan Krashevski, Soil Salinity Advisor, US-AID, Lahore

Mr. Curry Brookshier, Food and Agricultural Officer, USAID, Lahore

Dr. Albert Shaw, Washington State University Advisor, WPAU

Dr. Inam-Ul-Haque, Head, Soils Department, WPAU

Mr. Allah Bakhsh, Chief Engineer, Reclamation, WAPDA

Mr. S. M. Suid, Chief Engineer, Administration, WAPDA

Mr. Nur-Ud-Din, Soils Research, Land Reclamation Directorate

Dr. Kanwar Hussain, Director Ayub Research Institute (now Minister of Agriculture for Punjab Province)

3. V. Yevjevich, Civil Engineering
Philippines, Thailand, India, Pakistan
8 August to 9 September 1969

Dr. Yevjevich of the Civil Engineering Department made a world trip in August and September 1969. The portion of the trip supported by grant funds covered the period 11 September to 24 September for visits to Manila, Bangkok, New Delhi, Lahore, Rawalpindi, and Peshawar. The purpose of Dr. Yevjevich's visit to the above locations was to establish contacts in the Philippines, Thailand, India, and Pakistan regarding problems related to scarce hydrologic data and large continental droughts. The contacts will establish a base for studies and teachings oriented to develop competence in selecting methodologies for solving the above important problems.

4. D. B. Simons
West Pakistan
29 August to 23 September 1969

The portion of Dr. Simons trip to Tokyo and return was paid for by CSU. The portion of his trip from Tokyo to Pakistan was supported by grant funds. The purpose of Dr. Simons visit to Pakistan was to gather information for ideas and promotion of grant objectives.

5. E. V. Richardson
West Pakistan
1 September to 29 September 1969

The main purpose of Dr. Richardson's trip to Pakistan was in connection with other projects. While there he assisted in gathering information for ideas and promotion of the grant program. While in Pakistan he made field trips concerning water management projects for irrigated land, with special emphasis on delivery and removal structures and systems, and erosion and sedimentation problems associated with water supply and irrigation and removal of drainage water of irrigated land. The information obtained, in addition to being of benefit to other projects Dr. Richardson is involved with, was used to improve education and research programs on water management in the developing countries.

6. M. L. Albertson
Japan, Thailand, Pakistan, and Iran
30 August to 7 October 1969

Japan: Dr. Albertson visited Tokyo, Japan to attend a conference for the International Association for Hydraulic Research where discussions and research reports were given on water management problems, water delivery, and water removal problems.

Pakistan: In Pakistan he made contacts and developed agreements with various institutions in Pakistan for joint and cooperative research programs on problems of water management. These arrangements were for research in Agronomy, Agricultural Soils, Irrigation Engineering, Hydraulic Engineering, Rural Sociology, Agricultural Economics, and Political Science.

Tunisia: In Tunis, Tunisia, he met with Mr. Samuel Litzenberger, Head, Food and Agriculture Division, USAID, and Mr William McNeil, General Engineering Officer, Public Works Division, among others, to discuss and review USAID projects on watershed planning and management water resources development for drilling fifty wells, and the Medjerda Valley development.

Iran: In Teheran, Dr. Albertson visited with U.S. Embassy personnel and AID training personnel regarding Mr. M. Monadjemi, a Ph.D. graduate student in Agronomy, and CSU's plans for him to do his dissertation in Iran. The preliminary plans were developed at that time, and later firmed up by Dr. Schmehl, Professor of Agronomy at CSU, in June 1970.

7. M. L. Albertson
West Pakistan and Manila
22 November to 10 December 1970

West Pakistan: As Project Director for the Water Management Contract, he reviewed the research project with AID Mission officials as well as the sociology project initiated with the West Pakistan Agricultural University.

Manila: In addition, he visited the International Rice Institute in Manila where discussions were held regarding agricultural irrigation, water research engineering, soil and plant studies.

8. Bert L. Ellenbogen, Chairman, Department of Sociology and Anthropology and David M. Freeman, Assistant Professor, Department of Sociology and Anthropology
Greece and West Pakistan
18 October to 22 November 1970

Greece: Visited Greek government officials and scholars in Athens for the purpose of discussing water management studies having a significant sociology component as well as establishing a center for research in water management and socio-economic development.

West Pakistan: They also visited West Pakistan where they helped to establish some sociological courses and research projects at West Pakistan Agricultural University as well as participated in water management research program discussions with government officials.

9. Manuel Alers-Montalvo
Peru, Venezuela, and Costa Rica
17 July to 26 August 1970

Dr. Manuel Alers-Montalvo, Director of the Center for Latin American Studies, visited with officials from universities and other institutions of Peru, Venezuela, and Costa Rica in regard to specific ways in which CSU could be of help to their institutions in solving problems in water resources management. Specifically, to explore the possibilities of exchanges between faculty and students between these universities and CSU, as well as opportunities for collaborative research projects in the social sciences, natural sciences and agriculture. In addition, Dr. Alers-Montalvo presented a paper at the Congress of Americanists in Lima, Peru.

10. Dr. Hubert J. Morel-Seytoux, Associate Professor, Civil Engineering Department
North Africa
10 June to 9 July 1970

Dr. Morel-Seytoux visited several North African countries in June and July 1970, namely, Morocco, Algeria, Tunisia, and Lybia. As a result of this trip, a system of communications was established with competent persons in positions of responsibility. Hopefully, it will be possible to proceed with special studies of water resources development in North Africa in the near future

11. Dr. Edmund F. Schulz, Associate Professor, Department of Civil Engineering
India, Hawaii, Japan, Thailand, Hong Kong
12 April to 28 May 1971

The purpose of Dr. Schulz in making this round-the-world trip was to establish linkages with more than 100 outstanding scientists and high government officials in India, Pakistan, Thailand, Taiwan, Japan, and Hawaii. Some of his activities included presenting a paper at the Symposium of Water Resources, Indian Institute of Science, Bangalore, India; consultation with hydrologists in the above listed countries regarding modernization of methods of acquisition and retrieval of hydrological data including groundwater recharge experiments, discussions with agricultural engineers regarding consumptive use of water under the impact of multiple cropping practices, and acquiring data on optimum timing of irrigation on multiple cropping sequences through observing farming practices after harvesting crops--such data are essential to set up computer based simulation models.

12. Dr John O. Reuss, Associate Professor, Department of Agronomy
Dr. Huntley H. Biggs, Assistant Professor, Department of Economics
Mexico
7 to 16 June 1970

During June 1970, a group from CSU took a field trip to Mexico to investigate the water projects in the Balsas Basin. The above named faculty members accompanied the group to determine whether such a trip might be beneficial to faculty and graduate students associated with the Water Management Project to repeat in following years. The final report recommended a future trip be scheduled. This was endorsed by the International Interdisciplinary Committee

13. Huntley Biggs, Team Leader of Field Trip
Balsas River Basin, Michoacan, Mexico
16 to 24 March 1971

Background: Being a semi-arid country, one of the key aspects of the Mexican development strategy has been the stimulation of regional progress through the construction of multi-purpose water projects. Perhaps no other LDC has had such a long history of water resource development experience as Mexico even going back to pre-Columbian times. A number of river basin commissions have been established with the responsibility for promoting development in all of its aspects including health, education, agricultural production, irrigation works, electrification, and transportation. While most of the persons managing the river basin commissions are engineers, they are constantly faced with problems requiring interdisciplinary solutions

One such commission is the Balsas River Commission established as the Commission of Tepalcatepec in 1947. Fortunately, CSU has connections with an individual, Walter Illsley who has been intimately associated with the development of this river basin since its inception under President Lazaro Cardenas. Mr. Illsley received an M.A. degree in International Economics from Johns Hopkins University. He was in China from 1946-1953, part of his time being spent with the Agricultural Rehabilitation Program of the United Nations Relief and Rehabilitation Agency. For the past 16 years he has been living in Mexico practicing a weaving skill, which he acquired in China, and promoting community development projects on a voluntary basis. In addition, he has conducted several tours of U.S university students and faculty in the Michoacan area of Mexico These include Montana State University Friends World Institute in Long Island, and Putney School in Vermont Mr Illsley is a person thoroughly familiar with Mexico's culture and her development problems as they exist both at the community and at the national levels. He is also one of those rare individuals who is capable of exchanging ideas with persons from all disciplines and from all social levels.

14. Philip A. Hostermann
Afghanistan
8 October to 23 December 1971

The purpose of this trip to Afghanistan was to study the Helmand River Valley and other water resources in Afghanistan in relation to the grant

15. M. L. Albertson
Bulgaria and Nigeria
10 May to 6 June 1972

Nigeria: Dr. Albertson was the official representative at CUSUSWASH (Council of United States Universities for Soil and Water Development in Arid and Sub-Humid Areas) at the meeting of the International Institute of Tropical Agriculture in Ibadan, Nigeria. This meeting was held in conjunction with a research conference on tropical soils where a number of African soil scientists were in attendance, making it possible to provide an important linkage between the soils research in our water management contract and the IITA in Nigeria.

Bulgaria: Dr. Albertson attended the meeting of the International Commission on Irrigation and Drainage (ICID) Executive Council in Varna, Bulgaria. The agenda for this meeting included a world-wide survey on the Effects of Salinity in Irrigation Waters and their Effects on Soils and Crops and the Utilization of Saline Water for Irrigation. The total program dealt with on-farm water management in less developed countries and was an excellent opportunity to become informed on salinity research in other areas of the world, and to establish new linkages for further development of the grant.

16. Huntley H. Biggs
Mexico City
5 to 14 June 1972

Dr. Biggs' trip enhanced the competence of the faculty member in the water resources problem of a developing country in an arid and sub-humid environment. The knowledge gained from this experience is being shared with the other participants in the grant via the International Interdisciplinary Seminar. It also supported the research of a faculty member which hopefully will result in a publication that will be beneficial to other LDC's on a world-wide basis. It also established contacts with other institutions concerned with water resources management problems in the developing countries.

17 Christopher Dowswell
Guatemala
5 June 1972 to 1 January 1973

Mr. Dowswell went to Guatemala to collect data for his thesis as well as to establish contacts with institutions and individuals working in water resources and avail his services to assist in solving water problems confronting their society. He also collected literature on issues relating to water resources in Latin America which adds to our knowledge of water management problems abroad and provides resource information to the International Interdisciplinary Seminar.

18. George Radosevich
Nigeria
7 to 24 August 1972

Dr. Radosevich went to Nigeria in reply to a request from USAID/Nigeria through the Director of the Agricultural Bureau of Technical Assistance. The purpose of this trip and request was to assist in a comprehensive feasibility study in the area of irrigation development.

19. Huntley H. Biggs
Guatemala
14 to 23 March 1973

Dr. Biggs travelled to Guatamela City in order to review the research program of Mr. Chris Dowswell who needed faculty direction in designing his thesis research, and to offer advice as to how to proceed in this research. Dr. Biggs also made contacts with persons in the Ministry of Agriculture, AID/Guatemala and the Inter-American Development Bank to discuss the possibilities of CSU's becoming involved in Guatemala.

20. M. L. Albertson
William B. Hart
W. Doral Kemper
Evan Vlachos
Nigeria
23 to 27 October 1972

The four faculty members of CSU named above went to Nigeria at the invitation of the American Embassy at Lagos to participate in the IITA Seminar on "Prospects for Irrigation in West Africa." All four of them presented papers at this seminar. Their participation in the seminar will hopefully be instrumental in the establishment of a feasible, well-planned system of irrigation which will benefit the farming and urban communities of West Africa, and other nations as well.

21. M. L. Albertson
Afghanistan
10 and 11 February 1973

Dr. Albertson stopped in Kabul, Afghanistan in order to follow-up with a CSU graduate student regarding his research on the Helmand Valley Project as it relates to water delivery and removal systems. He further strengthened the linkage between CSU and USAID Mission personnel through the Agricultural Officer and the Educational Officer in meeting with them to discuss planning, development, management, and utilization of water resources with special emphasis on water delivery and removal systems and relevant institutional development related to the needs of the less developed countries.

APPENDIX E

New Water Resources Funding Since July, 1969

Department	Project Title & Leader	Sponsor	Date	Amount
Ag Eng	Water Quality Management Decisions in Colorado. G.V. Skogerboe			8,700
Ag Eng	Data Acquisition Systems in Water Quality Management. Russell Freeman	Fed. Water Poll. Cont.	07/01/70 12/31/71	48,909
Ag Eng	Grand Valley Salinity Control Demonstration Project. G.V. Skogerboe	Fed. Water Poll. Cont.	07/01/70 01/31/72	76,053
Ag Eng	Irrigation Return Flow Quality Literature Abstracting. G.V. Skogerboe	Environ. Pro. Agcy	02/01/71 01/31/72	29,269
Ag Eng	Optimal Water Quality Management. G.V. Skogerboe	OWRR	07/01/71 06/30/73	30,000
Ag Eng	Irrigation Return Flow Quality Literature Abstracting. G.V. Skogerboe	EPA	02/01/72 01/31/73	31,327
Ag Eng	Grand Valley Salinity Control Demonstration Project. G.V. Skogerboe	EPA	02/01/72 01/31/74	99,890
Ag Eng	System of Management for Optimum Water Utilization. W.E. Hart	Bur. Rec.	07/01/72 06/30/73	9,187
Ag Eng	Irrigation Practices, Return Flow Salinity and Crop Yields. G.V. Skogerboe	EPA	10/11/72 10/11/73	146,476
Ag Eng	Grand Valley Salinity Project G.V. Skogerboe	EPA	thru 01/31/74	8,493
Ag Eng	Irrigation Return Flow Quality Literature Abstracting. G.V. Skogerboe	EPA	02/01/73 01/31/74	29,216
Ag Eng	Systems of Management of Optimum Water Utilization. W.E. Hart	Bur. Rec.	07/01/71 06/30/73	9,188
Ag Eng	Artificial Recharge in W-Y Groundwater Management District. David McWhorter	W-Y Groundwater Mgmt. Dist.	07/06/71 12/31/71	3,325
Civil Eng	Selection of Test Variable for Minimal Detection of Basin Response to Natural or Induced Changes. Morel-Seytoux			9,750
Civil Eng	Development of Computer Program for Application of Stochastic Hydrology. V. Yevjevich	Bur. Rec.	06/01/70 06/30/71	10,300
Civil Eng	Theory and Experiments in Prediction of Small Watershed Response. V. Yevjevich and E Schulz	OWRR	07/01/70 06/30/71	41,000
Civil Eng	Metropolitan Water Intelligence Systems. M. L. Albertson	OWRR	11/01/70	100,000

Department	Project Title & Leader	Sponsor	Date	Amount
Civil Eng	Research Facilities–Water Resources Research Program of USGS. Carl Nordin	USGS	thru 06/30/71	14,120
Civil Eng	Hydrologic Stochastic Processes. V. Yevjevich	NSF	thru 06/30/71	20,000
Civil Eng	Theory and Experiments in Prediction of Small Watershed Response, Phase II. E. Schulz	OWRR	07/01/71 06/30/72	20,000
Civil Eng	Systematic Treatment of Infiltration with Applications. H.J. Morel-Seytoux	OWRR	07/01/71 06/30/73	25,000
Civil Eng	Stochastic Processes in Water Resources. V Yevjevich	NSF	11 15/71 11/14/72	85,400
Civil Eng	Investigation of Water Resources in Karst Region. V. Yevjevich	NSF	10/01/71 09/30/72	33,800
Civil Eng	International Symposium on Floods, Droughts, and Decision Making with Scarce Data. R. Longenbaugh	NSF	04/01/72 03/31/73	33,300
Civil Eng	Feasibility of Remote Evaporation and Precipitation Estimates. J. Ruff, W. Sadeh, and D.B. Simons	NASA	05/18/72 05/17/73	99,000
Civil Eng	Use of Remote Sensing to Obtain Data for Describing the Large River Environment. D.B. Simons	Army Eng.	thru 12/31/72	29,329
Civil Eng	Stochastic Analysis of Sediment Bed Transport. H. Shen and P. Todorovic	NSF	09/15/72 09/14/73	36,700
Civil Eng	Water Rights Tabulation Update. R. Longenbaugh	S. of Colo. Nat Res.	08/11/72 06/30/73	21,300
Civil Eng	Determination of Urban Watershed Response Time. E. Schulz	Dept. Army Corps Eng.	10/01/72 09/30/73	9,940
Civil Eng	Stochastic Processes in Water Resources. V. Yevjevich	NSF	11/15/72 11/14/74	90,300
Civil Eng	Investigation of Water Resources in Karst Region. V. Yevjevich	NSF	thru 12/31/73	39,600
Civil Eng	Systematic Design and Legal Regulations for Optimal Surface-Groundwater Useage. H.M. Morel-Seytoux	OWRR	07/01/72 06/30/73	16,550
Civil Eng	THEMIS Project. J. Cermak	ONR	07/15/72 07/14/73	96,528
Civil Eng	Environmental Impact of Mississippi River Channel Development. D.B. Simons	Dept. Army	10/17/72 12/16/72	8,000
Civil Eng	Water Data Bank Establishment. R. Longenbaugh	State of Colorado	08/01/72 06/30/73	85,050

Department	Project Title & Leader	Sponsor	Date	Amount
Civil Eng	Transport and Dispersion of Bed Materials in Open Channels. Shen and Todorovic	NSF	09/15/69 09/14/71	87,200
Civil Eng	Multivariate Analysis of Small Watershed Rainfall-Runoff Relations. Holland			6,500
Elec Eng	Rapid Measurements of Soil Moisture and Water Table Depth by a Short Pulse Radar. R. Vickers	Bur. Rec.	05/01/72 01/31/73	10,000
Human. & Soc. Sci.	Economic Analysis of Water Quality Standards. K. Nobe	OWRR	07/01/69 06/30/73	40,000
Human. & Soc. Sci.	Development Techniques for Estimating Potential of Water Resources Develop. Henry Caulfield	Utah State University	07/01/70 06/30/71	5,400
Human. & Soc. Sci.	Economic, Political, and Legal Aspects of Colorado Water Law. K Nobe			8,115
Human. & Soc. Sci.	Economic, Political, and Legal Aspects of Colorado Water Law. P. Foss			6,104
Human & Soc. Sci.	Technique for Estimating Potential of Water Resources Development. H. Caulfield	Utah State University	10/01/71 09/30/72	15,017
Microbio	Training Grant in Water Supply and Pollution Control. S. Morrison	Fed. Water Pol. Con. Ad.	07/01/70 06/30/71	52,754
Nat. Res Center	Economic. Political. and Legal Aspects of Colorado Water Law. J. Flack			7,337
Natural Sciences	Drainage Basin Evaluation and Influence of Landforms on Hydrologic Variables S. Schumm	U.S. Army Research	01/01/71 12/31/71	33,885
Political Science	Development of Techniques for Estimating Potential Water Resources Development. H.P. Caulfield	Utah State University	10/01/72 12/31/73	20,880
Vet Med	Training Grant in Water Supply and Pollution Control. S. Morrison	Fed. Water Poll. Cont.	07/01/69 06/30/70	55,492
Vet Med	Water Quality Study. S. Morrison	Eastman Kodak	03/01/70 02/28/71	10,800
Vet Med	Water Quality Study. S. Morrison	Eastman Kodak	03/01/71 03/31/72	14,400
Watershed Sciences	Management of Colorado Mountain Lands for Increasing Water Yields. J. Meiman	Bur. Rec.	07/01/72 06/30/73	30,000
Watershed Sciences	Application of Remote Sensing in Hydrologic Modeling of River Basins. D. Striffler	NASA	09/01/72 05/31/73	18,000
Agriculture	Experimental Study of Soil Water Flow Systems Involving Hysteresis. A. Klute			6,500

Department	Project Title & Leader	Sponsor	Date	Amount
Agriculture	Soil and Water Research. R. Whitney	Fed. Water Poll. Cont.	07/01/69 06/30/70	37,500
Agriculture	Systems of Management of Optimum Water Utilization. K. Brengle & H. Moore	Bur. Rec.	07/01/71 06/30/72	17,812
Agronomy	Soil and Water Research. R. Whitney	ARS	07/01/72 06/30/73	100,000
Agronomy	Systems ot Management for Optimal Water Utilization. K. Brengle	Bur. Rec.	07/01/72 06/30/73	17,812
Economics	Systematic Design of Legal Regulations for Optimal Surface-Groundwater Usage. R. Young	OWRR	07/01/72 06/30/73	10,450
Ext. Service	Soil and Water Research. F. Willhite	Fed. Water Poll. Cont.	07/01/69	37,500
Forestry	Identification of Urban Watershed Units Using Remote Multispectral Sensing. L. Miller			6,000
Forestry	Classification and Designation of Water for Specific Uses. A. Wilcox	Nat. Water Commission	06/30/70 06/30/71	14,400
Forestry	Management of Colorado Mountain Lands for Increasing Water Yields. R. Dils	Bur. Rec.	thru 06/30/72	30,000
Forestry	Snow-Air Interactions and Management of Mountain Watershed Snowpack. J. Rasmussen and J. Meiman	OWRR	07/01/71 06/30/74	26,000 9,000
Human. & Soc. Sci.	Systems of Management of Optimum Water Utilization. R.L. Tinnemeier	Bur. Rec.	07/01/71 6/30/72	3,000

4.

COLORADO STATE UNIVERSITY–WATER MANAGEMENT RESEARCH

W. Doral Kemper[1]

Objectives

General objective

To increase food production in the developing 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.

Coordinated objectives of the Utah State University and Colorado State University projects

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, and integration of this knowledge into systems for efficiently distributing water to farmers' fields.

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 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 adaptation 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 productive cropping systems 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, management, and utilization of water on the farm level.

These objectives have been developed in consultation with TA/AGR specialists and the personnel of the companion project at Utah State University. CSU has major efforts in progress to achieve the last seven of these objectives in Pakistan, Vietnam, or on the CSU campus.

General approach for achieving these objectives

Many water management problems that are constraints on crop production have been identified in cooperation with TA/AGR soils and water specialists, USAID Mission personnel and host country scientists. Factors identified as major constraints include: (1) Inadequate water for full crop production accentuated by mismanagement, seepage, and spillage losses from poorly constructed and maintained water courses and through over-irrigation on parts of the areas; (2) nonuniform distribution of water in the field due to inadequate leveling combined with the indiscriminate use of basin irrigation; (3) poor crop stands caused by inadequate water control during germination and by sodium and salinity in some of the soils and waters. Other factors which have been identified as constraints on production under some specific conditions include: (1) Water delivery schedules which do not provide adequate water during periods of critical need for specific crops; (2) low recovery of fertilizer N caused by leaching and denitrification under flooded conditions; (3) poor aeration in the root zone during long periods required for flood irrigation on slowly permeable soils; (4) dense compacted soils resulting from high silt, low organic matter and basin flooding irrigation. Where similar constraints have been encountered and relieved in other countries, the technology which brought about this relief is being tested within the framework of the physical resources available to the farmer and the socio-economic factors of the host country.

As the technologies prove to be practical this fact will be documented and publicized. If the technology is

[1]Director, Water Management Research Project, Colorado State University, Fort Collins, Colorado.

not practical in its original form. modifications will be developed and tested which will adapt the technology to the resources and socio-economic needs of the host country. In cases where technology has not evolved to relieve specific water management constraints such technology will be developed

Host country administrators. scientists. and extension personnel will be involved in the identification. adoption, and development of water management technology which removes constraints on crop production. so they will assist in bringing about its utilization To facilitate this utilization, to accelerate the adaptive research. and to help build water management expertise in the developing countries. this work will be done in cooperation with developing country institutions. When field party personnel participate directly in field research. they will be assisted by host country cooperators or research assistants who can benefit from this field training. When training a cooperating host country scientist is the most efficient way to solve particular water management problems. the scientist may be brought to CSU for the minimum time to obtain adequate training and do the necessary library research He will then return to his country to work on his country's problem under his country's conditions. In cases where solutions to problems and water management guidelines can be developed most effectively utilizing the facilities and personnel at CSU or USU, the work will be done on these campuses

In general CSU will address its efforts to specific needs of the Asian countries and USU to needs of the Latin American countries. However. the physical and socio-economic variables involved in each study will be carefully characterized to increase the extent to which the findings and resulting technology can be transferred successfully to other developing countries. Efficient research plot designs have been studied and adopted in common by the two universities. which will allow direct comparison of yield response surfaces to water and fertilization from the various countries where such studies are in progress Coordination of studies at the two universities occurs through discussion of research results and plans at least every six months. through exchange of reports, and through joint development of work plans.

Much of the research is directed to the solution of specific country needs as these needs are identified. The recognized problems involved in "on-farm water management" have been outlined Published and fugitive literature concerning these problems is being collected. When deficiencies in the literature regarding recognized water management problems are identified, these problems develop high priorities for future research. One of the most effective means for improving water management in the developing countries is to remove constraints which limit the development and adaptation of good water management technologies One of the primary constraints is generally poor access to the journals and books dealing with recent advances in water management. To help remove this constraint, and allow developing country scientists to locate the water management literature, CSU, USU, University of California, and the University of Arizona (the CUSUSWASH) are presently writing reviews (which will be assembled for publication and dissemination in the developing countries) of the major books, manuals, and guidelines on irrigation water management. The degree to which this published information fills the needs of developing country farmers, extension personnel, scientists, and government planners is being evaluated. Where needs for additional specific assemblages of water management information are identified the development of appropriate guidelines, journals etc will be undertaken by CUSUSWASH. This step is considered essential to maximize the transferability of the available and forthcoming research information and to develop the additional answers that often appear when information is brought together from different sources

Our research efforts to date have been directed primarily to problem diagnosis in the field and development of technology on the campus. Having identified some major constraints on the overall utility of water and having collected or developed technologies which have potential for relaxing these major constraints. the next phase of this work will deal primarily with evaluating these technologies under local conditions and adapting them to the specific resources of the farmers and the countries

An essential prerequisite to this local adaptive research was the development of a cooperative atmosphere and relationship with agencies and government officials of Pakistan and Vietnam These cooperative relationships have been developed and we are now in position to direct a larger portion of our field party time to adaptive research.

The objective of this project is primarily to develop and adapt water management technology to improve food production However, increased employment opportunities, adaptability to resources of small as well as large farmers, utilization of homemade rather than imported equipment, etc., are essential components of water management technology which will help the developing countries and their common people. Consequently identifying tools and changes in socio-economic factors which will allow subsistence level farmers to adopt improved water management technology and will produce opportunities for productive employment, is a vital portion of this research

Study by our Pakistan field party, of the technology adoption process, indicates that farmers do not accept technology unless they have seen a clear demonstration of its benefits under conditions similar to those under which they work A major reason for this attitude is the fact that the resources of these farmers are severely limited They must see how this technology can be adapted to their limited resources, or be shown how they can overcome these limitations. These demonstrations are much more effective if they are conducted on farmers' fields where the farmers can see that their practical problems of adaptation have been solved. The ideal demonstration is one where the farmers make an investment and a profit.

To provide research conditions under which the essential elements of good water management could be made available, and this practical credibility could still be established, practical improvement of several watercourses has been arranged through cooperative agreements between CSU, USAID, and agencies of the Pakistan Government. Opportunities for farmers to level their fields have been provided within these watercourses and plans are in process to evaluate the most promising water management technologies on these fields.

Areas of Concentration

These areas are those in which major constraints on crop production were identified in the previous section.

Avoidable water losses

Seepage and spillage losses from Pakistani watercourses result in appreciable reductions in the water available to the farmer at his turnout. A major part of these losses appear to be avoidable A major form of seepage loss stems from "dead storage" in portions of watercourse channels which are below the ground surface. This storage is filled each time a leg of the watercourse is used. Then when the water is turned to another leg this dead storage water evaporates or seeps to the groundwater. Several million acre feet of water are lost per year in Pakistan via this route. Realigning watercourses and elevating them is being tested as a means to eliminate these losses and as a means for providing better water control (e.g., siphons for furrow irrigation etc) Various types of watercourse lining are also being tested for seepage control.

Spillage losses are generally a result of poor maintenance accentuated by the accumulation of sediment in the watercourse which reduces its capacity. CSU studies of the effects of canal turnout design on sediment content of water entering the watercourse have shown that the sediment can be routed to watercourses where its presence is least damaging. Moreover, watercourse design criteria have been developed which could allow the deposition of most of the sediment on the fields rather than in the watercourse channel where it creates maintenance problems.

The primary means for preventing spillage losses is better maintenance Better maintenance is primarily a function of more effective water user organization. A worldwide spectrum of water user organizations has been cataloged by CSU and USU economists, lawyers, and sociologists and these are being evaluated to determine which of them have the best potential for being adapted to specific host country conditions and solving the maintenance and other watercourse problems.

Field evaluations by Dr. Clyma and his Pakistani cooperators show that, over-irrigation by factors from 2 to 5 occurs frequently on the portion of fields which are irrigated in SCARP areas. This failure of farmers to distribute their water over the optimum amount of land is associated with several problems such as: The charges for water, which are based on acreage of crops rather than amount of water used, arrival of water at the field is not coordinated with crop needs, etc., whose solutions are partially attainable through better water user associations etc. How. . if the farmer had better measures of the amount of water he is receiving and the needs of his various crops, he could adapt his cropping patterns and acreages to his present water delivery system and increase his cultivated acreage To facilitate adapting his cropping patterns and acreages to his existing water supply, structures which facilitate flow measurement are planned for the improved watercourses. The most promising structure for this purpose under the low head loss conditions of Pakistan, appears to be the cutthroat flumes whose design and testing was initiated at Utah State University and completed at CSU.

The other information necessary for rational water management is water holding capacity of the soil and consumptive use rates and rooting depths of the plants at various stages of growth in soils of different texture under conditions of adequate fertilization. Studies to obtain this data have been initiated by Dr. deMooy at two locations in Pakistan and are planned at three other locations. Weather data will be used in the Christiansen-Hargreaves (USU), Jensen and other consumptive use equations, combined with coefficients from the Pakistan sites where consumptive use, etc., have been measured, to obtain estimates of consumptive use for crops at other locations in Pakistan and other South Asian countries.

The degree to which farmers will use available structures to measure water flow, and use the resulting information, combined with consumptive use and soils information to plan their crop acreages and sequences will be determined. Technological and socio-economic facilitators to increase such use will be identified and tested.

Distribution of water within the field

Elevation variations coupled with the use of basin irrigation are the primary cause of poor uniformity of water distribution in Pakistani fields. More water enters the low lying areas because the water is in contact with these areas for a longer time and has a higher average head (Dr. Clyma and cooperators at Mona). Dr. deMooy and his cooperators at the Punjab Agriculture Research Institute have also found that in slightly saline soils the permeability of the low lying areas is appreciably higher than in the high areas. This difference appears to be associated with accumulation of more salt and Na in the higher areas Recognition of these facts has led to the conclusion that precision land leveling is a necessary prerequisite to reasonably uniform distribution of water under the prevailing basin system of irrigation.

Recognizing that the best land leveling techniques leave a variation of about one inch and that subsequent cultivations and irrigation water sediment increase this variation, it is apparent that the deviations from the mean application will be greater than 50 percent when mean applications are less than two inches of water. Consequently other met' ' applications, such as furrow irrigation, are being , determine whether they can distribute light applications of water more equitably to the plants within a given field.

The probability that furrow irrigation helps increase water distribution and yields is given credence by Utah State University experience in the Aconcagua Valley of Chile where they practically doubled maize yields in the whole valley by introducing a technology package which included furrow rather than basin irrigation. An unfavorable political climate forced evacuation of the USU team from Chile Follow up studies by the CSU field party and Pakistan cooperators are now underway to determine the degree to which furrow irrigation alone influences water distribution and crop yields.

The potential benefits of precision land leveling are generally greater than its cost. To help ensure that small subsistence level farmers can participate in the benefits of this technology, the degree to which small farmers are participating will be determined; physical and socioeconomic facilitators of participation will be identified, evaluated and made available to this disadvantaged group It is anticipated that these facilitators may include credit, efficient earth movers (adapted to bullock power), and village level demonstrations of the benefits of land leveling.

As the benefits of additional water management technologies, such as water flow measurement, furrow irrigation, etc.; are proven to be greater than their costs, opportunities for small subsistence level farmers to participate in these technologies will be ensured in a similar manner. A large portion of the socio-economic facilitators should be common to the various water management technologies.

Crop stands

Stands of summer crops on farmers' fields are commonly between 20 and 50 percent of the stands recommended for optimum crop production. Factors identified as inhibitors of seedling germination and emergence include:

1. Salinity of the irrigation water drawn from the tubewells.
2. Sodium in the soil which increases soil crusting and decreases seedling emergence.
3. Lack of adequate water on high spots for germination.
4. Crusting, as a result of post planting irrigation and rain.
5. Poor seed quality
6. Use of broadcasting and harrowing as the seeding method which leaves a large portion of the seeds at shallow depths where adequate water for germination is not available.

CSU studies on seedling emergence of corn and sorghum irrigated with saline water show that seedling emergence is often improved by reasonable phosphate fertilization.

Our studies on crust strength show that when water application is in furrows and wetting of the surface soil is by capillarity rather than by flooding, the strength of the crust over seedlings is reduced to levels which generally do not inhibit seedling emergence.

Reductions of salinity in the irrigation water and of Na in the soil are possible by management techniques to be discussed later which are being developed at CSU and in Pakistan.

Equipment adapted to the Pakistani farmers' power sources (generally bullocks) for ridging and furrowing soils (to allow non-crusting post plant irrigation) and for seeding at a controlled depth appears to be a necessary prerequisite for consistently good stands. Simple models of such equipment which could be manufactured by village artisans have been located and will be tested and made available to farmers on the watercourses under study The adoption of ridge and furrow cultivation will require other changes in water management and equipment items such as siphons or spiles or other means to distribute water into furrows On soils with low infiltration rates the common three or four-inch irrigation cannot be accommodated in reasonable size furrows and another prerequisite for proper furrow irrigation will be flexibility in the water delivery which will allow smaller and more frequent applications of water. To some extent this flexibility is presently achieved by some farmers who informally trade some of their water during their regular irrigation turns for water from a neighbor at intermediate times (Clyma Watercourse Observations)

Irrigation–fertility interactions

Analysis of past irrigation studies by our cooperators indicates relatively low yields and low recovery of fertilizer N at the higher levels of water application, equivalent to those which Dr. Clyma has found to be common farmer practice. These data and observations indicate that the farmers of the SCARP areas are leaching an appreciable portion of their limited and valuable NO_3 from the soil by over-irrigation.

This problem will be solved at least partially by applying the technologies which will reduce over irrigation by applying the correct amount of water to satisfy consumptive use and leaching requirements, and obtain more uniform distribution of water within the fields as outlined above.

Admitting that practical water management generally falls short of limiting the water application to the exact amount of water needed and of providing completely uniform distribution within a field, partial separation of the paths by which water and nitrogen fertilizer get to plant roots appears to be a supplementary answer to the NO_3 leaching problem. The degree to which this separation can be achieved by placement of fertilizer at various elevations in ridges and applying water at various levels in adjacent furrows is being determined and compared with broadcast fertilization and basin irrigation, using soils of different textures in lysimeters at CSU. The most promising combinations of fertilizer and water placement will be tested on the improved watercourses and fields in the Mona project and compared (yield and N recovery) to practices presently used by farmers.

In general maximum utility of the limited water supplies in producing food in Pakistan is limited by inadequate fertility, particularly N. To give the farmers the information they need to maximize the productive capacity of their water, fertility, land and other resources, yield response curves to water and fertility and their interactions are needed on the major crops. Realizing that these interactions and main effects are strongly affected by method of irrigation, (as well as soil texture, climate, and numerous other factors), it appears wise to determine the best methods of irrigation before committing the major portion of the project to obtaining water-fertility response surfaces. However, it is likely that present water management practices will persist in many parts of Pakistan and adjacent countries for several years. To provide farmers with water and fertilizer use guidelines under present conditions, Dr. Eckert has initiated cooperative studies at the major crops research stations in Pakistan to determine these fertility-water yield response surfaces for wheat, corn, cotton, and rice.

Utilizing saline groundwater

Rising groundwater levels and associated salinity are a common factor in most arid area irrigation systems. Means for determining which waters are usable, making poor quality waters usable, and separating usable from nonusable groundwaters are essential to maximizing the utility of these groundwaters and achieving the necessary ultimate salt balance for the irrigation project. These factors are particularly critical in Pakistan where over 25 percent of the irrigated lands are, to some extent, salt affected.

The common practice for installing tubewells has been to drill these to a depth of 200 to 300 feet to obtain good flow. Many of these tubewells have been closed down because their pumped waters contained water that was too high in total salts or Na. Some of these wells are in areas where there is from 100 to 300 feet of relatively good water overlying the saline water, but direct penetration of saline water and "coning" of the saline water to the well during pumping commonly contaminates the good water with the saline water below.

Physical and mathematical modeling of this coning phenomena and associated factors by Dr. McWhorter and his associates have provided several guidelines for skimming well design and operation. The effect of depth of penetration of the good water by the well and pumping rate, on amount and quality of water can now be estimated when the salinity profile and permeability of the aquifer is known.

This skimming well performance data coupled with information on the relative value of water as determined by its salinity would allow computation of guidelines for maximizing economic return from wells. The necessary economic evaluations have been planned and should be initiated shortly.

Field installation of skimming wells and observation wells designed to test the models and theory and provide good quality water for irrigation, is in process in Pakistan. These wells are being installed in an area where conventional deep tubewells have produced unusable water

To improve crop production and our estimates of the relative value of saline water, extensive studies are in process with our cooperators at PARI (Lyalpur) and Mona to determine the effect of various quantities and qualities of irrigation water on the yields of major crops and on the properties of soils which are critical to water management.

One of the few improvements in water quality which are near economic practicality is the introduction of Ca^{++} ion into the water which will then help displace Na from the soil thus improving infiltration, aeration and other properties of the soil There are gypsum deposits at several locations in Pakistan, but the cost of mining, loading, crushing and hauling the gypsum to the farms and spreading it on the land is generally higher (around 100 rupees/ton) than most farmers can afford. Analyses of the cost shows that almost 50 rupees per ton is associated with powdering the gypsum and spreading it on the land. An alternative would be to break the pit run gypsum into fragments less than 6 inches in diameter which could be done by hand laborers at a cost of less than 4 rupees per ton. and place this gypsum in a watercourse where it would be dissolved by the water trickling through it and carried to the land served by the watercourse.

The feasibility of this alternative appears high on the basis of data obtained at CSU on the rate of gypsum dissolution in beds of fragments as a function of fragment size, solution velocity. and ion concentration of the water percolating into the bed of fragments. These data, including head losses, provide guidelines which can be used for designing sections of watercourses for receipt of gypsum fragments of given size ranges to achieve desired levels of Ca^{++} in the irrigation water. In areas near gypsum deposits where hauling costs would be low this alternative may reduce the price of applied gypsum to the farmer to a small fraction of his previous price.

Studies are also underway at CSU to determine the mechanism and amount of Na removal from calcareous soils resulting from organic matter additions to soil followed by flooding for leaching, which is a common practice in Pakistan. High levels of CO_2 which solubilize Ca^{++} from the soil lime. and reduction of slightly soluble ferric iron to the more soluble ferrous form are apparently major mechanisms which achieve the reclamation. Organic matter additions will be compared in the laboratory and in the field to gypsum additions in terms of efficiency and cost for reclaiming soil.

Management of water and crops on heavy clay soils

Some of the greatest potential of water management to increase food production is in the lower deltas of the great tropical rivers past which major portions of the world's unused fresh waters dissipate to the sea. Here the cropping seasons can be extended from the present single rainy season to year round including the dry seasons. with considerably higher photosynthetic potential. In general the soils of these deltas are high in clay and common water management practices do not achieve the yield potentials inherent in the "upland crops" such as maize soybeans, sorghum. cotton etc Paddy rice culture is generally well adapted to these soils However needs for balanced nutrition and cropping systems sufficiently flexible to adjust to world markets require that crops in addition to rice be grown on these soils.

Major water management problems encountered with upland cropping on these heavy clay soils have been low infiltration rates and poor aeration of the soils during wet seasons. or following flood irrigation. Means will be developed at Can Tho for maintaining large size pores in soils which would facilitate higher infiltration rates and better aeration These studies will include incorporating rather than burning (present practice) the rice straw and other plant residues, and the use of crops with vigorous deep root system in cropping rotations.

Studies at CSU indicate that adequate large size pore space can be maintained in the cultivated layers of weakly structured soils of this type if they are wetted by capillarity from furrows following cultivation, rather than wetted by flooding. These indications will be further tested in the laboratory and in the field at Can Tho to determine the best methods of irrigation optimum elevations of furrows and ridges and water in furrows, widths of ridges, etc , for water management and crop production. Companion studies of plant adaptation to these heavy soil conditions and practical irrigation and drainage procedures will determine crops which should first be introduced to the delta as water control develops.

Field scale evaluation of water management technologies and adaptation problems

Adaptive water management research cannot be considered complete until the farmers, including the smaller less advantaged farmers have accepted. and benefitted from, the proffered technology. A deficiency of many past endeavors has been that practical problems, such as lack of equipment. suspicion of the benefits claimed. and general mismatching of the technology requirements with the farmers' resources, have prevented farmers from adopting new technologies.

To make sure that our adaptive research considers all the elements essential to making the technology practicable to the farmers, provision for field scale testing of the technology and evaluating the degree to which this technology is adopted by adjacent farmers have been developed by our Field Party Chief. Dr. Corey at Mona and Shadab.

As discussed earlier. there will also be opportunities for developing variants of the technology and socio-economic facilitators which will allow small and subsistence level farmers to participate in the benefits of the water management technology.

In these areas we will have improved and dilapidated watercourses, precision leveled and rough fields, several of our most promising technologies being tested on a field scale and a multitude of farmers who will sit as final judges of our adaptive research efforts

It is recognized that much of the information gained regarding technology adoption may be specific to the culture in which we are working On the other hand. these farmers appear to respond to economic, educational and physical factors in a reasonably logical manner. which indicates that a large portion of the socio-economic facilitators will be transferable to other cultures. along with the physical technology.

Transferability of Research

Campus research and field party research

Most of our research accomplishments to date which are apparently transferable are those which have been designed to test or develop theory and have been carried out under carefully controlled conditions. These include guidelines for: Construction and operation of skimming wells, design of turnouts for routing sediment to desired locations, optimal conjunctive use of well and canal waters, flumes for measuring water under low head loss conditions, watercourse cross sections for solubilizing gypsum at desired rates, methods of irrigation to maintain large-size pore space in the cultivated layers of soils, elevations of furrows and ridges, fertilizing the ridges and water in furrows to minimize leaching of NO_3, increases in seedling emergence in soils irrigated with saline water due to P fertilization, etc.

On the other hand, it can be logically argued that until these guidelines are evaluated in the field, they have no proven value. This initial transfer from laboratory to field is essential and unless such transfer possibilities exist, the laboratory work should be deleted in favor of some other endeavor. Once successful transfer or adaptation from the laboratory to the field has been achieved, transferability to other locations is generally probable.

Yield results in the field are generally a result of a few controlled and many uncontrolled variables. Transferability to other locations often depends on the degree to which the significant uncontrolled variables are similar. To some extent this transferability can be increased by measuring the uncontrolled variables. Then we know when they are similar. When we have a measure of the effect of the uncontrolled variable (e.g., rainfall essentially equivalent to irrigation) we can often estimate effects of its variation on the results.

The improvement of transferability possible by characterizing the weather, soil, and water characteristics at the site have been recognized by CSU and USU and have resulted in their efforts to characterize these factors extensively at their field sites.

Vehicle of transfer

The present vehicles of transfer are demonstrations, movies, journal articles, CUSUSWASH reports, theses and assorted other reports, and personal contacts. A need is becoming apparent to collect and summarize the most practicable water management technologies along with the facilitators which allow their adoption to the resources of small farmers in developing countries. Such a collection, when made available in condensed form at many locations throughout the world, would give those who are trying to improve water management an advanced base from which to begin their work. Identification of the technologies in such a collection with persons who have developed, adapted and improved them would also allow persons with problems to make contact with persons with experience and facilitate the technological transfer Production of an "on-farm water management manual" to accomplish these purposes is under serious consideration by CUSUSWASH.

Vehicles of transfer, such as publications, must generally be accompanied by convinced and dedicated personnel on the receiving end who will champion the technology in the new arena until it has had a fair trial. Part of this "personnel" component may be imported along with the technology, but eventually key persons from the new country must develop sufficient faith in the new technology that they will bring about its utilization. Information is needed on the best procedures for training and motivating such persons. Possibilities include: Training in the U.S., field experience in his own country under the direction of an experienced practitioner of the new technology, and selective travel and study in a third country where the technology has been adopted.

Teaching aids are needed which will aid these apostles of the new technology in spreading their gospel. For instance, we have produced two movies on land leveling and their utility should be evaluated. Sets of colored slides, accompanied by either "canned texts" or suggested texts to be used by the presentor when addressing different types of audiences should be developed to illustrate basic principles involved in water management, the benefits of improved water management and how to go about obtaining these benefits. Such sets of slides could be collected and texts suggested by members of our field parties and our campus personnel in the course of their studies.

5.

UTAH STATE UNIVERSITY–INSTITUTIONAL DEVELOPMENT PROGRAM

H. B. Peterson[1]

Introduction

Before assessing the accomplishments of the University it would seem appropriate to review the program objectives and project criteria of AID and Utah State University's proposal

Program objectives - 211(d)

"The Institutional Grants Program has for its purpose the development of the competence and expertise of U.S. research and educational institutions to deal with critical problems of economic and social development in less developed nations. There are certain identifiable shortages of properly trained personnel and gaps in knowledge and skills that restrict AID's efforts to carry out its programs of assistance in these countries. The Institutional Grants Program is designed to overcome these deficiencies. Individual projects are designed to serve the program needs of AID without a requirement for providing specific services. Institutional Grants are thus to be used to strengthen 'centers of competence' within educational and research institutions to build long-range resources in depth rather than to procure services for AID for specific limited purposes."

Project criteria

"An Institutional Grant Project must have built-in research, training, and advisory components. The creation of special capability in a particular area of knowledge about economic and social development must include the relevant technology and the capacity to pass it on to others. The capacity developed by the institution in its field or fields should enable it to do the following.

a. Develop capability in research

b. Develop capability in training; and

c. Put itself in position to provide consulting services.

Although it is AID's intention to require the Grantee to provide *ad hoc* informal consultant services directly under this institutional development grant. AID would expect, as the need arose to contract with the Grantee to obtain training and consulting services from the center of competence at the Grantee institution, once that center has become sufficiently established to provide such services without disruption to the work of the center. Thus AID would expect the Grantee to service, subject to agreement on compensation or other terms and conditions, AID requests for expert personnel to undertake short or long-term consultancies or contract work in the LDC's and to provide research services as requested."

Utah State Proposal

Title

Optimum utilization of water resources for agriculture with special emphasis on "on-farm water management."

Summary of proposal

The existing competency of the University as a center for world-wide training in irrigation and drainage will be further strengthened by this grant By securing and training additional essential professional staff, key staff members will be able to focus more attention on the irrigation problems of the less developed countries. The grant will make it possible to expand the basic program of teaching and research and to apply the research findings to world irrigation problems. It will provide support for graduate students and, thus, create additional professional strength and competence in the area of "on-farm water management" It is a natural complement to the existing research being conducted for AID. It will also provide for augmentation of the library holdings dealing with world irrigation and drainage practice

Utah State University has a vital interest in building on its long tradition of teaching, research, and service to the public regarding irrigation problems. Increased competence in this area will make it possible to serve better the less developed countries and respond to requests for assistance from all concerned in the basic resource development of these countries.

General objectives and scope

The major objective of the grant program is to increase and expand the existing competence of Utah State University in the science and technology concerned with "on-farm water management" with emphasis on the moisture environment on the farm as related to the special characteristics and problems of the less developed

[1]Professor and Head, Department of Agricultural and Irrigation Engineering, Utah State University

countries. Increased competence will be developed in the teaching and research activities as follows:

1. Expand its full time professional core staff which will focus its teaching and research activities on the technical disciplines which relate to maintenance of a proper moisture environment on the farm under less developed country conditions. These include irrigation and surface and subsurface drainage. Irrigation and drainage are complex arts requiring the application of the best knowledge of water, soil, climate, and crop sciences and engineering. Existing courses in this area will be re-evaluated and restructured as appropriate. New graduate courses, special short courses and seminars will be developed as required.

2. Expand its research in less developed countries to increase the knowledge and understanding of subjects such as water requirements of crops, moisture-fertilizer-crop response, management of irrigated soils, drainage requirements, salinity, water quality, movement of water in soils, methods of water application, management of irrigation water, and water-crop-soil system analysis.

3. Expand its total library holdings in irrigation and drainage and related disciplines, especially, foreign and international publications, so as to become a center of information on world irrigation and drainage practices.

While Utah State University has considerable on-going competence in these areas at the present time, the expanded full-time professional staff courses of study, library information, and research will enable the University to respond much more adequately than heretofore to requests concerning agricultural related water management problems from such entities as: USAID/Washington, USAID Missions, other state and federal agencies, other universities, educational groups, foreign governmental agencies, foreign water management institutions, local irrigation and drainage institutions, various business groups, farm groups, and interested private citizens.

Summary of Accomplishments

In reviewing the objectives and the accomplishments made during the first four years of the program, we find that the University is largely achieving the goals established as objectives.

The following paragraphs give some ideas of the activities and the impact that the 211(d) grant has had on the capability of the University. It is committed to excellence and leadership in the technical area of "on-farm water management" and to its extension to the developing countries in order to increase food production. We recognize that developing agriculture is probably the most effective way to generate capital and best fulfill distributional objectives in developing countries.

Professional staff

During the period 211(d) has supported in part acquisition of the following new staff members:

Dr. Jose Alfaro, a promising young irrigation engineer whose native language is Spanish. His services are very much in demand throughout Latin America.

Dr. E. Joe Middlebrooks, Division Head of the Environmental Engineering Department and distinguished environmental engineer, has given special attention to on-farm water quality problems.

Dr. Chris Lewis, a promising young agricultural economist specializing in agricultural water management.

Mr. Kenneth Bach, an irrigation engineer and teacher with broad international experience. Last month Mr. Bach accepted a two-year assignment for WARDA in Monrovia.

Mr. William I. Palmer, an economist with many years experience in agricultural water management including serving as Assistant Commissioner, U.S. Bureau of Reclamation, with AID and as head of the agricultural division of a large international consulting firm. Retired June 30, 1973.

Dr. David James, a very competent young specialist in irrigated soils. He is conducting research in El Salvador and Logan. He and a 211(d) student, William Rubink are working on the soil problem in Colombia.

Dr. Robert Hill, a promising young civil engineer with considerable farm irrigation design experience. He is teaching irrigation principles and conducting research in systems. At present he is working with the KPP model.

Dr. Jack Keller, specialist in sprinkler and trickle irrigation, has been associated with the University on a part-time basis for a number of years. Dr. Keller has extensive experience as a consultant in the United States and abroad. The 211(d) grant has permitted the University to retain a larger share of Dr. Keller's time, not because of increased funding capability, but because of the new opportunity for increased quality that commanded his interest and particularly because of the increased opportunities in the international development arena.

Dr. Larry King, was hired concurrently from the Battelle Institute, a general contractor for Atomic Energy Commission at Richland, Washington. Dr. King, though still in his early thirties, has already gained a national reputation both as a theoretician and a practical engineer specializing in the flow of water and solutes through soils. Even though Dr. King was not supported by 211(d) funds, it is very doubtful that the University could have commanded his services without the new strengths and promise implied by the 211(d) recognition.

Dr. James Thomas, a plant scientist, has been given some support to identify dryland grasses that will survive and produce under minimal moisture conditions. Dr. Thomas is fluent in Spanish and has been in Bolivia for four years.

Teaching

In addition to the appointment of new staff members that participate in the instructional program, the staff has been involved in the revision of many of the existing courses and the addition of new ones.

The following are examples of new courses that have been developed within the last year with the assistance of the 211(d) grant:

Agricultural Planning and Administration in Developing Countries.

Fertilizer Technology for Irrigated Crops.

Soil and Water Conservation and Waste Treatment.

Water Development in Latin America (taught in Spanish).

Drainage Principles.

Drainage Investigations and Design.

Teaching aids have also been improved. A 100-slide series with English and Spanish narration has been prepared to cover the history and development of sprinkler irrigation.

Under partial 211(d) sponsorship, John Merriman (of California Polytechnic Institute), Jack Keller, and Jose Alfaro have completed the text for a monograph on "Irrigation System Evaluation and Improvement." This will be test-taught during the coming year prior to final revision and publication. Both English and Spanish language editions will be published.

Nine chapters have been completed by Jack Keller and A. A. Bishop on Surface and Sprinkler Irrigation. This material is now being classroom-tested. A publishing company is interested in printing this text but no commitments have been made.

Dr. Raymond W. Miller, of the Soils and Meteorology Department, has joined Dr. H. B. Peterson and Dr. Komain Unhanand of the Agricultural and Irrigation Engineering Department in writing a monograph on the state-of-the-science pertaining to management of heavy soils. This is now in draft form and is being reviewed. Draft material has been reviewed by Colorado State University, for possible use on the Mekong River project.

Chris Lewis, Jay C. Andersen, Herbert H. Fullerton, and B. D. Gardner have completed the manuscript for a book, "The Role of Water in Regional Development," under partial support of the 211(d) grant. The manuscript is currently undergoing final editing. The book will total about 250 pages and will be published by the Lexington Press within a few weeks.

Dr. Glen Stringham has prepared the final draft, now under review, of an elementary manual on "Irrigation Fundamentals" to be used primarily for short-course instruction in developing countries.

Library improvement

The grant supplemented by additional University funds has enabled us to greatly improve the quality and quantity of the library holdings directly related to water management. New and old holdings have been made more readily available. A bibliography of 13,000 titles has been completed and is being published. All publications are now available for use by students, staff and visiting scholars. Largely as a result of our special program, the general attitude of the library staff has been improved as has the general utility of the library.

The Department of Agricultural and Irrigation Engineering also maintains a specialized library concerned with water rights and water law in Latin American countries. It contains microfilm cards or microfiche and has more than 450 books on the subject. This is one of the most comprehensive water law microfiche libraries available in the United States or South America. Many of the books are otherwise available only in the South American countries or in government libraries.

Language training

A total of 73 staff members, wives, and graduate students have received training in Spanish. Most completed the advanced course. In the area of water management, 19 staff members are now capable of lecturing in Spanish. Three of the staff have competence in Portuguese. This competence is especially valuable to the program and to staff members assigned to Latin American countries for research or consulting, or when teaching short courses or participating in seminars.

All of the U.S. graduate students receiving assistance from the program have obtained language training and of the 14 that have completed the program, seven have accepted work in foreign countries or are employed by companies doing consulting business in foreign countries. One is being cleared to conduct a short term investigation for us in El Salvador.

The staff in agriculture and engineering are cooperating in offering a Master's degree program to be taught in LDC's. Most of the courses will be taught in Spanish.

Research

While our research program relating to development is separately funded by grant AID/csd-2167, the 211(d) program has complemented and added intellectual support to that program. It has helped researchers by providing additional preparatory training in some cases and language training in most. It has been our objective to have the graduate students do their thesis research in at least partial residence on a research project in a developing country. However, because of logistic problems this has been limited, but all have worked on development problems, usually using real field information, from on-site research efforts. Typical of research topics studied are:

> Analysis of Colombian Precipitation to Estimate Irrigation Requirements.
>
> Effect of Irrigation Frequency on the Average Evapotranspiration for Various Crop-Climate-Soil Systems.
>
> (An) Economic Appraisal of On-Farm Water Management Practice in Developing Countries. A Study of Summer Paddy Rice Production in Guayas River Basin, Ecuador.
>
> Irrigation Design and Management Related to Economics.
>
> Impact on Rural Incomes of Improved Water Management Practices in Milagro County, Ecuador.
>
> Irrigation Water Management in Ecuador.
>
> Evaluation of Wind Effects as Sprinkler Stability and Spacing Criteria (conducted in El Salvador).

As an example of a short-term field study in response to a critical problem, Dr. D. James and a graduate student William Rubink, recently returned from an assignment involving a heavy soils problem in Colombia and have, for the first time, associated this with heavy metal toxicities. Within the past year we have provided experts for AID study teams in Nigeria and Pakistan and for the current Sahelian (Africa) drought study.

Jack Keller, Dean Peterson, and Howard Peterson have proposed a systematic approach to optimizing soil and water research programs insuring maximum transferability of information. Combining this with a system of nutritional indexing and analysis for both food products and populations proposed by Gaurth Hansen of Biochemistry, leads to a suggested methodology for combined regional development of nutritional delivery systems and agricultural potential. This type of development could be more effective than more conventional ones in reaching poorer people especially those outside of the market economy.

Consulting services

As a result of the additional qualified man-power provided through 211(d) assistance, the University has been able to make available the services of many highly qualified people for short term assignments; and, in one case, to grant a two-year leave of absence to help bolster AID's technical staff in Washington. Without 211(d) support, the University would not have been able to make the temporary services of Dr. Jack Keller, Dr. H. B. Peterson, Dr. J. Paul Riley, Dr. Bruce Anderson, Professor Kenneth Bach, Dr. D. Wynne Thorne, Dr. Dean F. Peterson, Dr. Rex Nielsen, Dr. Glen Stringham, Dr. Jay M. Bagley, Dr. Jose Alfaro, and other specialists available for consulting assistance to AID and other international development donors virtually on demand, nor could Dr. A. Alvin Bishop have been spared to serve as an on-farm water management specialist for TAB/AGR. Some specific examples of consulting activities include:

At the time of this writing, the University of Arizona, Colorado State, and Utah State have provided a consulting team for CUSUSWASH to spend a month in the Philippines.

Dr. E. J. Middlebrooks was recently one of the United States representatives at a seminar on "Water Pollution Control" held in Buenos Aires, Argentina. The seminar was sponsored by OAS and the Republic of Argentina. Seminar participants were composed of two representatives from each of the American States, a contingency of six engineers and scientists from Israel and many of the international organizations and assistance programs, i.e., AID, FAO of UNESCO, Pan. Am. Health Organization, and Peace Corps.

Dr. Jose Alfaro, brought to campus mainly by grant funds, has been a frequent participant in a variety of teaching and consulting activities. In the last few months he has been involved in the following:

1. *Where:* Santo Domingo, Dominican Republic
   Date: January 22-26, 1973
   Purpose: To participate in the Symposium on Savanna Soils of the tropics.
   Activities. In charge of water management section of the Symposium. Presented two papers, one on water requirements for the

southeastern region of the Dominican Republic and the other on the role of water management on agricultural production.
For Whom: This cooperation was requested by Prairie View A&M College, Prairie View, Texas.

2. *Where:* Port au Prince, Haiti.
Date: July 13-20, 1973.
Purpose: To teach irrigation short course.
Activities: Teaching to graduates from agricultural and civil engineering universities. The subject was irrigation and drainage systems design and management.
For Whom: CIDIAT

3. *Where:* Merida, Venezuela.
Date: July 23 - August 3, 1973.
Purpose. To teach sprinkler irrigation.
Activities. Teaching sprinkler irrigation to graduate student working for an M.S. degree at the "Universidad de los Andes" in Merida. Venezuela.
For Whom CIDIAT.

The consortium

Largely utilizing new capabilities generated by 211(d), a consortium consisting of the University of Arizona, University of California, Colorado State University, and Utah State University has been formed. Known as CUSUSWASH, an acronym based on its more lengthy title, "Council of U.S. Universities for Soil and Water Development in Arid and Sub-Humid Areas," this mechanism has provided the means for inter-university coordination of agricultural water management problems. Two general meetings are held each year. In these meetings the programs and plans in the subject matter area particularly as it relates to international development are reviewed jointly by the participating scientists, engineers, and administrators from the four universities and from AID. Besides coordinating efforts in order to gain increased efficiency and avoid duplication and facilitate short-term exchange of personnel, the Council has exercised leadership in developing a unified publication policy, exchange of information, and systems analysis techniques. Short-term consulting and study teams, such as the one now in the Philippines, are usually jointly manned by Council members.

CUSUSWASH recently became incorporated as a non-profit organization directed by a board of member-University representatives. It is now in a position to enter into contracts in its own right. It can now serve as a responsible organizing agent to bring together aggregations of personnel resources of the four universities and others as needed in response to needs for both short- and long-term investigations, research, and technical assistance The consortium has also developed a close communication and working relationship with the five-university consortium on Tropical Soils, also supported by 211(d) funding.

A very effective device in translating 211(d) competence into action is our "Basic Ordering Agreement" AID/csd-3703 negotiated last February. This permits us to respond rapidly with a minimum of red tape. Under this agreement we have already provided two expert teams for water management studies in Costa Rica and in the Philippines, and have developed and arranged this international symposium on "on-farm water management" at Park City.

Theses, Publications, Manuscripts

Theses

Analysis of Colombian Precipitation to Estimate Irrigation Requirements. Jim Hardee. M.S. Thesis, 1971.

An Economic Appraisal of On-Farm Water Management Practice in Developing Countries. A Study of Summer Paddy Rice Production in Guayas River Basin, Ecuador. Thomas L. White. M.S. Thesis, 1971.

Phosphate Content of Great Basin Ground Water and Methods for Appraising Their Contamination Potential. Fredrick C Shewman. Ph.D. Dissertation, 1971.

Effects of Selected Herbicides on Perennial Grasses and Water Pollution Under Tropical High Rainfall Conditions (in El Salvador). Richard Chase. M.S. Thesis, 1972.

Impact on Rural Incomes of Improved Water Management Practices in Milagro County, Ecuador. Phillip H. Lloyd. M.S. Thesis, 1972.

Use of Sprinkler Profiles to Predict Field Performance. Michael D. Moynahan M.S. Thesis, 1972.

Computer Simulation for Change in Groundwater Elevation for Atlantico-3, Colombia. Morgan Ely, M.S. Thesis, 1973.

Evaluation of Wind Effects as Sprinkler Stability and Spacing Criteria. Lanny R. Ptacek. M.S. Thesis, 1973.

Hydraulics of Trickle Irrigation Emitter lines. Grant Hanson. M.S. Thesis, 1973.

Irrigation and Non-Irrigation Alternatives for Reducing Sugar Cane Transportation Costs in Santa Cruz, Bolivia Lee M. Bailey. M.S. Thesis, 1973.

Irrigation Water Management in Ecuador. Craig Anderson. M.S. Thesis, 1973.

Sprinkler Performance Prediction When Operated in Unsteady Wind. Thomas Young. M.S. Thesis, 1973.

Theoretical Derivation and Economic Evaluation of the Double Centroid and Computer Minimized Cost Methods of Calculating Slopes for Land Grading. Herbert A. Paul. Ph.D. Dissertation 1973

Trickle Irrigation Salinity Patterns as Influenced by Irrigation Levels and Application Rates. Phil Tscheschke M.S. Thesis. 1973

Publications

Agricultural Contribution to Water Quality Deterioration. R A Gearheart E. J. Middlebrooks. D B Porcella. Water Users Workshop. USU. 1972.

Appraising the Phosphate Removal Capability of Soil. Frederick C Shewman, H. B. Peterson. Agricultural and Irrigation Engineering/Utah Water Research Laboratory. Utah State University 211(d)-2. 1973

Biostimulation and Algal Growth Kinetics of Wastewater. E J. Middlebrooks, et al. Journal of Water Pollution Control Federation. Washington. D.C. March 1971.

Chemical and Biostimulatory Properties of Cattle Feedlot Runoff E. J. Middlebrooks, Dan Filip Submitted for publication. Utah Water Research Laboratory. 1973.

(A) Draft Research Plan Prepared by the Ad Hoc Committee Relating to the Irrigation Management Program (IMP) of CUSUSWASH. Utah State University, University of Arizona, University of California Colorado State University. July 5 1972.

Duckweed as an Indicator of Nutrient Relations in Lakes and Streams. D W James. Richard Hunter Proc 22nd Annual Fertilizer Conf Pac. N.W., Bozeman, 1971

Effect of Irrigation Frequency on the Average Evapotranspiration for Various Crop-Climate-Soil Systems. A. L. Norero. J Keller. G. Ashcroft Accepted for publication. ASAE Proceedings. 1972.

Irrigation Design and Management Related to Economics J Keller. J P Riley R. J. Hanks. Paper presented to the Irrigation and Drainage Division Specialty Conference ASCE. Spokane. Washington. Sept. 26-28 1972

Medias De Aguas En Canales Por Media Del Aforador "Sin Cuello" por J. F Alfaro. Agricultural and Irrigation Engineering/Utah Water Research Laboratory. 211(d)-1, June, 1973.

Preliminary Examination of the Do-Anambra River Area, East Central State. Nigeria. H. B Peterson, Martin M. Fogel, George E. Radosevich Agency for International Development, United States Department of State, November, 1972.

Sprinkler Profile Analysis to Predict Field Performance. Jack Keller. M D Moynahan. L. R. Ptacek. Paper presented at the 1971 Winter Meetings. ASAE

(A) Strategy for Optimizing Research on Agricultural Systems Involving Water Management. Jack Keller, Dean F. Peterson. H. B. Peterson. Agricultural and Irrigation Engineering/Utah Water Research Laboratory. 211(d)-3, July. 1973.

What About Drip Irrigation. Jack Keller, R. J. Hanks. Utah Science, Vol. 92. 1972.

Manuscripts

Irrigation Fundamentals by Glen Stringham. An elementary manual to be used primarily for short course instruction in developing countries. This was done in cooperation with CIDIAT

Irrigation System Evaluation and Improvement. by John L. Merriam and Jack Keller. (Spanish edition by Jose Alfaro.) This will be used in class during the coming year before final revision and publication

On-Farm Water Management Bibliography. Merrill Library/Agricultural and Irrigation Engineering Department There are about 13,000 titles

(The) Role of Water in Regional Development. by Chris Lewis. et al. The manuscript is undergoing final editing. To be published by Lexington Press within a few weeks. (This received partial support from 211(d).)

Surface and Sprinkler Irrigation. by Jack Keller and A A Bishop. Seven chapters completed out of fourteen. and being tried out in courses

Water Management of Heavy Soils. by Raymond W. Miller. Komain Unhanand. and H. B Peterson. This is a state-of-the-art report on current knowledge on watering and draining heavy soils.

6.

UTAH STATE UNIVERSITY – WATER MANAGEMENT RESEARCH

Byron C. Palmer[1]

Background

It is estimated that over 200 million hectares of land are presently being irrigated in the world. The annual rate of increase is about 2.5 percent or 5 million hectares per year. There are over 500 million hectares of potentially irrigable land in different countries of the world.

In Latin America, approximately 7.8 million hectares are being irrigated. The various governments report that they have definite plans to increase this to about 16 million hectares in order to help meet their increasing domestic food requirements, develop export potential and provide employment opportunities for rural workers.

The irrigation technology developed in the United States and elsewhere cannot be transferred to an LDC without, in many cases, considerable modification. Indeed, in many situations, no appropriate technology exists to transfer. Historical development--laws--customs–are different. Soils and climate in the tropics are different, as are labor and machinery co: ts.

AID, recognizing the opportunities to assist in on-farm water management, and being aware of Utah State University's historical interest in Latin America, entered into a contract with USU in June, 1968, to provide assistance in on-farm water management research using Latin America as the primary research area.

The contract specifies general and specific objectives. However, it does not describe exactly where the actual work is to take place nor the investment to be made in each program nor the priorities between programs. These questions have been dealt with by negotiation between the contractor, USAID Missions, national irrigation research agencies and AID's Technical Assistance Bureau in Washington as opportunities to dovetail mission and national priorities with the contract objectives have been identified.

In addition to identifying priority topics for research, it has been necessary to develop an approach, or way of organizing the program. Over the five years of the contract, three closely related but distinct components have become well defined. These are:

1. Identifying programs which directly relate to the specific contract objectives.
2. Carrying out the research and analyzing the results.
3. Transferring the results to the users.

One of the many interesting problems related to administration of the contract is determining what percentage of the resources made available by AID to allocate to each component.

The contractor has tried to be alert to the needs and attitudes of AID and collaborating national agencies and strike an "acceptable" balance.

Project Objectives

General objective

The general objective of this research 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 those with other good management and cultural procedures. The research under this contract is aimed at water management problems in the semi-arid lands of the Latin American region but should 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 p :s, and supporting institutional structure.

Specific o ectives

"The specific research studies will be selected to meet the high priority needs of the Latin America area. 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 ı 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.

[1] Field Director. Water Management Research Program. Department of Agricultural and Irrigation Engineering, Utah State University.

3 The development of surface and sub-surface water removal systems to eliminate the hazards resulting from surface flooding and high water tables.

4. The identification of important factors to be considered in land preparation and leveling of the various 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 The development and adaptation 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 a productive cropping system consistent with farm size and available farming practices.

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

8 The identification of institutional factors (legal social, economic, religious, manpower, credit, etc.) that influence the efficient distribution, management, and utilization of water at the farm level."

Table 1. Location of programs by objectives during initial contract period.

Location	Objective							
	1	2	3	4	5	6	7	8
Bolivia		x						x
Brazil	x	x			x			
Chile	x	x		x	x		x	x
Colombia		x	x	x	x	x	x	x
Ecuador		x						x
El Salvador		x	x		x		x	
Guatemala		x						
Honduras		x						
Peru								x
Venezuela	x	x						
Logan, Utah			x			x		

Objectives:

1. Water conservation and utilization
2. Water conveyance and delivery
3. Drainage and surface flooding control
4. Land preparation and grading for water management
5. Water application
6. Integration water use factors for crop production
7. Water quality and salinity control
8. Institutional factors—legal, economic, etc.

Accomplishments to Date, Current and Future Programs

Table 1 summarizes the types of programs and the ten countries where field work has taken place. In order to relate accomplishments to objectives, programs will be reported under the eight specific objectives described above. Some of the programs are going on simultaneously using the same research plots with accomplishments being reported under different objectives. This may create the impression that programs are overlapping or fragmented. We hope we can convey to the careful reader a sense of interrelationship between all components in the program. We are collecting pieces but there is a place for each piece in our plans.

Objective 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.

Accomplishments to date

1. *Venezuela.* Our original contract proposal included a plan for conducting research in Venezuela. Work commenced on this objective in 1969 when the contractor located Dr. Ray Miller in Venezuela through a joint agreement of USAID/Venezuela, the Ministry of Public Works (MOP) and the OAS. He was located at the MOP agricultural research station at Guanare. Shortly after his arrival, USAID closed out their Rural Development Office and the research could not be supported directly by our contract. He did, however, receive direction and technical assistance from our contract staff. We, therefore, are reporting the work accomplished by Dr. Miller and his Venezuelan counterparts. This has been included in the annual reports of the Ministry of Public Works and in eight technical reports authored by Dr. Miller. (See listing in Appendix A).

2. *Brazil.* At the Pirapora project in Brazil's Sao Francisco Valley, several tomato plots were provided with supplementary irrigation during what is normally known as the "rainy season." These plots produced above average yields while those not irrigated were a total failure because of water stress.

3. *Chile.* The research in Chile commenced in the Aconcagua Valley when drought in the country was prevalent. Results from our studies showed that by using the soils maps, deep soils could be selected to store water for future crop growth. The water could come from any "off-season" supply such as from groundwater pumping when the pumps were not being used to meet the current crop needs. Before the trials were completed the three-year drought was over and the interest of the local collaborators turned to studies on water-fertilizer-crop interactions.

4. *Future programs.* The climatological research done by J. E. Christiansen and George H. Hargreaves reported under Objective 2 has made it possible for us to significantly expand the program under Objective 1 by developing methods for estimating effective rainfall. Northeast Brazil will be our primary research area. Here water balance studies will be made. We will identify and characterize the relationships between the factors that determine how much natural rainfall is likely to fall, to run off, and to percolate through the soil, and that which will be available for crop production during discrete time periods. The objective of this program will be to develop a methodology for determining for tropical areas strategies for making the best use of available rainfall in conjunction with supplemental irrigation. Activities will include:

- Rainfall probability analysis.
- Determination of effective rainfall.
- Determination of effective water storage capacity within the active root zone for several soils.
- Determination of evapotranspiration rates for several crops under various degrees of moisture stress
- Synthesis of all of these to determine total probable available rainfall and probable irrigation requirements for some major crops in wet and in dry seasons of each year.

The results should be helpful in determining the value of supplemental irrigation in wet season production and the probable irrigation requirements for dry season cropping.

Although Northeast Brazil will be the primary test site, the methodology developed to deal with this question will be applicable in any other comparable area. We have some evidence that the methods used by some commercial companies are not satisfactory for this purpose.

Objective 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

Accomplishments to date

A significant portion of the contract resources has been used to develop a methodology for determining crop water requirements for tropical climates using limited available climatological data. Since one of the objectives has been to determine how much water to deliver to a project or a farm it will be reported under this objective even though the information is useful in meeting all of the other objectives such as how to conserve and utilize the water falling on the land.

Professors Christiansen and Hargreaves, in collaboration with students and national counterparts have, using data from several hundred meteorological stations, developed equations for determination of evapotranspiration and potential evapotranspiration in tropical climates which give much better correlation with lysimeter and evaporation pan data than do the equations developed for conditions in the United States. Their equations have appeared in a number of our publications many of which were prepared in collaboration with national and international water development agencies.

1. *Bolivia.* A report entitled "Irrigation Analysis for Selected Crops, Santa Cruz" was prepared in English and Spanish under a USAID/Bolivia contract. The portion of the report dealing with irrigation requirements was based on data collected and analyzed under this contract.

A country-wide analysis of water differences and moisture availability in Bolivia was prepared and used by the British Technical Mission in Tropical Agriculture who prepared a country-wide Land Systems Survey relating soils, geology, climate, vegetative cover and elevation to agricultural suitability and crop adaptation

2. *Brazil.* Our major efforts during 1971 and 1972 were directed toward helping the Ministry of the Interior's Sao Francisco Development Agency set up three irrigated agricultural research stations, at Barreiras, Formoso, and Pirapora. Our resident researchers, Professors Gilbert and Austin, supported by backstopping from Professors Rex Nielsen, Howard Peterson, and Byron Palmer, gave direction in the design and operation of their research plots. A representative list of accomplishments includes:

- Design and installation of sprinkler and furrow irrigation systems.
- Introduction of gated pipe to the region.
- Redesign of inefficient delivery canals.
- Design of portable checks.
- Design of an underground delivery line.
- Design of a water-holding reservoir
- Training of Brazilian technicians on how to perform infiltration and soil moisture tests.
- Water-fertilizer interaction plot design and operation

3. *Chile*. Chilean collaborator, Juan Tosso came to USU and completed a Master's Thesis on "Analysis of Chilean Meterological Data to Estimate Evapotranspiration and Irrigation Requirements," in 1972.

4. *Ecuador* The Director of the Meteorological Department of Ecuador's Irrigation Institute (INEHRI), Sr. Jose Yepes spent three months at USU and many months in his own country collaborating with Christiansen and Hargreaves. The primary objectives of our collaboration with him were twofold:

1. Determine precipitation probabilities from existing Ecuadorian data.
2. Compute moisture deficiencies and moisture availability indices for some 126 stations in Ecuador.

5. *Venezuela* A Venezuelan student, Freddy F. Rondon was assisted in his study "Estimation of Irrigation Requirements for Venezuela" by his major professor, Jerald E. Christiansen.

6. *Studies outside of Latin America*. In order to evaluate the generality of the Christiansen-Hargreaves' equations, special attention was given to their application on data collected from Iran and Pakistan.

Two Iranian students, Hossein Mirnizami and Reza Khosravi prepared, under their supervision Master's Theses on "The Relationship Between the Climate and Dry Farmed Wheat in Iran" and "Pan Evaporation and Evapotranspiration in Iran."

A review of climatic data from Pakistan (provided by Colorado State University) was made. Results compared closely with those from Latin America.

Further analyses were made of evapotranspiration–climatic relationships using data from California, Ohio, Australia, Venezuela, Israel, and other locations. Crop coefficients data were revised and a tabulation of improved crop moisture use coefficients has been completed.

7. *Future programs* We now feel sufficiently confident in the Christiansen-Hargreaves equations to utilize them in programs related to the other objectives especially the Objective 1 programs previously described.

Colorado State University has several water conveyance programs underway and proposed for Pakistan which they have described. Their data, as it becomes available, should have application in several Latin American areas, especially where irrigation has been practiced for some time.

We continue to feel a need for a simple water totalizing device which can be used by farmers to measure flow in delivery ditches and furrows. Although considerable effort has gone into this problem by a number of researchers over the years, the devices developed have been either very inaccurate or quite expensive.

We intend to try and develop a small, cheap, accurate water totalizing device. If we are successful, it could save many millions of acre-feet of water now wasted in over-irrigation and many tons of fertilizer lost through excessive leaching.

Objective 3

The development of surface and sub-surface water removal systems to eliminate the hazards resulting from surface flooding and high water tables.

Accomplishments to date

1. *Colombia* In Northern Colombia, an area between Cartagena and Barranquilla which is a closed basin, was reclaimed about seven years ago from a swamp by the Colombian Agrarian Reform Institute (INCORA) and developed as an irrigation project. Crops have not done well there yet for a number of reasons

- High water tables in some areas.
- Poor infiltration rates.
- Soil salinity.
- Probable heavy metal toxicity.

USU has, since 1969, been assisting the Ministry of Agriculture's Research Institute (ICA) to identify the problems and resolve them

A 16-hectare site was selected near the Dique Canal to develop drainage criteria and a 4-hectare area nearby was dedicated to salinity control studies. Water-fertilizer interaction plots were set up at ICA's Malambito research station and a hydrologic model, simulating the impact of alternative land uses in the area on the level of the water table, was developed. The model was of particular value in determining alternative cropping and irrigation patterns in order to control the water table until adequate drainage and pump facilities could be developed for this closed basin.

The drainage research activity included:

- Surface drainage.
- Installation of 120 observation wells and 28 piezometers.
- Installation of several hundred meters of concrete and perforated plastic pipe which was tied into open drains.

A draft report has been prepared which shows the relative effect of the surface and sub-surface drainage, gives design criteria for buried drainage lines based on the pilot plot results and indicates the tonnage of salts removed from the plots.

Much of this information is transferable, not the least of which is how to do this kind of work in a "difficult" environment.

- Piezometer tubes were repeatedly stolen until they were set in concrete.
- Irrigation schedules were frequently interrupted because of breakdowns in project pumping equipment.
- Heavy trenching equipment was available in the area but was unserviceable for long periods.
- ICA counterpart staff had a high rate of turnover due mostly to having them promoted to Project Director positions in other parts of the country.

2. *El Salvador*. In the Zapotitan Valley near San Salvador where drainage problems have built up rapidly since irrigation was begun about five years ago, we developed, through pilot studies, criteria for draining soils of volcanic origin by perforated plastic pipe as a substitute for many miles of open drains. These require high maintenance costs and have, over two or three years of operation, built up very wide cross sections, encroaching on good farm land, roads, and bridges.

3. *Mole drain research*. The use of mole drains is being investigated since they potentially have a number of features of interest in developing-country agriculture. They are useful for:

- Wet season agriculture—keeping the root zone at field capacity which usually means being able to take better advantage of natural rainfall.
- Increasing multiple cropping opportunities.
- Getting the most growing period in short season areas.

Under some circumstances mole drains are useful where leaching to control salinity in the crop root zone is desirable.

A mole plow development program was begun on the USU drainage farm in 1970 and several new plow designs have been developed with two major objectives.

1. To prolong the life of the drains.
2. To minimize the power required to construct the drains.

Two of the mole plows have been field tested in Colombia. One has been built for testing in El Salvador. Two master's theses and two progress reports have been produced.

4. *Future programs*. Field testing will continue in Central America and Utah in order to determine, for a variety of tropical soils:

- Power requirements and installation costs.
- Useful life of the drains.
- Dewatering rates.
- Optimum soil moisture for installation.
- Number of days that planting can be advanced by installing mole drains.
- Effect on crop yields.

Objective 4

The 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.

Accomplishments to date

1. *Chile*. In an experiment designed to determine whether water intake could be improved through management of the soil, various amounts of chemical and crop

residues were plowed into the soil. Plowing in 110 quintales per hectare of the previous year's corn stalks resulted in a 38 percent increase in yield. This increase is attributed to the improved ability of the soil to accept and store water Time did not permit the evaluation of the chemical treatments.

2. *Colombia.* In the Atlantico-3 project, our field staff, Professors Olsen and Fullerton, with backstopping from Professor Christiansen, investigated a serious problem of soil variability of a 400-hectare citrus orchard. This orchard is irrigated by sprinklers and was not carefully graded before the trees were planted. The soil is somewhat saline and has a fairly low permeability. This had resulted in water collecting in depressions and leaching at the salts in these areas while on the high points, moisture was wicking up, evaporating and increasing the salt concentration. Piezometers installed under Professor Olsen's supervision by ICA confirmed the diagnosis This has resulted in a clear understanding by ICA and INCORA technicians of the need to provide surface drainage and better grading in order to farm these soils. Leaching plots related to solving the high salinity in this area are described under Objective 7 "Accomplishment to date."

3 *Future programs.* Moisture control in seedbeds has been studied in conjunction with the water-fertilizer experiments carried out in Chile and El Salvador We propose to continue to investigate the impact of proper seedbed preparation on yield under irrigated agriculture in conjunction with the water-fertilizer experiments which are described in Objective 6.

We will develop an optimizing model for determining the size of plots which can be leveled by hand or with small draft animals. This is of considerable interest in Brazil where many fields are being leveled this way. Field testing will be carried out there. This program will be coordinated with CSU's precise grading research program which is designed to provide techniques for grading where larger power units are available.

Objective 5

Development and adaptation 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.

Accomplishments to date

1 *Chile.* In the Aconcagua Valley the water-fertilizer interaction experiments described under Objective 6 contained a furrow irrigation treatment This compared so favorably with the traditional wild flooding of corn that most of the farmers in the Valley have adopted the complete technological package demonstrated as a result of our three years of plot work, i.e..

Better seedbed preparation.

Increased planting density.

Furrow irrigation.

Optimum water-fertilizer combination.

Incorporation of crop residue in the soil to improve infiltration.

This has resulted in a doubling of corn production (from 3800 to 7600 kg/ha).

2. *El Salvador.* In the Zapotitan Valley, sprinkle and trickle irrigation treatments have shown considerable savings in water used on beans, tomatoes, and cantalopes. Up to 90 percent of the water was saved using trickle irrigation compared with furrow irrigation of corn with no loss of yield. Economic evaluations of alternative irrigation methods are continuing including an evaluation of the residual nitrogen fertilizer remaining for the following crop There is reason to believe that there may be more of the fertilizer remaining in the soil where furrow irrigation is used

3. *Future programs.* We intend to identify and characterize the physical factors which must be considered in deciding how to irrigate. This will be used to develop a model which will respond to the question of how to irrigate a specific crop on a particular piece of land. In addition, two components of the question "when to irrigate" will be studied. In Northeast Brazil we will continue research begun by our Professors Gilbert and Austin in 1971 when they, with the Sao Francisco Development Agency collaborators, set out field plots to evaluate the benefits of supplemental irrigation during short drought periods occurring during the rainy season. They also made a start on characterization of the variables involved in irrigating to germinate crops planted shortly before the commencement of the rainy season. This tactic offers promise of greatly increasing the effectiveness of rainfed moisture and will be further investigated.

These studies will dovetail well with CSU's Pakistan research on "irrigation timing" during sensitive growth stages.

Objective 6

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

Accomplishments to date

Reference has been made to water interaction experiments being carried out. These have been one of the most visible components of our field activities and possibly the most productive.

1. *Brazil*. In Brazil, Gilbert and Austin's assignment was to introduce this type of work into SUVALE's new research and demonstration stations which they did at Pirapora and Barreiras in 1971 and 1972. The stations and information generated at the stations by our research are now being used in the training programs in preparation for the placing of farmers on the land as the brush is cleared and water provided to be used on these new lands.

2. *Chile*. In Chile, Kidman and Stutler spent three years working with local university and extension technicians, private and communal farmers in the Aconcagua Valley, a very dry but fertile valley about 100 km north of Santiago. Their work not only established the technology for doubling corn yields but also resulted in a very significant transfer of the results to users on both private and communal farms.

3. *Colombia*. In Colombia, Fullerton and Olsen, working with ICA and INCORA counterparts successfully introduced the methodology, but had difficulty in securing meaningful results in terms of water-fertilizer interaction because of the extreme random variability within plots. However, their investigations, which included sesame, soy beans, corn, sorghum and rice are showing increasingly strong evidence of heavy metal toxicity in the soil. This likelihood is of great interest to the Colombian government and is having a major impact on agricultural planning in this region. We found that irrigated soy beans and paddy rice are the most productive crops for the area.

4. *El Salvador*. Water-fertilizer interaction experiments were begun in the Zapotitan Valley in 1970 by Professor Griffin and continued by Professors Stutler and Kidman when they were moved there from Chile in 1972. This work is being done on two research stations operated by the Ministry of Agriculture's Research Department (CENTA) with the collaboration of the Irrigation Department (DGORD).

This work as already mentioned is tied in with other objectives–seedbed preparation irrigation method, water table control. A major effort is currently underway to determine the interaction of water with fertilizer, irrigation method, row spacing, planting density, and crop variety for about a dozen crops of economic interest to El Salvador.

5. *Future programs*. El Salvador and Brazil (Petrolina area) will be the major field areas for continuing the interaction experiments.

An important new component will be added. Conceptually we can think of yield response surfaces (production functions) where crop yield is a function of a number of parameters–climate, soil, topography, availability of water, method of water application including timing and amounts, etc. We intend, with the collaboration of the CUSUSWASH[2] consortium to identify and characterize the parameters which interact significantly with water. The objective is to develop a model which will respond to the questions for a particular field:

What should be grown?

What cultural practices should be used?

The model will not include some of the essential decision-making elements such as social parameters and some physical parameters which are not strongly related to water. However, these can be taken into consideration by traditional analytical methods or by others who could develop sub-routines, for example, crop disease parameters, to hook on to the irrigation model.

With the use of indigenous agricultural extension agents as key communication channels with the farmers, we expect ultimately to be able to provide a technology package to the farmer which will be an improvement over his traditional farming methods.

This is a long-range objective which has many social and economic ramifications. However, the state of the art in characterizing water-related physical parameters, modeling theory, computer science, and communications suggest that we ought now to systematize our energies toward providing even the smallest farmer with a technology package that is built on a very broad base of integrated data.

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 that will improve water and soil properties and by using salt-tolerant crops.

Accomplishments to date

1 *Chile*. As previously mentioned, a low water infiltration rate problem was solved in the Aconcagua Valley by incorporating part of the crop residue after harvesting corn in the upper 9 inches of the soil. This greatly simplified irrigating, and was a major contributor to the yield increase.

2. *Colombia*. The Atlantico project suffers from areas of high salinity. Work done previous to USU's arrival had convinced several researchers that there was also a

[2]CUSUSWASH–Council of United States Universities for Soil and Water Development in Arid and Sub-Humid areas. Members University of Arizona, University of California–Davis, and Riverside, Colorado State University, and Utah State University.

degraded sodic soil problem. However, our studies have failed to confirm this.

A dozen leaching ponds were constructed. Several were treated with gypsum. A final report is now being prepared. Indications are that leaching without soil amendments can very significantly reduce salinity in this area. We are also finding that paddy rice does exceptionally well in the leaching ponds and may provide a good income to farmers who want to reclaim saline lands while they are leaching them.

3. *Future programs.* Much more attention is being paid to getting water on the land in Latin America (and most other areas in the world for that matter) than to determining the long term effect of irrigation on the salt balance in the soil. Our work in Colombia has demonstrated successful techniques, applicable in many developing countries for carrying out, first a status study and secondly an ongoing monitoring of salt accumulation. We intend to apply these techniques in several other countries. Central America has several areas where salinity is, or soon will be, limiting yield. Negotiations are in progress with ROCAP (AID's Central American Regional Office) to identify priority areas where we can further develop the research techniques.

Objective 8

The identification of institutional and policy factors (legal, social, economic, religious, manpower, credit, etc.) that influence the efficient distribution management and utilization of water at the farm level.

Accomplishments to date

1. *Water rights and water law.* A water law digest was prepared centered in the Andean Pact countries with Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela providing the main source of the field data. Nearly 30,000 pages of water law data were collected from United States sources and taken to Quito, Ecuador, for analysis and comparison with the field data. A detailed water law digest is now completed for the Andean Pact countries. Draft copies of the publication are available in both English and Spanish and have been distributed to the appropriate government agencies in the countries concerned. A seminar is planned to review the publication and identify the laws and/or water rights which tend to restrain or facilitate good on-farm water management practices. The seminar is planned for Quito, Equador in January, 1974.

2. *Future programs.* The primary uses of the digest will be to assist legislators in identifying the facilitators and inhibitors to efficient water use in their own countries and in showing them how neighbor countries have dealt with these problems. CSU is developing similar data for countries where water use is based on Islamic law. These two programs will be used to develop a number of reports and an international seminar dealing with Anglo-Saxon, Spanish, and Islamic water law.

3. *Economics.* The development of yield response surfaces must include an economic evaluation before farmers will use it for decision making. In preparation for the development of the models described earlier, and in response to Mission and host country priority requests, we have evaluated and reported on the economics of various technological levels of rice farming in Ecuador and dairy farming in El Salvador. Considerable economic benchmark data has been accumulated from the Latin American countries previously mentioned. This is an integral component of all of the programs outlined and will be used increasingly as all new and adapted knowledge is subjected to the critical question of "is its introduction the best economic alternative available?"

Technology Transfer and Utilization

A major strategy to ensure technology transfer has been to involve national agencies (Appendix B), national researchers and extension workers to the highest degree possible in all of the research activities. In every country where we have had any type of activity, indigenous research, development and extension agencies look upon the work we are doing as an integral part of their own priority programs. Some of the places where we have been working, such as the north coast of Colombia and at the isolated Sao Francisco River stations in Northeast Brazil have been far from ideal from the point of view of a classical researcher whose goals are high output with a minimum of frustrations. But they were top priority areas for national governments and USAID Missions, so we have responded to the country and Mission priorities within the terms of the contract.

The measurement of utilization has, in a formal sense, been beyond the scope of this contract. However, some informal indications have been given under the "Accomplishments to date" headings which should indicate the rather high degrees of early utilization of results, at least in the countries where the field work is taking place.

USU and CSU are studying the need to publish jointly an irrigation manual which would be designed to aid national water management researchers in their activities.

We will propose to AID that the two universities conduct a travelling research seminar to further facilitate the transfer and utilization of the technology.

Appendix A

Publications prepared and planned

The following list describes manuscripts, publications, and reports prepared and being planned using resources provided by this contract. In most of the references cited other resources have been involved through data collection, assisting in the field research, actual publication of a report, etc. In order to assist reviewers of this report in understanding the linkages generated at the reporting level, the following coding which appears at the end of each reference, is provided.

(A) Data collected, report written and published using contract resources primarily.

(B) Report in thesis form only. Student supervision by professional staff associated with the contract. Copies available on request.

(C) Report published using contract resources in which local water-involved agencies collaborated.

(D) Report published by another agency. Data generated and analyzed by contract funds appears in the report.

Crop water requirements

1. Analysis of Colombian Precipitation to Estimate Irrigation Requirements. 1971. M.S. Thesis, Hardee, J. E. (B)

2. Investigaciones Sobre Evapotranspiracion y Requerimientos de Irrigacion. (23 page report with 13 maps.) 1970. Instituto Geographico Nacional (El Salvador C.A.) (D)

3. Irrigation Requirements in Latin American Countries. Second World Congress of Engineers and Architects, Tel Aviv, Israel. December, 1970. (Published in ITCO Review Vol. 1, No. 2, April, 1972, pp. 40-50.) Christiansen, J. E. and Hargreaves, G. H. (C)

4. Analysis of Venezuelan Data to Compare Computed Evaporation, Potential Evapotranspiration and Evapotranspiration Deficit. 1970. M.S. Thesis, USU, Rujirakul, S. (B)

5. Estimation of Evaporation and Evapotranspiration in Colombia. 1970. M.S. Thesis, USU, Stutler, R. K. (B)

6. Analysis of Chilean Meteorological Data to Estimate Evapotranspiration and Irrigation Requirements. 1972. M.S. Thesis, USU, Tosso, J. (B)

7. Estimation of Irrigation Requirements for Venezuela. 1972. M.S. Thesis, USU, Rondon, F. F. (B)

8. The Relationship Between the Climate and Dry Farmed Wheat in Iran. 1972. M.S. Thesis, USU, Mirnizami, H. (B)

9. Pan Evaporation and Evapotranspiration in Iran. M.S. Thesis, USU, Khosvaui, A. R. (B)

10. The following three reports were prepared by Professor George H. Hargreaves and published by UNDP-World Meteorological Organization–Proyecto Hidrometeorologico Centroamericano.

    a. Necesidades y Requerimientos para Irrigacion, Arenal y Vecindades, Costa Rica. Published by PHCA (D)

    b. Necesidades y Requerimientos para Irrigacion, Comayagua y Vecindades, Honduras. Published by PHCA (D)

    c. Deficiencias de Agua en Centro America y Panama. In press by PHCA. December, 1972. (D)

11. Irrigation Requirements and Climatic Evaluation for Venezuela. 1971. Christiansen, J. E. and Hargreaves, G. H. (C)

12. Requerimientos para el Riego de la Cana de Azucar. Santa Cruz, Bolivia. 1971. Hargreaves, G. H. (D)

13. Irrigation Analysis for Selected Crops, Santa Cruz, Bolivia. 1972. (Also available in Spanish.) Bolivian Utah State/USAID Study Team. (D)

Papers and reports in preparation

14. Requerimientos Hidricos de la Region Sud Oriental de la Republica Dominicana, Hargreaves, G. H. and Alfaro, J.F. Paper presented at the Symposium on Tropical Savannah Soils, Santo Domingo, Dominican Republic, January 22-26, 1973. (C)

15. Irrigation Requirements and Ground Water Development Paper prepared for presentation at the National Ground Water Symposium, Sao Carlos, Sao Paulo, Brazil, No. 27 - December 1972. Hargreaves, G. H. (C)

16. Groundwater Extraction and the Water Balance (A)

17. Irrigation Requirements for Grasses Including Turf. Hargreaves, G. H.

Drainage

18. Irrigation and Drainage by Mole Systems. Progress Report, 1972. (A) Progress Report, 1971. (C) Unhanand, K.

19. Effects of the Shape and Speed on Soil Resistance of the Mole Plow. 1971. M.S. Thesis, USU, Kasap, R (B)

20. Durability of Double Mole Drains. 1970. M.S. Thesis, USU. Sukwiwait, A. (B)

21. Mole Drainage Construction Optimum Moisture Content and Corresponding Power Requirement. 1970. M.S. Thesis, Polparsi, K. (B)

22. Irrigation Projects in Guatemala, Observations and Recommendations. 1972. Christiansen, J. E. and Olsen, E. C. III. (C)

23. A Theory of the Combined Mole-Pipe Drainage System. Spring 1972. M.S. Thesis, Kadir, T. N. (B)

24. The Performance of a Combined Mole-Pipe Drainage System. Fall 1972. M.S. Thesis, Tuamsangiem, K. (B)

25. Performance of Combined Mole-Pipe Drains in Heavy Soils. Fall 1972. Unhanand, K. (A)

Economics of agricultural water management

26. Public Irrigation Projects, Wind-fall Gains and the Distribution of Income. Summer 1972. Proceedings, Western Agricultural Economic Association. LeBaron, A. Whitaker, M., and Wennergren, B. (C)

27. Economic Aspects of Irrigation from Ground Water 1972. Presented at the Brazilian National Ground Water Symposium, University of Sao Paulo, December 1972. Hargreaves, G. H. (C)

28. Relative Rates of Return to Controlled Irrigation Among Classes of Summer Paddy in the Guayas Basin in Ecuador. May 1972. Department of Agricultural Economics, USU, M.S. Thesis, Aitken, P. (B) & (C)

29. Impact on Rural Incomes and Improved Water Management in Milagro County, Ecuador. May 1972. Department of Agricultural Economics, M.S. Thesis, USU. Lloyd, P. (B) & (C)

30. The Effect of Increased Water Supply on Net Returns to Dairy Farmers in Sonsonate, El Salvador. May 1972. USU. Whitaker, LeBaron, Wennergren, and Glenn. (A)

31 Evaluacion Economica de Rotacion Intensiva de Cultivos en Tierras con Riego. 1972. Prepared by the Centro Nacional de Technologia Agropecuaria Direccion de Investigacion Agropecuaria, El Salvador. (D)

On-farm systems analysis

32. A Hybrid Computer Model of a Hydrologic System within the Atlantico-3 Area of Colombia, South America, Progress Report. June 1971. Riley, J. P. and Israelsen, E. K. (C)

33. Combined Surface Water–Ground Water Analysis of Hydrological Systems With the Aid of the Hybrid Computer. Published in Water Resources Bulletin February 1972. Also published in Proceedings of International Symposium on Ground Water, Palermo, Italy, December 1970. Morris, W. J., Morgan, N. W., Wang, Bi-Huei, and Riley, J. P. (D)

34. Hybrid Computer Simulation of Ground Water Regimes, Paper presented at Annual Fall Meeting of American Geophysical Union, December 1971. Wang, B. and Riley. J. P (D)

35. Computer Simulation for Change in Ground Water Elevation for Atlantico-3, Colombia. 1972. M.S. Thesis, Ely, M. S. (B) & (C)

36. A Computer Model for Simulating Ground Water Table Elevations. Riley, J. P. and Wang, B. (A) (Manuscript only)

37. Irrigation of Community Gardens in Panama. Christiansen, J. E. (A)

Project progress reports

Water Management Research in the Arid and Sub-Humid Lands of Less Developed Countries.

38. Annual Progress Report, June 1968–October 31, 1969 (A)

39. Second Annual Progress Report, November 1, 1969–October 31, 1970 (A)

40. Third Annual Progress Report, November 1, 1970–October 31, 1971 (A)

41. Fourth Annual Progress Report, November 1, 1971–October 31, 1972 (A)

Water quality and salinity control

42. Estudios de Recuperacion en los suelos de Textura Ligera y Mediana de Proyecto Atlantico-3, Colombia. 1971. Watts, D. G. (C)

43 Report on Aquatic Weed Control and Water Quality Study in the Zapotitan Valley, El Salvador. 1971. Chase, R. E. (B)

44. Effect of Agricultural Use on Water Quality for Downstream Irrigation Use. Christiansen, J. E. (B) (In preparation)

Water application techniques

45. A Pipe Bend Flow Meter for Measuring the Flow of Water From a Well. 1971. Griffin, R.E. (A) (Manuscript)

46. Sub-Irrigation in the Zapotitan Valley, El Salvador. 1971. Griffin, R. E. (C)

47. Sprinkler System Distribution Evaluation Using the Superimposed Method. 1971. Griffin, R. E. (C)

48. A Study of Wind Velocity Profile at Santa Cruz Experiment Station, Venezuela. 1970. M.S. Thesis. Gutierrez, O. (B)

49. Sprinkler Profile Analysis to Predict Field Performance. 1971. Published by American Society of Agricultural Engineers, St. Joseph, Michigan. Keller, J., Moynahan, M. D., and Ptacek, R. L. (D)

50. The Use of Sprinkler Profiles to Predict Field Performance. 1972. M.S. Thesis, Moynahan, M. D. (B)

51. Irrigation with Siphon Tubes. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., Guilarte, T., and Chavez, E. (D)

52. Manejo Integral del aqua en la Produccion Agricola. 1973. Paper presented at the Symposium on Savannah Soils in the Tropics, Santo Domingo, Dominican Republic. Unhanand, K. and Alfaro, J. F (A)

Water interactions with other variables

53. On-Farm Water Management Research in the Aconcagua Valley, Chile. Third Annual Report, 1971-72. Kidman, D. C., Stutler, R. K., and James, D. W. (C)

54. Interim Report of Water-Soil-Crop Interaction Experiments in Chile. 1970-71. Kidman, D. C. and Stutler, R. K. (C)

55. Irrigated Corn Production Studies in the Zapotitan Valley, El Salvador. 1972. Griffin, R. E. (C)

56. Corn Studies in Los Llanos, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., Martinez, E., Bustillos, A., Gonzales, A., and Guilarte, T. (D)

57. Irrigation-Fertility Studies with Caraota. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., Martinez, E., Chavez, E., Bustillos, A., and Guilarte, T. (D)

58. Effectos de Differentes Niveles de Riego y Fertilidad y Cultivo del Arroz. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., and Bustillos, A. (D)

59. Investigations of Sugar Cane Growth in Las Majaguas, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., Bustillos, A., and Guilarte, T. (D)

60. Summary of Cambur Study; The First Nine Months. 1970. Prepared in Spanish and English by Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., Martinez, E., Gonzales, A., and Guilarte, T. (D)

61. Irrigation-Fertility Studies with Cambur. 1972. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University. Miller, R. W., Martinez, E. Gonzales, A., Guilarte, T., and Chavez, F (D)

62. Research Activities in Water Use and Soils in Los Llanos, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes, and Utah State University Miller, R. W. (D)

Water law

63. Water Legislation in the Andean Pact Countries—Digest and Comparative Study. Daines, D. R. (D) (Spanish and English)

64. Irrigation Distribution Organizations in Ecuador. 1973. M.S. Thesis. Anderson, D. C. (B)

Examples of reports planned for future publication

65. Land Drainage and Soil Reclamation Procedures in Arid and Sub-Humid Areas of Developing Countries

Using as an Example the Atlantico-3 Project, Colombia. 1973. Olsen, E. C., and Christiansen, J. E.

66. The Selection of Irrigation Method in a Wet-Dry Tropical Area Using as an Example Several Areas of El Salvador. 1974. Hansen, G. and LeBaron, A.

67-70. Water-Fertilizer Interaction on Crops—El Salvador. 1974. Kidman, D. C., Fullerton, T., Stutler, K., and James, D. W.

71. Increasing Efficiency of Soil Moisture in Northeast Brazil. 1975.

72. Determination of Water Storage Capacity for Several Tropical Soils. 1975.

73. Report on the Design of a Water Totalizing Device for Use in Small Irrigation Ditches--Progress Report. 1975.

74. Mole Drains—Their Range of Usefulness and Limitations, 1976.

75. How to Calculate the Best Plot Size for Hand and Animal Land Leveling for Basin Irrigation, 1978.

76. The Economics of Alternative Irrigation Methods, 1978.

77. Optimizing Model to Decide When and How to Irrigate, 1978.

78. The Relative Effect of a Number of Climatic Factors on Evapotranspiration in the Tropics - Thesis, 1976.

79. Water Law--Its Constraints and Facilitators in Irrigated Agriculture, 1976.

Water From a Well. 1971. Griffin, R. E. (A) (Manuscript)

APPENDIX B

Institutions Collaborating with USU Research Program

Country	Institution	Primary Role of Institution
Brazil	Ministry of Agriculture (MINAGRI)	General agricultural development
	Coordination of International Affairs (ICINGRA)	Coordinates collaborative agricultural programs with foreign agencies
	Secretariat of International, Economic and Technical Cooperation (SUBIN) of the Ministry of Planning and General Coordination	Coordinates on a country-wide basis international technical programs
	Department of Agricultural Research (DNPEA)	Supervises agricultural research in MINAGRI
	Institute for Agricultural Research for the Northeast (IPEANE)	Responsible to DNPEA for agricultural research
	Ministry of the Interior (MINTER)	General development
	Sao Francisco Development Agency (SUVALE)	Semi-autonomous agency development resources of Sao Francisco watershed area
Chile	Minag. Dept. of Research Minary Extension Dept. (SAG)	Studying many aspects of agricultural research. Develops technology transfers methods to farmers
Colombia	Colombian Agrarian Institute (ICA)	Operates agricultural research stations throughout country
	Colombian Institute of Agrarian Reform (INCORA)	Administers Agrarian Reform Act and supervises irrigation projects
Ecuador	Min. of Hydraulic Works	Operates irrigation projects
El Salvador	Minag. Div. of Research	Operates experiment station
	Minag. Div. of Irrigation	Operates irrigation projects

7.

COUNCIL OF U.S. UNIVERSITIES FOR SOIL AND WATER DEVELOPMENT IN ARID AND SUB-HUMID AREAS

Bruce H. Anderson[1]

The Council of United States Universities for Soil and Water Development in Arid and Sub-Humid Areas (CUSUSWASH) is composed of: a) Colorado State University, b) the University of Arizona, c) the University of California, and d) Utah State University. The Council is incorporated under the Utah Nonprofit Corporation and Cooperative Association Act. As a legal entity it can enter into contracts, receive grants, and otherwise become involved in programs of development.

As indicated in the title, major emphasis tends toward soil and water development, but the Council is not limited to this field alone. It can become involved in any and all aspects of development and at any level as determined by the Board of Trustees.

The development of CUSUSWASH has been a two-fold process. The first development being that of formulating a charter and agreement between the interested universities to define the purpose and objectives. The second step was that of formalizing the Council to the extent of its becoming a corporate body through which to conduct its business.

Purpose

The original goals and objectives of establishing a consortium of universities was based upon the interests of the United States through its Agency for International Development *to assist the developing countries.* It was anticipated that this assistance would require an increased level and competence of manpower resources. Also, a broader interdisciplinary type of approach to the solution of development problems in agriculture would be required. This in turn would necessitate better information and knowledge about the application of science, technology, and institution building in the areas where work would be done.

The interested universities were concerned to determine the technical needs of the various Lesser Developed Countries and regions in arid and sub-humid areas. How these needs would be met offered challenge and opportunity to the faculty and staff and hopefully benefits to the cooperating nations.

The specific objectives of the Council as listed in the original Charter and Agreement are as follows:

1. Seek ways to mobilize the respective capabilities and strengths of the member universities in order to provide the most effective program to meet their objectives.

2. Provide means by which the members may effectively discuss philosophy and objectives and exchange information which would enhance their common goals in development of arid and sub-humid agriculture; and cooperate in developing special educational programs such as seminars, conferences, visiting lectureships, etc., especially in LDC's.

3. Provide professional staff capability for preliminary assessments of programs and institution-to-institution relationships in order to facilitate development of specific programs in LDC's, to improve coordination among programs, and to enhance their technical excellence.

4. Assist in the development of uniform administrative procedures and provide coordinative assistance among the members regarding educational offerings and contractual and grant programs.

5. Provide a mechanism for possible exchange of students, staff, or graduate credit among the members in the relevant disciplinary areas where this is desirable.

6. Represent and assist the members on common items of interest before AID and in LDC's as agreed upon by the members.

With the interests of the universities identified and objectives set for the Council, and with the anticipation of participating in the program of the United States through AID, the Council was formed. Formal action to establish CUSUSWASH was accomplished in 1967 with three universities participating, namely: Colorado State University, University of California, and Utah State University.

Negotiations with AID resulted in two of the three charter members of the Council contracting to do water

[1]Executive Director, CUSUSWASH, Utah State University, Logan, Utah.

management research in selected areas of the world. The contracts were directly between each university and AID since CUSUSWASH *per se* was not a legal entity and could not enter into contracts. Negotiations with AID and the member universities also resulted in the awarding of grants to increase the competence of each university in its overseas endeavors. Colorado State University and Utah State University were selected to receive contracts and grants.

The University of Arizona had expressed interest in joining the Council and was brought into membership at a later date. Negotiations between AID and University of Arizona also resulted in a grant to that institution to improve its abilities and expertise in the area of watershed management.

Organization

The Council was organized with two representatives and two alternates to be appointed by the President of each university. It was anticipated that these representatives would reflect the broad interests of the engineering and agricultural sciences, the behavioral sciences, and the international programs and studies groups on each campus. A chairman would be elected from among Council members and also a secretary-treasurer. Each university was entitled to one vote and majority rule governed decisions.

The charter also allowed the Council to employ an executive director and such other staff as may be necessary to carry out the program. The Council may appoint committees and task forces for various purposes and allocate funds to finance its operations.

The original organization framework served the initial years of CUSUSWASH and many activities and programs were carried on by the member universities by inter-university committees or *ad hoc* arrangements. Concurrent with this development was the catalytic environment of AID representatives encouraging and at times insisting on a more coordinated, integrated effort between and among the member universities. Each university had to account for its own contract obligations with AID, but there was a serious effort made to consolidate and integrate reports to show a total effort in the area of water management research. It will not be the purpose of this paper to deal with the problems involved in operating research programs in developing countries, but rather to show the evolution of CUSUSWASH and its purposes up to the present time. The accomplishments of each university have been presented in other papers and will not be discussed in detail.

The second step in the evolutionary process culminated in the act of incorporation in 1972. Three universities were the basis for the corporate body of CUSUSWASH, Colorado State University, University of Arizona, and Utah State University. The articles of incorporation indicate that the corporation shall consist of six trustees, two from each university, the presidents of the respective universities being the incorporators. Shortly after the incorporation took place, the University of California joined the corporation bringing to four the member universities.

The Council decided, prior to its incorporation, that its needs would best be served by hiring a part-time executive director. The pressure of work and the detail of overseeing and coordinating the committees, reporting of activities on an integrated basis to AID, all demanded more time than part-time help could provide. Later, due to the same pressures, agreement was reached to provide an executive director for the time required to effectively carry out the purposes of CUSUSWASH, Inc.

The purposes of CUSUSWASH, Inc. have been broadened to provide whatever flexibility is required to do work of any kind in development of arid and sub-humid agriculture. Included would be educational programs, credit and non-credit courses, seminars, conferences, visiting lectureships, etc., especially in developing countries. The purposes as listed are quite lengthy, and are so stated to provide opportunity to CUSUSWASH to enter into agreements, contracts for specific work, receive gifts and grants, do research, training or whatever is agreed upon by the Board of Trustees. The basic limitation to the activities of CUSUSWASH is that imposed by reason of its status as a non-profit corporation as defined by the Act pertaining to such corporations.

Scope of Work

The activities of CUSUSWASH have changed somewhat since incorporation. A contract has been signed with an educational institution in Mexico for a cooperative program in research and development. Several proposals have been written and submitted for consideration to a number of agencies. The range of these proposals involves feasibility studies for a particular area; a pest control program for a country; a proposal including rainfed agriculture, animal protein production, training program and rural and village industries; and computer-based information coordination and dissemination for CUSUSWASH institutions. Many of these proposals are very recent, and offer a great many opportunities for service to a rather wide segment of the participating universities. Water management is an important factor in some of the proposals providing opportunity so that knowledge can be disseminated and assistance provided to peoples who desire to use it.

The Future

The universities involved in CUSUSWASH have indicated their interest and desire to be involved in worldwide development. The incorporation of the Council provides the mechanism whereby CUSUSWASH can do business with agencies such as AID, IBRD, IDB, ADB, Foundations such as Rockefeller, Ford, or Kellogg, other international credit or development bodies and interested countries and their agencies in furtherance of the programs of the corporation as agreed to by the parties concerned. The commitment made, the mechanism and organization formulated, CUSUSWASH looks forward to the future in anticipation of contributing something worthwhile to the developing world.

In return, it too hopes to benefit by what it learns from the interchange between its staff and those with whom they work. Hopefully the understandings which accrue through a mutually beneficial understanding of peoples and their problems will weave its way into the classrooms, into teaching, into research, and into living in today's world.

APPENDICES

APPENDIX A

GUIDELINES FOR SPEAKERS AND PANELISTS

SYMPOSIUM

AID's Role in On-Farm Water Management Research and Implementation

Park City, Utah

October 1-8, 1973

Guidelines for Speakers and Panelists

I. General statement

A. Purpose

"Thoroughly evaluate the agricultural water management problems of the developing countries taking into account the present research information that is available not only in AID projects but to other projects and to see how this fits into a world network to identify the gaps; and, secondly, to focus upon the interrelationships of the Colorado and Utah water project and how these relate to supporting each others' objectives and how the findings are applicable to similar problems among the various LDC's." (From Agenda of Water Management Consulting Panel Meeting, March 22-23, 1973.)

B. Objectives

The principal objectives of the seminar are to answer the following questions with regard to *research* on on-farm water management for both irrigated and rainfed agriculture.

1. What is the present status of knowledge throughout the world with respect to on-farm water management problems?

2. How is this knowledge being applied throughout the developing world and what are the major lacks of knowledge for its adaptation in the various parts of the world?

3. Who is doing what to help solve the remaining problems?

4. Are there breakthroughs which can be general or are all water problems site-specific?

5. If there are generalizable problems, how may these be approached in an interdisciplinary framework as needed?

On Friday, the Symposium will give attention to the program of centrally-funded AID research in the context of the foregoing questions.

C. Scope

Reference should be made to the earlier prospectus for additional information on background and philosophy of the Symposium.

Our primary concern is research directed to how to increase the agricultural productivity of water. Following Barlowe[1] we may wish to consider our discussion in terms of three framework categories:

1. The physical and biological framework.

2. The institutional framework.

3. The economic framework.

A fourth consideration is the total *system* itself, i.e., the integration of the three frameworks. In our discussion we may find it useful to think about Questions 1-5 in terms of each of the three frameworks and of the system as a whole.

[1] Jack Keller; Dean F. Peterson; H. B. Peterson. A Strategy for Optimizing Research on Agricultural Systems Involving Water Management. Utah State University. 211(d)-3. 1973.

II. Operational procedure

A. Typical daily schedule

8:00 to 12:00 a.m. Prepared papers with questions from the participants.

12:00 to 1:00 p.m. Lunch.

1:00 to 3:00 p.m. Individual study and informal group discussion.

3:00 to 5:30 p.m. Discussion by panel. This will be followed by a round-table discussion with all of the participants.

Evenings: Special group or individual assignments as necessary.

B. Prepared papers

These are intended as position or issue papers. They should be prepared in advance. If convenient. 60 copies may be brought to the Symposium or if a good copy can be mailed to the Office of International Programs, Utah State University, Logan, Utah, 84322, to arrive prior to September 25, 60 copies will be made for use of the participants; otherwise, we will reproduce them at Park City.

Papers should not exceed 15-20 single-spaced typewritten pages, briefer if possible, and should be typed on 8½ x 11-inch paper with 1¼-inch left hand margin. One reproducible copy should be provided to the Conference secretary.

Authors should be prepared to make an oral presentation of their papers in 20-30 minutes leaving adequate time for questions and discussions.

C. Panels and discussions

The purpose is to identify and document the most important points under the day's question. Full consensus may not be reached, of course. The Panel Chairman will be responsible for organizing the various issues raised by the authors and others into an orderly fashion and for arranging a balanced discussion of them. The Chairman and rapporteur should condense and summarize the day's work including recommendations to be presented by them to the group on Monday, October 8. Saturday and Sunday are reserved for this purpose if necessary and Chairmen and rapporteurs may wish to arrange supplementary conferences with individuals or groups as desired. Consideration should be given to AID's role and to those of other international agencies for efforts for which an international effort seems fruitful.

III. Program

A Question 1. In what phases of water management are we adequate or deficient in knowledge?

Each author is requested to identify the main problems and levels of adequacy or deficiency based on his knowledge or experience. These may be classified under the headings suggested in Paragraph 1C above. Since the time is too short to permit an exhaustive review, the author should draw on his expertise and experience to identify the most important or constraining problems.

He is requested to comment on the degree to which these problems must be solved specifically site by site, at the country level and to what degree they can be generalized. He should make appropriate comments on possible research approaches.

If possible, a compendium of the important research institutions and their specialties in the area may be included.

The Panel should discuss and assign priorities to the various problems raised and add others that they deem important. They should assess the potential for generalized research in contrast to site-specific research in each case.

B. Question 2. How can results be implemented in developing countries?*

Each author will draw on his experience to suggest devices for putting what is already known and new research results that may be obtained into practice. He may wish to discuss policy, organizational and institutional arrangements and the effectiveness of these. How do national goals of income distribution, employment, etc., enter into the picture? How can community effort be mobilized? How effective are pilot farms, extension and demonstration efforts, etc.? Are there researchable problems in the implementation phase?

The Panel may add to the experience of the various authors and attempt to identify the most effective strategies of implementation. It should consider the researchability of the question in general and at project and country level and may comment on desirable research programs, improved means for extending knowledge and for interaction.

*Sequence of Questions 2 and 3 have been interchanged from the original prospectus.

It should identify the most promising areas for international research or interchange of information and may wish to comment on organization and approach.

C. Question 3. What is the nature of the research to be done and where and how should it be conducted?

This discussion will overlap Question 1. Speakers should respond to the results of the discussion on Question 1 as much as practical, but will probably wish to prepare an advance paper as well. Particular attention should be given to what must be site-specific and what can be generalized. Authors may wish to mention existing institutions and their capability in research.

The Panel may amplify or supplement the specific issues or points raised by the authors. Attention should be given to possible organization, communication and data systems, types of research institutions needed, etc. The Panel chairman should insure that the Panel discusses all of the important points, especially the deficiencies, identified under the discussion of Question 1.

D. Question 4. What are the constraining problems to conducting and implementing research?

This question really contains two general topics: Constraints on conducting research and constraints on its implementation. The line the papers may take will depend upon the experience and interest of the individual authors. Two authors are AID research project directors, while two are concerned with implementation. Each author may concern himself with one facet of the general question rather than attempting to cover it comprehensively. While a paper should be prepared in advance, authors should adapt or supplement their comments so that they are responsive to discussions of Questions 1, 2, and 3.

The Panel may add aspects of the general question omitted by the authors and could address itself to ways to deal with constraints on conducting research by: a) Countries, b) international organizations, c) AID. This discussion might help identify the circumstances under which AID or an international agency might be most effective in research. It also needs to discuss constraints to implementation and could consider how changes in institutional arrangements, policy, etc., might avoid constraints and how removing constraints to implementation might be research.

E. Question 5. AID's program of centrally-funded research and institutional development in water management.

This discussion is designed to present AID's philosophy and legislative responsibility vis-a-vis centrally-funded research and institutional development and the operation of this program in relation to Missions, host countries, and other international agencies (Paper A). The next four papers are designed to describe specifically the development and research program of the three universities who are supported by AID central funds in the water management field and the operation of the integrating and coordinating consortium, the Council of U.S. Universities for Soil and Water Development in Arid and Sub-Humid Regions (CUSUSWASH). The latter four papers should include a description of objectives and specific activities with consideration given to relationship to the discussion topics of the previous four days. Some information should be given on logistics both for the research program and for the long-range effectiveness of the 211(d) grants. Paper F should describe, in a similar way, the objectives and efforts under AID's Tropical Soils program especially as it interfaces with water management.

The Panel should raise questions and judgments regarding the design, operation, and coordination of the program as it relates to the backdrop of the past four days' discussion, whether or not the priorities are correct; what changes in objectives or strategy, if any, might be desirable considering in particular what might be AID's best role utilizing its centrally-funded resources. The Panel might further consider deficiencies in the global research acquisition and knowledge delivery system and what might be appropriate both through AID Mission efforts and at the international level beyond what can be done with central funding.

F. Question 6. Recommendations

The five presentations by the Panel Chairmen and rapporteurs should report the conclusions of the five previous sessions and make their recommendations. These should be carefully discussed by the Panel and participants and the content of the final report agreed upon.

IV. Assignments

A. Question 1. Monday. In what phases of water management are we adequate or deficient in knowledge?

Paper A. Southeast Asia; K. Takase, Asian Development Bank.

Paper B; South Asia and Middle East; Jerry Eckert, Colorado State University, Pakistan.

Paper C; Latin America; A. Merea, IICA, Buenos Aires. Argentina.

Paper D; Africa; Osman Ahmed Ali Fadl, Sudan.

Paper E; General; Amnon Golan, IBRD, Washington. D.C.

Discussion Panel: E. Smerdon, Chairman; A. Bishop; G. Corey; C. Breitenbach, and the above.

Rapporteur. M. L. Peterson.

The four papers will be presented in the morning. This will allow about 40 minutes for each paper plus a coffee break. Discussion will be held in the afternoon. This will be introduced by the Panel. Following this, the discussion will be opened to the entire group. The Chairman and Rapporteur will be responsible for writing a summary of the discussion, including a statement in as much detail as practical, of the important areas of knowledge and deficiency. A similar format will be adopted for the following three days.

B. Question 2. Tuesday. How can results be implemented in the developing countries?

Paper A; Implementation of Water Management in India; B. B. Vohra, India.

Paper B; A Worldwide View of Implementation of Improved Water Management; C. Houston. FAO.

Paper C; Implementation of Water Management in Turkey; K. Bozkurt, Turkey.

Paper D; Implementation of Water Management in Southeast Asia; K Takase, ADB.

Discussion Panel: C. Anderson, Chairman; L. Anderson. A. Cornejo; C. M. Bolt, and Osman Ahmed Ali Fadl.

Rapporteur: J. Keller.

C. Question 3. Wednesday What is the nature of the research to be done and where and how to conduct it?

Paper A; Research for Rainfed Agriculture; A. Abusha'er, Jordan; N. Goetze, Oregon State University.

Paper B; Research for Irrigated Agriculture; Marvin Jensen, ARS.

Paper C; Systems of Soil Classification and Their Relation to Water Management; H. Ikawa, University of Hawaii.

Paper D; Systematic Approach to Optimizing Water Management Research; J. Keller, Utah State University.

Paper E; Climate and Agricultural Production; N. Rosenberg, University of Nebraska.

Paper F; International Irrigation Information Center; J. Shalhevet, Israel.

Discussion Panel: V. Chow Chairman; K. Takase; S. Rawlins; J. Montgomery; J. Shalhevet; H. Peterson; D. Kemper.

Rapporteur: P. Hubbard.

D. Question 4. Thursday. What are the constraining problems?

Paper A;	H. Peterson
Paper B.	G. Corey
Paper C;	B.B. Vohra
Paper D;	A. Cornejo
Paper E; Constraints on the Transfer of Research Results	D. F. Peterson

Discussion Panel: Phelan, Chairman; Bozkurt; Eckert; Houston; and Heady.

Rapporteur. N. Rosenberg.

E. Friday. AID's program of centrally-funded research and institutional development in water management.

Paper A; Introduction and Background; S. Krashevski.

Paper B, University of Arizona; D. Thorud.

Paper C, Colorado State University. D. Kemper; M. Albertson.

Paper D; Utah State University; H. B. Peterson; B. Palmer.

Paper E; CUSUSWASH, Its Role and Function; B. Anderson.

Paper F; Tropical Soils Project–Interrelationship to Water Management Projects; T. Gill.

Discussion Panel: Jensen, Chairman; Krashevski; Chow; Heady; and Young.

Rapporteur: Donnan.

F. Monday - Recommendations.

Reports on questions.

1. Smerdon, M. Peterson. In what phases of water management are we adequate or deficient in knowledge?

2. C. Anderson, Keller. How can results be implemented in the developing countries?

3. Chow, Hubbard. What is the nature of the research and where and how to conduct it?

4. Phelan; Rosenberg. What are the constraining problems?

5. Jensen; Donnan. AID's program of centrally funded research and institutional development in water management.

Discussion Panel. A. Ayers, Chairman; Bishop; Merea; Boskurt; Corey; and the above.

Rapporteur: D. F. Peterson.

APPENDIX B

MINUTES
WATER MANAGEMENT WORKSHOP
OFFICE OF AGRICULTURE TECHNICAL ASSISTANCE BUREAU
AGENCY FOR INTERNATIONAL DEVELOPMENT

MARCH 22-23 1973
MARRIOTT MOTOR HOTEL - ROSSLYN, VIRGINIA

Purpose

The primary purpose of this working session was to focus on and to try to identify the issues and plans for a symposium that will thoroughly evaluate the water management problems of the less developed world, taking into account the present research information that is available not only by AID projects but by other projects and to see how this fits into a world network to identify the gaps; and secondly, to focus upon the interrelations of the Colorado and Utah water projects and how these relate to supporting each other's objectives and how the findings are applicable to similar problems among the various LDC's.

Other workshop objectives were to: (1) Review the water management problems of developing countries (background); (2) review current AID programs and policies (more background); (3) discuss AID's key problem area, talent bank, and network ideas in relation to the developing country problems; (4) develop strategies and recommendations for strengthening the TA/AGR program in the area of water management and (5) determine individual interest and availability of consultants for service and involvement.

Participants

Consultants		AID/Washington
Carl Anderson	Soil Conservation Service	AA/TA, E Long
Paul Bedardt	Gainsville, Georgia	TA/AGR, O. J. Kelley
V. T. Chow	University of Illinois	TA/AGR, A. Ayers
W. W. Donnan	Pasadena, California	TA/AGR, A. Bishop
H. Haise	Agricultural Research Service, Ft. Collins, Colo.	SER/ENG T. Thompson
M. Jensen	Agricultural Research Service, Kimberly, Idaho	TA/AGR, J Urano
J. Keller	Utah State University	TA/AGR, J Malcolm
D F. Peterson	Utah State University	
J. Pehlan	Soil Conservation Service	
N J. Rosenberg	University of Nebraska	
E. Smerdon	University of Florida	

AGENDA

Water Management Workshop
March 22-23, 1973

March 22, Thursday

9:00- 9:15	Introduction–Get acquainted–Purpose of the Conference	Dr. Alvin Bishop
9:15-10:00	TA/AGR–What it is, what it is doing, and its goals	Dr. Omer Kelley
10:00-10:30	AID philosophy of technical assistance	Dr. Erven Long
10:30-11:00	Coffee Break	
11:00-11:15	Summary and charge to Panel	Dr. Alvin Bishop
11:15-12:15	Panel and open discussion of key problem area, networks, and talent bank	Dr Alvin Ayers Mr. Michael Galli Dr Tejpal Gill Participants
12:15- 1:45	Lunch	
1:45- 3:00	General and specific water management problems of developing countries	Dr D.F. Peterson Mr John Phelan Dr. Alvin Bishop

3:00- 3:15	Questions and discussion	
3:15- 3:30	Coffee Break	
3:30- 3:50	The current and proposed water management programs of TA/AGR–Research and 211(d) grants	Dr. Alvin Bishop
3:15- 4:15	Discussion	
4:15- 4:30	General discussion –assignments	Dr. Alvin Bishop
4:30- 5:15	Group meetings	

March 23, Friday

8:30- 9:15	Group meetings	
9:15- 9:45	Water projects planned and under construction by AID	Mr. T.R. Thompson
9:45-10:00	Discussion	
10:00-10:30	Coffee Break	
10:30-12:00	Presentation of work-group reports and discussion	Workshop Groups
12:00- 1:30	Lunch	
1:30- 2:00	Discussion of plans for Symposium	
2:00- 2:30	Indication of major interest in consulting service and assistance by participants	Participants
2:30- 3:00	Revisions and finalizing reports	Workshop Groups
3:00- 3:15	Coffee Break	
3:15- 4:15	Revisions and finalizing reports	Workshop Groups

Dr. Bishop

Dr. Bishop opened the workshop by giving a brief review of some of the objectives he hoped to obtain during the ensuing two days. He then asked each participant to introduce himself.

Dr. Kelley

Dr. Kelley presented a background review of AID in general and TA/AGR specifically. He stated that AID is a line and staff operation; a line operation in the various countries and a staff operation in Washington, D.C. The Technical Assistance Bureau (TAB) is a staff operation and has a major responsibility for technical know how in the various fields in which it functions. Thus, technical assistance in agriculture deals with agricultural problems. If a regional bureau in, say Bangkok, has an agricultural problem, the TA staff in Washington would send someone out to give consultation and guidance.

The agency's modus operandi has developed as follows:

In the 1950's it was thought that what was needed was extension-type personnel to tell the people in the less developed countries "how to do it." In addition there was a big impetus toward major institution building. Out of this has come a number of good agricultural institutions but there has been little or no attendant research effort generated in the developing countries.

If a developing country has need for five or six weeks' help on a problem, TAB will furnish the help or will contract for the help through a university or federal agency. If a regional bureau agrees that research should be conducted in a given region, then TAB enters into contracts with competent universities to conduct that research.

Thus, the agency has less direct hire and a lower profile overseas. TA/AGR used to have 50 people overseas, now it has 26. The general trend is to contract for this assistance. The areas of concentration of TAB are: Agriculture, nutrition, population, and health. In agriculture the response is toward soil and water, livestock, food legumes, food grains, and agricultural inputs like fertilizers, insecticides, and herbicides. AID does not respond to assistance toward specific commercial crops such as coffee, sugar, etc., nor to forestry because of the great emphasis of FAO in these areas.

AID does, however, participate in and foster the maintenance of the various International World Centers:

Wheat and corn	- Mexico
Lowland tropics	- Colombia
Potatoes	- Peru
Rice	- Philippines
Livestock diseases	- Kenya
Livestock production	- Ethiopia
Tropical agriculture	- Nigeria
Semi-arid tropics	- India

Aid provides about 25 percent of the budgets for these centers. From these centers there radiates a world network of information, seeds, techniques, and training, making it possible for the LDC's to take advantage of the best examples. CIMA has 25 outreach programs on wheat.

Dr. Donnan

Do you think there will ever be an International Water Management Center?

Kelley

Yes, a world center could be created but I think it will be several years before it is funded. Dr. Dean Peterson has been working on this and one of the items we sent out for review "Literature Review and Discussion of Water Management in Southeast Asia," by Peterson, is a step in that direction.

When I came into TAB, there was only minimal attention directed toward water management per se. Three years ago AID decided to fund the two research projects: (1) Utah State University--working in South America; and (2) Colorado State University–working in the Far East, principally Pakistan. In addition we have had various technical assistance programs in water management. Finally we have the 211(d) program where we provide grants to three western United States universities to upgrade their departments. I think Dr. Long intends to discuss these items.

Now about the Symposium; as you know, one of our primary aims of this workshop is to try to structure it for next fall. We want to cover the broad aspects of water management. We want to be brought up-to-date on the present state of the art. What are the problems, are we focusing on them; do we have a world network in the water field; how can we start a dialog on these problems?

Peterson
What about timing for this Symposium? There are a lot of other water-related meetings in the pipeline for summer and fall.

Kelley
We would like to have it in September or October if possible. After the conclusion of this workshop I am hoping we can better decide who, what, where, and when for the Symposium.

Kelley
I would like now to call on Dr. Long to elaborate further on AID philosophy and the progress we have made in the water management field.

Dr. Long
First of all let me express a real appreciation for the assistance you consultants can give to AID in the water management field. I want to talk about the concerns AID has in this area. Three and a half years ago, a restructuring of AID created TAB, and water management became of immediate concern. The agency began to talk about water as a problem and its importance in the interaction among soil, water, and fertilizers. The agency now has a major thrust in this area with particular emphasis on farm water management. Our principal investments in water problems are as follows:

(1) Research project with Utah State University in South America. Annual funding about $500,000.

(2) Research project with Colorado State University in Pakistan Annual funding about $500,000.

(3) 211(d) grant of $750,000 to Utah State University, to increase its capability in the field of on-farm water management.

(4) 211(d) grant of $750,000 to Colorado State University, to increase its capability in the field of water conveyance

(5) 211(d) grant of $375,000 to University of Arizona, to increase its capability in the field of watershed management.

We have had some negotiations with the University of California regarding a grant to increase its capability in the field of interrelationships of water use by plants.

As you may know, the research projects have been in operation for three years, and just recently the AID Advisory Committee has renewed the projects for one more year. This committee decides the order of emphasis which AID should put on working with irrigation farm problems in preference to rainfed farm problems. This is why the Symposium will be very important. The Symposium will be held to appraise the validity of the judgment of investing in the water management problem. I hope the Symposium will look at the water management situation in the less developed countries and assist us in making our decisions for future activity by AID.

I hope the Symposium will focus on three concerns:

1. Are there breakthroughs which can be general or are all water problems site-specific? If it is not possible to research breakthroughs, then we must reorient to a country-by-country procedure.

2. If there are generalizable potentials, is there a logical integration of the five projects listed above? Do these projects complement each other?

3. If there are generalizable potentials is the character of our effort in an interdisciplinary framework? Is there sufficient concern for integration of disciplines?

Does anyone have any questions about the Symposium?

Jensen
Will the Symposium be a small group or a large open meeting? Open to the public?

Long
The meeting will be open, *per se* but will be more or less by invitation. By that I mean we will invite competent people to prepare papers and to discuss our water management program. I hope this workshop can advise us on these matters.

Keller
To what extent will the conference be supported?

Long
The people we want in attendance will be subsidized.

Peterson

Where will the Symposium be held?

Long

It could be held here; possibly this would be good because six or eight AID people would be attending.

Smerdon

Will the Symposium address itself to the three questions you raised?

Long

Yes. We need answers to these questions, but there should be other concerns which you may develop during this workshop.

Kelley

A Symposium won't ever answer specific questions, but it will give us insights into decision making. If it doesn't do that in these areas, it will have failed.

Peterson

In the overall concept of research, has AID thought about the question "How do you make the system work?"

Long

Making research work is an art not a science. The great roadblocks lie in how to get people to adopt findings which have been proven. One of the Symposium's goals might be to discover ways to motivate people to use the proven techniques. Thus we might want to have several socio-economic people at this Symposium.

I regret that press of other duties prevents me from being with you for the rest of the time during these two days.

Coffee break

Bishop

As has been stated, we want to explore the validity of some of our projects. We have asked you to review the reports of some of our projects in water management. We get many requests for assistance in this area. We use consultants and we use the technical staffs of our two research projects. I would like to have some of our Washington staff discuss our key problem areas, our networks, and our talent bank. I'll pass the ball to Dr. Ayers.

Ayers

The prior speakers have covered most of the details of our five funded programs. Regarding our talent bank; from a water management point of view we feel our consultants are our talent bank and we augment the expertise of our Washington staff with them.

Peterson

How do you get clearances for consultants?

Kelley

We have a basic order agreement with both Colorado State University and Utah State University. If we can't clear someone quickly, we can request these institutions to hire them for short-term jobs. We also have arrangements with USDA and the Department of the Interior to provide federal experts by exchange agreements.

Galli

The "talent bank" concept allows us to move into any problem area with the best available talent in the USA.

Chow

To what extent have you developed the talent bank? Have you computerized it?

Ayers

Now we have a simple card index.

Galli

At this juncture we want to have a small select listing.

Smerdon

How much do you anticipate any one individual will be requested to perform as a consultant?

Kelley

This will vary with the demand for his particular services, etc. We may request one or two week's time of a consultant or in some cases three to six months.

Malcolm

With respect to the networks, there are two different concepts in AID.

1. There is the International World Center concept. For example, the Rice Research Center has an outreach network all over the rice-growing areas of the world.

2. There is the Consortium Concept, for example, we work with CUSUSWASH (Consortium of U.S. Universities on Soil and Water in Arid and Semi-Humid Areas). The four land grant universities in CUSUSWASH are Arizona, California, Colorado State, and Utah State.

Donnan

Regarding problem areas who decides what the problem is and how do you agree that something should be done?

Kelley

The decisions are made after requests come in from the regional bureaus. We wouldn't conduct research on a problem unless it was requested by the country mission.

Dr. Kelley discussed the constraints under which the two present research projects had to function during the first two years including wars, changes in administration within the countries, disagreements on priorities, clearances, etc.

Lunch break

Bishop

Introduced Dr. Peterson and Mr. Phelan and asked them to discuss general and specific water management problems.

Peterson

One can't make generalizations, but irrigation has been around for a long time and has been institutionalized country by country. For example, Qanats have provided irrigation water in Iran for 3,000 years. We will have trouble changing ingrained cultural patterns. In the developing countries, the farmer knows how to optimize his energy (sunlight-ox-family) and make the most of the management inputs available to him. If you give him more viable inputs, of which water is one, you will upgrade his production, but you must also provide him with incentives such as roads, markets, and goods for him to purchase with his new income.

In monsoon Asia, farmers grow one crop a year. If a farmer could manage his water, he could grow two. The World Bank and others have invested billions of dollars to develop water supplies, but little has been done to upgrade on-farm water management.

There are relationships among land and water resources and the people in the developing countries. In Asia, land and water are the limiting factors; in South America, people are the limiting factor. As we strive toward better on-farm water management, these constraints must be dealt with.

Here is a list of problems needing close attention. (Peterson discussed each of the problems in some detail.) (1) Water supply; (2) land leveling; (3) flooding, (4) salinity and drainage; (5) power for tillage and harvest (without adequate power, one cannot grow two crops); (6) credit; (7) adequate inputs to the farm, the district, the nation, the international zone.

Phelan

Phelan described the problems attendant to the overall SCS type thrust made to help get agricultural technology on the land in India and Southeast Asia. One of the big problems is the compartment-type institution concept in the developing countries with little or no dialog between departments. Irrigation agriculture, forestry, power, each is often isolated from the other and ignorant of the other's operations or functions.

Many of the cultures do not react to an interdisciplinary approach. The basic information to make a detailed land use plan is often not available. Bureaucracy is not anxious to change the status quo.

Training programs should be vertical rather than horizontal. There needs to be day-to-day contact in addition to periodic consultation.

The SCS had three projects in three states in India with three languages and three cultures and each had to be tailored specifically. The biggest challenge is to find ways to apply our technology to the cultures and practices of a given country.

Rosenberg

You mentioned the variability of rainfall, what about rainfall probability prediction? We can do it; it is readily available. Couldn't this be applied?

Jensen

You are right, we know many of these things but to get people to accept them is difficult. For example, the tensiometer has been with us for 45 years, but has not yet been adopted except on a limited basis.

Kelley

Some of our sophisticated techniques are beyond adoption even in the USA.

Phelan

Group action is a bottleneck in many problems of utilization of techniques. If a farmer can put in his own well, he will do it. Yet he often shies away from a cooperative venture.

Rosenberg

What about plant modification for water use efficiency? There is considerable attention given to efficient water use, increased photosynthesis, redesign of stomates, rebuilding of the plant structure.

Bishop

Yes. These are all correlary fields of endeavor and will have to be considered in the overall problems of water management on farms.

Coffee break

Kelley

After the coffee break, Kelley led further discussion regarding the two TAB research projects on water management and the 211(d) grants; their specific problems and their progress to date. The Utah State projects in South America have made remarkable progress due, in part, to the fact that Utah State had men in the field at the time the contract was formalized and thus could begin to carry out work within the countries involved. They have experts stationed in four countries and have research underway in seven countries. The Colorado State project in Pakistan was funded and then war broke out between Pakistan and India. This year the staff in the field has finally become a full complement of four scientists.

There was considerable round-table discussion of the International Research Centers and how they function. There was considerable discussion pro and con regarding how much water management research was being carried out as a part of the on-going plant research, at say the rice center or the corn-wheat center. It was agreed that while plot work to determine water requirements was probably being carried on, that the overall factors of on-farm water management were not being considered.

Bishop

At 4:15 p.m., Bishop opened up the discourse on the three panels which he wanted to convene. He indicated the workshop would reconvene as three separate panels as follows:

1. *Panel on the Symposium.* Peterson, Urano, Kelley, Phelan, Chow, Thompson, Anderson.
2. *Panel on Water Management in Irrigated Land.* Bishop, Haise, Keller, Smerdon.
3. *Panel on Water Management in Dryland Areas* Ayers, Bedardt, Jensen, Donnan, Malcolm. Rosenberg.

The charge to the Symposium panel was to try to structure a symposium for September or October, 1973.

The questions posed to the two water management panels were:

1. How can we find and document the state of the art?
2. How does the state of the art impinge on the problems of the developing countries?
3. What are the best ways to outreach?
4. What research needs to be done?
5. What modes need to be used for research?
   a. How much can be generalized?
   b. How much must be site-specific?
   c. How much can be done in USA and transposed?

The three panels met in separate groups until they were adjourned at 1730.

Friday, March 23, 0800-0930

There was a long round-table discussion by the entire workshop group regarding roadblocks to the adaptation of research findings.

Jensen

Jensen pointed out that water management is a day-by-day decision-making process rather than a seasonal or yearly decision.

Keller

Suggested that a study of the history of American demonstration farms might give insights into what to expect in the developing countries.

Smerdon

Suggested a check list might help to implement research to see that everything is included.

Chow

Indicated that science is transferable but the technology must be modified and blended. He suggested that a priority list of which problems to tackle first would help sort out the transfer of knowledge.

Donnan

Felt there would be great resistance to radical changes. Citing the example of how quickly a second generation farmer in Imperial Valley accepted new technology and how reluctantly a seventh generation farmer in Cache Valley, Utah, availed himself of newer practices.

Keller

Indicated that we tend to polarize on either space-age or stone-age technology and that someplace inbetween is where we can probably expect the best cost-benefit ratio.

Chow

In considering application of techniques to the developing countries, we perhaps should modify our cost-benefit ratios.

Ayers

What are the real priorities? Do we need research? Some priorities should come out of a sector analysis.

Peterson

Cited SCARP I in Pakistan as a good demonstration-type activity. Out of it has come a tremendous activity of private sector well installation; 10.000 per year.

Rosenberg

If you pull off the one item, water, you have a multitude of other factors which impinge on the overall problem: macro and micro climate; plant population, etc.

0940

Thompson

Reviewed the water projects planned and under construction by AID. He traced the history of the water projects program and stated that in 1962 there was a regional engineer in each of the seven regions. However, in 1972 all engineering was placed under one organization the Office of Engineering Management Services. Within this agency is the Water Resources Branch. The Office of Engineering Management Services has a two-fold responsibility:

(a) Special projects

(b) Operations (with five categories)
1. Water resources
2. Sanitary engineering
3. Telecommunications
4. Power
5. Mapping

The Water Resources Branch deals mainly with delivery problems to agricultural and urban areas. There has been a gradual reduction in water project activity over the years, due in part to activity by FAO, UNESCO, etc., and partly because the developing countries have become active in their own behalf such as Turkey, Iran, and Thailand.

Thompson described the ongoing programs in Bangladesh, Brazil, Nepal, Vietnam, Pakistan, Tanzania, Yemen, Afghanistan, Philippines, Indonesia, Korea, Laos, Thailand, and some reconnaissance work in Africa. (Thompson will append a listing of ongoing projects as a part of these minutes.)

Coffee break

After the coffee break the three panels convened in separate groups until luncheon time.

Friday, p.m.

Bishop

The entire workshop group was called into session by Bishop and it was decided that the Symposium panel should report on its findings after which discussion would be open.

Peterson

Had been chosen as spokesman for the Symposium panel and he indicated that his panel had received suggestions from the other two panels regarding possible themes and topics. From the Irrigation panel had come the following theme:

Increased World Food Production
through
Better On-Farm Water Management
(Considering dry, irrigated and drained land)

A seminar to consider existing knowledge research needs and processes applicable to a world network for improving on-farm water management practices to increase food production and income distribution on a global scale.

The Dryland panel had also offered suggestions for the Symposium as follows:

On-Farm Water Management–
Its Potential and Constraints for Meeting
Food Requirements in the Less Developed Countries

1. Identify:

a. Water management constraints in production per unit land area
b. Transferable science and technology
c. Requirements for adapting technology
d. Implementation time scales
e. Limitation of existing TA/AGR programs and policies in achieving goals

2. Develop recommendations and guidelines for TA/AGR to enhance the implementation of water management technology.

These suggestions had been carefully considered and partially incorporated into the final structure of the proposed Symposium. The Symposium panel felt that a five-day meeting should be convened. They proposed that four questions be formulated and that each question would be treated for a full day of review. Then on the last day there would be reports and summaries. For each of the first four days there would be several position papers and four or five discussors. The theme and questions are as follows:

AID's Role in On-Farm Water
Management Research and Implementation

Question Number 1: In what phases of water management are we adequate or deficient in knowledge?

Question Number 2: What is the nature of research to be done and where and how to conduct it?

Question Number 3: How can results be implemented in the less developed countries?

Question Number 4: What are the constraining problems?

Last Day: Recommendations.

It was suggested that there would be six or eight foreign experts invited who could more or less represent or bring forward ideas from the developing countries. There would be six or eight American consultants invited on the basis of their contributory potential. There would be six or eight AID people involved who would become resource people actively engaged in the Symposium debates.

Some of the possible presenters or discussors on various questions were as follows:

Question Number 1: Takase, Moorman, Peterson.

Question Number 2: Chow, Hopper, Jensen, Anderson, Kanwar, Keller.

Question Number 3: Williams, Bozkurt.

Question Number 4: Shimosaki, Vohra.

There was a lively round-table discussion regarding the structure of this Symposium and no concrete recommendations were arrived at for adopting a final agenda.

Bishop

Indicated that the recommendations would be reviewed by the TAB/AGR office and a final structure would be proposed. At that time someone would be appointed to ramrod the Symposium.

He then called on Dr. Ayers to report on the deliberations of the Dryland panel.

Ayers

Regarding the state of the art, dryland is probably the oldest farming system, and today accounts for about 80 percent of all cultivated acres. Although the practice is worldwide with evolutions in various areas to meet local conditions, the technology is probably most advanced in the U.S., especially the Midwest, West, and Southwest.

Models or management systems are nearing the operational stage. These models take into account the major factors or combinations of factors which promote or limit crop growth. Soil moisture, rainfall, snow, wind, sunlight, temperature, fertilizers, seeds, and other inputs are all taken into account in the model.

Farmers and scientists in various parts of the world have developed specific procedures for conserving and using soil moisture such as fallow planting, shelter belts, water harvest, contour terraces, stubble mulching, evaporation retardants, herbicides, etc.

The present competence rests primarily in the United States, mostly in state agricultural experiment stations and the USDA especially in the western half of the country. Other competence is scattered over the world in major centers in Australia, France, Netherlands, Great Britain, and Israel; and to a lesser extent in India, Turkey, and Tunisia.

The generalizable research can be listed as follows: Management models; production or capability goals; climatic studies with analogue situations; factors and practices to reduce evapotranspiration; depth of rooting; increased infiltration; drought resistance both architecturally for the plant and length to maturity.

The site-specific research and utilization involves adaptation of management models; adaptation of factors; modification of findings to fit the culture encountered.

Greater returns could be realized by adopting what is now apparent in the USA to the cultures of the developing countries. There are, perhaps, enough analogue soils, climates, and topographic factors in the west and southwest to cover most of the arid and semi-humid developing country regions.

The outreach can be accomplished by close tie-ins with network concepts. As an example, for rainfed wheat production, the adaptation within the developing country should be in close cooperation with the International World Center in Mexico.

The Dryland panel compiled a list of resource people who might be called upon to give consultation on the dryland problems.

Bishop

Then called upon Smerdon to present the findings of the Irrigation panel.

Smerdon

Presented the report for the Irrigation panel. This group felt that one of the important points was to continue to promote the words "on-farm water management." Emphasis should be placed on the aspect that water management is the key to increasing food production and that by refining that management technique you are utilizing a precious resource -- the developing country's water.

The research carried on to upgrade this management aspect should be adaptive research. How to adapt proven technical measures to the cultures of the developing countries–research to identify the restraints should be conducted. Research to find the best ways to change these restraints or to circumvent these restraints should be conducted.

Education and training must be carried out along with implementation. This involves impartation of knowledge all the way up and down. Those involved with water supply systems must be more aware of on-farm needs; the farmer must be trained to understand his role in the management chain. The primary target audience for any adaptive research should be the farmer.

The underlying principles of irrigation and research thereto are generalizable and can be transferred. The science of irrigation is transferable. The art of irrigation may not be transferable. There are some problems of distribution and application which may be in conflict with local institutions. These need to be resolved in the developing countries.

Research must continue until improvement is achieved. Research would involve considerable field trial and demonstration type activity. Research would involve a high degree of innovation of technology adaptive to the site-specific circumstance.

The Irrigation group felt it was not in position to comment on the adequacy of the Colorado State or Utah State contracts or whether AID was taking full advantage of the research available to them.

Coffee break

Bishop

Bishop asked for an expression from each of the consultants regarding his interest in and availability for part-time assignments.

APPENDIX C

THE INTERNATIONAL AGRICULTURAL RESEARCH NETWORK

1. International Rice Research Center (IRR)

Location: Los Banos, The Philippines (P.O. Box 583, Manila, The Philippines)

Research orientation

Multidisciplinary research intended to increase rice productivity, especially in Asia, and to improve its nutritive quality High yielding rice varieties, together with a package of management practices to greatly increase yields in important rice growing regions have been produced by combined efforts of plant breeders, pest control specialists, agronomists, soil scientists, irrigation and equipment engineers. Intensive research is underway to develop varieties with built-in resistance to pests, unfavorable soil and water conditions, and with genetic traits for improved protein content and quality, to support rice production in more of the widely differing environments in which rice is grown on a world-wide basis. Research into multiple-cropping systems and into problems of rainfed lowland and upland rice is supplemental to continuing research on rice grown under controlled irrigation.

US/AID proposes to provide about 25 percent of the operating and new capital requirements.

2. International Maize and Wheat Improvement Center (CIMMYT)

Location: El Batan, Mexico (Londres 40, Mexico 6, D. F.)

Research orientation

Established 1969 to assist developing countries to increase their production of corn and wheat. High-yielding, widely-adapted, semi-dwarf wheat varieties have been produced (building on long continued research by Rockefeller Foundation), and a package of cultural practices to exploit yielding capacity has been introduced successfully in many wheat deficient countries. Research is continuing on pest and drought-resistant variants of high-yielding varieties with improved protein content, that will extend profitable wheat culture into many additional developing countries. A parallel program on breeding corn for higher yields, improved nutritive quality, resistance to insect pests and diseases, tolerance of unfavorable soils and climates, continues to produce genetic types for plant breeders in many tropical environments. CIMMYT maintains the richest collection of corn germ plasm resources in the world for use by corn breeders in the tropics and subtropics.

3. International Center for Tropical Agriculture (CIAT)

Location: Cali, Colombia, S. A.

Research orientation

To identify and seek solutions to lowland agricultural problems in: (a) The infertile, highly acid savanna lands of Colombia and Brazil, (b) the lowlands of coastal plains and alluvial river valleys, and (c) the low mountain valleys in Latin America. Research is concentrating on beef, swine, cassava, beans, rice, and maize in agricultural farming systems. There is close cooperation with IRRI and CIMMYT. In connection with beef production, research includes attention to the forage legume, *stylosanthes guyanensis*. Additionally, there is concentration on immunization techniques for protection of livestock against hemoprotozoal disease that cause heavy losses in Latin America.

4. International Institute for Tropical Agriculture (IITA)

Location: Ibadan, Nigeria, Africa

Research orientation

Since 1968, study of problems for improvement of food production in the humid tropics, and on the soil and crop management requirements for developing a stable, permanent agriculture. Attention is focused on: (a) Farming systems for food production in the lowland tropics, (b) cereal improvement, in cooperation with IRRI on rice, and with CIMMYT on maize, (c) food grain legume improvement, with major attention to cowpeas and lesser attention to pigeon peas, lima beans, and soybeans, (d) root and tuber crop improvement with emphasis on yams, sweet potatoes, and cassava. Progress is being made in identifying strains of cereals and root crops with improved protein content: particularly the amino acid, lysine, that is generally deficient in such crops.

5. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

Location: Hyderabad, India

Research orientation

Established 1972 (a) to serve as the world center for improvement of genetic potential for grain yield and nutritional quality of sorghum, pearl millet, pigeon peas, and chickpeas; (b) to develop farming systems that will be more productive in the seasonally dry semi-arid tropics, and (c) to assist national and regional research programs in other tropical and subtropical regions.

Attention will be concentrated on farming systems that emphasize efficient soil management and utilization of rainfall for crop production.

The research staff is to be multidisciplinary, and international in character, fully assembled by 1974.

6. International Potato Center (CIP)

Location: La Molina, Peru, S. A.

Research orientation

Established 1972 to enhance world's capacity to meet goals of increased output and greater efficiency in production of potatoes for both highland and lowland tropical areas. The major projects include: (a) Development of a potato germ plasm bank for the full range of genetic variability for tuber-bearing Solanum species, (b) the development of resistance to potato diseases, viruses and insect pests, (c) the development of cold resistance, and (d) increasing the protein content of potato tubers. Completion of facilities, construction, and assembly of the international staff of research scientists is planned by end of calendar year 1974.

7. International Laboratory for Research on Animal Diseases (ILRAD)

Location: Kabete (near Nairobi), Kenya, Africa

Research orientation

This center will deal with important livestock diseases and their pathogens that occur in tropical and subtropical areas. It will undertake studies that require sophisticated facilities and specific research specialists that are generally beyond the capacity of individual countries. Such diseases are regional in their occurrence and cause severe losses of livestock if allowed to multiply unchecked.

ILRAD was scheduled for starting in FY73, but construction of facilities and assembly of the research staff will continue in calendar years 1974 and 1975.

8. International Livestock Research Center (ILCA)

Location: In Ethiopia, south of Addis Ababa

Research orientation

The initial effort will begin with the collection of information on tropical and subtropical livestock production, both published and unpublished, and the retrieval, storage, and classification of such information to serve research and development programs. The other research activities will be concentrated on techniques of rangeland management, livestock production, disease control, dry season animal nutrition, forage supplies, including supplemental forages, livestock reproductive performance, and all technological aspects of marketing. Priority will be given to cattle, sheep, goats, buffaloes, and camels, in that order. The institute will deal with production on dry ranges, in humid regions, and in mixed crop-livestock systems.

Funding of this institute was still under discussion in late 1973.

APPENDIX D

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