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# **Management-Focused Improvement of Irrigated Agriculture**



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# MANAGEMENT-FOCUSED IMPROVEMENT OF IRRIGATED AGRICULTURE

by

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## EXECUTIVE SUMMARY

Over the past five years, activities at Colorado State University (CSU) under the Water Management Synthesis II (WMS II) Project have addressed management-focused improvement of irrigated agriculture. These efforts were continuations of CSU's earlier involvement in the Pakistan On-Farm Water Management Research Project, Egypt Water Use and Management Project, and Water Management Synthesis I Project. These activities have contributed to the knowledge about and understanding of such improvement through diagnostic analysis workshops and studies, implementation planning workshops, and special studies, which have been extensively reviewed. Also included were specific efforts addressing particular questions; this paper reviews these specific efforts.

Water control for improved management at the project level has been bettered through a series of efforts. Sritharan developed computer simulation modules to consider project planning, design, and management alternatives from farm-level to project-level in an irrigation system, building on previous optimization, simulation, and design experiences (Sritharan, 1984; Clyma and Sritharan, 1984). This work uses a "bottom-up" approach by initiating planning and design at the farm level and incorporating information provided from a diagnostic analysis to improve the management of a system. It includes an optimal turnout area module, a turnout area water requirement module, a project-scale farm design module, a groundwater interaction module, a water issue strategy module, and an hydraulic simulation module. This approach is applicable for systematically improving the management of irrigation projects around the world.

The understanding gained through field studies and computer simulation studies was used to develop a design and management approach for level basins to improve farmer management of these field irrigation systems (Wattenburger and Clyma, 1988a; Wattenburger and Clyma, 1988b). This approach allows a farmer to apply specific, measured amounts of water to properly designed basins, even when water control does not exist. This approach is applicable to level basin irrigation world-wide and has the potential for substantially improving field irrigation system performance by improving farmer management.

Conjunctive use of water at the watercourse command level was considered by Choudhary (1987). Canal system management alternatives, on-farm water management alternatives, and optimal conjunctive use of groundwater were evaluated. The number of private tubewells and amount of water to supply were important variables. This approach is applicable for providing optimal private tubewell supplies to farms conjunctively with canal water. It also determines a pumping regime to control over-draft and waterlogging.

Mohammed (1987) looked at monitoring and evaluation for management decision-making at the project level. System performance parameters, criteria for acceptable levels of system delivery performance, and a

management plan were the essential components Mohammed included for improved daily management of water delivery systems. This approach provides a basis for project managers to establish goals, monitor results, and improve main system performance. The process is applicable for improving the management of all irrigation projects.

The above efforts integrate the main system with the on-farm system, focusing on a number of project-wide management needs. The application of these concepts to improving water control and irrigation project management are important results of these studies. While these studies focused on engineering, interdisciplinary approaches and strategies were explicitly included.

Two additional activities addressed the use of "high-tech" tools. One effort considered the use of satellite mapping to provide general information about irrigation projects (Martin, 1988). Digital classification of cloud-free, Landsat images proved to be a successful method for determining irrigated acreage and cropping patterns for major sub-commands. Irrigated acreage was determined to within 1 to 3 percent of other, ground-intensive methods. This approach is applicable for regular monitoring of irrigation command areas to establish cropping patterns and area irrigated.

The other activity addressed the use of microcomputers in the storage, retrieval, analysis, and use of information necessary to improve the management of irrigation projects. This effort consisted of developing and conducting workshops to provide necessary training to personnel who are expected to take advantage of computerized data management. Two types of workshops were developed and conducted: computer-assisted design and management, and irrigation data and project management. The basic purpose of these workshops was to acquaint personnel in developing countries with the use of currently available hardware and software pertinent to their needs. This approach is appropriate for improving data and project management by introducing and improving the use of computers.

## I. INTRODUCTION

Irrigated agriculture has contributed significantly to meeting development and food needs around the world, but at the same time, has not achieved its potential performance. The low level of performance and the high level of importance of irrigated agriculture suggested the need for a strategy for improving performance. Water Management Synthesis II (WMS II) Project focused on improving the management of irrigated agriculture to improve performance.

This paper summarizes new knowledge developed at Colorado State University (CSU) under the Water Management Synthesis II (WMS II) Project that is not explicitly presented in other project reports. In Chapter II, the background to this work is given in a review of some considerations in irrigated agriculture. Chapter III gives a brief discussion of the WMS II efforts addressing management-focused improvement of irrigated agriculture that have been documented extensively elsewhere. The intent of this discussion is to provide a proper context for the range of WMS II efforts in irrigation water management. Specific WMS II efforts that addressed management-focused improvement of irrigated agriculture are summarized in Section IV. These activities have not yet been adequately documented for their contribution to irrigation water management under WMS II. The discussion provides the following information about each activity:

- \* Issues addressed by each effort.
- \* The approaches taken by each effort.
- \* The new knowledge gained.
- \* Applications of that knowledge.
- \* Measured or expected impacts.
- \* Recommendations.

## **II. IRRIGATED AGRICULTURE**

### **A. IMPORTANCE OF IRRIGATED AGRICULTURE**

It has been estimated that irrigated agriculture produces roughly 33 percent of the world's food supply while representing only 18 percent of the world's cultivated land (Rangeley, 1987, p. 29). Historically, irrigation systems have been built for many reasons -- to provide insurance against drought, to suppress rebellious tendencies which tended to flare after bad harvests, to increase tax revenues, to obtain goods for foreign exchange, and to settle the landless (Freeman, 1988). Within the last 200 years, another motive has emerged -- a vision of steering societies toward economic and social development by transforming low input/low output agriculture into high input/high output agriculture. This vision includes:

1. Producing agricultural surpluses so that farmers can sell, rather than consume, most of the produce.
2. Increasing livestock numbers to provide increased draft power, meat protein, and other products.
3. Obtaining greater productivity per person per hour, liberating increasing numbers of people from farming to move to industry and to provide other services.
4. Making food and fibre a smaller part of household budgets, and so leaving resources available for obtaining the products and services of a technologically more advanced society.

This vision rests on newer technologies and organizational arrangements to harness and manage technology in agriculture -- especially irrigated agriculture (Freeman, 1988).

### **B. UNFULFILLED POTENTIAL**

In spite of its large contribution to the world food supply, irrigated agriculture has never really lived up to its potential (Clyma, 1986). Montague Yudelman (1987, p. 420), considering World Bank experience, suggested that irrigation projects seldom have met expectations. The failure of irrigation projects to fulfill their expected potential has been cited by many (Bottrall, 1978; Bottrall, 1981a, p. 67; Bottrall, 1981b, p. 122; Chakravarty and Das, 1982; Levine, 1972; Lowdermilk et al., 1978; Pant and Verna, 1983; Posz et al., 1981; Reidinger, 1974; Sharma, 1980; Steinberg, 1984; White, 1984, p. 259).

The WMS II Project has conducted intensive, interdisciplinary field studies of 14 irrigation projects in five countries. The results of these studies offer insights into the factors that contribute to the low performance of irrigated agriculture. Everywhere, the picture of poor irrigation project performance is seen with low levels of water

use efficiency, inequities in water distribution, and disappointing cropping intensities and yields (Alwis et al., 1983a; Alwis et al., 1983b; Clyma et al., 1983; Fowler and Kil Kelly, 1987a; Fowler and Kil Kelly, 1987b; Fowler and Kil Kelly, 1987c; Fowler and Kil Kelly, 1987d; Fowler and Kil Kelly, 1988; Haider et al., 1987; Jayaraman et al., 1983; Jayewardene and Kil Kelly, 1983; Laitos et al., 1985; Venkatraman et al., 1984; Wattenburger, 1987). The causes of these poor levels of performance are many, but include farmers possessing inadequate knowledge, skills, and access to services concerning the management of their individual farms; inadequate water control throughout the system; involved institutions and organizations operating under internally generated sets of objectives; and inadequate connection, both structurally and organizationally, between main systems and individual farms.

### C. PAST EFFORTS TO IMPROVE IRRIGATED AGRICULTURE

Many efforts have been made to increase agricultural production. The focus of attention in the 1950s and early 1960s was mainly on increasing irrigated area (Venkatesan, Peterson and Lowdermilk, 1987). From 1950 to 1970, the gross irrigated area of the world doubled to roughly 200 million hectares (490 million acres) (Framji and Mahajan, 1969, p. cxii; Rangeley, 1987, p. 29). By the 1970s, however, the rate of increase had begun to decline, and by the mid-1980s it had fallen off to approximately 4 million hectares per year (Rangeley, 1987, p. 29). The reasons for this declining rate include constraints associated with costs, the decline in suitable lands and available water resources, and adverse terms of trade for agriculture.

Efforts to increase the productivity of irrigated agriculture shifted from expansion to improvement in the 1960s and '70s with the "green revolution" -- the introduction of improved varieties of seed and use of fertilizers and pesticides (Venkatesan, Peterson and Lowdermilk, 1987). These efforts did meet with some success, but they still fell short of expectations. Some of this shortfall was a result of the improved seed varieties being much more sensitive to a lack of water than traditional varieties. Intensive field studies have indirectly verified this fact by showing that traditional varieties are grown at the tail ends of systems where water adequacy and reliability are uncertain (Jayewardene and Kil Kelly, 1983; Wattenburger, 1987). Farmers have found that traditional varieties produce more under stress than do new varieties. Also, the limited availability and high cost of new inputs, as well as the lack of appropriate information about them, have constrained their wide and effective usage (Wattenburger, 1987). If the water supply is unreliable, farmers are unwilling to risk investment in expensive and new inputs (Clyma, Lattimore and Reddy, 1982).

In the 1970s increased emphasis was directed towards improving the performance of irrigation projects. Performance was defined as a system's ability to deliver adequate and reliable supplies of water and provide for its equitable distribution. Most of this effort was put into rehabilitating physical works. It was found, however, that rehabilitated systems (physical improvements alone) did not achieve the reliable and equitable distributions that were intended and that they rapidly deteriorated to their pre-rehabilitation condition (Levine, 1986).



#### **D. IMPROVING THE MANAGEMENT OF IRRIGATED AGRICULTURE**

The focus on improving the management of irrigated agriculture sets the priority on improving performance. Improving the performance of irrigated agriculture requires that performance standards be established and that the current level of performance be measured. Information about actual levels of performance compared to desired performance is the basis for establishing the priority of improvement needs. Areas of lowest performance and highest potential for improving productivity and farmer well-being become the priority areas for improvement. Thus, focusing on improving management is a strategy for improving the performance of irrigated agriculture based on priority.

Improving the performance of irrigated agriculture by improving management seemed to take different approaches depending on the background, experiences, and disciplinary emphases of particular organizations. The varied experiences of CSU in conducting field studies of irrigation systems suggest that many of these approaches are appropriate, but are not complete and that completeness could be achieved with an interdisciplinary approach based on understanding the needs for improvement. This understanding would be gained from interdisciplinary field studies.

Determining which improvements to make should start by ranking problem areas according to their need for improvement and their contribution to improving irrigated agriculture. To establish priority areas, an interdisciplinary team needs to agree upon the objectives of irrigated agriculture. Then, priorities can be established based on identifying which areas of low performance are keeping the objectives from being met (Clyma, Lattimore and Reddy, 1982).

Determining priority areas for improvement requires interdisciplinary efforts to define and accomplish the improvements. For example, the water supply at the tail of a distribution system may be inadequate and undependable. The causes of this low performance may be improper designs and inappropriate management of the distribution system. However, in every instance of a system studied during a diagnostic analysis, the farmers were not properly organized to participate in effectively managing the overall system. In general, farmers were attempting to maximize their individual benefits rather than the overall performance of the system. Thus, both engineering and social-organizational issues were important. Often, other priority factors were found to contribute to the low performance of a distribution system.

The persistent areas of low performance in irrigation project management are the priority areas for research to develop new knowledge that will assist in improving management. Management as used here means "... the organization of people to accomplish stated objectives using a defined procedure according to a specific plan." (Clyma, Lattimore and Reddy, 1982). Svendsen, Merrey and Fitzgerald (1983) also suggested the emphasis of improving the management of irrigation systems.

Improving the management of an irrigation system involves defining the overall goals of the system; identifying long-term objectives which will lead to the realization of those goals; specifying short-term goals, which will combine to achieve the long-term objectives; planning specific activities to achieve the short-term goals; and determining who will be responsible for each activity. Each step of this process must focus on the defined overall purposes and related objectives of the system, and not just on an isolated part of the system. Considerations of the process should include the design and construction or rehabilitation of the physical and organizational subsystems, the maintenance of the physical subsystems and facilities, and improving the management of the total system, including effectively managing the physical, biological, and social-organizational processes in irrigated agriculture.

### **III. SUMMARY OF GENERAL WMS II RELATED EFFORTS AT CSU**

Improving the management of irrigated agriculture has been the emphasis of Colorado State University's involvement in water management over the past 15 years. This emphasis started with the efforts in on-farm water management in Pakistan (Clyma, Kemper and Ashraf, 1981) and the definition of a development model (Clyma, Lowdermilk and Corey, 1977). These efforts were a continuing focus for the CSU effort in Egypt (EWUP, 1984) and have been a major focus of graduate student research at CSU (Clyma and Sritharan, 1984; Gates, Clyma and Ley, 1981; Reddy and Clyma, 1982; Sritharan, 1984), and in the Water Management Synthesis I Project.

The above previous efforts have contributed important concepts and principles on which specific studies conducted under WMS II were based. The specialized studies reported in this paper were built on these previous experiences. Therefore, to establish the proper context for the activities discussed in Chapter IV, previous efforts are reviewed here.

#### **A. ON-FARM BEGINNINGS**

CSU's initial involvement in irrigation management improvement was the Pakistan On-Farm Water Management Research Project. This effort involved a systematic approach to improving irrigated agriculture based on detailed field studies. Prior to these studies, development projects in Pakistan had assumed that irrigation efficiencies were high (90% delivery and 85% field application efficiencies). These studies found, however, that delivery efficiencies were typically 50% to 60% and field efficiencies were less than 50% in many areas (Clyma and Corey, 1975). With the problem of low efficiencies realized, Pakistan has subsequently invested several hundred million dollars in improving on-farm water management over the last decade. The Pakistan On-Farm Water Management Project showed the need for and priorities of on-farm water management, including the need for detailed field studies to understand the system, conducted by trained personnel working in the field with farmers.

#### **B. A DEVELOPMENT MODEL**

Out of the Pakistan experience, a methodology for irrigation development began to evolve with an important emphasis on field studies (Clyma, Lowdermilk and Corey, 1977; Clyma, Lowdermilk and Lattimore, 1980). This development model consists of three phases: diagnostic analysis, development and assessment of solutions, and program implementation.

Diagnostic analysis is the study of an operating irrigation project by an interdisciplinary team to identify the priority constraints to agricultural production and farmer well-being. The focus of the study is on-farm, and farmer involvement with the team is important. The boundaries of each subsystem are expanded systematically, beginning at the farm, until a boundary of control is reached for water control, crop production, resource allocation, institutional services, and farmer decision-making (Clyma, Lattimore and Reddy, 1982).

Once the constraints have been identified, improvements are developed and assessed, again with the involvement of the farmers. Improvements from the field level throughout the canal system, and in organizations are all considered. Improvements are accepted for implementation only when their success in dealing with the priority constraints is proven and their requirements for implementation and adoption have been determined.

Implementation of improvements in a project is the final phase of the development model. Once improvements have been implemented, the development model can be applied again to make further improvements; therefore, it should be viewed as an cyclic process.

Some key aspects of the development model include farmer involvement during every phase. Identifying priority constraints and a focus on developing visible improvements are considered important to establishing trust and a working relationship with farmers. Trained personnel who accept and believe in the process are provided by retraining an existing organization or developing a new one (Clyma, Lowdermilk and Corey, 1977).

### C. DIAGNOSTIC ANALYSIS

The development, refinement and application of the first phase of the development model -- diagnostic analysis -- has been a central focus of Water Management Synthesis projects at CSU. Since 1977, the diagnostic analysis process has evolved into a strategy made of key concepts, procedures, and a methodology. Diagnostic analysis workshops, developed under the WMS I Project (Lowdermilk et al., 1983; Podmore and Eynon, 1983), were continued and improved under the WMS II Project. Sixteen workshops or studies have been conducted in five countries.

The goal of diagnostic analysis is to define the existing state of an irrigation system and identify its strengths and weaknesses. The irrigation system is usually an irrigation scheme or a few schemes. The diagnostic analysis methodology is a systematic, interdisciplinary inquiry and collection of field data for explaining irrigation system performance. Basically, the procedures followed in carrying out a diagnostic analysis include making a preliminary statement of system objectives, doing a reconnaissance survey of the system, revising the objectives and planning for the study, conducting detailed field studies, interdisciplinary data analysis and synthesis, and reporting of findings.

Manuals (Lowdermilk et al., 1983; Fowler, 1988) supplemented with handbooks, videotapes, and other materials have been developed by WMS II at CSU to facilitate the learning and use of the diagnostic analysis methodology. Thus far, the methodology has been applied in training workshops (which included field studies and reports) and long-term diagnostic analysis studies.

Diagnostic analysis was originally developed to provide a basis for systematic improvement of irrigated agriculture. The development model was suggested as a conceptual approach to improving irrigated agriculture. This systematic improvement process is still applicable for rehabilitating irrigation projects. Those aspects needing improve-

ment, as defined by an interdisciplinary team, would be dealt with -- not just the canal system or the capability to deliver water.

The significance of diagnostic analysis as a strategy for improving the management of irrigated agriculture has evolved from its initial application as a training workshop, in which a field study of a system was conducted. These initial efforts were perceived to be opportunities to train professionals in water management in an interdisciplinary, field-based understanding of irrigation systems. Bringing individuals from irrigation and agricultural departments together to study field irrigation systems has established continuing working relationships among professionals within and between involved countries. Some improvement efforts have resulted that altered the process of irrigated agriculture (EWUP, 1984) and produced limited improvements.<sup>1</sup>

The field studies of irrigation systems in different countries changed the research focus of WMS I and II and became the basis for refining a systematic process for defining systems and improving their performance through better management. The diagnostic process began to take on a structure and logic for determining how to study a system, for identifying problems and comparing them to agreed-upon objectives, for defining the cause of the problems, and for measuring the magnitude of their effects. In this process, priorities for improvement are established from these understandings, which improve performance. Thus, diagnostic analysis provided the understanding needed to initiate the improvement process for irrigated agriculture.

#### **D. SURFACE IRRIGATION STUDIES**

The understanding gained from field studies in numerous countries suggested that improving farmer decisions in the management of water applications to individual fields was a priority need. These field studies provided the basis for developing formal concepts and approaches for improving the management of on-farm irrigation systems. Design and evaluation procedures have been developed for graded border, level border or basin, and furrow irrigation systems to improve farmer management.

Gates, Clyma and Ley (1981) presented a process for evaluating and improving surface irrigation systems based on systems analysis theory. This approach describes surface irrigation in terms of on-farm water delivery, water application, water use, and water removal subsystems. The system is defined in terms of system parameters and state variables, and can then be modelled and studied to identify problems, generate design and management improvement alternatives, and evaluate those alternatives. The final step is to implement action programs with farmers for improved system performance. This approach, like the development model, is systematic and interdisciplinary in nature. The performance of the on-farm system is defined with respect to agricultural productivity and considers inputs in addition to water.

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<sup>1</sup>Some improvements resulted in Rajasthan, India, and in Bangladesh and Sri Lanka. These improvements were not as comprehensive as the results of the studies indicated.

The design of on-farm irrigation systems has been an exercise in maximizing irrigation efficiencies. Under many circumstances the most efficient system is not the most beneficial system. Irrigation systems designed to either maximize profits or minimize costs that satisfy certain specified constraints are desirable from the farmer's point of view. Reddy and Clyma (1982) presented such a design approach based on simulation and optimization concepts to improve the design and management process for level and graded borders, and graded furrows. This design procedure considers costs and benefits of design decisions, including the relationship between yield and system performance.

## **E. IMPLEMENTATION PLANNING**

The various diagnostic analysis efforts undertaken by WMS II provided trained personnel in the involved countries and detailed understandings of the projects studied. However, while these diagnostic analyses provided significant understanding, implementation of improved management based on the new understanding was difficult.

The recent efforts of WMS II in implementation planning in Command Water Management in Pakistan is another approach to improving irrigated agriculture based on the results of a diagnostic analysis study (Jones and Clyma, 1988). This approach has management and water management consultants facilitate a collaborative problem solving and planning process that encompasses developing and assessing solutions, and initiates implementation by developing detailed plans for improvements in the system and in the management of the system. Personnel of all the responsible organizations at the field and operational level, as well as at the executive and policy level, are involved in the process. Problems for which solutions are available are planned for direct implementation. Problems which need further study or testing to develop and refine solutions are dealt with by action research, as outlined in the development model. Improved performance in irrigated agriculture that benefits farmers is the focus of implementation planning.

Important concepts of this approach are that individuals and organizations can focus on achieving a common understanding of the problems to be addressed, agree on roles and responsibilities, plan how problems will be solved by a single organization or jointly by several organizations, establish inter-organizational coordination mechanisms, and receive input and support from all levels within an organization to accomplish the objectives of an agreed-upon management plan. The management plan that is developed becomes the basis for actions in the future to accomplish objectives, improve performance, and enhance capability to improve management in subsequent inter-organizational management plans.

It is believed that once the process of improving management is initiated, management will continue to improve. This evolution will be facilitated by problem solving using the power of small group processes, increased clarity of objectives and actions to accomplish objectives, improved coordination and mechanisms of collaboration, and monitoring and evaluation of system performance to facilitate making better management decisions (Jones and Clyma, 1988).

An outcome of implementation planning has been a refinement of the diagnostic analysis process (Clyma and Lowdermilk, 1988). Through the experience gained, it became clear that certain considerations are usually critical to an improvement effort, particularly water management and organizational management. Therefore, a diagnostic analysis study should focus on the considerations or constraints determined to be most important based on the objectives of the system. By focusing on priority constraints, the process of improving irrigated agriculture becomes less discipline-oriented.

## **F. SPECIAL STUDIES**

The WMS II special studies addressed the linking of main and farm irrigation systems in order to better control water (Freeman, 1988). This effort examined formal and informal organizational relationships between main system managers and farmers in their efforts to control water in irrigation systems in Pakistan (Shinn and Freeman, 1988), India (Bhandarkar and Freeman, 1988), Thailand (Paranakian, Laitos and Freeman, 1988), and Sri Lanka (Wilkens-Wells, Wilkens-Wells and Freeman, 1988).

The conclusion of this effort was that if there is any prospect for an authentic water revolution, it will come as a result of increased water control for farmers through the building of improved middle-level organizations whose arrangements satisfactorily link farms to state bureaucracies (Freeman, 1988). What is required is an organizational development process that helps organizations and individuals diagnose and overcome constraints to improving the performance of irrigated agriculture. Furthermore, the analysis of deficiencies in middle-level organizations and careful design of improved local farmer organizations between main and farm systems are activities that are strategic to the development of irrigated agriculture (Freeman, 1988).

## **G. KEY CONCEPTS**

The efforts reviewed above have been documented extensively as referenced throughout the preceding sections. The purpose of reviewing them here has been to establish the context in which further efforts have been made. This context includes a number of important concepts that have evolved from WMS II efforts. These concepts are identified below.

The first is an emphasis on improving farmer well-being by achieving the objectives of increased water control, increased agricultural production, conservation of resources, and acceptable return on investment. These objectives are the basis for defining the criteria for evaluating performance. For example, the efficient conveyance and distribution of water in main systems can be a necessary condition, but may not be a sufficient condition to achieve the objective of increased productivity. Therefore, a second concept is the need to identify and address constraints related to the specified objectives.

A third concept is that of having a farmer perspective. The farmer is the manager most directly involved with production. He must manage cropping patterns and varieties used, cultural practices and their timing,

inputs and services used, harvesting and marketing activities, as well as water application and removal -- all within the considerations of investment and income -- to produce a crop. The critical consideration is how well a farmer can manage his farm and not how closely the farmer follows the management strategy of the main system.

As a result of having a farmer perspective, a fourth concept is the need to focus improvement efforts at the farm level since the most critical management decisions related to agricultural production take place there. The fact is, all improvements must be made with a view to increasing the manageability of the on-farm system.

The complex and diverse set of factors farmers must manage are not independent of one another. Their interrelationships are often as important as their independent considerations. Therefore, a fifth concept is that of seeing irrigation as an integrated irrigated agricultural system and studying it as such.

The sixth concept relates to the fifth. If the system is to be viewed as an integrated whole, then to study it requires an interdisciplinary effort. The purpose is not to study each part or subsystem separately since the system is not simply the sum of its parts, but is an integrated whole. Therefore, all the necessary disciplines must be represented and must work together through an overall process to achieve significant and measurable improvement. This representation includes the farmers. The seventh concept is that processes such as diagnostic analysis and implementation planning, and specific concepts for improving management, can be developed, refined, and systematically applied to improve the management of irrigated agriculture.



#### **IV. OVERVIEW OF SPECIFIC WMS II EFFORTS AT CSU**

The development model and diagnostic analysis, as developed at CSU, provided an initial framework for and methodology to begin the process of improving irrigated agriculture. Further efforts have built upon this foundation. Those efforts which have been extensively documented elsewhere were reviewed in the previous chapter to establish the context for other specific efforts. This section reviews some additional specific efforts.

##### **A. PROJECT DESIGN AND MANAGEMENT**

The designs of irrigation projects have tended to focus on the main supply systems with simplistic assumptions being made about the nature of the on-farm systems they serve. The operational features of the main systems were not developed as a part of the designs, but evolved; yielding to some extent to the wishes of the farmers. Water management programs have been initiated to address the problems arising as a result of such design approaches. Many of these programs initially focused on the on-farm systems, while viewing the main system as fixed and unchangeable (Sritharan, 1984). It soon became apparent that this was an inappropriate view and that the design of main systems needed to be analyzed using the concepts developed through the management studies of on-farm systems.

As a result of such efforts, Sritharan (1984) developed an integrated design procedure for main systems in surface irrigation projects. The procedure synthesizes system operation and management with design and involves steps that previously had not been given sufficient emphasis. Clyma and Sritharan (1984) further outlined the concepts of this approach. The value of the approach is that systematic procedures have been developed using data from an interdisciplinary diagnostic analysis study and computer models to evaluate alternative planning objectives, design procedures, and management alternatives.

The structure of the approach is modular. Each module requires the input of information from the previous module (except for the first one) and from an interdisciplinary study of the system. The analysis of information and evaluation of alternatives is facilitated through the use of computer models developed for each module.

The first module determines the optimal turnout area based on the number of farmers involved, the possibility of their organization, and the probability of their cooperation (Sritharan, Clyma and Richardson, 1988a). The optimal turnout area was considered to be a compromise between increased system costs for construction and management of a delivery system for smaller command areas, and the complexity of organizing larger groups of farmers to work together to manage water at the farm level (Sritharan, Clyma and Richardson, 1988b). Criteria for evaluating farmer organizations' ability to manage, and economic costs and productivity benefits for different sized command areas were developed and applied in a case study.

The second module calculates the turnout area water requirement (Sritharan, Clyma and Richardson, 1984a). This calculation is accomplished in two steps. The first step is computing the unstressed (gross) water requirement, and the second is computing the scheduling in an optimal manner. Climatic information, agronomic and economic data related to the crops grown in the area, sociological data regarding the farmers' abilities to receive and control water, and information regarding the available water resources are all needed. The cropping practices to be used may be according to existing practices or suggested ones. These computations consider cropping patterns and schedules, groundwater levels, leaching requirements, and random variations in climatic variables. The scheduling problem for deficient or stress design is accomplished using the criterion of maximizing net benefits. The objective of this module is to describe the procedures by which the uncertainties in evapotranspiration can be accounted for, and by which, optimal depth scheduling for a multi-crop area can be calculated.

The third module determines the project-scale farm design parameters (Sritharan, Clyma and Richardson, 1984b). In this module an analysis is made as to how the scheduled depths are related to the field variables such as flow rate, time of application, and field geometry. Different field irrigation systems (graded and level border, and furrow) are considered. This analysis is conducted giving due consideration to optimizing the net benefit from the system and to the constraints the farmer may face in operating the system. Project-scale constraints and managerial decisions obtainable through the analysis are also considered. The procedure assumes initial canal parameters for the computation of conveyance losses.

The fourth module evaluates the long term effects of irrigation within a project on the water table (Sritharan et al., 1984). The purpose of this module is to evaluate the effects of irrigation system parameters on the water table and to decide on the necessity for changing farm designs and/or installing drainage arrangements. Canal losses, on-farm efficiencies, and groundwater pumpage are all considered. Plans for drainage can also be considered.

The fifth module determines water issue strategies (Sritharan, Clyma and Richardson, 1985). Continuous water issue and rotational water issue strategies, and the factors affecting the choice of strategies, were considered. This model allows the study of alternative approaches to distributing water that result in most effectively supplying the crop water requirements and the demands of farmers. Any suitable combination of continuous or rotational strategies can be adopted depending on its acceptability to project management and farmers.

The sixth and final module is a hydraulic simulation module. The objectives of this module are 1) to develop a hydraulic model of the main supply system which will enable modeling of response in the conveyance system, and 2) to use the model to find different response times so that operational schedules can be developed. The model is first used to determine the hydraulic design parameters. If those parameters are different than assumed in the third module, new parameters are assumed

and the process is restarted with the third module. Once an adequate response model and the hydraulic design of the system are complete, then the main system model is used to study operational features of the canal to improve delivery and operational features. These include delay times for increases and decreases in flow rate, procedures for operating gates to most effectively regulate flow, changes in hydraulic structures that can improve performance, and a specific detailed management plan.

The management plan is the basis for releasing flows, monitoring performance, and making improvements in management and performance. Control points for monitoring are selected, flow rates with time are specified, and gate operating procedures are defined. When operational problems are identified subsequently, the model is the basis for exploring new approaches to resolving the problem. Thus, the hydraulic model is the basis for confirming management performance and improving performance during the life of the project.

At each major step, the design of a project involves the selection of an optimum point between system performance and resources available. These optimal points are not always obtained by a process of single objective optimization. Such considerations can only be addressed through an interdisciplinary approach.

In this design procedure, project goals of equal water deliveries, equal levels of system performance, and equal returns to farmers are considered. Also, project designs consider the peak water requirements, the peak demand for water on the project, various water supplies, and the optimal design flow rate for each field dependent on the project goal.

This approach is significantly different from previous approaches to irrigation project design and management. This approach takes a "bottom-up" perspective, starting with the optimal turnout area and designing up through the system to provide both the physical structures and the management plan necessary to facilitate main system and on-farm water control. Conjunctive use planning is also considered, with control of waterlogging one of the goals. This process considers socio-economic, agronomic, and organizational requirements, as well as engineering ones. This approach can be used to design new projects or, more importantly to our considerations, plan for the rehabilitation and betterment of existing ones.

A main system management model based on this work for integrating on-farm and conjunctive use for optimal delivery of canal water was initially tested in Pakistan. Since then it has also been used to plan and design irrigation systems in Egypt. The initial efforts of CSU in modeling for planning, designing, and managing irrigation projects have shown the potential of these concepts and approaches for improving management. Further application of these management-focused approaches should improve the performance of irrigated agriculture.

Subsequent to the CSU modeling efforts, Utah State University (through WMS II) developed additional computer models to evaluate the design and management of irrigation systems. Their approach defines a

watercourse command and the fields and crops within the command. The commands are statistically defined for simulation purposes (Keller, 1987). The watercourse commands determine water requirements for consumptive use, but do not consider flow requirements for field system design and management.

The main system models provide the capability for system response and hydraulic simulation (Merkley, 1987). Additional capability for user interaction has also been provided. The main system model defines the watercourse command in terms of a time distribution of the crop water requirements. Thus, limitations exist in this model for integrating the farm and field system requirements and farmer demands into the management of the main system. The interdisciplinary definition of conditions, constraints, and inputs are not directly provided in the development of the main system model.

## **B. ON-FARM DESIGN AND MANAGEMENT**

Traditional design methods for surface irrigation systems assume that water control -- the ability to regulate the flow rate of water -- is both possible and practical at the field level. In reality, water control is not achievable at the field level in the majority of irrigation projects, particularly in developing countries. The flow rate a farmer receives from a main supply system can vary by a factor of two or more (Wattenburger, 1987). Farmers typically manage field irrigation systems without adequate knowledge, skills and services to achieve good water management. Therefore, traditional design methods do not provide a means by which the performance of surface irrigation systems can be improved effectively.

Because of the low levels of performance observed around the world, a special effort was made to develop a design procedure to facilitate farmer management of field irrigation systems. Wattenburger (1985) developed a design method whereby properly designed and constructed level basins could be managed without the requirement of water control and still achieve the desired performance. This design procedure allows a farmer using a properly designed and constructed level basin irrigation system to apply a specific, measured amount of water to a field. The farmer's criterion for this decision is a traditional one observed in many countries: the farmer irrigates until the water reaches the end of the field.

The approach used to develop this new design method was extensive computer simulations of the process. Zero inertia modeling was employed because of its accuracy and convenience of usage (Wattenburger and Clyma, 1988a). It was found that the flow rate into a basin can vary by several magnitudes and the amount applied will not vary by more than 5 to 10 percent. Not only could farmers apply specific amounts of water to a field with a regulated flow rate, but also this could be accomplished with a main system delivery of widely varying flow rates, which is characteristic of most irrigation projects around the world (Wattenburger and Clyma, 1988b).

To date, there has not been opportunity to test this approach in the field. It is believed, however, that this approach holds much promise in the improvement of on-farm water management in many countries. This approach does not assume an ability on the farmers part that they do not possess -- the ability to measure and control flow rates. Where application efficiencies are typically 50 percent or less as a result of an absence of water control, significant improvement is possible, even if optimal performance is impractical. In countries where level basin irrigation is widely used and water control at the field level is typically impractical, such as in Pakistan and India, this approach is recommended. Its use would involve designing the on-farm systems for the soil conditions encountered and the operational parameters of the main system involved. The operational parameters of the main system may need to be modified in order to facilitate the best achievable on-farm performance.

### C. CONJUNCTIVE USE

Traditionally, the water management of an irrigation project has addressed the management of canal water. Management strategies considering conjunctive use to optimize profit have not been extensively implemented. To address this issue, Choudhary (1987) formulated an optimal management model using linear programming to maximize a profit objective. This model can be used to determine the strategies for various conjunctive use management alternatives for crop production.

This model was used to develop conjunctive water management strategies for a number of water supply and management alternatives in the command area of a single watercourse in Pakistan. Three crops -- wheat, cotton and maize -- were considered over a growing period of 60 weeks. A multiplicative crop yield model was calibrated by evaluating the sensitivity coefficients for each stage of the crops. The calibrated yield model was used to predict crop yields under a given irrigation pattern and water stress levels. The irrigations were assumed to be applied in the beginning of each stage, and a uniform water stress among all the stages of each crop was adopted in the analysis. A relationship between the crop yield and water requirement was established for each crop using the predicted yield and the seasonal water requirement satisfied at various stress levels.

Linear models were fitted for more than one range of water requirement for each crop to represent crop yield in the objective function in terms of the seasonal water requirements, which were taken as the sum of the water requirements at each growth stage of the crops. The optimal crop water requirements for each stage of the crops were determined by an iterative procedure using alternative combinations of the yield-water requirement linear relations.

Aquifer response to pumping activities was incorporated into the optimal management model using the response coefficient or the discrete kernels of pumping. The discrete kernels of pumping for the hydrologic model area were generated for weekly periods of the crop year using a finite-element, groundwater flow model.

The selected aquifer was bounded on two sides by link canals. A steady state calibration of the groundwater flow model for the aquifer was completed using constant head boundary conditions, distributed recharge due to rainfall and irrigation, distributed withdrawal due to private tubewells, and point withdrawal due to public tubewells.

The optimum water requirements to be satisfied at each stage of the crops, the optimum number of wells required, and the weekly pumping strategies were determined for maximum net benefit from the watercourse command area. A number of alternatives for conjunctive use management, such as additional groundwater pumping, earthen watercourse improvement in conjunction with pumping, and watercourse lining improvement with pumping, were tested. For the system studied, a number of conclusions were drawn. These conclusions are summarized below.

The optimum water requirements were found to be different for each crop considered in the study. The pumped groundwater was found necessary to supplement the surface water supplies to meet optimum crop water requirements in all the alternatives tested. Pumping to control waterlogging can be planned, and excessive pumping that lowers the water table below acceptable levels can be controlled. Use of groundwater in conjunction with earthen improvement of the main watercourse was found to be the most profitable alternative for increasing the availability of water among all the alternatives tested. Pumping was the second most profitable means, while lining watercourses was found to be the least profitable method. However, the difference in net profit among the various alternatives was not large and was subject to variation within the cost coefficients used for pumping and improvement activities, and within the benefits derived from the improvement.

It is believed that the methodology developed in this effort can be successfully extended for application to the individual farm level in a watercourse command or to another watercourse command for developing conjunctive use management strategies. However, there are further refinements that can still be made. Further calibration and testing of the multiplicative yield model used for various crops is recommended. Also, the use of stochastic, as opposed to deterministic, characteristics of rainfall and canal water supply would be an improvement.

#### **D. MONITORING FOR MANAGEMENT**

The structural aspects of irrigation systems have long received intensive study, while the management aspects have received almost no attention. Traditionally, engineers have designed systems to meet certain fixed requirements. Generally, the concept is to design for the worst case, which does not allow for flexible operation of a system. The concepts and assumptions used in such designs account, in part, for the differences between realized and expected performance levels.

In an attempt to improve performance, monitoring was established on systems to provide information for making management decisions. As a result of these efforts, offices have been filled to overflowing with information records. These efforts have typically failed badly, however,

because inadequate consideration was given to what information was needed; how it could be gathered; who could most effectively gather it; how it was to be stored, retrieved, analyzed, and interpreted; and how it was to be used, by whom, to make what decisions (Wattenburger, 1987).

Mohammed (1987) sought to provide tools to monitor a conveyance system and make adjustments to attain better performance. The approach taken was first to develop and define parameters that describe the performance of an irrigation conveyance system and are useful for day-to-day management of the system. Second, a theory for monitoring the operational performance of an irrigation conveyance system using performance parameters was developed and tested. Third, a management plan that could be used to maintain and improve the performance of a conveyance system was presented and examined.

To maintain or improve satisfactory performance, an evolutionary management plan is presented. The major outcome of the management plan is that managers are required to formulate a plan that will result in the accomplishment of stated objectives. The plan is evolutionary in that the manager can adjust operational steps to continually improve performance. Also, operational actions are adjusted to conform to the dynamic nature of the system. Statistics are used to study performance over the project. Location and number of measurements needed in the monitoring and evaluation phase of the plan are important considerations. The feedback phase of the plan provides for adjustments in management based upon specific information.

This approach was tested on an irrigation system in northern Colorado. Also, a system in Baluchistan, Pakistan, was studied, and its performance without a formal management plan was evaluated. It was concluded that the following theory is practical: a system can deliver water dependably and equitably when a management plan containing appropriate feedback for monitoring and evaluation is used by system managers.

The management plan outline and structure provided a basis for planning within a system having a system manager and an adequate plan. Establishing goals for selected control points and feeding information back to management provided the necessary basis for improving management. The definition of performance parameters and levels was useful for defining the needs for performance improvement and is the basis for defining system performance in other systems. Monitoring and evaluation for management should be applied in other irrigation projects around the world to improve their performance.

## **E. SATELLITE MAPPING**

In an effective process for improving an irrigation project, an extensive amount of reliable information is required. Some of that information is extremely difficult, time consuming, and costly to obtain through traditional methods. One example of such information is accurate and sufficiently detailed maps of the irrigation system and land use. Accurate maps that include irrigated acreage data and type of crops are essential for effective rehabilitation and improvement, as well as management of an irrigation system.

Martin (1988) undertook to provide such basic data for four irrigation systems in Sri Lanka. The basic data required were the location and aerial extent of current and historic (designed) irrigation subcommand areas, and accurate, detailed maps of irrigation distribution systems.

An early assumption was that this basic information would be supplied, to the extent possible, by digital processing of satellite images and analysis by a computer-based geographic information system. However, upon initiation of the field investigation, relatively recent, high quality aerial photographs were discovered that covered most of the study area. This source was considered superior to the relatively low resolution satellite images as a source for some of the required information.

There was still interest in alternative computer-based techniques for similar areas in Sri Lanka and Asia where aerial photography is not accessible or is not cost-effective to obtain. It was decided that the basic data acquired under the primary objective would be used to assess the use of these alternative methods. Therefore, the secondary objective was to investigate the utility of computer-based geographic information systems and processing of satellite images to rapidly assess and monitor an irrigation system. If satellite image processing methods were successful in this study, the methods could be extended to other irrigation systems in similar areas.

The conclusion of this effort was that digital classification of cloud-free Landsat images was a successful method for determining irrigated acreage of major subcommands. Overall classification accuracy was 85 to 90 percent, while irrigated acreage was determined to be within 1 to 3 percent of other, ground-intensive methods.

High resolution, Systeme Probatoire d'Observation de la Terre (SPOT) satellite data are now available for Sri Lanka. These data are recommended for use in similar studies where higher resolution is required, such as mapping distribution systems and assessing specific field conditions. For determining gross irrigated acreage, it is uncertain that higher ground resolution would result in area estimates more accurate than that obtained with Landsat MSS (multi-spectral scanner), but site-specific accuracy may be improved.

Once a digital data base is established within a geographic information system, it can be used for further analysis of baseline conditions and for monitoring and evaluating irrigation system improvements. With the database developed in this study, for example, irrigated acreage for individual distributary channels or field channels could be quickly computed by a digital overlay of the service area boundaries. Water requirements could also be determined by another overlay with soils, cropping patterns, and related spatial data.

A computer-based, automated sampling procedure was used successfully in the Sri Lanka study. The information provided has subsequently been used by the Government of Sri Lanka and USAID in the implementation of a rehabilitation project. This procedure has since been used in Egypt,



also, under another USAID project to obtain maps of the command areas and information identifying command area problems. This second application has been even more successful because of the reduced clouds and better quality data that were available.

## **F. COMPUTER APPLICATIONS**

To introduce various potential applications of microcomputers in water management, the "Microcomputer-Assisted Design and Management of Irrigation Systems Workshop" was developed at CSU and was conducted jointly by CSU and USU staff in Bombay, India, in February 1987. This workshop was designed to demonstrate the capabilities of microcomputer software for use in irrigation system design and management, to assess the applicability of microcomputers for a specific project, to identify groups for training, and to recommend microcomputer-related training courses to meet particular needs in irrigation system development.

Both formal and informal exchanges among the participants contributed to an increased understanding of microcomputer technology. Specifically, the workshop participants suggested the following factors to consider when introducing microcomputer-assisted improvements in irrigation water management:

- \* As the first step, there is a need to develop the basic skills among the staff to use microcomputers in data processing and analysis and project management using commercially available software.
- \* The staff should not start with "canned" specialized irrigation software that is more sophisticated than is warranted.
- \* Institutions need to select specialized irrigation software that offer the most promising returns for the project and which lie within a project's financial and technical capabilities.

Other workshops on irrigation data and project management were conducted in Pakistan, Sri Lanka, and the USA. These three workshops were designed to develop the microcomputer skills of water management professionals for use in irrigation data processing and analysis, and project management. In addition, the professionals learned many potential uses of electronic data loggers for computer-assisted monitoring and evaluation. Most of the workshop participants had minimum experience in microcomputer operation or programming.

Based on these workshops, the following are some of the key lessons learned from this experience.

- \* A personal development training strategy is the best for this type of training. The emphasis should be on improving individual competence in microcomputer skills for use in irrigation water management. Methods should include a good balance of presentations, demonstrations, discussions, hands-on instruc-

tion, electronic tutorials, exercises, and example applications.

- \* Three weeks for this type of workshop seems to be the ideal length to give participants ample hands-on experience.
- \* For hands-on microcomputer workshops, the following ratios of participants and trainers provide a good interactive learning environment for participants: 6 participants to 1 trainer, 2 participants per microcomputer, and 18 to 20 participants per workshop.
- \* Workshops should utilize computer equipment having service support from local vendors, unless the training facility has the appropriate computer set-up, so that any needed repairs can be made quickly.

WMS II's microcomputer application effort demonstrated the worldwide potential for microcomputer-assisted improvement in irrigation water management. This effort in applying microcomputer software in irrigation design and management was only the beginning. There is a need to continue the search for appropriate microcomputer technology to use in improving irrigation water management.

## V. SUMMARY

Irrigated agriculture is, and will continue to be, a vital sector in the production of food and fiber. Irrigation projects have seldom realized their expected potential, however, with poor performance and low productivity the rule. Efforts have been made to improve irrigated agriculture (at least to increase the level of production) throughout the last 40 years. During the 1950s and 1960s, this consisted largely of efforts to expand the total irrigated area. During the 1960s and 1970s, the emphasis shifted from expansion to improvement with the "green revolution." In the 1970s, increased emphasis was directed towards improving the performance of irrigation projects by rehabilitating the physical works. All of these efforts met with limited success, and the need for more improvement continued. Therefore, improving the management of irrigation systems became the focus in the 1980s. Improving management is not at the exclusion of the preceding efforts, but includes integrating all of them to improve systems.

A focus on improving the management of irrigated agriculture has been the emphasis of CSU's involvement in water management over the past 15 years. This involvement has included the On-Farm Water Management Project in Pakistan, the Egypt Water Use and Management Project, the Water Management Synthesis I Project, and the Water Management Synthesis II Project. These efforts have significantly contributed to the body of knowledge concerning management-focused improvement of irrigated agriculture. Among these contributions have been a development model, which provides a framework for improvement; the concepts and methodologies of diagnostic analysis, which provide a means by which an irrigation project can be studied and understood by an interdisciplinary team so as to facilitate improvement; and the implementation planning process, which facilitates multi-level, multi-organizational, collaborative planning for irrigation project improvement. These contributions have been extensively documented and applied. Also, the concepts evolving from or becoming the foundation for these efforts have become well established.

Additional efforts have been made based on the contributions mentioned above. These specific efforts have also contributed to the body of knowledge concerning management-focused improvement of irrigated agriculture. These efforts have not been as extensively documented, however, so they have been summarized here. The objective is to make these contributions more widely known so that implementation of the concepts and approaches can be considered in more places. These efforts include considerations of project-level water control for management, field-level water management, conjunctive use of canal and groundwater, satellite mapping of projects, and computer applications to improve system management.

Sritharan (1984) developed an integrated approach for designing the main systems of surface irrigation projects. The procedure synthesizes the operation and management of systems with the design, and involves steps that have not previously been given sufficient emphasis. The value of the approach is that systematic procedures have been de-

veloped using data from a diagnostic analysis study and computer models to evaluate alternative planning objectives, design procedures, and management alternatives. Evaluations are made of the optimal turnout areas, turnout area water requirements, farm field designs, long term groundwater effects, water issue strategies, and main system hydraulics. All of these evaluations are conducted on an interdisciplinary basis and not just based on engineering.

The monitoring and evaluation of main system performance for management decision-making at the project level was addressed by Mohammed (1987). Because main system managers were observed to lack information for making management decisions, this effort developed a methodology for monitoring and evaluation for management. This approach focused on daily management of the system. System performance parameters, criteria for acceptable levels of system delivery performance, and a management plan are the essential components for improved daily management of water delivery systems. It was shown that through the use of such a management plan, with a feedback link that monitors and evaluates system performance, a system can distribute water more dependably and equitably.

Farmers manage field irrigation systems without the adequate knowledge, skills and services needed to achieve good water management. To address this problem, Wattenburger (1985) developed a design method based on extensive computer simulation studies to facilitate farmer management of level basin irrigation systems in the absence of water control. This design procedure allows a farmer using a properly designed and constructed level basin system to apply a specific, measured amount of water to a field. The farmer's criterion for this management is the traditional decision observed in many countries: the farmer irrigates until the water reaches the end of the field. The flow into the field can vary by several magnitudes and the amount applied will not vary by more than 5 or 10 percent. Not only can farmers apply specific amounts of water to a field, but this can be accomplished with main system deliveries of widely varying flow characteristics.

The conjunctive use of water at the watercourse command level was considered by Choudhary (1987). An optimal conjunctive management model with a net profit maximization objective was developed. This model evaluates the conjunctive use of rainfall, surface water, and groundwater to irrigate multiple crops. The optimum water requirements to be satisfied at each stage of the crops for maximum net benefit from the watercourse command area is determined. Then the optimal groundwater pumping strategies and the optimal number of wells needed to satisfy the optimal water requirements are developed for different management alternatives.

A study was undertaken by Martin (1988) with an objective of determining the utility of satellite image processing to rapidly assess irrigation systems in terms of area commanded and crops grown. Digital classification of cloud-free Landsat images proved to be a successful method for determining irrigated acreage and cropping patterns for major subcommands. Overall classification accuracies of 85 to 90 percent were achieved. Irrigated acreage was determined to be within 1 to 3 percent of other, ground-intensive methods.

An important component of management is the storage, retrieval, analysis, and use of information. Computers can be useful tools in accomplishing these activities. In the last few years, microcomputer utilization in developing countries has become a reality. With the WMS II Project, an excellent opportunity presented itself to transfer a significantly higher level of expertise from the United States to developing countries with the microcomputer technology now available. Two types of workshops were developed and conducted: computer-assisted design and management, and irrigation data and project management. The basic purpose of these workshops was to acquaint personnel in developing countries with the use of currently available hardware and software pertinent to their needs.

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