IRRIGATION DEVELOPMENT OPTIONS AND INVESTMENT STRATEGIES FOR THE 1980'S

INDIA

USAID

WATER MANAGEMENT SYNTHESIS PROJECT

WMS REPORT 6

INDIA/USAID

IRRIGATION DEVELOPMENT OPTIONS AND INVESTMENT STRATEGIES FOR THE 1980'S

This study is an output of
Water Management Synthesis Project
under support of
United States Agency for International Development
Contract AID/DSAN-D-0058
All reported opinions, conclusions or recommendations are those of the authors (contractors) and not those of the funding agency or the United States government.

Prepared by

Jack Keller* - Team Leader and Civil and Irrigation Engineer
Wayne Clyma - Agricultural Engineer
Matthew Drosdoff - Tropical Soils Scientist
Max K. Lowdermilk - Water Management Extension Specialist
David Seckler - Agricultural Economist

*Utah State University
Agricultural and Irrigation Engineering
Logan, Utah 84322

July 1981

WMS Report 6

PREFACE

This study was conducted as part of the Water Management Synthesis Project, a program funded and assisted by the United States Agency for International Development through the Consortium for International Development. Utah State University and Colorado State University serve as lead universities for the project.

The key objective is to provide services in irrigated regions of the world for improving the design and operation of existing and future irrigation projects and give guidance to USAID for selecting and implementing development options and investment strategies.

For more information, contact the Water Management Synthesis Project for information about the project and any of its services.

Jack Keller, WMS Coordinator
Agricultural & Irrigation Engr.
Utah State University
Logan, Utah 84322
(801) 750-2785

Wayne Clyma, WMS Coordinator
Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523
(303) 491-8285

FOREWORD

This report was developed to focus on AID's policies in assisting irrigation and the expected priority, size and nature of future irrigation efforts. It includes recommendations for focusing USAID/India assistance programs in irrigated agriculture through the present decade.

The irrigation study team visited India between November 2 and 22, 1980, to develop this report. The members of this team were:

Jack Keller, Team Leader and Civil and Irrigation Engineer
Wayne Clyma, Agricultural Engineer
Matthew Drosdoff, Tropical Soils Scientist
Max K. Lowdermilk, Water Management Extension Specialist
David Seckler, Agricultural Economist

The team approached the task of dealing with irrigation development options and investment strategies by first developing a set of key recommendations based on analysis of documents, discussions with field visits, and interviews with farmers. The background for arriving at these recommendations, plus other pertinent information was organized and is the body of this report.

The study team appreciates the time spent and frank discussions with many Government of India officials, and for this we are especially grateful to: Mr. C. C. Patel, Secretary for Irrigation: Mrs. R. M. Schroff, Joint Secretary for Irrigation; Mr. Ghosh, Chairman of the Central Water Commission and the other four members of the Commission: Mr. K. Ramesh Rao; Dr. B. D. Pathak, Chief Hydrologist, Central Groundwater Board; Mr. G. N. Kathpalia, Chief Engineer, Minor Irrigation; and Mr. K. S. Murthy, Irrigation Advisor to the Central Planning Commission. We wish to give special thanks to Mrs. R. M. Schroff for graciously hosting a luncheon for the team. We also appreciate the assistance of the State Government officials and officers who assisted us during our field tour and visits to: Gujarat, Haryana, Maharashtra, Rajasthan, and Uttar Pradesh.

In addition, the team appreciates the thoughtful and cordial assistance from the many Mission personnel who helped us. We give special thanks to Dr. Dean F. Peterson and Mr. Edwin D. Stains for arranging our schedule and accompanying us on many of our field visits. We also thank Director Priscilla M. Boughton for the complete assistance we received from the USAID Mission staff.

The draft report was reviewed by officials of USAID, IBRD, Ford Foundation and others. Revisions made reflect the comments received. Appreciation is expressed for the interest shown and the help provided.

A brief summary of the review team's itinerary in India follows:

Nov. 1		Arrive in India
Nov. 2		Study documents
Nov. 3		Meetings with USAID officials
Nov. 4	10:30	Mr. Patel, Secretary, Ministry of Irrigation; Mrs. Schroff, Joint Secretary, Ministry of Irrigation
	11:30	Mr. B. D. Pathak, Chief Hydrologist, Central Groundwater Board, Jamnager House
	15:00	Mr. R. Ghosh, Chairman, Central Water Commission
Nov. 5	09:00	Dr. Norman Collins, Ford Foundation
	11:00	Mr. G. N. Kathpalia, Joint Commission
	14:30	Mr. M. G. Padhey, Member, Central Water Commission
Nov. 6	10:30	Mr. K. S. S. Murthy, Irrigation Consultant, Planning Commission
	14:30	Dr. Michael, Water Technology Center
Nov. 7-9		Team discussions with USAID officials, review documents and begin assignments
Nov. 10-11		Visit Medium Irrigation Projects and Private Tubewells in Gujarat
Nov. 13-14		Visit Lift and Dug Well Projects in Maharashtra
Nov. 15		Travel and rest
Nov. 16		Visit Small Tank Projects in Haryana
Nov. 17-18		Visit Public Tubewell Projects in Uttar Pradesh with split team; visit Command Area Development Authorities in Rajasthan
Nov. 19		Work on report

Nov. 20		Visit Chaks in Major Irrigation Projects in Haryana
Nov. 21	10:30	Debriefing meeting with Mission
	13:30	Luncheon meeting hosted by Mrs. Schroff
Nov. 22		Depart from India

SUMMARY AND RECOMMENDATIONS

Irrigation in India has been practiced from ancient times and has expanded steadily since then. Irrigation development continues to be given high priority. By the end of 1979-80, the estimated irrigation potential stood at about 58 million hectares. This accounts for roughly 51 percent of the gross ultimate country potential of 113.5 million hectares. But, this considerable potential, already created, is under-utilized. According to a recent (1980) American Embassy Report (see Appendix A), there is a sizable gap between potential and actual utilization due to inefficient water management practices. The report suggests that a 25 percent increase in utilization can be obtained by improved on-farm delivery systems and in-field water management.

The importance of irrigated agriculture to India can hardly be over-emphasized. While only 37 million hectares out of the total 127 million hectares of foodgrains are irrigated, the irrigated area produces half (63 million MT) of the total grain produced. Average irrigated yields are 1,700 kg/hectare, while unirrigated yields are only 700 kg/hectare.

The conjunctive use of surface and groundwater is extremely important in India's irrigation development program. The average total annual surface water resources are estimated to be about 178 million hectare meters (Mha.m). However, this resource cannot be fully utilized due to the highly variable character of the flow and other limitations imposed by the country's geology and terrain. Given these limitations, the Irrigation Commission, in 1972, estimated the total directly usable surface flow for irrigation at 66.6 Mha.m. The National Commission on Agriculture estimates that this quantity will be sufficient for ultimately irrigating 73.5 Mha (58.5 Mha of major and medium irrigation projects and 15 Mha of minor projects) by the end of 2025 A.D.

The Central Groundwater Board has estimated that, by 2000 A.D., the total annual groundwater resources will be 57 Mha.m with recharge of 29 Mha.m from rainfall, 22 Mha.m from canal seepage and return flow, and 6 Mha.m seepage in return flow from groundwater systems. However, various factors limit utilization of the total groundwater for irrigation to an estimated 26 Mha.m. The National Commission on Agriculture estimates that this quantity is sufficient to ultimately bring about 40 Mha of new area under irrigation by 2025 A.D. Thus, pumped irrigation from groundwater is expected to account for 35 percent of the estimated total of 113.5 Mha by 2025 A.D.

The scope, structure and operation of existing and projected irrigation projects and enterprises are extremely varied in India. They range in sizes from small wells serving a few hectares to projects of over a million hectares. Irrigation is practiced under numerous different soil, topography, climatic, and crop conditions. Furthermore, there is considerable diversity in the policies of different states and the social relationships in different villages. Therefore, there can be no singular set of directives for irrigation development in India.

Government policy has emphasized extensive distribution (over a large area) of irrigation benefits from a given water supply while, at the same time, trying to achieve equitable distribution of these benefits within the extensive areas served. This dual objective is commendable; however, to accomplish it is indeed a challenge, especially considering the relatively limited resources of water, capital and professional irrigation management personnel, plus the political realities in India.

From a political point of view, every state and district, naturally, wants a share of irrigation development activity. This has resulted in thinly spreading the available resources between too many new irrigation projects and the operation of existing ones. Thus, many projects are started and not completed in a timely fashion. Most of the officially completed projects are incomplete in that they cannot deliver the planned-for stream of output benefits promised by planners and designers.

Most projects visited lack the following: (1) efficient and effective facilities to distribute water from the project canals (or pumps) to the farm fields; (2) efficient means to distribute predictable water supply to the plants growing on the fields; and (3) effective management of the total irrigation system between the plants and the water supply. These deficiencies cause much under-utilization of the irrigation facilities which have been constructed and result in considerable inequity in the distribution of benefits. We estimate that the utilization of the theoretical irrigation potential of the projects visited ranged from a low of about 10 percent up to 100 percent. Private wells were effectively utilized, but too many of the major and medium surface irrigation projects seemed to fall in the 50 percent utilization range.

Many projects are also uneconomical because only a fraction of the irrigation potential can be realized since relatively few (lucky) farmers are provided with a reliable water supply. These are the farmers who happen to have fields at opportune locations along the extensive canal distibution systems.

Fortunately, seepage from unlined channels and drains, plus percolation from excess and non-uniform irrigation, recharge the groundwater reservoir. This, in turn, may support intensive groundwater development in the command areas of under-utilized gravity irrigation projects. Thus, the project may function as an extensive water spreading system and the groundwater withdrawals recover some of the lost benefits and improve equity along with water control for farmers.

The non-saline aquifers underlying large alluvial plains serve as both excellent storage reservoirs and intensive water distribution systems, for they hold a ready supply of water beneath each field. If it were not for the unpredictable escalating cost, and more importantly, unreliability of energy (and, in some areas, salinity and waterlogging), a combination of private and public groundwater would usually be the most effective way to optimize irrigation potential from the under-utilized gravity projects. While it might be thought best to always use the surface water efficiently while it is on the surface, the reservoir function of the aquifer for carrying water from the wet to the dry season, the availability during drought years, and the higher distribution efficiency of private tubewells all argue to the contrary, if the energy is there and is not too expensive.

Government planners generally recognize that the irrigation potential which has already been created (in theory) cannot be realized without rehabilitating most projects. Much of what is called rehabilitation on projects visited is simply extension of the distribution system with the related structures for delivering water from the project canals and distribution to the individual farms. Extended delivery systems with improved management are needed to provide more equitable and reliable irrigation water to most farmers in the command area.

A report by Posz, Raj and Peterson (see Appendix A) points out the desirability of extending the canal system and providing field channels and gives a review of progress in this direction. Irrigation Departments have been charged with constructing and operating, at project cost, the canal system down to an outlet serving a farm area (called a chak) of 10 to 100 or more hectares. Farmers below the outlet are expected to construct the channels, and operate and maintain them to deliver water to their individual holdings. This is a responsibility which is beyond the technical and organizational capacity of most groups of farmers, many of whom operate one hectare or less. The result is that only about half of the 25 million hectares in major and medium irrigation schemes have field channels, and most of these are unreliable and inadequate.

In October 1978 the GOI instructed the states to include the channels from the 40 hectare level down to the eight hectare level as project costs for all new and rehabilitiation projects. Organized public sector credit is available for channels to each farm holding and on-farm development on the 76 CAD and foreign donor-financed projects in the country with unorganized credit (private) used by farmers where possible on non-CAD projects. Watercourses are commonly lined down to the eight hectare level. Present USAID policy is similar, except funding is provided for lining based on technical and economic considerations which in some cases would be down to the eight hectare level.

With a water delivery system and the necessary structures to control deliveries to each holding, total irrigation system management is the next necessary ingredient for success. A formal rational water delivery schedule, called a warabundi (see Appendix B) must be enforced in each chak to assure each farmer a fair share of water where a demand system is not practical. The main system must be managed to provide equitable and timely supplies of water to each chak and the total system must be maintained in good working order.

The team found ample evidence that Indian farmers, who have reliable and predictable water supplies, will commit substantialresources to effectively irrigate their holdings when this is economically justified. Millions of private tubewells, some of which have pipe distribution systems serving graded fields, are evidence of this. However, farmers do need credit and technical support to fully develop the irrigated potential provided. Farmers in some areas with water control provided by private tubewells are willing to pay six to nine times the water charges levied for canal supplies.

In 1973, the Central Government called on the states to establish Command Area Development Authorities (CADA's) to optimize irrigation potential. CADA's are given the task of providing management and technical assistance and coordinating financial support for improving on-farm water distribution and in-field application within the command area. In addition, CADA's coordinate other infrastructural inputs such as storage and markets and are charged with strengthening the organization of agricultural extension activities in general.

The CADA's now coordinate services for 76 major irrigation projects in India (covering a cultivable area of 15.3 million hectares), but their record has been mixed. The most obvious problems which the review team observed are that: (1) the main system (between the chaks and water supply) operation is unreliable because of poor management, inadequate maintenance and the lack of effective control structures; (2) there is little coordination between the main system management, which is the responsibility of the state's Irrigation Department and the CADA's, which are usually under the state's Agricultural Department; and (3) the CADA's themselves are weak and ineffective in many states because they only coordinate, not control, inputs and personnel from other agencies. The team considers the CADA concept to be sound. If the main weaknesses can be corrected, it can provide significant benefits in India and could be of importance in improving irrigation management in other countries.

Central and state governments are aware of the problems with CADA's and efforts are under way to remedy this situation. There is serious discussion concerning dividing the Irrigation Departments into two separate, but parallel, cadres. The traditional roles of planning, design and construction will likely be housed in one cadre. A new cadre staffed with professional irrigation system management personnel will be established to manage, operate and maintain (MO&M) the total irrigation system. However, since irrigation development is the prerogative of each state, a unified approach to system management may be long in coming. In the meantime, AID and other donors can play an important role by encouraging projects (through funding) that are designed to provide the needed delivery and control facilities and a coordinated program to manage the total irrigation system. The Central Water Commission is aware of the problems related to management and has commissioned a high level committee to find ways to improve the CADA concept.

Currently, the Mission's program is mostly directed at medium irrigation projects and the development of CADA's and training programs in the states of Gujarat, Maharashtra, and Rajasthan. The Mission is also involved in credit programs for minor irrigation (mostly wells and pumpsets). Projects which are being considered are a small tank rural development project with activities in several states including Haryana, medium irrigation projects under improved criteria in Maharashtra, establishment of a CADA for AID supported MIP's in Rajasthan and a minor irrigation scheme in Madhya Pradesh. (Medium irrigation projects serve 2,000 to 10,000 hectares and minor schemes serve 2,000 hectares or less). This is a well-thought-out program and it should provide a good base to build on in the future.

The Mission is also planning a project to support water management training and special studies which can have a long term positive impact on irrigation development in India. The Mission technical staff is hardly large enough to adequately serve this set of programs and projects. Besides program officers a technical field staff are needed to monitor progress and encourage desirable performance. The review team visited irrigation projects and facilities in most of the above-mentioned states. The recommendations which follow are based on team field visits, document reviews, and discussions with numerous officials at the national, state and project levels, and visits with many farmers while in their fields and villages.

Recommendations

We present these recommendations as kinds of objectives for AID's investment policy to emphasize in India during the decade of the 1980's. However, we realize that there are political, social, managerial and financial restraints, which often make it impossible to follow such objectives. They therefore should be considered as guides for future planning. We believe it is most important to maintain a pragmatic investment program and use our recommendations to focus on options and strategies rather than use them to control the program.

The team also recognize that the Mission will need a larger technical staff to carry out a program which addresses these recommendations and helps the central and state governments to significantly improve the performance of existing and future irrigation developments. In view of the short period of our visit and the magnitude of the irrigation potential in India and our own limitations for carrying out this task, we present our recommendations with a great deal of humility:

1. We applaud the Mission's current medium irrigation program and believe it provides a sound basis on which to build. We agree with the policy of having distribution channels constructed at project cost and/or credit mechanisms to each farmer holding; and the practice of 40 percent lining of watercourses to reduce losses. We recommend that additional lining and control structures be considered to make the farmer management unit smaller where possible based upon knowledge of soils costs and returns.

   We also recommend that the Mission expand its technical staff in order to properly monitor the field activities of this large and complex irrigation program. (A larger technical staff will become essential as the program expands.) We realize that some of this medium irrigation program is piggybacked on World Bank projects, but these, too, need more monitoring then the World Bank provides.

2. USAID should attempt to set up a model management irrigation system in a medium command area in India of, say, 4,000 to 10,000 hectares. The purpose of this model management system would be to rehabilitate an existing irrigation command to improve total crop productivity in the command area and to demonstrate the importance of effective management for other commands in India. Sucha model will require efficient management and distribution of water, control of other water-related inputs such as hybrid seed, fertilizers, and adequate credit for farmers.

3. In connection with a model management system, AID should energetically stimulate new technical innovations in irrigation systems. For example, it now appears to be clear that, for irrigation commands with hydraulic slopes of greater than 0.25 percent, PVC pipe distributaries are both cheaper and more effective than lined channels for carrying flows of less than two cubic feet per second. Quality installation is also more assured. With the remodeling AID should also sponsor intensive research and demonstration work on the use of small storage (surge) tanks within the command area to avoid some of the problems of night irrigation and intermittent electrical supplies on tubewells.

4. A particularly important deficiency in the management of irrigation systems in India is the lack of information on the actual performance of irrigation systems. We are pleased to find that USAID is beginning to sponsor innovative operational research and training in the design of rapid appraisal and monitoring systems for large command areas to determine the performance of these systems in efficiently delivering water to the fields at the right time, in the right quantity, to the right farmers.

5. There is a crucial need for better pre-investment and diagnostic surveys for all sub-projects in India. USAID recognized this need, but GOI tends to under-invert in pre-investment surveys. Before any new or rehabilitation project is undertaken, there should be a field analysis of soil characteristics, hydrological information, social systems, current cropping and irrigation practices, and land ownership and farming patterns in the command areas. The design evolving out of the pre-investment survey should explicitly address such issues as: soil-water relationships, water duty under alternative crop regimes; the economics of conjunctive use trade-offs and energy

requirements; the equitable distribution of water between users; and problems identified in the diagnostic review of systems to be rehabilitated. Explicit attention should be paid to providing physical facilities which fit the specific management structure intended to realize project objectives and the means of monitoring the performance of the system with respect to those objectives.

Irrigation systems should be diagnosed periodically in order to provide information for upgrading design assumptions (criteria) and provide necessary feedback for adequate system management. While design criteria must be momentarily fixed to provide a structure for each increment of investment capital, any set of criteria should be subject to change pending new technical, economic, and/or social developments and findings. A similar statement can be made for management organizations and programs.

Because of the scarcity of trained personnel in India, the study team recommends that the diagnostic surveys suggested above be phased into all AID projects as talent becomes available. Realizing that adequate numbers of trained personnel are not available in India for this, we recommend that AID support an appropriate training program. The objectives of this program should be to train multidisciplinary teams to systematically analyze the agronomic, economic, engineering, and social aspects of irrigation systems starting from the bottom (on-farm level) and synthesize the component analysis into an interdisciplinary diagnostic report describing how the system is working and how well it is producing the desired output (i.e., crop yields and equity of benefits).

The Water Management Synthesis Project (which has funded this India study) has already developed a pro forma training program and test materials to begin addressing this need. Since the team visited one course was given in Gujurat and another requested in Rajahistan. It is hoped that similar courses will become part of a continuing national training program.

6. It is clear that the quickest, most cost-effective means of bringing effectively irrigated acreage into production in India is through tubewell development. It must be realized, however, that India is undergoing a severe energy crisis which is reducing the pumping time of tubewells to perhaps one-half. The solution is to invest more in power

development, not to stop tubewell development. Power availability is expected to improve steadily with gaps narrowing sharply and being eliminated by 1990. It should be considered, however, that previous power development programs have not kept pace with projections and expectations. During drought years power demands increase and hydro power availability is at a minimum. The team therefore points out the obvious benefits of tubewells, but cautions against investment when availability of power may be too uncertain. The use of diesel powered pumping may be considered if adequate.

There are in India vast areas such as the Deccan plateau where groundwater is develped through hand dug wells into fractured rock with low specific yield. These wells can only be pumped four to six hours a day and even in areas of power shortage there is much room for development using off peak power.

7. In light of the absolutely crucial threat to the food production system of India posed by the power shortage, and the confusion we find in trying to pinpoint the practical and timely availability of energy for irrigation pumping, we recommend that AID give serious attention to helping the Government of India understand the nature and concentration of the irrigation pumping load. This is necessary to better utilize existing and potential power resources through seasonal load shifting and development of hydro and coal power facilities. AID should offer to provide a joint Indian-expatriate power consultancy team to investigate the current status of and opportunities for managing and developing power sources and improving operational efficiencies for tubewell and lift irrigation throughout India.

One of the suggestions for this team to investigate would be to create small captive power units in the 1,000 hp range (which have been shown to be economical in the United States) utilizing coal resources. Some of these plants may be located in the high groundwater table areas, such as the extensive coal reserve regions of Bihar. where many of the poorest people of India desperately need tubewell development. Also, these captive power stations could be scattered along the railway systems over groundwater areas in the Indo-Gangetic plain. The team should also investigate the possibility of small micro-hydel units in existing reservoirs, run of the river systems, and systems in the drop structures of large canal distributaries. For example, a small reservoir may be equipped with micro-hydel to generate electricity for tubewells cut on the periphery of surface irrigation commands (thereby making head-enders out of tail-enders). The power team should realize that it is not only cost that matters but also equity and the difference between production or no production from tubewells.

In addition, we suggest that official USAID policy for India consider investments in the development of electric power generation (and energy in general) as complementary to irrigation and, thus, equivalent to food production. In the Sixth Plan, half of the 15 million hectares of proposed developments depend on pumping (mostly from groundwater). In much of India, more power means more food!

8. While we did not see the waterlogged and saline areas of India ourselves, the Government of India is very concerned with the estimated four to seven million hectares of land which are seriously affected by these problems. Cost effectiveness suggests that canal water be used more effectively on the surface in the saline areas. This can be accomplished by lining channels to reduce water losses throughout the distribution systems and improving farm water management practices. Vertical drainage through tubewells, where practical, may be the best solution once waterlogging has occurred. This problem, however, can be solved only if power is available. Captive power plants for tubewell drainage may be a beneficial investment. AID may wish to constitute a special drainage and salinity team to advise the Government of India on this problem.

9. Over the next few decades, other than power shortages, the next most severe threat (after power shortages) facing food production in India is the rapid siltation of existing reservoirs caused by inundation of catchment areas. A recent survey of nearly 30 of the larger reservoir systems has shown that the current rate of siltation is on the order of three times the design rate. AID may be able to provide technical help in estimating the current rates of siltation into these systems and to devise programs for arresting the rate over the future. For example, there is a need for creating a program of soil and water conservation and aforestation in the catchment areas of some of the endangered reservoirs. One of the Government officials we visited suggested this type of project for AID

support. AID's current forestry project may provide guidelines for such future projects.

10. From studies conducted by the Ford Foundation, it appears that, in India, there is substantial under-exploitation of the opportunities for minor irrigation projects with small reservoir and tank developments (10 to 2,000 hectare command areas). In some areas, these small tanks can provide a means of relieving the pressure on tubewell facilities. For example, in the Maharashtra lift scheme area, there were many sites suitable for tank irrigation. The problem with small reservoir and tank developments is again a management problem, i.e., management of the watershed, reservoir, and complete distribution of the water. We recommend that AID support this area over the future and want to encourage the Mission's current efforts in developing such projects.

These minor irrigation projects are particularly attractive because they can be developed quickly. It only takes one to three years to go from implementation to delivering water to farmers. New medium irrigation projects typically take over five years, and major projects may take more than nine years.

11. USAID support to the Agricultural Refinance and Development or other credit agencies should be carefully evaluated in terms of specific objectives. For example, because of the power shortage as outlined above, it is not at all clear that tubewell development should be encouraged over the immediate future. Also, very close inspection should be given to credit facilities and subsidization for land leveling activities. The rate of default in many of these loans approaches 90 percent. Land leveling is, in essence, a private good which farmers can do themselves if they so desire. They should, however, be provided with adequate technical support and demonstration programs. For example, in new and rehabilitation projects, 10 percent of each farmer's land, up to a limit of one acre, might be leveled as a project expense, but the farmers should be expected to pay for the balance. Experience in other countries suggests that cost-effective, well-managed organizations which provide farmers with an appropriate land leveling service can be developed.

12. There needs to be a broadening of the base of expertise in water management through more effective use and training of

agricultural and irrigation engineers wishing to specialize in water management. Special training emphasis on water management will demonstrate the need for integration and application of the skills of crop production practices, extension, economics, management science and engineering. This training is especially needed in the CADA system. We recommend that AID develop appropriate training support programs to address this need.

INDIA/USAID

IRRIGATION DEVELOPMENT OPTIONS AND

INVESTMENT STRATEGIES FOR THE 1980'S

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

INTRODUCTION AND BACKGROUND

Irrigation in India has been practiced from ancient times and has expanded steadily since then. Irrigation development continues to be given priority, and, as of the end of 1979-80, the estimated irrigation potential stood at about 58 million hectares. This accounts for roughly 51 percent of the gross ultimate potential of 113.5 million hectares. But, the considerable potential, already created, is under-utilized. This is caused by a sizable gap between potential and actual utilization due to inefficient water management practices. It has been suggested that a 25 percent increase in utilization can be obtained by improved on-farm delivery systems and in-field water management.

Water Resource Development

Posz, Raj and Peterson prepared a report for the American Embassy in 1980 which provides an excellent summary of "Water Resource Development in India." This entire report is presented as Appendix A.

The importance of irrigated agriculture to India can hardly be overemphasized. While only 37 million hectares out of the total 127 million hectares of foodgrains are irrigated, the irrigated area produces about half (63 million MT) the total grain produced. Average irrigated yields are 1,700 kg/hectare, while unirrigated yields are only 700 kg/hectare. Where there is adequate water control from tubewells the yields are much higher.

The conjunctive use of surface and groundwater is extremely important in India's irrigation development program. The average total annual surface water resources is estimated to be about 178 million hectare meters (Mha.m). However, this resource cannot be fully utilized due to the highly variable character of the flow and other limitations imposed by the country's geology and terrain. Given these limitations, the Irrigation Commission, in 1972, estimated the total directly usable surface flow for irrigation at 66.6 Mha.m. The National Commission on Agriculture estimates that this quantity will be sufficient for ultimately irrigating 73.5 Mha (58.5 Mha of major and medium irrigation projects and 15 Mha of minor projects) by the end of 2025 A.D.

The Central Groundwater Board has estimated that, by 2000 A.D., the total annual groundwater resources will be 57 Mha.m with recharge of: 29 Mha.m from rainfall; 22 Mha.m from canal seepage and return flow; and 6 Mha.m seepage in return flow from groundwater systems. However, various factors limit utilization of the total groundwater for irrigation to an estimated 26 Mha.M. The National Commission on Agriculture estimates that this quantity is sufficient to ultimately bring an additional area of 40 Mha under irrigation by 2025 A.D. Thus, pumped irrigation from groundwater is expected to account for 35 percent of the estimated total of 113.5 Mha by 2025 A.D.

The scope, structure and operation of existing and project irrigation projects and enterprises are extremely varied in India. They range in size from small wells serving a few hectares to projects of over a million hectares. Irrigation is practiced on numerous different soil, topography, climatic, and crop conditions. Furthermore, there is considerable diversity in the policies of different states and the social relationships in different villages. Therefore, there can be no singular set of directives for irrigation development in India.

Government policy has emphasized extensive distribution (over a large area) of irrigation benefits from a given water supply, while, at the same time, trying to achieve equitable distribution of these benefits within the extensive areas served. This dual objective is commendable; however, to accomplish it is indeed a challenge, especially considering the relatively limited resources of water, capital and professional irrigation management personnel, plus the political realities in India related to irrigation development.

From a political point of view, every state and district naturally wants a share of irrigation development activity. This has resulted in thinly spreading the available resources between too many new irrigation projects and the operation of existing ones. Thus, many projects are started and not completed in a timely fashion; and most of the officially completed projects are incomplete in that they cannot deliver the planned for stream of output benefits expected by the planners and designers.

Irrigation System Operation and Management

The paper "Rotational System of Canal Supplies and Warabundi in India", which gives an excellent summary of system operation and management, is included as Appendix B. This paper was prepared in 1980 by Mr. G. N. Kathpalia, for the Department of Agriculture and Cooperation, GOI. This and other studies show that officials are aware of the needs for improvements and are forthright and candid about the operation and maintenance problems.

Most projects are lacking in: (1) efficient and effective facilities to distribute water from the project canals (or pumps) to the farm fields; (2) efficient means to distribute water to the plants growing on the fields; (3) effective management of the total irrigation system beetween the plants and the water supply; and (4) a system to assist farmers on a regular basis to improve irrigation and crop production practices.

These deficiencies cause under-utilization of the irrigation facilities which have been constructed and considerable inequity in the distribution of benefits from them. We estimate that the utilization of the theoretical irrigation potential of the projects we visited ranged from a low of about 10 percent up to 100 percent. Private wells were effectively utilized, but too many of the major and medium projects seemed to fall in the 50 percent utilization range. Where private tubewells provide water control farmers are willing tp pay six to nine times the wter charges levied for water from canals.

The projects are also uneconomical because only a fraction of the irrigation potential can be realized, since relatively few (lucky) farmers are provided with a reliable water supply. These are the farmers who happen to have fields at opportune locations along the extensive canal distibution systems.

Government planners generally recognize that the irrigation potential which has already been created (in theory) cannot be realized without rehabilitating most projects. Actually, much of what is called rehabilitation is simply extension of the distribution system with the related structures for delivering water from the project canals to the individual farms. Extended and improved delivery systems are needed in order to effectively manage projects so they can provide equitable and reliable irrigation water to most farmers in the command area.

The Posz, et al. report (see Appendix A) points out the desirability of extending the canal system and providing field channels and reviews progress in this direction. Irrigation Departments have been charged with constructing and operating, at project cost, the canal system down to an outlet serving a farm area (called a chak) of 10 to 100 or more hectares. The farmers below the outlet are expected to construct the channels and operate them to deliver water to their holdings. This is a responsibility which is beyond the technical and organizational capacity of most groups of farmers, many of whom operate one hectare or less. The result is that only about half of the 25 million hectares in major and medium irrigation schemes have field channels, and most of these are unreliable and wasteful.

The chak size was fixed at 40 hectares by the Planning Commission in the 1960's to clarify responsibility. For the past two years, due to pressure from the World Bank and other donors for new and rehabilitation projects, credit is now generally provided for channels to each farm holding and watercourses are lined down to the eight hectare level. Present USAID policy is similar, except funding is provided for lining the upper portion of the channel from the 40 hectare inlet to where it is estimated that the benefits are offset by costs.

With a water delivery system and the necessary structures to control deliveries to each holding, total irrigation system management is the next necessary ingredient for success. A formal rational water delivery schedule, called a warabundi (see Appendix B) must be enforced in each chak to assure each farmer a fair share of water where a demand system is not practical. The main system must be managed to provide equitable and timely supplies of water to each chak and the total system must be maintained in good working order.

The team found ample evidence that Indian farmers, who have a reliable and predictable water supply, will commit needed resources to effectively irrigate their holdings when this is economically justified. The millions of private tubewells, many of which have pipe distribution systems serving graded fields, are evidence of this. However, farmers do need credit and technical support to fully develop the irrigated potential provided.

Groundwater Recharge

Fortunately, the seepage from unlined channels and drains, plus percolation from excess and non-uniform irrigation, recharge the groundwater reservoir. This, in turn, may support intensive groundwater development in the command areas of under-utilized gravity irrigation projects. Thus, the project may function as an extensive water spreading system and the groundwater withdrawals recover some of the lost benefits and improve equity.

Non-saline aquifers underlying large alluvial plains serve as both excellent storage reservoir and intensive distribution systems, for they hold a ready supply of water beneath each field. If it were not for the unpredictable escalating cost, and more importantly, unreliability of energy supplied (and, in some areas, salinity and waterlogging), a combination of private and public groundwater would usually be the most effective way to optimize irrigation potential from under-utilized gravity projects. While it might be thought best to always use the surface water efficiently while it is on the surface, the reservoir function of the aquifer for carrying water from the wet to the dry season, the availability of drought years, and the higher distribution efficiency of private tubewells all argue to the contrary, if the energy is available and is not too expensive.

Water-Soil-Plant Interrelationships

In the various meetings with Government of India (GOI) officials involved with water resource development, everyone agreed with the need for greater efficiency in the utilization of water. Most of the attention in the past was given to design and construction of irrigation systems, especially the dams, main canals, and laterals. Civil engineers in Irrigation Departments had major responsibility for the projects and generally little attention was paid to allocation of sufficient resources for operation and maintenance, and to the problems of improved distribution and use of water at the farm level. Inadequate studies were often made of on-farm water demand for different crops on different soils under different rainfall probabilities. This has been one factor which has resulted in the large waste of water. This has been recognized by GOI in the formulation of the Sixth Five-Year-Plan which is now under consideration.

In the draft of the Sixth Plan there is increased concern for improving the total system; for example, it is stated that soil surveys will be organized in a coordinated manner for proper utilization of land resources. Cropping systems will be based on land capability and rainfall pattern, as well as water availability from irrigation sources.

In most of the irrigation projects, there are usually several types of soils with quite different physical characteristics and chemical properties. Differences in texture, structure, consistency, depth, micro-topography and other properties of the soil can have a substantial effect on water uptake and movement through the soil and on soil-plant interactions. Depth to the water table or perched water table and to a hardpan or rock layer and occurrence of salt layers in the profile are important parameters to measure. These and other soil properties and others need to be known and considered in designing an efficient irrigation system. They should be a part of the pre-investment survey and should be in sufficient detail to be useful for the design of the delivery system to the farm. The cost of these investigations is minimal compared to the total investment. No doubt, in parts of India most of the required data are available.

Often, when these kinds of data are available or studies have been made for the irrigation project they are neglected by the engineers who design the systems. Whether watercourses should be lined or not, estimates of seepage losses, drainage requirements and other questions can be more reliably forecast if soils data are available.

USAID IRRIGATION PROGRAM

The following Irrigation and Rural Electrification Assistance Program summary is taken from the USAID's "India-Country Development Strategy Statement - FY82", pages 36-138.

> Irrigation. The net contribution of irrigation to output and yield is rather difficult to quantify. Regression analyses suggest a yield differential of about 1.40 tons wheat equivalent per hectare between irrigation and unirrigated land, although this differential is not entirely attributable to irrigation alone. The crucial importance of irrigation lies in the fact that it enables the use of the new agricultural technology: fertilizer and fertilizer-responsive high-yielding seed varieties. Additionally, it enables multiple cropping and shifts in the cropping pattern from low-value to high-value crops. Multiple cropping is a major factor in increasing employment and providing food and fiber to meet the demands generated by population and income increases.
>
> AID-supported medium irrigation projects are underway in Gujarat and Rajasthan. Additional states will be selected for program expansion. It is also anticipated that AID may undertake "Phase Two" medium irrigation projects in Rajasthan and perhaps Gujarat. This has the advantage of capitalizing on our substantial investment in knowing these states and the officials who run them.
>
> USAID is considering support to on-farm development works in the command areas of medium irrigation projects to assure full utilization of investments. Such programs would be coordinated through the Agricultural Refinance and Development Corporations (ARDC) or other institutional finance agencies. Discussions are underway with ARDC and other officials regarding this possibility for the Rajasthan medium irrigation program.
>
> Minor irrigation (tanks, dug wells, tubewells, weirs, lift pumps) also provides investment opportunities. More than half of the 17 million hectare irrigation potential to be created under the draft Sixth Plan will be from minor irrigation. This program is strongly supported by the ARDC which USAID proposes to support through agricultural credit.

Irrigation development is expected to make major inroads on poverty in project areas. USAID will set criteria requiring subprojects to include predominantly small and marginal farmers to be eligible for AID-financing. For example, the appraisal team recommendation for the Rajasthan Project is for each subproject, more than 50 percent of benefited farmers must farm four hectares or less.

Rural electrification. India's public sector rural electrification program is also focused heavily on minor irrigation, serving electrical pump connections where institutional credit to individuals through ARDC also plays a major role. Rural Electrification Corporation (REC) schemes are justified on the basis of increased irrigated agricultural output and the reduced costs of pumping water. While not focused geographically, this program permits emphasis on AID target groups through concentration on the minimum needs and especially underdeveloped programs which focus on economically disadvantaged areas. Rural electrification also promotes higher employment through rural industries and greater labor demands of multiple cropping on irrigated land.

Currently, the Mission's program is mostly directed at medium irrigation projects and the development of CADA's and training programs in the states of Gujarat, Maharashtra, and Rajasthan. The Mission is also involved in credit programs for minor irrigation (mostly wells and pumpsets). Projects which are being considered are a small tank rural development project with activities in several states including Haryana. Medium irrigation projects under improved criteria in Maharashtra, establishment of a CADA for AID supported MIP's in Rajasthan and a minor irrigation scheme in Madhya Pradesh are being planned. The medium irrigation projects serve 2,000 to 10,000 hectares and minor schemes serve 2,000 hectares or less). This is a well-thought-out program and it provides a good base for future developments. We do caution, however, that the Mission technical staff is hardly large enough to adequately serve this set of programs and projects. Besides program officers, a technical field staff is needed to monitor progress and encourage desirable performance. The review team visited irrigation projects and facilities in most of the above-mentioned states.

Gujarat Medium Irrigation

The project consists of (a) the construction of new and the execution of ongoing Medium Irrigation Projects (MIP's); (b) the modernization or rehabilitation of existing MIP's to bring these up to standards established for new MIP's; (c) the establishment of a network of automatic discharge measuring stations (for river gaging); and (d) the monitoring and evaluation studies.

This project began in 1978 and is scheduled for completion in 1983. It involves 80,000 ha of new irrigated lands and 65,000 ha of rehabilitation on several subprojects. It is estimated that the activities will provide improvements to approximately 36,000 farms with the goals of: (a) to increase the level and security of small farmer income; (b) to expand rural employment opportunities; and (c) to increase the availability of food to the rural and urban poor. The project is funded as follows: USAID - $30M; IDA - $85M; and GOI - $100M, for a total of $215M.

General description. The Project is cosponsored by AID and IDA, with the latter financing the larger portion. It addresses problems of: (1) insufficient hydrologic data for dam construction; (2) high water losses in canals; (3) the problem of too large (40) public canal outlets which inhibit farm development; and (4) poor water management at the farm level. AID, IDA and GOG will divide proportionately the costs of canal lining and extension. IDA will finance improved hydrologic stations and a reorganization of the extension system.

Technical. The design criteria are:

1. The canal system will be fully lined down to the eight hectare public outlet;

2. Regulated outlets with a capacity of about one cubic foot per second to serve an area no larger than eight hectares on the average;

3. Canals designed for rotational irrigation;

4. A canal system designed to provide full irrigation deliveries to all areas when flows are less than 50 percent of capacity;

5. Structures for flow measurement from the head of the canal down to and including each minor; and

6. An emergency spillway for each reservoir.

A state government program under the Agriculture Department's

Soil Conservation Service handles land leveling of farmers' fields and construction of field channels below the government outlet. On new projects, channels to the farm fields will be constructed by contractors under Soil Conservation Service supervision. Farmers must repay the costs incurred at prevailing interest rates, but are given seven years to do so.

The state has a good network of rainfall stations, but stations for measuring runoff are few and have been operated sporadically. Under the project's terms, IDA will finance a stream-gaging network. Under the Bank agreement, at least one year of stream-gaging records should be available, and projects submitted for the second and third years should have two and three years' gaging records, respectively.

On-farm water management will be improved by canal lining, by use of holding ponds, and by better scheduling. The World Bank is developing a computerized approach to scheduling. This has some promise for allocating limited water resources more efficiently, and for encouraging changes from tradition.

Institutional. The direct responsibility for planning, implementation, operation and maintenance rests with the irrigation wing of the GOG's Department of Public Works. It prepares a proposal for each subproject. Each proposal, after GOG clearance, is submitted to the GOI's Central Water Commission for final approval. (The CWC is India's highest technical authority for water resources development, and has a capable staff of 1,000 engineers.) For projects exceeding a cost of $8 million or 12,000 hectares, IDA will retain review and appraisal authority.

IDA will finance a reorganization of the VLW system which will transfer the VLW's to the Department of Agriculture, strengthen applied agricultural research, establish a better link between research and extension, and increase staff mobility at all levels.

A system of 5,000 farm cooperatives in the state provides services to 80 percent of the farmers.

Social. In the short term, there will be increased demands for labor. Irrigated cotton, for instance, will require 140 man-days/ac of labor instead of 40 man-days/ac for rainfed cotton. In the long run, there may be a move to more mechanization. The irrigation construction works will also require large labor inputs (perhaps 1,200 laborers per dam.)

Economic. The internal rate of return (IRR) for the project, for new MIP's is 19 percent, assuming a cost of $1.740 per acre, and for modernization of old MIP's, costing $465/ac, the IRR is estimated at 28 percent. The economic criteria for acceptance of individual MIP's require a benefit/cost ratio exceeding 1.0, assuming an annual interest rate of 12 percent. On a one hectare farm, income is expected to increase from $148 to $658 due to the project.

Gross revenues for water charges have not been sufficient to cover project working expenses over time. Cost recovery is supposed to be based on a "betterment levy" which has been set at half the increase in land value due to an individual project, but the levies are seldom collected. Also, application of a uniform water rate (based on crop season) does not take into account the volumes used or the distance from the main canal. Lining canals will provide more reliable supplies and justify higher water charges. Also, increased production will produce more sales tax revenues.

Rajasthan Medium Irrigation

The Medium Irrigation Projects (MIP's) encompass cultivable command areas ranging from 2,000 to 12,000 ha. Each MIP wouldgenerally be composed of:

1. An earthfill storage dam with gated spillway (possibly with some tank storage);

2. A lined distribution network down to the ro hectare outlet level and based on need to the eight hectare level; and

3. An appropriate drainage network.

The average cost of an MIP has been estimated at about $1,500 per ha of cultivable command area.

This project began in 1980 and is scheduled for completion in 1985. The target group are small farmers (95 percent less than 10 ha) and the project goals are to increase small farmer income, expand rural employment opportunities, increase availability of food to rural and urban poor, and decrease the risk of drought to the producer in the state of Rajasthan. The project is funded as follows: USAID - $35M loan and GOI - $25M, for a total of $60M pluis a $0.5 million grant for special studies and training.

Technical. The GOR has identified 42 projects which could be called medium irrigation projects, ranging in size from 2,000 to 12,000 ha.

Under previously built projects servicing 40 ha public outlets, it has been difficult to organize the 10 to 20 farmers inhabiting the area to design, build and manage the watercourses to their fields. This has resulted in inefficient use of water plus great unreliability of water supply at the tail of the watercourse. Lined watercourses at the five to eight hectare level will allow the farmers to be greater risk-takers; i.e., to invest in the agricultural inputs necessary to increase production and optimize the benefits of irrigation.

In the northwest, where the Irrigation Department is constructing channel lining below the major outlet, the Department conducts the O&M on the lined or stabilized sections for up to two years. After two years, a committee composed of Irrigation, Agriculture, farmers, and headed by an Irrigation Department engineer, designs a rotational water delivery program according to the area and crops of each farm holder.

Institutional. The direct responsibility for planning, implementation and operation and maintenance of the MIP's rests with the Irrigation Department of the state of Rajasthan. It prepares project reports for each MIP encompassing a full project analysis. The MIP's need to meet certain pre-established technical and economic criteria in order to be eligible for financing under the project. In addition, an agricultural plan is required specifying cropping patterns and necessary improvements in agricultural supporting services to efficiently use the water developed by the project.

The MIP's are included in the GOR's annual development plan to be reviewed by the Planning Commission of the GOI. Subsequent to GOI approval of the plan, the selected MIP's are submitted to the Central Water Commission (CWC) of the GOI for approval.

Civil works are carried out by local contractors using labor intensive methods under supervision of the Irrigation Department. Support for on-farm development comes primarily through the "Training and Visit" system of extension.

Economic. For lining of existing watercourses with large seepages, the B/C ratio is between 2.5 and 3.5.

Loans for the construction of watercourse lining can be secured from the commercial banks and then made to the Rajasthan Development Corporation, which, in turn, employs the Irrigation Department to construct the lining. There may be 50 to 100 farm holders under each major turnout. The loan agreement is with each farmer and each is expected to pay his proportionate share. For capital costs above the major turnout, the government considers them as sunk costs and makes no attempt to recover them. The betterment levy on the farmer is assumed to help pay for the capital costs.

New Projects

Three new USAID projects related to irrigation development, which are in various stages of planning, are:

1. Land and Water Conservation (small tanks);
2. Maharashtra Medium Irrigation;
3. Rajasthan Command Area Development;
4. Madhya Pradesh Minor Irrigation Project; and
5. Water management training and special studies.

The Land and Water Conservation project involves building small tanks in rainfed hill areas. These tanks are protected from siltation by erosion control practices in the watershed and the water stored is used for supplemental irrigation during the winter season. This is truly an integrated rural development project and will serve hundreds of small villages, each with its own subproject.

The Maharashtra mip and Madhya Pradesh minor irrigation projects are similar to the Gujarat and Rajasthan Projects, except for more strict and innovative planning and design criteria and training programs. The Rajasthan CAD project will establish a CAD authority for mips (first in India) and will strengthen and improve upon the current CADA concept.

TECHNICAL ASPECTS OF PROJECTS VISITED

The team members visited 14 different projects in the states of Gujarat, Haryana, Maharashtra, Rajasthan, and Uttar Pradesh. A summary of the technical aspects of the project is presented in Table 1. (In future study teams, additional items of interest would be: investment cost per acre, annual pumping cost per acre, and relative equity of the system in terms of uniformity of distribution.) The following section defines the list of items presented in Table 1 and gives further details on some representative systems.

Delivery of Irrigation Water and System Operation

A distribution system for irrigation water is illustrated in Figure 1. The system starts at the headworks or diversions in major irrigation schemes, at a gate from a dam in medium or minor irrigation schemes and at a tubewell in public tubewell schemes. Private tubewells are fully controlled and operated by an individual or group of farmers. Schemes are classed by area commanded as major (over 10,000 ha), medium (2,000 to 10,000 ha), and minor (under 2,000 ha).

The main canal (Figure 1) carries water to the first branch of the system. Two or more canals carry water into the area irrigated. Distributaries are supplied from the main, branch and sub-branch canals. Distributaries supply outlets which command areas to be irrigated. The area commanded by an outlet may vary from less than one hectare for piped systems to 100 ha for systems using open channels, but typically is 40 ha for open channel systems. The major factor affecting the command area is topography, but village boundaries may also have an effect.

Regulators for controlling the flow depth and flow rates are available at the branch, sub-branch and distributary canal junctions. Both supply of water and demand for water may affect the allocation at each junction. The distributaries especially are frequently designed to operate only at the design flow and full supply level.

In India, the on-farm distribution system starts at the outlet on the distributary which serves the farm watercourse. The distributary outlet regulates the flow rate to the area commanded by the outlet. Typical on-farm distribution systems vary from the extremes of no distribution system, primarily in rice-growing areas, to a carefully designed and constructed channel to each eight hectares or each farm.

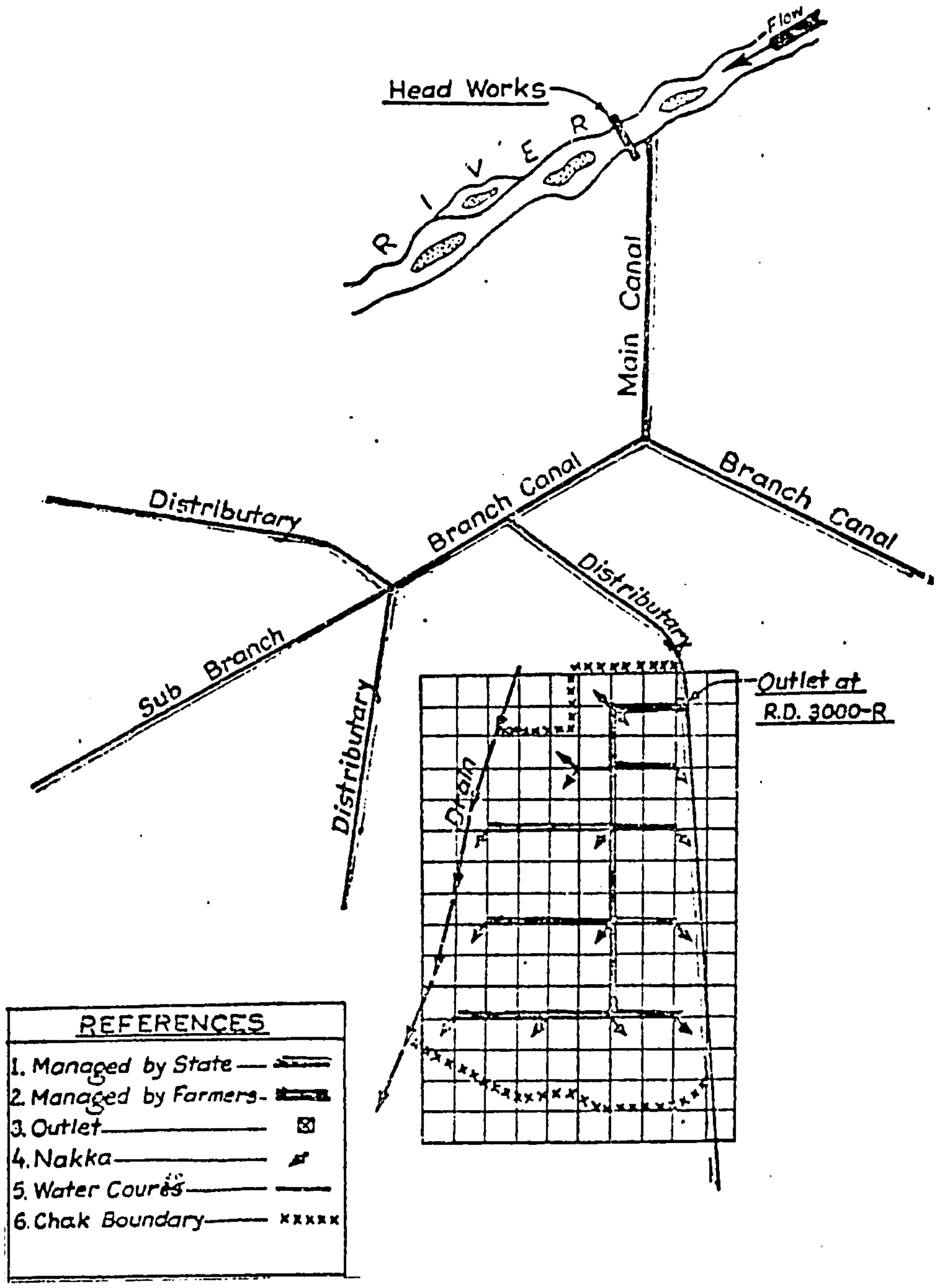


Figure 1. Typical Irrigation Distribution System.

Many variations of rules for distribution of water below the outlet exist but many are not operable. The primary method is by rotation, but this is frequently not implemented by farmers nor enforced by the Irrigation Department.

Figure 2 presents a schematic diagram of the on-farm irrigation system. Important aspects of the system are water control, crop production and the socio-economic subsystems. The water control subsystem has farm and field watercourses, delivery channels, an in-field irrigation system for application of water, the water use in the root-zone of the crop, and surface and subsurface drainage. The crop production subsystem involves tillage, seeds, fertilizer and other practices for effective yields. The socio-economic subsystem involves the economic factors for resource management, the institutional services and inputs and the important social relationships between individuals which enhance or inhibit effective farming. All are important aspects of the on-farm water management system.

Operation of the Rotational Water Delivery in Gujarat State

Our visit was to the tail of a distributary with three dividing outlets. The outlet command was supplied with a design flow of 1.0 cfs. Farmers on the outlet command received water for a time in proportion to the area served, the crop grown and assumed system efficiency of 50 percent to 65 percent. A trapezoidal flume was installed at the head of each watercourse for measurement and regulation of the outlet discharge. A sign posted near the outlet gave the time of the turn for each farmer on the watercourse.

The canal officer was responsible for regulating the flow of each outlet and could settle disputes and monitor use by the farmers on each outlet. The rotation turn time of each outlet was variable because of the area commanded. When the turn was complete, the outlet was closed and a companion outlet opened to complete the weekly rotation. Flow on each outlet was a full week or fraction of a week, but the distributary was designed for full supply level, continuous flow. No escape for excess water was observed on the distributary.

Watercourses also included a screw-type metal gate as the regulating outlet. Several large control structures were on one watercourse including an inverted siphon at a place where no road existed. Pipe outlets were located, apparently at each farm, but kutcha (earthen) outlets were also located in one watercourse resulting in direct flow to an adjacent drain.

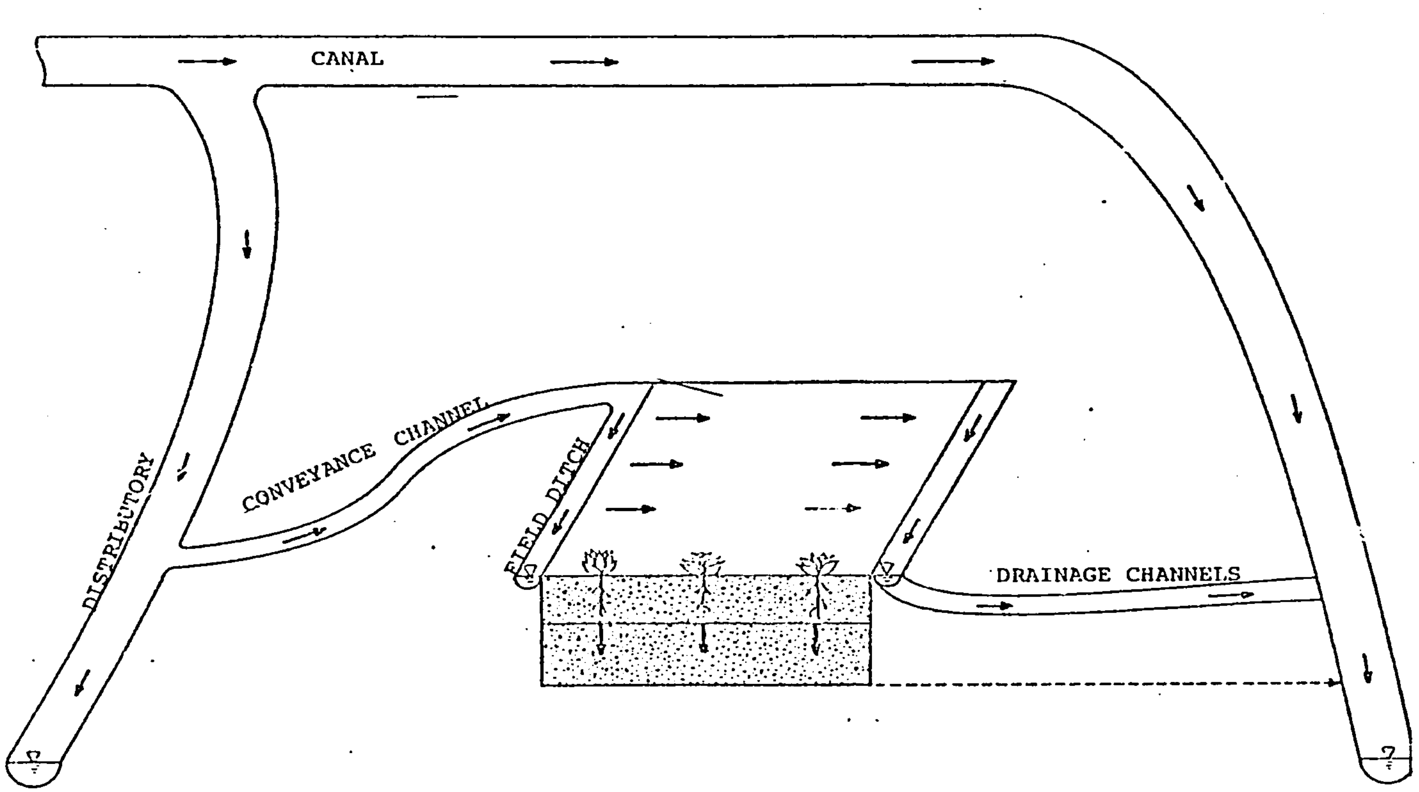


Figure 2. Idealized Sketch of a Farm Irrigation System.

One farmer had planted potatoes after rice. The potatoes were irrigated every 10 days beginning some days after planting. The potatoes were furrow-irrigated within a basin and the water stopped before the field was covered. Sometimes, because of uneven ground, part of a basin was irrigated from a different side to obtain complete coverage. About three or four such basins were located in the length of the field to obtain control of the water.

Tobacco was irrigated by a border system with each plant on a plow-constructed hill. Submergence of the plant resulted. In apparent low areas, no plants or plants of reduced height were observed.

The farmer had invested more than 7,500 Rs in potato seed, fertilizer and other inputs in getting his potatoes planted. He had both canal and tubewell water available.

The farmer who had planted potatoes had lowered the average elevation of his field by 10 cm using a tractor and blade to permit irrigation of the field with canal water. The fields usually had some discernible slope and undulations. Thus, it became necessary to break the field into very small basins since the potatoes required water control.

The tubewell previously mentioned had about 10 m lift, a discharge of 0.8 cfs and used a 15 hp electric motor, as well as a 17 hp electric motor to lift the water. Power was available for about 20 hours per day, according to the farmer.

Another stop was made at a private tubewell with an underground concrete pipeline. The nominal well capacity was one cubic foot per second with a turbine pump. The static water level was about 30 m. Cost of the water to other farmers was 12 Rs/hr. The underground concrete pipeline was nine inches in diameter, installed at a cost of four rupees per foot. The suction-discharge was six by four inches and the "shoot out" about two-and-one-half feet. A 20 hp electric motor was used. The monthly power bill was 600 Rs/mo. Five acres at a time were scheduled but the total area irrigated could not be determined. Power was available 20 hrs/day. The investment cost was 100,000 Rs.

Operation of the System in the Panam Irrigation Project (Gujarat)

A number of activities on this project are of interest. A significant number of reservoirs will be used for storage of excess irrigation water in the canal system. Thus, water not used at night and water not used because of local rains can be stored.

This reservoir storage can be released and made quickly available to farmers. Water from storage in the main dam would require several days transit time plus a minimum flow rate to make water available.

Outlets on this canal for distributaries and on other canals were of the screw type for regulating the discharge. Structures in the main canal were not adequate to regulate the flow rate and depth to fully use the adjustable nature of the distributary outlets. Watercourse outlets and distributary control structures were not adequate to regulate the variable discharge.

Many of the outlets and check structures were already nonfunctional. The watercourses discharged at elevations too low to serve adjacent fields. The distributary lining had already deteriorated significantly. Some sections did not have any cement between tile joints. In others, the top, side and bottom had eroded and the continuity of the lining had been destroyed.

Channels to each farm were of limited capacity and potentially subject to erosion. Fields had not received any improvement. The result was ineffective distribution of water, erosion of a number of fields, wild flooding as the dominant method of irrigation, and very poor use of irrigation water. No field drainage facilities were available.

Operation of the Gudha Medium Irrigation Project (Rajasthan)

This project is scheduled for an AID-financed modernization program. Among the activities scheduled are increasing the capacity of the dam, lining of canals, selective lining of distributaries and improvement of watercourses to a selective size.

The dam is presently under construction to increase the capacity. The spillway is also being enlarged and improved. This year, selective lining of the canal will be initiated, dependent upon availability of cement.

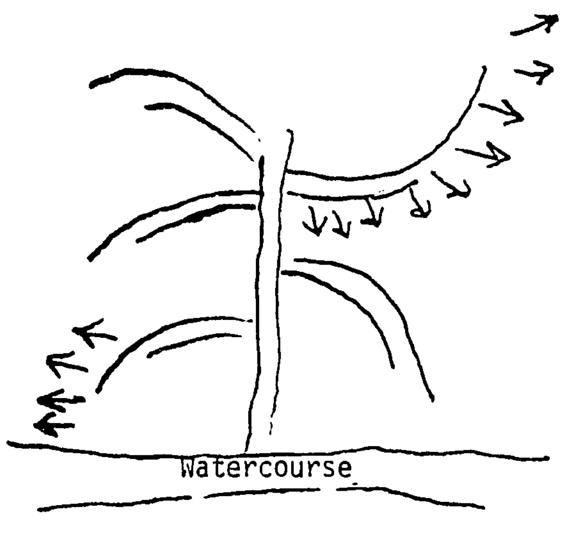
Present operation of the canal illustrates the quandary between system design and operation of irrigation canals. The present canal does not supply sufficient water to the total area so a 14-day rotation for the upper distributaries and a 14-day rotation for the lower distributaries of the command area is observed. The insufficient supply for the lower reaches is accentuated by the outlets for each watercourse.

A pipe provides the outlet to each watercourse. The outlet can supply the flow rate for which it was designed when the canal is flowing at approximately two-thirds of capacity. Thus, when the canal is operated at the full supply level, farmers on the upper reaches of the canal receive more water than their designated flow rate. This creates shortages on the lower reaches of the canal.

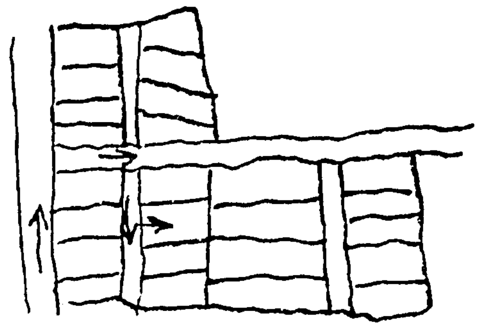
Control structures on the canal consist only of drops spaced at regular intervals. No checks to regulate flow-depth or gates for watercourse outlets were provided. No flow measurement structures were provided on the main canal. A gauge, provided on the upstream face of the drop structure for reading elevation, and a similar gauge on the downstream wall hut were not located appropriately for flow measurement. The structures also lacked clear delineation as to type of measurement.

A watercourse was selected by the Irrigation Department personnel for inspection. The upper sections of the channel had been cleaned and the banks had sufficient freeboard. Farther down the watercourse, cleaning and maintenance were needed. Nuccas were also frequent and not closed completely. A farmer was irrigating a field preparatory to sowing wheat. The channel was too low to supply the field and the farmer had difficulty containing the water in the channel.

Irrigation of the field was accomplished by wild flooding. The water was distributed to the field as follows:



The farmer, after sowing wheat, constructs small basins to irrigate the field as follows:



Distribution of water by farmers when attempting some water control.

The farmer estimated a 1/3 reduction in time to irrigate the field when using the small basins.

Water is applied to most fields by wild flooding. In some cases, gentle slopes result in erosion of the field. Some areas are difficult to irrigate because they are high. Large amounts of applied water and very poor distribution are characteristic of this method of irrigation.

The dam, canals, branch canals, distributaries, watercourses, and drains are all designed, constructed and operated by engineers. The field water application is left to the farmer to design, construct and operate. The application of water to the field is the means by which the water infiltrates into the root-zone for crop growth and yield. When field application is more efficient, the benefit counts for all sections of water distribution including that stored in the dam. Without effective application of water to the field, good seeds, proper fertilizer and other appropriate inputs and services such as credit and extension are less effective or have no effect at all.

In our studies of farmer-designed, constructed and operated field systems in Colorado, Chile, Pakistan, Egypt, Thailand and India, typical field efficiencies are as low as 25 percent and, for a season, do not average more than 50 percent. Proper design and construction of field application systems in Pakistan and Egypt halved the average amount of an irrigation application. Farmers need to be provided assistance in the design and construction of their field irrigation systems.

Operation of Chambal Irrigation Project (Rajasthan)

The project involves modernization and implementation of on-farm improvements. Canals and distributaries have been improved, but not lined. Outlets are pipes at appropriate locations in the distributary. The outlet for one watercourse review was located about one kilometer from the area irrigated because the distributary did not have sufficient elevation to command the outlet area. Farm outlets were pipes in the banks of the watercourse. Several cuts in the banks were also observed.

On-farm development consisted of the following items: (1) rebuilding of watercourses; (2) construction of roads and drains; (3) realignment of holdings; and (4) land shaping. Watercourses were reconstructed with appropriate control structures. Some junctions were lined, but no checks, culverts, drops or other control structures were observed. Roads and drains were constructed at the low area between watercourses. All farms then had direct access to the watercourse, the drain and the road. One farm was observed where the surface elevation increased toward the drain, making irrigation difficult.

Land shaping consisted of using a dozer and elevating scraper, also used to construct the roads and drains, to lower any high areas on a farm to at least 10 cm below the full supply level of the watercourse. Apparently farmers were promised additional leveling according to one farmer.

Realignment of holdings consisted of consolidating the holdings of a contiguous area into one geometrically arranged strip which extended from the watercourse to the drain. The width was determined by the area of the farm.

Irrigation of each farm was accomplished by three field application systems. In rice, a field watercourse was constructed along the length of the holding toward the drain and water was supplied to 10 x 10 or 15 x 15 m basins on adjacent sides of the channel. Since farmers practice puddling of the field to reduce seepage, the smaller basins might be assumed to have been water-leveled. Inspection of the water marks on rice plants in a partially harvested basin suggests at least a seven centimeter range in elevation in the few basins observed.

Most fields are irrigated by wild flooding with concurrent heavy applications, poor distribution, erosion in some fields and excessive ponding of water on the lower end of a number of fields. Very poor irrigation practices result.

The third method is the construction of in-field distribution ditches with very small basins irrigated on adjacent sides. These were present in only a limited number of fields especially on crops where water control is important. Neither of the methods result in a long-term trend of farmers leveling their farm. The 200 m length is ideal for an appropriately designed and constructed field irrigation system. Apparently because farmers have not designed and constructed field irrigation systems which use 200 m length of runs, future projects will reduce the distance between watercourse and drain with consequent increased consumption of land.

Discussions with the CADA personnel were very interesting. A description of working CADA should be developed for a transferable technology.

Operation of Chambal CADA (Rajasthan)[1]

Mr. Kumat described the organization of the CADA. All the agencies are under one command and the Area Development Commissioner has administrative authority over all the personnel in the CADA and controls the budget. The personnel represented included civil engineers, agricultural engineers, agricultural researchers, soil surveyors, agronomists, land development personnel, agricultural extension agents and mobile magistrates. The functions of these disciplines in the CADA are well-defined and there is a regular meeting each Monday of the heads of departments for policy decisions and exchange of information.

The CADA personnel were encouraged to keep up their professional interests through participation in professional meetings and short courses. The Commissioner can authorize leave for any professional up to one month in India for special training and attendance at meetings. Turnover in personnel is not great. Average tenure in the CADA is about three years, but several have been there much longer.

The Commissioner discussed strategies for the next five years. These include: (1) on-farm water management beyond the outlet with special attention given to warabundi, inputs, and extension services and (2) drainage.

---

[1]Notes from General Meeting with Area Development Commissioner, Mr. Kumat, and staff of the Chambal CADA at Circuit House, Kota, Rajasthan, November 18, 1980.

Estimation of water is largely based upon rule of thumb and type of crop grown. The research unit is making tests of the different soils on available water capacity, infiltration rates, permeability, etc., but these data are not used to help establish water requirements.

Apparently, there has been a substantial increase in yields since the project started. For example, paddy has increased from about two tons per hectare in 1974 to four tons per hectare in 1978-79. There are published reports on yields of main crops, rice, wheat, gram, etc., which indicate substantial increases in productivity. Controlled fertilizer experiments are being run which indicate good responses to N, P, and K.

About 85 percent of the rice area is planted to improved varieties of rice. The use of nitrogen has more than doubled since 1974 from 15 hg/ha to 36 hg/ha and P_2O_5 from 6 hg/ha to 16 hg/ha.

The CADA has the organization to control water flow in the distributaries to the outlets, but have not yet been able to devise procedures for effective control and on-farm monitoring. There was concern that insufficient funds were made available in project budgets for operation, maintenance, and monitoring of the system. The Commissioner suggested that a warabundi scheme, combined with farmer education, with a six rupee per hectare assessment, to be used for on-farm maintenance. This might provide incentives to farmers to maintain the system better. There is a plan for the second phase of the project to have a special water management training program for project personnel and for farmers.

The soils are primarily black cotton soils (dark clays). There are two kinds, one very heavy clay which is difficult to work. The other has a better structure. These soils tend to form a plow pan layer which restricts root growth. Experiments are being conducted with deep plowing to break up the pan, but there are not data yet to determine if this is economically feasible. About 10 percent to 12 percent of the command area has salinity and sodic problems.

Conversations before and after the meeting with agricultural engineers indicated their concern that data on groundwater hydrology, soils studies, cropping practices, farm size and ownership patterns be obtained before design of the irrigation system.

Comparison between Projects

Referring to Table 1, perhaps the items with the most striking contrast are the designated command area per cubic foot per second delivery capacity based on continuous flow; and the apparent intensity of irrigated cropped land during rabi (winter dry season). These items together give some of the area actually irrigated during rabi per cfs which is an indication of how well the water (and the system) are being utilized. For example, the Haryana river run project has a delivery capacity of 800 ac/cfs and an intensity of about 33 percent; thus, about 250 ac were actually being irrigated with cfs.

This can be compared with the Uttar Pradesh Public Tubewell Project, with lined watercourses, which commands 350 ac/cfs, based on 16 hours per dry pumping. However, at present, there is only enough electricity to pump the average well for four hours a day. Converting to determine the equivalent command based on continuous pumping gives: 350 x 24/4 = 2100 ac/cfs. Since the cropping intensity is only about 10 percent, about 210 acres were actually being irrigated with each equivalent cfs based on continuous flow.

Unfortunately, we did not try to get an estimate (official and/or visual) for apparent intensity, until midway during our trip, thus, the many blanks. The other items in Table 2 are self-explanatory. Lined watercourses, controlled measuring gates, and firm (pucca) management of water deliveries are essential for equitable distribution of water, especially where the water supplies are tightly stretched, as in the Haryana and Uttar Pradesh projects mentioned above, which have similar equivalent actual irrigated ac/cfs. The Haryana system has these features and, consequently, the irrigated land was equitably spread throughout the command area. On the other hand, the Uttar Pradesh tubewell system did not have all of the necessary physical and management features. Thus, according to farmer interviews, deliveries were not equitable; some farmers said they receive no irrigation water now that the electricity is only available four hours per day.

Table 1. Comparative Summary of Technical Information for Projects Visited.

ITEM	PROJECT Mahi	 Pungam (pipe)	 Panam	 Kadana (pilot)	 Fatewadi (river run)	 Kiwale (lift)	 Gudha
Type of project	Medium surface with storage	Medium surface with storage	Medium surface with storage	Medium surface with storage	Medium surface, river run	Minor lift	Major surface with storage
Extent of watercourse lining	None	Pipe to 4 fields	To outlet	None	None	None	Experimental sections
Farm outlet level (acres)	37-70	6-20	20	20	100-400	20-40	20-100
Control to on-farm system (nukka)	Screw gates with flume	Pipe valve	Slide gate	Screw gate with flume	None	Mud dams	None
Control to watercourse	-	Pipe valve	Screw gate with flume	Screw gate with flume	None	None	None
Command acres per cfs based on continuous delivery	40-80	120	100	80	60 (Paddy only)	70	75
Apparent irrigation intensity - rabi	-	-	-	-	>10%	15%	-
Rotation between distributaries	Continuous	Continuous	Yes	None	Yes	None	14 days/ month
Rotation between outlets & distributaries	Pucca[1]	Continuous	Kutcha[2]	Pucca	None	Kutcha	14 days/ month
Rotation between farmers	Pucca	Kutcha	Kutcha	Pucca	Field to field	Kutcha	Kutcha
Soils and topography	Deep sandy loam flat	Sandy clay loam flat	Sandy loam hilly	Sandy loam flat	Sandy salty and black cotton	Black cotton 6"-24" rolling	Well-drained sandy loam mostly

[1]Pucca means disciplined and firm [2]Kutcha indicates loose and relaxed

Table 1. (Continued)

ITEM	PROJECT Chambal	Nada (Sukhomjari)	UP Public Tubewells	UP Public Tubewells	Gujarat Tubewell	Maharashtra Dugwell	Haryana @Rohtak
Type of project	Major surface with storage	Minor small tanks	Deep tubewell	Deep tubewell	Shallow tubewell	Dugwell	Large surface river run
Extent of watercourse lining	Very limited	To within 200 ft of each field	Pipe	To outlet	Pipe to fields	Pipe to fields	Some with 50% rule[3]
Farm outlet level (acres)	50-150	2-4 ac	18	30-60	1-2	1-2	40
Control to on-farm system (nukka)	Some	Alfalfa valve	Screw gate	Mud plug	Bolted plate	Bolted plate	Slide gate gate
Control to watercourse	None	Valve with wier	Direct from TW	Direct from TW	Direct from pump	Direct from pump	Submerged orifice
Command acres per cfs based on continuous delivery	167	50-60	250[4]	350[4]	-	100[5]	800
Apparent irrigation intensity - rabi	-	100[6]	20%	10%	-	100%	33%
Rotation between distributaries	21 days/month	None	None	Yes	Yes	Yes	Yes
Rotation between outlets & distributaries	21 days/month	Pucca	Pucca	Kutcha	Pucca	Pucca	Pucca Warabandi
Rotation between farmers	Kutcha	Pucca	Kutcha	Kutcha	N/A	N/A	Pucca Warabandi
Soils and topography	Black cotton w/15% mild salinity	Deep silt loam hilly	Silty loam flat	Silty loam flat	Deep sandy loam flat	Black cotton 24" deep	Silt loam

[3]lining in all sections, running about 50% lime [4]based on adequate electricity to pump 16 hrs/day (now, only 4-6 hrs/day) [5]only plan to pump 5-6 hrs/day [6]two irrigations during rabi

ORGANIZATIONAL EFFECTIVENESS OF PROJECTS VISITED

Discussions with irrigation officials at the central and state government levels reveal an awareness of the large challenge and problems of irrigation development in the 1980's. First, there is an awareness of water management reaching to the farm level and the need for water management training or staff development at all levels of the irrigation system from the reservoirs to the farm. Secondly, there is a felt need for greatly improved monitoring and evaluation approaches within and of the system which will provide feedback to decision centers in the delivery of water and also to state and central government decision centers to improve the operation of projects and systems, planning, and policy-making. Thirdly, the GOI is aware of the need for greater uniformity in CADA organizations, irrigation rules and regulations, land development policies, and also in water management training across the states. Fourthly, the Center (GOI) will likely plan a stronger role in policy decisions and provision of certain facilities for research, monitoring, training, water codes, water price policies and other irrigation matters in the future.

Since water is primarily a state subject, it is important that the Center clearly delineate its role and provide strong policy commitment, guidelines and facilities for the states. The proposed separation of design and construction from operation and maintenance and the creation of a strong career structure for water management will go a long way towards giving prestige and status to an area long neglected.

Increasingly, the organizational effectiveness of irrigation projects and programs in India needs to be evaluated in terms of:

- -- increased predictability of delivery of water
- -- increased productivity of water
- -- improved equity of water distribution
- -- improved maintenance of a valuable resource and improvement program
- -- improved ability of cost-effectiveness and recovery of investments
- -- investment of the farmers in the farm systems

Until recently, as in most countries of the region, irrigation organizations had been developed which did not take into consideration the soil, topographical, water-plant relationships or social factors in the projects they designed and constructed. The reasons for this are inadequate training of personnel and/or lack of experience in dealing with construction and maintenance of such systems. India has found, as many countries have, that, with increased population pressures creating more demands on irrigated agriculture, along with the high costs of irrigation development and improvement, approaches must be evolved which will result in more efficient and cost-effective water management at the farm level.

Farmers in a democracy like India are now demanding more predictability and control of water for increased crop production. Farmers in general want more organizational control and discipline for water as a reliable agricultural input. Both the complexity and scale of systems are such that the basic challenge of all organizations involved is of Himalayan proportions.

There is ample evidence, especially where there are private tubewells and open wells, that farmers who have water control know the value of water as evidenced by the way they manage water as an input, purchase it, and maintain their field channels for improved distribution. Where water is a public good and the technology is indivisible, except in some strong warabundi schemes in northern India, there is ample evidence of inadequate organization in terms of coordination and integration to provide adequate delivery of water and equitable distribution, as well as maintenance of public outlets, collective farm structures, and farm channels.

In terms of several selected organizational dimensions, a tentative breakdown of organizational effectiveness of projects visited is presented in Table 2. The table was developed from both observations and information received during the several short field visits.

Synthesis of Effectiveness

Several general observations are synthesized from this table showing various dimensions of organizations of projects visited:

1. The structure of the CADA organization is generally accepted, however, there is still a search to find the most effective organizational model. The most impressive organizational structure, in terms of workable coordination of agencies and integration of services is that of the Chambal Project. Perhaps this is due to the longer experience, low turnover of staff, and the ability of the authority to exert pressure for policy decision-making for field operations. The clear lines of authority under good leadership and an authority budget make this an effective approach.

Table 2. Quick Evaluation of Project Organization: Projects Visited in Field Trips.

Dimensions	S. M. Mahie Rotational Pilot	Panam Command	Padang	Fatewadi Proposed Project (Desire AID help)	Kiwale River Lift Project	Gude Project Rajasthan (Desire AID Assistance)	Chambal	Haryana State Minor Irrigation T.W. Project
1. Structure	CADA* type. Irrigation has straight-line authority. Agriculture works through Panchayat Samitis--gets involved in politics	CADA type (same)	CADA type (same)	Desire to develop CADA Will use typical structure	Under Supt. Engineering Irrigation Department	Irrigation Department operation wants to develop CADA approach--Irrigation will work to 8 ha outlet?	Highly structured organization at top with competent CADA leader. They view this as a model authority located in CADA and can aggressively move on decisions	Straight line Department to the farm level. Not set up on CADA basis
2. Coordination	Loose because T&V* works outside CADA Agriculture--does not have straight-line authority. Involved in Panchayat system. Irrigation dominated	Very loose--Irrigation SCS,* Extension, credit Irrigation responsible to 8 ha unit. Farmers request water--deputy engineer makes decisions--field channels by SCS poorly designed. Rough to no LL.* Irrigation people complain about SCS help. All agencies blame each other. Lack of good coordination	Very loose organization of Irrigation--SCS, Extension department, and credit--Irrigation dominated. CADA has no real control over extension salary. Differentials between agriculture and irrigation in salary scales	Irrigation alone delivers water to outlets in rotation and to tanks. Extension works separately	Loose--the project started during a drought period crash program. Land development Corporation identified and laid out channels and did only LL rough land leveling	Hope to coordinate project at Chambal but agricultural engineers fears they will not be utilized at farm level prior to raising dam and improving canals. Prior to improvement should ascertain topography, soils, size of farm holdings. A difference of views about planning and implementation of program. Officials seem to think of planning as top down	Regular meetings each Monday to discuss issues and get action. Lines of authority appear clear, coordinate irrigation department, land development authority, credit, research and supplies. A mobile magistrate and extension staff at the top are experienced. Started coordination in 1974--have a single budget, extension is under the CADA--average turnover of personnel is 3-4 years	Little coordination with other departments. Operate separately, i.e., extension, etc.
3. Integration Farm Level	Fair at best because field work and delivery of water not tied. Irrigation works to the turnout and beyond with rotation and also make crop assessments	Integration poor as work. No agency handles improved irrigation practices. LL problem due to compulsion. Recovery rate is only 10-15 percent. Field channels not complete after two years	Poor--after two years field channels poorly designed, incomplete, and poor repair--compulsion not working. Payment rates for farm and channel LL very poor. LL is only rough leveling. Reports of rake-off by Irrigation Kharqueens in filling out irrigation demand requests	None--irrigation department only delivers water	Poor coordination--some sites were poorly selected. Thin soils, rural erosion are evident	Hope to integrate Irrigation, Land Development Corporation, and Extension. A mobile magistrate to be used to decrease those who damage structures, steal water, and who do not follow rules	Agencies appear to be fairly well integrated. Complaints of agricultural engineers is that they do not have much role in design of systems, therefore have to make the system work after it is built. Drainage system not working due to poor design and maintenance	Within the Irrigation Department the work is functionally organized such as a Supt. engineer of Planning, of operations, of revenue, etc. Credit for financing lining by Agricultural Refinance Development Corporation is available. Extension is not closely integrated into project
4. Organization for rotation system within command	Good--is working farmers prefer because reduces head end problem and conflict. Rotation units 37A, 70A and 60A each observed	None--farmers desire and request discipline; farmers major worry is water predictability and field channels	None	None--only proposed	None--a demand system	None to implement	Some areas have implemented--will focus more in future	Very good--is working and farms have more predictable supplies
5. Maintenance								
a. Canals	Fair	Poor	Fair	Poor	No canals	Poor	Fair	Good
b. Distributory	Fair	Poor	Poor	Poor	Poor	Poor	Fair	Poor
c. Outlets	Good	Poor	Poor	Very poor	Poor, broken	Poor, broken	Poor--some broken	Good
d. Farm level	Poor	Worse than poor	Very poor	None	Very Poor	None	Poor--many structures broken	Good
6. Enforcement Codes & Rules	Fair on rotation system	None farmers want discipline and want Irrigation to collect revenue	Rules not enforced for stealing water, damages farmers report want more discipline	None	None	None big farmers have own outlets--operational farm sizes large	Little enforcement but mobile magistrate handling on canals now will focus more on this--at farm level very little enforcement	Enforcement good cards and notes
7. Monitoring								
Main System	Daily reports of canal levels	Daily reports of canal levels	Daily reports	Daily reports	Little daily	Daily reports	Daily reports twice	Daily
Distributing Level	Chowkidars casual monitoring	Casual monitoring	Casual	Casual	Casual	Casual	Monitor	Daily
Outlets	Chowkidars casual monitoring	Chowkidar but farmers operate system, many structures	Chowkidars but farmers operate	Almost none, gates destroyed, farmers open and operate outlets	None	Almost none	Casual	
Farm System	Casual visits of Kh	None	None	None	None	None	Very little but wants to start monitoring and measurements at tails with report back system	By farmers
8. Farm Level	Fair but VLW cannot rise above supervision in career structure, also LWIS under pressure by Panchayats, no LWIS trained WM	No indication there is organization. None trained non agent		No indication of any	None	None	Fair--trials and little training in WM	Poor to Fair
9. Officials Attitudes	Extremely paternalistic do for and to but not with	"Farmers will not cooperate" "Don't know the value of water" Paternalism		"Farmers will cooperate etc. etc. (want a project)"	Poor, can't pay, won't pay, won't cooperate extreme paternalism	Very paternalistic, must force for new, must do for them, won't cooperate	This is an issue here. Some have typical paternalistic views. Others feel that farmers can and will play a role if adequate water is supplied and incentives utilized	More positive within
10. Farmers Organization	Irrigation groups and T&V contact farmer Fair	None	Paternalism "Farmers need to be told"		None	None		Will Cooperate

*CADA--Command Area Development Authority; T&V--Training and Visitation Extension System; SCS--Soil Conservation Service; LL--Land Leveling

2. There is a need felt to link all aspects of management of water delivery from the reservoir, distribution at the outlet, and on-farm use, rather than to continue to attempt to operate as though these units exist as separate entities.

3. As irrigation organizations with engineering expertise and long experience move closer to the farm level, it is apparent that the problems become more complex and the work less prestigious. Few staff are equipped by expertise or experience to handle the tough organizational and human problems of adequate delivery, equitable allocation, on-farm improvements, and direct services to farmers. It is doubtful if many truly interdisciplinary teams could be assembled easily in India to properly analyze problems at this level, develop appropriate solutions, and implement and monitor improvement, which farmers will maintain adequately on a continuing basis. In the absence of other approaches, the engineering approach of technology and the administrators' use of regulations have been tried as a means to achieve farmer involvement, but have not been successful. In brief, there are several areas of need which should be addressed in the development of future manpower for work in water management.

   a. General inability of all but a few officials to understand the total irrigation system from the reservoir to the farm as one which must be closely coordinated, linked organically, and managed as a total system, instead of three or more systems.

   b. Except for a few officials at both central and state levels, a widespread lack of understanding about what water management is, as well as a lack of understanding of how and why the present system works as it does, from the canals to the farm level.

   c. A long traditional inability on the part of irrigation engineers and others to understand and appreciate the role of other disciplines in the design and operation of all aspects of a complex irrigation system.

   d. The strong assumption that most problems in the delivery, distribution, application and removal of water can be solved with more technology and more regulations, combined with widespread paternalistic beliefs about what farmers can and will do.

4. Farmers want more predictable supplies than rainfall and, with this certainty, they desire improved organizational approaches to achieve discipline in the distribution of water. Farmers need improved services at the farm level which, if provided adequately, will create more credibility in government. An example is that many fields leveled by bulldozers and graders are far from level for good field application. Methods need to be developed to gain more involvement and cooperation once adequate water is assured. Farmers need both incentives and discipline, but complusion alone will not produce results. Land consolidation and enforced cropping patterns will likely not work anywhere; however, more flexible approaches and adequate incentives will, if implemented properly. Few farmers have realized or have yet seen the full benefits possible from a comprehensive set of improved on-farm practices.

5. Maintenance of the systems at canal, distributary, outlets, and on-farm levels, in general, range from only fair to very poor. As one reviews project budgets, one gains the impression that maintenance is given a very low priority at all policy levels. One wonders if this is a reflection of the low level of prestige and "prosperity" in maintenance activities. Without farmer cooperation, no improvements will last long anywhere.

6. Except in a few projects like Chambal, where only a beginning has been made with the use of a special CADA Mobile Magistrate or the rotation scheme in Rhotak, there is not sufficient concern for enforcing existing codes which are adequate to cover offenses, such as stealing water, damage of structures, upkeep and maintenance of farm channels.

7. Monitoring of the system on a regular and systematic basis appears to take place only on the main canals and on rotation systems where farmer demands are used as a basis for supply of water. On rotation systems, measuring devices are located at the heads of watercourses. The commissioner at Chambal suggests correctly that measuring devices and communication systems should be used for regular monitoring of tails of systems to ascertain how well the system is functioning.

8. Everywhere, the extension aspect of water management is weak for several reasons. First, in most CADA areas, the

new T&V system is not completely under the CADA as in Chambal. Secondly, the Agriculture Department, unlike the Irrigation Department, works through the Panchayat Samities and does not have a direct line organization for quick decision-making. Thirdly, nowhere are there subject matter specialists backing up extension workers with training in on-farm water management improvement. The Irrigation Department organizes farmers for the rotation system but the extension gets caught up in Panchayat politics and the larger, more powerful farmers capture their services. A study needs to be made of the operational sizes of farms versus the legal sizes because superficial field information suggests that the operational units of joint farms are much larger than the units recorded by the Land Revenue Department. If this is true, then the eight hectare or 20 ha outlet command approach in all places should be questioned. Each outlet requires higher costs and increased demand on thin administrative resources. Also, the operational size of farm units may suggest problems of larger and more powerful farmers taking inequitable supplies of water and not cooperating in on-farm improvements because they know that existing rules and codes will not be enforced. Some of the best managed irrigation schemes in Asia, such as those in Taiwan, Japan, and Korea, combine strict discipline and swift justice of offenders with flexibility for farmer involvement.

9. At all levels of government, there is a longstanding paternalistic view that farmers will not cooperate. The view is that programs therefore must be designed to regulate them and provide services for them. When predictable water supplies and creditable services are provided, then there is a need to identify the adequate mix of "the carrot and the stick." To date, paternalism plus inadequate services and a "soft approach" have yielded little farmer involvement. Farmers usually will only organize when they perceive it in their best interests to do so and not because they are commanded to organize. Fourthly, few attempts have been made to involve farmers in the design, planning and implementation of farm-level projects which are meant to benefit them. It is doubtful that Indian farmers are all that different from Pakistani farmers who have provided labor to develop their own improved watercourse with assistance from engineers.

10. The warabundi organization is a useful tool for predictable water deliveries in areas of scarce canal supplies. While

this tool for improved regularity in supplies has become widely accepted in northern states, in other areas there appears to be a lack of understanding of the basic requirements of the warabundi system. The model exists in the Punjab and Haryana and the procedures involved in its implementation should be made widely available in India. Project leaders in the south should consult more with colleagues in the north about the warabundi system, its prerequisites, and methods for implementation. At the farm level, this system should be instituted and maintained because it is a proven indigenous method which has been tested for over a hundred years in northern India. Visits to the Punjab and Haryana indicate that the warabundi rotation system is working. Where farmers have more predictable and regular water supplies, they tend to cooperate more in on-farm improvement programs. The organizational structure of some projects in the north is more well-knit with more carefully delineated responsibilities and more trained staff than in most other areas of India. Long tradition in the north has evolved a good organizational tool which reduces some of the paternalistic procedures now being used in most CADA organizations in other areas.

In summary, India has gained much experience in irrigation development. The rotation system, the outlets to serve small command areas, and the new policies proposed are all positive innovations. Government officials and project personnel are well aware of areas for improvement, especially in software innovations. India has developed much expertise and experience in hardware development and is willing to experiment. The 1980's will provide a challenge to personnel at all levels to evolve software approaches which will work in the conditions of India (see Training section). Hardware approaches have outrun the ability to develop software approaches, and, unless the latter are improved radically, the CADA's and other projects may face the problem suggested by one high-level official, i.e., widespread discontent that the CADA investments are not returning adequate economic and social benefits to millions of farmers in India who, in total, will continue to present a formidable pressure group on policy-makers and political leaders. India, however, is involved in one of the world's largest experiments in irrigation improvement. These efforts should be supported and carefully evaluated, not only for continued improvements, but for lessons from which other countries can profit.

COMMAND AREA DEVELOPMENT AUTHORITIES

In 1972, India launched an ambitious new program to attempt to increase agricultural productivity in the command areas of major irrigation projects: the Command Area Development program, later formalized into Authorities (CADA's). The function of the CADA was not less than to attempt to obtain optimal agricultural production in command areas by improving and coordinating all inputs to the farmers in these areas, not only irrigation, but other agricultural inputs as well.

CADA's are given the task of providing management and technical assistance and coordinating financial support for improving on-farm water distribution and in-field application within the command area. In addition, CADA's coordinate other infrastructural inputs such as storage and markets and are charged with strengthening the organization of agricultural extension activities in general.

The CADA's now coordinate services for almost all of the 60 major irrigation projects in India (covering a cultivable area of 13 million hectares), but their record has been mixed. The most obvious problems which the review team observed are that: (1) the main system (between the chaks and water supply) operation is unreliable because of mismanagement, poor maintenance, and the lack of effective control structures; (2) there is little coordination between the main system management, which is the responsibility of the state's Irrigation Department and the CADA's, which are usually under the state's Agricultural Department; and (3) the CADA's themselves are weak and ineffective because they only coordinate, not control, inputs and personnel from other agencies.

The central and state governments are aware of the problems with CADA's and efforts are under way to remedy this situation. There is serious discussion concerning dividing the Irrigation Departments into two separate, but parallel, cadres. The traditional roles of planning, design and construction will be housed in one cadre; a new cadre staffed with professional irrigation system management personnel will be established to manage, operate and maintain (MO&M) the total irrigation system. However, since irrigation development is the prerogative of each state, a unified approach to system management may be long in coming. In the meantime, AID and other donors can play an important role by encouraging projects (through funding) that are designed to provide the needed delivery and control facilities and a coordinated program to manage the total irrigation system.

Problems with Implementation

Naturally, the CADA development represented a major invasion of the traditional territory of many bureaucracies already assigned the task of administering these inputs and a power struggle was quickly set in motion (one area in which bureaucracies do move quickly!) The result has been a rather bewildering variety of structures and functions of the CADA's in various states: some are in the Irrigation Departments, some in the Agricultural Departments, some are more or less powerful coordinating agencies between these departments and other agencies.

In general, it can be said that the success of the CADA's has depended on the dedication, power and abilities of individuals in the CADA organizations, while the failures have been due to systemic problems in the structure and functions of the CADA organizations themselves. A brief review of some of the systemic problems may help to prepare the way for improvements in this obviously sound innovation in agricultural management.

First, many CADA's became mired down in problems of land consolidation. The farmers fiercely resisted consolidation of their scattered plots into one unit. While this resistance is sometimes interpreted as irrational behavior, it is our opinion that it is quite rational. In labor-intensive, small-scale agricultural systems, very little is gained by large fields, while scattered plots over different soils, slopes and elevations provide considerable advantage in dispersion of risks. Also, the farmers do not always trust the land leveling design for fear of ending up with high spots, low spots and/or excessive loss of topsoil, etc. Because of the resistance to consolidation, programs were delayed for years, in some cases permanently, while these disputes were debated in the courts. Eventually, the CADA's had to de-emphasize the land consolidation components of their programs in order to get on with what was, after all, the essential part of their job: delivering irrigation and other inputs to the farmgate.

Second, they ran into a formidable problem in delivering irrigation water because the irrigation departments were often unwilling or unable to deliver water to the outlets in the correct quantities at the proper times and, in some cases, were not even willing to inform the CADA's when the water might be expected. Thus, when CADA personnel promised water to the farmer, they could not deliver the goods because the distributary was empty. This problem substantially reduced the credibility of CADA personnel.

Third, the CADA's were rarely able to obtain control over "other agricultural inputs"; seeds, fertilizers, credit and extension generally remained with other agencies and there was little coordination with the CADA organization.

Fourth, the CADA's were staffed mainly (in some places, exclusively), with people deputed from other agencies. These people were naturally oriented toward the objectives of their own agencies and generally kept their loyalties to those agencies rather than to the CADA's. Indeed, as one CADA manager observed, other agencies often used the CADA mainly as a "dumping ground" for unwanted personnel.

Fifth, the CADA's encountered the near universal budgetary problems of operation and maintenance activities in competition with construction activities, even within their own organization. The budgetary emphasis should be the other way, as the manager of a large U.S. company recently observed, "Everyone knows it is much easier to make a kid than to raise one."

By pointing out the problems of the CADA's we do not wish to convey an impression of total failure. As noted before, some CADA managers were able to overcome these problems and establish success in bridging the gap between the outlet and the farmgate with corresponding increases in production. We believe the CADA experience in India, with improved organizational forms, points the way to the solution of the problem of the management gap.

New Management Model

With these problems in mind, the remaining pages of this discussion will attempt to outline some of the principle features of a management model for the CADA's which may help to overcome some of these problems. The objective is not to attempt to establish a single CADA format for each state, but rather to provide a basic model which is capable of acquiring a variety of different forms in response to conditions specific to each state. The emphasis here is on the CADA as a management entity, not necessarily as an operating entity. The basic principle is that it does not matter which agency does the work, so long as the work is done and is known to be done.

In this model, existing agencies would be encouraged to continue working in their traditional area of expertise so long as they actually perform according to a management program mutually agreed upon by themselves and the CADA. The CADA would primarily function at the policy management level, its principle function being to assure that the objectives explicated in the management program are actually realized, to hold the operating agencies' "feet to the fire" with respect to their own agreed-upon program. The CADA should have the power to take over direct management of operations when the operating agency fails to perform. But this power should be exercised only as a last resort. With the power in hand, as is so often the case, it rarely needs to be exercised.

There are two logical organizational divisions, or "Groups" of an agricultural production system in a command area. The first is the Irrigation Systems Group (ISG); the second is the Crop Systems Group (CSG), as they shall be called here. These groups can be established through the existing line agencies with managerial oversight by the CADA.

The objective of the ISG is to oversee the efficient and equitable delivery of water from the headgate to the farmgate of the irrigation system. The best hope for achieving this task, in our opinion, is through the warabundi system. Naturally, the appropriate organization to operate this system is the ID. The ID should operate on the basis of a "turnkey contract" between the Design and Construction Divisions and the ISG Division. The latter, in effect, "buys" a project from the former according to specifications which the ISG and the CADA help formulate. Thus, the people who have to operate the system are able to acquire a system which is physically operable. After constution, and a testing period, the system is handed over to the ISG, while the Construction and Design divisions move on to other projects.

It is essential, if the ISG is to be in the ID, that this unit be given all the stature, power and career opportunities of the Construction and Design units. It is also necessary that people in the ISG be provided with intensive training programs in management, not only in good practices of engineering and agronomy, but also in the philosophy and techniques of management science, so that they can be oriented to the task before them. Some ID's are making this transition to management thinking, some, in the future, doubtless will make the transition, some will not. In the latter case, the CADA must necessarily take over operations, with their own ISG Division.

The problem of managing other agricultural inputs is, in principle, much more difficult than that of managing irrigation. The reason is that the only rational objective for a CSG is optimal yields from farms, yet the span of control over agricultural inputs stops at the farmgate, with the individual farm manager. Thus, there is a break in the chain of control, rather similar to the break at the outlet in most irrigation systems, but a break which cannot be resolved simply through organizational changes. The CSG can only provide inputs to farmers, yet the CSG must be held accountable for outputs from farmers.

Actually, this kind of management operation is not so unusual as it may first appear. In fact, it has a very close analogue in those forms of business organization known as "franchise operations", such as McDonald's hamburger stands, or Coca-Cola distributors. In these cases, operations are highly decentralized to individual ownerships of retail distribution facilities, the franchise, while the franchiser acts as a wholesaler of management services and such infrastructural inputs as advertising. In return for thse services, the franchiser shares in the profits of the franchisee. A franchise operation is a decentralized operation with a clear division of labor between local operations, which the individual entrepreneur can manage best, and infrastructural operations which require a larger entity to manage. This franchise model, with the CSG acting as franchiser and the farmer as franchisee, is precisely what is needed in the formulation of the CSG; and an in-depth study of franchise operations would be an instructive exercise in formulating such a group.

Another difficult technical problem in the management of agricultural inputs is that they tend to be an integrated package. Improved seeds do little good without the correct application of fertilizers. Seeds and fertilizers need prompt delivery, requiring localized godowns. Ready access to credit is usually necessary for intensive agriculture and, of course, efficient marketing, along with crop processing and storage, are necessary to provide the basic inducement for all these other inputs.

The CSG, in a word, must control an integrated package of inputs if it is to be held accountable for agricultural production from a given land and irrigation base. All avenues of "passing the buck" should be plugged so that "seeds" cannot blame "extension" and "extension" cannot blame "fertilizer" (the most common avenue for passing the buck, where these entities all blame "irrigation", is already closed in this system through close performance monitoring of the ISG). Thus, all these agricultural inputs must be placed under management of a single CSG, accountable to the CADA. Again, it is not necessary that the CSG actually take over operations from existing agencies charged with these inputs so long as these agencies are closely integrated to deliver the complete package of inputs at the correct times and their performance is monitored by the CADA.

While this is not the place to go into management details, it should be noted that the Training and Visit (T&V) program, developed by BenOr for extension services, shares many of the management advantages of the warabundi system of irrigation. In both systems, one knows what the state of the system should be at any given time and place. The training and the visiting activities of the extension agent are routinized into a kind of "warabundi." Thus, one can monitor performance in both systems. The T&V system tries to establish effective coordination links between the extension service and agencies which already exist for the supply of inputs. It has been found that whenever field extension agents are given input supply functions, this detracts from their technical extension work.

Lastly, there is the question of how the CADA is to acquire the power to manage along these lines. This is essentially a political question far beyond the present range of expertise. However, one important point in this problem may be made. If the CADA would simply carry out the fundamental task of monitoring and auditing the performance of the operating entities, they would, by performing that indispensable task, create a basis of power. Knowledge is itself a form of power.

The problem now is that, since the performance of neither the irrigation nor of the agricultural input systems in command areas is monitored, much less audited, nobody knows precisely where the problems are. One cannot find any but the most cursory and vague information about input flows into farms, or yield flows from farms, even in areas currently under CADA organizations. The CADA's have remained basically administrative systems oriented to inputs, rather than management systems oriented to outputs. While there are managers in CADA's, there are no CADA's that are managers. Until this transformation occurs, the great productive potential, latent in the CADA concept, will remain under-utilized.

OPTIONS AND STRATEGIES

Expansion and Intensification Options

Optimizing crop production per unit of water or unit of land requires that water be available on demand when needed by the crops and disposed of (through drains) when in excess. Where a demand system is not provided or practical, water deliveries should at least be equitable, reliable and predictable. Where farms are large, such as in the U.S., (40 ha or more) a single farmer (or, at most, two or three farmers) owns and farms all the land in a given unit command area. Thus, a single owner-operator is responsible for maintaining and operating all the irrigation facilities served from a headgate. In fact, a very large individual farm may be served by two or more headgates, in which case the project canal system is, in effect, part of the irrigation infrastructure on the farm. When serving large farms, the irrigation, extension and service groups only need to relate to a relatively few farmers, which, in turn, operate and manage their land and inputs such as land consolidations, watercourses and farm needs.

In countries such as India, where farms are small (typically one or two hectares) it has heretofore been deemed impractical for the project to control and operate canal systems to subdivide and deliver water to each farm. Typically, the unit command areas range from eight hectares to over 100 ha, thus, each headgate serves a number of farmers. They must work together to manage water deliveries plus maintain the watercourses, turnouts, field roads and drains within their command areas. Often the watercourses with adequate turnouts, field roads and drains are not provided with the project; thus, the farmers must depend on paddy to paddy flow or organize to finance and construct the needed infrastructure for the unit command area.

Hypothetically, so called "water users associations," made up of the community of farmers holding land within each unit command area are set up. In turn, these associations may be charged with the construction, maintenance, management and operation of their unit command area infrastructure. This is a formidable task which, we believe, is well beyond the political, financial, managerial, and/or technical capabilities of most communities of farmers. Consequent failures of the water users' associations inevitably result in inequitable distribution and inefficient water use.

Membrane Concept

In order to better visualize the problem at hand, we like to think of the physical objective of an irrigation project as being able to stretch the water like a membrane uniformly over the intended command area. A uniform membrane over the entire command area represents an equitable system.

If the membrane is not stretched out and held in place, it merely remains in globs at "head-enders" scattered throughout the project. Irrigators in these areas usually apply excessive amounts of water, much of which is lost to deep percolation, and this, along with seepage losses from the conveyance and drainage system, enter and fill the groundwater reservoir. Fortunately, in many surface projects, the groundwater system acts as a great equalizer, relaxing tensions in the system and providing each individual field with a potential supply of water. Unfortunately, to utilize this supply requires capital for wells and pumpsets and a continuous supply of costly energy; and these are resources which are in short supply, especially for small farmers.

During our field visits, we found all types of unit command area water distribution problems. The net result is that for many projects we visited, the irrigated land is less than 50% of the land that could potentially be irrigated with the available water supply. Obviously, when one considers the very large civil works investments which have already been made in these projects, more attention must be directed toward water management at the farm level. Furthermore, a concept of overall project management from the farmers' fields up through the whole system must also be initiated.

Membrane Tension

Planners design projects with different concepts of the desirable stretch of the farm water supply per unit area of land for a given set of soils and topography plus climatic and crop program conditions. One might think of this as a measure of the tension designed into the system where:

Tension = function of (design delivery flow rate/unit area, soil topography, climate, cropping programs)

Using a reference crop and weather data, the basic flow rate/unit area which is needed to satisfy peak crop water requirements (after accounting for rain and soil water storage) at 100 percent application efficiency, can be estimated. Dividing the "design flow rate/unit area" by this "basic flow rate/unit area" gives a ratio which might be referred to as "project water density". A density of

1.0 means that farmers could produce optimum crop yields per unit of area only if they achieved 100 percent on-farm efficiency.

Some field crops will produce about 90 percent of potential yield when supplied with only about 75 percent of peak water requirements. Where water is in short supply, resulting in significant under-irrigation, practically attainable water application efficiencies[2], with adequate systems and good management, are in the neighborhood of 75 percent. Therefore, a reliable project water delivery density in the neighborhood of 1.0 can give optimum production per unit of water while still enticing farmers to use HYV's and the needed inputs for high yields.

A system with a water density of 1.0 is a high tension system and usually if the density is designed below 1.0 the farmers will elect to irrigate less than all the land under the command. For example, with a density of 0.5, farmers will elect to irrigate only about 50 percent of their land at a given time, providing the system is very efficient (or perhaps only 25 percent if their systems are very inefficient due to soils and topography). In either case, farmers with more water could produce more from their individual holdings. It is not too difficult to visualize the very high tensions, and thus the quality of the water delivery system and management discipline needed to get equitable distribution to allow each farmer to irrigate only 50% of his or her land.

It is our opinion that farmers served by a high tension system which provides reliable water deliveries will strive to efficiently irrigate their lands. However, they normally need technical assistance for on-farm water management and land leveling plus credit for land leveling and constructing field channels. On the other hand, farmers served by low tension systems (2.0 density) will tend to rely on inefficient practices.

Planned tension. We found a great deal of variation in the level of tension which planners were designing into the systems. The level of tension selected is a product of the physical, social and political environment.

In India, high tension systems are common. For example, a river run project we visited in the state of Haryana (see Table 1) provided

---

[2]Here, water application efficiency is defined as the ratio of the quantity of water effectively put into the crop root zone and utilized by growing crops to the quantity delivered to the unit command area, the efficiency being expressed as a percentage.

one cubic foot per second every other week to 400 acres (one cubic foot per second continuous flow for 800 acres) during the rabi wheat season. This gives a water density of about one-third; and, as expected, only about one-third of the command area was irrigated during rabi. The system had lined on-farm watercourses and effective delivery systems management using warabundi (rotational delivery); then, as might be expected, there was a high degree of equity and farmers had done a commendable job of leveling their land for efficient irrigation.

For contrast, in Bangladesh and Thailand, planning is for low-tension systems. For example, in the Northeast Small Scale Irrigation Project in Thailand, a project water delivery density of 1.7 is planned. This will allow farmers to meet peak water demands of all crops while maintaining an irrigation efficiency of 60 percent.

With densities over 2.0, there may be little trouble with equity within the project command, providing the delivery system is sufficient and reliable and fields have been reasonably well-leveled and there is at least some management input. What happens in high tension systems without adequate management is that the "head-enders" opt for low tension (plenty of water) and the "tail-enders" get no water for all.

We would suggest that a density function of less than 1.0 for single-cropping programs, or 0.5 for double-cropping programs, be reviewed with caution. This is because the economic and management costs of such projects too often exceed potential benefits, even when taking into acount theoretical and political equity issues. In fact, water densities of 1.2 (and 0.6) would appear more appropriate. Even here, caution is needed in considering density on an average seasonal vs. a peak use period basis after allowing for conjunctive use possibilities.

Main and On-Farm Investments

All irrigation projects (other than hand-pumps) serving farmers with small individual holdings should have well-managed and adequate farm distribution and field application systems. This is essential in order to have high water use efficiencies and equitable distribution of water within the command area. Gravity projects and lift projects of over a few hundred hectares must also have reliable and well-managed main distribution systems. Small lift and well projects must have reliable pump sets including a maintenance program for them plus availability of fuel for power. In any event, the first order of business is to have a reliable, predictable and equitable water supply delivered to each farm watercourse in the command area.

Traditionally, the main distribution systems down to the farm turnouts and/or the pump sets are managed by some project authority. The question always arises as to how much area should be served by each project-controlled turnout or pump set. This is because the project costs appear to be less for larger turnouts because the group of farmers are expected to cooperate in getting the water to their individual fields. This would be true if efficiency and equity were achieved; but, in most cases, where the on-farm distribution system is the responsibility of the farmers, the area actually irrigated is much smaller than project goals. Thus, project costs per unit area actually served (output) may be higher than where most all on-farm distribution is the responsibility of the project.

In general, the larger the group of farmers who must cooperate below the project turnout or pumpset, the more difficult will be the job of achieving equitable and efficient distribution of irrigation water. Furthermore, the lower the anticipated project water delivery density, the greater the physical facilities per unit area irrigated and more rigid the management system must be.

Elements of the Project

Projects can be formulated by endless combinations of the following inputs:

Water delivery density
Capital (invested and for maintenance)
Management (irrigation department, extension, water users associations and individual farmers)
Labor (farmers)
Energy

The assemblage and expected output from any given project formulation is dependent on the distribution and social circumstances and the degree of cooperation which can be expected between agencies and farmers.

An important paradox is that low density projects which are usually designed to maximize output and equity in terms of numbers of individual farmers served must be expensive per unit of irrigated area. This is because the high tension inherent in such projects necessitates intensive, as well as extensive, distribution systems, and strong project management from the individual farms to the water source.

To be effective, the management authority for the total command area must have control over both the main system and unit command area distribution system. Furthermore, the management philosophy and understanding must be able to visualize the project from the bottom (crop water needs) up, as well as from the top (water supply) down. In addition, many other inputs such as extension advice, HYV need, fertilizer and credit, to name a few, must be provided, along with timely applications of water to reap the essential crop production benefits for success.

A total command area management concept requires both a new way of thinking and training. This is necessary to establish dedicated cadres of operating and management personnel who know how to maintain, monitor and control irrigation systems to optimize crop production while providing equitable inputs and assistance to the farmers.

The Issue of Training

Conversations with irrigation officials at the central and provincial levels of government, as well as with both Project Managers and field staff, indicate an awareness for appropriate training in the areas of irrigation system management and in on-farm water management areas. India has a large cadre of engineers trained in design and construction of irrigation works, hydrologists and other specialties. However, there are few opportunities for short course staff development in areas related to management of water in irrigation projects from the reservoirs to the farm level. India's vast plans for developing one of the largest irrigation systems in the world and present focus on farm level improvements require that more emphasis be placed on management. Although management science is over 20 years old, few attempts have been made to the application of management science to complex irrigation systems.

This section deals with several areas or types of training which should be considered. Such training is not viewed as a substitute for present training courses, formal or informal, but as a complement to all types of specialty training already institutionalized in India. This fits in well with the plans underway to develop a special water management institute for junior, middle and senior staff. It also fits with the desire to develop a special wing and career structure in the Ministry with a focus on interdisciplinary water management training, as some existing projects and future projects will likely be designed with special funds for selected types of training. The types of training discussed in this section include:

- Management of the main system
- Management of projects
- On-farm water management project staff
- Monitoring and evaluation of projects
- Professional water management courses at universities

All over the world, formal disciplinary training related to irrigation, while producing experts in certain fields, has neglected management of complex irrigation systems. Engineers have learned how to design and build irrigation systems and have evolved rigorous analytical tools, but have not learned much from conventional courses on system management. Hydrologists are experts on the hydrological cycles and movements of water both on the surface and underground but do not integrate this knowledge with a method for efficient management of manmade systems. Soil scientists and agricultural engineers typically can measure percolation rates, evapotranspiration and crop water demands but cannot relate the knowledge to management of the total farm system. Economists dealing with water are interested in costs and benefits, water pricing and monitoring of output, but seldom give advice on how this fits with system operation and maintenance. Social and organizational experts study the allocation and distribution of water, water codes and laws and some aspects or organization, but seldom do they know how to work with other disciplines in design, improvement, and operation of irrigation systems.

It appears that the important concept of management of water in both the main and the minor system is a subject which most often falls between all these disciplines. While, today, on-farm water management is a burning issue throughout the world, it should be realized that improvements cannot singularly accomplish the desired output. In fact, on-farm improvements will reach a rapid ceiling in increased benefits unless the total system is managed more efficiently from the field back to the reservoirs. There is some evidence from the Philippines, Taiwan and, even, India, which suggests that management improvement should begin first at the top or, at least, the same time the farm subsystem is being improved. More training and more incentives should be given to all levels of management from the initial reservoir to the on-farm level.

Main System Management

Managers of main systems handle many functions. They include:

1. Distribution and scheduling of water from the reservoirs to the canals and to the outlet;

2. System operational maintenance and improvement of structures;

3. Coordination of all levels of staff involved, and integration of requisite services;

4. Satisfying the demands of industry and agriculture;

5. Equity in distribution, conflict identification and resolution;

6. Diagnostic research, monitoring and evaluation for central and state decision-making centers;

7. Emergency procedures in time of natural disasters and war;

8. Conjunctive use measures;

9. Interpretation and application of irrigation codes; and

10. A continuous search to make water deliveries more predictable for the end-users.

India probably has as much combined experience in designing and operating large irrigation systems as any country, but times have changed and the new demands on irrigation are not those envisioned by the early British and Indian engineers whose major concerns were not the same as those facing the present agricultural sector which must feed and provide fiber for 600 million people. Like the Canal and Drainage Act of 1873, the old concept that hard disciplinary training is sufficient to operate systems is now antiquated.

The management sciences, relating to business, have made a great contribution, especially in the private sector. Appropriate management training has much to offer system operators at all levels of complex irrigation systems. Even with a Ph.D. in engineering, a senior engineer can no longer be expected to move up to a management position and comfortably excel in a management task for which he has not been adequately trained.

Special types of management training are suggested for various irrigation organization levels, which make decisions relative to the main system:

1. Officials with Central Water Commissions.

   Four to six weeks of operational research methods, organizational theory and methods, management by objectives, project analysis and evaluation, information systems design and operation.

2. Officials with Planning Commission.

   Four to six weeks project appraisal, feasibility analysis, cost and benefit analysis, integrated planning, impact assessment.

3. Officials with Specialized Boards.

   (Groundwater, CADA's). Same as 1., but with special focus on area of specialty, plus planning, evaluation and monitoring systems, analysis of results, and reporting.

4. Executive Engineers (Hydrological Units).

   Understanding of total system operations, with focus on farm level monitoring systems, utilization of monitoring systems, staff supervision, selection and staff development.

5. Superintending Engineers (Canal Systems).

   Understanding of systems operations, monitoring feedback information for decisions, understanding of on-farm systems management.

6. Officials who monitor the system.

   Monitoring systems design, feedback, information systems, etc.

Project Management

Given the existing 77 projects under 44 CADA's and future projects (involving crores of rupees), as well as the fact that these are complex, large-scale projects involving personnel from many disciplines and agencies, the task of management is a challenge for even expert managers. The task is made even more difficult by the fact that both legal and educational means are used to gain compliance with farmers of diverse backgrounds and cultures.

Those chosen to manage these crucial projects range from career civil servants, such as Divisional Commissioners, to Chief Engineers. A special short course could be developed for these project managers. Such a course might include special focus on some of the following areas: management by objectives, monitoring and evaluation, staff selection, coordination of agencies, integration of services, logistics, conflict diagnosis and resolution, information management and communication, staff appraisal techniques, development of work plans, and a general understanding of how irrigation systems work at the farm level.

On-Farm Water Management

Those who work on CADA projects come from several disciplines and organizations where they did not have the opportunity to gain a systems approach to the new science of on-farm water management. While some staff may need training and/or observation tours outside India, there is critical need for such training to be institutionalized in-country. Plans are underway to develop a special career structure for water management in irrigation and support institutes where such training can be provided. In a few countries, experience suggests the need to separate on-farm water management and operation and maintenance of systems from the institutes which focus on design and construction.

The type of training suggested evolves from a model currently being refined and tested as part of the Water Management Synthesis Project. It is a systematic hands-on type of training which is presented under a real field situation with only about 20 percent of the time devoted to classroom sessions during the six-week training period. The course concentrates on developing interdisciplinary teams who give specific skills in diagnosing a real system to determine its operational components and how they work to achieve system goals. Priority constraints and their causes are determined and used in developing or applying solutions.

Key concepts which are taught along with specific field methodologies include: systems approach, teamwork, action-oriented research, farm and client involvement, management orientation, evaluation and monitoring, collaboration and communication.

This hands-on course utilizes a two-volume training manual which includes how-to-do methodologies, audio-visuals and films, and team exercises to be performed in the field. The irrigation system is studied, its components or subsystems analyzed, and methods sought for its improvement. As shown in Table 3, the farm system includes water control, agronomic, social and economic aspects. These are analyzed and studied as components, then combined, through synthesis, to show how the system should function in the real world. All disciplines are then integrated in the approach used, as suggested by Figure 3. Emphasis is given to the management unit of a farm irrigation system, as well as the physical and institutional environment in which that unit operates. Unlike some others, this approach stresses farmer participation at all phases of a systematic research development process, including diagnostic analysis, development of solutions, assessment of solutions, and project implementation.

Those trained in this new approach can help improve the CADA's in various ways:

1. Interdisciplinary teams to identify and prepare new projects;

2. Interdisciplinary teams to implement existing projects; and

3. Interdisciplinary teams for monitoring and evaluation of existing projects.

In terms of a new career structure for water management, operation and maintenance of improved systems, those who gain this type of training will gradually move up through the ranks. With incentives they will become project managers and decision-makers, who understand the physical, biological, economical, social and organizational dimensions of the complex on-farm subsystem.

Water management is not the simple summation of: the water policies and codes which regulate a system; the organizations which deliver and schedule water; the farmer-user; the plants, soils, seeds and inputs for crops; water user organizations; and improved technologies. It is how all of these procedures and inputs are combined and utilized efficiently to improve crop production and levels of living for rural people.

Monitoring and Evaluation of Projects

Presently, CADA projects recognize the need for improved monitoring and evaluation in order to keep on target, define approaches, and diagnose weaknesses. Those involved in this task need to complete the same on-farm management training course as project staff. A team is required if this is to be done adequately. These teams also need additional training in terms of the collection of certain data required at the state and central government levels. They especially need to develop the skills of designing for evaluation, collecting and managing data, data analysis and interpretation, and reporting for both technical and non-technical audiences.

Those who excel in on-farm water management training could be selected for the monitoring and evaluation teams. However, at present, incentives, budgets, facilities, and training for this purpose are totally inadequate. In one project examined, only 0.1 percernt of the total project budget was alloted to this task.

In the same project in Maharashtra, only 1.1 percent of the total budget was alloted for all types of training. This is in contrast to the first on-farm water management project in Egypt, where at least 25 percent of the budget was set aside to train the personnel needed in the team approach to on-farm water management. In the future, when large-scale projects are implemented, these trained personnel will be key individuals.

Professional Programs at Universities

As India moves ahead in irrigation development, focusing on water management, there is a need to utilize project experiences and data, in order to develop the necessary university curricula. Unless the universities take a larger role in preparing future personnel for the tasks required in water management, irrigation development in India cannot take place, as envisioned, through the year 2000. In one neighboring country, universities are becoming involved in both on-farm development and the introduction of relevant material and field data into their courses. In India's large irrigation development program, field manuals, new methods and even some of the project staff should become part of the university program. The Irrigation Department is making innovative changes and, since it depends on the Educational Ministry to provide manpower, it has a role in helping the universities become more progressive in training the type of staff it will need in the future. It is apparent that engineering education in India has not changed sufficiently over the last thirty years to meet the new demands of the country.

Table 3. Major Functions and Elements of Farm Irrigation Subsystems.

SUBSYSTEM	MAJOR FUNCTIONS	MAJOR ELEMENTS
1. Water Control		
a. Water Delivery	Delivery of sufficient quantity and quality of water to the field.	Canal, main ditch, field ditches, slope, size and shape of channels.
b. Water Application	Application of desired amount of water at the proper time in a uniform manner to meet crop tolerances for production desired while satisfying leaching and erosion control standards.	Water supply rate, field geometry, field topography, soil infiltration rate, irrigation method.
c. Water Use	Supply water requirements for crop growth, maintain acceptable levels of salinity, maintain appropriate environment (soil-air) temperature, ensure adequate nutrients, provide appropriate soil conditions.	Water quantity and quality, soil type, nutrient availability, evapotranspiration.
d. Water Removal	Provide necessary surface drainage, maintain given salinity levels, provide root aeration, improve workability of land.	Leaching requirements, evapotranspiration rate, drainage facilities, soil type/subsoil type.
2. Agronomic	Management of physical and biological resources to produce food fiber, and specialty crops; ensure long-term productivity of crops.	Plants, climate, temperature, water topography, soil, physical, biological, chemical aspects, nutrient supply, insect control, management practices.

Table 3. (Continued)

SUBSYSTEM	MAJOR FUNCTIONS	MAJOR ELEMENTS
3. Social	To provide the social and organizational supports needed for successful manipulation of farm irrigation systems to achieve individual and social goals in both the short and long run.	Facilities (institutional services), activities (collective, etc.), rules (norms, laws, etc.), communication (extension, etc.), linkages (institutions), beliefs, knowledge.
4. Economic	Appropriate resource allocation, maximization of production, optimize decision-making process.	Land, labor, capital, markets, risk/uncertainty, cost/benefits, consumption.

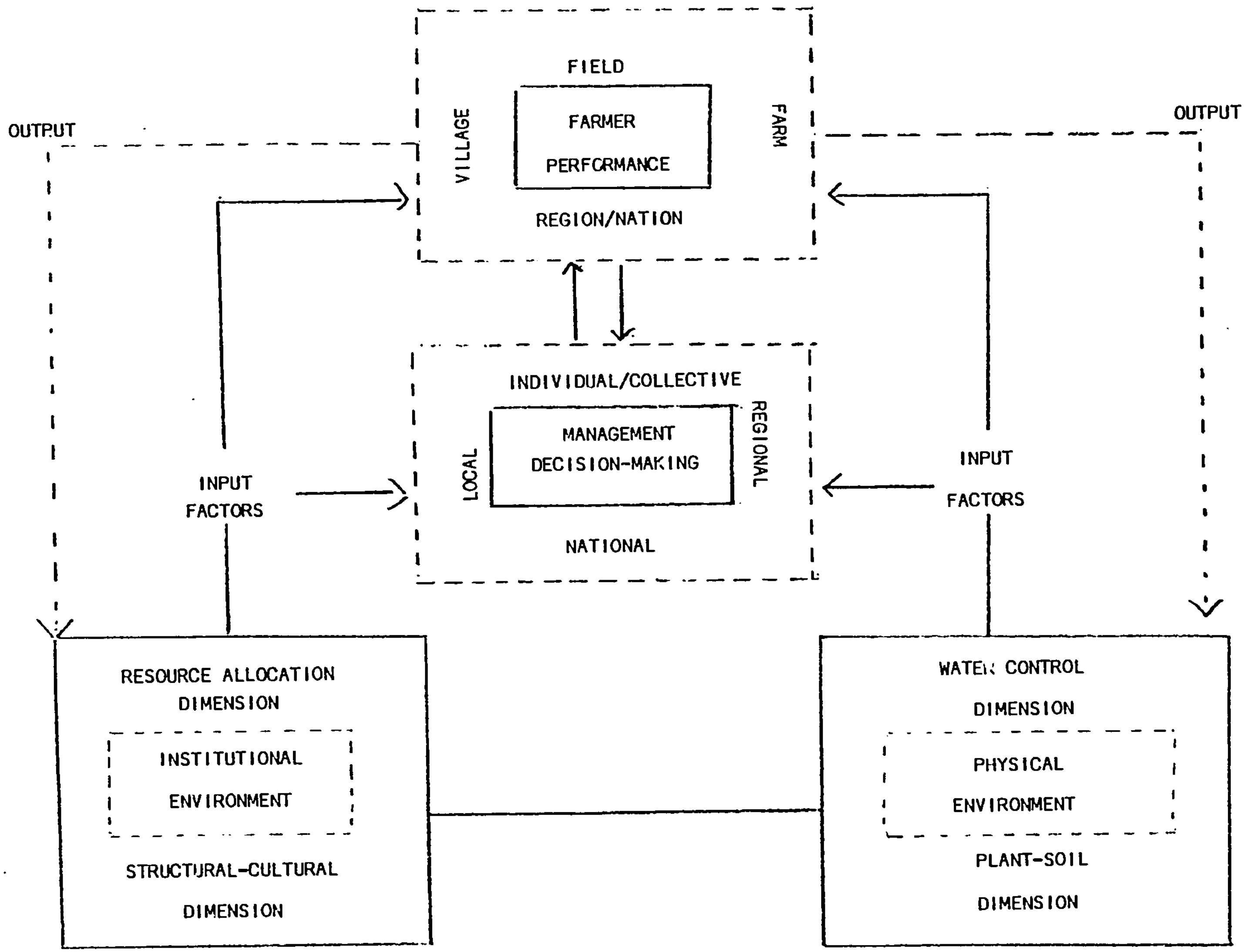


Figure 3. Management Decision-Making Framework.

APPENDIX A

WATER RESOURCE DEVELOPMENT IN INDIA

by

Gary S. Posz, Economist
Bodh Raj, Economist
Dean F. Peterson, AID/ARD

WATER RESOURCE DEVELOPMENT IN INDIA

by

Gary S. Posz, Economist
Bodh Raj, Economist
Dean F. Peterson, AID/ARD

Introduction and Summary

The future of India will be to a significant degree determined by the success of water resource development over the remaining decades of this century. Water is the lifeblood of India. If used fully, it is a resource that would double the area of agricultural land now irrigated, triple existing electric generating capacity without burning oil or coal and concomitantly afford a means of beginning the local dispersion of a growing population that is concentrated along the lower reaches of natural watersheds.

The failure of the 1979 monsoon -- which produced one of the worst droughts of recent record and caused an eight to ten percent drop in agricultural production and near stagnation in the economy -- highlighted the stark fact of India's continuing absolute dependence on water. India's economy is becoming relatively more dependent on commercial energy, but it remains more critically affected by water supplies than any other single factor. Water is the single most important input to agricultural production. Agriculture contributes over 40 percent of national income, about 80 percent of the population lives in rural ares, and about 74 percent of the workforce is depending on agriculture for their livelihood. Success in developing a well-managed, adequate supply of water will critically influence whether India -- the home of one-third of the world's poor -- will free itself from poverty and continue on its present course as the emerging dominant power in the South Asia region.

Yet provision of adequate water for crops and other uses in India is unusually complicated by the paradoxes of its climate and geography; although the average rainfall is about 120 cm (which is slightly more than the global terresterial mean of 99 cm), it is seasonal and often erratic in timing and geographical distribution, resulting in frequent catastrophic droughts or floods. Though the discharge of India's large river systems is quite high, they flow mainly in the Gangetic plain; the surface water resources of the Deccan, the largest arable land area, are significantly smaller. Groundwater resources are likewise unevenly distributed. Groundwater is abundant in the Ganga (Ganges) Basin with its deep alluvial soils, while the rocky Deccan plateau has comparatively little groundwater. Thus, the apparent abundance of water in India is illusory.

Surface water, estimated at 178 million meters (m.ha.m),[1] and about only 37 percent of which represents utilizable flow owing to limitations imposed by the country's geology and terrain, continues to be the principal resource. Potential groundwater development attainable by the end of this century is estimated by the Central Groundwater Board at 57 m.ha.m. of which nearly 46 percent is usable.

Irrigation development continues to be given priority with irrigation potential estimated at about 58 milion hectares at the end of 1979-80; this accounts for roughly 51 percent of the gross ultimate potential of 113.50 million hectares. Total investment in irrigation from the beginning of the planning era in 1951 to 1978 amounted to approximately Rs. 93 billion on major, medium and minor projects. Expenditure on irrigation in future plans, in order to reach the ultimate target potential by the year 2000, is expected to be substantial. But the considerable potential already created is, so far, underutilized; there is a sizeable gap between potential and actual utilization due to inefficient water management practices. The remedy is increased construction and improved operation of distribution channels, including reduction of transit losses and provision of regulatory structures and crop planning. Together these measures could increase utilization by as much as 25 percent. Rapidly escalating construction costs constitute a growing drain on state finances and increase the already high financial subsidy given to irrigation. Though they have been increased, water charge rates remain relatively low in terms of farmers' ability to pay.

Owing to the millieu of subsidies and price control in the agricultural sector, the economics of irrigation subsidy is a very complex subject which has not been rigorously studied. The water rate is only one element. Farmers receive only about 70 percent of the economic value of agricultural produce, for example, but this is offset somewhat by other subsidies.

With surface water in the Ganga basin now almost fully developed, irrigation in this region will depend on greater groundwater use. Ganga groundwater resources are among the largest in the world, but their current use and further development is constrained by fuel and power shortages. Diesel fuel to run small pumps is growing very scarce and prohibitively expensive while

---

[1]Volume equivalent to covering 1 million hectares with one meter of water.

breakdowns in electric power generation with resultant load shedding frequently damage pumps and impair operating efficiency.

Expansion of the area under irrigation in this region will depend on increasing the availability of power to rural areas. Full realization of irrigation potential in the Ganga basin will require that the GOI assign a high priority to the rural electrification program.

With water sharing in the Punjab regulated by a 1960 treaty with Pakistan, India's international boundary water problems are now confined to the eastern region. India and Bangladesh are locked in a dispute over sharing Brahmaputra flows. India needs to augment low flows in the Ganga to provide sufficient water to keep Calcutta port from silting up. Although India and Bangladesh have conferred on this issue several times recently, no mutually agreeable solution of the problem is in sight. India has reportedly taken a hard line in these negotiations, rejecting out-of-hand efforts by Bangladesh to involve Nepal in the dispute, and has said that it will take unilateral steps to prevent damage to the port of Calcutta.

Continued progress in water resource development over the near term will depend on how much emphasis the GOI places on improving utilization of existing irrigation potential. Competing political priorities make it unlikely that the central government will try to force water law reforms aimed at improving water use practices through state assemblies, where there would be sharp resistance from landholders. Still, recently increased allocation in the Draft Sixth Plan (currently under revision) for constructing field channels and refurbishing existing works as well as for supplementary groundwater development and rural electrification indicate that the GOI assigns a high priority to mobilizing resources to improve irrigation efficiency and extend its potential.

To make optimal use of water resources, provide effective flood control and achieve the long-term water development goal of Indian planners -- doubling present irrigation capacity by the year 2000 -- will require major inter-basin transers via a national water grid. One such plan, the highly publicized "Garland Canal," has for all practical purposes been shelved by the GOI on technical and economic grounds. It seems likely that a national grid will be developed incrementally, with a series of projects gradually extending the system throughout the country. Many of the country's larger schemes underway or planned have required or will require interstate agreements, and negotiating inter-basin transfers has proven to be very time consuming. Legal battles between states over water rights will probbly delay planning and implementation of inter-basin transfers but will not prevent their ultimately being implemented.

The Ganga and Brahmaputra river basins provide an excellent example of what could be accomplished in multi-state water resource development. Over three-quarters of the non-irrigated land with irrigation potential lies in these two river basins (the northern states of Uttar Pradesh, Bihar and West Bengal which are directly south of the Himalayas and west of Bangladesh). The same region, together with India's two northern-most states (Jammu-Kashmir and Himachal Pradesh), is estimated to encompass undeveloped hydro-electric power sites with a total generating capacity of more than 23,000 MW, the equivalent of the country's present installed electric generating capacity. Also, the country's most extensive coal deposits are located adjacent to the Brahmaputra delta region in the southern part of Bihar and contingent regions of West Bengal and Orissa. Thus, existing climatic and geographical elements for large increases in agricultural and industrial output of the Ganga-Brahmaputra heartland can be utilized by: (a) construction of dams and reservoirs in the north and northwest to increase the reliable supply of water for irrigation and electricity generation; and (b) construction of an electric grid to connect the hydro-electric stations with coal-fired power stations in the southeast, diversifying the energy source of electricity generation, to provide reliable distribution of electricity to 25 percent of India's population.

Mobilizing the investment resources for such major projects is, however, likely to become increasingly difficult in the fact of escalating construction costs and growing scarcity of capital. Moreover, competing investment priorities will probably divert resources from these projects. The issue will turn on whether scarce capital will be devoted directly to irrigation, or to industrial sectors, some of which also provide vital support to agriculture.

So, without downplaying the vital importance of water to India's future, scarcity of capital, as well as other constraints in the economy, will probably slow the rate of water resource development which India has demonstrated since independence, particularly the rate of expansion in the area under irrigation.

The Resource

Rainfall Patterns

The June to September southwest monsoon contributes from about 75 to 90 percent of rainfall in most parts of India. Rainfall occurs during October to December only in the extreme south and southeastern regions under influence of the northeast monsoon. Thunderstorms produce limited rainfall in some parts of the country during the hot weather between March and May. These rains are important only for the early spring rice crop in West Bengal and the Assam tea crop. The northern part of the country receives some irregular and unreliable rainfall during the winter which is significant for the wheat crop, particularly in unirrigated areas. As illustrated by Maps Nos. 1 and 2, about half of the country receives an annual average rainfall of 100 cms. or more. Large areas of the northeast and western coast receive rainfall of more than 200 cms. While some locations such as the Khasi Hills receive more than 1000 cms., parts of Rajasthan receive little if any at all. Since most rainfall occurs only during three months of the year, assuring a water supply to agriculture and industry for the remainder of the year poses a serious challenge to India's planners.

Drought-Prone Areas

The complex system of monsoon winds, the arrangement of mountain ranges, the variability of rainfall and the erratic patterns of tropical storms produce well-defined regions and pockets of excessively low rainfall. Regions of water scarcity are defined by the Irrigation Commission as areas with rainfall of less than 100 cms. of which 75 percent is not received in 20 percent or more of the years and where irrigation is less than 30 percent of the cropped area. Rainfall in the northwestern drought-prone area is less than 75 cms and as little as 40 cms. in some parts. Where it is not irrigated, this area is among the most famine-prone in the country. The second area is the so-called "shadow" of the Western Ghats where annual rainfall is less than 75 cms. and highly erratic. Because it is thickly populated, periodic drought conditions in this area cause much suffering and damage. In addition to these two main areas of water scarcity, represented by the cross-hatched area on Map No. 3, drought-prone pockets are scattered throughout the country.

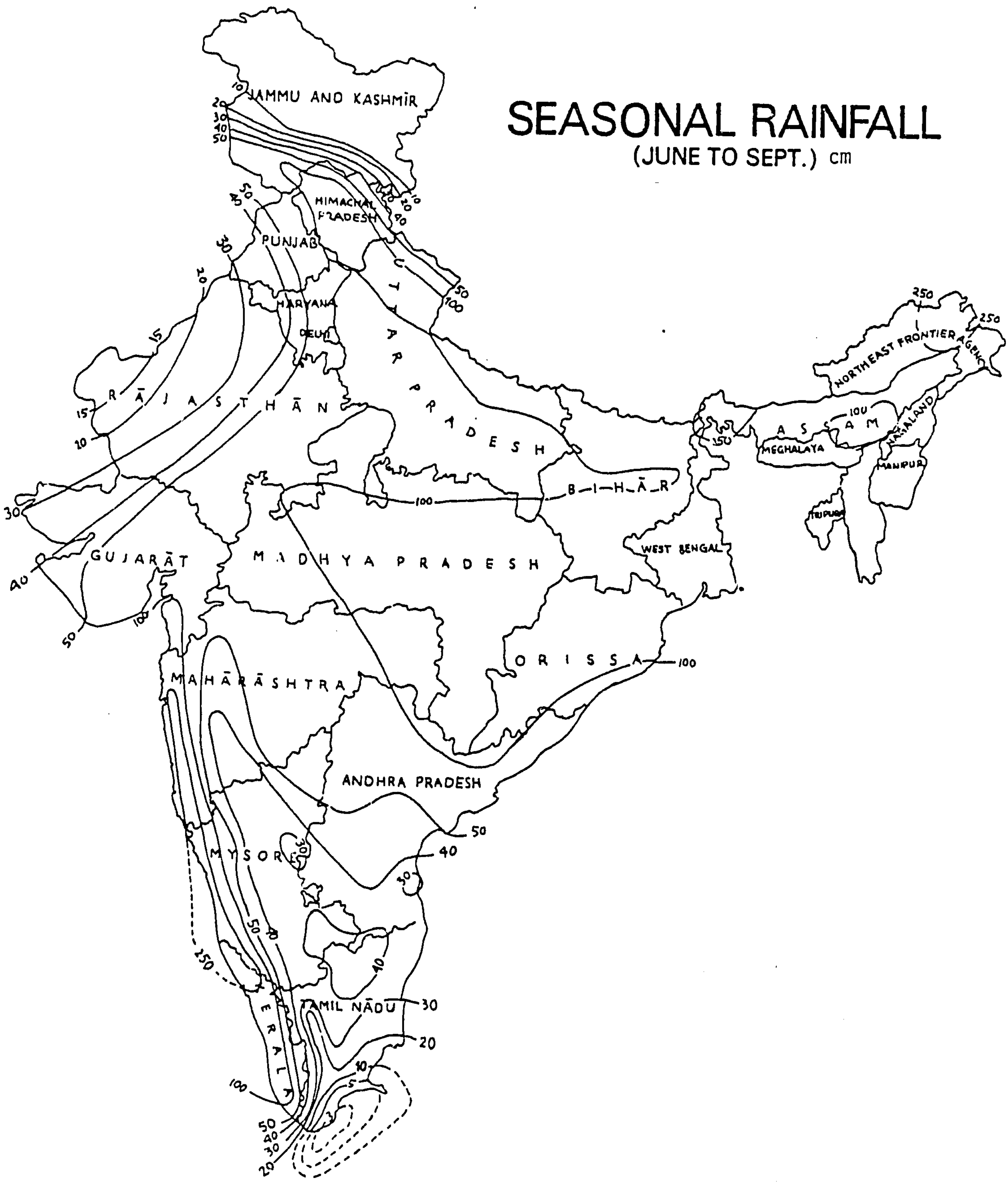
Surface Water

An assessment by the Central Water Commission, based on analysis of streamflow data from 80 sources, places the total surface water resources of India at about 178 m.ha.m. This resource cannot be fully utilized due to the highly variable character of the flow and other limitations imposed by the country's geology and terrain. India's rivers and other major geographic features are shown on Map No. 4.

The bulk of river flows is concentrated during the four months

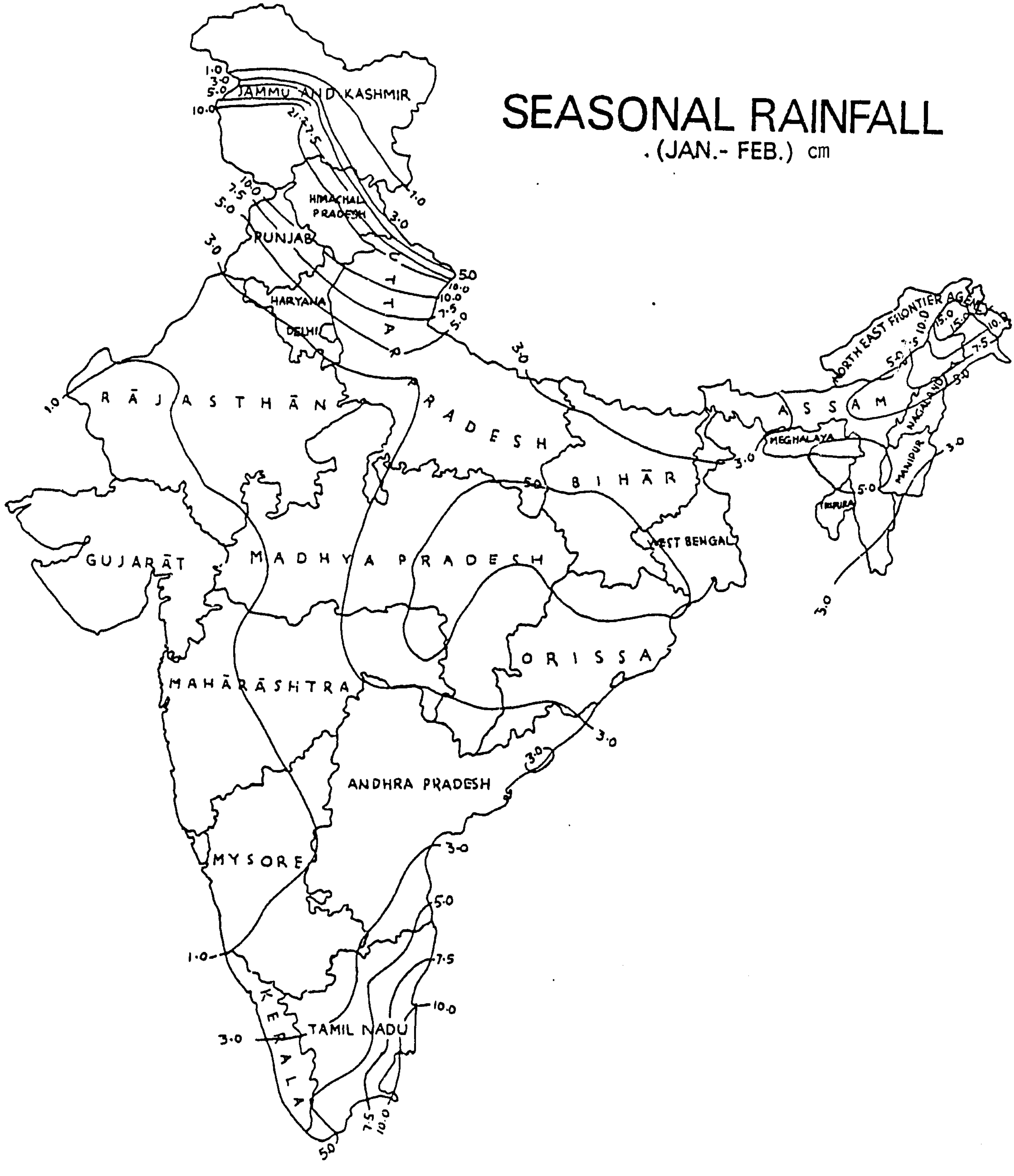
SEASONAL RAINFALL

(JUNE TO SEPT.) cm

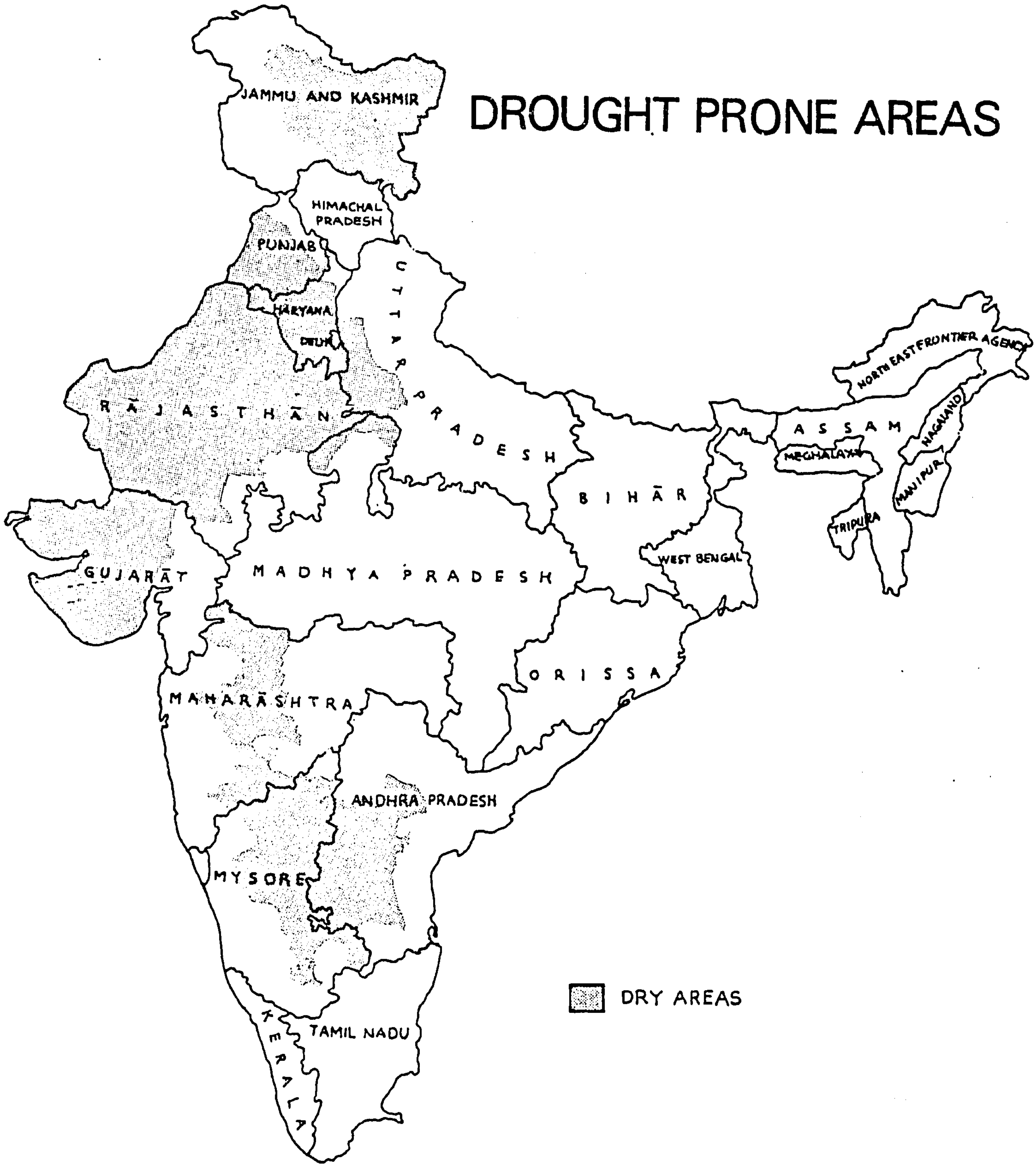


SEASONAL RAINFALL

(JAN.- FEB.) cm



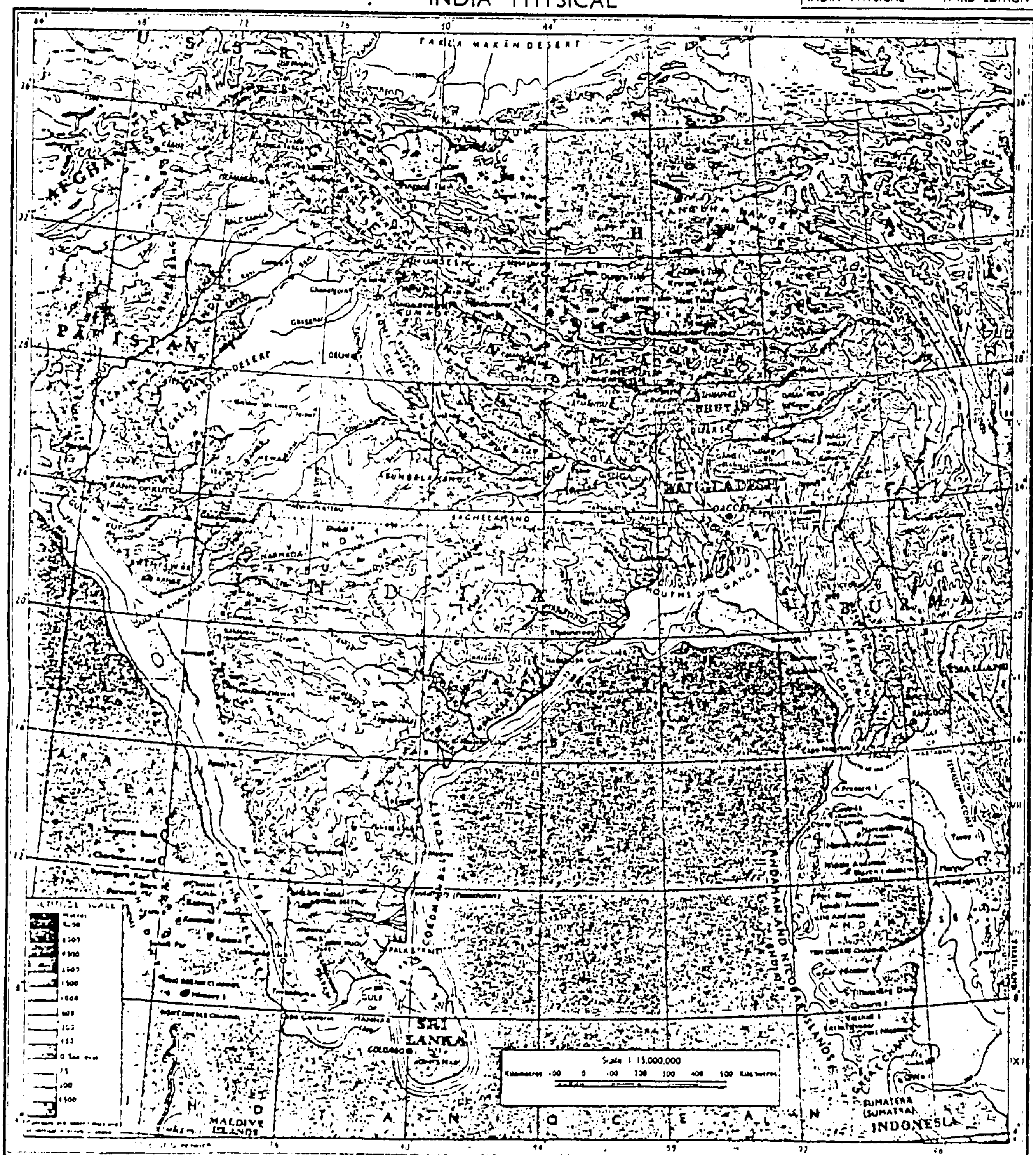
DROUGHT PRONE AREAS



MAP NO. 4

Refer to this map as :- 1:15,000,000
INDIA—PHYSICAL THIRD EDITION

INDIA - PHYSICAL



Published under the direction of Dr. Hari Narain, M.Sc., D.Phil., Ph.D., Surveyor General of India.
1974.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

Refer to this map as :- 1:15,000,000
INDIA—PHYSICAL THIRD EDITION

when rain occurs. To conserve this water, construction of large storage works to hold flood flows passing to the sea would be required. However, suitable sites for construction of storage dams are limited. The utilizable quantity of river water also depends on the availability of suitable sites for its diversion, the quality of the water itself and the proximity of the flowing water to land fit for cultivation, as well as the dependability of flow. Given these limitations, the Irrigation Commission in 1972 estimated the total utilizable flow for irrigation t 66.6 m.ha. The following table gives the details of this estimate region by region:

Estimate of Total Utilizable Flow for Irrigation
(in million hectare meters)

Basin	Average Annual Run-Off	Utilizable Flow
Indus Basin	7.70	4.93
Ganga Basin	51.00	18.50
Brahmaputra Basin	54.00	1.23
West Flowing Rivers	28.80	6.92
East Flowing Rivers	34.80	38.80
Luni and Ghaggar Basin	1.70	1.22
Total	178.00	66.60

Source: Irrigation Development in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980

The National Commission on Agriculture estimates that this estimated usable flow will be sufficient for ultimately irrigating an area of 72 m.ha. by the end of 2025 A.D. Of the total usable flow, 58.5 m.ha. will be irrigated by major and medium irrigation projects and 15 million ha. from minor irrigation projects.

Groundwater

Groundwater resources are dynamic: they are expanded by rainfall, seepage from irrigation canals and reservoirs, and the return flow from irrigation as well as inflow from rivers. The Central Groundwater Board has made the following estimate of total groundwater resources of the country attainable by the end of the century.

Estimate of Groundwater Resources by 2000 A.D.
(in million hectare meters)

Contribution from rainfall	29
Seepage in return flow from canal systems	22
Seepage in return flow from groundwater systems	6
Influent recharge from the drainage system, including drains, streams, rivers, etc.	Negligible
Total	57

Source: Irrigation Development in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980

Various factors, however, limit utilization of the total quantity of water stored in the ground: evaporation/transpiration losses from forest, water logged and marshy areas; inevitable afflux into rivers; and maintenance of a minimum base flow in the rivers for committed usage on existing canal systems and for ecological reasons. These factors reduce groundwater usable for irrigation to an estimated 26 million ha.m. The National Commission on Agriculture estimates that this quanitity is sufficient to ultimately bring an area of 40 million ha. under irrigation by 2025 A.D. The bulk of the estimated ultimate potential may, in fact, be realized by the turn of the century.

Distribution of groundwater is governed by two factors: rainfall and geology. The greatest concentration of groundwater is found in the alluvial plains of the Indus, the Ganga, the Brahmaputra and their tributaries; the inland valleys of the Narmada, Tapi and Purna rivers of central India; and the coastal alluvial plains. These formations comprise about one-third of the total land area in the country but contain 50 to 60 percent of total usable groundwater resources. The next more productive source of groundwaer is the semi-consolidated sandstone formations, but these account for only 5 percent of total land area. Nearly 65 percent of total land area is covered by consolidated formations (about three-quarters crystalline rock and one-quarter basaltic rock) where groundwater availability is limited and dependent on weathering and fracturing of the formation.

Irrigation

The Rapid Expansion of Irrigation Since Independence

Irrigation in India has been practiced from ancient times and has expanded steadily since then. Upon partition of the country in 1947, the area under irrigation stood at 19.4 million ha. Left with 80 percent of the prepartition population and having lost to Pakistan 17 percent of the irrigated area of undivided India on which the country was largely dependent for cereals, fibers and oilseeds, the new Indian government was confronted with a massive food deficit. Irrigation was therefore given the highest priority at the beginning of the planning era in 1950. As a result, gross irrigation potential from major, medium and minor projecs more than doubled from 22.60 million ha. in 1950 to 52.25 million ha. in 1977-78. The following table shows this rapid transformation of rainfed to irrigated land.

Irrigation Potential
(gross million hectares)

Plan Period	Major & Medium	Minor Irrigation: Ground	Minor Irrigation: Surface	Minor Irrigation: Total	Total Irrig.
1. Pre-Plan (1950-51)	9.70	6.50	6.40	12.90	22.60
2. End of 1st Plan (1955-56)	12.19	7.63	6.43	14.06	26.25
3. End of 2nd Plan (1960-61)	14.33	8.30	6.45	14.75	29.08
4. End of 3rd Plan (1965-66)	16.56	10.52	6.48	17.00	33.56
5. End of Annual Plans (1968-69)	18.10	12.50	6.50	19.00	37.10
6. End of 4th Plan (1973-74)	20.70	16.50	7.00	23.50	44.20
7. End of 5th Plan (1974-78)	24.77	19.80	7.50	27.30	52.25
8. Addl. Target (1978-79)	1.35	1.05	0.25	1.30	2.65
9. Addl. Target (1979-80)	1.10	1.25	0.25	1.50	2.60
10. Target (6th Plan)	6.50	7.00	1.50	8.50	15.00
11. Ultimate Feasible	58.50	40.00	15.00	55.00	113.50

Source: Irrigation Development in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980

Total investment on major and medium projects during the 1950-51 to 1977-78 period was Rs. 54.54 billion. The area under minor irrigation increased during this period by 14.4 million ha. as a result of an outlay of Rs. 20.02 billion in the public sector and Rs. 18.12 billion of institutional credit extended to cultivators by the Land Development Banks, commercial banks and cooperative banks, with refinancing through the Agricultural Refinance and Development Corportion (ARDC). There was an additional sizeable investment in minor irrigation projects from private sources by farmers themselves in achieving this total increase in minor irrigation.

The sixth Five Year Plan (now being revised) envisages creation of an additional irrigation potential of 15 million ha.: 6.5 million ha. from major and medium irrigation projects at an investment of Rs. 67.02 billion and 8.5 million ha. from minor irrigation projects with a public sector investment of Rs. 14.15 billion, about Rs. 22 billion of institutional investment, and Rs. 10 billion by farmers themselves. The emphasis is to be on: (a) higher utilization of existing potential; (b) speedy completion of ongoing projects; (c) efficient maintenance of the existing irrigation sysem; and (d) an assured supply of water to small farmers. Plans also call for monitoring water flows and use of remote sensing techniques. However, the long term goal is an increase in irrigation growth from 26.5 percent of total potential in 1977-78 to 33.4 percent in 1982-83 and increasing further to 39.4 percent in 1987-88 and 46.2 percent in 1992-93. This assumes doubling of the gross irrigated area from 45.31 million ha. in 1977-78 to 92.13 million ha. in 1992-93 which roughly works out to 81 percent of the maximum potential irrigated area based on presently known reserves of surface and groundwater. Benefits flowing from irrigation by states are shown Tables 1 and 2.

Investment figures during successive plan periods are shown in the following table:

Investment on Irrigation
(Rs. billion)

Plan Periods	Major & Medium	Minor: Plan Outlays	Minor: Institutional	Minor: Total	Total
First Plan (1951-52/1955-56)	3.80	0.76	Neg.	0.76	4.56
2nd Plan (1956-57/1960-61)	3.80	1.42	0.19	1.61	5.41
3rd Plan (1961-62/1965-66)	5.81	3.28	1.15	4.43	10.24
Annual Plan (1966-69)	4.34	3.26	2.37	5.63	9.97
4th Plan (1969-74)	12.37	5.13	6.61	11.74	24.11
5th Plan (1974-78)	24.42	6.31	7.80	14.11	38.53
Total	54.54	20.16	18.12	38.28	92.82
6th Plan (1978-83)	67.02	14.15	22.00	36.15	103.17
Likely during 1978-79	9.76	2.37	2.70	5.07	14.83
Approved for 1979-80	10.96	2.22	3.75	5.97	16.93

Source: Irrigation Department in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980.

TABLE 1

BENEFITS FROM MAJOR AND MEDIUM IRRIGATION SCHEMES

(000 hectares gross)

Name of State	Ultimate Irrigation Potential	Irrigation From Pre-Plan Schemes	Benefits from Plan Schemes to End of 1977-78		Target of Addl. Benefits During 1978-83		Potential to End of 1982-83 Including Pre-Plan Schemes	Percentage of Potential to End of 1982-8 of ultimate Potential
			Pot.	Ult.	Pot.	Ult.		
Andhra Pradesh	5,000	1,676	1,107	1,021	470	220	3,253	65
Assam	970	---	61	31	85	50	146	15
Bihar	6,500	404	1,898	1,151	670	620	2,972	44
Gujarat	3,000	33	924	501	340	300	1,297	43
Haryana	3,000	436	1,274	1,090	160	120	1,870	62
Himachal Pradesh	250	---	---	---	4	2	4	8
Jammu & Kashmir	250	43	57	49	39	15	130	52
Karnataka	2,500	308	700	645	361	273	1,494	60
					+125 (a)			
Kerala	1,000	158	274	252	160	140	592	59
Madhya Pradesh	6,000	513	743	493	640	560	1,896	32
Maharashtra	4,100	255	868	395	650	570	1,773	43
Manipur	135	---	---	---	37	20	37	27
Meghalaya	20	---	---	---	--	--	--	--
Nagaland	10	---	---	---	--	--	--	--
Orissa	3,600	455	871	871	250	200	1,576	44
Punjab	3,000	1,220	1,033	1,028	100	80	2,353	78
Rajasthan	[illegible],750	320	1,056	846	570	350	1,946	71
Sikkim	20	---	---	---	---	--	---	--
Tamil Nadu	1,500	891	287	269	150	30	1,228	82
Tripura	100	---	---	---	---	--	---	--
Uttar Pradesh	12,500	2,553	2,919	1,846	1,407	1,400	6,879	55
West Bengal	2,310	440	980	960	380	350	1,800	78
Total States	58,315	9,705	15,052	11,448	6,489	5,300	31,246	53
Union Territories	160	-	10	10	14	2	24	15
All-India	58,475	9,705	15,[illegible]2	11,458	6,503	5,302	31,270	53

(a) Benefits from non-plan

Source: Draft Sixth Five Year Plan, 1978-83 Revised, Planning Commission

TABLE 2
BENEFITS FROM MINOR IRRIGATION SCHEMES
(000 hectares net)

Name of State	Ultimate Irrigation Potential	Irrigation From Pre-Plan Schemes	Benefits to End of 1977-78 Potential/ Utilization	Target for Additional Benefits During 1978-83 Potential/ Utilization	Benefits to End of 1982-83 Including Pre-Plan Schemes Target	% of Potential Estimated As At the End Of 1982-83 To Ultimate Potential
Andhra Pradesh	4,200	1,060	1,800	305	2,185	52.02
Assam	1,700	230	287	155	442	26.00
Bihar	5,900	1,020	2,100	1,440	3,540	60.00
Gujarat	1,750	440	1,355	195	1,550	88.57
Haryana	1,550	280	1,175	190	1,365	88.06
Himachal Pradesh	285	60	91	17	108	37.89
Jammu & Kashmir	550	270	314	19	333	60.54
Karnataka	2,100	1,545	925	250	1,175	59.95
Kerala	1,100	[illegible]	315	55	370	33.64
Madhya Pradesh	4,200	650	1,400	710	2,110	50.24
Maharashtra	3,200	[illegible]	1,505	265		55.31
Manipur	105	5	20	11	31	29.52
Meghalaya	100	7	18	17	35	35.00
Nagaland	80	5	35	24	59	73.75
Orissa	2,300	280	520	465	985	42.83
Punjab	3,550	814	2,830	234	3,064	86.31
Rajasthan	2,400	1,225	1,760	123	1,883	78.46
Sikkim	22	N.A.	7	6	13	59.09
Tamil Nadu	2,400	1,250	1,890	167	2,057	85.71
Tripura	115	10	33	18	51	44.35
Uttar Pradesh	13,200	2,900	7,590	3,095	10,685	80.94
West Bengal	3,800	800	1,300	700	2,000	52.63
Total-States	54,607	12,886	27,350	8,461	35,811	65.58
Total-Union Territories	250	15	90	35	125	50.00
Total-All India	54,857	12,901	27,440	8,496	35,936	65.51
or Say	55,000	12,900	27,300	8,500	35,800	65.00

Source: Draft Sixth Five Year Plan, 1978-83 Revised, Planning Commission

From the initiation of planned development in 1950 to the end of the fifth Five Year Plan, 146 major and 756 medium projects have been undertaken. Of these, 40 major projects and 447 medium projects were completed by the end of the Fifth Plan with 106 major and 309 medium schemes remaining to be completed in the Sixth Plan. Thus, most irrigation projects in India have been completed since independence.

The development of minor irrigation works in terms of physical units (excluding tanks and diversion projects for which precise figures are not available) is shown in the following table:

Development of Groundwater Structures
(in '000' nos.)

Plan Period	Dugwells	Pvt. Shallow TWs[2]	Public Deep TWs	Elec. Pump-sets	Diesel Pump-sets
1. Pre-Plan (1950-51)	3,860	3	2.4	21	66
2. End of 2nd Plan (1960-61)	4,540	20	8.9	200	230
3. End of Annual Plan (1968-69)	6,110	360	14.7	1,090	720
4. End of 4th Plan (1973-74)	6,700	1,140	22.0	2,430	1,750
5. End of 5th Plan (1977-78)	7,425	1,700	30.0	3,300	2,500
6. During 1978-79	210	200	3.4	300	200
7. Target (1979-80)	280	250	3.9	400	200
8. Target 6th Plan	1,200	1,200	10.0	2,000	1,000
9. Ultimate Feasible	12,000	4,000	60.0	12,000	5,000

Source: Irrigation Development in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980.

Development of the Ganga Basin

Because in much of the irrigated area of India surface water resources have been harnessed to the maximum extent feaible, further development of irrigation will require maximum utilization of groundwater to supplement supplies from surface sources. Much of this potential is in the Ganga basin which is among the largest groundwater reservoirs in the world. The basin holds about 26 m.ha.m. of gross renewable groundwater. The following table shows the ultimate irrigation potential, that already utilized, and that which is available for further development from groundwater in the six states of the basin:

---

[2] TW = Tubewell, the Indian term for a machine-drilled well.

Development of Irrigation Potential in '000' ha.

State	Ultimate Feasible	50-51	Achievement up to 60-61	68-69	73-74	77-78	Balance
Bihar	4,000	170	260	500	800	1,200	2,800
Haryana	1,400	275	300	550	1,000	1,150	250
Madhya Pradesh	3,000	250	330	485	700	900	2,100
Rajasthan	2,000	950	1,020	1,250	1,400	1,450	550
U.P.	12,000	2,300	2,800	4,700	5,300	7,000	5,000
West Bengal	2 500	Neg.	Neg.	120	250	400	2,100
Total	24,900	3,945	4,710	7,905	9,450	12,100	12,800

Source: Irrigation Department in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980

This data shows that, except for Haryana and Rajasthan, enormous groundwater resources remain untapped. Estimates indicate that the four states of Uttar Pradesh, Bihar, West Bengal and Madhya Pradesh have groundwater potential sufficient to sustain four million additional wells and tubewells capable of irrigating an additional area of 12 million ha. The slow progress of groundwater development in these states is to some extent due to problems encountered in mobilizing institutional investment, but the chief problem is the lack of electrical power and shortage of diesel fuel as well as rising energy costs. Extension of power lines into rural areas is lagging, and in those areas where infrastructure exists power generation has been inadequate. Consumption of power for irrigation as a percentage of total power sold is only 9.8 in Bihar, 1.2 in West Bangal and 8.3 in Madhya Pradesh. The continuing lack of growth in the agricultural sector and power shortages have jeopardized the groundwater development program in these states. Public tubewells designed to run almost around the clock in peak irrigation periods have been most seriously affected. Normally running 3,000 to 4,000 hours a year, power shortages have reduced their operation to as little as 1,000 hours per year.

The Critical Role of Rural Electrification in Irrigation Development

Rural electrification coupled with an assured supply of power will be a fundamental requirement of further expansion of the minor irrigation program, because electricity provides the most economical and efficient means of lifting groundwater which offers greater potential for future expansion than surface water.

The use of diesel powered pumps and water lifting devices operated by draft animals are the alternatives. But they are cumbersome and comparatively much more expensive to operate. The scarcity and rapidly increasing price of diesel fuel has, in fact, significantly hampered the progress of minor irrigation programs in recent years. Rural electrification must, therefore, be assigned a high priority in future planning and supported by adequte programs for additional power generation.

Rural electrification projects are financed by the Rural Electrification Corporation, Ltd., (REC) set up by the Government of India in 1969-70 together with the Agricultural Refinance Development Corportion (ARDC). The REC promotes agricultural production through minor irrigation and extends favorable credit terms for electrification of remote backward areas. This will also help in utilization of untapped groundwater potential in states where it has remained largely unused for want of capital financing. Financial resources of the REC consist of equities subscribed by the government, loans from the government, reserves and surpluses and market borrowing.

The REC has recently introduced a new program called the Special Project Agriculture (SPA) having a capital outlay of Rs. 3.60 billion to provide energy to 600,000 pump sets during the Sixth Plan. The sixth Five Year Plan calls for energization of 2 million pump sets and electrification of 100,000 villages during 1978-83. Financed by commercial banks, the ARDC and the REC on an equal basis, this program envisages projects covered by eight year loans up to a total of Rs. 3 million for each project and 14 year loans up to Rs. 5 million for each project. There is a two-year moratorium on repayment of these loans. The REC financing component of these projects is at a nine percent rate of interest and the rest is at 10.5 percent. The program is expected to accelerate provision of energy for irrigation pumps.

The REC since its inception has approved 2,840 projects involving loan assistance of Rs. 10.52 billion for electrification of 189,000 villages and provision of energy to 1.19 million irrigation pumps. Nearly Rs. 6.95 billion have been dispersed up to September 1979, and 59,000 villages have been electrified and 424,000 pumpsets have been energized as of June 1979 under the REC program. The annual increase in electrification reached about 9,000 villages and 94,000 pumpsets during 1978-79.

Irrigation Project Administration

After independence irrigation development continued to be a state subject and public irrigation works, except for a few very large interstate projects, are designed, constructed and managed by state public works and irrigation departments. The Central Power and Water Commission (CPWC), now the Central Water Commission (CWC), was set up in the central government to set standards and review, to monitor plans and implementation of major and medium irrigation projects, and to deal with development of interstate rivers under the Ministry of Irrigation and Power. With more than 1,000 well-trained and experienced engineers, CWC is the country's primary technical authority for water resources. Funds for construction and operation and maintenance are budgeted to the state Irrigation Departments by the state governments. The source of funds is state revenues, and grants and loans from the Center. The latter are made contingent upon compliance with CWC technical standards and central government policies.

A program for administration of minor irrigation works was established in the Ministry of Agriculture for the country as a whole, including all private works such as well, tanks and channels and pubic works costing less than Rs., one million each. Minor irrigation works have recently been redefined as those having irrigated potential of less than 2,000 hectares. In 1973, major and medium irrigation under the Irrigation Department was transferred to a new Ministry of Agriculture and Irrigation (MOA) and hydro-power to the Ministry of Energy. The Irrigation Department, which was transferred out of MOA to the Ministry of Irrigation and Power in January 1980, is now a separate Ministry. Minor works continue under MOA. Much of this program is in the private sector and the GOI has developed means for substantially increasing the supply of credit for drilling and energizing wells and for rural electrification infrastructure both through cooperative and private banks, and the Agricultural Refinance and Development Corporation, in the public sector. Various departments in state governments, including public works, irrigation and agriculture, as well as revenue, manage certain aspects of the program.

Groundwater development was managed by the Exploratory Tubewells Organization (ETO) set up in the Ministry of Agriculture in 1954 with USOM (now USAID) financing and technical assistance. In 1972 this organization became the Central Groundwater Board which also took over the former Hydrological Survey of India. The Central Groundwater Board is responsible for: macro-level hydrogeological investigations; deep exploratory drilling; monitoring water table behavior, developing methodologies for special problems encountered in planning assessment and development and management of groundwater resources.

Development Costs and Water Rates

With the expansion of irrigation development throughout the country and the gradual increase in construction costs[3] after independence, the productivity criterion for financing irrigation projects followed under British rule was found to be inhibitive. Productivity was calculated as the ratio of receipts from water charges in any year to the unpaid capital and operation and maintenance costs plus interest up to that year. The rate of return test was initially lowered in 1949 from 6 to 3.75 percent, but eventually this rate was also found to be too high. Irrigation policy planners evolved the view that state investment policy should be determined by a broader criterion than that of direct revenue returned to the state. Studies by the Planning Commission between 1958 and 1961 showed that substantial direct and indiret economic and social benefits accrue from irrigation: double cropping, diversification and better quality of crops, higher yields, larger incomes, and greater employment opportunities for hired labor, and in addition there were indirect benefits like the establishment of processing industries, expansion of consumer industries, retail trade and transport and communictions. On recommendation of the Nijalingappa Committee, the Government of India therefore accepted benefit-cost analysis as the basis for evaluating irrigation projects. A 10 percent annual rate of return (based on project life of 50 to 100 years) from direct benefits measured as increased income to cultivators is now used to calculate the benefit-cost rtio (B/C) ratio. Projects with a benefit-cost ratio of less than 1.5 are generally not considered for approval except in drought-prone areas of in areas where socially and economically disadvantaged groups predominate.

Water Rate Policy - Irrigation Subsidy

The water pricing isues raises three questions: (1) financial feasibility for farmers; (2) financial fesibility for government; and (3) economic feasibility for society.

Irrigation water pricing policy has been examined over the last twenty years by a number of authorities. There is a consensus among these studies that a policy for regulating water rates should have the following principal elements:

---

[3]Average construction cost has risen from Rs. 2,000 per hectare in the late 1960s to a current level of about Rs. 10,000.

--Water rates should in no case exceed 50 percent of the additional net benefit to cultivators and should vary from 20 to 50 percent depending on local socio-economic conditions.

--Absent data regarding production of crops per unit of land before and after irrigation, the water rate may be related to the gross income from crops and should range between 5 and 12 percent of gross income with the upper limit being applicable to cash crops.

--The rate should not vary from project to project except for quality of service. Any variation in rate should be small and irrigation works in a state should not impose a heavy financial burden on general revenues.

--Water rates should be levied on cropped area basis except where measurement of water for irrigation on a voluntary basis is feasible.

Implementation of thes recommendations would help rationalize water pricing plicy bsed on the principle of farmers' ability to pay; however, with a strong agricultural lobby, state legislatures are reluctant to raise rates. Nevertheless, water rates have risen as much as 100 percent over the past twenty years in many areas. Even if the recommendations were implemented, major and medium irrigation would continue to require heavy financial subsidies by government. The extent of economic subsidy, however, is unclear. The B/C ratio used in India is based on fnancial returns rather than economic values. Becuase of price controls, farmers receive only about 70 percent of economic value (as set by world markets) for their crops, but this is partially offset by subsidies for production inputs. Correction for most of these distortions is made in feasibility studies for projects funded by the World Bank and USAID which require an economic B/C ration of 1.0 based on interest of 12 percent, thus reflecting an economic subsidy equal to the difference between opportunity cost of capital and 12 percent or the calculated internal economic rate of return for projects having B/C ratios greater than 1.0.

Improving Water Management Practices

Despite the remarkable progress in harnessing surface water resources through the construction of large and small dams, headworks, regulators and canal systems since independence, the utilization of the enormous irrigation potential created by this infrastructure has been slow owing to failure to develop adequate water management techniques and policies. Of the total irrigation potential of 24.95 million ha. created by major-medium irrigation schemes through the end of the Fifth Plan, only 21.16 million ha. were actually being utilized. More significant is that the production benefit derived from utilized irrigation potential has been far below the optimum level. The following table shows the relative contribution from unirrigated and irrigated cropped areas to total foodgrains productions potential in the country at the beginning of the planning era and at present (1977-78):

Production of Foodgrain from
Irrigated vs. Unirrigated Areas

	Units	1950-51	1977-78
Total Area under Foodgrains	million ha.	97.3	127.0
a) Unirrigated area under foodgrains	million ha.	79.0	90.0
b) Irrigated area under foodgrains	million ha.	18.3	37.0
Yield	kg/ha		
a) Unirrigated		500	700
b) Irrigated		900	1,700
c) Combined		522	988
Estimated Production	million MT		
a) Unirrigated		38.5	63.0
b) Irrigated		16.5	62.9
c) Total		55.0	125.09
		(Actual	125.6)

Source: Irrigation Development in India - Tasks for Future, Indian Agricultural Research Institute, February, 1980.

According to this estimate, the average yield of irrigated foodgrain per ha., increased from about 0.9 metric tons (MT) in 1950-51 to about 1.7 MT per ha. during 1978-79. Experience in other countries shows that average yields of 4-5 MT per ha. from irrigated areas are quite common. Thus, the priority task of irrigation development in India is to improve water management so as to obtain better yields and derive full economic benefit from the country's huge investment in irrigation.

Field Channels

The single most important requirement for quick and efficient utilization of irrigation potential created is construction and maintenance of field channels from the canal outlet to individual fields. On surface water projects the Irrigation Department constructs and operates at project cost, conveyance and distribution channels down to an outlet serving an area (called a chak) of firm usage as low as 10 to more than 100 hectares or even larger. From the outlet, farmers are expected to construct the channels and operate them to deliver water to individual holdings, often less than one hectare, a responsibility for which they have neither the organization nor technical capacity. The result is that these channels are unreliable and wasteful. In order to clarify responsibility, in the 1960s the Planning Commission issued a directive fixing chak size at 40 hectares. Out of a total command area of something over 25 million ha. covered under major-medium irrigation schemes, it is etimated that as much as 12-13 million ha. may be without field channels. Over the past two years, under World Bank and other donor pressure, the Central Water Commission and the Planning Commission have directed that field channels be provided for plots up to eight hectares in command areas as part of irrigation projects. The Center would provide 50 percent funds consisting of 25 percent loans and 25 percent grants with the remaining funds to be raised by states. These policies represent significant progress and it is now up to state governments to insure that the lag in creation of irrigation potential at the outlets and construction of field channels is reduced to a minimum.

Command Area Development

Realizing that optimum development of irrigation potential required careful, systematic administration of water distribution and water management practices, the GOI in 1973 called on the states to establish Command Area Development (CAD) authorities to plan on-farm works, modernize headworks, canals and other infrastructure such as warehousing, marketing and village to market roads, and generally to strengthen the organization of agricultural extension activities. Forty-three CAD authorities now coordinate services for almost all of the 60 major irrigation projects in India covering a cultivable area of 13 million ha.

Water Delivery Schedules

After construction and maintenance of field channels, the most important priority is establishment and enforcement of schedules for delivery of water to the fields, particularly for those less advantaged farmers at the tail ends of the distribution system.

Over the last fifty years, a turn schedule system has been developed in northern India which provides for delivery of water to each farmer in the command of an outlet for a specified period in proportion to the size of his holding and according to a turn schedule prepared in advance. For the most part, the schedules are established by the farmers themselves and if they are not satisfied, they can appeal to irrigation authorities. Since the quantity of water allocated to each farmer is fixed, this system induces the farmer to use water more efficiently. Unfortunately, the use and administration of turn schedules remains haphazard and water use is as a result less efficient than would be the case if they were formalized and carefully administered. Upon appeal by farmers or on is own initiative, when authorized by state governments, the Irrigation Department can establish and enforce a formal rotation on a prescribed schedule known as warabundi. Even in states where warabundi has been authorized for a number of years, progress towards full utilization has been negligible and the majority of states have yet to initiate it.

Crop Planning

Efficient water use is also significantly enhanced by planning crop patterns in irrigated areas based on soil types and regional agro-climtic conditions. Because water rather than land is the scarce resource, maximum production occurs through optimizing production per unit of water rather than per unit of land, thus crops are grown at less than full water supply and double and triple cropping gives way to single cropping of larger areas. Within the available water supplies, crop varieties should be selected to give equivalent yields with minimal amount of moisture over a short duration so that their growing period does not conflict with crops to be grown in the following season. Significant gains in production can result from double or multiple cropping if the sowing of such crops as rice, peanuts, arhar (pigeon pea) is advanced through use of groundwater-irrigated nurseries. With crop patterns thus determined on the basis of available irrigation water and other factors, water distribution can be synchronized with crop requirements. In many irrigation systems where infrastructure is otherwise satisfactory, failure to match irrigation water supplies and cropping patterns is the main factor responsible for unsatisfactory levels of productivity.

Modernization

Most surface irrigation projects cannot meet crop requirements owing to excessive transit losses and inadequate regulatory structures on canals. On some projects canal capacities themselves are a constraint. Transit losses are particularly critical. Unlined canals lose between 20-50 percent of the volume of water they are designed to transport. GOI irrigation planners therefore have assigned a high level priority to remedying these defects, undertaking such measures as canal lining and construction of regulatory works, so that water requirements of crops during peak periods are met and application of fertilizers and other inputs is timely. Modernization of existing works ranks as a leading priority in the sixth Plan.

The Model Irrigation Bill

Concurrent with the expansion of irrigtion works in India during the 19th century, the British colonial administration enacted a number of laws regulating and controlling water in state-owned canals and works. These laws varied considerably between states and within states. There grew up a multiplicity of laws covering various aspects of irrigation mnagement and administration, often providing for multiple lines of authority and diversified control for operation and management of irrigation works which diffused responsibility and was ultimately against the best interests of the states as well as the irrigators. Moreover, these laws did not cover aspects of irrigation policy which assumed greater importance after independence: conjunctive use of surface and groundwater, construction of on-farm development works, including field channels, field drains, cropping patterns and drainage, and enforcement of proper maintenance of irrigation works previously maintained by ex-landlords and zamindars.

The Second Irrigation Commission therefore recommended in 1972 that the irrigtion laws in each state be simplified and consolidated into a single statute uniformly applicable within all regions in the state. This recommendation resulted in drafting of the Model Irrigation Bill which has been circulated to the states for consideration and adoption with suitable modifications, if any, to accommodate prevailing conditions and practices in the states.

Since it would eliminate many long-standing practices and run counter to vested interests of larger land holders, the Model Bill is controversial. This and the complexity of the subject make it unlikely that many states will amend existing law along these lines in the foreseeable future.

The Model Groundwater Law

Increasing use of high yielding varieties has accelerated the over-development of groundwater. Controls were needed to prevent overuse of groundwater with the concomitant hazards of lowering the water table, well failure, saline infestation, and reduction in committed base flow in rivers. A model Groundwater Bill along these lines was prepared and circulated to the states by the Union Department of Agriculture in 1970. Because under Indian law all groundwater vests in the government and there is no possibility of groundwater being acquired by precipitation, there are no legal barriers or constitutional problems preventing passage of such an act.

Thus, a comprehensive legal framework governing construction, maintenance, management and utilization of area irrigation works has been drafted; it is now up to the various sate governments to take the required action to implement it. But, like irrigation law reform, this is a controversial, complex subject and not likely to be enacted soon.

Flood Control

Flood control continues to be a major problem in India. Damage caused by floods over the last two decades has averaged about Rs. 1,500 million a year. In 1978, the country experienced some of the worst floods of recent record, affecting large areas of Haryana, Uttar Pradesh, Bihar and West Bengal while the states of Kerala and Tamil Nadu were hit by tropical storms which also produced flooding. Total damage amountd to Rs. 10.91 billion, a level of devastation only exceeded by the unprecedented floods of 1954.

Rivers causing serious floods fall into three groups. The first group consists of all the rivers below the Tropic of Cancer. In this group only the Narmada and the Orissa rivers -- the Brahmani, Baitarni, Burhabalang -- and the interstate river Subarnarekha have yet to be controlled.

The second group includes the Ganga and its tributaries. Of this group the areas most seriously affected are north of the Ganga and lying between the Ghaghra and the Mahanadi tributaries. The Ganga itself causes erosion at a number of places. Floods in this area affect the most densely populated areas of the country. As all these rivers are international and flow from Nepal, flood control requires to some extent cooperative planning between India and Nepal. The southern tributaries of the Ganga ae the Yamuna and the

Son. Sub-tributaries of the Yamuna such as the Chambal, the Sind and the Betwar are subject to serious flooding which has, however, diminished somewhat in recent years as flood control works are extended on these rivers.

The third group comprises rivers in the Brahmaputra Valley in India. Here the prevalence of earthquakes, landslides and heavy silting seriously complicates the construction of flood control works. Since rivers passing through North Bengal, such as the Tista, Torsa and Jaldhaka are international, their management will require cooperative planning with Bangladesh in order to be effective.

While considerable protection has resulted from works already constructed on rivers such as the Mahanadi, in the Indus and Tapi Basins, large areas of the country remain subject to serious flooding. Concerned by the magnitude of the flood control problem, the GOI established in 1976 the National Flood Commission to identify areas requiring immediate protection and to prepare a comprehensive plan for optimum multi-purpose utilization of water resources.

The National Flood Commission in its report submitted recently to the GOI has recommended a 22-point program for flood control as part of the strategy for optimal utilization of water resources. The program calls for setting up a central control agency under the chairmanship of the Prime Minister assisted by a strong technical group. Other major recommendations include: (a) afforestation and soil conservation; (b) greater coordination among different agencies engaged in flood protecion such as railways, national highways and state irrigation/flood control departments; (c) establishment of a national council for mitigating disaster: and (d) flood control tax. The Draft Sixth Five Year Plan (1978-83) (now under revision) estimates that the total area liable to flooding is 34 million ha. It is economically feasible to extend flood protection to about 80 percent of this area. The plan allocates Rs. 9 billion to various flood control projects and calls for preparation of master flood control plans. Major programs include construction of embankments, excavation of drainage channels, construction of storage reservoirs in upper river catchments and reservoir regulation to control flood discharges.

A National Water Grid

While most of India's immediate and near term water requirements can be met by surface and groundwater development within river basins, interbasin water transfers are necessary and will be increasingly so over the long term. Major interbasin projects have already been undertaken. These include the Periyar Diversion, the Kuirnool Cuddappa Canal, the Beas-Sutlej link and the Rajasthan Canal.

Indian planners have considered means by which some of the surplus water of the Ganga system can be pushed southward as far as the tip of the Peninsula. The idea of a national water grid was first proposed by Dr. K. L. Rao in 1972 when he was the GOI Minister for Irrigation and Power. UNDP conducted a preliminary feasibility study. The plan was not pursued further because of objections about engineering and environmental aspects of the project.

The highly publicized "Garland Canal," advocated by Dr. Dinshaw J. Dastur, a prominent engineer, would entail an investment of Rs. 150 billion and calls for the construction of two mammoth canals, the Himalayan Catchment Canal and the Central, Deccan and Southern Plateau Canal, to provide irrigation water throughout India. The GOI, though, appears to have shelved the proposal on grounds that it is not feasible either from an engineering or economic standpoint. GOI planners have not, however, abandoned the concept of a national water grid; they appear to favor an incremental approach rather than a massive, comprehensive project such as that proposed by Dr. Dastur.

The GOI is now considering a national water development plan which would link different rivers in the country and would undertake multi-purpose development of water for flood control, irrigation, drinking water, hydroelectric power generation and navigation.

The extension of such projects on a country-wide scale involves careful consideration of costs and benefits, possible alternatives, technical feasibility, and a firm, reliable assessment of ground and surface water resources. Long distance water transfer also involves careful consideration of long-term plans for industrial growth and urban development.

Most importantly, interbasin transfer requires a concensus among claimant states and regions regarding water distribution, and negotiation of agreement between states is only slightly less complicated and acrimonious than negotiating international ones. The recently completed Narmada River agreement took several years and probably will be challenged in the courts. Interstate rivalry could thus be a major deterrent to achievement of this goal.

Hydroelectric Power

India's economically exploitable hydroelectric potential was assessed during a 1953-1960 survey by the CPWC at 41,100 MW. at a 60 percent load factor. This estimate was based on specific projects in various river basins for which topographical and hydrological data were available. Subsequent surveys indicate that the country's hydro potential is much larger if seasonal and secondary sources including micro-hydel projects are taken into account. Although a detailed updating of the earlier survey of potential has not been undertaken, the Central Electricity Authority (CEA) estimates that India's hydroelectric potential is 76,000 MW. at a 60 percent load factor, equivalent to an annual generation of 400.5 TWH. (TWH = KWH x 10^9.) The following table shows recent estimates of hydroelectric potential by region at a 60 percent load factor, the earlier CWPC assessment is shown for comparison:

Assessment of Hydroelectric Potential in MW

	CWPC (1953-60)	CEA	Percentage change in power potential
Total	41,000	76,200	85.4
Northern	10,700	27,800	159.8
Eastern	2,700	7,500	177.8
Western	7,200	7,600	5.6
Southern	8,100	13,100	61.7
Northeastern	12,400	20,200	62.9

Source: Ministry of Energy, Department of Power, 1978-79 Report

Hydro Potential Development and Under Development
(in MW at 60 percent load factor)

	Potential developed and under development (1)	Potential (2)	(1) as percent of (2) (3)
Total	12,804	76,200	16.8
Northern	4,226	27,800	15.2
Eastern	1,451	7,500	19.4
Western	1,330	7,600	17.5
Southern	5,554	13,100	42.4
Northeastern	243	20,200	1.2

Source: Ministry of Energy, Department of Power 1978-79 Report

Hydro potential now developed or currently under construction represents about 17 percent of the total potential of 76,200 MW. Most of the remaining potential is in the northern and northeastern regions. One of the factors contributing to slow progress in hydro potential appears to be the engineering problems entailed in dealing with large unstable rivers and active seismic conditions. A regional comparison of developed potential and potential is shown in the table at the bottom of the preceding page.

Although electrical power development will continue to be assigned a high priority by the GOI and the Planning Commission, hydroelectric resources are not likely to be fully utilized because of the high initial cost and the long construction period required for hydro projects. This is borne out by projections in the draft Sixth Plan. Hydro capacity is projected to increase by 42 percent, from 10,016 MW to 14,240 MW over the Plan period compared to a 95 percent increase in thermal generation capacity from 13,059 MW to 25,526 MW over the same period. Although renewed emphasis is now being placed on development of India's vast hydro potential, and the GOI in cooperation with state governments is investigating possible hydro sites in Jammu and Kashmir, Arunachal Pradesh, Sikkim and the Andaman and Nicobar Islands, resource constraints may prevent significant development at this juncture. Nevertheless, the Government of India is thinking in terms of an integrated development plan for the northeastern states, which is a region of challenging geographical and geophysical characteristics. The dams proposed will not only produce much needed power, but provide a measure of flood control during heavy monsoons. Because the area is seismically active, careful scientific studies will have to be conducted in connection with the design and construction of the high dams.

International Boundary Waters

India's international boundary water problems are now largely confined to the eastern region. A 1960 treaty with Pakistan governs water resource sharing in the Punjab and assures Indian access to flows in the Ravi, the Beas and the Chenab rivers.

The chief obstacle to management of water resources in the lower reaches of the Ganga and of the Brahmaputra rivers is the dispute with Bangladesh over low flows in the Ganga. For perhaps two centuries or more the discharge of the long, slow Ganga river has been shifting toward its eastern distributaries, which now lie in Bangladesh. Its westernmost outlet, the Bhagirathi-Hooghly, has been losing water, and also has been silting up, thus reducing the draft of ships that can come to Calcutta, now limited to about 26 feet, despite continuous dredging. The new bulk and container port, Haldia, south of Calcutta, offers only a little more draft. This situation is at its worst in the dry season, and to solve it a barrage and canal was finished by India across the river at Farakka in 1976, capable of diverting a flow of over 40,000 cusecs into the Hooghly. Dry season Ganga flows, however, can go as low as 15,000 cusecs and the removal of 40,000 cusecs would leave Bangladesh's districts on the Ganga without adequate water for maintaining navigation and preventing sea water infiltration. By embarrassing India through "internationalizing" the dispute in the UN, Bangladesh forced India to accept a split of the annual low water diverted at Farraka giving Bangladesh the greater part of it for the five years 1977-82, pending a long range settlement which would "augment the dry season flow of the Ganga."

There are two major proposals on the table to accomplish this: India wishes to link the far more voluminous Brahmaputra to the Ganga by a canal which would cross a portion of Bangladesh and enter the Ganga above Farakka. However, reduction of already low dry season flows in the Brahmaputra would aggravate the water supply situation in Bangladesh. Moreover, Bangladesh objects to the loss of a certain amount of her land which would be used by the canal, and counter proposes the impounding of monsoon water in a series of Ganga system upstream dams, many of which would be in Nepal, and releasing the water during the dry season. This would involve Nepal's joining the talks.

The concept of an internationally supported study of potential "eastern waters" development perhaps leading to a large-scale collaborative project across national frontiers was touched upon very lightly by President Carter during his February 1978 visit to New Delhi, and in effect seconded soon thereafter by the then U.K. Prime Minister Callaghan. There has been little concrete response from the south Asian countries actually involved, however, and in light of the unsuccessful Indo-Bangladesh Joint Rivers Commission meeting in February 1980, there is little current prospect of a positive response.

The Joint Rivers Commission also established a committee in December 1978 to examine sharing of flows in the Tista river. During the meetings in February the Bangladesh representative also objected to the construction of a dam on the Indian side of the Tista river in the absence of an agreement on water sharing. Prospects of an early settlement of these issues with Bangladesh, therefore, appear remote unless a high-level political decision is made.

Conclusion

Because India's economy is predominantly agricultural and agriculture depends on firm water supplies, continued economic growth in India will be heavily contingent on further development of irrigation. India has created vast irrigation potential since independence but has been much less successful in utilizing that potential effectively. Scarcity of financial resources, aggravated by rapidly escalating construction costs, will be the major constraint on creation of new irrigation potential in the future, but will be only one of several constaints in shifting emphasis to the more economically effective but politically less attractive task of achieving better water utilization. Field channels, land development, rural roads, warehouses, markets, credit, production inputs, and technical know-how effectively integrated into irrigation development schemes will be required to accomplish this task. But in addition to this heavy investment in rural infrastructure and technical training, improved organization and political commitment will be essential.

Uneven distribution of water resources presently denies irrigation to the majority of India's farmers. To extend irrigation to its maximum potential will require inter-basin water transfer on a substantial scale. While proposals for spectacular schemes to double present irrigation potential (113 million hectares by the year 2000) have generated a great deal of attention and comment, a national water grid is likely to be realized by increments rather than as a single grandoise scheme. The lengthy interstate negotiations and often acrimonious litigation which much precede large-scale inter-basin transfers will impede water development but will not be insurmountable obstacles. A balanced, Pareto-optimal allocation of the resource will probably be achieved in these negotiations, but they will proceed at a deliberate pace. On the international side, allocation and augmentation of low-season flows in the Ganga-Brahmaputra Delta in both India and Bangladesh are the basic issues. Their resolution will depend on the more political tone of the relationship between India and Bangladesh than on technical considerations.

The GOI seems prepared to assign a very high priority to mobilization of resources to improve water utilization. The Draft Sixth Plan shows substantially higher allocations for construction of field channels, modernization of existing works, development of groundwater and rural electrification, and for Command Area Development programs designed to integrate rural infrastructure and service in major irrigation projects. But this program must compete for scarce resources with other investment priorities including large-scale inter-basin canals in the irrigation sector, and with requirements in industrial sectors, some of which -- power, transportation and fetilizer -- also provide vital support to agriculture.

While economically justified by benefit/cost analyses, irrigation is heavily subsidized by public financing. The direct charge rates for water set by state legislatures will continue to be difficult to increase. Generally, they are insufficient to reimburse any of the capital costs. On the other hand, low ceilings on commodity prices paid farmers and a less than simple system of subsidies make equitable repayment a complex, inadequately analyzed or understood problem. International donors continue to press the GOI and states to increase water rates but with limited success. It is clear that heavy financial subsidy of irrigation will continue.

Owing to basic principles in legislation enacted a century ago, subsequent state legislation, amplification by legal interpretation and administrative regulation, there is a great variation in fixing responsibility for water resource administration and in details of implementation among states and even among localities within states. Enactment of GOI-drafted model state laws on ground and surface water would implement a more orderly and uniform administrative process and strengthen authority to conserve water. However, to enact this legislation would require a sustained, energetic effort by the GOI to overcome resistance in state assemblies by landowners and others with a vested interest in the status quo. The GOI has other more pressing issues it must pursue with the states which will take priority over water law reform. It is therefore unlikely that the model water bills will be enacted. But failure to pass them will probably not be a serious deterrent to irrigation development. Much has and can continue to be achieved simply through administrative interpretation of existing laws.

In sum, without gainsaying the strategic importance of water development to India's future, scarcity of economic resources and competing political and economic priorities, as well as constraints in other sectors, will likely slow the rate of water development, particularly expansion of the area placed under irrigation, which has prevailed from independence.

APPENDIX B

ROTATIONAL SYSTEM OF CANAL SUPPLIES AND WARABUNDI IN INDIA

by

G. N. Kathpalia
Government of India

ROTATIONAL SYSTEM OF CANAL SUPPLIES AND WARABUNDI IN INDIA

by

G. N. Kathpalia

Introduction

Rural economic growth in India is dependent to a great extent on agriculture; more people are involved and dependent on it than on any other sector of the economy. Agricultural growth, with social justice, depends mostly on the development of water resources and its proper distribution, as water is one of the prime inputs for adopting the modern technology of agriculture. The National Commission on Agriculture has estimated that, when all the water resources have been developed, only about 110 million hectares of cropped area, out of a gross sown area of about 210 million hectares (in the future), can be irrigated, provided the most efficient use of irrigation supplies is made through proper management of its distribution, minimizing the losses in conveyance, proper preparation of fields and suitable cropping patterns are adopted, taking into account the soil and agroclimatic factors.

Satisfactory distribution and efficiency of irrigation water use depend on:

1. Efficiency of the conveyance system from the head of the canal up to each outlet of about 40 hectares block.

2. Operation and regulation efficiency of the canal system.

3. Efficiency of conveyance systems within the 40 hectares block up to each holding.

4. Equitable distribution of water among the farmers within the 40 hectares block.

5. Field application efficiency.

Improvement in the efficiency of the conveyance system up to the outlet of 40 hectares block is receiving adequate attention. The efficiency of operation and regulation of the canal system and that of conveyance and distribution within the 40 hectares block has been rather low in most projects and needs much greater attention. It is this aspect which is proposed to be discussed in this paper.

The responsibility for development of water resources for irrigation through major and medium projects and its delivery up to the irrigation outlets (commanding an area of about 10 to 40 hectares) rests with the irrigation departments. The distribution of irrigated water beyond such outlets has been left to the farmers concerned, although it is expected that the State Departments of Agriculture/Irrigation would give necessary technical guidance to the farmers. But, due to lack of water distribution systems within the outlet command (field channel) up to each holding, and there being no organized institutional arrangement for allocation and distribution of water among the numerous farmers within each outlet command on most of the irrigation projects, the efficiency of water use within the outlet commands has been rather low. The cultivators who are responsible for distribution of water among themselves seldom join together to construct field channels and there have been, in most states, no legal or administrative compulsions for them to come together to construct, maintain and operate the field channels to achieve equitable distribution of the available water among themselves. As a result, the method of water distribution in most of the projects, especially in paddy areas, has been one of continuous flooding under which the irrigation water flows from one field to the next lower one. In such an arrangement, the farmers do not have any control over the water. The farmers in the head reaches and those who are strong in the society invariably utilize the bulk of the available irrigation water, denying the tail-enders and the weaker sections of the society their due share. This results in excessive irrigation in some areas, leading to waterlogging and salinity conditions and scarcity of water in other areas, causing crop failures or reduction in yield. In order, therefore, to ensure the availability of irrigation water to each and every farmer within the outlet command, independently, and on an equitable basis, a system of field channels and rotational method of distribution of irrigation water is required within the outlet command which should be so designed as to fit in with the rotational operational of distributaries, etc.

Present Practice of Distribution and Management

Rotational running of canal system. The main canals of all irrigation systems are run continuously except for a closure of two to 12 weeks in a year, depending upon the need for maintenance and repairs, and the cropping pattern prevalent in the canal command area. A wide range of practices are followed in different projects, with regard to rotation of supplies in branches, distributaries and minors up to the outlet. These can be divided into the following categories:

1. Paddy during kharif:

   a. In the Cauvary system (Tamil Nadu) and some other projects, all channels run continuously, without any control, from a certain date when the water is released from the reservoir until the maturity of the crop. Field to field irrigation by flooding is practiced. In that system, there is reuse of water.

   b. In Lower Bhawani Project, Tamil Nadu, the distributaries taking off from the main canal run in rotation in alternate years, supplying water for two crops in a year, one being paddy, the other being irrigated dry for the full area covered by these distributaries. The channels which run in a particular year run continuously throughout the crop seasons, i.e, from January to April and then from August to December.

   c. Some of the branches and distributaries, in the northern states of Haryana, Uttar Pradesh and Bihar, run continuously during the period of transplanting of paddy and, thereafter, the supplies are rotated, depending upon the rainfall.

2. a. Particularly during Rabi, the branches, distributaries and minors are run in rotation in all the northern states. The rotation is generally in multiples of a week. All the outlets covering an area of about 20 to 100 hectares are simultaneously run along with the distributary or minor from which they take off. In Andhra Pradesh and Tamil Nadu, the water supply level in the distributary is maintained at the designed level whenever the channel is running. The outlet size is correlated to the area to be irrigated, according to the proposed cropping pattern, and all the outlets are fixed at a certain level below the full supply level in order to maintain constant head and a proportionate APM discharge. In Punjab and Haryana, APM outlets are provided which ensure proportionate discharge, even at a variable head of water in the distributary.

   b. In Gujarat and Maharashtra, where applications are invited before the season and crop areas are sanctioned, particularly for sugarcane, the distributaries also run in rotation. But, all the outlets from the particular distributary or minor do not run simultaneously and are opened in rotation within the period of two weeks for which a distributary runs at a time. In Gujarat and Maharashtra, the outlet sizes have no correlation with the area irrigated and are of standard size, generally 30 to 40 cm in diameter. These outlets are fixed at the bed level of the channel. The water supply is controlled with the help of different openings of the gates. The distributaries and minors do not run with a fixed discharge and the water supply level varies from time to time, depending on the requirement. The outlets supply water according to the demand of the farmers and, thus, an outlet may run for a day or so, depending upon the area, while the distributaries may be running for a period of two weeks. Thus, the water supply to the outlets is also rotated within the distributary.

Thus, there is a basic difference in the design and operation of the channel system as practiced in the northern and southern states and that in Gujarat and Maharashtra.

Distribution of water within the outlet command. Water is made available at the Government outlets according to predetermined schedule. The beneficiary farmers are expected to distribute it among themselves. The various practices of distribution prevalent at present are given below:

1. In Northern India, in the states of Punjab, Haryana, Uttar Pradesh and parts of Rajasthan and Bihar, a system of distribution of available water on an equitable basis, proportionate to the area of the holding and the proposed/prevalent cropping pattern in the project, is being practiced. The rotation period is generally seven days. This is known as "warabundi" or "tateel" in different states. The warabundi system varies to the extent that the allocation may be villagewise, groupwise (thok) or individual farmerwise. The system has legislative and administrative support in these states, but is optional. Sometimes the farmers practice this system on their own also. Recently, this system of warabundi, with allocation of time to groups and each farmer during rabi season for light irrigated crops with minors running continuously, has been introduced on the Pochampad Project.

2. In Maharashtra, parts of Karnataka, and Gujarat, the available water is distributed by rotation in 14 to 21 days, proportionate to the cropped area sanctioned by the Government on receipt of the applications from the farmers known as "shejpali". The Irrigation Department has the authority under an Act to specify the area that can be grown under each crop and areas under sugarcane and other perennials are generally restricted. There is a penal rate for any deviation from a specified crop. The bigger landholders are allocated less water and defaulters of water charge payment may not be allocated any water until the dues are paid.

c. In Tamil Nadu and some other states, the farmers have arotation system of distribution of water among themselves on a one-and-one-half to four day basis for paddy crops and a larger interval for other crops. Here also, the water allocation is for a specified crop in a season and there is a penal rate for any deviation, especially if paddy is grown in unspecified areas or seasons.

d. In other projects in Bihar, West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, and Kerala where paddy is the main crop, the practice of irrigation is from field to field by flooding, as the field channels to each holding do not exist.

Regulation of canal system. There are two systems of regulation prevalent in India which can be termed as upstream control and downstream control. These are the normal practices which are prevalent in other parts of the world with different degrees of sophistication and control.

The upstream control system consists of ascertaining the quantity of water available in the reservoir and releasing it for the particular command area, from a fixed date at the beginning of the crop season, until the maturity of the main crop. In this system, the main canal runs continuously and the distributaries may be rotated in some projects with limited control structures. In this system, no effort is made to ascertain the demand of the farmers, on a weekly or fortnightly basis, which may vary due to rainfall and the staggering of the crop sowing from distributary to distributary and year to year. This system of regulation is practiced in most of the southern states, both for paddy and other crops. In the case of Gujarat and Maharashtra, there is a slight modification to the extent that applications are invited in the first instance and water supplied to only those farmers who have been sanctioned a particular area of each crop.

The downstream control system of regulation envisages the demand of the farmers being judged and reported by the lowest Government official (controlling about 1,000 hectares) to the Assistant Engineer, minorwise and distributary-wise, which takes into account the rainfall in the area, the stage of the crop growth and the area under different crops at that particular time, and is reported on a weekly basis. The Assistant Engineer, in turn, reports his demands on this basis to the Executive Engineer and the S.E., who controls the releases of the main canal. Care is taken to limit these demands within the available water in that particular crop season of the year. It is on this basis of feedback from the field that the regulation orders, with regard to the quantity of water to be released in different branches, distributary and minors, are issued by the respective officers every week. Although the supply of water to different distributaries and minors is worked out in advance, depending upon the forecast of available water for every crop season, the flexibility to adjust the supply into different minors and distributaries, to take into account, particularly, the rainfall area under each crop and the crop stage is kept in view. Generally, the distributary or minor is run with 10 percent over or up to 20 percent below the full capacity, depending on the demand, or kept closed to avoid the temptation of tampering with the distribution system. Such a system can be called a semi-demand, semi-rotation system which, although not satisfying the demand of each and every individual farmer, does satisfy the majority of the farmers on a particular minor or distributary. This system is in practice in Uttar Pradesh, Punjab, Haryana and Rajasthan. This system tries to avoid wastage of water due to operational problems to a good extent and, thus, has better operational efficiency.

The regulation of such a system is facilitated through a set of gauges, duly calibrated from time to time, fixed on all channels from the main canal to the minor at the head of the channel, and, also, at every 15 to 20 kilometers, depending upon the location of structures like falls, escapes and regulators. These gauges are reported daily, at 8:00 a.m., through a system of telegram and telephone communication to all the concerned officers of the Irrigation Department. The regulators and head of the different channels have wooden planks, or steel gates, which may be operated manually, mechanically with a gear system, or electrically for regulating the water supplies. These various types of gates are being used, depending upon the size of the channel.

This system of regulation is facilitated through an organization which, besides being responsible for this work, is also responsible for assessment of irrigation charges, enforcement of warabundi, and prevention of damages to the canal system, irregularity of regulation orders, and unauthorized irrigation.

Limitation of existing systems. The present way of water distribution in the canal system, regulation of its supplies, and distribution of water among the farmers within the outlet command has a number of limitations which do not allow efficient use of water and its proper management for optimum agricultural production to the satisfaction of the individual farmer. These limitations are:

1. Canal System:

   a. The canal capacities and control structures are inadequate for an efficient system of water supply and meeting the peak demand at the right time;

   b. The maintenance of the canal system is not up to the mark due to lack of funds and inadequate technical attention;

   c. Some of the canal systems are designed for a rigid cropping pattern and 100% intensity of irrigation in a crop season which leaves little choice for more efficient use of water;

   d. Lack of, or inadequate provision of, a drainage system, which limits the choice of crop, and intensity of irrigation, particularly in heavy soil areas.

2. Regulation of canal system. On most of the projects, the upstream control system of regulation is adopted, which is inefficient and unsatisfying to the farmer in terms of timely and reliable supplies. Such projects have inadequate organization for changing over to the downstream control system if desired.

3. Distribution of water among the farmers within the outlet command.

   a. Absence of any institutional or regular system on most of the projects for equitable distribution of water among the farmers.

b. In some states like Gujarat, Maharashtra and Bihar, procedural difficulties, such as prior application, come in the way of water being supplied and used for light irrigated crops, particularly during the kharif season in areas where the rainfall is normally sufficient in most of the years to meet the requirements, but has erratic distribution.

c. In some of the states, where a system of warabundi or something similar to it is practiced, the present design of warabundi does not ensure the same quantity of water per hectare among the tail-end farmers, compared to those in the upper reach, because of the losses in earthen field channels not being taken into account.

d. In Uttar Pradesh, where warabundi is practiced and there is a system of formation of groups of farmers (thok), these are formed, not on the basis of contiguous location of their holdings, but, on the relationship between the various farmers, though their holdings may be scattered within the outlet command. This leads to wastage of water and time.

e. The fixation of a cropping pattern through a system of localization and/or penal rates for non-adherence is less conducive to efficiency and satisfaction of the farmer in the present circumstances, due to wide fluctuations of market rates for various crops from year to year.

Improvements Needed in Interrelated System of Distribution and Regulation

An irrigation project, at present, has an overall efficiency of 25 to 40 percent which can be improved to about 60 percent, mainly through a better distribution system which would give higher agricultural production with the same amount of water. This can be attained by ensuring a reliable, timely and adequate supply of water to each farmer with freedom to grow any crops he likes, within certain limits, with the water allocated to him. The improvements necessary are:

1. To adopt a rotation system of water supply for the distributaries and minors, with downstream control system of operation. For this purpose, the canal design

practices may be reviewed in regard to canal capacities and the need for various control structures up to the outlet level to enable efficient system of operation.

2. The funds and the organization required to be adequately provided for better maintenance of the canal system to enable its operation in the desired manner at all times of the year. This would more than repay itself in terms of higher production through satisfactory and reliable service to the farmer.

3. The system of fixing the cropping pattern, localization and providing for 100 percent intensity of irrigation in one crop season should be modified to allow flexibility of choice of crop to the farmers within certain limits and to provide for intensity of irrigation which would induce the farmer to use the water efficiently and also encourage development of groundwater wherever possible.

4. Due to varying soil conditions and to enable the freedom of choice of crops within certain limits to the farmer, particularly in heavy soils, adequate provision and maintenance of drainage systems are essential.

5. Introduction of warabundi system, i.e., a system of rotational water supply within the outlet command according to the improved design as indicated later in the paper, which would ensure equitable distribution of water to all farmers, irrespective of their location or status.

6. To have an institutional arrangement which would enable the farmers to be organized, trained and guided for distributing the water supplies among themselves within the outlet command to start with, and later on, even enable them to operate the minors themselves.

7. The water rate for various crops should have an interrelationship which would encourage the light irrigated crops to be irrigated even during kharif, for bringing about stability in the production and utilization of available water.

Objectives of Rotational Water Supply and Warabundi

The word "warabundi" has been used in the states of Punjab, Haryana and Rajasthan to describe a certain system of distribution of water within the outlet command. In Uttar Pradesh, the word "osrabandi", and, in Gujarat and Maharashtra, "shejpali", have been used to indicate their systems. In Tamil Nadu, "vara-varam" means week-to-week, while, in Punjabi and Hindi, "wara" means turn. As such, it has been considered the most appropriate word to indicate a system of distribution on a rotational basis. In this paper, the word "warabundi" is being used in a broad sense to indicate the improved system of distribution of water among the farmers within the outlet command so as to ensure timely, adequate and equitable distribution of water, on a weekly, or multiple of a week, basis. It would facilitate application of water to an individual field in a stream size which is efficient and can be well-managed by farmers, thereby reducing the time and labor required for irrigation. Better water control, freedom of sowing any crop within certain limits, higher unit area yield and larger irrigated area can be achieved per unit of water by adopting warabundi. It will help to reduce wastage of water, the water disputes, loss of lives, litigation, and increase the reliability of water supplies, particularly to the weaker section of the society and to those situated at the tail-end of the command areas. It also enables the farmers to know in advance when the water would be available and the amount of water that he would receive so that he can plan the cropping operations accordingly. This would, in turn, encourage the farmers to use inputs like better seeds, fertilizers and credit, leading to increased production and higher return from the investments made.

The main objectives, as stated above, can be achieved by ensuring a good design of warabundi, which would take care of the soil conditions, drainage, agroclimatic factors, availability of water, proposed suitable cropping patterns and socioeconomic factors of the area. Keeping those in view, certain general principles and guidelines can be laid down for working out the details in each particular project. Any practice of warabundi would have to ensure participation and involvement of the farmers through persuasion and demonstration. The degree up to which the Government should have the control, and thereafter only guide and help, can be decided by each state. Such a system should be applicable and enforced on all projects. There should be an organization with legislative and administrative backing to enforce and maintain discipline for operating the system.

Major Problems in Implementing Warabundi

Warabundi has been practiced in some of the states in India for the last 50 years or more, but has been neglected or given much less attention than it deserved for the past 25 years. It has not been recognized as an important instrument for an equitable distribution of water and ensuring a timely and adequate supply of water to each farmer within the outlet command. Recently, this has been introduced and tried in the states of Andhra Pradesh, Gujarat, and Maharashtra. Here, a variant of the existing system and the new objectives has been successfully tried. Some of the problems being faced in its introduction and implementation can be divided into three categories: technical, administrative, and social, which are explained below.

1. Technical:

   a. The canal design or existing canal capacities and control structures up to the outlet are not suitable to supply adequate and timely water;

   b. The field channels may not exist with adequate control structures;

   c. The outlet size and gate are not suitable or not fully provided.

2. Administrative. In some states, applications are invited under the existing law and, as such, the allocation of time on a permanent basis to each farmer cannot be done. This necessitates the allocation of time every year and every crop season. There is a penalty for using the same amount of water in additional land area under the restricted crop by using the water efficiently. The relevant Act and Rules would have to be amended.

3. Social. The bigger farmers, or those farmers located in the head reach of the field channel, who have been getting more than their due share of water, are not willing to forego their extra share, even though it may not really be required. A lot of persuasive and administrative effort is required to bring them into the fold of new discipline.

Role of the Farmers

As the water within the outlet command is to be distributed among all the farmers having their holdings within the command, it is the farmer alone who has to put in the effort to use the water efficiently for optimum agricultural production, with increased benefits to himself. It is, therefore, essential that his participation and interest are fully ensured in the process of distribution of water and its use. As such, the role of the farmer cannot be minimized and certain responsibilities have to be shouldered by him. He has to be organized to take care of these responsibilities in the proper manner. The responsibilities would be to ensure:

1. That each farmer takes water for the time allocated to him and does not take other farmers' shares; and

2. Maintenance of the channel and the regulation of the gates of his holdings.

In order to ensure that these responsibilities are properly shouldered by the farmers, it is necessary that all the farmers within the outlet command of about 10-40 hectares, which may number from 15 to 60, depending upon the size of the holding, are grouped into five to eight groups. The group leaders then can choose a leader for the outlet command. The flexibility of the warabundi system would permit the interchange of time due to various reasons and settlement of day-to-day disputes temporarily within the group, with the help of the group leader, and among different groups, with the help of the outlet leader. These outlet/pipe committees can be known by different names given locally such as chak-samities, farmers' associations, etc.

After the time and day allocated to each farmer and group has been calculated, as per design discussed later, it would be desirable to give it a wide publicity through notice boards and allocation cards, so that every farmer is aware of his rights and share of water responsibility and, thus, does not suffer through ignorance.

In order to carry out the responsibility of maintenance of channels and structures within the outlet command which are of a community nature, it would be necessary to collect funds and provide labor. It would be desirable to give a legal framework for such an organization to function properly both in terms of organization and the budgeting of funds for carrying out the maintenance works regularly.

In addition to the basic responsibility indicated above, after it has been fully taken care of, this organization could also take up other responsibilities and works, at a later stage, in which all the farmers are interested, such as development of groundwater, custom service of a tractor and other equipment, arrangement for transport of inputs and produce to the markets.

Design of Warabundi

The design of any distribution of water within the outlet command assumes that the field channels up to each holding have been constructed and are properly maintained. The following parameters with various factors should be considered for a satisfactory introduction and operation of the "warabundi" system.

The proposed cropping pattern for each distributary or minor should be determined based on the availability of water, prevalent practices, soil characteristics, agroclimatic factors and socioeconomic conditions. The optimum sowing period for maximum production on the whole canal system and its staggering for each distributary and minor for minimizing the canal capacities, without harming the production, should be considered, particularly for the main crop, such as rice, wheat, cotton, etc.

Irrigation depth. The required amount of water must be applied when it is needed by the crop. If more water is applied than is needed to bring the moisture level up to field capacity, the excess water will be lost in seepage and may result in waterlogging and reduced yields in soils with impeded drainage. Thus, water to be applied in each irrigation depends on the amount of initial available moisture in the soil, water-holding capacity of the soil, the moisture extraction depth of the crop, field irrigation efficiency and the behavior of the crop to moisture stress. Experiments have shown that most of the crops thrive well when irrigated before the soil moisture depletes below 50% of available moisture-holding capacity. Generally, the irrigation depth may vary from five to 10 cm, keeping the above factors in view.

Irrigation intervals. The irrigation interval depends on the depth of irrigation and the daily consumptive use of a crop and on the amount of available moisture in the moisture extraction zone between the field capacity and the starting moisture level before irrigation. Since the consumptive use of a crop varies with its growth, the irrigation interval would have to be decided, considering the period of highest consumptive use of the crop grown. Since usually more than one crop is raised in a crop season in an outlet command, it would be necessary to select the irrigation intervals in such a way that either the selected interval or its multiple is suitable for all the crops grown. The interval selected is normally for the crop which is more sensitive to irrigation. For operational and regulation convenience, it is better if the irrigation interval is taken as a week or multiple of weeks so that each farmer can be alloted a fixed day and time, which is easier to remember. In the case of paddy, where the water requirement is very high, the irrigation interval may be kept as three-and-one-half days or half a week.

Size of irrigation channels. The size of the irrigation channels should be such that the flow could be easily handled by the farmers. Further, it should be sufficient to achieve high water application efficiency. Under our field conditions, where landholdings vary widely, the size of the channel would normally be determined by the size of the smaller holding. Channel discharges ranging between 15 to 30 liters/second (0.5 to 1.0 cusec) are considered adequate from the point of view of handling by individual farmers and for efficient irrigation. In case of sandy soils and, in flatter areas, such as in Haryana, Punjab and Rajasthan, higher discharges up to 75 cusecs are being handled by the farmers but, in case of heavy soils with low infiltration rates and rolling topography, smaller discharges should be preferred.

The size of the irrigation channels is kept the same throughout the length of the field channels for implementation of the warabundi as the full stream of water is used by one farmer at a time for ease in distribution. The capacity of the channels should be adequate to carry the peak demand of water requirement and conveyance losses for the designed irrigation intervals.

Size of the outlet. The size of the outlet would depend upon the stream size as determined. The size of the outlet should be such that, when fully open, it would be able to supply the full stream size requirement with a head of 25 to 30 cms at full supply level of the minor or distributary. This assumes simultaneous running of all outlets on the minor when it is running. This obviates the control of the gate on the outlet and reduces the administrative cost. The Adjustable Proportionate Module (A.P.M.) outlet should preferably be fixed so that proportion to discharge is available on all the outlets when there is a change in the supply levels in the minors, which normally should be regulated to fluctuate between the limits of -10 percent to +20 percent of the normal discharge depending upon the demand in that particular week. In the situation of a lesser demand, it would be desirable to increase the interval between the irrigations, rather than to run the channel with less discharge, which may tempt the farmer to count irregularities in the regulation and distribution of water.

Criteria for working out the time for each holding. The proportionate time allocated to each farmer would be on the basis of a week and for day and night irrigation, thus considering 168 hours. The following criteria should be considered:

1. The allocation of irrigation time for each holding should be proportionate to its area for a projected cropping pattern and intensity.

2. In order to help the worker, farmers identified as medium, small and marginal farmers, with holdings ranging from two to four hectares, one to two hectares, and less than one hectare, it would be desirable to consider allocating them water for a higher intensity of irrigated cropping than others.

3. In working out the time for each holding, water travel time from the outlet to the farm gate and from first farm gate to subsequent farm gate should be taken as common time and, as such, not allocable to anyone. In order to keep this period to the minimum, it would be desirable to keep the sequence of water supply in contiguous farmers, one after the other, rather than in a haphazard manner or starting from the tail-end when more time would be spend in conveyance.

4. Seepage losses take place in the channels which are more pronounced in case of earthen channels in sandy soils as a result of which the stream size gets reduced as it travels from one farm gate to another and, in a good number of cases, the reduction is up to 60 or 70 percent of that in the initial stream size when it reaches the tail-end holdings. Thus, the seepage losses should be compensated by allocating proportionately more time to farther away holdings.

5. In the case of paddy crops, grown in pervious soils with steeper slopes in the lower reaches, some water is received through seepage from the upper fields. In such cases, proportionately less time could be allocated to holdings in the lower reaches.

6. The starting time for the warabundi for the first holding on any outlet should be based on the opening time of the main channel and the travel time for the water to reach the head of the outlet. The opening time for the channel opening every week should be the same

all the time. This is necessary if the channels are running intermittently by rotation. During continuous running of the channel, this would not be a factor. The time of the opening of the channel gate can be changed each year by 12 hours, so that the farmers having their turn at night would have day-time and vice versa.

The design of the warabundi, as indicated above, after considering the various parameters, aims to achieve the equitable distribution of water with the involvement of the farmers with minimum administrative cost and least chance of interference from the lowest Government official or big farmers. Since the water has to be distributed to a large number of farmers, with a multiple of variable conditions, the best efficiency of water use that could be achieved can be on the basis of a downstream system of regulation, with a rotation of the canal supplies, with an interval of half-week, one week, two weeks, or three weeks, depending upon the various factors discussed above. Thus, only the irrigation interval has been kept variable for operational ease. The efficiency could certainly improve if not only the irrigation interval, but also the stream size, is made variable and regulated every week. This would involve higher administrative cost and more sophisticated regulation which may not be commensurate with the increase in efficiency in the present circumstances. However, this could be experimented with under different conditions in various projects and actual field data obtained. If found beneficial, this could be introduced at a later stage.

Organization

For the successful introduction and establishment of waribundi on a permanent basis, it would be necessary to have adequate organization support. This organization would need:

1. Extension staff for motivating and persuading the farmers;

2. Engineering staff for design of the irrigation distribution system and its construction from the outlet up to each holding, following the criteria indicated earlier;

3. Revenue staff for indicating the latest position with regard to each operational holding and bringing up to date records of land where necessary; and

4. Cooperative staff for motivating and guiding the farmers with regard to credit arrangements from institutional sources, particularly where land leveling and development within the farmers' holdings are required.

Thus, it would be seen that the staff of the various disciplines and departments would have to work in a team to introduce the system of warabundi, depending upon the responsibilities alloted to different departments in various states. At present, this work is being done and coordinated under the CAD program wherever CAD authorities have been set up. At the field level, depending upon the situation in various states, either a team, as stated above, can be set up or, in the future, the possibility of training one man in all of the above disciplines can be envisaged in order to expedite the work with fewer coordinating problems.

The details of the organizational setup for warabundi and downstream regulation system are not being indicated as it would depend upon the existing setup of the irrigation, agriculture and revenue departments and the responsibilities entrusted to them in different states. However, it would be preferable to set up this organization under the irrigation department which is mainly responsible for the distribution of water which should be extended up to each holding. This organization, built up from the field level under each Assistant Engineer and Executive Engineer, can be called the revenue wing of the Irrigation Department, in addition to the engineering staff. The staff of this wing would, preferably, have agricultural qualifications, if possible, and be specially trained for this particular work.

Staff would also be required for maintenance of warabundi, assessment of crops irrigated and feedback information, with regard to water requirements for regulating the water supplies according to crops. At present, these functions are being done in various states by different departments. It would be preferable to combine these functions with one man in the Irrigation Department at the lowest field level, so as to improve the efficiency and also reduce the cost.

Lesislation

In most of the states, legislation, in the form of Irrigation Acts and Land Improvement Acts, exists, which covers major areas for which legislation is required, such as warabundi, Water Users' Associations, regulation of the canal system, and preventing unauthorized irrigation or damage to the distribution system. A model draft bill for irrigation was proposed by the Department of Irrigation, Government of India, and circulated to all the states for enactment as irrigation as a state subject. However, certain modifications may have to be made in the existing Acts to suit the new system of distribution now proposed, with some changes in the rules and regulations framed under it, to incorporate all the experiences gained.

The legislation for warabundi should cover the following:

1. Warabundi should be introduced on a compulsory basis on all outlets and among all farmers who are eligible for sharing the water;

2. There should be a provision to review the warabundi every five years to take care of change of ownership, and inclusion of additional area due to various reasons;
3. Rules and regulations should be framed under this Act which would incorporate the various parameters to be considered for the design of the warabundi, depending upon the local conditions for each project and state;

4. There should be a system of quick redress and punishment of any person who violates the rules and regulations framed under the Act and for implementation of the warabundi system; and

5. Maintenance of field channels by the department concerned, at the farmer's cost, if he does not do it.

Recommendations

Efficient use of water for irrigated agriculture for obtaining the optimum productions depends upon the number of links of the irrigation system, some of which, at present, are rather weak. The weaker links in the whole irrigation system for equitable distribution of water are:

1. Maintenance of the canal system up to the outlet in a good condition;

2. Operation and regulation of the canal system;

3. Conveyance system within the 10-40 hectares block; and

4. Equitable distribution of water within the outlet command.

With the emphasis on the construction of the field channels and the recognition of its necessity by most of the states, the other three links now need to be emphasized and more attention paid. These links are comparatively less costly in the whole irrigation system, but need a great deal of organizational, legislative and motivational effort on the part of the Government and the involvement of the farmers. The warabundi and the downstream control system of operation of canals can, alone, give confidence for an assured water supply to the farmer of further boosting of agricultural production. This workshop may recommend the following action in this regard:

1. In the projects, where field channels have been constructed, warabundi should be introduced at least on two distributaries on a trial basis, taking into account the local conditions; where the system is alredy in vogue, it may be improved and cover all the projects.

2. Downstream control system of regulation of canal supplies may be tried with proper organizational support.

3. On the basis of the above trial, legislation and organizational setup required should be finalized.

4. Detailed guidelines may be prepared by each state on the basis of the above experience for introducing the downstream system of regulation for rotational system of water supply and warabundi for all the irrigation projects in the state.

5. Workshops may be arranged in all the states to discuss this subject in the light of local conditions with participation of all the concerned officers of different disciplines.

APPENDIX C

SUMMARY OF
OFFICIAL IRRIGATION TEAM
MEETINGS IN NEW DELHI
NOVEMBER 2-8, 1980

by

Irrigation Team

SUMMARY OF OFFICIAL IRRIGATION TEAM MEETINGS IN NEW DELHI, NOVEMBER 2-8, 1980

by

Irrigation Team

Briefing Meeting at AID with Riggs and Peterson November 4, 1980

One major issue is extensive irrigation vs. intensive irrigation. State politicians want to start more projects while neglecting improvement of existing systems. The World Bank focus is on lining all channels on existing systems. Lining canals doubles the investment but conserves water and is more effective in the long run. The other option, expanding the number of projects, will reach more people with less efficiency. AID has opted for lining main and lateral canals. The question is: which of all of these options is the best option?

Another issue is whether investments should be primarily in state tubewells and in minor irrigation projects of under 2,000 ha or in the private sector of tubewells and pumps to serve farms of under 40 ha. In Rajasthan, there is a question whether AID assistance should go all the way down to the farm level.

AID's present policy is one of geographical concentration in the northwest, primarily in Gujarat, Rajasthan, and Maharashtra. AID has investments primarily in medium projects (2,000 to 10,000 ha command area). Dean suggests looking into medium projects in Himachal Pradesh and minor projects in Madhya Pradesh. AID may invest several hundred million dollars in India's irrigation in the next decade ($700 to $1,000 million), but this is highly problematical.

Meeting with Patel, Schroff and Other Central Government Officials of the Ministry of Irrigation - November 4, 1980

After a brief description of the roles of the Center and the states in irrigation, its potential and development, Mr. Patel discussed interstate and intrastate relatioships, and international water transfers, re: Pakistan (Indus Basin) and Bangladesh (Brahmaputra). Annually, India spends about $1.6 billion on major irrigation projects and five billion Rs on minor ones.

The government policy is to minimize dependency on outside funds. Only 1.5 percent to 2 percent of foreign exchange is used.

They emphasize the importance of using their own technical staff and resources wherever possible.

One of the major constraints is land productivity. Center wants to give more emphasis to agricultural support services. Drainage is a big problem.

There are serious problems in water storage. There is too little water for winter. Almost two-thirds of the water goes to the seas.

A National Water Plan is being developed to add 35 million ha for irrigation to the present projected 113 million ha. There is also interest in optimizing both extensive and intensive irrigation.

Energy for tubewells and pumps is a problem because of the high price of oil. Other energy sources for lift devices, such as solar, wind, etc. should be explored.

Meeting with R. Ghosh, Acting Chairman of Central Groundwater Board and B. D. Patak, Chief Hydrologist - November 4, 1980

India has conducted extensive geohydrologic surveys to identify active aquifers for tubewell development. North India has been mostly completed and plans are to complete the whole country in the coming years.

Groundwater development is largely a private sector activity with state tubewells in certain strategic areas. The Center's job is to make the surveys and pass on the data to the states for their use.

There are hydrograph stations operated by the Center and states, which provided five checks, January to April since 1969; probably not done so extensively anywhere else.

Tubewells, especially private ones, give a farmer water control so critical for crops. Tubewells also keep the groundwater table under control.

There are 22 million ha irrigated partly or wholly by groundwater, of which about two-thirds are wholly irrigated by groundwater.

In terms of equity in tubewell schemes, small farmers under two hectares get 25 percent subsidy; medium-size holders get 20 percent and groups of farmers get 50 percent. The 1980's will focus more on the private tubewell sector because of lower costs in administration and management.

Energy for tubewells is a problem, more so in some states than others. Availability of electricity varies from four to 12 hours per day in the states. The price of diesel fuel is a factor.

Another major problem in geohydrological surveys is to locate aquifers and estimate their depth, quality, and yield potential. India has some of the best groundwater hydrologists in Asia. The Central Board has about 500 and 400-500 hydrologists graduate each year.

Mr. R. Ghosh and Staff at Central Water Commission
November 4, 1980

Mr. Ghosh wants to establish a management and monitoring unit in the Commission with a career structure for agronomists, engineers, economists and sociologists who work as multidisciplinary teams. They want the states to follow this model in order to focus more on monitoring operations and maintenance. The unit would be separate from design and construction. Command area development has 67 projects to monitor. Program just started and is feeling its way. Thus far, some 24 projects have been looked at.

Training is needed in water management at all levels. An Institute of Water Management is planned. The key is to get the departments working together. Some teams are in the CADA's now and the state of Maharashtra is doing the training in this mode. It is necessary to select specialists in engineering, agronomy, economics, etc. and they provide additional training so each specialist can appreciate the other's discipline. A career structure is needed with sufficient incentives. Special training needs are:

1. Senior Engineers - 6-8 week short course

2. Middle-Level Engineers - 3-4 month short course

3. Junior-Level Engineers - 12 month program

The plan is to start the program in April, 1981.

Ford Foundation Staff (Norman Collins, Roberto Lenton, Matt Dagg and David Seckler) - November 5, 1980

The staff reviewed the past involvement of the Ford Foundation in training and its relationship with universities. The Foundation built the Water Technology Center at PUSA and started the Institutional and Training Center in 1973.

The present major focus is on field research and development of human capital. Water is a major area ($700,000 per year). Last year, some $2 million were given in grants, half for water. Total operating budget is about $5 million/year, mostly on human development.

A training program was started at Harvard in 1975 at all levels in the social sciences, including management. The program is for six months to two years, depending on the kind of training. Each year, about 25 to 30 students are in the program. A network has been developed, composed of those who have returned from overseas programs. It appears to be making a significant impact.

Current emphasis is on small task area development and training in that area. The model Sukhomajri Project is an example of this.

Several of the Ford staff indicated strong support for an International Water Management Research and Training Center in India. There are constraints in pushing the software approach with emphasis on field research training because the image of training is classroom lectures. ICAR has no social scientist and does not appreciate the need to have one.

There is a lack of interaction between the social science and physical science institutes. There is no mechanism, at present, to encourage an interaction.

Mr. Kathpalia - Joint Commissioner (Water Management), Minor Irrigation and Command Area Development - November 5, 1980

Mr. Kathpalia described the scope of small tank development in India, which is mostly in the Southern States. A surface irrigation of 15 million ha is projected, of which eight million hectares are completed. About 1.5 million ha are targeted for the Sixth Plan. Small tanks from 30-40 ha (up to 2,000) are the responsibility of the state. Tanks less than 30-40 ha are the responsibility of local communities.

During the last five years, there has not been much progress and, only recently, has the Center given much help.

Tanks without outlets are percolation tanks primarily for recharging wells downstream.

States have records of existing tanks and area responsible for operation and maintenance.

Involved in Remote Sensing to identify areas for tanks, soil erosion, siltation, etc. Cooperating with NASA.

The cost of minor and medium irrigation projects about the same: 10,000-15,000 Rs/ha.

All projects greater than 40 ha are checked by the Irrigation Department of each state. The demand for water comes from local communities. The Center helps in design so as to have some standard.

The time lapse between studies and beginning of construction to delivery of water is: (1) minor irrigation - 3-4 years; (2) medium - 5 years; (3) major - 10 years. The appeal of small tanks is :

1. Their construction period is short;

2. They can satisfy regional demand for special projects;

3. They provide local employment opportunities; and

4. They meet needs in marginal tank areas.

In Madras, tanks are linked to provide irrigation water.

There is a lack of coordination in the soil conservation program.

CADA'S

In 76 projects of some 15 million ha, there are 44 authorities. One million ha have land leveling (target is three million). About three million ha have field channels. Farm holdings range from one-half to six hectares. An additionalfour-and-one-half million hectares for field channels are called for in the Sixth Plan.

Of the CADA projects, the best ones are in Rajasthan, Madhya Pradesh, UP, and Maharashtra. The projects in Haryana, Gujarat and

Bihar are making significant progress. Due to the low level of management, the projects in Bengal, Orissa and Assam are considered to be very poor. There are organizational problems for the following reasons:

1. The states are not sure who has responsibility;

2. There is no control authority;

3. There is no field unit for implementation and monitoring;

4. It is difficult to depute profesionals from a line organization.

There are several different CADA models:

1. Gujarat - Each department does its own work and there is a coordinator for the various departments.

2. Rajasthan - A commissioner and an area development committee with a Chief Irrigation Officer, Land Development Officer, Credit and Cooperation Officer, Extension Officer down to the village level worker.

3. Madhya Pradesh - Director with full-line authority over the different specialists.

Water management training of village worker - high school graduate with one-and-one-half years of training and one month of specialized training for advising farmers. Farmer depends on village level worker for advice in water use, etc. Scheduling now added as additional chore.

There are three systems of water distribution:

1. Weekly rotation in the north

2. In UP, the rotation is every 10 days. All the water is not utilized. A lot of water is used for sugarcane.

3. In the south, rice is the main crop and there is continuous flow from field to field. Considerable water and fertilizer are wasted.

A major problem is that of monitoring water use and control. There is a lack of mobility which they had in earlier years with horses.

Dr. K. S. S. Murthy, Consultant to Planning Commission
November 6, 1980

Dr. Murthy described the policy of the government to improve the efficency of irrigation systems in India in cooperation with the state governments. The Sixth Five Year Plan will emphasize completion of ongoing projects rather than stretching resources to the breaking point by beginning new projects with new projects. Exception will be in drought-prone areas and in tribal areas with the focus on smll projects. A major exception is a large project planned for Gujarat.

Awareness of the importance of water has grown, but the development of water resources has not kept pace with demand. The potential is not being realized fast enough and, as a result, the discontent of the farmers has increased. Investments have not given the expected returns.

Not able to meet demand for support services such as availability of inputs, such as fertilizers, pesticides, etc. Pricing and marketing policies are inadequate, e.g., sugarcane was lost last year due to poor marketing mechanisms and, as a response, farmers planted less sugar this year and prices are high.

Described National Water Plan to provide an additional potential of 35 million ha for irrigation in the 21st century, in addition to the planned estimated potential of 113.5 million ha of which less than half is under irrigation at present. Of this additional 35 million, 25 million is estimated to be supplied from surface irrigation and 10 million from groundwater. This will involve linking of rivers and transfers from abundant sources to storage areas. An additional 40 million megawatts of electricity would be generated under this plan.

Greater emphasis needs to be given to training in water management and administration. Engineers concentrate on design and construction and give little attention to management in operation and maintenance, largely because it has lower status and fewer career opportunities. Design and construction should be separated from management and more incentives should be provided to get better people in management: higher salaries, better housing in the field, better facilities, etc.

Farmers seem to manage their private tubewells very well. The management problems are with government projects.

Dr. Soud, Former CADA Manager, Now Additional Director of Extension - November 6, 1980

CADA's are in trouble. GOI should develop to each field, not to 40 hectare block. Consolidation by compulsion will not work. Farmers want reliable water supply.

T and V extension grew out of Chambal CADA project. New system is better than the old, but has problems in training trainers (SMS) who train VLW by lectures and reading assignments. Wanted to send some SMS to Israel for water management training course. Also, thought of using water technology training center.

Extension workers fear evaluation reports. In the old system, VLW requested to do everything. Need to convince other agencies not to use them.

In the past, there was little or no communication between people and extension workers. Now some training of VLW is done at the research stations so there is some progress.

Dr. Michael, Director, Water Technology Center November 6, 1980

The Water Technology Center is a unit under the India Agricultural Research Institute and has been in operation for eight years. They have about 25 graduate students as M.S. and Ph.D. candidates with 40 fulltime teaching and research faculty in 15 different disciplines. Advanced degrees are offered in the Agricultural Sciences and related disciplines: Agricultural Engineering, Agricultural Physics, Agronomy, Entomology, Plant Physiology, Soil Science, and Agricultural Chemistry.

There are specialized courses for senior scientific staff from the universities and research institutions. There are interdisciplinary courses on water management for field staff and practical training courses for field and research staff.

There is basic and applied research done in all aspects of water management leading to more efficient use of water and land resources for optimum crop production.

There is a collection of low-lift pumps collected from various regions and countries which are being tested.

APPENDIX D

REPORTS ON IRRIGATION TEAM MEETINGS WITH GOI OFFICIALS IN NEW DELHI NOVEMBER 2-8, 1980

by

Dean F. Peterson, USAID/India

These reports contain the bodies of five memoranda which were written between November 12 and 14, 1980, and addressed to:
The Files - Irrigation Team
Memo Nos. 1 through 5.

REPORTS ON IRRIGATION TEAM MEETINGS WITH GOI OFFICIALS
IN NEW DELHI, NOVEMBER 2-8, 1980

Meeting of Asia Bureau Irrigation Review Team with Ministry of Irrigation - November 4, 1980

Present at this meeting were:

Mr. C. C. Patel, Secretary for Irrigation
Mrs. R. M. Schroff, Joint Secretary for Irrigation
Mr. M. G. Padhye, Member, Plans and Projects, Central Water Commission
Mr. M. N. Venkatesen, Member, Water Resources, Central Water Commission
Mr. G. N. Kathpalia, Chief Engineer, Minor Irrigation
Mr. B. K. Saha, Deputy Commissioner, Command Area Development
Mrs. Rada Singh, Deputy Secretary, Ministry of Economic Affairs
Mr. C. D. Khoche, Undersecretary, Ministry of Irrigation
Dr. Jack Keller, Team Leader
Dr. Max Lowdermilk, Team Member
Dr. Wayne Clyma, Team Member
Dr. Matthew Drosdoff, Team Member
Dr. Dean Peterson, USAID
Mr. Edwin D. Stains, USAID

Doubtless the Team will produce its own report; however, I thought it useful to record my own impressions and conclusions.

Mr. Patel outlined the scope and size of the Sixth Plan which remains about as in the Draft. Investments mentioned were $8.8 billion for major and medium projects and $4.4 billion for minor, largely in the private sector. Main problem is utilization and efforts will be made to optimize through emphasis on command area development. Land productivity, not land area is the main constraint. Attention needs to be given to conjunctive use of groundwater and to drainage. Steps will be taken to supplement irrigation construction with needed drainage.

Academic training for civil engineers is good, but need to enhance water management training. There is a Water Management institute at Roorkee, a staff training college will be started in CWC and water management training activities are being started in several states. The CWC staff college will try to support and enhance state training activities.

Reservoir storage is a severe problem in India, especially because of the monsoon climate. There are severe limitations on storage potential. Present storage is 130 million acre-feet (MAF), about 1/5 that of the U.S. India uses about 220 MAF by water now, with 540 ultimate. With groundwater, about 113.5 million hectares irrigated cropped area (gross area) can be developed.

Under a national network plan with full state cooperation, an additional 18 million hectares can be developed. International cooperation could add another 18 million, bringing the total to 36 million. India does not desire to detract from potential of neighboring countries but international cooperation will result in comparable benefits for them also.

India will proceed to develop its irrigation sector as rapidly as resources become available and needs cooperation of other countries soon (presumably contiguous countries).

CWC monitors and Center sets standards, but states are slow to respond. (Donors can help by promulgating Center policy under their loan agreements.)

Irrigation is an indigenous program, requiring only 1.5-2 percent foreign exchange. World Bank support is $500 million (annually ?) and supports mostly major projects. Medium and minor projects are best for AID. Any help will be appreciated.

Surface irrigation projects at 1.2 - 2.5 irrigation intensity will be planned. Groundwater development will raise this to about 1.5. Groundwater development potential is created by surface irrigation. Ultimately, about 70% of cropped (gross) area will be irrigated.

The Sixth Plan provides Rs 10,900 crores for major and minor irrigation and Rs 5,000 crores for minors with Rs 740 crores for CAD. (Not clear if Rs 740 is part of Rs 5,000 or in addition). Rs 1,900 crores are expected from institutional credit with Rs 1,000 (admittedly, too low) from farmers' resources for minor irrigation.

In response to Lowdermilk's question of what AID might do, command area development was mentioned. Mrs. Schroff intervened, stating that external assistance expedites completion in contrast to proliferation of more projects. She was enthusiastic about AID's interest in training and strongly commended AID's attention to the recommendations of the Indo-U.S. Subcommission on Agriculture, mentioning several of the proposed activities in some detail: flood management, operation of multiple purpose systems, such as Chambal, Beas and Bhakra. CWC would be involved but each project management could have responsibility. Lining is being given greater emphasis and is needed to supply water delivery peak need periods. Where groundwater exploitation is already high, consideration must be given to the effects of lining on groundwater supply.

In response to a question about cement, Mr. Patel thought the shortage might be overcome in a couple of years. Irrigation is trying to economize on the use of cement. There are other commodity difficulties: steel and explosives, for example.

Energy for groundwater is being given high priority in rural areas. Intersectoral allocation and distribution of power is difficult. It is hard to control use. Studies are being made of power availability to tubewells and of alternative sources of energy for lifting waters. Nothing very exciting has turned up yet, but Patel seemed fairly optimistic that something might.

Meeting of Asia Bureau Irrigation Review Team with Central Groundwater Board (CWGB) Officials - November 4, 1980

Those present at this meeting were:

Mr. R. Ghosh, Acting Chairman, CGWB
Mr. B. D. Pathak, Chief Hydrologist, CGWB
Mr. G. N. Kathpalia, Chief Engineer, Minor Irrigation, GOI
Mr. H. M. Kaul, Engineer, CGWB
Mr. K. M. Chadha, Deputy Secretary, Ministry of Irrigation
Dr. Jack Keller, Team Member
Dr. Max Lowdermilk, Team Member
Dr. Matthew Drosdoff, Team Member
Dr. Wayne Clyma, Team Member
Dr. David Seckler, Team Member
Dr. Dean Peterson, USAID/India
Mr. Edwin D. Stains, USAID/India

Dr. Pathak stated that India wants to complete all hydrological surveys and delineate the various aquifers by 1990. Resurveys are needed at about five year periods. This includes exploratory drilling, measurement of aquifer productivity and demarcation of groundwater provinces.

About one-fourth of India's groundwater area is alluvial or soft rock. Hard rock is about three-fourths. Private wells outnumber public, but are smaller, about 0.5 cusecs in contrast to 1.5 cusecs for public wells.

About 5,000 indicator wells are monitored simultaneously five times annually by state and Center. Besides level, some quality samples are taken. There are quality laboratories in all regions. More data are needed on wells in Irrigation Command Areas.

Water levels in Ganges Basin, three to six meters in north and up to 15 meters in the south.

Subsidies include 25 percent, 35 percent on credit loans to small and marginal farmers, respectively, and 50 percent for small farmer cooperatives.

CGWB looks at lining to see what effects will be on existing wells. A concept of water-spreading utilizes kharif channels with pumping for rabi. About two-thirds of the groundwater-irrigated area is outside of canal areas, however. Public tubewells are installed only where private tubewells are difficult to arrange. Over the past five years, a census has been undertaken to determine replacements required.

The model groundwater bill has not yet been passed by any state. Overexploitation is only indirectly controlled by credit and power allocations.

Of 40 million hectares estimated groundwater potential, 22 million are developed with an additional seven million targeted for Sixth Plan; 15-16 million pumpsets were mechanized by electrification or diesel during last plan period; 25 million are targeted for Sixth Plan period. Motivations to apply for credit involve an arrangement to do all the paperwork in one place.

Pumping is also limited by number of hours power is available. Future use of animal power will be limited.

Punjab University studies shows efficiency of pumps is decreasing. Technical advice on pumps is provided where the farmer takes his loan. No studies have been made of water distribution systems for pumps. Dug wells in hard rock areas produce 1/4 to 1/3 cusecs in contrast.

Hydrological training is limited. A six-weeks training course is provided with an additional five weeks in the field. About 500 are employed at the Center.

Meeting of Asia Bureau Irrigation Review with Central Water Commission (CWC) - November 4, 1980

Those present at the meeting were:

Mr. R. Ghosh, Chairman, CWC
Mr. M. N. Venkatesan, Member, Water Resources, CWC
Mr. M. G. Padhye, Members, Project and Planning, CWC
Mr. M. G. Sadanandam, Civil Engineer, Project Planning Cell, CWC
Mr. K. Ramesh Rao, Chief Engineer, Technical Extension Wing, CWC
Dr. Jack Keller, Team Leader
Dr. Max Lowdermilk, Team Member
Dr. Matthew Drosdoff, Team Member
Dr. Wayne Clyma, Team Member
Dr. David Seckler, Team Member
Dr. Dean Peterson, USAID/India
Mr. Edwin D. Stains, USAID/India

Generally, there was little to add that had not been said in the first meeting with Mr. C. C. Patel in the morning.

More specifically, Mr. Venkatesan stated that CWC wants to set up a water management cell under an additional member for water management. He has in mind a multidisciplinary group. CWC has already visited 24 projects and advised the states of water management steps to be taken.

For implementation in the states, a two-tiered structure is visualized: one for construction and one for water management. The latter will be multidisciplinary and could be headed by any discipline based on personal competence. A training program with the purpose of broadening the multidisciplinary perspectives of the specialist, rather than to make everyone a generalist, is visualized. New personnel will be recruited for water management.

AID could help build CWC staff college. Staff college would accept candidates from other Asian nations and (CWC) would be interested in AID assistance in this program.

UNDP provides technical assistance in systems planning on the Mahanada River.

CADA organization will be discussed at Ministry level.

A model irrigation law has been developed by CWC (copy obtained full, but certain parts are being implemented depending on the political situation, particularly recent legislation in Maharashtra.

USAID opportunities depend on size of U.S. contribution. Areas where greater emphasis is needed are drainage and reclamation of salinized soils. Venkatesan particularly stressed the following:

1. A large-scale program is needed to correct waterlogging;

2. National Water Plan, feasibility assistance on national water grid;

3. Restoration of mini-watershed damage to be done by people under loan arrangements; and

A Watershed Management Corporation to implement has been proposed.

Visit with Chief Engineer - Minor Irrigation and Command Area Development - November 5, 1980

Those present at this meeting were:

Mr. G. N. Kathpalia, Chief Engineer, Minor Irrigation, GOI
Mr. D. R. Arora, Deputy Commissioner, Minor Irrigation, GOI
Dr. Jack Keller, Team Leader
Dr. Max Lowdermilk, Team Member
Dr. Wayne Clyma, Team Member
Dr. David Seckler, Team Member
Dr. Matthew Drosdoff, Team Member
Dr. Dean Peterson, USAID/India
Mr. Edwin D. Stains, USAID/India

Minor Irrigation. Mr. Kathpalia stated that minor surface irrigation potential is 15 million hectares with eight million to be developed. This subsector, which uses tanks, has not gone well. It has been left to local initiative and silting is a problem. Andhra Pradesh, Karnataka, and Madhya Pradesh are states where this type is most prevalent. Ordinarily, the State Irrigation Department handles 40-2,000 ha. Maintenance arrangements vary by state.

"Percolation" tanks are designed to recharge groundwater and are usually accounted for as groundwater development, but State Irrigation Departments may take them up.

For new projects, states are encouraged to construct distribution systems to farmers' fields. Minor projects have the advantage that construction time is shorter than for medium or major. They are particularly popular with local people who can be relied upon to suggest them. Concentration of priorities is in tribal areas. Costs range from Rs 10,000 to Rs 15,000 per hectare. The only donor sponsor is World Bank in Karnataka. The Center is trying to help standardize designs. Ordinarily operation and maintenance is by the state. There are no water users' organizations. Command area development has not been initiated but should be.

Soil conservation, forestry and minor irrigation are not well-coordinated.

Command Area Development. Forty-nine CADA's operate on 76 major projects covering 15 million hectares. Organizations differ in each state. Field channels (watercourses) have been constructed for three million hectares and land-leveling done on one million hectares. Sixth Plan target is one-and-a-half million hectares.

Major factor in CADA performance is organizational. Best ones are in Rajasthan, Madhya Pradesh, and UP. Mediocre ones exist in Gujarat and Bihar. The ones in Bengal, Assam and Orissa were rated as poor. Organizational factors are: (1) definition of agency responsibility for the work; (2) state policy decision-making; and (3) effective field organization. The center supports half the cost of salaries if the work gets done.

An assistant engineer should complete 2,000 hectares per year.

Extension specialists are given one year training plus six months in the field.

Traditionally, in the Northern States, water is ordinarily allocated by area of farm under command with weekly rotations of streams from ungated outlets. In Maharashtra and Gujarat, farmers must apply. Formerly, requests must be satisfied, but lately shortages have made allocation necessary. Gated outlets are used and stream rotated on a ten-day basis. Rice dominates in the southern states. Ordinarily, irrigation is field-to-field, with no rotation and no field channels. Rotation is needed in order to grow crops other than rice and for improved rice varieties so that field channels are now being required.

Gujarat has one irrigation cooperative initiated about one year ago. It sells water to cooperatives at about one-half the rate and cooperative distributes (USAID should investigate this possibility).

Studies in Tamil Nadu and Orissa show that installation of field channels saves about 50 percent of the water formerly lost.

Visit with GOI Planning Commission Irrigation Consultant November 6, 1980.

Present at the meeting were:

Mr. K. S. Murthy, Irrigation Adviser to the Planning Commission, GOI
Dr. Jack Keller, Team Leader
Dr. Max Lowdermilk, Team Member
Dr. Wayne Clyma, Team Member
Dr. Matthew Drosdoff, Team Member
Dr. Dean F. Peterson, USAID/ARD

Murthy, an engineer, was Secretary to the Irrigation Commission (1972). He has had considerable U.S. experience with USBR.

Priorities for irrigation sector under Sixth Plan are:

1. Optimize benefits from facilities already created.

2. Complete projects already started (as many as possible).

No new projects will be started, except in Narmada and, in other exceptional cases, such as drought-prone areas, tribal areas, etc. Develop all existing potential of 113.5 hectares by 2,000. An outline has been developed for a National Water Plan. This, with international cooperation, will add an additional 25 million hectares of surface and 10 million hectares of groundwater with 40,000 megawatts power and is targeted for the 21st century.

The country now has 28,000 mw of power of which 8,000-9,000 is hydro. Sixth Plan proposes 22,000-24,000 mw additional (1/3 hydro, 2/3 thermal).

Mr. Murthy recognizes public irrigation is in difficulty because it is not meeting farmers' needs. It's not delivering and agricultural programs, such as land leveling are not getting done. The Program is losing credibility with the farmers. Investments are not paying. Both financial and economic returns are too low. Market mechanism washes out farmer incentives. In contrast, where private wells are available, farmers are willing to pay the cost.

Regarding USAID's role, the World Bank has a corner on much of the sector, thus restricting options. In Madhya Pradesh and Orissa, irrigation development is low and these are good targets. The other opportunity is to assist the states and center in their modernization programs. This will require considerable training.

Each state is being asked to start an institute and CWC will begin a staff training college. Water management must be emphasized. Instruction on soil, water, and plant relationships is necessary. Strategy is to change from "building" to "managing". There have not been professional incentives in the latter.

The center has little leverage with the states and donors should assist.

USAID can come into training in a large way. There are very limited training resources in soil, water, and plant areas, as well as modernization. International training is necessary. Indigenous training does not work.

Estimated needs are 30,000-40,000 with a core of 5,000-6,000 trained; at the present, 300-400 per year are being trained. Mr. Murthy thinks GOI would go for a USAID project to train several hundred per year in the U.S. Trainees would be middle-level, 30-35 years of age, and must make commitment to return.

Farmers with well irrigation understand irrigation adequately and water supply is reliable. Assuming a reliable surface water supply is provided, farmers will also respond quickly. The need is to understand system requirements, so it can be properly managed.

APPENDIX E

OPTIMIZING YIELDS USING CLIMATE AND THE WATER BALANCE*

by

George H. Hargreaves
Research Director
International Irrigation Center
Utah State University

*This appendix is added for the purpose of illustrating a methodology and for providing background information that can be used in evaluating and comparing rainfed agricultural benefits with those from irrigation. Monthly probabilities of precipitation occurrence provide significant basic resource information. The use of daily rainfall records can be used to calculate 10 day and other short time period precipitation probabilities. These more detailed studies are strongly recommended as part of future agricultural development planning.

OPTIMIZING YIELDS USING CLIMATE AND
THE WATER BALANCE

by

George H. Hargreaves

The Water Balance and Yield

An evaluation of the water balance at 40 locations in India was made from the 30 years records of the World Meteorological Organization. Mean climatic values were summarized together with a moisture availability index, MAI. MAI is the 75 percent probability of precipitation occurrence, PD (that amount equaled or exceeded three-fourths of the time), divided by the potential evapotranspiration, ETP (MAI = PD/ETP).

The crop growing season for rainfed agriculture was taken as a number of consecutive months with MAI values exceeding 0.33. A month of excessive precipitation was defined as one with a value of MAI exceeding 1.33.

Of the 40 locations analyzed, all but seven has growing seasons of three or more months. Twenty-three locations had one or more months of excessive rainfall and nine had more than three months of excessive precipitation, indicating a suitability for rainfed rice. The median condition indicated a four months growing season with two months of excessive rain.

A computer regression analysis of those months for which MAI values exceeded 0.33 indicated that values of the 75 percent probability of occurrence, PD, could be reliably estimated from the mean monthly precipitation, PM. The equation for monthly rainfall in mm can be written

$$PD = -19 + 0.71 \times PM \qquad (1)$$

The coefficient of determination, R^2, ws 98 percent. This provides a useful means for estimating the values of PD for all 368 locations for which rainfall data are available in the publication by Wernstedt.[1]

---

[1]Wernstedt, "World Climatic Data." Climatic Data Press, Lemont, Pennsylvania, 1972, 522 p.

At Begampet (Hyderabad) the MAI values indicate nearly a four month growing season for rainfed agriculture. The maximum monthly MAI is 0.75 for July. Precipitation is less than optimum during all months. However, rains are fairly intense. Kampen and Krishna[2] describe a system of raised 1.5 meter width beds and furrows on variable slopes. This procedures improves surface drainage while increasing infiltration into the soil root zone. Slopes of the beds and furrows varied with soil type but averaged 0.5 percent. The surface drainage, water conservation and management permitted use of improved cropping systems that increased the value of crop production three-fold over the traditional practices.

In areas where rainfall is excessive during several months and where soils or other conditions are not well suited to rice, the yields of general crops on fairly flat topography have been significantly improved by planting on broad (20 to 40 meter) raised (40 to 80 cm) beds located in the direction of the slope. Benefit cost ratios on this type of improved surface drainage have usually been reported to exceed 5 to 1.

The type of water management to be selected depends to an important degree upon the amount and intensity of rainfall and the crops to be grown. Crop selection is determined principally by the market demand and the availability of soils, climate and water supply to achieve a satisfactory level of profitable production. Water management and crop technology transfer can be accomplished with a good degree of success providing the principal requirements for economical production are similar. Water, its management and climate (temperature is often the controlling variable) are the most important considerations.

In order to quantify the effect of water deficits on yield FAO[3] has adopted the Stewart Model relating relative yield decrease to relative evapotranspiration deficit and an emperically-derived yield response factor, ky. The equation can be written

$$1 - \frac{Y_a}{Y_m} = ky \quad 1 - \frac{ET_a}{ET_m} \qquad (2)$$

---

[2]Kampen, Jacob and J. Hari Krishna, "Resource Conservation Management and Use in the Semi-Arid Tropics. ASAE Technical Paper No. 78-2072, 1978.

[3]FAO Irrigation and Drainage Paper No. 33, "Yield Response to Water," 1979, 193 p.

in which

Y_a = actual harvested yield
Y_m = maximum harvested yield
k_y = yield response factor
ET_a = actual crop evapotranspiration
ET_m = maximum evapotranspiration

The following values of the yield response factor for the total growing period are given by FAO:

Crop	ky	Crop	ky
Bean	1.15	Sorghum	0.90
Cotton	0.85	Soybean	0.85
Groundnut	0.70	Sugar Cane	1.20
Maize	1.25	Spring Wheat	1.15

The average value of ky for these crops is about 1.00 indicting that an evapotranspiration deficit of 25 percent decreases yields on the average by about 25 percent also. Water application efficiencies frequently decline as application rates approach optimum for maximum yield. Therefore, a reduction of 25 percent from optimum application will usually result in something less than a 25 percent reduction in yield.

The FAO yield response factors assume that other factors including fertility are near optimum. If nitrogen is deficient an upper limit on yield is fixed by this limitation and less water will be required to produce optimum yield. The complexity of these interactions causes much confusion in the evaluation of optimum water management practices.

An evaluation of maize response to nitrogen, N, from high yielding hybrids grown in Israel, the United States and Central America indicates that for the hybrids grown on high base status soils the optimum application of N is given by the equation

$$N = 0.32 \times ET \text{ (maize)} \qquad (3)$$

in which N is kg/ha of nitrogen and ET is actual crop evapotranspiration in mm for the total growing period. If water is deficient and ET is low then increasing applications of N may decrease yields.

Table E-1 gives climate, the water balance and potential evapotranspiration for the 40 locations mentioned above. The table headings are as follows:

Heading	Description
PM	Mean monthly precipitation in mm
PMI	Minimum monthly recorded precipitation (30 years)
P79	The 79 percent probability of precipitation occurrence
P60	The 60 percent probability of precipitation occurrence
PMX	Maximum monthly recorded precipitation
TMC	Mean monthly temperature in degrees Celsius
HM	Mean monthly percent relative humidity
HMC	Percent relative humidity calcuated from sunshine
S	Percentage of possible sunshine
SC	Percentage of sunshine calculated from HM
PD	Dependable precipitation - the 75 percent probability of precipitation occurrence
ETP	Potential evapotranspiration
ETDF	Potential evapotranspiration deficit (ETP - PD)
MAI	Moisture availability index (PD/ETP)

Equation 3 indicates that the amount of nitrogen that can profitably be applied for maize production is determined principally by the adequacy of water to meet crop water requirements. With high yielding hybrids and adequate water an increase of one kg/ha of nitrogen application (up to about 140 kg/ha) will increase maize grain production by more than 30 kg/ha. At present prices this results in a benefit cost ratio of 7 or 8 to 1. Applying somewhat less than a full water adequacy significantly reduces the potential profit available from fertilizer application.

For many crops on various irrigation projects the average cost of water plus labor required to apply the water is about ten percent of the total crop production expense. A reduction of 25 percent in water applied to the crop does not necessarily indicate that there will also be a similar reduction in crop evapotranspiration. With less water available there is a higher incentive for better efficiency and greater uniformity of application.

The cost of water plus its application at the field level usually is only a fraction (say, 10 to 20 percent) of total production costs. If a reduction in water applied produces a corresponding reduction in yield and a much lower reduction in total production costs, it would seem desirable that whenever possible a full irrigation supply should be delivered. Fully adequate irrigation facilitates optimization of benefits from other inputs such as seed and fertilizer.

The above analysis indicates that the most profitable water management practice is to provide enough water so that water will not be significantly limiting on crop production. However, optimizing the value of water and the profitability of crop production involves an understanding of various interactive factors. At most locations in India there is a three or more months rainy season. The use of irrigation to make up a rainfall deficit during a critical period in the crop growth cycle can produce very large benefits from limited water applications.

From the above discussion it seems clear that in order to maximize the value of a limited water resource it is necessary to develop a good understanding of water production functions and water-fertility interactions and also to make use of some form of probability analyses of rainfall occurrence.

Recommendations

Considering the need for increased food production and for capital growth, investment in agricultural production needs to be carefully programmed based upon a knowledge of the available resources and the best use that can be made of those resources. The limited available evaluation of climate and rainfall indicates a very large potential for rainfed agricultural production. There appears to be also a major possibility of improving irrigated yields through a better utilization of rainfall on the irrigated lands.

The potential for increased crop income from improved surface drainage and the optimization of fertilizer applications also seems very large. In order to take advantage of these opportunities it is recommended that the following activities be given priority:

1. A country-wide study to determine the water requirements for optimizing crop production of the principal crops grown.

2. A reconnaissance evaluation of climate potential evapotranspiration and the moisture availability index for the 368 rainfall stations presented in "World Climate Data."

3. A compilation of daily rainfall records in preparation for making probability analyses of rainfall amounts during 10 day periods throughout the crop growth cycle.

4. Preparation of estimates of optimum levels of fertilization for both rainfed and irrigated crops using known results from experiments in India and from other areas of similar climate.

5. An evaluation of possible benefits from improved surface drainage and water conservation based upon the experience of ICRISAT (International Crops Research Institute for the S[illegible]i-Arid Tropics) and that from the semi-arid and humid [illegible]ical areas.

6. A co[illegible]try-wide zoning of suitability of climate for rainfed pro[illegible]uction of the principal crops grown in India and estimates of potential yields and optimum fertilization levels.

7. An evaluation of water deficits in rainfed agriculture and of the potentially large benefits possible in some areas by supplying supplemental irrigation to optimize production.

8. Initiation of a major program in water-fertility interaction research in order to prepare studies showing isoquants of production as a function of water and fertilizer with equations to show the optimum relationship defined by the place where the isoquants change direction. Also, graphs should be prepared indicating potential increase in production per kg of fertilizer at various levels of fertilization.

9. A major educational and training program to acquaint extension agents, agronomists and engineers with the various factors of crop production and as to how these interact one with another.

Table E-1. The Water Balance for India.

AGRA INDIA EL= 169 LAT= 27 10 N LONG= 78 2 E KS= 9.1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	16.	9.	11.	5.	10.	60.	210.	263.	154.	23.	2.	4.	767.
PMI	0.	0.	0.	0.	0.	0.	62.	23.	3.	0.	0.	0.	374.
P79	0.	0.	0.	0.	0.	8.	106.	163.	40.	0.	0.	0.	529.
P60	7.	0.	1.	0.	2.	22.	161.	217.	79.	0.	0.	0.	562.
PMX	72.	57.	72.	33.	58.	356.	389.	618.	609.	162.	23.	24.	1202.
TMC	14.8	18.0	23.3	29.7	34.5	35.0	30.9	29.3	28.9	26.2	20.6	16.1	25.7
HM	61.	43.	36.	26.	27.	41.	71.	79.	63.	52.	45.	55.	51.
SC	57.	66.	73.	78.	78.	70.	49.	42.	51.	63.	67.	61.	63.
PD	1.	0.	0.	0.	0.	11.	119.	174.	43.	0.	0.	0.	501.
ETP	73.	92.	150.	198.	243.	231.	182.	154.	146.	133.	96.	75.	1774.
ETDF	72.	92.	150.	198.	243.	220.	64.	-20.	98.	133.	96.	75.	1420.
MAI	.02	.00	.00	.00	.00	.05	.65	1.13	.33	.00	.00	.00	.32

AHMADABAD INDIA EL= 55 LAT= 23 4 N LONG= 72 38 E KS=10.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	4.	0.	1.	2.	5.	81.	316.	213.	163.	13.	5.	1.	804.
PMI	0.	0.	0.	0.	0.	0.	37.	2.	0.	0.	0.	0.	307.
P79	0.	0.	0.	0.	0.	18.	135.	87.	24.	0.	0.	0.	515.
P60	0.	0.	0.	0.	0.	64.	203.	151.	67.	0.	0.	0.	716.
PMX	57.	4.	12.	26.	45.	291.	949.	589.	637.	94.	53.	14.	1453.
TMC	20.3	22.8	27.1	31.3	33.5	32.7	29.4	29.3	28.7	28.4	24.5	21.1	27.3
HM	45.	36.	33.	33.	46.	59.	78.	79.	71.	51.	41.	43.	51.
S	90.	91.	78.	81.	83.	64.	36.	32.	55.	83.	92.	91.	73.
PD	0.	0.	0.	0.	0.	28.	151.	100.	33.	0.	0.	0.	557.
ETP	119.	133.	176.	211.	245.	208.	149.	132.	156.	171.	135.	117.	1952.
ETDF	119.	133.	176.	211.	245.	180.	-1.	32.	123.	171.	135.	117.	1641.
MAI	.00	.00	.00	.00	.00	.13	1.01	.76	.21	.00	.00	.00	.29

AKOLA INDIA EL= 282 LAT= 20 42 N LONG= 77 2 E KS= 9.4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	9.	8.	7.	7.	11.	146.	261.	170.	178.	46.	28.	6.	877.
PMI	0.	0.	0.	0.	0.	28.	98.	19.	22.	0.	0.	0.	430.
P79	0.	0.	0.	0.	0.	71.	164.	112.	87.	1.	0.	0.	700.
P60	0.	0.	0.	0.	0.	107.	225.	127.	125.	12.	0.	0.	820.
PMX	64.	85.	51.	72.	71.	362.	477.	505.	810.	205.	342.	46.	1365.
TMC	22.0	24.0	28.3	32.5	35.3	31.8	27.7	27.1	27.3	26.7	23.1	21.1	27.2
HM	45.	33.	27.	24.	29.	53.	74.	75.	72.	54.	45.	45.	48.
SC	70.	77.	80.	82.	79.	64.	48.	47.	50.	64.	70.	70.	67.
PD	0.	0.	0.	0.	0.	79.	177.	115.	95.	3.	0.	0.	725.
ETP	115.	130.	187.	219.	246.	202.	164.	156.	145.	148.	119.	108.	1941.
ETDF	115.	130.	187.	219.	246.	124.	-13.	41.	50.	145.	119.	108.	1472.
MAI	.00	.00	.00	.00	.00	.39	1.08	.74	.65	.02	.00	.00	.37

Table E-1 Continued.

ALLAHABAD INDIA						EL= 98	LAT= 25 27 N		LONG= 81 44 E			KS=10.6	
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	20.	22.	14.	5.	8.	100.	283.	333.	195.	40.	6.	6.	1032.
PMI	0.	0.	0.	0.	0.	0.	129.	109.	40.	0.	0.	0.	607.
P79	1.	4.	0.	0.	0.	36.	180.	249.	99.	1.	0.	0.	822.
P60	13.	11.	1.	0.	1.	71.	237.	293.	123.	14.	0.	0.	918.
PMX	75.	99.	81.	44.	47.	257.	476.	915.	405.	181.	92.	63.	1676.
TMC	16.4	19.1	25.1	30.7	34.7	34.3	30.1	29.1	29.0	26.5	21.1	17.1	26.1
HM	67.	51.	35.	24.	27.	47.	76.	81.	77.	61.	55.	63.	55.
S	75.	83.	74.	78.	72.	54.	38.	38.	57.	76.	86.	85.	68.
PD	4.	5.	0.	0.	0.	43.	192.	258.	104.	4.	0.	0.	842.
ETP	92.	110.	160.	203.	234.	199.	157.	147.	157.	152.	115.	95.	1820.
ETDF	88.	105.	160.	203.	234.	156.	-35.	-112.	53.	148.	115.	95.	1210.
MAI	.04	.05	.00	.00	.00	.22	1.23	1.76	.66	.02	.00	.00	.46

BANGALORE INDIA						EL= 921	LAT= 12 58 N		LONG= 77 35 E			KS= 9.1	
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	3.	10.	6.	46.	117.	80.	117.	147.	143.	185.	54.	16.	924.
PMI	0.	0.	0.	2.	20.	5.	28.	33.	8.	29.	0.	0.	588.
P79	0.	0.	0.	8.	59.	56.	65.	70.	86.	89.	6.	0.	798.
P60	0.	0.	0.	21.	91.	71.	97.	101.	109.	151.	34.	5.	868.
PMX	19.	90.	72.	162.	287.	171.	150.	344.	267.	522.	179.	86.	1283.
TMC	20.9	23.1	25.7	27.3	26.9	24.3	23.2	23.3	23.3	23.3	21.7	20.5	23.6
HM	59.	47.	43.	51.	61.	73.	78.	77.	75.	74.	69.	65.	64.
S	73.	78.	76.	69.	62.	39.	25.	34.	41.	49.	55.	64.	55.
PD	0.	0.	0.	11.	66.	59.	72.	77.	91.	102.	12.	1.	813.
ETP	132.	142.	180.	181.	177.	126.	102.	119.	124.	130.	117.	119.	1648.
ETDF	132.	142.	180.	170.	111.	67.	30.	43.	33.	28.	105.	118.	1159.
MAI	.00	.00	.00	.06	.37	.47	.70	.64	.73	.79	.10	.01	.49

BEGAMPET INDIA						EL= 545	LAT= 17 27 N		LONG= 78 28 E			KS=10.3	
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	2.	10.	13.	23.	30.	107.	165.	147.	163.	71.	25.	5.	761.
PMI	0.	0.	0.	0.	0.	30.	41.	26.	61.	2.	0.	0.	481.
P79	0.	0.	0.	4.	5.	54.	115.	77.	87.	24.	0.	0.	628.
P60	0.	0.	1.	12.	14.	78.	144.	119.	107.	53.	1.	0.	726.
PMX	26.	96.	114.	163.	116.	324.	313.	334.	362.	269.	229.	69.	1158.
TMC	21.6	24.0	27.2	30.3	32.3	28.9	26.0	25.7	25.5	25.0	22.3	20.7	25.8
HM	57.	47.	41.	42.	41.	62.	75.	76.	77.	67.	59.	57.	59.
SC	68.	75.	79.	78.	79.	63.	51.	50.	49.	59.	66.	69.	66.
PD	0.	0.	0.	5.	7.	59.	121.	86.	91.	30.	0.	0.	649.
ETP	120.	135.	185.	206.	229.	185.	161.	156.	141.	142.	121.	113.	1893.
ETDF	120.	135.	185.	203.	222.	126.	40.	70.	50.	112.	120.	113.	1493.
MAI	.00	.00	.00	.03	.03	.32	.75	.55	.65	.21	.00	.00	.34

Table E-1 Continued.

BELGAUM INDIA EL= 753 LAT= 15 51 N LONG= 74 32 E KS=10.0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	1.	2.	12.	57.	87.	211.	505.	284.	120.	168.	38.	7.	1492.
PMI	0.	0.	0.	1.	5.	52.	173.	87.	39.	21.	0.	0.	896.
P79	0.	0.	0.	19.	25.	109.	333.	165.	67.	78.	3.	0.	1193.
P60	0.	0.	0.	40.	45.	184.	478.	226.	85.	101.	13.	0.	1303.
PMX	17.	50.	46.	165.	293.	508.	809.	680.	281.	516.	142.	65.	2278.
TMC	22.1	23.7	26.5	27.7	27.3	24.1	22.5	22.5	23.0	24.3	23.3	21.5	24.0
HM	50.	45.	47.	59.	69.	79.	91.	89.	85.	73.	60.	53.	67.
SC	71.	74.	73.	64.	56.	46.	30.	33.	39.	52.	63.	69.	56.
PD	0.	0.	0.	23.	29.	125.	363.	178.	71.	83.	5.	0.	1221.
ETP	128.	136.	177.	176.	171.	139.	112.	116.	118.	133.	124.	120.	1649.
ETDF	128.	136.	177.	152.	142.	14.	-252.	-61.	47.	51.	119.	120.	772.
MAI	.00	.00	.00	.13	.17	.90	3.25	1.53	.60	.62	.04	.00	.74

BIKANER INDIA EL= 224 LAT= 28 0 N LONG= 73 18 E KS= 9.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	6.	7.	6.	5.	7.	27.	87.	104.	45.	6.	3.	2.	305.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	91.
P79	0.	0.	0.	0.	0.	5.	24.	36.	0.	0.	0.	0.	191.
P60	0.	0.	0.	0.	0.	13.	43.	68.	7.	0.	0.	0.	213.
PMX	28.	53.	55.	35.	56.	89.	311.	337.	224.	82.	44.	17.	635.
TMC	13.6	17.2	23.5	29.6	34.6	35.6	33.1	31.3	30.7	27.1	20.2	15.1	25.0
HM	53.	41.	34.	23.	25.	38.	59.	64.	57.	41.	39.	48.	43.
SC	66.	75.	79.	85.	84.	76.	62.	58.	64.	75.	76.	70.	72.
PD	0.	0.	0.	0.	0.	7.	28.	43.	1.	0.	0.	0.	197.
ETP	74.	94.	154.	206.	253.	245.	215.	190.	169.	146.	99.	76.	1921.
ETDF	74.	94.	154.	206.	253.	239.	187.	147.	167.	146.	99.	76.	1842.
MAI	.00	.00	.00	.00	.00	.03	.13	.23	.01	.00	.00	.00	.10

BOMBAY INDIA EL= 11 LAT= 18 54 N LONG= 72 49 E KS=12.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	2.	1.	0.	3.	16.	520.	709.	419.	297.	88.	21.	2.	2078.
PMI	0.	0.	0.	0.	0.	92.	206.	83.	43.	0.	0.	0.	903.
P79	0.	0.	0.	0.	0.	251.	517.	193.	115.	19.	0.	0.	1692.
P60	0.	0.	0.	0.	0.	465.	609.	344.	182.	38.	1.	0.	1877.
PMX	21.	14.	6.	64.	153.	1011.	1310.	1265.	1245.	385.	164.	24.	3482.
TMC	24.3	24.9	26.9	28.7	29.9	29.1	27.5	27.1	27.4	28.3	27.5	25.9	27.3
HM	68.	67.	68.	69.	70.	79.	85.	85.	83.	77.	70.	67.	74.
S	85.	86.	79.	78.	75.	41.	17.	22.	42.	70.	83.	85.	64.
PD	0.	0.	0.	0.	0.	296.	536.	225.	129.	23.	0.	0.	1731.
ETP	140.	145.	182.	197.	212.	151.	96.	107.	135.	165.	150.	140.	1820.
ETDF	140.	145.	182.	197.	212.	-145.	-440.	-118.	6.	142.	149.	140.	611.
MAI	.00	.00	.00	.00	.00	1.96	5.59	2.10	.95	.14	.00	.00	.95

Table E-1 Continued.

CALCUTTA INDIA EL= 6 LAT= 22 32 N LONG= 88 20 E KS=10.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	13.	24.	27.	43.	121.	259.	301.	306.	290.	160.	35.	3.	1582.
PMI	0.	0.	0.	0.	11.	68.	132.	152.	56.	23.	0.	0.	909.
P79	0.	2.	3.	9.	56.	174.	195.	224.	183.	90.	0.	0.	1330.
P60	1.	12.	9.	26.	78.	221.	275.	254.	264.	102.	1.	0.	1560.
PMX	66.	138.	157.	152.	369.	510.	585.	629.	521.	474.	239.	32.	2221.
TMC	20.2	23.0	27.9	30.1	31.1	30.4	29.1	29.1	29.2	27.9	24.0	20.6	26.9
HM	67.	59.	57.	63.	69.	78.	83.	84.	83.	79.	69.	68.	72.
S	77.	77.	72.	70.	63.	36.	29.	31.	40.	59.	76.	79.	59.
PD	0.	4.	4.	12.	61.	184.	212.	230.	200.	93.	0.	0.	1378.
ETP	111.	123.	172.	191.	203.	148.	132.	133.	134.	143.	123.	109.	1723.
ETDF	111.	119.	168.	180.	142.	-36.	-80.	-97.	-66.	50.	123.	109.	723.
MAI	.00	.03	.02	.06	.30	1.24	1.60	1.73	1.49	.65	.00	.00	.80

CHERRAPUNJI INDIA EL=1313 LAT= 25 15 N LONG= 91 44 E KS=10.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	20.	41.	179.	605.	1705.	2375.	2855.	1827.	1231.	447.	47.	5.	11437.
PMI	0.	0.	8.	87.	717.	1367.	930.	685.	281.	16.	0.	0.	8105.
P79	0.	7.	31.	312.	1111.	2102.	1701.	1202.	705.	110.	0.	0.	9639.
P60	4.	30.	86.	473.	1390.	2403.	2143.	1406.	1135.	257.	4.	0.	10765.
PMX	104.	133.	760.	1472.	3278.	5683.	4563.	3482.	2500.	1435.	284.	41.	15707.
TMC	11.7	13.3	16.7	18.6	19.2	20.0	20.3	20.5	20.5	19.1	15.9	12.9	17.4
HM	73.	67.	68.	80.	87.	94.	95.	93.	91.	84.	75.	75.	82.
SC	55.	61.	60.	47.	38.	26.	24.	28.	32.	42.	53.	53.	43.
PD	1.	12.	43.	346.	1170.	2165.	1794.	1245.	795.	141.	1.	0.	9875.
ETP	68.	79.	115.	118.	118.	99.	97.	102.	95.	94.	78.	66.	1129.
ETDF	67.	68.	72.	-228.	-1051.	-2067.	-1696.	-1143.	-700.	-47.	77.	66.	-6582.
MAI	.01	.15	.37	2.93	9.87	21.95	18.42	12.21	8.34	1.50	.01	.00	8.74

CUTTACK INDIA EL= 27 LAT= 20 48 N LONG= 85 56 E KS=12.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC	ANN
PM	10.	27.	13.	26.	70.	207.	355.	365.	252.	168.	41.	5.	1545.
PMI	0.	0.	0.	0.	3.	67.	148.	159.	137.	5.	0.	0.	884.
P79	0.	0.	1.	0.	23.	118.	245.	244.	197.	55.	0.	0.	1288.
P60	0.	7.	4.	9.	42.	165.	264.	316.	217.	103.	2.	0.	1452.
PMX	34.	189.	100.	152.	230.	517.	681.	823.	455.	494.	233.	96.	2372.
TMC	22.3	24.9	29.0	31.8	32.9	31.1	28.6	28.6	28.9	27.9	24.5	21.9	27.7
HM	63.	59.	57.	61.	63.	71.	81.	83.	81.	76.	67.	65.	69.
SC	74.	78.	80.	76.	74.	66.	53.	50.	53.	60.	70.	72.	67.
PD	0.	1.	2.	2.	27.	128.	249.	259.	201.	65.	0.	0.	1322.
ETP	120.	134.	189.	208.	227.	201.	176.	167.	156.	147.	124.	112.	1902.
ETDF	120.	133.	187.	207.	200.	73.	-73.	-92.	-45.	82.	123.	112.	2027.
MAI	.00	.01	.01	.01	.12	.64	1.41	1.55	1.29	.44	.00	.00	.67

Table E-1 Continued.

DALTONGANJ INDIA EL= 221 LAT= 24 3 N LONG= 84 4 E KS=10.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	31.	28.	21.	9.	13.	140.	346.	358.	223.	57.	7.	4.	1237.
PMI	0.	0.	0.	0.	0.	37.	76.	122.	78.	0.	0.	0.	708.
P79	5.	7.	1.	0.	0.	64.	256.	249.	147.	14.	0.	0.	1000.
P60	14.	17.	7.	2.	4.	95.	297.	312.	192.	37.	0.	0.	1140.
PMX	111.	99.	91.	40.	59.	362.	621.	638.	448.	220.	54.	54.	1857.
TMC	16.9	19.3	24.5	29.7	33.9	33.0	29.0	28.3	28.2	25.7	20.5	16.9	25.5
HM	65.	54.	41.	31.	29.	53.	77.	81.	78.	67.	62.	64.	58.
SC	63.	72.	81.	89.	89.	73.	51.	46.	50.	61.	65.	64.	67.
PD	7.	9.	2.	0.	1.	71.	265.	261.	156.	19.	0.	0.	1077.
ETP	88.	106.	167.	213.	256.	223.	176.	159.	145.	135.	101.	85.	1855.
ETDF	81.	97.	165.	212.	255.	153.	-89.	-103.	-11.	117.	101.	85.	1063.
MAI	.08	.09	.01	.00	.00	.32	1.50	1.65	1.09	.14	.00	.00	.59

DARBHANGA INDIA EL= 49 LAT= 26 10 N LONG= 85 54 E KS=10.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	20.	14.	10.	20.	57.	190.	330.	291.	247.	70.	7.	2.	1253.
PMI	0.	0.	0.	0.	0.	72.	74.	109.	41.	0.	0.	0.	851.
P79	0.	1.	0.	0.	17.	105.	166.	199.	108.	10.	0.	0.	1046.
P60	5.	8.	1.	1.	44.	137.	244.	234.	174.	29.	0.	0.	1183.
PMX	114.	59.	124.	92.	140.	480.	673.	609.	649.	327.	65.	17.	2522.
TMC	16.8	19.1	24.0	28.7	30.5	30.3	29.3	29.3	29.0	26.8	21.9	18.0	25.3
HM	76.	63.	49.	47.	57.	73.	81.	82.	81.	75.	73.	77.	65.
SC	52.	64.	76.	77.	70.	55.	46.	45.	46.	53.	55.	51.	55.
PD	1.	2.	0.	0.	23.	112.	182.	206.	122.	14.	0.	0.	1074.
ETP	76.	96.	156.	193.	211.	185.	170.	160.	141.	126.	92.	74.	[illegible]
ETDF	75.	93.	155.	193.	188.	74.	-12.	-46.	19.	112.	92.	74.	1017.
MAI	.01	.03	.00	.00	.11	.60	1.07	1.29	.87	.11	.00	.00	.64

DARJEELING INDIA EL=2127 LAT= 27 3 N LONG= 89 16 E KS=10.5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	22.	27.	53.	103.	187.	522.	713.	573.	419.	116.	14.	5.	2760.
PMI	0.	0.	0.	11.	67.	225.	208.	339.	177.	6.	0.	0.	2202.
P79	0.	3.	14.	62.	123.	333.	583.	471.	301.	18.	0.	0.	2432.
P60	6.	14.	41.	79.	159.	427.	693.	542.	368.	45.	2.	0.	2564.
PMX	240.	97.	156.	260.	421.	1402.	985.	824.	802.	561.	127.	31.	3792.
TMC	6.4	7.7	11.2	14.3	15.7	17.0	17.5	17.5	17.2	15.1	11.3	8.1	13.3
HM	80.	81.	75.	76.	88.	93.	95.	92.	91.	83.	79.	79.	84.
SC	47.	46.	52.	51.	36.	29.	23.	30.	31.	43.	48.	48.	40.
PD	1.	9.	20.	66.	131.	353.	606.	486.	315.	24.	0.	0.	2460.
ETP	49.	54.	88.	107.	105.	94.	90.	96.	85.	82.	61.	50.	963.
ETDF	48.	45.	69.	42.	-26.	-259.	-516.	-390.	-230.	58.	61.	50.	-1048.
MAI	.03	.17	.22	.61	1.25	3.74	6.73	5.05	3.69	.29	.01	.00	2.56

Table E-1 Continued.

DHUBRI INDIA EL= 35 LAT= 26 1 N LONG= 89 59 E KS=10.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	11.	19.	45.	154.	481.	644.	448.	305.	328.	145.	12.	1.	2593.
PMI	0.	0.	0.	4.	216.	295.	129.	108.	53.	0.	0.	0.	1712.
P79	0.	2.	2.	76.	302.	413.	233.	200.	191.	44.	0.	0.	2127.
P60	0.	10.	7.	101.	378.	525.	387.	248.	280.	107.	0.	0.	2443.
PMX	62.	70.	193.	434.	869.	1078.	996.	649.	911.	411.	98.	12.	3669.
TMC	17.7	19.8	24.1	26.6	26.4	27.2	28.1	28.3	27.8	26.1	22.3	18.9	24.4
HM	76.	65.	60.	68.	81.	88.	87.	85.	87.	83.	79.	77.	78.
SC	52.	63.	67.	60.	46.	37.	38.	41.	38.	44.	49.	51.	49.
PD	0.	4.	3.	81.	318.	440.	265.	210.	210.	57.	0.	0.	2194.
ETP	79.	97.	147.	163.	157.	141.	150.	150.	125.	113.	88.	76.	1464.
ETDF	79.	93.	144.	81.	-161.	-299.	-115.	-61.	-85.	55.	88.	76.	-105.
MAI	.00	.04	.02	.50	2.03	3.12	1.76	1.41	1.68	.51	.00	.00	1.48

DUMKA INDIA EL= 149 LAT= 24 16 N LONG= 87 15 E KS=10.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	20.	27.	14.	29.	81.	207.	370.	349.	274.	125.	15.	3.	1514.
PMI	0.	0.	0.	0.	0.	56.	158.	147.	92.	7.	0.	0.	983.
P79	0.	4.	0.	2.	34.	141.	268.	250.	155.	56.	0.	0.	1300.
P60	5.	11.	2.	7.	53.	179.	343.	303.	255.	80.	0.	0.	1477.
PMX	139.	146.	85.	172.	234.	435.	790.	629.	522.	697.	139.	16.	1941.
TMC	17.9	20.5	26.2	30.3	31.7	30.5	29.5	28.3	28.3	26.5	21.9	18.5	25.8
HM	59.	47.	41.	43.	57.	73.	83.	83.	81.	72.	61.	57.	63.
SC	69.	79.	82.	81.	70.	56.	44.	44.	47.	57.	67.	70.	64.
PD	1.	5.	0.	3.	38.	149.	284.	261.	176.	61.	0.	0.	1337.
ETP	95.	113.	174.	206.	217.	186.	162.	155.	141.	133.	106.	93.	1750.
ETDF	94.	108.	174.	203.	179.	37.	-121.	-106.	-35.	72.	106.	93.	802.
MAI	.01	.05	.00	.01	.18	.80	1.75	1.68	1.25	.46	.00	.00	.75

DWARKA INDIA EL= 11 LAT= 22 22 N LONG= 69 5 E KS=12.5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	2.	2.	1.	0.	0.	49.	220.	77.	42.	5.	19.	2.	419.
PMI	0.	0.	0.	0.	0.	0.	6.	1.	0.	0.	0.	0.	37.
P79	0.	0.	0.	0.	0.	1.	44.	12.	1.	0.	0.	0.	217.
P60	0.	0.	0.	0.	0.	13.	114.	18.	7.	0.	0.	0.	290.
PMX	23.	23.	11.	1.	8.	239.	813.	357.	265.	45.	379.	42.	1080.
TMC	20.5	22.1	24.9	27.2	29.1	30.1	29.5	27.7	27.5	27.3	25.7	22.3	26.1
HM	58.	65.	75.	78.	80.	79.	93.	94.	81.	76.	61.	55.	73.
SC	81.	74.	63.	59.	56.	57.	52.	50.	54.	61.	78.	84.	64.
PD	0.	0.	0.	0.	0.	4.	59.	13.	2.	0.	0.	0.	232.
ETP	115.	119.	150.	165.	182.	185.	174.	163.	151.	144.	130.	118.	1797.
ETDF	115.	119.	150.	165.	182.	182.	116.	150.	149.	144.	130.	118.	1720.
MAI	.00	.00	.00	.00	.00	.02	.34	.08	.01	.00	.00	.00	.13

Table E-1 Continued.

FORT COCHIN INDIA EL= 3 LAT= 9 58 N LONG= 76 14 E KS=11.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	10.	34.	50.	145.	364.	756.	572.	386.	235.	333.	184.	37.	3106.
PMI	0.	0.	2.	49.	56.	290.	276.	121.	21.	117.	1.	0.	2115.
P79	0.	1.	9.	71.	116.	582.	380.	223.	95.	157.	86.	3.	2553.
P60	0.	9.	22.	118.	251.	672.	490.	317.	173.	264.	152.	11.	3043.
PMX	68.	129.	245.	314.	1178.	1100.	1070.	1172.	530.	906.	441.	204.	5318.
TMC	26.9	27.5	28.5	28.7	28.3	26.5	25.9	26.1	26.3	26.7	27.0	26.9	27.1
HM	67.	71.	74.	75.	81.	87.	87.	87.	84.	82.	77.	69.	78.
SC	69.	64.	61.	59.	52.	43.	43.	43.	48.	50.	57.	66.	55.
PD	0.	3.	12.	81.	144.	601.	403.	243.	111.	179.	100.	5.	2656.
ETP	155.	148.	174.	173.	164.	137.	140.	143.	144.	147.	141.	149.	1814.
ETDF	155.	145.	162.	92.	19.	-464.	-263.	-100.	33.	-33.	41.	145.	-67.
MAI	.00	.02	.07	.47	.88	4.40	2.88	1.70	.77	1.22	.71	.03	1.46

GAUHATI INDIA EL= 54 LAT= 26 5 N LONG= 91 43 E KS=10.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	11.	19.	53.	171.	274.	292.	301.	263.	190.	90.	11.	5.	1679.
PMI	0.	0.	0.	12.	99.	117.	140.	90.	35.	0.	0.	0.	1048.
P79	0.	4.	11.	99.	182.	206.	205.	173.	125.	36.	0.	0.	1390.
P60	1.	9.	32.	131.	246.	245.	271.	211.	141.	67.	3.	0.	1619.
PMX	65.	71.	159.	400.	565.	589.	533.	595.	448.	292.	53.	26.	2032.
TMC	16.4	18.6	22.3	25.5	26.7	27.9	28.4	28.5	28.2	25.7	21.4	17.6	23.9
HM	79.	62.	55.	66.	74.	83.	82.	83.	83.	82.	82.	81.	76.
SC	49.	66.	72.	62.	55.	44.	45.	44.	44.	45.	45.	47.	52.
PD	0.	5.	15.	106.	195.	214.	220.	181.	129.	43.	1.	0.	1430.
ETP	73.	96.	145.	161.	172.	157.	165.	156.	135.	114.	83.	70.	1527.
ETDF	73.	91.	130.	56.	-24.	-57.	-55.	-25.	7.	71.	82.	70.	419.
MAI	.00	.05	.11	.65	1.14	1.36	1.33	1.16	.95	.37	.01	.00	.94

INDORE INDIA EL= 567 LAT= 22 43 N LONG= 75 48 E KS=10.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	85.	1.	3.	3.	13.	145.	316.	267.	221.	48.	22.	3.	1127.
PMI	0.	0.	0.	0.	0.	16.	56.	70.	39.	0.	0.	0.	592.
P79	0.	0.	0.	0.	0.	53.	237.	113.	102.	2.	0.	0.	839.
P60	0.	0.	0.	1.	0.	106.	271.	203.	156.	13.	0.	0.	950.
PMX	40.	8.	35.	30.	98.	409.	690.	707.	767.	174.	217.	19.	1743.
TMC	17.9	19.9	24.5	29.1	32.3	30.1	26.1	25.1	25.1	24.1	20.5	18.3	24.4
HM	50.	35.	25.	25.	32.	60.	81.	83.	77.	53.	44.	47.	51.
SC	72.	82.	88.	88.	84.	65.	44.	42.	49.	70.	76.	74.	70.
PD	0.	0.	0.	0.	0.	64.	244.	132.	113.	4.	0.	0.	862.
ETP	100.	117.	176.	211.	240.	197.	153.	141.	135.	142.	112.	99.	1823.
ETDF	100.	117.	176.	211.	240.	133.	-91.	9.	22.	138.	112.	99.	1265.
MAI	.00	.00	.00	.00	.30	.33	1.59	.94	.84	.03	.00	.00	.47

Table E-1 Continued.

JAGDALPUR INDIA   EL= 553 LAT= 19 5 N LONG= 82 2 E KS=10.5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	5.	15.	17.	51.	65.	212.	396.	380.	246.	115.	24.	4.	1530.
PMI	0.	0.	0.	2.	4.	34.	140.	203.	51.	12.	0.	0.	1072.
P79	0.	0.	0.	26.	23.	114.	278.	295.	140.	52.	0.	0.	1337.
P60	0.	1.	6.	38.	51.	154.	353.	338.	232.	88.	6.	0.	1494.
PMX	44.	146.	79.	126.	154.	498.	632.	664.	485.	312.	113.	40.	2230.
TMC	20.2	22.8	26.5	29.5	31.5	28.7	25.1	25.3	25.8	24.8	21.4	19.3	25.1
HM	57.	59.	40.	43.	47.	67.	84.	85.	83.	75.	67.	62.	64.
SC	69.	67.	81.	79.	76.	60.	42.	41.	43.	52.	60.	65.	61.
PD	0.	0.	1.	29.	29.	122.	294.	304.	159.	60.	1.	0.	1373.
ETP	113.	121.	182.	203.	222.	181.	143.	139.	132.	131.	109.	103.	1780.
ETDF	113.	121.	181.	174.	194.	59.	-150.	-165.	-27.	71.	106.	103.	781.
MAI	.00	.00	.01	.14	.13	.68	2.05	2.19	1.21	.45	.01	.00	.77

JODHPUR INDIA   EL= 224 LAT= 26 18 N LONG= 73 1 E KS= 9.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	8.	5.	2.	2.	6.	31.	122.	146.	47.	7.	3.	1.	380.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	135.
P79	0.	0.	0.	0.	0.	9.	40.	35.	1.	0.	0.	0.	269.
P60	0.	0.	0.	0.	1.	13.	63.	95.	13.	0.	0.	0.	342.
PMX	57.	48.	15.	20.	32.	154.	391.	544.	207.	88.	39.	23.	778.
TMC	17.1	19.9	25.2	30.3	34.4	34.3	31.3	29.2	29.4	27.7	22.7	18.7	26.7
HM	41.	30.	25.	23.	31.	45.	65.	71.	61.	37.	29.	37.	41.
S	84.	87.	76.	79.	79.	71.	50.	47.	69.	87.	92.	89.	76.
PD	0.	0.	0.	0.	0.	10.	45.	48.	4.	0.	0.	0.	204.
ETP	98.	113.	161.	203.	244.	228.	184.	164.	173.	164.	121.	99.	1953.
ETDF	98.	113.	161.	203.	244.	219.	140.	116.	169.	164.	121.	99.	1847.
MAI	.00	.00	.00	.00	.00	.04	.24	.29	.02	.00	.00	.00	.15

KOTA INDIA   EL= 257 LAT= 25 11 N LONG= 75 51 E KS=10.3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	9.	4.	5.	3.	7.	79.	311.	268.	135.	15.	6.	3.	845.
PMI	0.	0.	0.	0.	0.	4.	30.	46.	10.	0.	0.	0.	336.
P79	0.	0.	0.	0.	0.	30.	172.	153.	35.	0.	0.	0.	587.
P60	2.	0.	0.	0.	1.	56.	250.	190.	83.	1.	0.	0.	760.
PMX	40.	13.	31.	35.	38.	216.	714.	704.	444.	111.	44.	36.	1305.
TMC	17.9	20.8	26.3	31.8	36.2	34.9	30.0	28.6	28.9	27.7	22.9	19.0	27.1
HM	53.	37.	25.	19.	21.	41.	70.	75.	68.	45.	41.	49.	45.
SC	71.	82.	89.	93.	92.	79.	56.	51.	58.	76.	79.	74.	75.
PD	0.	0.	0.	0.	0.	35.	188.	161.	45.	0.	0.	0.	528.
ETP	94.	115.	180.	227.	272.	243.	190.	169.	159.	156.	116.	94.	2016.
ETDF	94.	115.	180.	227.	272.	208.	2.	8.	114.	156.	116.	94.	1536.
MAI	.00	.00	.00	.00	.00	.15	.93	.95	.29	.00	.00	.00	.31

Table E-1 Continued.

LUDHIANA INDIA EL= 247 LAT= 30 56 N LONG= 75 52 E KS=10.3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	35.	35.	29.	11.	9.	54.	191.	173.	136.	35.	3.	14.	725.
PMI	1.	0.	0.	0.	0.	0.	72.	29.	0.	0.	0.	0.	353.
P79	11.	3.	6.	1.	0.	12.	123.	101.	13.	0.	0.	0.	541.
P60	20.	13.	11.	4.	3.	35.	164.	140.	34.	3.	0.	0.	659.
PMX	138.	146.	130.	81.	53.	146.	508.	368.	699.	588.	25.	64.	1402.
TMC	13.0	15.7	21.1	27.3	32.7	34.1	31.3	30.3	29.5	25.6	19.5	14.6	24.6
HM	71.	63.	55.	40.	31.	41.	67.	74.	67.	55.	56.	63.	57.
SC	55.	63.	69.	80.	86.	79.	59.	53.	59.	69.	66.	56.	67.
PD	13.	5.	7.	2.	1.	17.	132.	109.	17.	1.	0.	0.	563.
ETP	62.	73.	131.	187.	246.	244.	203.	175.	155.	129.	66.	62.	1758.
ETDF	49.	73.	124.	185.	246.	227.	71.	66.	137.	129.	96.	62.	1455.
MAI	.21	.07	.05	.01	.00	.07	.65	.62	.11	.00	.00	.00	.32

MADRAS INDIA EL= 16 LAT= 13 0 N LONG= 80 11 E KS=11.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	24.	7.	15.	25.	52.	53.	83.	124.	118.	267.	308.	157.	1233.
PMI	0.	0.	0.	0.	0.	9.	21.	22.	21.	70.	6.	1.	672.
P79	0.	0.	0.	0.	0.	23.	44.	69.	62.	140.	138.	20.	911.
P60	3.	0.	0.	8.	1.	37.	60.	105.	99.	203.	210.	58.	1048.
PMX	136.	64.	263.	133.	389.	130.	266.	231.	279.	892.	808.	599.	2135.
TMC	24.5	25.9	27.9	30.5	32.7	32.5	30.7	30.1	29.7	28.1	25.9	24.6	28.6
HM	73.	73.	71.	71.	65.	59.	64.	68.	71.	79.	80.	77.	71.
S	77.	85.	82.	79.	72.	53.	40.	50.	54.	57.	57.	65.	64.
PD	1.	0.	0.	2.	0.	26.	47.	77.	70.	153.	153.	28.	940.
ETP	149.	158.	197.	207.	216.	178.	154.	170.	166.	157.	132.	133.	2016.
ETDF	148.	158.	197.	207.	216.	152.	106.	94.	96.	4.	-21.	105.	1459.
MAI	.00	.00	.00	.01	.00	.15	.31	.45	.42	.98	1.16	.21	.47

MANGALORE INDIA EL= 22 LAT= 12 52 N LONG= 74 51 E KS=11.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	5.	2.	9.	40.	233.	980.	1059.	577.	279.	206.	71.	18.	3479.
PMI	0.	0.	0.	0.	0.	441.	417.	277.	33.	69.	0.	0.	2452.
P79	0.	0.	0.	5.	69.	779.	841.	381.	151.	108.	6.	0.	2991.
P60	0.	0.	0.	13.	112.	847.	979.	470.	225.	144.	52.	1.	3293.
PMX	61.	24.	90.	128.	752.	1437.	1678.	1236.	637.	488.	206.	158.	4703.
TMC	26.5	26.9	28.1	29.3	29.1	26.7	26.0	26.1	26.1	26.8	27.1	26.9	27.1
HM	67.	71.	71.	71.	75.	87.	89.	89.	86.	82.	73.	65.	77.
SC	68.	64.	64.	64.	59.	43.	39.	39.	45.	50.	62.	70.	56.
PD	0.	0.	0.	7.	78.	793.	870.	400.	167.	116.	16.	0.	3054.
ETP	147.	141.	175.	182.	182.	140.	137.	138.	138.	144.	141.	147.	1812.
ETDF	147.	141.	175.	175.	103.	-653.	-733.	-262.	-29.	28.	125.	146.	-634.
MAI	.00	.00	.00	.04	.43	5.65	6.34	2.90	1.21	.80	.11	.00	1.69

Table E-1 Continued.

MASULIPATAM INDIA EL= 3 LAT= 16 11 N LONG= 81 8 E KS=12.0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	1.	11.	9.	18.	36.	106.	199.	152.	156.	264.	110.	15.	1077.
PMI	0.	0.	0.	0.	0.	9.	47.	20.	53.	38.	0.	0.	628.
P79	0.	0.	0.	0.	4.	42.	106.	77.	104.	130.	6.	0.	876.
P60	0.	0.	0.	2.	14.	78.	179.	134.	125.	204.	28.	0.	998.
PMX	8.	111.	91.	101.	174.	490.	466.	317.	300.	621.	397.	256.	1701.
TMC	23.6	25.2	27.4	29.9	32.3	31.9	29.1	29.0	28.7	27.9	25.1	23.3	27.8
HM	75.	74.	73.	73.	69.	65.	75.	76.	79.	80.	75.	74.	74.
SC	60.	61.	62.	62.	67.	71.	60.	59.	55.	54.	60.	61.	61.
PD	0.	0.	0.	0.	6.	50.	121.	89.	108.	146.	11.	0.	902.
ETP	122.	127.	167.	182.	209.	207.	185.	181.	161.	147.	126.	118.	1933.
ETDF	122.	127.	167.	182.	203.	158.	64.	92.	53.	2.	115.	118.	1402.
MAI	.00	.00	.00	.00	.03	.24	.65	.49	.67	.99	.08	.00	.47

MINICOY INDIA EL= 2 LAT= 8 18 N LONG= 73 0 E KS=11.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	35.	25.	16.	52.	200.	293.	212.	200.	144.	185.	141.	76.	1579.
PMI	0.	0.	0.	1.	5.	105.	48.	35.	30.	20.	24.	0.	1050.
P79	8.	1.	0.	12.	81.	201.	122.	75.	56.	80.	68.	21.	1379.
P60	15.	6.	4.	33.	122.	289.	200.	170.	120.	161.	111.	50.	1591.
PMX	148.	136.	90.	140.	626.	544.	502.	451.	348.	452.	337.	282.	2248.
TMC	26.1	26.7	27.7	28.7	28.8	27.7	27.3	27.3	27.3	27.1	26.6	26.5	27.3
HM	77.	75.	74.	75.	77.	81.	81.	81.	79.	79.	78.	77.	78.
SC	57.	59.	61.	59.	57.	52.	52.	52.	55.	55.	56.	57.	56.
PD	9.	2.	1.	16.	90.	219.	138.	95.	69.	97.	77.	27.	1421.
ETP	143.	142.	172.	172.	172.	152.	157.	160.	159.	156.	141.	141.	1867.
ETDF	133.	140.	171.	156.	82.	-67.	19.	65.	89.	59.	64.	114.	1026.
MAI	.07	.01	.00	.10	.52	1.44	.88	.59	.44	.62	.55	.19	.76

MOHANBARI INDIA EL= 111 LAT= 27 29 N LONG= 95 1 E KS=10.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	39.	61.	100.	204.	356.	507.	523.	419.	352.	166.	27.	21.	2775.
PMI	0.	9.	4.	82.	146.	267.	297.	211.	131.	6.	0.	0.	2209.
P79	19.	30.	48.	127.	258.	421.	402.	280.	264.	97.	4.	7.	2448.
P60	31.	58.	69.	160.	288.	459.	452.	381.	320.	133.	11.	11.	2681.
PMX	101.	149.	232.	464.	707.	764.	877.	729.	667.	450.	129.	62.	3300.
TMC	15.2	17.7	20.6	23.3	25.3	27.3	27.8	28.1	27.6	24.8	20.2	16.5	22.8
HM	83.	76.	70.	72.	82.	74.	74.	72.	75.	86.	85.	88.	79.
SC	44.	52.	59.	57.	45.	55.	55.	57.	53.	40.	41.	37.	50.
PD	22.	36.	52.	134.	264.	429.	412.	301.	276.	105.	5.	8.	2497.
ETP	65.	81.	124.	145.	152.	173.	179.	174.	145.	102.	74.	58.	1473.
ETDF	43.	45.	71.	11.	-113.	-256.	-233.	-127.	-131.	-2.	68.	51.	-572.
MAI	.33	.44	.42	.92	1.74	2.48	2.30	1.73	1.30	1.02	.07	.13	1.70

Table E-1 Continued.

MUKTESWAR/KUMAON INDIA EL=2311 LAT= 29 28 N LONG= 79 39 E KS= 9.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	56.	56.	45.	34.	51.	143.	332.	285.	200.	79.	4.	23.	1305.
PMI	0.	0.	1.	0.	2.	18.	101.	114.	49.	0.	0.	0.	353.
P79	7.	11.	18.	5.	15.	67.	218.	196.	86.	1.	0.	0.	1106.
P60	42.	39.	35.	29.	32.	105.	282.	242.	154.	13.	0.	4.	1196.
PMX	247.	168.	130.	89.	167.	401.	748.	551.	491.	477.	32.	117.	2254.
TMC	5.8	7.1	11.1	15.5	18.7	19.1	17.6	17.3	16.5	14.1	11.2	7.9	13.5
HM	58.	53.	48.	40.	43.	65.	91.	93.	87.	65.	51.	47.	62.
SC	60.	63.	66.	71.	69.	54.	28.	24.	33.	54.	64.	67.	55.
PD	14.	17.	22.	10.	19.	75.	231.	206.	100.	4.	0.	1.	1125.
ETP	51.	60.	96.	130.	158.	141.	99.	86.	84.	86.	66.	55.	1111.
ETDF	36.	43.	74.	120.	140.	66.	-133.	-119.	-16.	82.	66.	54.	413.
MAI	.28	.28	.22	.08	.12	.53	2.35	2.38	1.19	.04	.00	.02	1.01

NAGPUR INDIA EL= 310 LAT= 21 6 N LONG= 79 3 E KS= 9.4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	14.	19.	22.	20.	13.	210.	407.	288.	173.	65.	17.	3.	1251.
PMI	0.	0.	0.	0.	0.	57.	163.	156.	62.	0.	0.	0.	618.
P79	0.	0.	0.	3.	0.	126.	277.	187.	86.	9.	0.	0.	998.
P60	0.	1.	5.	8.	2.	146.	375.	238.	150.	21.	0.	0.	1190.
PMX	104.	157.	104.	129.	101.	498.	592.	449.	375.	209.	162.	24.	1931.
TMC	20.7	23.8	27.7	31.9	35.6	32.5	27.6	27.1	27.3	25.9	22.0	20.4	26.9
HM	51.	37.	32.	30.	26.	53.	77.	79.	75.	63.	51.	53.	52.
S	85.	90.	79.	76.	75.	48.	25.	29.	44.	73.	86.	90.	66.
PD	0.	0.	1.	4.	0.	130.	298.	198.	99.	12.	0.	0.	1036.
ETP	122.	139.	182.	208.	241.	176.	117.	120.	136.	155.	128.	119.	1845.
ETDF	122.	139.	181.	204.	240.	46.	-180.	-78.	37.	143.	128.	119.	1103.
MAI	.00	.00	.01	.02	.00	.74	2.54	1.64	.73	.07	.00	.00	.56

NEW DELHI/SAFDARJUNG INDIA EL= 216 LAT= 28 35 N LONG= 77 12 E KS= 9.1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	25.	22.	17.	7.	8.	65.	211.	173.	150.	31.	1.	5.	715.
PMI	0.	0.	0.	0.	0.	2.	4.	15.	0.	0.	0.	0.	322.
P79	3.	0.	1.	0.	1.	13.	114.	77.	42.	0.	0.	0.	517.
P60	13.	2.	8.	1.	4.	30.	162.	119.	108.	1.	0.	0.	632.
PMX	74.	128.	64.	57.	54.	415.	464.	551.	359.	238.	16.	68.	1533.
TMC	14.3	17.3	22.9	29.1	33.5	34.5	31.2	29.9	29.3	25.9	20.2	15.7	25.3
HM	62.	47.	39.	25.	25.	39.	67.	73.	65.	49.	44.	55.	49.
S	71.	80.	68.	69.	60.	46.	42.	46.	59.	82.	90.	80.	66.
PD	5.	0.	2.	0.	2.	17.	124.	86.	56.	0.	0.	0.	541.
ETP	78.	97.	140.	182.	203.	187.	170.	164.	153.	143.	106.	81.	1720.
ETDF	72.	97.	138.	182.	208.	171.	46.	79.	102.	146.	106.	81.	1427.
MAI	.07	.00	.02	.00	.01	.09	.73	.52	.35	.00	.00	.00	.31

Table E-1 Continued.

PAMBAN INDIA EL= 11 LAT= 9 16 N LONG= 79 18 E KS=11.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	66.	19.	24.	69.	24.	5.	9.	12.	16.	175.	308.	196.	922.
PMI	0.	0.	0.	2.	0.	0.	0.	0.	0.	20.	33.	20.	459.
P79	8.	0.	0.	17.	0.	0.	0.	0.	0.	94.	176.	79.	704.
P60	34.	5.	1.	36.	12.	0.	0.	0.	5.	159.	297.	120.	834.
PMX	268.	91.	143.	216.	141.	70.	68.	89.	68.	338.	586.	840.	1568.
TMC	26.0	26.6	27.9	29.5	30.1	29.5	29.0	28.9	28.9	28.1	27.0	26.0	28.1
HM	81.	77.	75.	77.	77.	78.	79.	79.	80.	81.	83.	83.	79.
SC	52.	57.	59.	57.	57.	56.	55.	55.	53.	52.	49.	49.	54.
PD	13.	1.	0.	21.	3.	0.	0.	0.	1.	108.	201.	88.	731.
ETP	134.	138.	171.	172.	178.	166.	169.	171.	162.	155.	132.	127.	1973.
ETDF	120.	137.	170.	151.	176.	166.	169.	171.	161.	47.	-70.	40.	1437.
MAI	.10	.01	.00	.12	.01	.00	.00	.00	.01	.70	1.53	.69	.39

POONA INDIA EL= 559 LAT= 18 32 N LONG= 73 51 E KS= 9.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	2.	0.	3.	18.	35.	103.	187.	106.	127.	92.	37.	5.	715.
PMI	0.	0.	0.	0.	0.	1.	37.	25.	17.	4.	0.	0.	455.
P79	0.	0.	0.	0.	0.	50.	101.	66.	45.	24.	0.	0.	563.
P60	0.	0.	0.	3.	11.	88.	160.	85.	99.	64.	4.	0.	655.
PMX	35.	5.	38.	66.	182.	187.	397.	277.	310.	257.	209.	71.	1183.
TMC	21.3	23.1	26.5	29.3	29.9	27.5	24.9	24.6	25.0	25.5	22.9	21.1	25.1
HM	55.	44.	37.	39.	49.	68.	81.	81.	77.	67.	58.	56.	59.
S	86.	89.	83.	79.	77.	48.	22.	28.	45.	68.	79.	84.	66.
PD	0.	0.	0.	1.	2.	58.	113.	70.	56.	32.	1.	0.	582.
ETP	132.	141.	186.	202.	215.	157.	102.	113.	133.	152.	132.	125.	1789.
ETDF	132.	141.	186.	201.	213.	99.	-11.	43.	76.	120.	131.	125.	1455.
MAI	.00	.00	.00	.00	.01	.37	1.11	.62	.42	.21	.01	.00	.33

SAGAR INDIA EL= 551 LAT= 23 51 N LONG= 78 45 E KS=10.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	30.	13.	10.	4.	8.	145.	463.	418.	228.	44.	24.	7.	1394.
PMI	0.	0.	0.	0.	0.	1.	175.	195.	48.	0.	0.	0.	763.
P79	0.	0.	0.	0.	0.	73.	289.	262.	111.	4.	0.	0.	1155.
P60	12.	1.	1.	1.	1.	111.	364.	341.	145.	12.	0.	0.	1284.
PMX	181.	57.	99.	28.	64.	333.	915.	984.	623.	229.	167.	49.	2192.
TMC	18.1	20.7	25.5	30.3	33.9	31.3	26.3	25.3	25.6	24.9	21.7	19.1	25.2
HM	51.	36.	26.	21.	24.	52.	87.	87.	79.	53.	39.	43.	50.
SC	71.	82.	83.	91.	89.	71.	37.	37.	47.	70.	80.	77.	70.
PD	3.	0.	0.	0.	0.	81.	304.	279.	118.	6.	0.	0.	1182.
ETP	98.	117.	178.	219.	255.	212.	141.	132.	133.	143.	116.	100.	1844.
ETDF	96.	117.	178.	219.	255.	132.	-163.	-146.	15.	137.	116.	100.	1053.
MAI	.03	.00	.00	.00	.00	.38	2.16	2.11	.89	.04	.00	.00	.64

Table E-1 Continued.

SILCHAR INDIA EL= 29 LAT= 24 49 N LONG= 92 48 E KS=10.6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	15.	46.	131.	313.	493.	594.	547.	488.	379.	207.	44.	7.	3263.
PMI	0.	0.	2.	67.	217.	301.	386.	86.	163.	59.	0.	0.	2139.
P79	0.	9.	37.	179.	347.	493.	414.	306.	234.	109.	1.	0.	2951.
P60	2.	18.	75.	252.	421.	537.	488.	453.	323.	160.	8.	0.	3111.
PMX	88.	120.	369.	679.	966.	1024.	929.	356.	698.	458.	375.	62.	4423.
TMC	18.6	20.3	24.0	26.1	27.0	27.9	28.5	28.5	28.3	26.9	23.4	19.9	24.9
HM	73.	65.	63.	69.	79.	84.	85.	84.	84.	82.	77.	75.	77.
SC	55.	63.	64.	59.	49.	42.	41.	42.	42.	45.	51.	53.	51.
PD	0.	11.	45.	124.	363.	502.	430.	337.	253.	120.	2.	0.	2985.
ETP	85.	100.	146.	160.	163.	153.	157.	153.	134.	118.	95.	83.	1546.
ETDF	85.	89.	101.	-34.	-200.	-349.	-273.	-184.	-119.	-1.	92.	83.	-709.
MAI	.00	.11	.31	1.21	2.23	3.28	2.74	2.20	1.89	1.01	.03	.00	1.93

TRIVANDRUM INDIA EL= 64 LAT= 8 29 N LONG= 76 57 E KS=11.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	19.	21.	44.	122.	249.	331.	211.	164.	123.	271.	207.	73.	1935.
PMI	0.	0.	0.	2.	7.	74.	82.	23.	11.	92.	17.	2.	1229.
P79	0.	0.	8.	80.	70.	198.	123.	78.	39.	154.	93.	14.	1497.
P60	7.	5.	22.	102.	161.	288.	172.	119.	66.	209.	164.	39.	1698.
PMX	113.	125.	184.	213.	1055.	607.	557.	451.	444.	525.	535.	246.	3036.
TMC	26.9	27.3	28.3	28.3	28.3	26.5	26.1	26.3	26.7	26.7	26.6	26.8	27.1
HM	71.	71.	73.	77.	81.	86.	85.	83.	91.	83.	83.	75.	79.
S	74.	76.	70.	57.	51.	32.	34.	47.	54.	47.	49.	66.	55.
PD	1.	1.	11.	85.	89.	217.	133.	87.	45.	166.	108.	19.	153[illegible].
ETP	165.	162.	188.	169.	161.	117.	125.	148.	156.	143.	132.	152.	1816.
ETDF	163.	161.	177.	83.	72.	-100.	-9.	62.	111.	-23.	24.	133.	854.
MAI	.01	.01	.06	.50	.55	1.86	1.07	.58	.29	1.16	.22	.13	.35

VERAVAL INDIA EL= 8 LAT= 20 54 N LONG= 70 22 E KS=12.[illegible]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	1.	1.	0.	5.	5.	135.	305.	146.	65.	28.	7.	1.	699.
PMI	0.	0.	0.	0.	0.	1.	21.	5.	0.	0.	0.	0.	225.
P79	0.	0.	0.	0.	0.	11.	98.	39.	13.	0.	0.	0.	493.
P60	0.	0.	0.	0.	0.	61.	201.	68.	32.	0.	0.	0.	624.
PMX	14.	12.	6.	138.	102.	506.	719.	583.	417.	293.	142.	16.	1327.
TMC	21.5	22.3	24.7	26.7	28.5	29.5	27.9	27.1	27.1	27.5	25.9	23.1	26.0
HM	57.	61.	71.	75.	83.	83.	89.	89.	85.	73.	59.	53.	73.
SC	79.	76.	65.	60.	50.	50.	40.	40.	47.	63.	77.	83.	61.
PD	0.	0.	0.	0.	0.	21.	120.	45.	17.	0.	0.	0.	513.
ETP	121.	123.	154.	166.	169.	169.	151.	144.	140.	150.	134.	124.	1745.
ETDF	121.	123.	154.	166.	169.	148.	31.	99.	123.	150.	134.	124.	1543.
MAI	.00	.00	.00	.00	.00	.13	.79	.31	.12	.00	.00	.00	.29

Table E-1 Continued.

VISHAKHAPATNAM INDIA EL= 3 LAT= 17 43 N LONG= 83 14 E KS=12.0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	7.	15.	9.	13.	53.	88.	125.	99.	167.	261.	90.	17.	944.
PMI	0.	0.	0.	0.	0.	20.	35.	21.	50.	70.	0.	0.	473.
P79	0.	0.	0.	0.	5.	50.	72.	45.	72.	141.	1.	0.	754.
P60	0.	0.	0.	2.	19.	74.	96.	62.	142.	222.	26.	0.	854.
PMX	55.	94.	66.	78.	299.	211.	394.	233.	384.	607.	386.	251.	1342.
TMC	23.4	25.3	28.1	30.6	31.9	31.3	29.3	29.5	29.0	28.1	25.7	23.7	28.0
HM	77.	72.	71.	76.	77.	80.	82.	81.	83.	78.	69.	71.	76.
SC	58.	63.	65.	59.	58.	54.	51.	52.	49.	56.	67.	65.	58.
PD	0.	0.	0.	0.	8.	55.	77.	49.	87.	158.	6.	0.	777.
ETP	115.	128.	170.	179.	194.	180.	173.	173.	153.	149.	131.	119.	1864.
ETDF	115.	128.	170.	179.	186.	125.	96.	125.	66.	-9.	125.	119.	1424.
MAI	.00	.00	.00	.00	.04	.31	.45	.28	.57	1.06	.05	.00	.42

1 DOCUMENT REVIEW

2 NEPAL/USAID: IRRIGATION DEVELOPMENT OPTIONS
AND INVESTMENT STRATEGIES FOR THE 1980's

3 BANGLADESH/USAID: IRRIGATION DEVELOPMENT OPTIONS
AND INVESTMENT STRATEGIES FOR THE 1980's

4 PAKISTAN/USAID: IRRIGATION DEVELOPMENT OPTIONS
AND INVESTMENT STRATEGIES FOR THE 1980's

5 THAILAND/USAID: IRRIGATION DEVELOPMENT OPTIONS
AND INVESTMENT STRATEGIES FOR THE 1980's

6 INDIA/USAID: IRRIGATION DEVELOPMENT OPTIONS
AND INVESTMENT STRATEGIES FOR THE 1980's

7 GENERAL OVERVIEW

WMS REPORTS ARE AVAILABLE FROM:
WATER MANAGEMENT SYNTHESIS PROJECT
AGRICULTURAL & IRRIGATION ENGINEERING
UTAH STATE UNIVERSITY
LOGAN, UTAH 84322
(801) 750-2785