PB-219 727

THE PROBLEM OF WATER SCHEDULING IN WEST PAKISTAN: RESEARCH STUDIES AND NEEDS

Garth N. Jones

Colorado State University

Prepared for:

Agency for International Development

November 1971

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FORT COLLINS, COLORADO

NOVEMBER 1971

WATER MANAGEMENT
TECHNICAL REPORT NO. 13

PK 631.7-J77a

PB-219 727

"The Problem of Water Scheduling in West Pakistan: Research Studies and Needs"

November 1971

Garth N. Jones

Colorado State University
Department of Political Science
~~Fort Collins, Colorado 80521~~

Proj. 931-17-120-489

AID/csd-2162

Department of State
Agency for International Development
Washington, D.C. 20523

Technical
6/68 - 11/71

The capacity to build and maintain the irrigation system has exceeded the capacity to manage the allocation of water for maximum agricultural production. The irrigation system was not designed to supply total crop water needs plus leaching requirements, but rather to provide sufficient water during the growing season to avoid complete crop failure and famine. In recent years the irrigation system has been substantially modified by increasing its storage capacity and by tubewells which utilize the storage capacity of the vast Indus aquifer. The irrigation system, in at least part of the Punjab, now has capacity to vary its water deliverance. Consequently, it is now possible to consider the development of irrigation scheduling based upon crop and soil needs. Reorganization of the irrigation system to achieve optimum delivery scheduling appears to be a formidable and long-term but worthwhile effort involving major changes in the social and physical structures. His relatively rapid acceptance of new seed, installations of private tubeweels etc., indicate that the Pakistan farmer is receptive to new technology. Consequently, the most rapid XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX "water management" payoff will probably result from providing farmers who have access to controllable water with the technology which can help that control achieve maximum yields.

17b. Identifiers/Open-Ended Terms

*Water resources development, *Water-supply

631

43

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THE PROBLEM OF WATER SCHEDULING IN WEST PAKISTAN: RESEARCH STUDIES AND NEEDS

Water Management Technical Report No. 13

by

Garth N. Jones
Department of Political Science

with comment by

William D. Romig
Chief, Water Resources Branch
Office of Capital Development and Engineering
Bureau for Near East South Asia
Agency for International Development
Washington, D. C.

Prepared under support of

United States Agency for International Development
Contract No. AID/csd-2162
Water Management Research
in Arid and Sub-Humid Lands of the
Less Developed Countries

Colorado State University
Fort Collins, Colorado
November, 1971

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ID71-72GNJ8

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Reproduced in this form for the purpose of checking statements and figures for accuracy. The author would appreciate comments and criticisms on this paper's contents.

V

ACKNOWLEDGEMENTS

The author would like to acknowledge and thank the following persons who read this paper and offered a number of constructive suggestions: Raymond L. Anderson, Natural Resources Economics Division, Economic Research Service, U.S. Department of Agriculture, Fort Collins, Colorado; Earl Summers and William D. Romig, Near East South Asia Region, Agriculture and Engineering, U.S. Agency for International Development, Washington, D. C., and Khalid Mahmood, Pakistan Department of Irrigation, now on special assignment on the water management research project at Colorado State University.

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THE PROBLEM OF WATER SCHEDULING IN WEST PAKISTAN: RESEARCH STUDIES AND NEEDS

THE PROBLEM OF WATER SCHEDULING IN WEST PAKISTAN: RESEARCH STUDIES AND NEEDS*

by

Garth N. Jones

I. Introduction

In the mid-1960's, West Pakistan's irrigation agriculture was extensively investigated and a large number of impressive studies issued or published.[1] Although these studies provide unusual insights into this nation's agricultural problems and mark out a number of areas demanding

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*This is the second of a projected series of problem identification and research needs studies on Pakistan's irrigated agriculture, as a cooperative research venture between Colorado State University and Pakistan counterpart research and educational institutions which is financially supported in part by the U.S. Agency for International Development. The first was: Garth N. Jones and Raymond L. Anderson, "The Problem of Under-Irrigation in West Pakistan: Research Studies and Needs," Fort Collins: Water Management Program, Colorado State University, 1971 (processed). Accepted for publication in the Journal of Rural Development and Administration, Pakistan Academy for Rural Development, Peshawar, West Pakistan.

[1]Several exhaustive bibliographies have been prepared which reference most of these studies. See Garth N. Jones and Shaukat Ali, A Comprehensive Bibliography, Pakistan Government and Administration (Lahore: Public Administration Research Centre, 1969); Garth N. Jones, A Comprehensive Bibliography, Pakistan Government and Administration, Volume Two (Peshawar: Pakistan Academy for Rural Development, 1971), and Garth N. Jones and others, Water Management for Agricultural Production in West Pakistan: Special Reference to the Institutional and Human Factors (Peshawar: Academy for Rural Development), forthcoming.

The principal analytical study based on the field reports is by Pieter Lieftinck, A. Robert Sadove, and Thomas C. Creyke, Water and Power Resources, A Study in Sector Planning (Baltimore: Published for the World Bank as Administrator of the Indus Basin Development Fund by the Johns Hopkins University Press, 1969), three volumes. Much of the data for this work is drawn from the 23 volumes prepared by Sir Alexander Gibb and Partners, International Land Development Consultants, and Hunting Technical Services (London and Arnhem), Programme for the Development of Irrigation and Agriculture in West Pakistan (Washington: International Bank for Reconstruction and Development, 1966).

further investigation and research, the important problem of scheduling water on the farms was scarcely mentioned.

Possibly, the principal investigators believed that this was an obvious problem and that because of the severe constraints within the irrigation system little could be accomplished in the immediate future in developing realistic irrigation schedules. The delivery of the water to the farm fields in relation to crop and soil needs appeared to be an insoluble problem.

Vicious Circle of Low Water Supply and Low Agricultural Production

West Pakistan's agriculture is caught in a vicious circle of a low water supply and a low level of agricultural production, and to a considerable extent these two are closely related. The principal result of this situation is the widespread and chronic practice of under-irrigation. The farmers live close to famine conditions and their principal concern is to produce sufficient food and fiber to meet their immediate needs. Thus, because of unreliable water supplies, they practice distributing water over as many acres as possible to assure a harvest.[2]

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[2]This is discussed by Garth N. Jones and Raymond L. Anderson in their, "The Problem of Under-Irrigation in West Pakistan: Research Studies and Needs," Fort Collins: Water Management Program, Colorado State University, 1971 (processed). Accepted for publication in the Journal of Rural Development and Administration, PARD. It is a well known fact that the system was originally designed for extensive rather than intensive irrigation. Intensive irrigation implies maximizing land utilization and production per unit area. It involves the use of modern technology and the scientific application of agriculture inputs (seeds, fertilizers, water, etc.). Extensive irrigation connotes spreading the irrigation facilities over as large an area as possible with the objective of extending the benefits to a maximum number of persons (the greatest good to the greatest number). This is not an easy problem to resolve as indicated in the following: "Intensive versus Extensive Irrigation," IOCID Bulletin (New Delhi), January 1971, 2-4 and Rashid Ahmad Malik, "Irrigation Development and Land Occupance in the Upper Indus Basin," unpublished Ph.D. dissertation, Bloomington: Department of Geography, Indiana University, 1963.

Building in System Response

Although West Pakistan's irrigation system is not presently designed to provide water to the farmer on a regular basis, let alone on a crop need or a farmer demand, the requirements of modern agriculture technology increasingly demand that water availability become less erratic. Because of emerging changes, flexibility can now be built into the irrigation system, which was not possible in the past, to provide water delivery to the farmer on a more rational basis compatible with crop needs. This is largely a consequence of: (1) expanding of the reservoir capacity, namely Mangla and Tarbela, and, (2) the tapping of the vast underground water reserves with the rapid and widespread development of both public and private tubewells. Further system response is possible by developing improved diversion schedules in the canal networks and by the construction of a large number of small impounding reservoirs.[3] Thus, the development of irrigation schedules which will result in higher crop yields per acre, especially in those irrigation commands where substantial quality underground water supplies are available, becomes a real possibility.

Growth of Irrigation Supplies

Research investigations reveal that about 45 million acre feet (MAF) of usable groundwater could yearly be made available for irrigation which compares to a total withdrawal in 1965 of about 10 MAF.[4] As shown

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[3] See Sir Alexander Gibb and others, Programme for the Development of Irrigation and Agriculture in West Pakistan, 1966, volume 5. Of course, another possibility would be the wholesale redesign of the network of lower canals and the reduction of canal water losses. The high cost excludes this, however.

[4] Lieftinck, Sadove, and Creyke, *op. cit.*, volume 11, 74.

in Table 1, the full utilization of this potential is scheduled to be reached by 1985. An additional five million acre feet, more or less, is projected to be developed by the year 2000 which would largely be a product of improved agricultural practices and more effective water control, including the mixing of water of various qualities.

These statistics must be compared with the present and the projected development of the supplies of surface or canal water. As shown in Table 2, in 1965 the total watercourse deliveries to the principal canal commands in the Indus Basin was 58 MAF surface water and 10 MAF groundwater. By 1985 this should increase to 77 MAF surface water and 40 MAF of groundwater. The percentage contribution from groundwater is expected to more than double between the years 1965 to 1975. After 1975 the ratio between the water sources should remain fairly constant, approximately 67 percent surface water and 33 percent groundwater. Eventually, groundwater should account for approximately 40 percent of the total irrigation supplies in the Punjab and 12 percent in the Sind.[5]

Facilitative Factors for Change: Summary Note

In light of these rapid developments, it now appears that attention can be directed towards developing innovative approaches to the scheduling of irrigation water in the watercourses, and that this is particularly the case in the productive agricultural areas of the Punjab where

[5] Ibid., volume 1, 109 et seq.

Table 1*

RATE OF GROUNDWATER DEVELOPMENT

(MAF/year)

	1965	1975	1985	2000
Private Tubewells (in CCA)	5.3	7.0	3.5	--
Public Tubewells	2.7	22.0	36.5	44.0
Persian Wheels	1.7	1.0	--	--
Total in CCA	9.7	30.0	40.0	44.0
Private Tubewells Outside CCA	1.0	2.8	5.0	6.5
Total	10.7	32.8	45.0	50.5

Legend: MAF means Million Acre Feet
CCA means the portion of the cultivable area which is commanded by canal irrigation

*Taken from Pieter Lieftinck, A. Robert Sadove, and Thomas C. Creyke, Water and Power Resources of West Pakistan, A Study in Sector Planning (Baltimore: The Johns Hopkins Press, 1969), Volume III, 75.

Table 2*

RELATIVE USE OF SURFACE AND GROUNDWATER
MEASURED AT WATERCOURSE HEAD

Reference Year	Surface Water		Groundwater		Total
	MAF	Percent	MAF	Percent	MAF
1965	58	85	10	15	68
1970[a]	56	75	19	25	75
1975	63	68	31	32	94
1985	77	66	40	34	117
2000	91	67	44	33	135

[a]The estimate for 1970 was derived from sequential analysis data, with some adjustment for surpluses occurring during rabi period and the effect of the adopted pumping pattern (including pumping needed for lowering of water table in project areas) on surface water use.

*Taken from Pieter Lieftinck, A. Robert Sadove, and Thomas C. Creyke, Water and Power Resources of West Pakistan, A Study in Sector Planning (Baltimore: The Johns Hopkins University Press, 1968), volume I, 109.

over 65,000 private tubewells are now operating.[6] Increased delivery control over the time and the amounts of irrigation water is not the only encouraging development. The potential for better irrigation water management through adaptive research based on studies and findings conducted in particularly the semi-arid regions of the United States and Mexico are high, as already demonstrated with the successful Mexi-Pak wheat program.

Previous attempts in the United States to relate observed irrigation efficiencies to field, soil, crop, and management characteristics were not very successful because of the diverse factors causing large variations in the timing and the amount of water applied at each irrigation were so complicated that the resulting irrigation efficiencies appeared to be no more than random events.[7] This situation is not unique to the United States but is common to all irrigation systems. However, the capacity to introduce improved irrigation practices has substantially increased over the last 15 years. This is a result of better control and

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[6]A survey by the West Pakistan University of Engineering and Technology notes that, in rounded figures, within the last 15 years approximately 80,000 private tubewells have been sunk. Of this total, 65,000 or 81 percent are found in three divisions: Sargoda 12,000 or 15%, Lahore 25,000 or 31% and Multan 28,000 or 35%. These areas encompass a grand total of 2,118,900 acres. See West Pakistan University of Engineering and Technology, "A Study of the Contribution of Private Tubewells in the Development of Water Potential in Pakistan," a report prepared for the Planning Commission, Lahore: 1971 (processed), especially 60 *et seq.*

[7]Much of this section builds on: M. E. Jensen, D. C. N. Robb, and C. E. Franzoy, "Scheduling Irrigations Using Climate-Crop-Soil Data," A Paper Contributed at the National Conference on Water Resources Engineering of the American Society of Civil Engineers, February 3-5, 1969, New Orleans, Louisiana: 1969 (processed).

measurement facilities,[8] improved system design criteria,[9] more reliable methods for estimating evapotranspiration,[10] increased knowledge of each crop's response to soil moisture levels,[11] and commercially available soil moisture instrumentation for timing irrigations.[12]

Because of these developments in the irrigation system and technology, new decision-making tools can now be made available to the farmer for determining better the intervals between irrigations and the proper amounts of water to apply. The introduction of realistically-conceived watering schedules in Pakistan now moves into the realm of possibility. The present haphazard procedure based essentially upon fixed rotation schedules for canal water and irrigating when the neighbor does for tubewell water can be replaced with irrigation scheduling that provides water in time and amount to achieve maximum crop yield in both the terms of quantity as well as quality. The importance

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[8] A. R. Robinson and A. S. Humphreys, "Water Control and Measurement on the Farm," Irrigation of Agricultural Lands, Monograph No. 11 (Madison, Wisconsin: American Society of Agronomy, 1967), 828-64.

[9] A. A. Bishop, M. E. Jensen, and W. A. Hall, "Surface Irrigation Systems," Irrigation of Agricultural Lands, Monograph No. 11 (Madison, Wisconsin: American Society of Agronomy, 1967), 865-84.

[10] M. E. Jensen (ed.), "Evapotranspiration and Its Role in Water Resources Management," Proceedings of a Conference, American Society of Agricultural Engineers, December 1966 (St. Joseph, Michigan: 1966), 1-66.

[11] R. M. Hagan, H. R. Haise, and T. W. Edminster (eds.), "Irrigation of Principal Crops," Irrigation of Agricultural Lands (Madison, Wisconsin: American Society of Agronomy, 1967), Section X, 607-770.

[12] H. R. Haise and R. M. Hagan, "Soil, Plant, and Evaporative Measurements as Criteria for Scheduling Irrigations," Irrigation of Agricultural Lands, Monograph No. 11 (Madison, Wisconsin: American Society of Agronomy, 1967), 577-604.

of irrigation scheduling is magnified when the water supply is short and the cost is high or when the soil conditions exist which restrict water movement or root development. Under-irrigation eventually results in saline soil. Over-irrigation often creates a serious drainage problem. Water use is at a minimum when the amount of water is just equal to the consumptive use and the leaching requirement. To achieve higher irrigation efficiencies, the present irrigation scheduling practices need to be improved.

The remaining part of this study deals with the research and other necessary requirements to develop and incorporate scientifically formulated water schedules within the practices of West Pakistan's irrigation system.

II. Developing a Water Scheduling Program

Efficient irrigation requires control of the available soil moisture reservoir. This demands adequate knowledge of the soil moisture content at all times and the application of sufficient water to refill the soil moisture reservoir and to take care of the leaching requirement for salt control, where this is necessary.

Models for Irrigation Scheduling

Models for more accurately scheduling irrigations, involving both time and amount, can be divided into: (1) those employing direct measurement of soil moisture levels and (2) those employing predictive approaches based on estimated soil moisture depletion. Successful irrigation water management programs exist which are based on each of these models.[13]

Data Inputs. Both models require the processing of tremendous amounts of data. The use of computers to facilitate tedious computations becomes necessary. The models require essentially the same climate-crop-soil data, which for Pakistan conditions are still largely inadequate. Once these data become available and field experiments held, it becomes possible to determine which of these two models are best suited to Pakistan's needs.

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[13] See Jensen, Robb, and Franzoy, *op. cit.*, especially 3 *et seq.*

Operationalizing an Irrigation Scheduling Program

Three basic categories of program activities are required to operationalize an irrigation scheduling program: (1) undertaking water use studies, (2) conducting adaptive research, and (3) installing an irrigation management service. Substantial progress must be made in the first two categories of program activities before it is possible to give consideration to the third category, i.e., the installing of an irrigation management service.

Water Use Studies. Water use studies, conducted largely under the World Bank Pakistan project, have indicated extremely low field efficiencies.[14] It has been estimated, although working with inadequate data, that the farmers are obtaining less than 40 percent effective use of the on-the-farm irrigation water.[15] Additional water use studies, therefore, need to be made that:

1. Analyze the use of water under the present irrigation practices,

2. Identify the sources of loss and waste of irrigation water, and

3. Secure additional knowledge of the relationship between water use, irrigation practices, crop use, climate, and soils.[16]

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[14] See Gibb and others, Programme for the Development of Irrigation and Agriculture in West Pakistan, volume 10, "Watercourse Studies." Lieftinck, Sadove, and Creyke, op. cit., volume 11, especially 253 et seq. These studies note that more investigation must be given to the losses in the canal systems and in the watercourses.

[15] See Nazir Ahmad, "Water Conservation Studies for West Pakistan," Reprinted from Symposium on Role of Engineering Research in the Development Economy of Pakistan (Lahore: West Pakistan Engineering Congress, 1966), volume IX, 119-40.

[16] The studies made by U.S. Bureau of Reclamation on the use of water on federal irrigation projects are the kind that are required. See particularly Bureau of Reclamation, Region 7, "Use of Water on Federal Irrigation Projects, 1965-69," four volumes, Denver: Bureau of Reclamation, Department of the Interior, 1970 (processed).

Detailed data for nearly every watercourse must be collected on water deliveries, rainfall, surface runoff, solar radiation, temperature, irrigation and cultural practices, crop yields, soil types, and physical layout. Against the standards and specifications of the theoretical models and the findings of the field experiments, these data must be analyzed to determine how well the farmer is performing within the constraints of his water system.

Because of the size and complexity of Pakistan's irrigation system, considerable ingenuity will be required in conducting the water use studies. The physical uniformity in the layout of the irrigation system, however, will greatly facilitate the geographical organization for undertaking such studies.

Suggested as a research methodology to simplify this problem is the concept of "thermodynamic" efficiency which is defined and measured by the ratio of used output to total output.[17] The total output is always equal to the total input. A common sense objective, therefore, is to increase efficiency in a given system by reducing the unused waste energy outputs.

This approach, and one strictly thermodynamic, considerably simplifies the problem in studying water use at the farm level by centering attention on identifying waste in any form. Once a determination is

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[17]This concept for the essay is drawn from the stimulating discussion by Bertram M. Gross in his Organizations and Their Managing (New York: The Free Press, 1968), 449-50. He notes on page 449 that: "For the engineer efficiency is measured by the ratio of unused output to total output. Thus when an engine uses fuel containing 100 units of energy and provides 85 units of used energy, efficiency is 85 percent. The remaining 15 units of energy input comes out in the form of heat or smoke. This, also, is output -- but in an unused form. If the unused output, or waste, can be reduced to 10 percent, then the efficiency of the engine will be raised to 90 percent."

made that certain inputs or outputs are not being used, this becomes an indication of inefficiency. The problem then is to distinguish between unavoidable or tolerable degrees of waste and avoidable or intolerable degrees of waste. Often this can be quickly determined by making a well-designed checklist survey of those factors which contribute to increased efficiency such as clean ditches, well-designed layout of farm laterals and water distributing facilities, and performance levels of water user organization(s) and of community cooperative activities.[18]

In sum, this concept of efficiency, as a praticable way of reducing the gap between the actual and the potential, can become an effective operational device in contributing to increased water utilization and thereby increased agricultural productivity, the principal purpose of a well-designed water scheduling program.

Adaptive Research. Knowledge on the time, the frequency, and the quantity and the quality of water to produce maximum crop yields must emerge from research under Pakistani conditions. This does not imply that agricultural research conducted elsewhere has no relevance to Pakistan: quite to the contrary, as the remarkable success story of Mexi-Pak Wheat indicates, or in even broader terms, the so-called "Green Revolution."

The perplexing problem is how Pakistan can capture the benefits of the relevant agriculture research being produced at other agricultural

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[18]Such a checklist to my knowledge has never been prepared. Presently, as part of its workshop research and training program the Agricultural Development Council of New York is trying to develop such a checklist. For a preliminary effort see Garth N. Jones, "Profile on the Evaluation of Local Irrigation Institutions," Fort Collins: Water Management Program, Colorado State University, 1971 (processed).

experiment laboratories throughout the world and yet undertake research appropriate for its own needs? Research in any form is a too costly and time-consuming venture to disregard what may be taking place elsewhere.

West Pakistan is fortunate in that its agricultural conditions are similar to those found in the semi-arid Southwestern regions of the United States and Mexico.[19] Much of West Pakistan's needs can be met through adaptive research, like that taking place concerning the dwarf wheat varieties being developed at the Centro Internacional de Mejoramiento de Maiz y Trigo, CIMMYT (International Center of Maize and Wheat Improvement), in Mexico.

The principal problem is how to establish effective linkages with reputable national agricultural research institutions. The solution of this problem is somewhat beyond the purpose of this essay, but remains an important one confronting Pakistan's future agricultural development and certainly bears on the development of realistic irrigation development programs.[20]

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[19] For more details see Jerry Bruce Eckert, "The Impact of Dwarf Wheats on Resource Productivity in West Pakistan Punjab," unpublished Ph.D. dissertation, East Lansing: Department of Agricultural Economics, Michigan State University, 1970.

[20] For discussions along these lines see Lester R. Brown, Seeds of Change, The Green Revolution and Development in the 1970's (New York: Praeger Publishers, 1970), especially Part II, "Transferring Technology;" Report of the Joint Pakistan-American Agriculture Research Team (Washington: Agency for International Development, 1968), especially Chapter 7; Chester E. Evans and others, Need of and Plan for Research on Water Use and Soil Management Towards Meeting India's Food Shortages (New Delhi: Agency for International Development, 1968?), and Joint Indian-American Team Report, "Efficient Water Use and Farm Management Study, India," Prepared for Agency for International Development and the Government of India, Los Angeles: The Ralph M. Parsons Company, 1970 (processed).

Installing an Irrigation Management Service. The undertaking of water use studies and the conducting of adaptive research will contribute little to increased agricultural productivity unless there exists: (1) a computer model(s) for integrating these research findings, (2) an organizational delivery system providing for the utilization of this new knowledge and technology by the farmer, and (3) a constant monitoring and evaluation program with "feedback" return to the principal decision makers.

Even with the present state of knowledge and technology, the principal constraining factor affecting irrigation efficiency is a lack of knowledge by the irrigator about the soil-moisture conditions of his fields. The farmer needs considerable technical assistance to help him in determining when to irrigate and how much to apply.[21] The watercourse studies conducted by the World Bank Teams indicate that seasonal irrigation efficiency could substantially be increased by eliminating unnecessary irrigations and by applying the proper amounts of water at the appropriate time in the plant's growing cycle. The benefits accruing from a well organized irrigation management service are numerous and substantial including increased crop yields, reduced fertilizer costs and labor costs, better control over the salinity and waterlogging problem, and improved quality of return water flow.

Computer Models for Integrating Research Findings. A computer model will need to be developed that schedules both the irrigation

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[21] On this subject I have only been able to find one such study, for Pakistan, Howard N. Watenpaugh and Muhammad Hussain, "Crop and Irrigation Guide, Pakistan Punjab Area," Lahore: Land Reclamation Directorate, West Pakistan Department of Irrigation and Power and Agency for International Development, 1966 (processed).

applications on the field (in the watercourses) and the water deliveries through the system (especially the lower canal distributaries). By using a technique of computerized forecasting, a potential overload or underload in any part of the delivery system can be detected and adjustments in water deliveries can be made. Such a computer model can assist in the redesign of the lower distributaries of the irrigation system and in the determination of the most desirable plan for distributing irrigation water to the farmers.

A number of computer models in the United States have been developed which could be adapted to Pakistan's conditions. Two such models are noted.

(1) Jensen-Heerman Computer Model. This is essentially a predictive model based on estimated soil moisture depletion.[22] It was first developed by Dr. Marvin Jensen of the Agricultural Research Service in Kimberly, Idaho. Additional model modifications have been made by Dr. Dale F. Heerman of the Agricultural Research Service, United States Agricultural Department, Fort Collins, Colorado. It now has been used in several regions in Western United States.

In the computer model estimates of daily evaporation and transpiration for each crop are processed. When combined with experimental data

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[22]The mathematical formula is found in Jensen, Robb, and Franzoy, op. cit., 5-7. The following are two further model adaptations: M. E. Jensen and D. F. Heerman, "Meteorological Approaches to Irrigation Scheduling," Fort Collins: Agricultural Experiment Station, Colorado State University, 1970 (processed), and D. F. Heerman and M. E. Jensen, "Adapting Meteorological Approaches in Irrigation Scheduling in High Rainfall Areas," Fort Collins: Agricultural Experiment Station, Colorado State University, 1970? (processed). The following is a progress report on the application of adapted Jensen model, R. J. Brown and J. F. Buckheim, "Water Scheduling in Southern Idaho," A paper presented at the National Conference on Water Resource Engineering, American Society of Civil Engineers, January 11-15, 1971, Phoenix, Arizona (Denver: Bureau of Reclamation, Department of Interior, 1971).

on allowable soil moisture depletion for each crop and a particular soil, the date and the amount of water to be applied at the next irrigation immediately following each irrigation can be predicted.

(2) Anderson-Maass Model. The central purpose of this model is to evaluate how well irrigation enterprises distribute their water resources.[23] It is not designed, as is the Jensen-Heerman model, to specifically determine the scheduling of water, but rather to evaluate how effectively the water user organizations and the farmers utilize their irrigation water. In this sense it becomes an extremely useful instrument in the development of realistic watering schedules, and in especially identifying and isolating the engineering design, the social and the management constraints.

Organizational Delivery System. Putting new knowledge and technology to work has proved to be one of the major constraints in any agricultural development program. An irrigation scheduling program demands a well organized delivery system that reaches to each individual farmer and careful supervision that the schedule is being followed.

While a strong organizational infra-structure is required, nothing is as important as the existence of well-organized farmer water user organizations. This becomes a basic prerequisite for initiating any water scheduling program. With only a few exceptions, such organizations

[23] Raymond L. Anderson and Arthur Maass, A Simulation of Irrigation Systems, The Effect of Water Supply and Operating Rules on the Production and Income on Irrigated Farms, Technical Bulletin No. 1431 (Washington: Economic Research Service, Department of Agriculture in Cooperation with the John Fitzgerald Kennedy School of Government, Harvard University, 1971).

are not found in Asian societies.[24] Possibly, this problem cannot be separated from the broader one of building a viable rural structure. The installation of an irrigation scheduling system rests upon a number of other progressive rural features and institutions.[25]

Monitoring and Evaluation. In many respects this is the most important, and yet primitively developed, aspect of such a program.[26] The effective installation of a watering schedule will have implications that go way beyond any increases in crop yields. As the experience of the "Green Revolution" indicates, new social and technological innovations have far reaching consequences that even extend to the third or fourth social order of affairs.

The Anderson-Maass model, as already discussed, can be a useful research instrument for the monitoring and the evaluation of changes in the distribution of water to the farmers. This model simulates the

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[24] This aspect could be regarded as the neglected aspect of irrigational development. Only a few studies exist on the subject of local irrigation organization, and most of them published 40 or more years ago. Leading references are found in Garth N. Jones and others, Water Management for Agricultural Production in West Pakistan: Special Reference to the Institutional and Human Factors (Peshawar: Academy for Rural Development), forthcoming. A few circles, however, are becoming aware of this organizational deficiency. See the Proceedings of the FAO/UNDP Regional Seminar on Measures to Accelerate Benefits from Water Development Projects by Improved Irrigation, Drainage, and Water Use at the Farm Level, Manila, Philippines, October 7-16, 1970. A digest of this conference is found in "FAO/UNDP Regional Seminar," ICID Bulletin, January 1971, 82-85. The following gives a good account for Bali; C. J. Grader, "The Irrigation System in the Region of Jembrana," in W. F. Wertheim and others, Bali: Studies in Life, Thought and Ritual (The Hague: W. Van Howe Ltd., 1960), 267-88.

[25] The following work by Arthur Mosher is extremely useful, A Progressive Rural Structure (New York: Frederick A. Praeger, 1970).

[26] For an expanded discussion on this point see Gross, op. cit., especially Chapter 25, "Evaluating: Basis of Control."

consequences of six system goals: efficiency, equity, redistribution of income, resolution of social conflict, popular participation, and convenience of water use. The first three goals can be somewhat quantified and measured. The latter three goals are more difficult to evaluate and measure, although useful determinations can be made under carefully designed programs.[27]

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[27] For a fuller discussion see Garth N. Jones, Planned Organizational Change, A Study in Change Dynamics (New York: Frederick A. Praeger, 1969), especially Chapter VIII, "Goals in Change," and "Evaluation of Local Irrigation Institutions: The Systems Approach," Fort Collins: Water Management Program, Colorado State University, 1971 (processed).

III. Towards an Institutional Arrangement in West Pakistan

The first word of the heading of this major section, "towards," was carefully selected. Since very little empirical social science research has been undertaken in West Pakistan, it is very difficult to postulate the institutional requirements necessary to support modern and productive agriculture. Institutional building consists of more than the establishing of a complex of organizations. This is certainly the basic requirement. However, infused into such a complex are new goals and values which take on distinctive outlooks, habits and other commitments that cover all aspects of organizational life and lend a social integration which goes well beyond the situation of formal command and coordination. More specifically this includes a set of laws and regulations, inter and intra-organizational relationships, and cultural attributes which guide and undertake activities designed to serve society.[28]

At this time three important aspects will be discussed which are considered important toward the development of an adequate organizational infra-structure to support a water scheduling program: (1) identifying basic organizational structure, (2) need for land and water law reform, and (3) developing local water user organizations.

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[28] See my Planned Organizational Change, A Study in Change Dynamics, 1969 and Howard V. Perlmutter, Towards a Theory and Practice of Social Architecture, The Building of Indispensable Institutions (London: Tavistock Publications, 1965).

Identifying Basic Organizational Structure

Over most of Pakistan's irrigation history, the principal need has been the construction and the renovation of elaborate irrigation works.[29] Thus, the capacity to build and maintain the irrigation system has exceeded the capacity to manage the allocation of water for maximum agricultural production. However, with the completion of the major irrigation works drawing rapidly to a close, the managing of water becomes increasingly a principal concern and a major problem.

The solution for this problem will not be easy, since a number of agencies have jurisdictional authority over the management of water and the water works.[30] The break-up of the West Pakistan one unit into four provinces, with separate irrigation departments complicates the situation, but this equally could provide the organizational decentralization necessary to constructively resolve the problem.

Water Space Concept. The concept of water space becomes a useful means by which to examine the organizational infra-structure necessary to support water scheduling program.[31] The concept carefully denotes in relationship to time and space the interplay of land, water, and social institutions. Various kinds of social institutions can be used to achieve

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[29] For more details see Aloys Arthur Michel, The Indus Rivers, A Study of the Effects of Partition (New Haven, Connecticut: Yale University Press, 1967), especially Chapters 3 and 8.

[30] See Robert Schmidt, Water Management in West Pakistan (Peshawar: Academy for Rural Development, 1971).

[31] This section rests heavily on the following article by Courtland L. Smith and Harland I. Padfield, "Land, Water, and Social Institutions," in William G. McGinnies and Bram J. Goldman (eds.), Arid Lands in Perspective (Tucson: The University of Arizona Press, 1967), 327-36.

the effective integration of people and communities within a given water space. The institution may be an association, a board, a commission, a municipality, or some other organizational form which integrates together in cooperative working relationships farmers, local communities, and even nation states.

Five useful points of analysis may be derived from this concept: (1) successful development and management of water resources require either one water user institution for the water space or one superordinate water user institution with coordinating powers, (2) as development within a waterspace proceeds, a broadening in scope and interests of the management agency institutions therein must occur, (3) norms and cultural values vis-a-vis land and water use must be commonized or coordinated within the waterspace domain, (4) development of a waterspace is an exceedingly complex subject which may give undue economic advantages to one group over another, and (5) each water relevant institution must develop its own behavior blueprint unique to the people and cultural patterns found in a given region.

The critical aspect of this discussion is that the boundaries of the waterspace and the highest jurisdictional authority must be coterminous, much as a nation controls the airspace above it. This does not mean that there may not be smaller and lower levels of regional authority. Such regional areas are often necessary to achieve full and effective use of the water resources. However, there must eventually be one higher regional authority which is responsible for the management and the development of the entire irrigation system within the waterspace territorial boundaries.

This requirement has not been fully met in West Pakistan. Jurisdictional authority is split between the four separate provincial irrigation departments and the West Pakistan Water and Power Development Authority (WP-WAPDA). WP-WAPDA is responsible for most of the development of the irrigation system and the irrigation departments for the management of the canal water within their geographical jurisdictions. There are virtually no controls over the management of the private tubewells, and most of the public tubewells remain under WP-WAPDA's authority. Basic agricultural research is carried out by a number of educational institutions, governmental agencies, and quasi-government institutions.

Irrigation Departments: Basic Organizational Units. Although not meeting the full criteria of the water space concept, the four provincial irrigation departments provide sound organizational units within which to initiate a water scheduling program. At this time it appears that an effective water scheduling program will have a "high payoff" only in the Panjab region where now over 65 percent of the private tubewells are located. Within the next 15 years it has been projected that at least 45 percent of the Punjab's irrigation water will be derived from tubewells and 55 percent from canals. In the Sind region it will be more difficult to develop a realistic water scheduling program, since the amount of tubewell water will probably never exceed 20 percent of the total supply.

Need for Land and Water Law Reform

A water scheduling program will accomplish little unless the law and institutions controlling the use of land and water permit decision-making flexibility to apply the proper amounts of water in relationship to the crops needs. The traditional warabandi system of delivering fixed amounts of water at fixed time periods needs to be changed.[32] The effect of the Moslem rule of law principle that land and water rights are inseparable warrants investigation.[33] If this legal principle should continue, for example, it will be exceedingly difficult to apply water at the place and the time most needed. The question of the relationship between land revenue and water charges to water uses and cropping patterns requires study. For illustration, the charge for canal water is assessed against the farmer on the basis of (1) the kind of crop planted and (2) the acreage irrigated which may have little resemblance to the amount of water required for maximum crop yield, or, for that matter, even actually delivered to the farmer. Only a few built-in incentives are found in the system for farmers to economize their scarce water resources. How these incentives can be increased requires attention.

Developing Local Water User Organizations

In West Pakistan we find the wasteful paradox of a great and modern irrigation system, with water control visited in higher authority, delivering water to a certain point (the off-take of a minor canal to a watercourse) where the traditional institutions largely take over the most important function, the allocation of water between the farmers and for the crops planted. A variety of bureaucratic controls and lower-level

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[32]As already stated, little exists on the actual practice of distributing water in the watercourses. The IBRD studies probably give the best account. See Gibb and others, Water Supply and Distribution, 1966, volume 5, Annexure 7 and Watercourse Studies, volume 10, Annexure 14.

[33]The treatises on water law are very scarce. A listing of these are found in Jones and others, Sources of Information on Water Management in West Pakistan, forthcoming. The following represents a brief synopsis: Dante A. Caponera (ed.), Water Laws in Moslem Countries, FAO Development Paper No. 43 (Rome, Italy: Food and Agriculture Organization of the United Nations, 1954), especially 160-66.

governmental and quasi-governmental personnel are used to strengthen the organizational need to regulate the allocation of irrigation water at the watercourse level. How this is accomplished is the "Dark Continent" of West Pakistan's irrigation system. The few studies made on rural life indicate that considerable room for improvement exists, and many of them point out the need for local water user organizations.[34]

A surprising aspect of Pakistan's irrigation development, unlike that typically found in many irrigation societies,[35] is that such organizations have not emerged out of operational needs. This topic in itself constitutes an interesting research question.

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[34]This is part of the larger problem of Pakistan's rural structure where private associations of all kinds are virtually non-existent. For an inventory of associational development see Garth N. Jones, "Community Associations in Pakistan: A Survey of Organizational Development," NIPA Journal (Karachi), 8(March 1969), 2-86. Also see Dean F. Peterson and A. Alvin Bishop, "Development of Irrigation Institutions in the Near East and South Asia, 1956-66," in Water for Peace, Proceedings of an International Conference (Washington: Government Printing Office, 1967), volume 5, 462-71.

[35]For a few studies see Thomas F. Glick, Irrigation and Society in Medieval Valencia (Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 1970); "Development Aspects of Hydraulic Societies" in J. H. Stewart (ed.), Irrigation Civilizations: A Comparative Study (Washington: Pan American Union, 1955); Robert F. Gray, The Sonjo of Tanganyika: An Anthropological Study of An Irrigation-Based Society (London: Oxford University Press, 1963), and Rene Millon, "Variations in Social Responses to the Practice of Irrigation Agriculture," in Richard B. Woodbury (ed.), Civilizations in Desert Lands, Anthropological Papers No. 62 (Salt Lake City: University of Utah, 1962), 56-88.

Preliminary investigation reveals a system of bureaucratic dominance which may be a constraint on productive water use.[36] The establishment of viable and locally operated local water use organizations appears to be an important new construct required in West Pakistan's future water development. These organizations should be conceived for the maximum constructive participation by the local irrigators and institutions for innovative change. If not, they could either become another means by which to dominate the local people, becoming the instrument of despotism as so ably described by Karl A. Wittfogel,[37] or institutional "roadblocks" in the total irrigation system. Such organizations must be established as an incremental development within a well functioning hundred year old irrigation system.

In short, watering scheduling programs will require effective local organizations. How to establish such organizations remains a difficult question and requires much basic research on the water bureaucracy and the rural society at-large.[38]

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[36] The problem of bureaucratic dominance in the rural areas is treated in the two following essays: Mashihuzzaman, "Administrative Obstacles to Voluntary Organizations in Pakistan" in Inayatullah (ed.), Bureaucracy and Development in Pakistan (Peshawar: Academy for Rural Development, 1963), 180-94, and, Sarshar Ahmad Khan and Mazaffar N. Quershi, "Voluntary Organization and District Administration," in Inayatullah (ed.), District Administration in West Pakistan: Its Problems and Challenges (Peshawar: Academy for Rural Development, 1964), 149-60.

The inadequacies of the water management bureaucracy is indicated in the following case study where it took two and a half years to change a lateral in a watercourse: Iftikhar Ali Qureshi, "Administrative Delays, Supply of Canal Water Through Intervening Water-Course," Administrative Staff College Quarterly, 5(March-June 1967), 94-109.

[37] See his Oriental Despotism, A Comparative Study of Total Power (New Haven: Yale University Press, 1957).

[38] For a discussion of what is required see Community Organization for Irrigation in the United States (Rome: Food and Agriculture Organization, 1952).

IV. Summary and Conclusions

The benefits of a well-designed and administered water scheduling program appear numerous and substantial. Pakistan, as a consequence of 100 years of modern irrigation, has considerable organizational infra-structure, professional and scientific talent, and management capacity to initiate such a program. Its farmers have an understanding of soil-plant-water relationships. The present problem is not so much human as system design. The irrigation system was not designed for full delta irrigation (supplying total crop water needs during the growing season along with the leaching requirements), but rather as a means to provide supplemental water in time of crop need to avoid famine conditions. In recent years the irrigation system has been substantially modified by increasing its storage capacity and by the exploiting of the vast Indus underground water reservoir. The irrigation system, especially in the Punjab region, now has capacity to vary its water deliverance. For the first time it is possible to consider the development of irrigation scheduling based upon crop and soil needs.

A variety of talent will be required to develop and install an effective water scheduling program. The task is one that requires an inter-disciplinary approach and a concerted program effort. The easiest aspect will undoubtedly be the development of the knowledge and technology, since much of this can be acquired from adaptive research and found in West Pakistan are established and reputable research institutions for irrigated agriculture.

A more difficult aspect will be the development of an organizational infra-structure and a management capacity which will put this new knowledge and technology to work. This will require much innovative thinking and new social institutions. Some observers may state that the principal "bottleneck" will be convincing the farmers as to the importance of applying the proper amounts of water at the most appropriate time, since he occupies the key decisionmaking position in the total irrigation system. Such a negative view appears unwarranted. The West Pakistani farmer has already historically demonstrated several times his high adoptive and adaptive capacities. As he quickly capitalized on the technology of the tubewells and the so-called "miracle seeds." There is no reason to believe that the same would not occur, if it were satisfactorily demonstrated to him that a water scheduling program would yield a high return. The most positive factor is the Pakistani farmer. The questionable factor is the capacity of higher level authority to play a truly innovative role. Required is a neat working relationship between the formal government administrative machinery and the traditional agrarian society. How to forge this relationship constitutes a "knotty" problem.

Nevertheless, the continued possibilities to exploit the soil and water resources are rapidly declining. With the rapid expansion of the tubewells and the lowering of the water table, the deterioration of agricultural land is increasingly a problem of poor water management on the farms rather than that of inadequate design of the canal system. Already millions of acres of once productive agricultural land has been lost because of poor irrigation practices. Time has now arrived that this problem must be addressed in more definite terms of a management program than in the past. The problem cannot completely be resolved by engineering design and operation, although considerable improvement has been made in the engineering features of the water delivery system which has already contributed substantially to West Pakistan's agricultural progress. The weak component at the present time is the allocation of water to the farmer. The initiation of a water scheduling program could be the means to correct this situation.

Comments

William D. Romig
Chief, Water Resources Branch
Office of Capital Development and Engineering
Bureau for Near East South Asia,
U.S. Agency for International Development,
Washington, D.C.

Dr. Jones mentions in his paper the problem of low water supply and low agricultural production and touches upon the limitations built into the surface water system. The observations are sound. However, in considering the irrigation systems of Pakistan and India, it should be remembered that the objective at the time of the design of the works was a subsistence living for the maximum number of people in an agricultural economy. Under the "state of the art" and the needs of the time, an "extensive irrigation" concept appeared logical. However, the effects of salinity had not yet been recognized and understood. Likewise, the agricultural requirements have changed and the urban areas demand more food and fiber than provided under a subsistence system. Unfortunately, many of the government officials do not clearly understand the changing needs and the potentialities for improvement. Therefore, the extensive irrigation philosophy still guides the action of many in responsible positions. Modern water management concepts are relatively new and are not widely understood even in the United States. Therefore, one cannot be very critical of the conditions in Southern Asia.

The surface water systems were designed for an extensive concept of irrigation, and, also, to be operationally simple. For the conditions of a century ago, they were marvels of efficiency. This basic factor, however, renders it very difficult to significantly alter the method of water delivery. The canals do not have the capacity for better scheduled deliveries to such a vast acreage. Extensive enlargements of the canals would be difficult and probably more expensive to maintain. Also the added water may not be available when needed. A more flexible operating schedule, even if possible, would require a great increase in trained manpower. However, the general availability of groundwater permits wells to be interspersed throughout the surface water system which can supplement the surface water system and provide water supply flexibility.

The government tubewells under the SCARP program (Salinity Control and Reclamation Projects) are designed to serve from one to three "village" groups. Thus they can be, and generally are, operated almost on an "on-call basis." The private wells belonging to individuals or simple cooperative also provide such flexibility. Fortunately, the farmer can sense the water needs of his crop much better than detached officials, and demands water. The result is significant increases in crop yields in areas having wells. The wells also provide much needed drainage and sufficient leaching water to reduce or control salinity. This also adds to the crop yields. Undoubtedly, the farmers could do better with some type of training, but they seem to be learning by practical experience.

Dr. Jones raises the question whether we want maximum crop yield per acre of land, maximum crop yield per unit of water, or maximum return per unit of input? Although these questions are often debated, their differences generally have little bearing on the practical water requirement, especially if salinity is a significant factor. Leaching water must be provided above the actual evapotranspiration (consumptive use) occurring in the field. Also, moisture deficiencies at critical stages of plant development will sharply decrease the crop yields. Although it is possible to reduce the soil moisture at non-critical times and to schedule the leaching water effectively, this takes skill approaching that of a laboratory. It would be highly unlikely that the average farmer in a large area of irrigation could develop such skill. It would be even more unlikely that every farmer can do so. From a practical standpoint, it is better to aim for the water use that is "just equal to the consumptive use and the leaching requirement," as stated in the paper. Even this must recognize the farmer's abilities to achieve good irrigation efficiencies. We should, however, recognize that the leaching water requirement may be met, at least in part, by water "lost" in the "irrigation efficiency" portion of the computation. Leaching water, or part of it, may also be supplied by non-crop season rainfall or flooding.

Dr. Jones' paper recognizes the need for a knowledge of soil moisture in order to accomplish efficient irrigation. Equally important is a knowledge of root depth. As a plant grows, its daily evapotranspiration (consumptive use) increases and its roots extend deeper so that it needs more water but can extract more water from the soil profile. Knowledge of these latter factors along with soil porosity control the amount of water to be applied to fill the soil reservoir and the frequency of irrigation. Currently, the deliveries of surface water in approximately uniform quantities of water at uniformly spaced intervals, fails to properly utilize the soil reservoir and often restricts root growth and plant development as the plant matures. Again farmer education (training) would be helpful. However, the farmer tends to learn by practical experience and will gradually approach the correct procedure, if not prevented by outside restrictions.

The paper discusses a program of research and studies and "installing an irrigation management service." Such studies and research would be useful, if geared into a workable management program. To be workable, the management arrangement would have to have an impact from the highest government levels down to the poorest farmer. Therefore, it is futile to discuss the studies and research until the workability of the management service is assured. It is a major effort, even if it is only directed at the few million acres currently having significant well developments. In order for the program to succeed, it is essential that an interest in improved water management assistance be exhibited by those influential in the operation of the irrigation facilities. The program should then be designed to work outward from that point of interest.

Fortunately, West Pakistan is not standing still in this regard, even if there is no formalized program. The physical works that have been designed and built in recent years under the guidance of foreign consultants and technical advisors, include allowances to facilitate more effective irrigation. As these works go into use, practical experience is pushing the irrigated agriculture closer to the "ideal." With time, enough people will note the improvements and link them with the causes. At that time, hopefully, a desire for a more scientific approach will occur.

Dr. Jones implies that technical assistance to the farmer has been neglected because he has found only one published study dealing with irrigation water use. It should be recognized that publications have little value in spreading ideas to the farmers of South Asia, because they cannot read. Likewise, irrigation farming advisors in the area are generally too busy to write things just for publication. Admittedly, there are not enough well trained advisors to give all farmers all the help that they might want.

People should exercise care in blaming farmers for slow progress. In situations such as this, the farmer who has always irrigated has a pretty good idea how to get the most out of what he has. He needs advice most when he wants to attempt a change that departs significantly from his past experience. There is little purpose in trying to refine a farmer's irrigation practices, under a condition of restricted water supply, until he has the water necessary to affect a significant change. Then he can use some advice. However, farmers are generally shrewd and will make appreciable progress without help.

The paper contains a remarkable list of reference publications. However, I failed to notice mention of two significant sources of information on the basic subject. The so-called "Revelle Report" ("Report on Land and Water Development in the Indus Plain" by the White House--Department of the Interior Panel on Waterlogging and Salinity in West Pakistan, January 1964) provides an extensive analysis of the general problem of irrigation and salinity. Although this report is relatively old, it touches on many of the ideas in the paper by Dr. Jones. Also of significance are the series of feasibility reports on the individual SCARP's prepared by Tipton and Kalmbach of Denver. These reports discuss in detail the plans for the various projects and outline the anticipated use of water. They contain carefully developed water requirement data, by months. These are modified for the leaching water requirements and used as a basis of well design and location to supplement the surface water system. These have been computed for several different cropping patterns, and various localized conditions. Basically, this is the first step toward effective water management, adjusted to allow for practical operation rather than near perfection. Ideally, better water management can be accomplished, but the basic concepts are there from the standpoint project design. The reports do not deal with the organizational arrangements, however.