REPORT OF A PLANNING WORKSHOP ON

# IRRIGATION WATER MANAGEMENT

THE INTERNATIONAL RICE RESEARCH INSTITUTE

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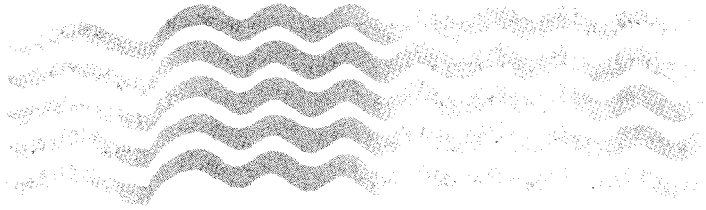

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The responsibility for this publication rests with the International Rice Research Institute.

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# FOREWORD

Irrigation expansion in the major rice-growing countries has been a primary component of agricultural development in the last 10 to 15 years. Rice-producing countries have recognized that good water control is a prerequisite to full utilization of high-yielding modern rice production technology to meet the growing demand for rice and other cereals. There is ample evidence, however, that various technical, economic, and socio-institutional problems impede the realization of the anticipated benefits from investments in irrigation. For example, in most rice-producing countries of the tropics, irrigation water use efficiency is abysmally low. And effective institutional frameworks to improve this efficiency are lacking or unused.

The International Rice Research Institute and its collaborators in national irrigation organizations are keenly interested in identifying factors constraining irrigation water use efficiency and in developing techniques to increase that efficiency. One of the roles IRRI plays is to sponsor conferences and workshops to permit interchanges among scientists and engineers interested in increased water use efficiency.

This publication comprises the issue papers presented and discussed in a Planning Workshop on Irrigation Water Management held at IRRI 26-30 March 1979. More importantly, it includes the recommendations prepared by the participants suggesting specific irrigation water management research issues to which IRRI and other research organizations should give priority. These recommendations are extremely valuable because they help the researchers focus their attention on meaningful problems.

The workshop participants included 46 research scientists, research administrators, and irrigation agency policy makers and project implementors from 9 countries -- Bangladesh, India, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand, U.K., and USA.

Much of the success of the workshop was due to the excellent planning by the organizing committee of which Drs. S. I. Bhuiyan,

# OPENING ADDRESS

N. C. Brady

This workshop brings together Irrigation Water Management specialists from all over the world to share knowledge on ways to improve that management and to identify research that IRRI and others should do to further improve it.

During the past 5 years, IRRI's planning procedures have increasingly used the approach taken in this workshop. We recognize that IRRI's primary purpose is to do the research that scientists and engineers, particularly those from the countries where IRRI serves, feel is needed. We ask leaders from national programs where rice is a primary crop, and those from the more industrialized nations, to join us in assessing the *state of the art* in each important research area we serve. Two important questions are asked:

1. What should be the research priorities for the next 5 years?

2. Which of these priorities require IRRI input? Which are IRRI uniquely suited to carry out and which are best done by the national programs?

In asking these questions we are acutely aware of the scarcity of the financial and human resources to support and do research. This forces us, with your help, to distinguish between research that is interesting and can be done someday from research that must be done now to assure adequate food in the future.

The 22nd annual meetings of the FAO-sponsored Intergovernmental Group on Rice held in Manila last week brought up two important points:

Director general, International Rice Research Institute, Los Baños, Philippines.

1. This year the supply of rice and, in fact, of most staple foodstuffs is good. India, the Philippines, and Korea, which were importing rice 5 years ago, are now exporters or have built up comfortable national stocks. Even in Indonesia and Bangladesh, which are regular importers of large quantities of rice, production levels are up and there is general optimism among agricultural leaders.

2. But, in the long run, continued food shortages are expected. By 1985, for example, the global demand for rice is expected to be 3 million tons in excess of supply. Some countries will continue their dependence on imports but the exporters will not be able to fully meet needs.

At IRRI considerable thought has been given to the probable sources of the additional rice needed to meet the projected increases in demand. How much can come from increased cropped area? How much will likely come from increased yields on land currently under cultivation? How much will likely come from increased cropping intensities in areas already under cultivation?

The combined judgments expressed in the *IRRI Long Range Planning Committee Report* suggest:

- In Asia there will be likely only small increases in land under cultivation -- most of the arable land is already in use. In Africa and South America, considerable increases in cultivated area can be expected but economic considerations may tend to hold this expansion in check.

- In Asia slightly more than half of the additional production needed in the next 20 – 25 years will likely come from increased yields of crop given on land currently under cultivation.

- About half of future increases will come from increased cropping intensities -- by increasing the number of crops grown each year on land now under cultivation. About 70% of this increase will come from rice and the remainder from upland crops grown in rotation with rice.

- Irrigation will play a significant role in providing the extra food needed. Nearly 70% of the extra rice and associated crops will likely be produced in areas with at least some irrigation, leaving only 30% for the area

dependent solely on rainfall. It is easy to see why we believe irrigation is important and that it does deserve research attention.

Recognizing irrigation's importance, we face three important questions:

1. To what extent will lack of information that research can provide constrain the development of irrigation projects or, once developed, constrain their effective utilization? These constraints may relate to policies and practices of the agencies controlling the water use, to the inadequacies of water distribution in a given command area, or to the failure to involve the farmers in any way in decision making with respect to irrigation water.

2. Which of the many researchable areas are most important to remove constraints from effective irrigation water management?

3. Of the high-priority research areas identified, which are the most appropriate for an international institute such as IRRI to become involved in? To answer involves further questions:

   - Which are better handled by national organizations without outside help?

   - Which can be performed only by the organizations in or outside the country, which are providing funds for the project?

   - Which should involve organizations with more interdisciplinary inputs than IRRI can muster?

We hope to find answers to these questions through this workshop.

# HARDWARE AND SOFTWARE: AN ENGINEERING PERSPECTIVE ON THE MIX FOR IRRIGATION MANAGEMENT

Gilbert Levine

Irrigation as the practice of supplying water to crops in amounts and at such times that yield is not impaired has three elements implied: 1. that the irrigator has appropriate knowledge of the relationship between crop yield (quantity and quality) and water applied to the soil; 2. that there is an adequate supply of water; and 3. that there is a mechanism for applying the water in accordance with the knowledge.

It is the last element that I address.

## MECHANISM FOR APPLYING WATER TO THE LAND

The mechanism for applying water to the land must be expanded to include the additional functions required for effective system operation: the maintenance of essential infrastructure and the management of water-based conflicts. I explore five propositions:

- Each of the basic functions of irrigation systems -- water delivery, maintenance, and conflict management -- has requirements both for physical infrastructure (hardware) and for nonphysical managerial inputs (software).
- Within each of these primary activities there is a significant degree of choice and dependence between the hardware and software elements.
- Designers of irrigation systems rarely consider the full range of choices nor recognize the degree of dependence between the elements.

Professor of agricultural engineering and director, Center for Environmental Research, Cornell University, Ithaca, New York, USA.

- The particular combination of hardware and software that is appropriate for specific situations depends on the interaction of several physical, social, and economic factors.

- Our knowledge of this interaction is limited and to a large extent qualitative and descriptive.

Water delivery, maintenance, and conflict management requirements

In general, and in its simplest form, the *mechanisms* for applying water to the land can be considered to consist of three parts: a *set of physical works* that can move the water from its source to the crop; a *plan* that defines the activities to be undertaken; and the *people,* individually and in groups, who implement the plan.

*Water delivery.* Basic to water delivery is the *physical infrastructure.* At a minimum, in gravity systems this includes a diversion structure, a main canal, and the subsidiary channels that permit the flow of water under the degree of control anticipated for the system. To vary water delivery control, devices and associated measurement structures are needed. In addition to the channels and control and measurement components, there is a need for communication infrastructure. Depending on the degree of control desired, there is a need for different levels of communication. The physical communication infrastructure may vary from bicycles to telephones to automated delivery of operational information. Examples of all types can be found, even in the rice-growing areas of Southeast Asia.

The *plan* for water delivery generally specifies the rules for water allocation, relating both to amount and timing, and the roles at least for the bureaucratic personnel, either individually or by groups (Coward and Levine 1978). Typically, the rules assume a specific response behavior on the part of the irrigator, i.e. that the irrigator will grow the crops anticipated by the designers, use specific techniques in the distribution of the water over the land, and achieve an expected level of water efficiency.

The plan is usually based on the assumed water supply-demand situation that the system is to meet -- the design condition. It may include modified rules and roles for conditions other than the design condition. Usually, of greatest concern are those situations when the water supply is less than that assumed for the design condition.

In government-controlled systems, especially those in which rice is the primary crop, water delivery plans are usually relatively simple, with respect to rules and roles. Typical are rules that specify continuous delivery of a specified flow rate, e.g. 1.5 liters/s per ha, between specified dates. A slightly more complex version might specify different flow rates for different time periods reflecting predicted changes in demand, e.g. land preparation, transplanting, main field, and harvest periods. Similar patterns of specified changes in flow rates might reflect anticipated variation in supply, especially in run-of-the-river systems.

In the foregoing situations the specification of roles tends to be restricted to the bureaucratic hierarchy. To the extent that there are expectations for irrigator involvement, roles are not usually specified.

As greater concern for efficient use of the water resource has developed (in many cases a result of concern for more efficient use of investment resources) there has been an increase in complexity of water delivery plans. Some form of rotational irrigation is typical of the increased complexity. In situations where crops other than rice are anticipated to be of importance, rules may be developed to permit irrigators to request deliveries, by date or amount, or both. This *demand* type system (usually constrained to control excess demands) is considered the most modern because it permits maximum irrigator flexibility. With this type of delivery rule, the specification of roles, of individuals and of groups, is more fully developed. Typical is the frequent inclusion of some type of water-user association, which may have some allocation responsibilities.

The *people* component of the water delivery function includes the members of the irrigation bureaucracy and those in the farming community with irrigation responsibilities. As suggested earlier, the roles of those in the bureaucracy are usually specified (with variable detail) citing responsibilities and authorities. By contrast, the roles, responsibilities, and authorities of the farmer-irrigators are seldom defined, although frequently there are implicit responsibilities particularly related to on-farm water distribution practices.

*Maintenance.* From the standpoint of the physical infrastructure, the maintenance activity has two aspects -- direct and indirect. The latter may be more important. Direct maintenance infrastructure includes integral components of the primary delivery

system such as desilting works, sediment sluice gates, etc. It also includes the equipment used primarily for maintenance, such as dredges, backhoes, etc.

The indirect aspect of the physical component of maintenance is a function of the physical characteristics of the basic water delivery structures. Channel shape, materials used, and type and number of special structures all have major implications for the amount and type of maintenance required, necessary skills to perform the maintenance, and relative balance between investment costs and annual expenditure.

*Plans* for irrigation system maintenance usually include provision for routine and special activities. The routine activities, including such mundane elements as painting structures and cleaning channels, are intended to maintain the original capability of the system to deliver water according to the delivery plan. The special activities are invoked when damage that is not covered by the routine maintenance program occurs.

The maintenance plan is accompanied by the specification of duties for the individuals and groups who are assigned responsibilities. Within the irrigation bureaucracy, maintenance may be the responsibility of a special unit or an associated duty of operational (water delivery) personnel. In many cases, a combination pattern exists, with operational personnel having routine maintenance responsibilities and the larger and special maintenance needs handled by specifically designated units.

In contrast to the water delivery function, specific maintenance roles are usually assigned to the farmer-irrigators, as individuals and in groups. Typically, the individuals are assigned maintenance responsibility for the channels that border or pass through their parcels; they may have some responsibilities for the channels serving their parcels. In the group context, the farmer-irrigators may be assigned responsibility for the larger type jobs, including special repairs, and they may be assigned responsibility for the collection of funds to support both operations and maintenance.

*Conflict management.* Inevitably, because irrigation takes place in environments of significant variability and involves relatively large numbers of individuals and groups, it produces some degree of conflict. The conflict can be internal, within the bureaucracy, between the bureaucracy and the farmers, or among the farmers. To minimize conflict, it is desirable to have widespread agreement on system objectives and procedures, a high level of

system performance, and a communication system that provides for an effective interchange through all levels within the system. Rarely do all these exist in a single system, and conflict can be anticipated.

Of primary importance in the conflict management area are the *software* elements of the implementation mechanism: the *plan* for adjudicating infractions of system rules. This plan identifies both the responsibilities and the authorities assigned to specific individuals and groups, as well as the specific procedures. Typically, the procedures proceed from informal mediation to the more formal processes of the legal system. Frequently, this set of conflict management procedures is accompanied by a set of procedures for minimizing the occurrence of conflict. These are an intrinsic part of both water delivery and maintenance activities, but extend beyond the effective implementation of those activities. Specifically, in potential conflict situations, e.g. water supplies much below normal, procedures are identified to increase the security of system operation and to increase the degree of communication between the farmers and the system bureaucracy.

The *hardware* component associated with conflict resolution is also of the indirect type and is typified by structural design and devices that help to increase the security of the system. Construction that makes it difficult to breach the channels and locks on adjustable gates are examples.

The *people* related to conflict management activity may involve those not associated with the basic operation and maintenance activities. At some stage in the settlement process, in many systems there is a relatively independent individual or group to act as an impartial mediator or judge. This may be a formal part of the general irrigation structure in the country or a component of the regular judicial system.

The foregoing has attempted to clarify the relative roles of the physical infrastructure and nonphysical components of irrigation systems by considering them in the light of their basic functions. This approach, however, tends to suggest a degree of independence of those functions and of the physical and nonphysical components that should not, and presumably do not, exist in systems as they occur in the field.

Degree of substitutability between the *hardware* and *software* elements

There is a wide range of hardware technologies available for delivering irrigation water. On one end, there is the primary

dependence on overland flow with a minimum of channels, on the other a completely closed system that delivers water to individual plants in the field. These technologies can accommodate the range of rules for water delivery, from continuous to rotation to demand, although with different requirements for maintenance, different opportunities for conflict, and major differences in the associated roles and rules.

Within this range of technologies there is a range of relative reliance on physical infrastructure vis a vis the nonphysical aspects. This reflects a zone of substitutability between these components. The magnitude of this zone and its characteristics may differ substantially among the different types of technologies.

The relative reliance on physical infrastructure and the nonphysical inputs can be examined by considering two sets of technology, representing different levels of monetary investment but having as goals the meeting of individual farmer needs and reasonable use of the water resource.

Let us assume that the primary crop is rice. In a low-investment context, a realistic assumption is that the system will be run-of-the-river, with a permanent or semipermanent diversion structure, a main canal, and secondary and other channels as deemed necessary. The degree of channelization can range from service directly to individual irrigation parcels to a terminal point that serves an area with many parcels.

*Water delivery.* If the basic water delivery rule is *continuous* flow, the channel configuration of service to individual holdings places a maximum emphasis on physical infrastructure and a minimum on the nonphysical inputs. The operating plan is simple, there is minimal need for communication, there is little need for neighbor cooperation. On the other hand, there is maximum need for security within the system because the opportunity to interfere with water flow exists continuously.

As the terminal point incorporates more and more farmers, the physical infrastructure established by the *formal* system decreases and the dependence on nonphysical elements increases, the latter primarily an inverse function of the degree of adequacy of the water supply. This increased dependence on *software* occurs primarily within the terminal areas and among the irrigators. As the number of farmer-irrigators served from a single terminal increases, the requirement for formalization of these nonphysical

inputs can be expected to increase. At some point in this aggregation of units, depending on topography, the need for conveyance dhannels, and especially for controlled division points, will persist even if the system control point is moved further up the system. The trade-off, or substitutability of physical for nonphysical elements, ceases et this point.

If the water delivery rule is *rotation* the range of alternatives changes. Rotation can occur at a number of levels within the system. If it occurs at the parcel level the only channel that must be increased in size (above that for continuous flow) is that serving the individual parcel. As rotation occurs at successively higher levels in the system, the number of channels that must have enlarged capacities increases. Usually accompanying the increase in channel capacity is an increase in control structure complexity. These increases in *hardware* (or at least the costs) are partially offset by the reduced security needs along the channels within the rotation zones. This reduction occurs because of both reduced need and reduced opportunity for interfering with the water flows (Wickham and Valera 1976). The needs for operating personnel also are reduced as rotation occurs at higher points in the system. Thus, the *rotation* rule increases the level of investment and the requirements for both physical and nonphysical inputs and also changes the type and location of substitutability between these inputs.

The *demand* rule has similar impacts. To serve individual irrigators on a demand schedule would require delivery channels of enlarged capacity (at least to that of the *rotation* rule) and a major increase in the control inputs. The latter would be both physical (some type of measuring device) and nonphysical, relating to communication needs between the irrigator and the ditch tender and internally throughout the bureaucratic structure of the system. In irrigation systems with small-holder rice as the primary crop it is unlikely that an individual *demand* rule would be considered appropriate, but a group demand mode is sometimes used. In this situation there is an increase in the requirement for cooperation and coordination internal to the group, reducing that required between individual irrigators and the irrigation bureaucracy.

The next level upward in investment intensity would occur when *storage* sufficient to balance annual water flows is incorporated into the system. Usually accompanying this investment is the *need* to more effectively utilize the water resource and the *opportunity* to do so. This generally results in an increased emphasis on water efficiency.

With this emphasis, traditional *continuous* flow is usually not considered an appropriate operating rule. At the least, periodic adjustments to the flow rate, based on need, are anticipated. This imposes a requirement that evaluation of needs be made in the field and transmitted through the system.

Thus, a storage-based system not only increases the investment in major physical infrastructure; it also imposes a need for greater inputs of managerial elements. It also expands the area of substitutability between the physical and nonphysical aspects, primarily as they relate to control. Two basic modes of control exist, *centralized* and *decentralized.* In a centralized system of a storage type -- especially where that storage is a significant distance from the command area -- it is necessary to have:

- a monitoring system at the local level to identify needs,
- the successive aggregation of this information at each control point in the system,
- the transmission of the aggregated data to a central allocative body,
- the decisions about allocations transmitted to the reservoir authorities, and
- notification back to the water management authorities at each of the control points.

Ultimately the farmer-irrigators are informed. This type of control is exemplified by the Upper Pampanga River Irrigation System in the Philippines. This same pattern would hold for both a *rotation* and a *demand* operating schedule.

Decentralized control could be achieved in two ways: by providing water to the control points, at whatever level of decentralization, and according to a specified rule *with* and *without* intermediate storage. In both cases, the decentralization reduces the need for effective information flows and for coordination throughout the entire system. Both can reduce the *administrative* losses of water associated with fluctuating releases.

Decentralization without intermediate storage suggests that the system will operate at lower levels of water efficiency than those theoretically possible with a centralized system. (It is not obvious that this would really be the case.)

Decentralization with intermediate storage reduces short-term demand fluctuations on the basic supply. Depending on the location and amount of the intermediate storage there will be variable reductions in needs for communication, coordination, and management skills. Intermediate storage should permit local flexibility in delivery scheduling, thus providing increased flexibility of cropping schedule and irrigation practice. Many examples of this combination of primary supply and intermediate storage exist -- in China (where these are called *melons on the vine* systems), the United States, and Brazil.

In Brazil, a system called the Alexander Gusmao project illustrates an extreme. Intermediate storage, equivalent to 2 or 3 days irrigation, is provided on each 10-ha farm; each storage is supplied by a continuous flow; there is essentially no communication requirement, except for emergency situations; and each farmer can utilize the irrigation water as he desires. As a result some farmers grow vegetables, with water distribution by sprinklers; others grow fruit trees, with water distribution by gravity in furrows; and others flood-irrigate rice. In this case there has been a maximum substitution of *hardware* for *software* in the main system and maximum utilization of the irrigators' managerial skills.

*Maintenance.* As suggested earlier, there are both direct and indirect aspects of the maintenance *hardware.* In both cases there are significant areas of substitutability with respect to the software, as well as interacting requirements.

In considering these topics it may be more useful to look at them directly in the context of potential problems rather than by comparison of the run-of-the-river and storage systems examples.

Important maintenance problems can be associated with the diversion structures, other control and measurement structures, and the conveyance channels. The diversion structures can be constructed using a variety of materials -- earth, rocks, concrete, etc. -- and each has a different probability of failure under specified flow conditions and a different level and type of investment associated with it. The *hardware-software* trade-offs and interrelations are obvious. Structures constructed of local materials are usually cheaper and more suitable for local construction skills, but must be maintained or replaced relatively frequently. This imposes the requirement that the system be able to mobilize the local inputs at the required frequency. By contrast, concrete and steel require less maintenance, but may require skills and resources not locally available when repair is necessary.

The system now must be capable of mobilizing these external resources, with less frequency but with similar speed as when local materials are used.

The situation with channel maintenance is similar. Sedimentation can be reduced by desilting works or by carrying the sediment into the channels, where periodic cleaning might be done by machine or by hand. The use of machines imposes special needs for their maintenance, including mechanical skills, spare parts, etc. Hand cleaning requires greater efforts at labor management. Comparable relations exist in relation to control of channel vegetation.

The maintenance requirement is influenced not only by the materials used in construction and by the conditions of the local environment, but also by the operating rules. As greater flexibility is designed into system operation, reflected by greater variation in channel flows and by more control structures, maintenance needs increase. Variable flow levels in channels encourage rodent and other animal activity and subsequent channel erosion and sedimentation. In addition, as channels are extended deeper into the farming area the magnitude of the maintenance requirement increases significantly.

*Conflict management.* The *software* component is the larger element in the context of conflict management. Again there are both direct and indirect elements. Here the indirect elements refer to the appropriateness of the operation and maintenance rules and the effectiveness with which they are implemented. The first step in conflict management obviously is to identify potential sources of conflict and to attempt to eliminate them.

There is a relatively limited zone of substitutability between the direct *software* and *hardware* elements in the context of rice irrigation in Asia. In principle, it would be possible to substitute automatic alarms for a program of control point surveillance, but the basic requirement is a system of acceptable rules coupled with an appropriate enforcement and mediation or judgment system.

## Design of irrigation systems and range of choices

The system design process normally has a sequence of decision-making that proceeds from the general to the detailed, with decisions about the basic water supply (run–of–the–river, storage, groundwater) made very early, decisions about general operating

rules made at a later stage, and decisions about specific organization, extent of the conveyance system, and structural details made still later in the process. There is some iteration in this process, with information developed in later stages being used to modify the decisions of the earlier stage, but the modifications usually relate to details rather than to basic approach, and tend to reflect adherences to the original ideas rather than open consideration of the developing alternatives and choices. As a result early decisions are crucial and tend to reflect a bias toward or at least an emphasis on the physical infrastructure.

Under present conditions, and from the perspective of the designer, there is considerable rationale for this approach. The fundamental decisions about type and general extent of the system usually reflect important political inputs. Significant changes in these decisions require greater interaction with policy and political agencies and groups. The complexity of relationships suggested in the two preceding sections -- and to be expanded upon in the next section -- coupled with the lack of definitive understanding of those relationships, makes the decision base uncertain. When this is accompanied by a lack of procedures for reasonably efficient and at least somewhat objective consideration of the choices, the lack of significant evaluation of the choices is understandable.

When the disciplinary make-up of the design teams -- with primary, if not complete, emphasis on technical skills (engineering, soils, agronomy) -- is recognized, the emphasis on the *hardware* elements is almost inevitable. This tends to be true even where management specialists, extension specialists, sociologists, and other social scientists are involved in other aspects of the total project development, such as the credit system. This tends to be the case, even where there is an early emphasis on the development of water-user groups. The role or roles for these groups are likely to be identified by *a priori* judgments rather than by analysis of potentials and trade-offs. Frequently, these roles are identified in terms of bureaucracy-perceived needs not by consideration of system optimization. When understanding of the time frame for the active design process is added to the foregoing, the logic of the traditional decision-making process becomes evident.

## Combination of *hardware* and *software* appropriate for specific situations

The recognition that a number of factors must be considered as decisions are made about specific elements of irrigation system

activities is implicit in the foregoing sections. To make it more explicit it may be helpful to examine one important decision -- how far to extend the water distribution system.

From the standpoint of efficiency in distributing water throughout the command area it is desirable to have a sufficient density of channels for a number of reasons. These have been detailed by Thavaraj (1973) and can be summarized as follows:

- presaturation and land preparation can be accomplished more rapidly;
- the cropping schedule can be intensified;
- more uniform distribution of water is possible;
- variable topography can be irrigated with less water; and
- delivery problems can be identified and isolated more easily,

But there are also disadvantages associated with this extension:

- channels cost money to build and maintain;
- channels occupy land area that might otherwise be used for cropping;
- channels may interfere with agricultural activities. If the channels are relatively permanent they can inhibit adjustment to a changing agricultural environment; and
- where the channels are to provide maximum benefit, there will be associated costs for control structures.

With a situation of combined benefits and costs it is difficult to identify a general recommendation for channel density. Thus, factors that affect the indicated benefits and costs must be considered.

The primary physical factors to consider are the topography, the average land gradient and the variability of topography, and the adequacy of the water supply. For hydraulic reasons the areas with flatter slopes require greater channel density than steeper areas to achieve the same degree of water control. Similarly, those areas with more topographic variability require greater channel density than more uniform areas.

Within limits, the more abundant the water supply the lesser the needs for channel density. These limits are related to the topographic considerations and to the expanded needs for drainage channels as more water is supplied.

Directly related to the topographic and water factors are those related to agricultural practice. In general, the greater the channel density the greater the opportunities for cropping flexibilility. This does not imply complete freedom to make independent decisions either within the unit served or for the unit in its entirety. Other factors such as insects and diseases, availability of labor or machines, etc., which are not bounded by the irrigation channels, affect that freedom.

Depending on the topography, there will be a differential effect of channel density on cropping flexibility. A proportionally greater flexibility could be expected to result when channel density of a specified level is provided for the areas of steeper topography than for the flatter, primarily because of the better drainage associated with the steeper areas.

The economic factors affecting the decision to extend the reticulation system are both direct and indirect. The direct, relating to costs of channel construction and maintenance, are straightforward in concept, although frequently difficult to evaluate in practice. This is particularly true for estimates of maintenance. It becomes especially difficult when the channels are planned to extend beyond the direct responsibilities of the irrigation bureaucracy. In this case there is a tendency not to evaluate the full maintenance costs, and to expect that they will be assumed by the farmer-irrigators. Experience in many areas has shown that expectations of this type are not necessarily realized. Compounding the problem of cost evaluation is the range of materials available for construction, with different impacts related to initial costs, construction costs, and subsequent maintenance,

The indirect economic factors are reflected primarily in the degree to which the farmers have incentives to use the opportunities theoretically offered by the increased water control in the successively smaller independently served areas. If the crop and cropping schedule are not likely to change, there may be little economic benefit for the farmer from this increased capability (Taylor 1976). If the water is otherwise controlled to provide reasonable water delivery, there may be little or no increase in water efficiency from the extended channels, or even from the more intensive rotation operating rule (Wickham and Valera 1976). Thus, an evaluation of the potentials for responding to the new

capabilities is essential before a rational decision about channel density can be made.

The importance of social factors as influences on irrigation system performance has gained increasing recognition in the past few years. This is especially true of the organizational factors, which have obvious relevance to the design question under consideration here. In the case of relatively small farming units, even where channels are extended to individual units by the irrigation bureaucracy, control of the delivery to those units and maintenance of the channels by the bureaucracy is extremely difficult. The number of employees required becomes prohibitive. The solution proposed, almost universally, is some type of farmer organization, which would take over the control and maintenance responsibilities internal to the user area. The appropriate size of that organization and the feasibility of its carrying out anticipated responsibilities depends on the local sociocultural environment. In Taiwan, the basic small group is about 150 farmers (about 1 ha/farmer) with subsets down to 10 (Ko and Levine 1972); in Malaysia it is suggested that 10 to 15 farmers (20-25 ha) be grouped into a neighborhood Irrigation Service Unit (Thavaraj 1978). In a reasonably homogeneous social situation at the local level, the extent and location of the delivery channels can be determined on the basis of the physiographic conditions. It can be visualized, however, that some social situations would inhibit the effective working of a small group formed primarily around a water channel designed to meet only physical conditions.

The irrigation designer intent on making the most appropriate decision about the extent of reticulation for a specific system thus is faced with a significant set of data collection, analysis, and integration problems.

## Interaction of factors affecting the *hardware-software* mix

The ideas suggested to this point have been presented primarily in descriptive terms. To some extent the direction of relationships between interacting factors has been indicated, but there has been essentially no presentation of magnitudes nor shapes of these interactions. To a major extent this is due to the lack of such information. In recent years a number of studies have attempted to describe more completely and more accurately the management activities, capabilities, and constraints of in-systems of different types: Coward (1976), Ko and Levine (1972), Nickum (1977) , and Ongkingco (1973), among others. These have added to a qualitative understanding and to the subsequent growth of interest and concern in this area. But studies that have

attempted to define relationships among these factors or to make experimental comparisons of alternative combinations have been few, with the studies by Wickham et al (1974) and Miranda (1975) as notable exceptions.

It seems appropriate, therefore, from the standpoint of this workshop to at least suggest some of the basic questions within which the question of balance between investment in *hardware* and inputs of software is embedded. It is not difficult to identify a number of illustrative examples from the perspective of the irrigation system designer:

- What water efficiency should I use in establishing the command area?
- What are the most appropriate operating rules for water delivery?
- To what level should terminal facilities extend?
- At what point should control be transferred to the farmers?
- To what extent should I avoid (or utilize) nonlocal materials?

These do not represent the only important design questions, but are obvious ones.

To identify the research questions associated with these design questions and to develop the appropriate research techniques is more difficult. One example may suffice to make the point. For the first question, one can develop a number of questions, some of which are research in nature. It is clear that this design question has important physical, economic, and organizational components. From the physical perspective, information is required about the seepage characteristics of the areas through which conveyance channels will be placed. With this information, and relative costs of various types of construction materials and procedures, it is a standard engineering exercise to determine the cost (both investment and estimated annual) to save specified amounts of water. In a similar way, the seepage and evapotranspiration requirements can be established with reasonable accuracy and precision.

Of more uncertainty is the variation in water usage as a function of management inputs and the costs of those inputs. It is clear that for rice production a major water use variable is

related to land preparation and evidence suggests that this is related to the way water is delivered. Thus, a significant research question might be:

*How does the use of water vary in relation to stability of water delivery during land preparation?*

Presumably this could be investigated either experimentally or by studies of existing situations. Variables might include different levels of uncertainties and different rates of water delivery.

A second research question logically is raised:

*What is the effect of density of conveyance network on stability of water delivery?*

Recognizing that rotation of water during the land preparation period is theoretically the most efficient water delivery method, yet aware that this rule is not adhered to even in systems that generally use the rotation rule, research that attempts to explain this paradox would complement the first two.

This workshop provides an opportunity to explore these types of questions in more depth, and to characterize the research in relation to its degree of site specificity.

Some questions in each individual design situation are so dependent on the specific of the local environment that they might logically be included in the planning and design process. Others may suggest aspects of generality that answers could be applied on a larger scale -- provincial, national, or regional. To the extent this can be done, it will be helpful in establishing priorities for the different types of research organizations with concerns for irrigation problems.

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# IN SEARCH OF A WATER REVOLUTION: QUESTIONS FOR MANAGING CANAL IRRIGATION IN THE 1980s

Robert Chambers

This paper is concerned with the main system operation of large and medium-size canal irrigation in South and Southeast Asia. The argument and the conclusions are designed to complement and support the many initiatives -- including improved design and construction, physical improvements to delivery systems, field layout and leveling, agronomic and hydrological research, and community-level organization -- that are being undertaken or contemplated to improve large and medium-size irrigation systems.

## VALUES AND CRITERIA

A first step is to be clear about objectives and values. The values that underlie this paper are concerned with permanently reducing and eliminating rural poverty. The relevance and potential benefits of irrigation hardly need spelling out: increasing food production especially with the new technologies; stabilizing flows of food and income from year to year; spreading food and income flows more evenly round the year, and reducing seasonal shortages and stress; slowing, arresting, and reversing processes of impoverishment; and where there is population pressure, supporting and retaining rural populations and reducing rural to urban migration. This paper calls for a search for analysis, understanding, and ideas with practical applications; and this directs attention to those areas about which less is known and where the chances of breakthroughs may be greatest.

In practice, there are multiple criteria for assessing what constitutes improvement in an irrigation system. The following criteria can all be applied to institutions, to water

Institute of Development Studies, University of Sussex, Brighton, United Kingdom.

distribution and allocations, to other elements in an irrigation system, and to choices between alternative directions in research and action.

## Productivity

This refers to the ratio of production, or of some measure of economic value of production, to scarce resources used or consumed. There is thus productivity of labor, land, other scarce resources, or an irrigation system as a whole. In considering priorities in irrigation, the most useful gauge is often, though by no means always, the productivity of water, because water is often the most limiting factor. But it must be recognized that each situation must be assessed separately, and that water may be limiting only at some time of the year.

## Equity

This refers to a fair distribution of resources and livelihoods. In its most common usage, it describes the equitable distribution of water to cultivators, but in a wider sense it includes opportunities for secondary and tertiary employment generated by irrigation. Population support is one aspect. In many environments it is critical to provide adequate livelihoods for a larger number of people the year round. Where water is scarce, water should be thought of in terms of the livelihood-intensity of its alternative uses. This may include the smoothing of seasonal troughs in food and income flows, and providing continuity of work, employment, and production around the year. These seasonal aspects are especially significant for reducing poverty and preventing impoverishment (Chambers et al 1979).

## Stability

This refers to the capacity for long-term sustained irrigation without environmental depletion, deterioration, or loss of productivity. This refers particularly to avoiding salinity, silting, flooding and waterlogging, weed and pest infestation, erosion, and groundwater depletion.

## Utility to irrigators

This refers to the utility to irrigators of the quantity, timing, and predictability of the water they receive

or obtain. Different analysts have used different words to describe water supplies: reliability, including a reduction of uncertainties surrounding water supply (Harriss 1977), and *predictability*, *certainty*, and *controllability* (Reidinger 1974). Utility to irrigators can be divided into appropriateness and predictability of water delivery. Appropriateness here includes quantity, place of delivery, timeliness, and controllability; and predictability includes both reliability (low risk of failure) and certainty (knowledge of the planned delivery and of the low risk of failure).

In any irrigation system there will be tradeoffs between these four criteria, and quantification of those tradeoffs may often be difficult. The criteria can be used as a checklist for determining priorities when appraising an irrigation system.

## THE POTENTIAL IN IRRIGATION SYSTEM MANAGEMENT

Surprisingly little research and writing in the social sciences is directly relevant to the management of the bureaucracies which manage medium and large irrigation systems.[1] There are, however, indications that this is an area with considerable potential. Again and again, analysis of other aspects of irrigation leads toward the importance of efficient and predictable operation of the larger irrigation system. The report on a 1976 research seminar on irrigation systems in Southeast Asia cites relevant evidence from the Philippines and the Pekalen Sampean Irrigation Project in East Java (Lazaro et al 1977). Valera and Wickham (1976), reporting on action research in the Philippines, wrote:

> "In traditionally managed systems, there is little benefit to be realized from intensive on-farm development as long as the supply of water in the distribution canal is unstable and unpredictable. For example, farmers with easy access to water have little incentive to build on-farm ditches because they already receive more than enough water. Farmers at the lower end of the system likewise cannot be expected to build ditches if the supply of water in the canal is not sufficient to supply these ditches reliably."

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[1]Exceptions include the work of Ali (1978, 1979), Bottrall (1978a, b; see also Newsletter of the ODI Irrigation Organization and Management Network, 1978 to present), Moore (1979), and Wade (1975a, b; 1976; 1978; 1979a, b). Many of the points made in this section have already been made by these authors.

Other research suggests that farmers are likely to cooperate in off-farm water management activities provided adequate and timely delivery of water in the main irrigation system can be assured (Duncan 1978, Valera and Wickham 1976). Much earlier, in Sri Lanka, the sociologist with the UNDP appraisal mission for the Mahaweli Gange irrigation project found at least three of his survey findings pointing at system water management as a concern, causing him to conclude that research on the operation of the irrigation bureaucracy was needed (Barnabas 1967, Chambers 1975). But the furthest one usually taken into the bureaucracy is at the lowest level -- the ditchtender or his equivalent, as in the studies and analyses of Coward (1973; 1976a, h). The operation of the larger system remains, in Wade's phrase, a *black box.*

Let us consider the potential from improving main system management.

- The area under command of canal irrigation is large and increasing. The net area under bureaucratically managed canal irrigation in South and Southeast Asia is about 50 million ha. In its 1978-83 five-year pian India alone has planned to extend that by no less than 8 million ha (India Planning Commission 1978). On a smaller but nationally significant scale, Sri Lanka has embarked on accelerated implementation of the Mahaweli Project. With the priority attached to extending irrigated area by these and other national governments and by the major donors, especially the World Bank, a sustained and substantial increase can be foreseen in the area under command of canal irrigation in South and Southeast Asia.

- There is accumulating evidence that improved management can achieve both production and equity objectives on existing systems.

At one level, this can be seen in terms of expected potentials which are not realized. It is common for the areas actually irrigated to fall far short of those planned. An example is the Uda Walawe project in Sri Lanka. It was estimated that 32.794 ha could be developed (ADB 1969), but in 1977-78 only 7,287 ha were receiving water. Water was issued freely at the top end when the planned hectarage implied stringent controls on water issues. As always, there were multiple explanations at different levels, including porous soils and inappropriate cropping patterns. But even allowing for errors in earlier

appraisals, less permissive management of water allocations could have enabled a much larger population of irrigators to benefit and much more to be produced.

Elsewhere, five examples of improved management that have led to benefits in production and equity have been identified.

- Two were responses to water shortage crises which led to temporary tightening of water issues and higher production by more irrigators than would otherwise have occurred: the first was on a command of 74,899 ha in Andhra Pradesh in 1976 (Wade 1979a); the second was on a command of 5,263 ha of the Rajangana Scheme in Sri Lanka, also in 1976 (Shanmugarajah and Atukurale 1976).

- In a third example, water scarcity was induced, administratively. This was on the Tungabhadra High Level Canal in Andhra Pradesh (Wade 1978). The canal served a potential cultivable irrigated area of 45,344 ha but by 1976 was irrigating only 34,008 ha or 75% of that potential. Resolute administrative tightening of controls and enforcement of existing regulations in 1976 improved water supplies to the tail end and induced a large-scale switch from paddy to crops that made more productive use of the water.

- The fourth and fifth examples are monitored experiments in the Philippines. The results reported are striking. In 1975, IRRI researchers working jointly with the National Irrigation Administration (NIA) introduced improvements in water distribution on Lateral C of the Peñaranda River Irrigation System (PENRIS), an area of about 5,700 ha. Production in the 1975 dry season increased by 97% on the base year (Valera and Wickham 1976). In a later experiment, another IRRI team working with the NIA on the Lower Talavera River Irrigation System (LTRIS) reported increased production of about 602 (Early 1979 and personal communication), despite serious pest attacks in the succeeding dry season.

If a 10-20% improvement in system productivity could be achieved in South and Southeast Asian canal irrigation, additional production could amount to tens of millions of tons of foodgrains; and much of this would be produced by tailenders who are at present relatively deprived of access to water.

To realize this potential well-focused and unbiased studies are needed. But there are professional problems.

- The professional skills of economists and engineers are more fit for appraisal, design, and construction than for operation and management.

- Irrigation management problems can be sensitive issues to the irrigation bureaucracies; they may not be researched because of that (Bottrall 1978a). De Los Reyes (1978) indicates how water rotation schemes are affected by pressures placed by influential persons on the irrigation officials, or that result from social relations between farmers and irrigation management staff.

- There is also the temptation of blaming the irrigators for water waste rather than examining how water is distributed and supplied.

- The problems and behavior of the staff who manage irrigation systems have been historically a neglected research area for various reasons, which include the sensitivity issue and the lack of interest of any given group of professionals. But changes in water distribution require changes in the behavior of the concerned staff. Unless their rationality is understood as part of the system, attempts to improve water distribution may not succeed.

## ISSUES IN ACTION RESEARCH

In seeking any change in the allocation of resources, a basic question is *who will gain and who will lose.* If all will gain, change is easier. If some must lose, it is necessary to anticipate their resistance and to find ways by which it can be overcome, or by which the group can be compensated for or reconciled to their loss. Land reform has often foundered because the powerful and well-off must lose. Water reform is, however, not so clear-cut. It affects three groups of people: top-enders, tailenders, and the irrigation staff.

In seeking to achieve water reform, three questions can be addressed:

1. *Can all irrigators gain?* In the five examples cited earlier,. less water was issued to top-enders than they would have received without the reform. Top-enders usually resist such changes, believing they will lose by them. The challenge here is to see whether the supply of water to the tailend can be improved without the top-enders losing.

Top-enders who receive less water may, however, lose in many ways.

- Top-enders may be using flooding to inhibit weed growth; without enough water they may lose yield to weeds, or be forced to substitute labor or herbicides for water.

- They may believe, perhaps correctly, that they get higher paddy yields with flowing water, which is cooler, than with standing water, which is warmer.

- Where land is uneven, as Duncan (1978) has pointed out, farmers who flood their fields increase yields from the high parts, which otherwise would not receive adequate water. Farmers with localized small areas of high seepage may also want plenty of water to prevent those areas from going dry early.

- Farmers may have crops at different growth stages so they want a continuous water supply. If farmers fear the risks of not having their fields full of water, deep flooding is an insurance.

Despite these possible losses from insufficient water, the question of whether there might be a situation in which farmers would prefer less water should be considered. In three of the five cases cited here, top-enders either may not have lost, or may actually have gained, from the reform. The Tungabhadra example is complex and equivocal and demonstrates room for maneuver, with some farmers apparently prepared to sacrifice quantity of water or the growing of an accustomed crop for other benefits; however, no clear conclusion about gainers and losers can be drawn.

Top-ender benefits in the cases from the Philippines were clearer. On the PENRIS system, Valera and Wickham (1976) reported substantial increases in production in all sections of the scheme, although the increase rose sharply towards the tail end. For the four main sections, top to tail, the percentages of increase (area cultivated x yield) from the 1973 dry season to the 1975 dry season were 23, 69, 154, and 1,494% respectively. Top-enders' main gain in the first year (1974) was from a higher area planted, and in the second year (1975) from an increase in yield. Tail-enders gained from both. On the LTRIS system (Early 1980), laterals were monitored at the top, middle, and tail. A comparison of the 1976 wet season yield before intervention and the 1977 wet season yield after intervention showed yield increases

of 94 and 62 for two top-end laterals, 16 and 10 for two middle laterals, and an average of 104 for three tail-end laterals (*Ibid*, Table 3). Yields leveled up at the top end and tail end, having previously been highest in the middle.

There had previously been excessive water at the top in both PENRIS and LTRIS; this excess was transferred through to the tail. The situation was far from zero sum for top-enders, although they were initially cautious about the changes. They gradually came to support the new scheme once they were assured of an adequate share of water even in times of water shortage (Valera and Wickham 1976). The question, then, is whether in a given situation top-enders can indeed benefit, according to their own criteria, from water redistribution. One of the most significant trade-offs may be between timeliness and predictability of water supply on the one hand, and quantity of water on the other. In a state of near-anarchy, farmers are likely to prefer a continuous flow. In a controlled situation, they may perceive a higher utility in less water predictably supplied. Their benefits may derive from:

- more timely operations;
- more retention of fertilizer and fertility in the soil;
- less waterlogging;
- greater ease of water control at the field level;
- more predictable and perhaps lower labor inputs for water control and release of time between waterings for other activities;
- an additional crop if adequate water is saved and delivered;
- a switch to more profitable crops that use less water and that cannot be grown with flooding.

An action research priority should, therefore, assess to what extent, in what circumstances, and how reform can benefit top-enders, or at least not penalize them. This may be more common in areas of higher rainfall and top-end flooding, like the Philippines, than in areas of lower rainfall, like central India. This question requires the combined expertise of engineers, agronomists, and agricultural economists and of other disciplines. Wherever top-enders can gain, or not lose, as in the Philippine examples, reform should be less difficult. There

may be many such opportunities. But it is likely that analysis will also reveal many systems in which top-enders do have to lose, where reform will therefore be more difficult, and where it may require a deliberate institutional component if it is to succeed.

2. *Institutional engineering: can decisions be enforced?* Because water is a valuable resource for which there is competition, solutions to water problems must often have an institutional or political component. Where top-enders have to lose, there will be an especially strong case for "institutional engineering." Action research priority here is to explore possible alternative solutions to the problem that will suit the physical and socio-economic environment of the farmers concerned. Identification of existing cases where there are irrigation constituencies and management committees, analysis of comparative experience, and innovation of approaches for adaptation, introduction, testing, and development elsewhere should be considered priority research problems.

The reform adopted in the Tungabhadra High Level Canal, as cited by Wade (1978), is an interesting and relevant example. Redistribution of water from top-enders to tailenders was sought by an administrator and an engineer. Some top-enders were to lose, notably those who had been growing paddy when their land had not been zoned for it. An enabling factor in the success of the reform appears to have been that the Minister for Local Government represented a constituency in the tail end, which could not reliably receive water if much of the upper reach was growing paddy (Wade 1978). This raises the question whether special representation of the tailenders' interest can offset the advantages that top-enders enjoy through their physical position. Perhaps a management committee, which can make decisions about water allocations between groups, can be created with an overrepresentation of tailenders to offset their physical disadvantages. Such a management committee might legitimize the unpopular work of staff who have to deny water to those who unduly want it.

3. *Management: how will the irrigation staff be affected?* The problem here is to identify the different behavior required of the irrigation staff and to make it sensible for them to adopt that behavior.

A realistic understanding of the real world of the irrigation staff is necessary. One must understand "how irrigation

officials at various levels actually make decisions, the sorts of pressures that are brought to bear on them and their response to those pressures. (One must know, too, the decisions they do not make and the pressures that are *not* brought to bear on them)" (Wade 1975a).

Bottrall and Wade have shown that the real world of irrigation staff is researchable. As in bureaucracies generally there are informal as well as formal systems. There are cases of political influence, of civil servants being threatened with transfer, of unofficial augmentation of official salaries, of falsification of water flow records, of turning blind eyes to infringements. There are also instances (see, for example, Wade 1978) of imagination and courage on the part of civil servants who resist pressures and manage to improve production and the equity of water distribution.

In many reforms, two changes in behavior are likely to be needed: first, resisting pressure from some irrigators for more water; and second, disciplined control of water movements in terms of timing, quantity, and location. Both changes require staff incentives that override counter-incentives. Decisions about water allocations made or endorsed by management committees representing all cultivators may legitimize action that is unpopular with some groups. In addition, a more disciplined and tightly controlled organization may often be a necessary complement. Detailed attention to procedures, as for example by Valera and Wickham (1976), Honadle (1978), and most recently Benor (Andhra Pradesh Command Area Development Department 1979), is also likely to be part of any effective reform; and experiences such as that with the pasten system of water distribution in Indonesia are likely to be relevant (Pasandaran and Taylor 1976).

But whatever the mix, more action research is needed to identify and develop combinations of approaches that will make it rational for irrigation staff to behave in the desired manner, and especially at times to deny water to irrigators who want it. Irrigation staff must gain from reform; or, if they must lose, it must be made rational for them to accept their loss. Unless this issue is tackled realistically, water reform cannot be expected to succeed.

## AN APPROACH TO APPRAISAL: QUESTIONS TO ASK

It is understandable that approaches to appraising existing irrigation systems should ask and seek to answer questions raised by the concerns of the professions and disciplines involved. The

questions normally asked in hydrology, engineering, agronomy, economics, and community-level sociology are important. Their importance varies among systems and among zones within a system. But on their own they do not cover the management and operation questions raised in this paper. In particular, they bypass questions of distribution and allocation of water in the operation of the main system and questions of who may gain and who may lose in any changes in distribution and allocation.

The following questions can be addressed to an existing irrigation system:

- What water (quantity, timing, probability) is available?
- How (quantity, timing, place) is it in practice distributed?
- Using the criteria of productivity, equity, stability, and utility to irrigators, how can it be redistributed so that all concerned -- top-enders, tailenders, and water management staff -- will gain?
- What steps can be taken to achieve the changes needed?
- What changes in institutions and procedures will make it rational for those who will lose to accept their loss?

These questions are suggested as a framework or core for appraising an irrigation system, for identifying key technical questions, and for determining interventions.

## THINKING TOWARD A WATER REVOLUTION

The potential of action research on these lines can best be established by trying it out. A precondition for success is a multidisciplinary tolerance and openmindedness among those who take part. This entails introspection about the ways in which irrigation systems are viewed.

For the future, perhaps scientists and engineers should not allow themselves to regard such questions as *a people's problem* and therefore beyond their competence. Nor should social scientists allow themselves to dismiss a defect in water distribution as *a technical problem.* My suggestion is for biological scientists and engineers to come to think like social scientists, for social scientists to come to think like engineers and biological scientists, and for all to think in terms of the manage-

ment of people and of political economy, of who gains and who loses. A priority for the 1980s is to learn how to train such professionals, and then actually to train them so that people of different disciplinary backgrounds think more like one another, so that more interdisciplinary collaboration takes place in the same brain, and so that collaboration between individuals on teams can be more effective.

The challenge, then, is not just for action research; it is also cognitive. It concerns loosening, broadening, and balancing the ways in which professionals see irrigation and irrigation systems. For this, new syllabi and new methods are needed. As Carl Widstrand has pointed out (1978), it takes a very special kind of person, a social scientist for whom training is not yet provided, to take part in interdisciplinary work on water programs. No doubt something can be achieved with traditional learning approaches such as workshops, seminars, and conferences, although these can become repetitive rituals for celebrating unawareness. Other approaches include the use of games and role-playing, with irrigation engineers playing tail-end farmers, sociologists playing engineers, agriculturalists playing farmers' representatives, and so forth.

Whether water reforms could amount to anything that could be called a water revolution remains to be answered. Much depends on the speed, vigor, and imagination of any action research undertaken to find ways of changing main system management and the behavior of irrigation staff. The difficulty of such work may deter it, as may its lack of a disciplinary base. But not to attempt it can be a tragic loss of opportunity. For what is at issue both builds on and goes further than the green revolution. With a water revolution, perhaps millions of tailenders currently deprived by their disadvantaged access to water could, through a better water supply, benefit more not just from the water but also the new seed-water-fertilizer technologies. Whereas the green revolution achieved large increases in food production but brought about mixed equity effects, a water revolution would achieve both production and equity objectives at the same time. The search for such a revolution may be difficult but the stakes are high enough to seem worth a try.

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# ECONOMIC ANALYSIS TO SUPPORT IRRIGATION INVESTMENT AND MANAGEMENT DECISIONS

Donald C. Taylor

This paper is intended to show the potential for economic analysis to provide insights for those entrusted with decision making on irrigation investment and management in Asia. The word *irrigation* in this paper includes all functions related to effective water control in crop production, including drainage and flood control.

Particular attention is given to empirical economic literature and ongoing research studies of Asian irrigation. Although the focus of the paper is economics, I believe that effective irrigation research by economist must involve collaboration with practitioners and researchers in the physical and biological sciences, particularly engineers. This collaboration is especially critical at stages when problems for research are identified, research designs are formulated, data are collected, and research findings are interpreted.

The paper is organized around two central themes: alternative approaches to irrigation infrastructural development and selected issues in irrigation policy and management. This was based on a consideration of (1) the content of available literature and ongoing research, and (2) my judgment on how investment and management strategies might be meaningfully conceptualized by irrigation decision makers.

## ECONOMIC ANALYSES OF ALTERNATIVE APPROACHES TO DEVELOP IRRIGATION INFRASTRUCTURE

A country's irrigation infrastructure may be developed by constructing new irrigation projects, rehabilitating the infrastructure in existing irrigation projects, and providing more

Associate for Malaysia, Agricultural Development Council, New York, and visiting associate professor of agricultural economics, Malaysian Agricultural University, Serdang, Selangor, Malaysia.

intensive terminal infrastructure in existing irrigation projects. The latter involves extending infrastructure so that individual fields are supplied more directly with irrigated water (Lazaro et al 1977). Under the second alternative, existing structures may be improved as well as rehabilitated.

Each approach involves a rather unique set of issues. The challenges are to determine realistic technical alternatives in particular circumstances and to analyze each alternative from economic and financial standpoints. It is recognized that the analysis of technical alternatives involves several perspectives besides economics, e.g. social, cultural, institutional, ecological, and environmental.

This section reviews briefly a recent report, which emphasized strongly the need for developing irrigation infrastructure in Asia, outlines the nature of economic analysis that can be used to evaluate alternative investment possibilities in irrigation, and reviews research on the economics of infrastructural development in Asian irrigation.

## The Trilateral Commission Report

The recent Trilateral Commission Report on strategies to reduce malnutrition in developing countries (Colombo et al 1978) concludes that water control is the most fundamental constraint to increased food production in Asia, and that the rate of future investment in Asian irrigation infrastructure must accelerate considerably. Their proposal calls for US$52.6 billion to be invested over the next 15 years to develop irrigation in Asia.

Initial analysis of the worldwide food situation led the Commission Task Force to see that:

1. at least 460 million people in the world are malnourished, and

2. in recent years the tendencies are strong for expanded food grain exports from North America and expanded food grain imports into Asia and the Far East.

Deterioration in the trade pattern for Asia and the Far East is most marked for rice. The growing Asian rice deficit, the existence of a thin international rice market, a superior protein quality in rice compared to wheat, and the judgment that the potential for increasing rice productivity in Asia is substan-

tial, led the Commission to select rice production in Asia as the specific food production target to be emphasized over the next 15 years.

The Commission's judgment on the substantial potential for increased rice productivity in Asia was based primarily on their noting a strong positive relationship between rice yields and irrigation rates (irrigated rice area ÷ total rice area) in various Asian countries. Six alternative strategies for increasing production were examined:

1. converting uncultivated land into adequately irrigated land,

2. converting rainfed land into adequately irrigated land,

3. converting inadequately irrigated land into adequately irrigated land,

4. converting uncultivated land into inadequately irrigated land,

5. converting rainfed cultivated land into inadequately irrigated land, and

6. converting uncultivated land into rainfed cultivated land.

Alternatives 1, 2, 4, and 5 involve four variants of the *new project* approach mentioned above. The third involves *intensified terminal infrastructure. Rehabilitation* was not explicitly considered by the Trilateral Commission.

The distinction between *inadequately irrigated* and *adequately irrigated* land is based on the density of irrigation canals, with 50 m/ha as the cutoff point between the two categories.

The prospective cost of infrastructural development and the increment in yields that could be expected to result from each investment alternative were then estimated (see Table l), based on experiences in 10 irrigation projects financed by the Asian Development Bank from 1968 to 1972. Using the cost per ton of expected additional rice production as their decision-criterion, the Commission concluded that Alternatives 2 and 3 would be most economical. They also indicated that investment projects involving these alternatives may take less time to complete than investment projects involving the development of formerly uncultivated land.

Table 1. Illustrative model indicating capital investment for six alternatives to increase rice production by 1 ton/ha per year.[a]

| Land status | Virgin land (un-cultivated) | Rainfed paddies (no irri-gation) | Inadequate irrigation (irrigation canals of less than 50 m/ha) | Adequate irrigation (irrigation canals of more than 50 m/ha) | cost of infra-structure (US$/ha) | Rise in paddy yield (t/ha) | Cost of addi-tional paddy (US$/t) |
|---|---|---|---|---|---|---|---|
| Paddy rice yield (t/ha) | | | | | | | |
| Wet season | 0 | 1.0 | 3.0 | 3.5 | n/a | n/a | n/a |
| Dry season | 0 | 0 | 1.0[b] | 2.5[c] | n/a | n/a | n/a |
| Annual total | 0 | 1.0 | 4.0 | 6.0 | n/a | n/a | n/a |
| Investment alternatives | | | | | | | |
| 1 | → | → | → | → | 3,000 | 6.0 | 500 |
| 2 | | → | → | → | 1,500 | 5.0 | 300 |
| 3 | | | → | → | 400 | 2.0 | 200 |
| 4 | → | → | → | | 2,600 | 4.0 | 650 |
| 5 | | → | → | | 1,100 | 3.0 | 367 |
| 6 | → | → | | | 1,500 | 1.0 | 1,500 |

[a]Data based on ten irrigation projects financed by the Asian Development Bank during 1968-72, modified for inflation. [b]Based on the assumption that only 1/3 of the area planted during the wet season can be planted in the dry season; the yield during the dry season for the total area is 1/3 that of the wet season. [c]Based on the assumption that only 2/3 of the area planted during the wet season can be planted in the dry season; the yield during the dry season for the total area is 2/3 that of the wet season. Source: Colombo et a1 (1978, 26), but with a slightly revised format.

## Economic methodology for evaluating alternative irrigation investments

The methodological descriptions I use here are intended to be illustrative. In-depth treatments of the methodologies are not given; neither are the methodological approaches indicated exhaustive.

Preproject feasibility studies determine whether contemplated projects are economically and financially viable. The studies are usually done by consulting firms or line-operating government agencies. Hardness of data, length of time for study, and depth of economic analysis are often quite restrictive with preproject feasibility studies.

Postproject evaluation studies are undertaken to provide feedback to planners on the extent to which intended goals are being met, identify possible weaknesses in projects, meet the conditions of international lending agencies (Carruthers and Clayton 1977), and distill from previous experiences lessons for a more realistic and effective planning of future irrigation development projects. The studies utilize data from actual experience in the project being studied. The pressures for a fast completion of postproject evaluations are usually less than with preproject studies, thereby usually permitting postproject evaluations to involve deeper and more comprehensive analysis.

Unlike preproject evaluations, many postproject evaluations involve formal economic research. This paper is limited to postproject evaluation studies.

The basic approach in postproject evaluation studies is to compare the actual realized performance of a project over one or more recent seasons with either:

- the projected performance of the project before it was undertaken,
- the preproject situation as recorded in benchmark surveys or as recalled by respondents, or
- the performance of otherwise comparable areas without irrigation.

The direct project benefits are measured through some combination of main-season area and yield benefit and off-season area and yield benefit. (Because seasonal-boundaries are often

blurred in the tropics, changes in cropping patterns and cropping intensities often need to be studied within a more complex framework than the main season-off season framework indicated.) The forms of benefits studied depend on the specific conditions surrounding the project under study and on data availability.

Measuring the direct project benefits involves comparing the net returns from irrigated production with the opportunity cost of pre- (or without) project cultivation. Measuring the direct project costs involves discounting the costs required for infrastructure construction, and estimating the annual costs of operating and maintaining (O&M) the infrastructure.

Procedural questions requiring attention in postproject evaluations are:

- how long projects must be in operation until their benefits mature to a point where it is meaningful to quantify the benefits, and
- over how long a period an evaluation should extend to permit satisfactory analysis of year-to-year variations in such factors as weather, pests, and prices.

*Actual vs projected project performance.* Following this approach requires preproject feasibility study reports that can be made available to researchers. The evaluations usually compare projected and actual benefits, projected and actual costs, and, on the bases of these, projected and actual measures of project worth, e.g. cost-benefit ratios (CBR), internal rates of return (IRR).

If actual values differ from projected values, attention is given to determining the extent to which the differences are *real,* which reflects differences in physical achievements, vs monetary, which reflects unanticipated changes in the prices for construction materials, farm inputs, and crop value.

*Actual after-project performance vs before-project situation.* This approach enables direct before-after comparisons to be made within a project. The *after-project* circumstance is measured in terms of the recent actual experience with the project. The *before-project* circumstance is reflected either in terms of socioeconomic benchmark data reflecting the preproject condition, or by asking project beneficiaries to recall preproject conditions. Because suitable socioeconomic benchmark data often are

not available, and the length of effective memory recall for most respondents, especially for detailed quantitative data, can be expected to be quite limited, this approach is frequently not feasible.

An additional inherent problem with this approach is separating the effect of irrigation on production from the effect of other efforts to enhance productivity that may have been undertaken during the duration of the irrigation project. Examples of the latter are improved availability and distribution of farm inputs and credit, intensified extension services, and improved market facilities.

*Cross-sectional "with-without" project comparisons.* This approach involves comparing recent actual performance in the *with-project* situation with the recent actual performance and otherwise similar *without-project* circumstance.

The major limitation to this approach is possible difficulty in finding a *without-project* situation that can be considered similar in all respects, except the presence of irrigation, to the *with-project* situation. These similarities concern most directly the physical and biological environment, the infrastructural and institutional environment, and the human social and cultural environment.

A researcher can never be 100% confident that the *without-project* situation selected for study has has desired characteristics. In practice, however, it is frequently possible to make a close enough *guesstimate* for this approach to be used.

## Economic research on investments in Asian irrigation infrastructure

This section is oriented toward constructing new irrigation projects, rehabilitating existing infrastructure, and intensifying terminal infrastructure. Some of the studies I cited, however, deal with irrigation investments involving more than one type.

*Constructing new irrigation projects.* Depending on hydrological and other engineering considerations, new projects may involve river-diverted, pumped, or reservoir-stored sources of supply. Water supplies from diversion projects are usually least dependable, especially during the dry season. The financial,

ecological, and social costs for diversion and pumping projects are usually less than those for storage schemes because the latter usually involve relatively more elaborate infrastructure and the displacement of people and natural habitats through reservoir flooding.

Studies involving the economic evaluation of new irrigation projects in Asia include those of Carter (1969) and the World Bank (1975) on the reservoir-storage Muda Irrigation Scheme in Malaysia; Huelgas and Torres (1979) on seven diversion irrigation schemes under the National Irrigation Administration (NIA) in the Philippines; Otten and Reutlinger (1969) on eight ongoing irrigation and other water resource development in various parts of the world; P.E.O. (1965) on six irrigation projects in India; Singh and Misra (1965) on the Sarda Canal System in India; Small (1975) and Trung (1979) on the Chao Phya Project in Central Thailand; and Tagarino and Torres (1979) on the Philippines' Upper Pampanga River Project. The Chao Phya Project is a classic example of an irrigation project whose infrastructure has evolved over time. Initially, the Chainat diversion dam and the primary water distribution network were constructed. The Bhumiphol and Sirikit dams and reservoirs were next constructed to provide dry-season irrigation. Finally, attention was given to localized on-farm consolidation and development.

To gain a more concrete idea about the nature and interpretation of postevaluation analyses, the findings from three of the above studies -- Muda, the average of the seven NIA schemes, and Salandhi in India (Table 2) -- are summarized. The summary is intended to illustrate the nature and interpretation of post-evaluation studies, not to suggest anything on the comparative performance of irrigation country-by-country. The projects covered were purposively selected; the samples were nonrandom and small.

For all three studies, actual irrigation costs exceeded projected costs. For the Muda and NIA schemes benefits were different as well. As a result, the overall performance of the Salandhi project was lower than that projected, and the overall performance of the Muda and NIA schemes appeared to be considerably better than projected.

A study of the direct benefits of irrigation, however, showed a major contrast in the actual vs projected performance between the Muda and the NIA schemes. Actual yields and production efficiency -- lower-than-expected production expenses were interpreted to reflect higher-than-expected production efficiency -- in Muda were substantially higher than those projected, whereas the actual yields and production efficiency in the NIA schemes

Table 2. Postproject evaluation of the Muda Irrigation Scheme, seven NIA schemes, and the Salandhi Irrigation Scheme.[a]

| Criteria | Muda | Seven NIA schemes | Salandhi |
|---|---|---|---|
| Overall performance | Actual IRR[b] 18% vs 10% projected | Actual net farm income double that projected | Actual IRR 17.3% vs 18.6% projected |
| Direct benefits: actual level vs projected level (%) | | | |
| Area irrigated | −7 | −32 | same |
| Yields | +25 | −45 | same |
| Farm production expenses | −3 | +200 | same |
| Rice prices | +20 | +300 | same |
| Direct cost: actual level vs projected level (%) | | | |
| Construction | +7 | +15 | +47 |
| O&M | +33 | +55 | same |

[a] Adapted from World Bank (1975) for Nuda, Huelgas and Torres (1979) for seven NIA schemes, and Otten and Reutlinger (1969) for Salandhi. [b] IRR = internal rate of return.

were much less than projected. The conclusion, then, is that the physical performance of Muda has indeed been much above that projected, but that the apparent better-than-projected performance of the NIA schemes is illusory. Farm incomes were much higher in the NIA schemss because of unexpectedly high rice prices in the year of study, not because the physical performance of the project exceeded expectations. (In a fundamental sense, the postproject evaluation of the NIA schemes is unfair. Six of the seven schemes under study had been operational for only 1 year prior to their evaluation, a period much too short for farmers to adapt to and exploit fully the opportunities of their new irrigation environment .)

The actual construction costs for all schemes were more than projected, reflecting a combination of construction delays (inflation-induced cost increases) and unanticipated construction needs (*real* cost increases). Operations and maintenance costs in the Muda and NIA schemes were also considerably higher than projected. The extent to which these reflect greater-than-projected O&M needs, less-than-projected efficiency in the performance of O&M, and unexpected cost-price inflation, was not indicated in the reports, however.

*Rehabilitating existing infrastructure.* Because of inadequate maintenance, the infrastructure in irrigation system sometimes deteriorates over time. Inadequate maintenance may arise, for example, because too low priority is given to maintenance, maintenance budgets are too small, or civil disorder disrupts normal maintenance functions. Investments to rehabilitate infrastructure to its original function include repairing and expanding the capacity of diversion dams, desilting irrigation channels, repairing and replacing water control structures, improving service roads, and providing additional training for O&M personnel.

Investments in the rehabilitation and improvement of infrastructure are expected to increase the amount and reliability of irrigation water supplies and hence to increase the potential for agricultural production. The basic economic question is whether such potential increases in production more than offset the added investment in irrigation. A subsidiary issue in the rehabilitation of some projects is the extent to which government grants to rehabilitate infrastructure induce local community resources to be used in production.

Studies involving the economic evaluation of rehabilitating existing infrastructure in Asia include Hafid and Hayami (1979)

on the Saebah and Takkapala Communal Irrigation Systems in West Java and South Sulawesi, Indonesia; Kikuchi et al (1978) on the Cavite Communal Irrigation System in Zambales, Philippines; Taylor (1979) on the large-scale Pekalen Sampean Irrigation Project in East Java, Indonesia; and Zulkifli (1978) on the Geunteut and Garut *Sedarhana* (simple, small scale) Projects in Aceh, Indonesia.

The nature of rehabilitation and the methodology used in the study of the five small-scale irrigation systems were more or less the same. Each project involved a gravity-diverted source of water supply. The major component of the rehabilitation in each project was making the project's water diversion structure more permanent and higher. Some attention was also given to installing more water control structures and lining with concrete critical canal sections.

Random samples of farmers within each project were interviewed. Data on the most recent crop season(s) were used to reflect the after-project situation. Data on the before-project condition (from 1 to 3 years preceding the interviews) were obtained through memory recall.

The forms of measured benefit varied much from one project to another (Table 3). In some cases, data on a particular variable were not obtained because no change with respect to that variable had been caused by the rehabilitation. In other cases, data covering actually realized benefits were not collected and analyzed because of logistical difficulties in securing the desired data.

Communal labor was valued with different assumed wage rates. The estimates of benefits with communal labor valued at the wage rate of hired farm workers were conservative, in that much of the rehabilitation took place during slack seasons in crop production and in circumstances in which off-farm employment opportunities were generally quite limited. The estimates of benefits with communal labor valued at zero, on the other hand, probably overstated the real project benefits, because some labor used in the rehabilitation could in all likelihood have found off-farm employment. From the standpoint of communal labor, then, the *real* benefit-cost ratio for each project probably rests somewhere between the two shown for it in Table 3. No matter which wage rate assumption, however, the profitability of rehabilitating each of the five irrigation systems studied is very high. The authors of the studies acknowledge, however, that the projects selected for study were few and not necessarily representative of the full range of rehabilitated communal projects.

Table 3. Postproject evaluation of investments to rehabilitate selected small-scale irrigation systems.

| | Saebah, West Java | Takkapala, South Sulawesi | CCIS,[a] Zambales | Geunteut Aceh | Garut Aceh |
|---|---|---|---|---|---|
| Form of benefit measured | | | | | |
| Main season | | | | | |
| Area | Yes | Yes | No | Yes | Yes |
| Yield | No | No | No | Yes | Yes |
| Off-season | | | | | |
| Area | Yes | Yes | Yes | No | Yes |
| Yield | No | No | Yes[b] | No | Yes |
| Benefit-cost ratio,[c] with communal labor valued at: | | | | | |
| Farm wage rate | 2.5 | 3.5 | 3.0 | 3.6 | 3.7 |
| Zero | 21.7 | 28.9 | 6.9 | 3.8 | 4.2 |
| Investment-inducement coefficient, with communal labor valued at:[d] | | | | | |
| Construction wage rate | n.a. | n.a. | 1.50 | n.a. | n.a. |
| Farm wage rate | 4.4 | 5.4 | 1.75 | n.a. | n.a. |

[a]Cavite Communal Irrigation System. [b]A substantial change in cropping pattern also took place after rehabilitation. [c]The rate of interest in computing the benefit-cost ratios is 15% for the Geunteut and Garut systems, and 12% for all other systems. [d]n.a. = not available. Sources: Hafid and Hayami 1979, Kikuchi et a1 1978, Zulkifli 1978.

The postproject evaluation of three of the irrigation systems involved an additional dimension -- the effect of external government funds for rehabilitation on the mobilization of local community resources. The impact was measured in terms of an investment-inducement coefficient, defined as the ratio of total project cost to government resources used in the project. The

values of these coefficients are severalfold, suggesting that the rehabilitation of small irrigation projects can effectively mobilize low opportunity cost resources, especially rural labor, for the construction of social overhead capital.

The nature of rehabilitation and the methodology and findings in the study of the rehabilitation of the large-scale Pekalen Sampean Irrigation Project were much in contrast to those of the small-scale irrigation projects (Taylor 1979). The rehabilitation primarily emphasized desilting of channels and the repair of water control structures rather than the restoration of original water-diversion capacities.

The methodology for measuring the benefit of rehabilitation was different because the benefit had to be estimated before the rehabilitation was actually initiated. The approach was to identify sub-areas within the project that had different degrees of infrastructural deterioration, and to select purposively sub-areas to serve as proxies for the *before-* and *after-rehabilitation* conditions. The criterion for determining degree of deterioration was the projected (in some cases the actual contracted) expenditure per hectare for the rehabilitation, with sub-areas having low expenditures assumed to reflect after-project conditions, and those with high expenditures assumed to reflect *before-project* conditions.

In marked contrast to the earlier mentioned studies, this one showed no immediately observable impact of rehabilitation on production,perhaps mainly because the rehabilitation did not overtly improve this project's water supply situation by increasing its water-diversion capacity. Further, O&M was found to be more intensive in those irrigation blocks that were most deteriorated, thereby indicating that extra O&M was substituted for infrastructural deficiencies. It is also possible that the original system was somewhat overdesigned, so that a moderate extent of deterioration did not impair minimum water deliveries to farmers' fields. If so, the rehabilitation could be viewed as having precluded losses in production in later years had the rehabilitation not been undertaken when it was.

These various studies on infrastructural rehabilitation suggest that the impact of rehabilitation depends on the nature of the rehabilitation activities undertaken and on their timing relative to the degree of deterioration. Studies aimed at further elaborating these aspects would provide useful guidelines for future rehabilitation decisions.

*Intensifying terminal infrastructure.* Most Asian countries have given increased attention in recent years to intensifying terminal irrigation infrastructure. For example, this approach is described as the third and most recent phase of long-term irrigation development in Thailand (Trung 1979) and Malaysia (Pang 1979). Miranda and Levine (1979) and Wickham and Valera (1979) evaluate more intensive terminal infrastructure and rotational irrigation that have recently been introduced in the Philippines.

The Trilateral Commission's emphasis on this approach to infrastructural development (third alternative), therefore, does not break fresh ground. Because the magnitude of their proposed investment in terminal irrigation facilities is so large, however, and because most Asian governments are now giving priority to this approach, I briefly examine three common means to intensify terminal infrastructure, noting the rationale for and the methodology and findings of evaluation studies of each.

1. *Inecreasing the density of field channels.* Investments in terminal infrastructure may involve intensifying the density of field channels in an irrigation system, thereby bringing irrigation water closer to individual farmers' fields. In this way, fields that are difficult to irrigate conventionally can be given more reliable water supplies. In addition, farmers formerly dependent on irrigation water that moved from plot to plot over other farmers' fields can receive water directly from the system. Localized deepwater flooding can also sometimes be alleviated by on-farm drainage ditches. An upgrading of farm service roads usually accompanies increased density of field channels.

Studies that evaluate this approach consider capital construction costs and the higher costs for operating and maintaining the expanded infrastructure. Counterbalanced against these added costs is the expectation that the added water control provided by the more intensive infrastructure will improve agricultural production.

Easter (1975, 1977) and Kumar (1977) undertook a study to evaluate the impacts of more dense field channels in Sambalpur District, Orissa, India. Farmers in *improved villages* having unlined field channels were compared with farmers in *control villages* in which water moved plot-to-plot.

Their studies showed that improved villages generally have:

1. fewer water control problems,

2. somewhat higher cropping intensities,

3. higher levels of input use, and

4. higher yields.

Easter's (1977) production function estimates showed fertilizer to be the most important variable in explaining production in both seasons. The production elasticity for fertilizer in the improved villages was higher than that in the control villages in the wet season, thus implying that the presence of field channels enhanced the productivity of fertilizer. In the dry season, however, the fertilizer production elasticity for the control village was higher. Thus, most but not all of these findings support the contention that the presence of field channels improves agricultural production.'

Another study on farm ditch density is by Tabbal (1975) in the Peñaranda River Irrigation System in the Philippines. This engineering study measured *system performance* in terms of the number of days that sample paddies were drained of surface water (called *stress days*). Stress days were then related to a series of variables, including farm ditch density. The study showed a slightly positive (but statistically insignificant) relation between ditch density and stress days, thereby indicating that the objective of improved water control through more farm ditches was not achieved.

Available empirical research results, therefore, show conflicting impacts of denser networks of field channels on water control and agricultural production. This is not surprising. The permeability of soils and the relative elevation of neighboring irrigated plots, for example, certainly will influence the effectiveness of added field channels on improving irrigation and agricultural performance. What these findings clearly suggest is a need to be cautious in adopting programs to intensify terminal irrigation infrastructure uniformly throughout irrigation systems. Identifying existing inadequacies in water distribution

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[1]Easter (1977) estimated an internal rate of return of 429% for the investment in field channels; Kumar's benefit-cost ratio on the field channel investment was 16.5. The reliability of the cost data going into these calculations would seem questionable, however, because the assumed construction and O&M cost per hectare for the field channels were less than US$2.00 and US$0.40, respectively.

first, and then molding field channel programs to specific needs would seem much more well advised.

2. *Improving the quality of field channels.* Earth-lined channels are most common in Asia today. Depending on soil permeability, however, conveyance losses may be considerable. Controlling weeds in earth-lined channels in tropical regions of Asia requires almost continuous attention. The potentially adverse hydraulic-flow properties of earth-lined channels are accentuated by weed growth. Earth-lined channels can also be rather easily obstructed by truant-minded irrigators. These shortcomings have prompted interest in upgrading the quality of field channels, especially by lining channels with concrete or other impervious materials.

Upgrading the quality of field channels obviously entails capital investment. Counterbalanced against this added cost are the possibilities of reduced O&M and water savings. To the extent that water savings result, expanded agricultural production of course becomes a possibility.

Again, the findings of studies evaluating the impact of upgrading field channels are mixed.

Pang (1979) reports on a comparative study of earth-lined channels and fiberglass-reinforced polyester (FRP) flumes in Malaysia's Lemal Irrigation System in North Kelantan. The FRP flumes cost more to construct, but require less land (and hence involve lower land acquisition costs) and have lower O&M costs. The FRP flumes are easier and speedier to construct, thereby disturbing less crop schedules and involving less soil relocation and compaction. The added cropping intensity and higher yields thereby enabled, when taken into account with the changed costs of irrigation, showed a 45% IRR to the FRP investment. This study did not consider the benefits of reduced seepage and the FRP flumes, nor the possible disadvantages (e.g. with respect to overland movement) of FRP flumes other than their higher cost.

Soltani (1976) studied 2 dryland-crop farms (about 35 ha each) in Fars province, Iran. One farm involved flood irrigation with unlined channels, the other furrow irrigation with lined channels. Water losses and application efficiencies, and their implications to agricultural production, were monitored. The budget analysis of these data, although not particularly precise, led Soltani to conclude that investment in the improved irrigation facilities was *economically feasible.*

Nazir's (1974) study of field channel lining in Pakistan examined alternative levels of investment in canal lining and associated degrees of water savings. He concluded that larger investments in channel lining were uneconomical.

3. *Land leveling.* Under certain circumstances, leveling land will enable a more even distribution of water over an intended irrigation area, less land being taken out of production for bunds and field ditches, and less soil erosion because of the gentler movement of water. Labor required for distributing irrigation water and problems of field drainage and flooding may also become less. Counterbalanced against these possible benefits, however, are the costs of undertaking the land leveling, and possible short-term decreases in yields because of disruptions to topsoil.

I know of only one systematic study evaluating the economic returns to investments in land leveling in Asia, namely, that done by Johnson et al (1978) in Pakistan. This study showed a benefit-cost ratio of 1.62 for an investment to upgrade traditional land leveling (TLL) into precision land leveling (PLL). They used regression analysis to relate yield to a series of variables, one of which was the maximum range of variation in elevation within individual fields. This range for PLL fields varied from 4.8 to 10.8 cm with a median value of 6 cm; the range for TLL fields varied from 7.8 to 16.8 cm, with a median value of 12 cm. The sign of the regression coefficient for the variance-in-elevationvariable in each production function was negative, as expected. But the coefficient on this variable was significantly larger for the PLL fields than for the TLL fields, thereby seeming to imply unexpected increasing returns to added investments in land leveling.

## ECONOMIC ANALYSIS OF SELECTED IRRIGATION POLICY ISSUES

Irrigation policy makers must make decisions on a variety of issues other than the mix of strategies to follow in developing their country's irrigation infrastructure. This section gives attention to four such issues: intensive vs the extensive irrigation water application, infrastructural vs managerial investment, extent vs distribution of irrigation benefits, and strategies to use in securing repayment for irrigation. These issues, although discussed separately from one another, and from the issues raised in the prior section, are interrelated.

## Irrigation water application intensity

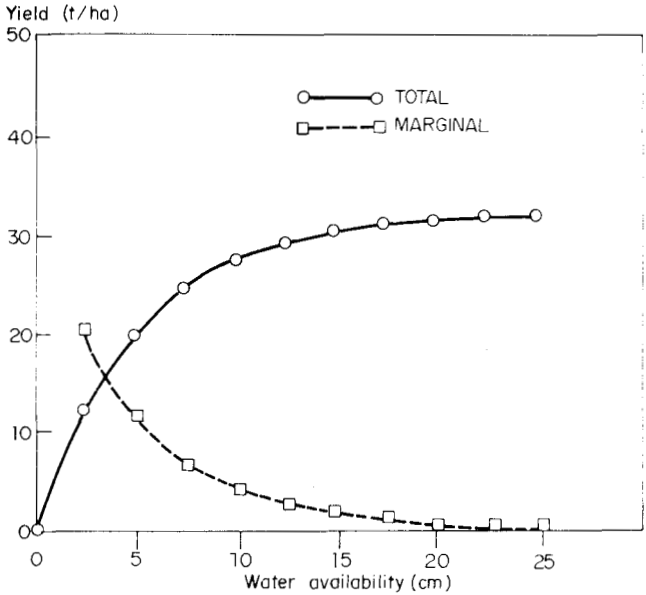
Of the topics treated in this paper, the research on Asia covers this one least well. Over the next 15 to 20 years, however, I believe this topic may become one of the most important. Prospects of being able to retard the faster trend of increase in new demands for water relative to the trend of increase in new sources of water supply are extremely remote. In such a situation, there is a growing need to examine possibilities for less intensive use of water.

One reason why irrigation water application intensity is relatively neglected in the literature may be the perspective held by many that crops have *water requirements* rather than that crops *demand water.* The first view assumes that the water requirement at each critical stage in a crop's life cycle is fixed. The second assumes that under different cost-price circumstances the optimum amount of water to use, and the crops for which the water is used, may differ.

Our consideration of irrigation water application intensity involves examining crop production responses to different levels of water application, and the returns to water from rice versus from upland crop production. Implications of these two sets of findings to the design and management of irrigation systems are then explored.

*Crop production response to water.* Pleasuring the physical productivity of irrigation water is difficult. Field conditions that determine the relation between water and crop output are numerous and difficult to control or monitor. Different crops and varieties often respond differently to different irrigation treatments. Further, the timing of water application may be as important as the amount of application.

It is not surprising, therefore, that relatively little research on economic levels of irrigation seems to have been undertaken in Asia. I am aware, however, of three studies on wheat, namely, Kemper et a1 (1978) at three sites in Pakistan; Elinhas et a1 (1974) at Delhi, India; and Quereshi et a1 (1975) at Faisalabad (formerly Lyallpur), Pakistan; and of several studies on rice reported in Herdt (1980) and Wickham (1979). Key issues in the rice-water response studies include the overall yield-water application intensity (mm/day) relationship, the impact on yields of water stress at different stages in the growth of the rice plant, and interactions among irrigation, fertilizer, and other inputs in influencing yields. I limit




**1.** The response of wheat to water availability, Delhi, India (Minhas et al 1974).

consideration to an illustrative crop response function for wheat (Fig. 1).

In this illustration, the response to successive increments of water availability up to 10 cm is substantial. From 10 to 20 cm, the rate of response diminishes considerably, and thereafter approaches zero. Thus, applying 20 to 25 cm of water would maximize per-hectare yields, but not the potential overall returns of water. I return to this point in my discussion of system design and management.

*Returns to water in rice vs dryland-crop production.* Much of the area in Asia suitable for irrigation is flat and has heavy soils. Such land is much better adapted to wetland rice than to dryland crop production. In other areas, however, dryland crops can be grown on the same lands as rice. Two such examples are the 400,000-ha Tungabhadra Irrigation Project in Karnataka, South India, and the 274,000-ha Pekalen Sampean Irrigation Project in East Java, Indonesia.

Because the irrigation requirement of dryland crops is considerably less than that for wetland rice, there is interest,

especially in water-scarce areas, in exploring possibilities of irrigated dryland crop production. In this section, I compare the relative profitability of wetland rice and dryland crops in each of the above-mentioned projects (Taylor 1971, 1978). The next section examines briefly, among other things, the special requirements in irrigation design and management for dryland-crop production.

Conventional profitability measures for crop enterprises are net returns to Sand and capital (Table 4, cols. 1 and 2). With respect to these conventional profit criteria, wetland rice is more profitable than dryland crops in the Tungabhadra Project, and much more profitable than the dryland food grains in the Pekalen Sampean Project. With respect to the returns-to-water criteria (Table 4, cols. 3 and 4), however, dryland crops are more than twice as profitable as rice in the Tungabhadra Project, and the margin of rice over the food grains in the Pekalen Sampean Project is much reduced. In fact, the net return per unit of water for soybean in Pekalen Sampean is more than that for rice, whereas the net return per unit of land area of soybean is one-third that for rice. These findings, then, indicate a

Table 4. Returns to wetland rice and dryland crop production, Tungabhadra Irrigation Project, India, 1969-70; and Pekalen Sampean Irrigation Project, Indonesia, 1973-74.

| | | | Per unit of water relative to paddy | |
|---|---|---|---|---|
| | Net return[a] (US$/ha) | Gross return (per US$ cost) | Net return[a] | Paddy equivalent |
| Tungabhadra | | | | |
| Wetland rice | 206 | 2.10 | 1.00 | 1.00 |
| Dryland crops | 140 | 1.95 | 2.05 | 2.09 |
| Pekalen Sampean | | | | |
| Wetland rice | 102 | 1.55 | 1.00 | 1.00 |
| Tobacco | 177 | 2.61 | 6.85 | n/a |
| Soybean | 29 | 1.33 | 1.15 | 0.24 |
| Maize | 21 | 1.42 | 0.84 | 0.84 |

[a]Net return is computed by subtracting from gross return, all paid-out costs except that €or water, and the imputed values of all important self-owned resources except land. viz.. family labor, seed, and power. n.a. = not available.
Adapted from Taylor 1971, 1978.

substantial difference in the relative profitability of wetland rice vs dryland crops, depending on whether returns to land (capital) or returns to water are considered.

Two policy implications follow. The first applies most immediately to the Tungabhadra Project. Farmers in that project generally prefer to grow rice; indeed it is in their best economic interest to do so. But government, for whom water is limiting, wants farmers to grow dryland crops; if farmers do, the project's output can be double that from growing only rice. This conflict between farmers and government cannot readily be solved by persuasion or tightened administration and management. [2] Changing price incentives to farmers, for example, through raising the rate charged for irrigating wetland rice or providing assurance of relatively higher and more stable prices for the dryland crops, would be much more effective (perhaps essential) in bringing the perspective of farmers and government into consonance.

The second policy implication has to do with system design and management. In projects where dryland crops are technically feasible, it would appear important to examine the economic possibilities for designing the systems with facilities suitable for less water-intensive dryland crop production.

*The design and management of irrigation systems.* Several scholars advocate the design and management of irrigation systems for less water-intensive irrigation, e.g. Rao (1978) and Wade (1978). Their arguments are based primarily on higher expected returns and a wider distribution of benefits among irrigators from less intensive water use. Others express considerable reservation concerning this possibility, primarily because it entails larger irrigation costs -- both construction and O&M -- and greater production risks for irrigators.

I first examine some technical questions concerning system design and management for rice versus for dryland crops, and then explore possibilities for economic research to provide insights on the possible resolution to this issue.

The lower water requirement and more efficient use of water by dryland crops, compared to wetland rice, have already been mentioned. In some cases, dryland crops are more profitable than wetland rice. There are however, certain limitations (Takase and Wickham 1977):

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[2] Wade (1978) sees much more potential than I do for using administrative effort to induce desired changes in cropping changes.

1. Land leveling is more critical with dryland crops. Otherwise water may not reach somewhat high elevations in the fields in the same way it can if the fields are flooded with standing water as for rice.

2. The soils' bias of much of Asia's irrigated land toward wetland rice has already been mentioned. In lighter soils, where dryland crops may be feasible, much of the potential water saving between wetland rice and dryland crops is lost through conveyance losses along canals and through infiltration losses.

3. Dryland crops require more water control. They cannot take advantage of the more or less natural plot-to-plot movement of water as does rice. Further, without careful control over seepage and overland flows, conflicts may arise when rice, sugarcane, or dryland crops are grown in close proximity with each other (Tantigate 1979).

The basic issues in system design and management vis-a-vis water application intensity appear, in summary, to be:

Should irrigation systems be designed to irrigate relatively small command areas with more or less guaranteed water supplies, and thereby lead to relatively high and stable yields over time? Or, should the systems be designed and managed to use the given amount of water to irrigate larger systems areas, thereby benefitting more people, and realizing that:

- less water-intensive consuming crops requiring more water control may have to be grown,

- the incidence and severity of irrigation water shortages may increase, thereby accentuating possibilities of conflict among farmers in using the scarce water supplies,

- average yields may be less because of the adverse effect on plant growth from mild water stress,

- levels of production from the system may drop severely in years of water shortage, and

- the costs of irrigation may become more?

Johnson (1978) deals with part of these issues in his study of cropping intensity and water shortages in Punjab, Pakistan. His use of a linear programming model with wheat grown under four alternative levels of irrigation shows that returns can be maximized from spreading irrigation over the entire available area, even though at some sacrifice in average yield levels.

A more comprehensive study embracing the vast majority of issues outlined above is by Lewis (1969). Although this very imaginative study examined an irrigation project in Nebraska, USA, it was well written and could provide pertinent methodological insights for similar studies in Asia.

## Irrigation water management

Good water management involves supplying water in amounts and at times suitable to crop needs. Although many professionals use the term *water management* to mean the management of water on farmers' fields, in this paper I look at water management more broadly. In particular, I consider water management to also include water distribution in main irrigation delivery systems.

This workshop's participants are all well aware of the heightened awareness in Asia these days of striving to improve irrigation water management. The challenge is to determine ways to do so. I outline three possible approaches:

1. *Diagnose where within irrigation systems the main problems of water distribution are, and the underlying causes for those problems.* This simple suggestion is based on the presuppositions that needs for improved water management in all irrigation systems are not identical, and that financial and managerial resource limitations make it unwise *to try to & everything everywhere at one time.* Thus, setting priorities is essential.

The first step in setting priorities is to determine whether problems of inequitable water distribution are greater within *main systems,* i.e. within primary and secondary water distribution channels, or within *terminal systems,* i.e. at the level of tertiary channels and farm ditches. This is essential to determine the level within an irrigation project where additional managerial and other resources should be concentrated. A host of studies show that water availabilities are less for irrigators far from sources of water supply: Chambers (1974) in Sri Lanka; Eyre (1955) in the Twelfth Irrigation Cooperative, Japan; Gillespie (1975) in the Lam Pra Plerng Irrigation Project, Northeast Thailand; Mizra (1975) in Pakistan; Orenstein (1965) in Poona District, India; Pasternak (1968) in the P'u-Wei Irrigation System, Taiwan; and Reidinger (1971) in Hissar District, India. Although this finding indicates the existence of water distribution problems, it is not sufficiently specific to enable determination of managerial strategies to overcome the problems. Only a moment of reflection will indicate the

futility, for example, of concentrating managerial (or infrastructural or both) resources at the terminal level if parent main systems are not functioning well.

The approach for determining where problems of water distribution are greatest is straightforward. It involves establishing a sample design with stratification along primary and secondary channels, as well as stratification away from tertiary turnouts. If the irrigation blocks under study are small, simple random sampling may be more appropriate. If this approach is followed, the location of each respondent relative to canals and turnouts must be known (plotted on a map, if possible) so that the analysis can differentiate satisfactorily between main and terminal system water distribution problems. If water-measuring devices are present, actual discharge flows can be monitored. In the absence of water-measuring devices, the degree of water adequacy for individual farmers' fields can be based on the physical observation of *water stress* days and the judgment of water inadequacy by irrigators or local irrigation officials or both. Multifactor analyses can then be undertaken in which output is regressed against *conventional* inputs and one or more water inadequacy or location variables. Monitoring the equity of water distribution is, of course, more important in the dry season than in the wet season.

The second step is setting priorities to determine underlying causes of any inequities in water distribution. It is critical to know, for example, whether water shortages in rice fields arise because of water shortages in the main system, water stealing by those close to sources of water supply, obstruction in plot-to-plot water flow by intervening irrigators, or pressures on local irrigation officials from economically or socially powerful irrigators. Certain causes could be overcome most effectively by improvements in infrastructure, others by tightened administration and management, and still others by fuller community participation in water management decisions. To select a type of remedial action *a priori* without knowing the nature of the existing problem and whether that problem can be effectively dealt with by the action is obviously suboptimal.

The pioneering work in Asia on equity of water distribution in main vs terminal systems was done in the Philippines by IRRI scholars. This research shows that problems of inequitable water distribution in Central Luzon are greater within the main irrigation systems than at terminal levels (Wickham and Valera 1979). The conclusions are similar in recently completed studies of two canal systems in Andhra Pradesh (Wade 1979) and an irrigation project each in northwestern India, Indonesia, and Pakistan (Bottrall 1978).

Although these studies all show similar findings, it should not necessarily be concluded that the most pressing problems of water distribution in Asia are in main systems. Further empirical studies, under a variety of irrigation environments are needed. Several scholars are undertaking studies with emphasis on main vs terminal system water distribution, e.g. Asnawi (1979) in West Sumatra, Indonesia; Palanisami (1979) in the Lower Bhavani Project, Tamil Nadu, South India; Sharma (1979) in the Dhora Project Uttar Pradesh, India; and Taylor et al (1978) in the Kemubu Irrigation Project, Malaysia.

2. *Study local irrigation management and administration.* Before embarking on programs that attempt to improve irrigation water management, I would submit the usefulness of studying current managerial and administrative practices in irrigation. Such studies can provide insights on both the strengths and weaknesses of current practices. Knowing more clearly the nature of an existing situation can facilitate the formulation of pertinent and systematic strategies for overcoming problems within that situation.

I briefly note the findings of three instructive studies on irrigation management and administration. They are presented as examples of types of useful research that economists and other scientists might undertake.

The first involves a field study on water management procedures in the Pekalen Sampean Irrigation Project in East Java (Pasandaran 1979, Taylor 1978). Water management in that project evolves from planning decisions to design of cropping systems to effectively use anticipated water supplies, and operational decisions to allocate water among and within planted areas. These decisions use the indigenous concept *pasten,* which describes a relationship between the water supply available at the intake gate or turnouts, and the water needed by crops at different growth stages.

In planning cropping systems during the wet season, the main need is to determine the staggering of planting dates among irrigation blocks (*golongan* system) that is as rapid as possible and yet does not exceed the bounds of available water supplies. In the dry season, the need is to determine a combination of wetland rice and dryland crops that is consistent with farmer preferences, on the one hand, and with expected water supplies on the other. In both cases, local irrigation officials use the *pasten* concept to make what otherwise are complex decisions,

After crops are planted, if actual water flows fall below expected values, rotational irrigation (*giliran* system) may be used. The form of rotation depends on the severity of water shortage as reflected by the *pasten* ratio. The more severe the water shortage the more localized the form of rotation. For example, in a mild water shortage, rotation among secondary channels may be followed, whereas with severe water shortage, rotation may be practiced among farm-parcels.

In conclusion, this field study shows an operational system of water management decision-making that is based on a combination of rather sophisticated principles built around the indigeneus concept *pasten*, and a certain pragmatism in the field. Other provinces in Indonesia and nearby countries searching for ways to improve water management may find further study and use of this indigenous technology more helpful than importing so-called modern water management technology.

Wade's (1979) study of the management and administration of two canal systems in Andhra Pradesh showed an inverse relation between degree of water shortage and extent of managerial input into water distribution decisions and implementation. Studying the managerial responses to water shortage provided insights for improving regular ongoing water management policies and practices in the irrigation systems.

Wade's focus on the *irrigation bureaucracy* showed possibilities for improving irrigation performance. For example, officers in charge of personnel matters are undertrained and overworked. Under these conditions, decisions on staff assignments are often arbitrary, with a consequent lowering of staff morale. Added resources in personnel management, building work incentives into job descriptions, encouraging greater feedback from field personnel, and increasing the respectability of canal operations as opposed to design and construction are examples of steps that could be taken to improve irrigation water management. Difficulties in achieving such objectives are sure to be encountered. Lack of a list of specific needs such as this, however, leaves to chance the designation of areas for emphasis in plans to improve water management.

Bottrall's (1978) study of organization and management of large-scale irrigation schemes in India, Indonesia, and Pakistan led to the formulation of an analytical framework that can be used to evaluate and improve irrigation system performance. The framework involves a comprehensive description of the local resource base; evaluating system performance against productivity, equity, environmental, and cost recovery criteria; the diagnosis

of reasons for shortfalls in system performance; and on the basis of this, a determination of possible remedial actions.

Aspects of irrigation management and administration that Bottrall believes require attention include:

- clear interdepartmental coordination,
- improving the prestige of irrigation operations relative to that of design and construction,
- improved water allocation procedures and irrigation extension, and
- increasing personnel motivation and staff promotion aspects.

Again, several of these problems are rather intractable. But determining which ones are most critical in particular irrigation systems can be a first step toward more systematic attempts at problem solution.

3. *Examine the trade-off between more irrigation infrastructure and improved human and managerial resources* (see also Levine 1980). Opportunities for, and limitations to, irrigation water management in any irrigation system can be found in the combination of physical infrastructure and human resources that it has.

There seems to be a fairly strong tendency to think about achieving improvements in water management through improved physical facilities. For example, lining irrigation channels is being emphasized in several countries including Malaysia; this approach reduces the human requirement for channel maintenance. Monitoring water flows electronically and pushing buttons to operationalize water control structures can lead to less need for operations personnel.

Possible reasons for countries evolving toward more capital intensive infrastructure are that the infrastructure is visible and therefore has appeal of its own, and that international lending agencies generally prefer to underwrite capital construction costs rather than investments in human and managerial resources (Takase and Wickham 1977). Factors within countries that temper the substitution between infrastructure and management are the relative completeness and condition of existing infrastructure, the cost and relative availability of capital

material items vs labor, and the attitudes and experience of management in allocating time and effort to supervising field staff.

Counterbalanced against these general tendencies toward an increasing reliance on physical infrastructure relative to human and managerial resources are, for example, the Water Management Training Program for the Upper Pampanga River Project in the Philippines that began in 1975 (Bagadion et al 1979), and the National Irrigation Extension Training Center that is being constructed now in Kelantan, Malaysia. The Philippines program concentrates on improving the skills of irrigation personnel, through emphasis on irrigation water management, irrigated rice crop production, irrigation behavior, and group action.

Research on the rate of substitution between irrigation infrastructure and human and managerial resources includes that proposed by Lazaro and Wickham (1976) in a 1976 research seminar on irrigation systems in Southeast Asia held in Los Baños, and which presumably provides the basis for Jerachone's (1977) economic evaluation of irrigation in Northeast Thailand. The proposed research provides for varying levels of intensity in field-level irrigation infrastructure and management. The construction and management requirements, as well as the irrigation and agricultural performance, of each of four infrastructure-management alternatives are to be studied. The study's central hypothesis is that the most efficient infrastructure-management combination may not be the most physically sophisticated. Useful economic analyses in this study include evaluating the returns to investment and determining the extent and distribution of benefits for each of the four infrastructure-management alternatives.

## Irrigation's impact on income and wealth distribution

Because relatively few agricultural development strategies are more capital-intensive than irrigation, it is usually expected that irrigation development will accentuate regional disparities in income. In other words, the relatively high per capita investment involved in irrigation compared to that in most other government rural development programs implies that beneficiaries to irrigation tend to be relatively more favored than beneficiaries to other government programs. The income gap between regions that receive developmental assistance and those that do not, of course, inevitably widens over time. Reinforcing this tendency for irrigation to increase regional income disparities is the frequent positioning of irrigation projects in areas

where agricultural production potentials are already relatively high.

A second dimension to income redistribution with irrigation is the differential impact of irrigation on different groups of direct beneficiaries. Economists frequently examine income distribution with:

- an *earner-share* approach that apportions project befiefits among landlords, farm operators, and hired labor. A *factor-share* approach, which apportions benefits among land, labor, and capital (operator's residual),
- a Gini ratio-Lorenz curve analysis that examines the degree of income or wealth disparity among farm owners or operators.

The earner-share approach was used in the earlier-mentioned studies by Kikuchi et a1 (1978) and Zulkifli (1978) on the rehabilitation of small-scale irrigation projects, and by Taylor et a1 (1979) in the Pekalen Sampean Irrigation Project. Table 5, with findings for the Cavite Communal Irrigation System, illustrates the nature of their findings.

The after-project gross value added per farm is 2.44 times the before-project value. Each earner-group derives substantial (from 2.3 to 2.8 times) absolute benefits from the rehabilitation. The relative shares to landlords and farm operators decrease slightly, whereas the relative shares to hired labor increase by 18%. The shares to different earner-groups are not strictly comparable, in that the share to farm Operators reflects their *gross returns* minus the costs expended by them, whereas the share to hired labor includes no corresponding reduction from their *gross returns* for the energy expended by them. Further, the share to hired labor involves the aggregate payment to labor. The magnitude of that share implies nothing about changes in per capita wage earnings. Because hired laborers are usually poorer than landlords and farm operators, these findings indicate a positive effect of rehabilitation on both average levels of income and the redistribution of the income.

Zulkifli found each earner-group in the Geunteut and Garut Projects to derive absolute benefits from rehabilitation, but the extents of benefits were less than those for the Cavite System. Changes in the relative shares among earner groups were somewhat mixed, but very small.

Table 5. Changes in the shares of farm output and income before and after the rehabilitation of the Cavite Communal Irrigation system.

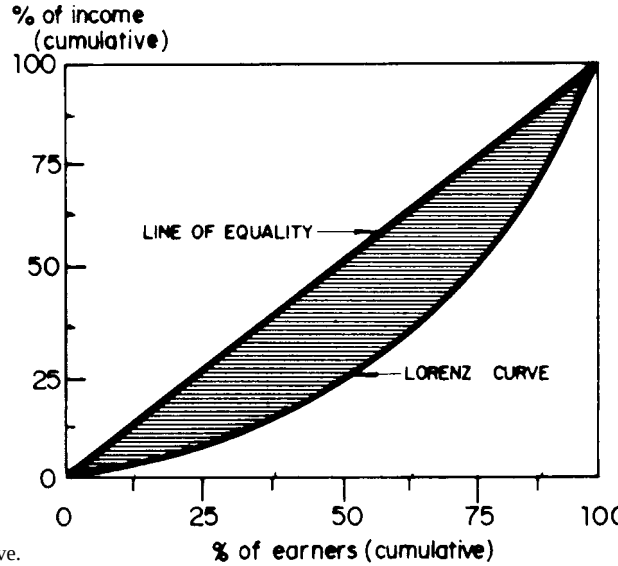
| | 1972 dry season (kg rice equivalent) | 1974 dry season (kg rice equivalent) | In-crement (%) |
|---|---|---|---|
| Output per farm | 823 | 2110 | 256 |
| Payments to current inputs | 86 | 310 | 356 |
| Gross value added per farm | 737 | 1800 | 244 |
| Absolute shares of value added: | | | |
| Landlord | 355 | 820 | 230 |
| Farm operator | 217 | 520 | 240 |
| Hired labor | 166 | 460 | 279 |
| Relative shares of value added (X): | | | |
| Landlord | 48 | 45 | -6 |
| Farm operator | 30 | 29 | -3 |
| Hired labor | 22 | 26 | 18 |

Source: Kikuchi et al 1978.

Taylor et al (1979, based on Table 26) found substantial absolute benefits to each earner-group from irrigation in the Pekalen Sampean Project. Further, the relative share to labor increased by 156%, indicating even stronger positive income redistribution effects than for the Cavite System.

These studies, although few, suggest that the cliche *the rich are getting richer and the poor poorer* does not not hold for irrigation. In absolute terms, all earner-groups derive benefits, and in relative terms the poor (namely, hired labor) either hold their own or gain. Again, further empirical studies are needed to determine how widely applicable these results may be.

The other common approach for analyzing income redistribution involves Gini ratio-Lorenz curve analysis. A Lorenz curve (Fig. 2) relates the cumulative percent of income that accrues to in-




2. Hypothetical Lorenz curve.

come earners who are arranged in ascending order of income. If everyone has the same income, the Lorenz curve will simply be the diagonal. If some people earn less income than others the Lorenz curve will lie below the diagonal. The Gini ratio reflects the area between the actual Lorenz curve and the diagonal. The lower the ratio, the lower the extent of disparity of income among earners.

Jegatheesan (1977), for the 100,000-ha Muda Irrigation Project in Malaysia, and Zulkifli (1978) for the Geunteut and Garut Projects, used the Gini ratio method to describe the extent of disparity among each project's farm operators. Jegatheesan's study utilized 1966 data to represent preproject conditions and 1972-73 and 1975 to reflect changes (if any) over time in the distribution of postproject benefits. Although farm sizes tend to become slightly more disperse over time, farm incomes do not (Gini ratios are roughly 0.35-0.40). This finding is also supported by Lai (1977) in his study of Muda. Zulkifli found little difference in income disparity before and after rehabilitation. The ratios for his small schemes (roughly 0.20-0.25) reflect more egalitarian income distributions than those in the large Muda Project. This apparent pattern of less disperse income among irrigators in small schemes may be coincidental, although some people would argue that it is not.

These findings lend additional support to the possibility that within-project interpersonal income disparities do not become accentuated with irrigation. Further studies of income distribution, especially in different irrigation environments,

would provide useful insights on this critical policy dimension. An additional study on the impact of Asian irrigation on income distribution is Dow (1977).

## Securing repayment for irrigation

The issue of water charges in Asia is still as controversial and unresolved as it was 10 years ago (Takase and Wickham 1977). Key policy dimensions are whether water charges should be increased, and whether payment systems involving indirect charges for water should be changed so as to involve direct (possible volumetric) charges. Some people argue that irrigation charges should be increased to provide incentive for more efficient use of water. If the charges are area-based, however, such reasoning lacks validity. Once an area-based water rate is paid, the charge becomes fixed; no matter how high the rate, a farmer incurs no penalty for using more water. A charge based on the duration or rate of flow, on the other hand, would provide economic incentive for saving water, for the more water used the more that must be paid. Dealing with these issues involves a host of complex interrelated factors, including the extent to which possible changes in water repayment policy will affect income redistribution, the generation of government revenue, the efficiency of water use, and incentives for changes in cropping patterns (Taylor 1976).

Several researchers have conducted empirical research in Asia to shed light on the need for possible changes in policies to secure repayment for irrigation: Chaudhary (1978) for canal irrigation in Pakistan; Izadi (1975) in the Maru-Dasht Plain in Iran; Minhas (1968) in Pakistan; Srinivasan (1976) for India; Tagarino and Torres (1979) for the Upper Pampanga River Project (UPW) in the Philippines; Taylor (1971) for the Tungabhadra Irrigation Project in India; Taylor (1979) and Taylor et a1 (1979) for the Pekalen Sampean Irrigation Project in East Java; and Torres (1972) for the Santa Cruz System in the Philippines. Gardner et a1 (1974) and Singh (1978) suggest changes in irrigation repayment policies for Iran and India, but their suggestions are not empirically based.

To make more clear the nature of economic research that can be undertaken to inform irrigation repayment policy decisions, brief attention is given to the nature of three studies.

Tagarino and Torres' study to determine the repayment capacity of farmers in the UPRP was prompted by actual payments

for irrigation in the systems comprising the UPRP during the past 5 years being only 37% of the assessed rates. Because the study was undertaken in 1974-75 and the UPRP went into full operation only in 1975, the results of this study are only preliminary.

Their analysis of construction costs involved the apportioning of *joint project costs* among the main using-sectors of the UPRP water supply, and discounting those costs attributable to irrigation to an annual basis. The resulting annualized *financial* construction cost (US$ per hectare) was 75, which when combined with the project's annual O&M cost of 19 gave a total annual financial cost for UPRP irrigation of 94. The then current annual irrigation fee was 45, implying that about 48% of the project's total financial cost was expected to be repaid by irrigators.

The net values of production (US$) per hectare were 261 under projected *normal* conditions and 470 under *future potential* conditions. Because the mean family living expense converted to a per hectare basis was $33, farmers would have adequate income to meet the irrigation fee of $45/ha, only under *future potential* conditions. This indicates an important reason for difficult-to-collect irrigation fees in the UPRP.

Chaudhary examined the cost of tube well irrigation in Pakistan to generate insights on repayment policies for canal irrigation. In the absence of canal water being sold in the market, it is not possible to observe directly the value of canal water in agricultural production. Because many canal irrigators in Central Punjab were found to have recently purchased tube wells to augment their water supplies, using the cost of tube well irrigation to approximate the value of canal water was reasonable.

The costs per hectare of tube well irrigation for the major irrigated crops were determined. Deducting canal water rates enabled the indirect determination of *economic rent* to canal irrigation. Economic rent represents the maximum ability of farmers to pay for irrigation. Although the surplus of economic rent is *substantial,* Chaudhary suggested *social* and *political considerations* and steps to ensure more timely water deliveries required attention before a decision to possibly increase the level of the canal irrigation fee can be made.

Taylor (1979) examined possibilities for higher and more direct payments for irrigation in the Pekalen Sampean Irrigation Project (PSIP). Estimates were made of:

- the benefits to farmers from irrigation, to determine farmers' ability to pay for irrigation,
- present payments by farmers for irrigation, and
- present and prospective O&M expenditures.

The study showed the 1973-74 yields of various crops to be from 30-55% higher with irrigation, and a total annual direct benefit from irrigation of about US$200/ha. Farms are small (about 0.5 ha of rice land each) and family sizes are large (6 to 9 members each), however, resulting in an annual per capita income from agriculture of only US$20.

An extension of this study (Taylor et al 1979) showed the gross production value of irrigated agriculture in the PSIP to be 3.6 times that of rainfed agriculture, indicating that the project's direct benefits increased by 3.6 times. Each of the four types of indirect benefits to PSIP irrigation also increased by at least 3.6 times:

1. a 4.4-fold increase in food self-sufficiency, amounting to 3.4% of national food imports in 1973 and 1974;

2. a 3.6-fold increase in foreign exchange savings amounting to about 15% of Indonesia's deficit in *current account* balance-of-payment in 1973-74;

3. a 4.6-fold increase in employment, providing added employment opportunities for about 200,000 full-time workers; and

4. a 4.4-fold increase in agribusiness volume, amounting to about 0.5% of Indonesia's GDP in 1973 and 1974.

These findings confirm the existence of large indirect benefits to irrigation in the PSIP (they neglect attention to larger quantities of lower-priced food that irrigation enables), and show that it can be wrong to say that farmers are *subsidized* if they do not pay the full cost of irrigation.

Although Indonesia has no water tax, farmers pay indirectly for irrigation through the differential, in land development taxes between *dry land (tanah darat)* and *wet land (tanah sawah).* They also pay local ditchtenders for services in operating terminal systems, and contribute cooperative labor *(gotong royong)* to maintain the terminal systems. In 1973-74 the land tax differential was US$10.85/ha and the value of the terminal level evaluation service was US$9.lO/ha. The current and projected

O&M expenditures for the main system were US$2.00 and 6.75, respectively, and terminal O&M expenditures were US$9.10.

These findings indicate that despite the nonexistence of *water tax* in Indonesia, farmers were already paying more for water than was being, and for the foreseeable future needed to be, spent on O&M. Because indirect benefits to irrigation were also substantial, land taxes in the PSIP increased almost 20 times from 1967 to 1974 (when rice prices increased by 14 times), and irrigators in the project were relatively poverty-stricken, an increase in water charges was not recommended.

A possible justification for converting systems of indirect irrigation repayment into direct nominal water charges is that the visibility of the direct charges will cause farmers to use water more carefully. High cropping intensities (from 2.5 to 3.0 crops/year), carefully monitored and modest applications of irrigation water to dryland crops, and generally careful decision-making on the allocation and distribution of irrigation water in the PSIP, however, suggest limited scope for achieving more efficient land and water use. Further, if a system of direct water charges were introduced, the cost of collecting the charges would increase substantially because a whole new administrative structure and staff would be required. Changing to a system of direct nominal water charges was, therefore, not recommended.

Although each of these three studies concludes that levels of water charges should not be increased, one cannot conclude that water charge policies in all irrigation projects should be left unchanged. The economic-financial environment surrounding individual irrigation projects is too site-specific for broad generalizations to be made. The more important value of these studies is their illustration of the types of economic and financial analysis that can be undertaken in irrigation projects in which policies and procedures for repayment are under review.

## CONCLUSION: AN AGENDA OF POSSIBLE RESEARCH TOPICS FOR THE FUTURE

Based on the current and prospective issues in Asian irrigation development I have outlined, and on what is currently known about these issues, the following topics could meaningfully receive attention when formulating future research programs in the region. The relative importance of the various topics, will, however, differ in different countries.

- Postproject evaluation of investments to construct new irrigation projects, rehabilitate existing infrastructure, and intensify terminal infrastructure. The evaluations should include determining the extent and distribution of both direct and indirect benefits, returns to investment, and rates of project completion and project utilization for:

  - these three types of infrastructural development;

  - different types of irrigation, e.g., reservoir storage, gravity-diversion, pumping, controlled drainage;

  - different scales of irrigation projects, with perhaps extra attention on small-scale irrigation; and

  - private vs publicly developed irrigation facilities.

- Examination of technical and economic trade-offs between rehabilitation and maintenance, and between more irrigation infrastructure and improved human and managerial resources;

- Evaluation of alternative strategies of planned water application intensity in designing and managing irrigation systems;

- Determining the extent of increase over time in the real cost per unit of area developed for irrigation;

- Determining the relative importance of expanded main season irrigated areas, expanded off-season irrigated areas, and increased yields in explaining increases in rice production over time;

- Determining where within irrigation systems the main problems of water distribution are, and the underlying causes for the problems;

- Study of local irrigation management and administration;

- Study of repayment policies for particular irrigation projects;

- Evaluation of alternative methods of exploiting groundwater, and possibilities for the conjunctive use of groundwater and surface water; and

- Study of integrated river basin development and multipurpose uses of water supply.

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# AN APPROACH TO SOLVING IRRIGATION SYSTEM MANAGEMENT PROBLEMS

Alan C. Early

Rice, one of the most important cereal crops for the developing countries of the world, is grown on about 140 million ha from sea level to elevations of 2,500 m, from tropical to temperate climatic conditions, from mountain terraces to alluvial plains, from irrigated regimes to rainfed conditions, and from favorable to toxic soil conditions where no other crops will grow (IRRI 1979). Forty-two percent of rice is irrigated, mostly by gravity from river diversion works or storage reservoirs.

In the Philippines, the National Irrigation Administration (NIA) administers the operation of 123 large irrigation systems serving a rice growing area of 561,300 ha (IRRI 1975). It is upgrading existing irrigation systems and constructing new ones based on modern irrigation designs as two major thrusts of the Philippine government in boosting rice production. It envisions the increase of the country's national systems irrigable areas to 2.35 million ha in the year 1985 (NIA 1975). The Philippine government has recently placed large investments in new irrigation infrastructure including reservoirs. The Upper Pampanga River Integrated Irrigation Systems (UPRIIS) in Central Luzon was the first large project of this kind completed in the Philippines. Its reservoir can store and supply enough water for the entire service area of more than 86,000 ha during the dry season, compared with the 30-50% dry season capability of the traditional irrigation systems. This irrigation system has a more complete canal network, terminal facilities including control and measuring structures up to the turnout level, and farm ditches in greater density per hectare.

The tremendous investment commitments being made to irrigation infrastructure provide a challenge to obtain a suitable design

Associate agricultural engineer, Irrigation Water Management Department, International Rice Research Institute, Los Baños, Philippines.

for the prevailing human resource and water resource availability circumstances. A more important and more difficult task is the management of water of sufficient quantity and in a timely schedule over the entire service area for the complete cropping season -- a major challenge for irrigation systems in South and Southeast Asia.

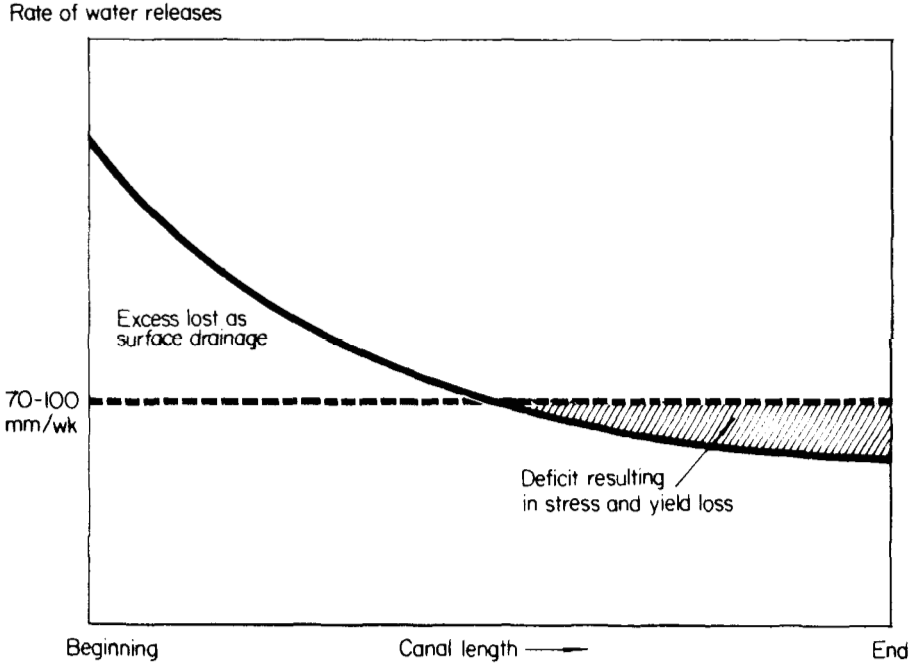
The management of irrigation systems has not been extensively researched except in those cases where serious water quality or water scarcity problems exist. The approaches in irrigation system management are generally trial-and-error efforts to fulfill crop needs, taking into account certain known or estimated losses. The level of management required by an irrigation system determines specific levels of control and measurement structures utilized and corresponds directly to the scarcity of water. Above a threshold level of structural improvements there is a range of management (human skills) that substitutes for physical components (structures and facilities). This range of substitution of management versus structural facilities and the question of intensity of facilities versus the cost of water available are important research issues, and have implications for investment, design, and management of systems.

The cases of intensive management of extremely scarce water resources in Taiwan and Israel are too often held as a pattern for irrigation water management investments in the developing nations of the humid tropics, where water is not as scarce and has a much lower value. These developing nations are also well endowed with human resources that to a certain extent, when properly trained and utilized, can substitute for extensive physical facilities through intensive system management.

## PROBLEM STATEMENT

Tabbal and Wickham (1976), Valera and Wickham (l976), and Early et al (1978) have observed the tendency for water maldistribution to occur over the secondary and primary components of Asian irrigation systems (Fig. 1). This maldistribution results in major differences in water availability from one tertiary unit to another. Generally the tail end portions have serious deficiencies of water, whereas the head or upper sections have excess water. This general maldistribution provides the challenge for an innovative irrigation system management to achieve equitable irrigation access for all farmers.

The objective of this study was to operationally achieve equitable water distribution by controlling the flow distributed in the laterals and the turnouts for the cropping activities and the respective water requirements of those activities.




**1.** Hypothetical distribution of the rate of water releases along the length of an irrigation canal, and the estimated minimum rate (70-100 mm/wk) required for optimal rice production.

Associated studies that have been developed include a land preparation study (Valera and Wickham 1978), a drainage water reuse study (Cablayan et a1 1978), sociological case studies (Tapay 1978), a communication study (Tapay et a1 1980), a tertiary level water distribution study (Moya and Early 1980), and a system management simulation study (Gilles 1980). A seepage and percolation study, the economic evaluation of system management, and the main system management study are nearing completion.

## METHODOLOGY

### Selection of the study area and the respondents

With the recognition of the common maldistribution of water in gravity irrigation systems, a memorandum of agreement and detailed plan of work between the NIA and IRRI were developed for research on the implementation of irrigation system management. The 2,500-ha Lower Talavera River Irrigation System (LTRIS), a subsystem within the UPRIIS, was chosen as representative of reservoir-supplemented systems in the country.

A sample of 184 farmer-irrigators and sample paddies were selected by the use of a grid placed across the system map at a 360-m spacing. Three major lateral components within the system were chosen as representative of the head, the middle, and the tail of the system; Lateral A, Lateral E, and the combination of Laterals G, H, and I were used for detailed observation of system performance.

### Benchmark data collection and system upgrading

The benchmark data were collected through pretested, structured, and open-ended interview schedule. The following information was gathered before the project and selected components were repeated at the end of each season thereafter:

- background characteristics of the farmers such as age, education, nonfarm income, number of children, distance from the farm and from water source, and other information pertinent to water management;
- basic inputs of rice production such as land, labor, and cash capital, and rice yield from the preceding season; and
- farmers' assessment of system personnel performance and of water flows at different points of the canal, experiences of water shortage and irrigation problems, both physical and social issues.

Crop-cut yield sampling for the 1976 wet season was undertaken in mid-December on the grid sample of farmers to provide benchmark information on the yield of rice before the study. Because of construction activities no dry season crop was harvested in 1976-77. A detailed work plan was constructed to

facilitate project implementation. An inventory of the system control and measuring structures was conducted to determine those that would be serviceable for the study and those that would require improvement. System structural improvement was completed during the 1976-77 dry season.

## System management implementation

In the past, farmers often placed checks in the canals as they wished, to the disadvantage of farmers further downstream in the system. Farmer meetings were held to disseminate the objectives of the study, and the joint NIA-IRRI staff asked the farmers for their cooperation, primarily through non-interference with the management of the main canal, laterals, and sublaterals. An information campaign was implemented on a pilot basis in the 1977 wet season to explain to the farmers how the project was designed to provide each of the lateral canals and turnouts with the correct amount of water and that farmers obstructing the primary canals would make this impossible. The campaign was expanded and strengthened in the 1977-78 dry season. In the 1978 wet season, one of the methods used in the campaign was the distribution of a water management calendar based on the sequence of farming activities in the irrigation year and with monthly captions and scenes emphasizing positive irrigation behavior.

The detailed plan of operations outlined the three major elements in system management as measurement, control, and monitoring. Measurement deals with water supplies, areas, and water requirements. Control refers to the calculation of target discharges and imposing water control using available structures. Monitoring refers to maintaining a record of system performance and providing rapid feedback when problems occur. Intensive field training and periodic follow-up workshops were used to emphasize these elements and the skills required by the NIA-IRRI staff to implement the program.

## Measurement element of system management

*Water supplies and requirements.* During the implementation, daily data collection on the flow of irrigation water, rainfall, evapotranspiration, and seepage and percolation were collected by the LTRIS system personnel. The water supplied and requirements were expressed weekly in mean daily millimeter equivalent depth. Rainfall and evaporation were measured at four strategic places within the command area of the system.

*Status of farming activities.* As a regular part of the weekly management task, the LTRIS staff completed a record of the areas in each category of farming activity, including area to be land soaked, area under land soaking, area under land preparation, area to be transplanted, area under normal irrigation, area under terminal drainage, area to be harvested, area fallowed, and uncultivable area.

## Control element of system management

*Target discharge computation.* The complete farming activity inventory with corresponding water requirement for each category allowed calculation of target discharges for each lateral canal command area and tertiary units along the laterals. The target flows were computed as the total water requirement assuming no rainfall and varied for specific farming activities. During the first year the general guidelines were 1.5 and 1.8 liters/second per ha for land soaking and preparation, and 1.2 and 1.4 liters/second per ha after transplanting rice for the wet and the dry season, respectively.

*Water control.* To accomplish the objective of providing water to each area in accordance with its requirement, control and measurement of irrigation water were implemented at the headworks of the main canal, laterals and sublaterals, and selected turnouts during water distribution. Water suspension or reduced irrigation was practiced to save water at the reservoir and avoid over-irrigation when substantial rainfall occurred.

## Monitoring element of system management

*Crop-cut yield sampling.* Grain yield determination is one important monitoring element of system management in evaluating system performance on a seasonal basis. Crop-cutting was used to estimate the grain yield of rice in the 184 observation paddies. Crop-cut samples from 8 $m^2$ of the standing crop from two locations within the paddy were threshed. The grain was weighed and the yield corrected to 14% moisture content, expressed in tons per hectare.

*Water adequacy.* The stress-day concept was used in evaluating water adequacy on the sample paddies (Wickham 1971). The stress-day concept was defined as the seasonal accumulated number of days in excess of three for any drying period during which the paddy was continually without standing water. The

depth of water above or below the soil surface was measured in short observation wells, and the data were used for correlation with the stress-day observations. The measurements were assessed three times per week throughout each cropping season.

*Interviews and participant observation.* Farmers were interviewed at the end of each season to monitor economic information and social-institutional issues related to the management of the irrigation system. Data obtained from the 184 farmer respondents provided the seasonal variation of farmer-perceived yields and economic data on costs and returns from rice farming. They also indicated farmers' response to the innovative management of the system. The participant observation technique was used primarily to document farmers' negative behavior such as checking of canals, construction of extra turnouts, and opening and closing of the gates. These are all referred to as the farmers' interference behavior. The day-to-dayfarmer response regarding system performance was recorded and included the farmers' reaction to the fluctuation of water supply, maintenance and repairs of physical facilities, and performance of duties by personnel. A daily traverse was followed by the participant observer in sections of the system depending on the critical stage of crop growth and water availability.

## Data management and analysis

*Systematic data management.* Systematic data management is the collecting, checking, processing, analyzing, and reporting of a large volume of information through efficient personnel utilization, maintenance of high standards of data quality and accuracy, and rapid turnaround using electronic data processing machines.

*Data coding.* Coding in the data management system used time and location identifiers. Twelve identifiers indicated particular parameters about the location where data were collected as an index level for analysis. Five of those identifiers were preprinted on precoded data sheets, one for each particular type of data gathered.

*Computer graphics.* The computer output used was a printer plotter and a computational package called the Synagraphic Mapping Systems Package (SYMAP). SYMAP was used with basic background information indicating size of rotational service areas, location

of canals, location of creeks and water bodies in the vicinity, location of the Talavera River, the diversion sites, and the location of settlements on a basic grid.

Most of the measurements of the management variables from the LTRIS study involve a dimension of space, notable either as definitional measurements expressed as a proportion of a linear length, area, or volume, and the latter refers to the positional displacement, with respect to a conventionally set reference, about which measurement occurred. Data from these measurements with emphasis on location are generally known as spatial data.

The types of locations used in the mapping of the LTRIS data are a sub-space location which is measured on a rotational area basis and the point location with measurement on a farm basis. To the latter belong yield data, seepage and percolation, stress day measurements, etc. The data are scaled from 1 to 10 according to intensity and the printer uses a series of 10 figures from a decimal to a solid black figure to provide visual representation of the magnitude of data.

*Analysis of sociological and economic data.* At the end of each cropping season an economic questionnaire provided data for monitoring the system's performance. All the forms were precoded and high standards of data quality were maintained by avoiding transfer of data before keypunching. On a seasonal basis, a series of precoded questionnaires was used to look at the farmer's attitudes about the system's performance and the system's responses to the farmer's needs. The set of identifiers for the physical management data was used for the economic and social-attitudinal data on the system. Relationships between the selected dependent variables such as farmer characteristics and water management-related variables, and the farmer's location along the main canal and lateral canal used the chi-square ($x^2$) statistical test with a 0.05 level of significance.

## RESULTS AND DISCUSSION

The management approach was implemented by the regular NIA operations staff, including 1 supervisor (WMT-1) for every 2,500 ha and 5 water management technologists (WMT), each for every 500 ha. Water tenders, generally high school graduates, numbered 10 and were responsible for 250 ha each. The IRRI staff augmenting the NIA staff was one full-time research assistant who is an agricultural engineer, two part-time research assistants in sociology and statistics, two full-time field assistants, and three to five

part-time data processors. The IRRI equivalent of 4 full-time staff augmentation was the only outside input of resources in the research effort. The results reported here are a small sample of indicative system performance parameters for the first year of the study, 1977 and 1978 wet and dry seasons.

## Benchmark measurements and comparisons

The first result of the project was the inventory of structures in the system, which required some rehabilitation before they could be fully used in measuring and controlling water. Although not structurally perfect, LTRIS is probably the best equipped gravity system in the Philippines.

Yield estimates from crop-cut sampling before the implementation of the study in the 1976 wet season averaged only 2.9 t/ha. This was largely due to an inadequate water supply.

The benchmark data pertaining to farmer characteristics were analyzed to test the hypothesis that location is an important determinant of these characteristics. The farmer characteristics that were investigated and found significantly related to location in the main canal were tenure status, place of ancestral origin, level of education, distance between home and farm, and dispersion of farm parcels.

To determine the prevailing conditions regarding water shortage, farmers' satisfaction with irrigation performance and other water-related information were obtained. During the 1976 wet season there was a significant association between water shortage and location along the main canal of the system. Compared with farmers at the end portion, a higher number of farmers at the upper and middle sections of the main canal did not experience delay in land preparation due to water shortage. Neither did they suffer any water shortage on their farm. However, 5% of the farmers at the end portion of the canal experienced water shortage at the reproductive stage in an area of 0.25 or more hectares. A higher proportion of farmers at the upper and middle sections of the canal were satisfied with the system performance.

When farmers were asked to rate the flow of water at the main canal, a significant relationship was found between satisfaction with water flow and farmers' location along the main canal. A large number of farmers at the upper and middle parts of the canal rated the flow of water as good; the percentage for farmers at the end of the canal was relatively lower. Farmers' solutions to

irrigation problems included contacting fellow farmers, contacting water authorities, resorting to water stealing, resorting to canal checking, and *giving up.* Among these variables only three exhibited a significant association with location along the main canal. A higher percentage of farmers at the upper and middle sections contacted the water authorities. A higher proportion of farmers in the same locations said that they never resorted to water stealing. The frequency of canal checking was higher in the upper and middle sections of the main canal.

When comparing water flows in the 1976 wet season with flows in the earlier years of the project, most farmers indicated that delivery was much better. When asked to enumerate their perceived need for additional turnouts at the time of the benchmark survey, the majority of the farmers at the head and middle of the system indicated no need for additional turnouts, but half of the tail end farmers wanted more. The physical improvements which farmers thought were necessary to improve irrigation performance were classified into system level and farm improvements. The system improvements ranged from legalization of the extra turnouts to maintenance of the irrigation facilities, whereas farm improvement dealt with the construction and maintenance of farm ditches, drainage canals, and other farm facilities. When asked about water management aspects that needed improvement, the farmers cited the water tender's close supervision of water deliveries, communication between the farmer and the NIA personnel, rescheduling of water deliveries to February and March, good service from NIA personnel, and fairness and immediate action of NIA personnel in granting water.

## System management performance evaluation

To accomplish the objective of providing water to each area in accordance with its requirement, target rates of water flow were established throughout the system, based on total water requirements assuming no rainfall. The target-flow concept provided the system personnel a standard to shoot for, and a basis for providing feedback to guarantee the target flows.

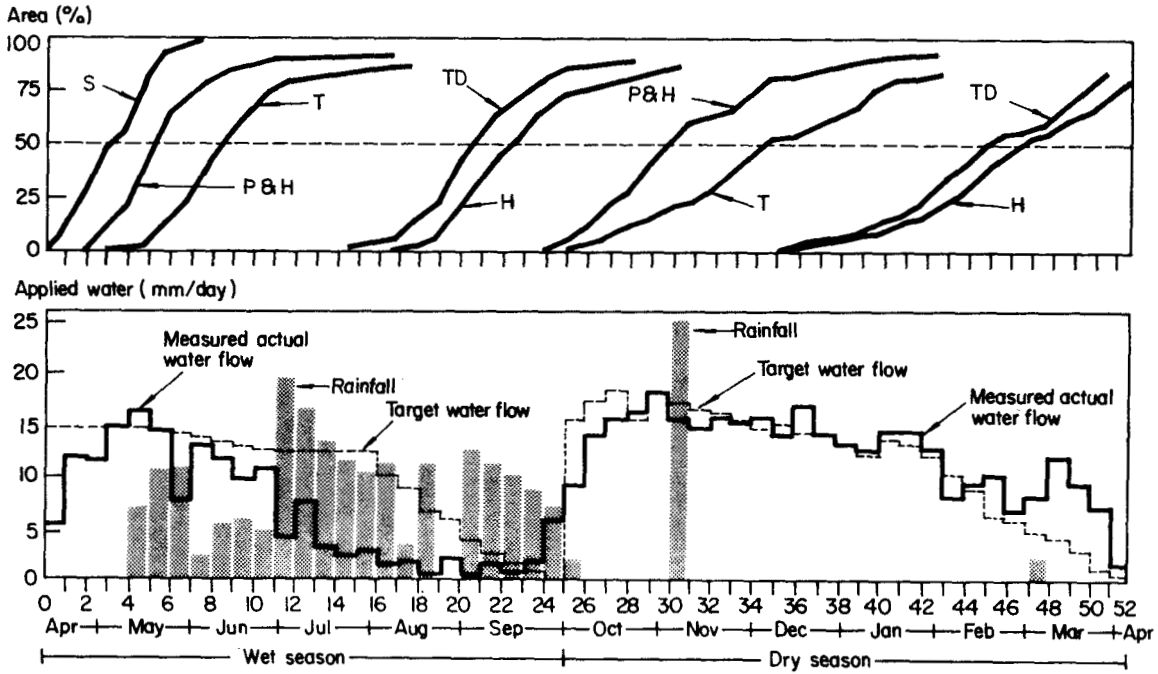
*Actual versus target discharge and rainfall.* During the first 3 weeks of the wet season water was insufficient to reach the target. Farmers continued their old practice of checking, hence the downstream farmers did not receive much water until the 4th week. Nevertheless, sufficient irrigation water deliveries after the first month enabled tail end farmers to catch up with the regular cropping schedule. After transplanting,

irrigation water was reduced and water release was suspended at the headgate of the system, lateral canals and turnouts, because the target discharges were met in part by rainfall. After June, rainfall was effective in supplying most of the target water requirement (Fig. 2).

The wet season target discharge discrepancies for the entire system and the pilot laterals A, E and G, H, and I collectively indicated water deficiency in the earliest weeks and significant water excesses thereafter. The dry season crop started immediately after the wet season crop was harvested. There was no cutoff of irrigation water delivery throughout the UPRIIS service area. This decision was made by the Irrigation Planning Committee of UPRIIS in consultation with the farmers and other government agencies to save the water ordinarily used for the land soaking requirement. The schedule was disseminated to the farmer through radio broadcasts, farmer meetings, and individual contacts by the LTRIS personnel. The overall system showed good target discharge achievement without the interference of rainfall (Fig. 2). The dry season target discharge discrepancies indicated a very mixed relationship of deficit and excess. The system as a whole indicated approximately 50% of the weeks with deficit and 50% with excess as did Laterals G, H, and I. Lateral A had water deficit and Lateral E had water excess during most of the season.

The dry season crop started in September for those farmers whose first crop was harvested early and rainfall was utilized to meet the target water flow (Fig. 2). The formal start of the dry season was in the second week of October. Target water flows were computed based on the actual area harvested in the wet season. During the first three weeks of the dry season, the target water flows were not met because the farmers of Lateral A preferred to start land preparation later and transplant in December to avoid a flowering period in January or February when strong winds would reduce their expected yields. They were encouraged to plant with farmers in other sections because the cutoff date was tentatively set for March 1978, with April and May reserved for annual maintenance. The Lateral A farmers ultimately followed their own schedule and flows were extended to accommodate them.

Lateral A was still included in the computation of target water flows, but actual water flows delivered to them were only at the rate of 1/3 to 1/2 of the normal target (weeks 26 to 32) just to saturate the soil and encourage them to start sooner. Full target water flows were only met from week 33-46 when Lateral A farmers started their farming activities. Extension of water delivery for 2 weeks (20 March-14 April 1978) was given to the Lateral A farmers who were late in transplanting and Lateral E




**2.** Percent area soaked (S), plowed and harrowed (P&H), transplanted (T), terminally drained (TD), and harvested (H); average daily target water flow, measured, actual flow and rainfall in mm/day, by weekly intervals. Lower Talavera River Irrigation System -District II, Upper Pampanga River Integrated Irrigation System-National Irrigation Administration, Nueva Ecija, Philippines, 1977 wet season and 1977-78 dry season.

farmers who planted third crops. Four weeks before the cutoff date, actual water flows were doubled against the target water flows (Fig. 2), to allow storage of more water on the paddies for crop use after the irrigation cutoff.

*Grain yield.* Yield estimates from crop-cut sampling showed that the mean yield was much higher in the 1977 wet season than in the 1976 wet season and 1977-78 dry season. The low grain yield in the 1976 wet season was due largely to inadequate water supply, whereas the decrease in the 1977-78 dry season was due to the virus disease grassy stunt, the insect called stem borer, and rat infestation for those farmers who harvested earlier or later crops. There was no significant difference in yield levels among the head, middle, or tail sections in either season of the first year of the project (Table 1).

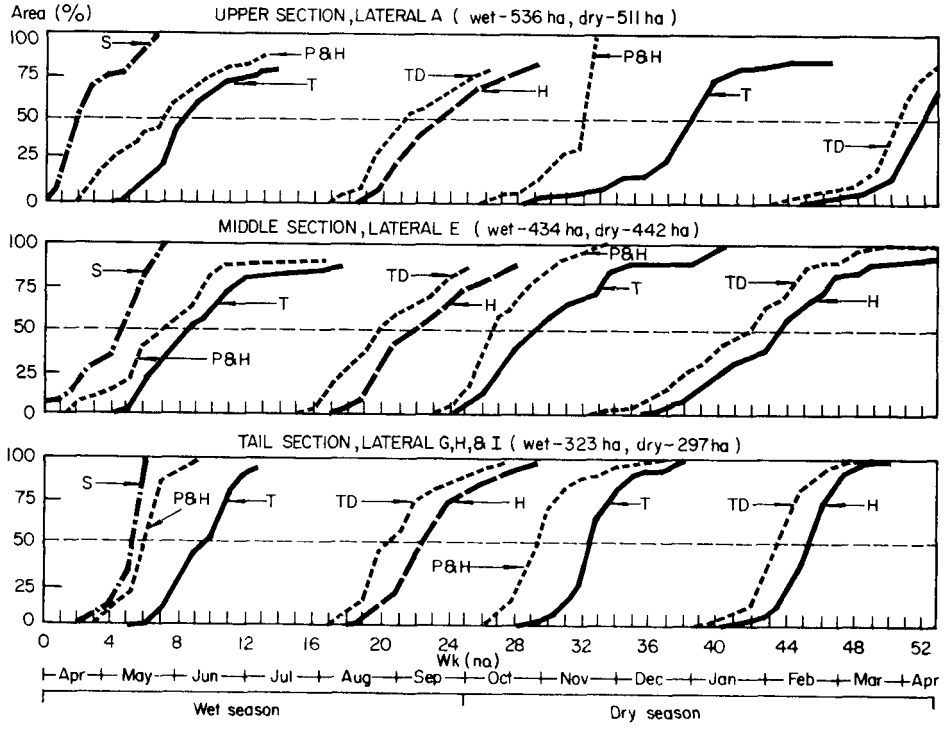
*Status of farming activities.* The duration of each phase of land preparation through transplanting was estimated and presented by the cumulative graphical percentage area soaked, plowed and harrowed, transplanted, terminally drained, and harvested starting from the first day of water delivery. Land soaking was completed in 50% of the LTRIS area after 3.3 weeks; plowing and harrowing was 50% completed after 5.4 weeks; and 50% was transplanted after 8.7 weeks. In the wet season there was a large discrepancy between the first and the second half of the system. It took 9.6 weeks to complete land soaking, 17 weeks to complete 90% of the area that was to become the entire land preparation area, and 18 weeks to complete 85% of the area that was to become the entire transplanted area (Fig. 3). In part, land preparation was lengthy because some farmers in the tail end of Laterals E and G had crops remaining from the previous dry season and some farmers in Lateral A lacked capital to start their land preparation, a factor causing 14% of the area to remain unplanted.

The tail section (served by Laterals G, H, and I) was able to soak 100% of the area in 6 weeks, plow and harrow the 98% portion that was prepared 9 weeks, and transplant the 96% of the total area which became all the area transplanted to a rice crop in 14 weeks. This was considerably earlier than in the upper section (Lateral A) and middle section (Lateral E), despite difficulty in obtaining water at the beginning of the season (Fig. 3). Most of the vegetable and maize crops were planted in this section. It appears that this area has more industrious farmers, is closer to a market, and has soil that is lighter and better adapted to vegetables than the other parts of the LTRIS.

Table 1. Mean crop-cut grain yield on consecutive sections, Lower Talavera River Irrigation System (LTRIS), District II, Upper Pampanga River Integrated Irrigation Systems-National Irrigation Administration (UPRIIS-NIA), Nueva Ecija Province, 1976 wet season and 1977 wet and dry seasons.

| Section | Lateral canal | 1976 wet season | | 1977 wet season | | 1977 dry season | |
|---|---|---|---|---|---|---|---|
| | | Samples (no.) | Yield (t/ha) | Samples (no.) | Yield (t/ha) | Samples (no.) | Yield (t/ha) |
| 1 | A | 9 | 2.16 ac* | 25 | 4.20 ab | 28 | 2.50 a |
| 2 | B | 10 | 2.62 ac | 30 | 4.25 ab | 28 | 2.40 a |
| 3 | D and F | 7 | 3.71 bb | 27 | 4.30 ab | 27 | 3.10 a |
| 4 | E | 9 | 4.10 bb | 31 | 4.50 ab | 31 | 3.30 a |
| 5 | G, H, and I | 13 | 2.40 ac | 23 | 4.90 ab | 32 | 3.20 a |
| Weighted av | | | 2.90 | | 4.40 | | 2.90 |

* The statistical significance (P = .05) of differences in mean yields from section to section in a given season is denoted by the first letter in the pair by difference compared vertically down the column. The statistical significance of differences in yields within a section from year to year in the wet season is denoted by the second letter of paired letters compared horizontally across the page.




**3.** Percent area soaked (S), plowed and harrowed (P&H), transplanted (T), terminally drained (TL), and harvested (H) for Lateral A (upstream section), E (midstream section). G, H, I (downstream section) by weekly intervals. Lower Talavera River Irrigation System-District II, Upper Pampanga River Integrated Irrigation System-National Irrigation Administration, Philippines, 1977 wet season and 1977-78 dry season.

In the 1977–78 dry season, the tail section (Laterals G, H, and I) completed the plowing and harrowing, and transplanting, of 98% of the area in 12 weeks, much earlier than the upper section which completed the same operations for 80% of the area in 22 weeks. The middle section (Lateral E) accomplished plowing of all the area in 15 weeks and transplanting in 16 weeks (Fig. 3). This situation was similar to that in the 1977 wet season. The gap between plowing and harrowing and transplanting in the tail section was only a week, compared to 3.5 weeks in the 1977 wet season. The tail section farmers had developed trust in the system and the field personnel as indicated by their willingness to hasten farming activities.

*Seepage and percolation (S&P) and evapotranspiration (ET).* Average rates of S&P, based on field measurement, were computed using the inclined gauge. During the 1977 wet season (July to August) when rainfall was high, the mean daily S&P and ET rates ranged from 4 to 6 and 3 to 4 mm/day, respectively (Table 2). In the 1977–78 dry season, the values for mean daily S&P ranged from 3 to 5 mm/day and ET from 4 to 5 mm/day (Table 3). These

Table 2. Average rates of irrigation (IR), rainfall (RN), evapotranspiration (ET), seepage and percolation (S&P), and water use efficiency (WUE)[a] by weekly intervals. Lower Talavera River Irrigation System (LTRIS), District II, Upper Pampanga River Integrated Irrigation Systems–National Irrigation Administration (UPRIIS–NIA), Nueva Ecija Province, 1977 wet season.

| Irrigation week no. | Date | IR (mm/day) | RN (mm/day) | ET (mm/day) | S&P (mm/day) | WUE (%) |
|---|---|---|---|---|---|---|
| 13 | 7–13 Jul 1977 | 7.7 | 16.3 | 3.3 | 6.7 | 42 |
| 14 | 14–20 Jul 1977 | 3.3 | 13.3 | 3.6 | 5.7 | 56 |
| 15 | 21–27 Jul 1977 | 2.2 | 11.4 | 3.6 | 5.7 | 68 |
| 16 | 28 Jul–3 Aug 1977 | 2.9 | 9.8 | 4.0 | 4.1 | 64 |
| 17 | 4–10 Aug 1977 | 1.6 | 11.2 | 4.2 | 4.6 | 69 |
| Weighted av | | 3.5 | 12.4 | 3.7 | 5.4 | 60 |

[a] $WUE = \left(\frac{ET + S\&P}{IR + RN}\right) 100.$

Table 3. Average rates of irrigation (IR), rainfall (RN), evapo-transpiration (ET), seepage and percolation (S&P), and water use efficiency (WUE)[a] by weekly intervals, Lower Talavera River Irrigation System (LTRIS), District II, Upper Pampanga River Integrated Irrigation Systems-National Irrigation Administration (UPRIIS-NIA), Nueva Ecija Province, 1977-78 dry season.

| Irrigation week no. | Date | IR (mm/day) | RN (mm/day) | ET (m/day) | S&P (m/day) | WUE (%) |
|---|---|---|---|---|---|---|
| 39 | 5-11 Jan 1978 | 12.9 | 0 | 5.0 | 2.7 | 60 |
| 40 | 12-18 Jan 1978 | 12.3 | 0 | 4.2 | 2.8 | 57 |
| 41 | 14-25 Jan 1978 | 14.4 | 0 | 4.6 | 3.2 | 54 |
| 42 | 26-Jan-1 Feb 1978 | 14.3 | 0 | 3.8 | 4.6 | 59 |
| 43 | 2-8 Feb 1978 | 12.6 | 0 | 4.0 | 4.7 | 69 |
| Weighted av | | 13.3 | 0 | 4.3 | 3.6 | 60 |

[a] $WUE = \left(\frac{ET + S\&P}{IR + RN}\right) 100.$

S&P rates are higher than those expected for heavy soils, but are possible in LTRIS because part of the area served by the system is located on coarser soils along the riverbank of the Talavera River.

*Water-use efficiency (WUE).* Based on the S&P and ET rates, the weekly system-wide water use efficiency varied from 42 to 69% with a mean of 60% in the 1977 wet season (Table 2). The range of weekly water use efficiencies was 54 to 69% in the 1977-78 dry season, with a mean of 60% (Table 3). The system-wide WUE was 43 and 51% in the 1975-76 wet and dry season. The WUE increased to 60% for both the 1977 wet season and 1977-78 dry season (Table 4), a marked improvement in system performance.

## Farmers' evaluation of system management after the first year

Farmers' evaluation of the system performance was determined by asking the farmers to indicate their satisfaction with water flows at various rice growth stages. Other data sought were those on farmers' satisfaction with day-to-day management of the

Table 4. Average rate of water use efficiency (WUE). Lower Talavera River Irrigation System (LTRIS), District II, Upper Pampanga River Integrated Irrigation Systems-National Irrigation Administration (UPRIIS-NIA), Talavera, Nueva Ecija Province. 1975 dry season, 1976 dry season, 1977 wet season, and 1977-78 dry season.

| Cropping season | Months | WUE (%) |
|---|---|---|
| 1975 wet season | Jul-Aug | 43[a] |
| 1976 dry season | Jan-Feb | 51[a] |
| 1977 wet season | Jul-Aug | 60 |
| 1978 dry season | Jan-Feb | 60 |

[a]Source: UPRIIS-NIA Water Control Coordinating Center (1977).

system components and their responses to the different aspects of system administrative management such as payment of irrigation fee, performance of NIA personnel of their duties and responsibilities, and other water-related information.

*Farmers' satisfaction with system performance.* Data for the 1977-78 dry season reflect a high proportion of satisfaction with the flow at four stages of crop growth (Table 5). The majority of the farmers in all sections of the canal indicated that the water flows were better in the 1977-78 dry season than in the 1975-76 dry season (Table 5).

*Farmers' response to improved system management.* With respect to the farmers' adoption of the NIA schedule for concurrent lateral planting, a significant difference was obtained for farmers in the middle section who did not follow the NIA schedule. These had the Sibul Pond as source of water besides the LTRIS dam, and so had an advantage in early planting. Because they harvested earlier, many of them were able to plant the third crop of rice. Most of the reasons for inability to follow the schedule were lack of capital for inputs, insufficient water, and industry of some of the farmers (Table 6).

Table 5. Farmers' satisfaction with the management aspect of an irrigation system. Lower Talavera River Irrigation System (LTRIS), Nueva Ecija Province, 1977 – 78 dry season.

| Management aspect | Farmers (%) | | | |
|---|---|---|---|---|
| | Not satisfied | Slightly satisfied | Satisfied | Very much satisfied |
| Dry season water supply | 13 | 21 | 62 | 4 |
| Water tender's performance | 9 | 1% | 74 | 5 |
| Water management technician's performance | 15 | 21 | 62 | 2 |
| Current farming returns compared with those of a year ago* | 54 | 24 | 16 | 6 |
| | *Not better* | *Slightly, better* | *Better* | *A lot better* | *The same* |
| Assessment of present farming conditions compared with those before construction of the LTRIS system | 6 | 8 | 55 | 27 | 4 |

*Significance of location. $X^2$ = 17.141 df = 8. Significance at P = .05.

*Farmer conflicts over water and related matters.* There was no substantial evidence that conflicts were prevalent in the 1977 – 78 dry season. The problems were quarelling over the priority of water use, lack of water, and farmers' unwillingness to follow the schedule of water delivery (Table 7). Most of the conflicts were settled by the water tenders and the water management technologists (Table 8). About 67% of the farmers indicated that conflicts were settled by the water tender, by the water management technologist, or by the combined efforts of the two. The farmers themselves settled only 5% of the conflicts.

Table 6. Reasons for farmers' non-adoption of the National Irrigation Administration (NIA) schedule to plant concurrently in one lateral with respect to location. Lower Talavera River Irrigation System (LTRIS), 1977-78 dry season.

| Reason | Farmers | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Upper section (n = 18) | | Middle section (n = 43) | | End section (n = 12) | | Total (n = 73) | |
| | No. | % | No. | % | No. | % | No. | % |
| Rotation water is not enough if planted at the same time | 4 | 22 | 18 | 43 | 4 | 33 | 26 | 35 |
| $x^2$ = 15.08* DF = 2 | | | | | | | | |
| Lack of capital | 5 | 28 | 5 | 12 | 2 | 17 | 12 | 16 |
| No available labor fee and farm machinery | 2 | 11 | 6 | 14 | 3 | 25 | 11 | 15 |
| Farmers' willingness to plant ahead | 2 | 11 | 4 | 10 | 0 | 0 | 6 | 8 |
| Different rice varieties | 1 | 6 | 2 | 5 | 0 | 0 | 3 | 4 |
| No answer | 1 | 6 | 0 | 0 | 1 | 8 | 2 | 3 |
| Others | 3 | 16 | 8 | 16 | 2 | 17 | 13 | 19 |

* (significant at P = .05).

*Improvement and performance by system personnel.* Seventy-four percent and 62% of the farmers were satisfied with the water tenders' performance and the water management technologists' performance, respectively (Table 5). Farmers' satisfaction was not entirely consistent with their response on improvement of performance of duties and responsibilities because a greater proportion of them indicated satisfaction with the service of the water tenders and water management technologists. Some reasons for the satisfaction were the farmers' understanding that the NIA personnel were doing their best to help, lack of water

Table 7. Frequency of occurrence and type of conflicts regarding water use with respect to location in the Lower Talavera River Irrigation System (LTRIS), Nueva Ecija Province, for the 1977 – 78 dry season.

| Frequency | Farmers | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Upper section | | Middle section | | End section | | | |
| | No. | % | No. | % | No. | % | No. | % |
| Zero | 45 | 28 | 61 | 38 | 24 | 15 | 130 | 81 |
| 0ne | 7 | 4 | 9 | 6 | 7 | 4 | 23 | 14 |
| Two | 0 | 0 | 1 | 0 | 3 | 2 | 4 | 2 |
| Three and above | 2 | 1 | 2 | 1 | 1 | 1 | 5 | 3 |
| Total | 54 | 33 | 73 | 45 | 35 | 22 | 162 | 100 |
| *Type of conflicts* | | | | | | | | |
| None | 36 | 22 | 47 | 29 | 15 | 9 | 98 | 60 |
| Quarrel over priority in the use of water | 7 | 5 | 8 | 5 | 7 | 4 | 22 | 14 |
| Farmers don't follow schedule of water delivery | 2 | 1 | 1 | 1 | 6 | 4 | 9 | 6 |
| Destruction of embankments | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 1 |
| Lack of understanding/ communication during time of water distribution | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 1 |
| Problems on physical facilities | 4 | 2 | 3 | 2 | 0 | 0 | 7 | 4 |
| Lack of water | 2 | 1 | 6 | 4 | 4 | 3 | 12 | 8 |
| Problems with schedule of water delivery | 0 | 0 | 1 | 1 | 2 | 1 | 3 | 2 |
| Drainage problem | 2 | 1 | 5 | 3 | 0 | 0 | 7 | 4 |
| Total | 54 | 33 | 73 | 45 | 35 | 22 | 162 | 100 |

Table 8. Farmers' response to question on who settle disputes in cases of conflict and problems relating to water with respect to location in the main canal at the Lower Talavera River Irrigation System (LTRIS), Nueva Ecija Province, in the 1977 – 78 dry season.

| Farmers' response | Farmers | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Upper section | | Middle section | | End section | | | |
| | No. | % | No. | % | No. | % | No. | % |
| 0 - No answer | 11 | 7 | 11 | 7 | 4 | 2 | 26 | 16 |
| 1 - Water management technologist | 4 | 2 | 11 | 7 | 2 | 1 | 17 | 10 |
| 2 - Water tender | 9 | 6 | 12 | 7 | 9 | 6 | 30 | 19 |
| 3 - Chairmen of IG's | 2 | 1 | 3 | 2 | 1 | 1 | 6 | 4 |
| 4 - Local leaders | 0 | 0 | 4 | 2 | 3 | 2 | 7 | 4 |
| 5 - Government officials | 0 | 0 | 2 | 1 | 0 | 0 | 2 | 1 |
| 6 - Combination of 1 and 2 | 22 | 14 | 22 | 14 | 7 | 4 | 51 | 32 |
| 7 - Combination of 2 and 3 | 0 | 0 | 1 | 1 | 4 | 2 | 5 | 3 |
| 8 - Combination of 1 and 5 | | | | | | | | |
| 9 - Combination of 2 and 4 | 1 | 0 | 1 | 1 | 2 | 1 | 4 | 2 |
| 10 – Combination of 4 and 5 | | | | | | | | |
| 11- Combination of 1 and 4 | 2 | 1 | 2 | 1 | 2 | 2 | 6 | 4 |
| 12 – Farmers themselves | 3 | 2 | 4 | 2 | 1 | 1 | 8 | 5 |
| Total | 54 | 33 | 73 | 45 | 35 | 22 | 162 | 100 |

$x^2$ = 21.481 df = 20 P = NS

problems, and good relations between the NIA personnel and the farmers.

*Farmers' payment of irrigation fees.* When farmers were asked if they had paid irrigation fees, more than 60% indicated that they had made only partial payments, only 6% paid the whole amount (Table 9). The reasons for nonpayment were low production (14%), poor financial situation (14%), and use of money for other purposes and for paying other debts (12%). The data on regularity in payment of irrigation fees indicated that a slightly higher number of farmers in the middle and upper sections were paying regularly. Thirty-eight percent of the farmers said that regular payment did not help improve irrigation service, 5% indicated it greatly improved service (Table 9). Farmers did not have any incentive in paying the irrigation fees because the majority (97%) said that their water service was the same whether or not they paid. About 3% said that withholding of payment did help to force the authorities to provide better water service (Table 9).

Table 9. Farmers' payment performance and opinions about payment of irrigation fees. Lower Talavera River Irrigation System (LTRIS), Nueva Ecija Province, 1977-78 dry season.

| | No payment (%) | Partial payment (%) | Full payment (%) | No response |
|---|---|---|---|---|
| Farmers' payment performance | 1 | 64 | 6 | 29 |
| | *No improvement (%)* | *Slightly improved (%)* | *Improved (%)* | *Greatly improved (%)* |
| Farmers' opinion on the effect of payment on service | 38 | 30 | 27 | 5 |
| Farmers' opinion on withholding payment forcing better water service | 97 | 2 | 1 | 0 |

*Comparison of current farming returns with those prior to project.* When asked to compare their present farming returns with those of a year ago, only 6% of the farmers indicated "very much satisfied" and 16% said they were "satisfied." Fifty-four percent were not satisfied. Dissatisfaction of the majority of the farmers may be attributed to decline in per hectare production in the 1977 dry season (Table 1) brought about by virus and insect infestation. There was a significant relationship between farming returns and farmer's location along the system. A comparison of present farming conditions with those before the construction of irrigation facilities in the area showed that 55% of the farmers considered their present condition "better" because of access to water for more than one crop a year, 27% "a lot better", and only 4% indicated "no difference" (Table 5). No significant relationship was found between this variable and farmer's location along the canal.

*Observed farmers' behavior.* Farmers' behavior was observed as the number of times farmers committed each type of negative behavior (Table 10). The highest occurrence was in the checking of canals -- observed more than 17 times/week -- followed by the making of illegal turnouts. About 52 farmers were reported opening and closing gates at will.

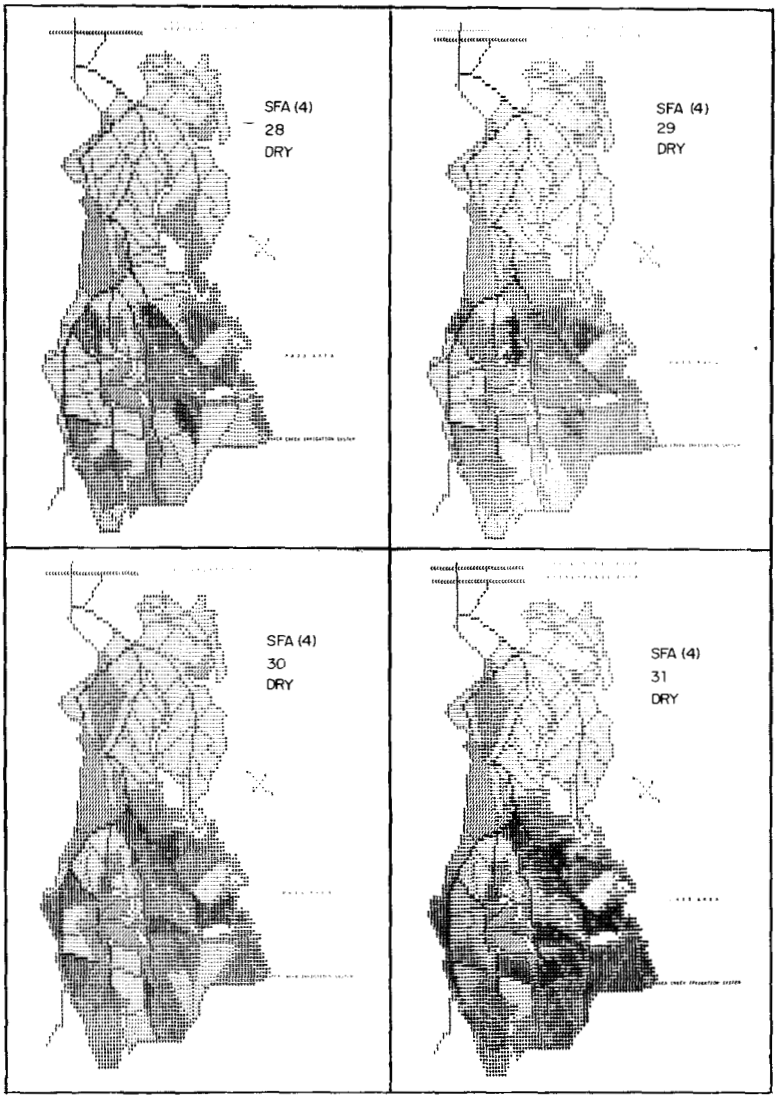
Out of the total 75 negative behavior occurrences observed in the 1977-78 dry season, checking of canals was observed 9 times per week and opening and closing of gates, 7 times per week. A negligible number of farmers made illegal turnouts and broke equipment. This finding was not conclusive because observations were more intensive in the 1977 wet season than in the 1977-78 dry season. The evidence indicated that farmers' negative behavior significantly declined with time and with the implementation of the project.

## Graphical data presentation by computer

A new method of mapping by computer was utilized to gain a better understanding of the spatial relationships of performance parameters within the system. Two particular relationships of major interest were the status of farming activities and the target flow achievement. The four consecutive weekly maps showing the status of farming activities are presented in reduced form to show the change of conditions from week to week. Transplanting for weeks 28-30 indicates an increasing density of darkness corresponding to pending completion (Fig. 4). The target flow achievement maps are shown only for the end of the

Table 10. Mean weekly observed number of farmers who demonstrated negative irrigation behavior. Lower Talavera River Irrigation System (LTRIS), Nueva Ecija Province, 1977 – 78.

| Period | Checked canal | Constructed illegal turnouts | Opened and closed gates | Broke embankment | Others | Total |
|---|---|---|---|---|---|---|
| 1977 wet season | 17.3 | 12.7 | 7.7 | 2.4 | 0.6 | 40.7 |
| 1977 – 78 dry season | 8.8 | 0.7 | 6.8 | 0.2 | 0.5 | 16.9 |




**4.** Transplanting component - status of farming activity at 4 consecutive weeks. Lower Talavera River Irrigation System, Philippines, 1977-78 dry season.

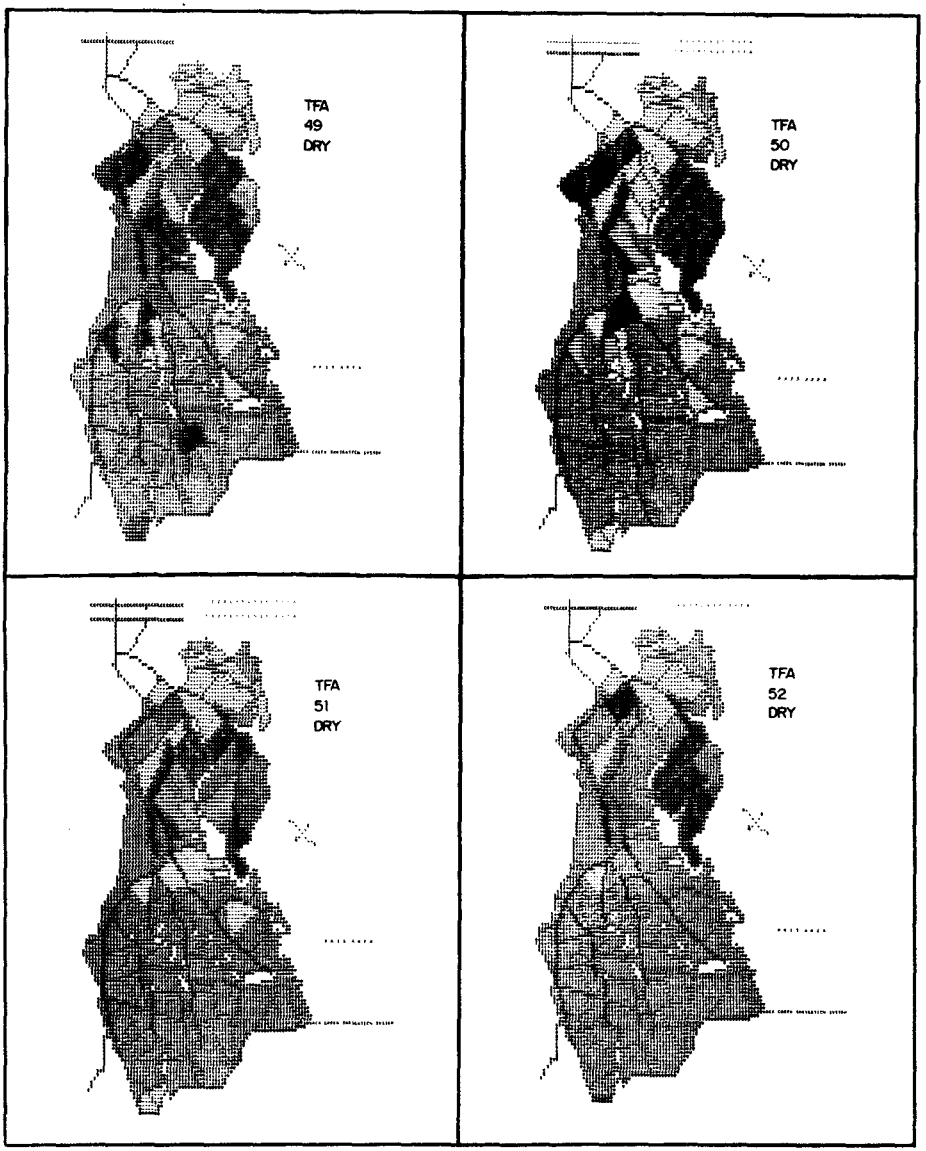
season (weeks 49-52) to indicate the onset of terminal drainage as the density of darkness lessens (Fig. 5). While the method is expensive for use in system management activities, the purpose of the test was merely to demonstrate its potential utility for future consideration.

## SUMMARY AND CONCLUSIONS

The survey of initial conditions in the LTRIS system provided the basis for determining the structural requirements for systematic measurement and control of irrigation water. The initial yield survey indicated that the irrigation system as a whole was performing above the national average for irrigated rice production of about 2.9 t/ha. The interview of farmer respondents confirmed the hypothesis of a relationship between a number of farm, farmer, and system performance characteristics and position in the irrigation system.

The 1977 wet season performance indicated that after the sustained monsoon rains from the first week of July, the actual water flows were drastically cut back to allow the use of rainfall in target discharge achievement. During the period of normal irrigation from July through September, only about 45% of the total rainfall was used effectively in lieu of irrigation water because of the extreme variability in rainfall intensity on a week-to-week planning and decision-making basis. During this season only 85% of the total area planned was actually planted: 76% at the head, 86% at the middle, and 96% at the tail. The sequence of farming activities indicated quite uniform performance from the head to middle and tail laterals, a measure of the uniformity of water availability over time. The 1977 wet season average yield obtained by crop-cutting was 4.2 t/ha. During the 1977-78 dry season, the target water flow and measured actual water flow showed excellent agreement due to strictly imposed system management and lack of rainfall interference. In this season the total area planted to rice was only 80% of the total, and a marked range of cropping activities occurred with delays increasing from the tail to the head of the system. The dry season average yield was only 2.9 t/ha, partly because the very wide spread of the cropping activities provided ideal conditions for insects, diseases, and rats. About 3% of the farmers obtained a third crop of rice. The water utilization efficiency increased from the preproject levels of 43 and 51 % for the wet and dry seasons, to 60% for both seasons.

The farmers were reluctant to express satisfaction with the system performance, but were in good agreement that the water




5. Target flow achievement at Lower Talavera River Irrigation System, Philippines, 1977 wet season.

supply was more reliable in the 1977-78 crop year than in the previous year. Middle farmers were much more able to follow the irrigation agency schedule because of greater flexibility in their water supply. The irrigation agency personnel were called upon most frequently to mediate local conflicts over water use which, in general, were not intense disputes. The farmers' performance with respect to the payment of irrigation fees continued to decline during the project, even though a marked increase in the visible consumption of consumer goods and farming implements occurred. As the farmers possessed more materially, they seemed to want even greater volumes of material goods, and were more inclined to put off paying their irrigation fees. Farmers were in general agreement that their farming returns were better than before the project was implemented. The occurrence of farmer negative behavior in the form of checking, water stealing, destroying flow-measuring devices, and general interference in the operation of the system was observed to be much less intense with the implementation of the project and as the farmers realized a much more reliable water supply.

The innovative method of irrigation system management has demonstrated a marked improvement of system performance with the application of simple and rational techniques of measurement, control, and monitoring. When streamlined for ease of operation this innovative approach has potential for greatly improving irrigation system performance in wetland rice production in the humid tropics.

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# STUDIES IN WATER MANAGEMENT ECONOMICS AT IRRI

Robert W. Herdt

Lack of adequate water control is a major constraint to rice production and high rice yields in developing Asia. Rural development projects are often centered on the irrigation component. National policy alternatives for increasing rice production generally include irrigation. Irrigation absorbs large investments, often financed by national or international bankers who require evidence of economic viability before lending. For this reason, the study of benefits and costs of irrigation has received considerable attention.

Irrigation projects attract development banks and aid agencies because they utilize large amounts of capital, result in highly visible infrastructure, and provide a service necessary for development. At the same time, agencies charged with operating completed projects have many problems -- difficulty in collecting fees from farmers, difficulties in operating systems, water shortages, and lack of community cooperation in maintaining systems, among others. These difficulties may be because too many resources are made available for irrigation too quickly. Inefficient projects result from the lack of *absorptive capacity* of irrigation agencies. Another problem is that the productivity of systems is often overestimated whereas the costs are often underestimated so the implementing agencies have unrealistic expectations about the financial payoffs.

There are, however, strong pressures within developing countries for continual expansion of irrigation systems. The desire for food self-sufficiency often overrides economic criteria on irrigation as well as other food production decisions (Mangahas 1975). The bureaucratic pressures within irrigation agencies for continuous growth and expansion of the agency power and budget

Agricultural economist, International Rice Research Institute, Los Baños, Philippines. The helpful comments of J. C. Flinn are acknowledged, without implicating him in the remaining deficiencies of the paper.

means that there is great pressure to see that projects have favorable benefit-cost ratios.

Some analysts believe it is socially desirable to spread the costs of irrigation projects over the entire society rather than the farmer users. Taylor (1978) argues that hired laborers, farm-related businessmen, and consumers all enjoy substantial benefits from the increased production resulting from the introduction of irrigation and hence those groups ought to bear part of the costs.

If a project does not pay for itself, the costs generated by the project must be serviced by income earned from other sources in the economy. If projects generate less income than they cost, the difference is paid in taxes, or in the form of higher prices generated by inflation that results from government deficits. Countries must, therefore, have good estimates of irrigation productivity.

Because the two institutions most closely associated with irrigation project preparation -- the financing development banks and the irrigation authorities -- have strong interest in favorable project evaluations, national planning agencies should carefully evaluate such projects and compare them with alternative opportunities. Even if a political decision is occasionally made in favor of an uneconomic food production project, countries cannot make such decisions continuously without courting serious financial difficulties. Hence it is also the long-run advantage of the banks and irrigation agencies to insure that projects are viable.

## VALUE OF AND PROJECTED NEED FOR IRRIGATION

Analysis of growth in rice production in 7 Asian countries with annual growth of output exceeding 2% shows that irrigation is a major contributing force to output growth. The data in Table 1 show that expansion of irrigated land accounted for more than half the output increases in many countries and that residual yield grains, i.e. those not attributable to fertilizer and therefore presumably arising largely from irrigation, were important in most other countries.

We analyzed the prospects for Asian rice production and found that investments in fertilizer and irrigation at somewhat higher than historical levels would likely be inadequate to increase production at any annual rate higher than 2.4% (Herdt et a1 1978) Only by shifting the response to fertilizer above its current

Table 1. Estimated proportion of growth in rice output attributed to components of area and yield for selected Asian countries, mid-1960s to early 1970s.

| Country | Period | Annual rate of production growth (%) | Percentage points attributed to | | | |
|---|---|---|---|---|---|---|
| | | | Area | | Yield | |
| | | | Irrigated | Unirrigated | Fertilizer[a] | Residual- |
| Pakistan | 1965-73 | 7.9 | 1.4 | 0 | 1.7 | 4.8 |
| Malaysia | 1965-73 | 5.7 | 3.7 | 0.1 | 1.4 | 0.5 |
| Sri Lanka | 1965-72 | 5.6 | 0.5 | 0.1 | 3.5 | 1.5 |
| Indonesia | 1965-72 | 4.8 | 2.2 | -0.3 | 1.1 | 1.8 |
| Philippines | 1965-73 | 3.4 | 1.2 | -0.3 | 1.5 | 1.0 |
| India | 1965-70 | 3.2 | 0.4 | 0.2 | 1.5 | 0.9 |
| Thailand | 1965-72 | 2.1 | 0.2 | 1.7 | 0.3 | -0.1 |

level can the expected 3% rate of growth in demand be met. The Trilateral Commission study emphasized the need to greatly expand investments in irrigation almost to the point of ignoring other sources of growth (Colombo et al 1978). Other studies and projections have the same basic conclusion.

In studies of the factors keeping farmers' rice yield low, water control has always had an overriding effect. But in most cases, it has been impossible to measure this effect because of the difficulty of controlling water in farmers' fields. In the first aggregate examination of constraints (Herdt and Wickham 1975) lack of water control was identified as accounting for up to 402 of the difference between the apparent potential and actual national yields in the Philippines.

The IRRI Statistics Department compared farmers' and high levels of inputs to determine the constraints to yields of the various factors as used by farmers. Water was added to certain treatments in farmers' fields. Its contribution to yield increases was substantial -- 0.9 t/ha. Fertilizer contributed 0.7 t/ha and other factors contributed 1.8 t/ha in the dry season (IRRI 1974). The general approach of factorial experiments in farmers' fields was adopted in the International Rice Agroeconomic Network (IRAEN) to study yield constraints.

The IRAEN project has not included the effect of water as a constraint because of the difficulty of augmenting water in farmers' fields. Despite this difficulty, the importance of water is recognized, and many studies have been conducted to quantify

the yield-constraining effects of water, or conversely, to quantify the yield-increasing effects of irrigation.

In the following section I review studies quantifying the benefits of irrigation and discuss analyses using such estimates. The final section outlines current work on economics of irrigation.

## BENEFITS OF IRRIGATION

There are two fundamentally different approaches to determining the yield benefits of irrigation: the response function approach and the comparative approach. The first quantifies the biological yield response of rice to water, the second compares yields on irrigated and nonirrigated fields or farms. Both have advantages and disadvantages.

### Response functions

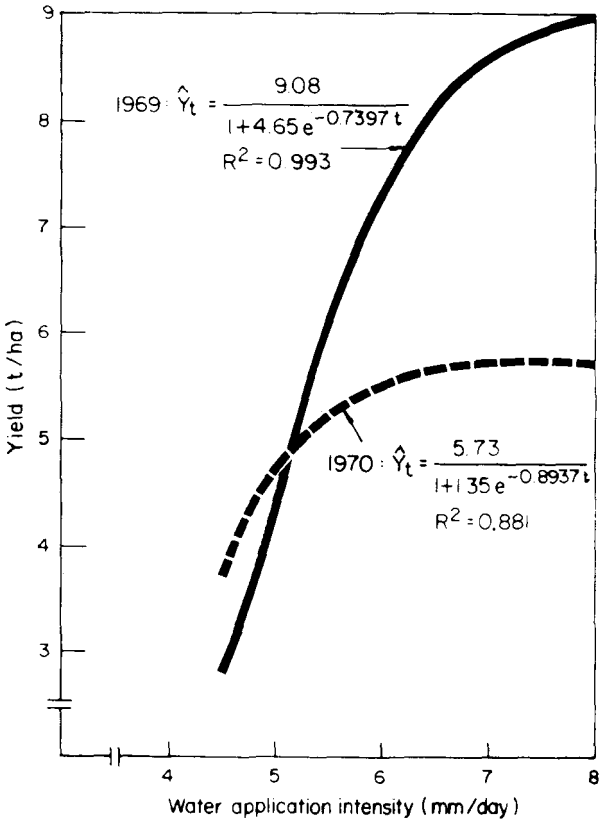
The response function approach hypothesizes a causal relationship between water, other inputs (often fertilizer), and the resulting crop yield. Algebraically this is stated as:

$$\text{Yield } (Y) = f \text{ (water, fertilizer, other inputs).}$$

The researcher seeks (or creates) a set of data with variable water and fertilizer levels and attempts to relate yield to such inputs. Experimentally oriented researchers nay prefer to use data generated from experiments in which water and perhaps one other factor (e.g. fertilizer or variety) are varied with other factor constant. The result can be summarized as an equation, for example:

$$\text{Yield } (Y) = (9.08)\ (1 + 4.65^{e\ -\ 0.74t}) - 1$$

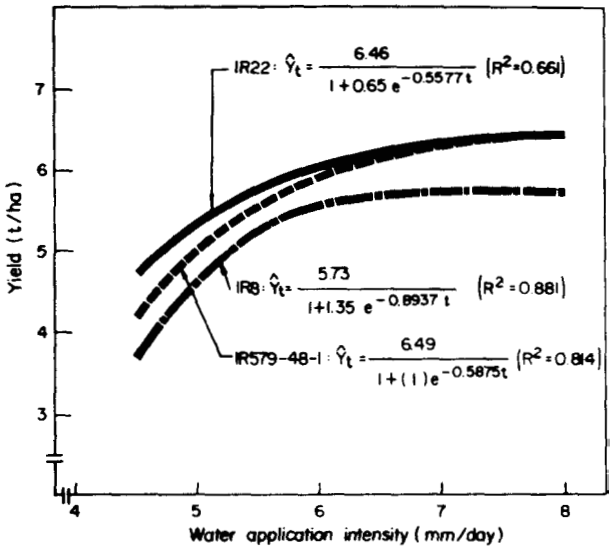
which was reported as the yield response of IR8 (in wetland culture) to water application at IRRI in 1969 (IRRI 1971). Water was measured in mm/day. A problem with this approach at this level of simplicity is illustrated in Figure 1. When the 1969 results were compared with those for the same variety in the same experiment the subsequent year, different results were obtained. More rain fell in 1970 and distribution was more even resulting in less hours of sunshine and potential evaporation. Total solar energy for 45 days before harvest was 25.0 kcal/cm$^2$ in 1969 compared with 22.5 kcal/cm$^2$ in 1970. In 1970 soil moisture rarely fell below field capacity even for the low level of water application.




**1.** The yield response of IR8 under wetland culture to water application intensity. IRRI, 1969 and 1970 dry season ($t$ = 1 for 4.5 mm/day, $t$ = 2 for 5 mm/day . . . . . $t$ = 8 tor 8 mm/day).

Some factors in determining the response of rice to water are thus enumerated but uncertainty still prevails over the basic question of how rice responds to water. It depends on many factors. One factor is hypothesized to be variety. Experiments are efficient for quantifying varietal differences in response as illustrated in Figure 2, but these differences appear relatively minor.

More recent work in the reaction of the rice plant to drought has shown extremely wide differences in rooting depth, root distribution, leaf water conservation, and a host of other factors that indicate real promise of finding varieties that respond differently to water stress (O'Toole and Chang 1979). There is substantial information in this area of great use to plant breeders. However, that body of knowledge does not quantify the effects of soil texture, seepage, percolation, solar radiation, natural rainfall, and other site-related factors -- factors




2. Yield response to water input of IR22, IR579-48-1, and IR8. IRRI, 1970 dry season (t = 1 for 4.5 mm/day, *t* = 2 for 5 mm/day . . . . . *t* = 8 for 8 mm/day).

affecting the yield of the rice crop and central to the question of yield benefits.

A second alternative is to observe a wide range of water conditions and other relevant inputs in farmers' fields and relate those factors to yield. This approach has been widely used by IRRI economists. One problem lies in the measure of the water variable. Experimentally it is possible to control and measure the rate of water application but in farmers' fields control is unreliable and measurement is difficult. In addition the rice plant is affected more by the lack of water than by the amount used in the field because losses in the field are not available to the plant.

Wickham (1973) developed the concept of the stress day as an index that could be related to wetland rice yield. Initially he defined a stress day as a day the rice field is without standing water. Because the biggest proportion of stress days occur during a few prolonged drought periods, and because there is a transition between wet and dry soil, he then argued that the first few days of stress would not affect yield. The best results were obtained by omitting the 3-day period. The hydrologic basis for 3 days was that typical rice soils hold 10 mm of water in the root zone. Evapotranspiration of 3 mm/day gives about 3 days before moisture is completely exploited.

Hence, stress days was defined as days in excess of 3 when the paddy is continuously without standing water. Early stress was defined as occurring from transplanting to 60 days before harvest (DBW) and late stress as occurring from 60 to 30 DBH. Using these definitions, yields were related to stress days and nitrogen fertilizer in a multiple regression equation. Several studies used a similar approach.

The response functions using the stress day concept are not a direct measure of irrigation benefits because the quantity of water delivered is not entered into the function, but they are useful relationships. Because the plant responds to water *in the paddy,* or to the lack thereof, if one can measure or predict water in the paddy, one can measure irrigation benefits.

Extending the response function to include inputs besides water and fertilizer can result in a very complex equation as illustrated by the three response functions calculated by Mandac (l974), Rosegrant (1976), and Mandac and Herdt (1979) (Appendix Table 1). These functions were estimated to provide a comprehensive basis for making judgments about rice yield response to soil factors, solar radiation, weed control, and insect and disease damage within a wide range of conditions. They attempt to incorporate some of the interactions believed to exist between moisture stress, solar radiation, fertilizer use, and biological factors. Although too complex to be understood directly they can be simplified to give responses like those in Table 2 by substituting observed or *typical* levels of solar radiation, weed control, pest damage, etc.

These response functions can be used to predict yield at various levels of fertilizer and stress, and to evaluate the potential productivity of irrigation projects. To use them for such purposes, one must quantify the expected number of stress days from characteristics of the irrigation area and type of system, then contrast these to nonirrigated areas. For example, what are the benefits of irrigation if a rainfed wetland rice site typically encounters 20 stress days and farmers in the area apply 30 kg fertilizer/ha?

Suppose further that one is considering two types of irrigation -- the first a simple protective system and the second a highly sophisticated system. The former is much less expensive but can reduce the number of stress days by 50%, the latter is more expensive and can cut stress days by 90%. Table 3 summarizes the yields and yield benefits that are predicted by the 4 response functions.

Table 2. Effect of specified independent variables on rice yield (kg/ha) in response equations from four IRRI studies, Philippines.

| Independent variable | Response equation from[a] | | | |
|---|---|---|---|---|
| | Wickham 1973 | Mandac 1974 | Rosegrant 1976 | Mandac and Herdt 1979 |
| | *Wet season* | | | |
| Fertilizer[b] (kg/ha) | 41.5 | 14.9 | 13.7 | 12.4 |
| (Fertilizer)* | -0.50 | -0.03 | -0.06 | -0.03 |
| Stress 1 (days) | -50.2 | 30.1 | | |
| Stress 2 (days) | -20.4 | -63.1 | -23.5 | |
| Fertilizer x stress | 0.76 | -0.34 | -0.39 | -0.21 |
| Constant | 2790 | 1394 | 2781 | 2843 |
| | *Dry season* | | | |
| Fertilizer (kg/ha) | 17.9 | 14.9 | 20.0 | 18.3 |
| $(\text{Fertilizer})^2$ | -0.14 | -0.03 | -0.06 | -0.03 |
| Stress 1 (days) | -35.2 | 30.1 | | |
| Stress 2 (days) | -94.4 | -63.1 | -86.2 | |
| Fertilizer x stress | 0.54 | -0.34 | -0.39 | -0.21 |
| Constant | 3600 | 1649 | 2781 | 4007 |

[a]Sources: See papers listed in the references. [b]In the first three functions fertilizer is nitrogen; in the fourth, nitrogen + phosphate.

The protectively irrigated condition is assumed to have 10 stress days in the wet season and 20 in the rainfed condition. The advanced system has 2 stress days. The system is assumed to provide at least protective irrigation on some part of the dry-season area and the better system provides an adequately irrigated condition of 2 stress days.

The predicted benefits vary widely across the four equations. The Wickham and Rosegrant equations show relatively greater yield benefits in the dry season than in the wet season for an equal reduction in stress days. This conforms to some *a priori* hypotheses about evaporative demand and results from the difference in yield response to fertilizer and water reflected in the wet- and dry-season functions in those two studies (Table 2). The other two equations do not show the seasonal difference in yield response because the functional form was not designed to do so. This suggests that response functions should be relatively rich in the water-related terms to be most useful for irrigation analysis.

Table 3. Rice yields predicted from estimated response equations with 30 kg N/ha and various levels of moisture stress, Philippines.

| Season | Stress days (no.) | Response equation from[a] Wickham 1973 | Mandac 1974 | Rosegrant 1976 | Mandac and Herdt 1979 |
|---|---|---|---|---|---|
| | | *Predicted yield (kg/ha)* | | | |
| Wet | 20 | 3335 | 1279 | 2434 | 3062 |
| Wet | 10 | 3460 | 1545 | 2786 | 3125 |
| Wet | 2 | 3560 | 1761 | 3068 | 3176 |
| Dry | 10 | 3525 | 1800 | 2348 | 4466 |
| Dry | 2 | 3914 | 2016 | 3132 | 4517 |
| | | *Predicted yield benefit (kg/ha)* | | | |
| Wet | 20 – 10 | 125 | 266 | 352 | 63 |
| Wet | 10 – 2 | 100 | 216 | 282 | 51 |
| Dry | 10 – 2 | 389 | 216 | 784 | 51 |

[a]See Table 2 and Appendix Table 1.

The response functions, even as they exist, permit estimation of the indirect yield benefit often associated with irrigation systems. The most important one is commonly assumed as an increase in fertilizer use and hence higher yields. This can be illustrated by substituting a different level of fertilizer into the functions in Table 2 and calculating the predicted yield. A further advantage is the reflection of diminishing returns to fertilizer so that one can make more realistic estimate of the likely, or profitable, level of fertilizer application that will occur with different levels of sophistication (reflected in various levels of stress), fertilizer prices, and rice prices.

With an adequately specified response function, appropriately measured variables, and a wide enough data base one can measure the water-related yield constraints to farmers' yields even without including water as a variable in the experiments. For example, with the 3 years of constraints experiments by the IRRI Agronomy Department on more than 50 farmers' fields in Central Luzon the quite acceptable, although somewhat complex, response function shown in the last column of Appendix Table 1 has been estimated (Mandac and Herdt 1979). The trials were separated into low- and high-yielding groups on the basis of farmers' yields. The average values of the independent variables for the two groups were substituted into the response function and the

Table 4. Yield difference and proportion of yield difference between high- and low-yielding groups of farms explained by four different sets of variables, Nueva Ecija, Philippines, 1974-1977.

| | Wet season | | Dry season | |
|---|---|---|---|---|
| | t/ha | % | t/ha | % |
| Actual yield difference | 2.361 | 100 | 1.311 | 100 |
| Explained difference | | | | |
| Inputs (fertilizer, weed control, insect control, and seedling age) | 0.074 | 3.1 | 0.337 | 25.7 |
| Water and weather (solar radiation, moisture stress, typhoons) | 0.988 | 41.9 | 0.456 | 34.8 |
| Insect pests and diseases | 0.351 | 14.9 | 0.173 | 13.2 |
| Soils (organic matter, extractable phosphorus) | -0.051 | -2.2 | 0.020 | 1.5 |
| All interactions | 0.308 | 13.0 | 0.289 | 22.0 |
| Total explained difference | 1.670 | 70.7 | 1.275 | 97.2 |
| Unexplained difference | 0.691 | 29.3 | 0.036 | 2.8 |

Source: Mandac and Herdt 1979.

yield-constraining effects of each group of factors were estimated. Table 4 shows the yield constraints attributable to various factors using this approach. Water and weather factors, which explain 42% of the difference, dominate the constraints in the wet season, but even in the dry season they account for nearly 0.5 t/ha.

Response functions are powerful tools in the analysis of irrigation benefits, fertilizer use, and other related questions. However, they are difficult to estimate and different functions do not always provide similar answers. The data requirements for estimating the more complex functions are extensive. An alternative is to determine irrigation benefits by comparing irrigated and nonirrigated production conditions.

## Comparative approach

The comparative approach appears to be straightforward -- one simply compares the yield on an irrigated field with that on

a nonirrigated field. Complications immediately become obvious when one defines the water conditions existing in the nonirrigated field. If the comparison is done in the dry season, with no water applied to the nonirrigated field, in most parts of Asia no rice will be harvested. In the wet season, the yield will depend highly on the amount and distribution of rainfall. Hence the comparative approach is highly site- and time-specific. It is often used to predict benefits in proposed irrigation project, and sometimes used *ex post* to determine how, realistic *ex ante* predictions had been.

The approach can also be used to determine broader questions such as the distribution of irrigation benefits among various groups, or the difference in production practices between irrigated and nonirrigated areas. It can reflect the totality of differences between irrigated and nonirrigated areas, especially if conducted after farmers in the irrigated area have become accustomed enough to irrigation to use it most efficiently.

Table 5 summarizes the findings of some comparative studies on the overall benefits of irrigation. Although such studies can provide information on the economic benefits of irrigation projects, their findings are highly dependent on the weather conditions during the study year, on the availability of a good comparative site, on the accurate recall of interviewees, and on assumptions about the time pattern of the stream of benefits.

Table 5. Summary of recent comparative studies of irrigated and nonirrigated farms.

| Data source | Unit | Annual farm output, production costs, and net returns | | | | | |
|---|---|---|---|---|---|---|---|
| | | Farms with project | | | Farms without project | | |
| | | Output value | Input cost | Net return | Output value | Input cost | Net return |
| Dozina et al (1978) | ₱ | 3431 | 1193 | 2238 | 2071 | 689 | 1382 |
| Bantilan et al (1978) | ₱ | 4630 | 2873 | 1757 | 3862 | 2774 | 1088 |
| Tagarino and Torres (1978) | ₱ | 3950 | 3068 | 882 | 1423 | 1546 | -123 |
| Toquero (1972) | ₱ | 2482 | 2313 | 169 | 719 | 664 | 55 |
| Hafid and Hayami (1978) | Rp | 96000 | 85000 | 11000 | - | - | - |
| Hafid and Hayami (1978) | Rp | 71000 | 40400 | 30700 | - | - | - |
| Husin (1978) | kg | 3369 | 1299 | 2070 | 2334 | 840 | 1494 |
| Husin (1978) | kg | 3108 | 1653 | 1541 | 2766 | 1481 | 1303 |

In addition, one is likely to depend on farmers' estimates of yields, which may be unacceptable to irrigation project personnel.

On the other hand, comparative studies can yield some useful specific information. For example, the Hafid-Hayami, Dozina et al, and Husin studies considered the degree to which low-opportunity-cost labor could be mobilized to create low-cost irrigation systems. The distribution of benefits and costs among farmers, landowners, and hired labor was obtained in the Dozina study (Table 6), and Husin compared the income distribution among farmers before and after the rehabilitation of the Sederhana he studied (Table 7). These studies document relatively low cost approaches to improving water availability.

Table 6. Output per farm, input costs, and gross value added for different rural groups before and after rehabilitation of the Cavite Communal Irrigation System, Castillejos, Zambales, Philippines.[a]

| | 1972 (US$) | 1974 (US$) | Change (%) |
|---|---|---|---|
| Output per farm | 100 | 257 | 157 |
| Current inputs per farm | 11 | 38 | 245 |
| Gross value added | 89 | 219 | 146 |
| Distribution of gross value added | | | |
| Landowners | 43 | 100 | 133 |
| Farm operators | 26 | 63 | 142 |
| Hired labor | 20 | 56 | 180 |

[a]Source: Dozina et a1 1978.

Table 7. Income distribution before and after Sederhana irrigation rehabilitation, Aceh, Sumatra, Indonesia.[a]

| Location | Yr | Net returns from rice cropping | | | | | |
|---|---|---|---|---|---|---|---|
| | | Relative share (%) by quintile groups | | | | | Gini coefficient |
| | | Bottom 20% | Second 20% | Third 20% | Fourth 20% | Top 20% | |
| Geunteut | 1974 | 7 | 14 | 18 | 23 | 38 | 0.284 |
| | 1978 | 8 | 13 | 19 | 24 | 36 | 0.266 |
| Garut | 1974 | 7 | 13 | 16 | 24 | 41 | 0.316 |
| | 1978 | 6 | 12 | 16 | 23 | 42 | 0.336 |

[a]Source: Husin 1978.

## INTEGRATED ANALYSES OF IRRIGATION ISSUES

Studies of the benefits of irrigation, or the yield constraints imposed by inadequate water, when matched with cost estimates, provide basic information useful for project evaluation. An area of more direct interest for economic analysis lies in the utilization of irrigation studies for larger integrated analyses that could assist in decision-making.

There are three (recent) examples of such integrated analyses:

1. A study that explains the decisions of farmers with different qualities of irrigation using various assumptions about risk and policy (Wickham et al 1978);

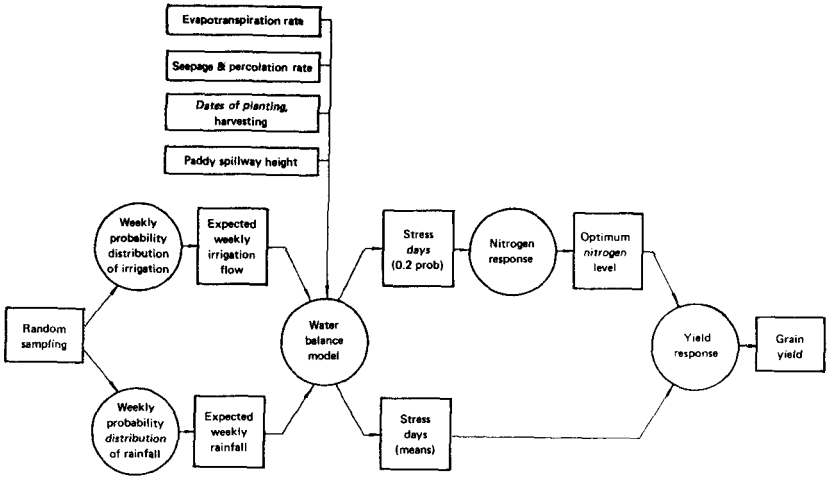
2. A study that examines the prospects and policy for Asian rice production and the associated required investments (Herdt et al 1978); and

3. A comparison of price support and irrigation investment for achieving rice self-sufficiency in the Philippines (Hayami et al 1977).

The Wickham, Barker, and Rosegrant (WBR) study builds on the estimated production function shown in the third column of Table 2 through a model outlined in Figure 3. It incorporates estimates of evapotranspiration, seepage and percolation, planting dates, and spillway heights with expected weekly irrigation flows and rainfall probabilities within a water-balance model that predicts stress days. The optimal level of fertilizer is determined from the response function using any specified rate of return to fertilizer cost. The result is a prediction of fertilizer use and production.

In the exercise by WBR, yields for poor, average, and good irrigation for the wet season and for various qualities of irrigation in the dry season were estimated. Irrigation qualities were defined from a 1969-70 study of irrigation flows in 11 Philippine sites and a 1973 study of 4 sites in the Peñaranda system. The probability of weekly rainfall was computed based on data for 26 years from Cabanatuan City. Simulated rainfall for the model was obtained by sampling from the distribution. Evapotranspiration rates were obtained from estimates for Central Luzon.

Seepage and percolation (S&P) rates were determined by farm practices, soils, and their topographic position. The model




**3.** Flow diagram of a water-balance model for stimulating stress days and yields of irrigated wetland rice.

specified minimum, moderate, and high S&P rates, but with little evidence as to the frequency with which each occurs, except that WBR believed that most irrigated rice land in Asia has S&P rates between the minimum and moderate rates.

The entire model was computerized to allow a number of calculations to simulate the variability in outcomes that might occur over time. Means and variances of the predicted optimal fertilizer levels and yields were calculated.

A direct measure of risk from drought stress is reflected in the simulated occurrence of high stress days in the model, which resulted in a reduced response to fertilizer and low yields. The probability of low yields reflected the distribution of rainfall. It was assumed that farmers would avoid risk by choosing their fertilizer level consistent with the number of stress days occurring with a 20% probability. That is, rather than choosing fertilizer based on the mean stress, farmers were assumed to be more conservative. That accounted for risk caused by variable water status, but risks of insect and disease attack, marketing problems, and other factors still existed. Because of that, the price ratio of fertilizer was computed for each combination of conditions for modern varieties (MV) (Table 8) and traditional varieties (TV).

Table 8. Mean stress days at probability levels and corresponding optimum rates of nitrogen use and grain yield,[a] at 4 levels of irrigation performance and 3 rates of seepage and percolation (S&P),[b] with modern varieties and 24 years of rainfall date from Cabanatuan City, Philippines, 1976.

| Irrigation performance[c] | Minimum S&P: Stress days (no.) 0.2 probability | Minimum S&P: Stress days (no.) Mean | Minimum S&P: Optimum N use (kg/ha) | Minimum S&P: Grain yield (t/ha) | Moderate S&P: Stress days (no.) 0.2 probability | Moderate S&P: Stress days (no.) Mean | Moderate S&P: Optimum N use (kg/ha) | Moderate S&P: Grain yield (t/ha) | High S&P: Stress days (no.) 0.2 probability | High S&P: Stress days (no.) Mean | High S&P: Optimum N use (kg/ha) | High S&P: Grain yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Dry season* | | | | | | | | | | | | |
| Ideal[d] | 0.0 | 0.0 | 118 | 4.08 | 0.0 | 0.0 | 118 | 4.08 | 0.0 | 0.0 | 118 | 4.08 |
| Good | 3.5 | 2.6 | 106 | 3.65 | 8.2 | 4.9 | 91 | 3.24 | 13.6 | 9.6 | 73 | 2.52 |
| Average | 8.7 | 5.2 | 89 | 3.19 | 14.7 | 9.7 | 70 | 2.48 | 19.4 | 15.1 | 54 | 1.72 |
| Poor | 15.8 | 9.0 | 66 | 2.53 | 21.1 | 15.0 | 49 | 1.69 | 21.4 | 18.8 | 48 | 1.26 |
| *Wet season* | | | | | | | | | | | | |
| Ideal[d] | 0.0 | 0.0 | 81 | 3.12 | 0.0 | 0.0 | 81 | 3.12 | 0.0 | 0.0 | 81 | 3.12 |
| Irrigated | 2.4 | 1.6 | 73 | 2.94 | 3.1 | 2.1 | 71 | 2.89 | 11.3 | 7.9 | 44 | 2.28 |
| Rainfed | 8.1 | 5.1 | 54 | 2.55 | 11.6 | 7.5 | 43 | 2.30 | 20.4 | 16.8 | 14 | 1.52 |

[a] Means of 100 trials each for 4 planting dates. Stress days include means and expected values for the second year out of 10 (0.2% probability level), and are computed only during the 8th through 12th week of crop growth. Optimum N is computed using 0.2% probability level stress days and shadow price ratio of 6.5:l of nitrogen to rice with the equations $Y = 2485 + 20.6\ N - 0.06\ N^2 - 91.6\ S - 0.39\ NS$ (dry season) and $Y = 2197 + 16.2\ N - 0.06\ N^2 - 47.8\ S - 0.39\ NS$ (wet season). Yield calculations use mean stress days and optimum N. [b] Minimum, moderate, and high rates of S&P are 0, 32, and 105 mm/week, respectively, in the dry season and 0, 14, and 105 mm/week in the wet season. [c] Samples from three distribution made up of above-average, average, and below-average (good, average, and poor) discharges measured from several canal systems, 1969-74. [d] Ideal irrigation eliminates all stress days regardless of the amount of water required. Corresponding yields are computed directly without simulation.

Using these procedures, WBR calculated three wet and three dry season yield increments: from rainfed to average irrigation with TV, 2.0 and 0.9 t/ha in the dry and wet seasons; from TV to MV with average irrigation, 0.9 and 0.6 t/ha in the dry and wet seasons; and from MV with average irrigation to MV with ideal irrigation, 1.2 and 0.2 t/ha in the dry and wet seasons. As pointed out by Small (1978), one could consider other increments as well, or one could measure them in different order and hence get different results. The total procedure shows how the response function can be effectively used.

The examination of the prospects for Asian rice production also utilizes fertilizer response curves for irrigated and non-irrigated rice production to calculate the rough order of investment requirements for meeting the demand for rice in Asian countries in 1985 (Herdt et a1 1978).

In that analysis the geographic land area in rice production is assumed to remain constant through 1985, but the distribution of that land among the major types of rice (TV, MV, rainfed, and irrigated), including the amount of double-cropped land, is based on irrigation investment. Labor supply is assumed to be adequate. Fertilizer availability is projected based on past trends. The use of fertilizer on irrigated TV, irrigated MV, rainfed TV, and rainfed MV is based on the fertilizer response functions, total fertilizer availability, area in each type of rice, and the assumption of efficient allocation among the four types of rice. Technological changes can be exogenously introduced in the level of investments needed to achieve stated constant rates of growth in output.

The projections of the model suggest that the area of irrigated rice should grow at about 3%/year for rice production to keep pace with demand (Table 9). This is somewhat above the 2.4% registered from 1965 to 1970 and substantially above the 1.8% registered between 1973 and 1374. Annual investment costs are estimated to be at least double the levels reached in the past 15 years (in real terms). In addition to investments in irrigation and fertilizer, the exercise suggests the need to raise the response to fertilizer above the present level being achieved by farmers. That will require more research and extension as well as quality irrigation.

These results agree with the spirit of the Trilateral Commission report (Colombo 1978), which estimated that $50 billion would have to be invested between now and 1993 to meet the rice requirements of Asia. The Trilateral Commission requirements are

Table 9. Projected rates of increase of irrigation, fertilizer, and technology[a] and associated output growth, and investment required, South and Southeast Asia, 1974-85.

| Run | Inputs to the model | | Outputs of the model | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Irrigated area (%/yr) | Fertilizer (%/yr) | Production (%/yr) | Implied N:rice price | Annual investment ($ million) | | | |
| | | | | | Low fertilizer | | High fertilizer | |
| | | | | | Imported | Domestic | Imported | Domestic |
| *Verification* | | | | | | | | |
| V1[b] | 2.4 | 18.5 | 3.0 | 6.6 | 861 | 866 | 164 | 1133 |
| V2[b] | 1.8 | 7.8 | 2.8 | 6.9 | 715 | 742 | 768 | 773 |
| *Projections with inputs increased* | | | | | | | | |
| 1 | 1.5 | 12-8[c] | 1.6 | 1.4 | 1072 | 960 | 1530 | 1237 |
| 2 | 2.0 | 12-8 | 1.8 | 1.8 | 1252 | 1140 | 1768 | 1475 |
| 3 | 3.0 | 12-8 | 2.3 | 2.6 | 1641 | 1529 | 2256 | 1963 |
| 4 | 3.0 | 12-9.5 | 2.4 | 0.8 | 1754 | 1619 | 2435 | 2080 |
| *Projections with improved technology and inputs* | | | | | | | | |
| 5 T[c] | 1.5 | 12-8 | 2.5 | 5.5 | 1272 | 1160 | 1730 | 1437 |
| 6 T[c] | 3.0 | 12-8 | 3.0 | 6.8 | 1841 | 1729 | 2456 | 1963 |

[a] Modern varieties covered 6% of irrigated rice land in 1963-67, 33% in 1968-72, and 57% in 1973-74. They are assumed to cover 90% of irrigated and 30% of rainfed land by 1985. [b] These are the verification runs, V1 covers the 5-year period 1963-67 to 1968-72 and V2 covers the 3.5-year period 1968-72 to 1973-74. [c] Fertilizer applied to rice grows at 12%/year in 1974. That rate declines gradually to 8%/year by 1985.

somewhat higher than our own, but this is due to somewhat different projections of demand.

The third integrative irrigation-related study is the comparison of price incentives and irrigation investment as alternative ways to stimulate rice production sufficiently to achieve rice self-sufficiency in the Philippines (Hayami et al 1977). Social costs and benefits were determined using the consumers' surplus/producers' surplus model. Because irrigation investment is made over a period of time, it was necessary to convert the benefits and costs of price supports and irrigation into the same time dimension.

The analysis considered government costs, farm producers' benefits, and net foreign exchange savings. Irrigation costs were calculated for two qualities, referred to as *NIA average* and *UPRP* standard, reflecting prevailing Philippine costs. Fertilizer response curves similar to those used by WBR were used to determine yields and fertilizer use.

The Hayami et al analysis showed that *despite its large initial capital cost, irrigation investment imposes less finan-*

Table 10. Benefits and costs associated with alternative policies to achieve self-sufficiency in rice, Philippines, 1975.[a]

| | Price policy | | Irrigation investments | | | |
|---|---|---|---|---|---|---|
| | Rice price support | Fertilizer subsidy | NIA av 12% | NIA av 18% | UPRP standard 12% | UPRP standard 18% |
| Annual stream (US$ millions) | | | | | | |
| (1) Government cost | 106 | 51 | 10 | 13 | 10 | 13 |
| (2) Producers' benefits | 70 | 65 | 20 | 17 | 18 | 14 |
| (3) Foreign exchange savings | 62 | 39 | 40 | 31 | 31 | 22 |
| Benefit-cost ratio: | | | | | | |
| $\frac{(2) + 0.05\ (3)}{(1)}$ | 0.69 | 1.3 | 2.2 | 1.4 | 2.0 | 1.2 |

[a]Source: Hayami et a1 1977. [b]The % refers to the rate of interest used in capitalizing the irrigation costs.

*cial burden on the government than the manipulation of product and input prices in the long run* (Table 10). In terms of the social benefit-cost ratio, the irrigation development is clearly more efficient than rice price support. But it becomes inferior to fertilizer subsidy if a high discount rate is applied to a large-scale, high-cost project.

## CURRENT RESEARCH IN IRRIGATION ECONOMICS

Irrigation economics research is under way in four general project areas :

1. measurement of the yield-constraining effects of water and other factors;

2. evaluation of alternative intensities of on-farm water management as part of a larger project of the Irrigation and Water Management Department;

3. identification of the distribution of the direct benefits of irrigation in a previously rainfed areas of Iloilo; and

4. a systematic evaluation of the relative economics of various types of irrigation systems in the Philippines.

The identification and measurement of yield constraints imposed by water and other factors is by three techniques:

1. locating factorial constraints experiments in parts of irrigation systems expected to experience different degrees of water stress;

2. monitoring water, pest, and management factors in a set of farmers' fields in the Angat River Irrigation System near the head, middle, and tail of the lateral, sub-lateral, and ditches being sampled; and

3. making crop cuts and interviews in farmers' fields selected when harvesting is under way, also in the Angat system.

Data will be analyzed using multiple regression to determine yield constraints and response to water and other inputs. Results, techniques, and costs of the second and third approaches will be compared with each other and with the experimental approach to

determine if any one of the approaches is substantially better than the others.

The study of alternative intensities of water management at the farm level by the Irrigation and Water Management Department, IRRI, has two economic components. The first is an attempt to determine the cost of differences associated with establishing the various degrees of water control. Because the alternatives range from simple to complex, there will be rather large differences. The second is the determination of yield- and intensity-related production benefits by farmers in the areas with various levels of intensities. This involves a benchmark study of production input use and intensity of a representative sample of farmers over each of the types of management. The benchmark will be followed by yearly monitoring of yields and after 4 or 5 years by a follow-up survey to determine the yield impact of the various treatments. Table 11 shows the benchmark data obtained in the 1978 wet season. This project should provide some empirical insights into the desirability of highly intensive farm-level water management systems.

The study of the distribution of direct irrigation benefits involves detailed data for 4 crop years of a set of 40 cooperating farmers in an Iloilo area that was rainfed in 1976 and that has subsequently become irrigated. The canal has made increased cropping intensity possible on some farms, thereby increasing employment opportunities. At the same time the new technology of direct seeding has been introduced and adopted, making double-cropping of rice by some rainfed farmers possible. The allocation of irrigation gains among farmers, landowners, and laborers is being studied.

The third general study is designed to determine the costs of installing and operating representative examples of the different types of irrigation systems existing in Central Luzon to understand the relative value of the various types of systems. Samples from recently constructed irrigation systems will be selected from among all systems built in Central Luzon in the past 10 years. Initial emphasis will be on determining the costs of the systems and the factors associated with those costs. Quantifying performance of the various types of systems will have second priority.

Information from these studies, together with existing information, will make possible a more generalizable quantification of the relationship between water input and rice production. To the degree that such a quantification is successful, the tools of economic analysis can be brought to bear on such issues as

Table 11. Average farm size, yield per hectare, and level of some production inputs used by type of system, land class, and cluster, 1978 wet season.

| System, land class, and cluster | Samples (no.) | Av farm area (ha) | Yield (t/ha) | Production input (₱/ha)[a] Fertilizer | Insecticide | Herbicide |
|---|---|---|---|---|---|---|
| *IPRIIS* (Reservoir) | | | | | | |
| Flat rice land | | | | | | |
| San Leonardo | 30 | 1.85 | 2.42 | 352 | 139 | 38 |
| Sta. Arcadia | 29 | 1.42 | 2.76 | 453 | 168 | 38 |
| Gapan | 30 | 2.14 | 2.23 | 478 | 162 | 45 |
| Sloping rice land | | | | | | |
| Sta. Barbara | 29 | 1.56 | 2.08 | 444 | 121 | 4 |
| LTRIS, Lat. A | 28 | 1.49 | 2.41 | 414 | 128 | 1 |
| PRIS, Lat. F | 29 | 1.29 | 2.97 | 432 | 157 | 17 |
| Dual class land | | | | | | |
| MCIS homestead | 29 | 1.75 | 3.29 | 252 | 107 | 30 |
| MCIS Bantug | 29 | 1.80 | 2.84 | 237 | 147 | 11 |
| Sto. Domingo | 28 | 1.40 | 2.76 | 278 | 105 | 27 |
| Land consolidation pilot project | | | | | | |
| (Sloping) with leveling | 6 | 2.20 | 2.36 | 318 | 176 | 47 |
| without leveling | 6 | 1.26 | 1.29 | 459 | 142 | 11 |
| Land consolidation pilot project | | | | | | |
| (Dual) with leveling | 12 | 2.24 | 2.00 | 270 | 136 | 32 |
| without leveling | 11 | 1.88 | 1.88 | 267 | 128 | 41 |
| *AMRIS* (Diversion type) | | | | | | |
| Flat rice land | | | | | | |
| Surgui | 30 | 0.68 | 2.74 | 207 | 56 | 16 |
| Bobon | 29 | 0.55 | 2.30 | 152 | 53 | 10 |
| Birbira | 28 | 0.58 | 2.47 | 263 | 63 | 15 |
| Sloping rice land | | | | | | |
| Pitombayog | 30 | 0.85 | 3.81 | 390 | 127 | 11 |
| Gosood | 30 | 0.87 | 3.38 | 475 | 89 | 8 |
| Cabugbugan | 29 | 1.08 | 3.26 | 317 | 87 | 10 |

[a]US$1=P7.35.

water pricing, water allocation, and the distribution of water benefits. The analysis of water as an economic input, like fertilizer for which demand and productivity can be calculated, can help solve the problems confronting irrigation agencies and accelerate solution of the world's food problem.

Appendix Table 1. Estimated rice response functions from four studies relating inputs and environmental factors to yield (kg/ha), Philippines.

| | Wickham 1973 | | Mandac 1974 | Rosegrant 1976 | Mandac-Herdt 1979 |
|---|---|---|---|---|---|
| | Wet | Dry | | | |
| Constant | 2790 | 3600 | 1009 | 1079 | 1248 |
| Nitrogen (N)[a] | 41.5 | 17.9 | 14.9 ** | | |
| $N^2$ | -0.50 | -0.14 | -0.029* | -0.06** | 0.029** |
| Early stress ($S_1$) | -50.2 * | -35.2 | -30.1 ** | | |
| Late stress ($S_2$) | -20.4 | -94.4* | -63.1 ** | 110.7 ** | |
| N x $S_1$ | 0.76* | 0.54 | | | |
| N x ($S_1$ + $S_2$) | | | -0.339** | -0.39** | -0.21 ** |
| Solar radiation (SR), kcal/cm$^2$ per 45 DBH[b] | | | 33.5 ** | | 99.5 ** |
| Seedling age, days | | | -4.1 | | -10.1 ** |
| Insect damage, index | | | -10.8 | -7.87** | |
| Phosphorus fertilizer | | | 5.0 ** | 3.8l** | |
| Weed control 1 | | | 6.35 * | 160 ** | |
| N x SR | | | | 0.91** | 0.83 * |
| Weed control 2 | | | | 297 ** | |
| Weed control (P/ha)[c] | | | | | 0.69 ** |
| Insect control (P/ha) | | | | 1.47** | 0.47 ** |
| % clay | | | | 20.4 | |
| SR X ($S_1$ + $S_2$) | | | | -8.95** | |
| Insect damage x fertilizer | | | | | -0.114** |
| Disease damage index | | | | | -25.7 ** |
| Disease damage x fertilizer X organic matter | | | | | 184 ** |
| Extractable P | | | | | 2.45 * |
| Typhoon dummy | | | | | -416 |
| $R^2$ | .21 | .49 | .62 | .72 | |

[a] Kg rough rice/kg nitrogen, [b] DBH = days before harvest.
[c] US$1 = P7.35

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# WATER ALLOCATION, DISTRIBUTION, AND USE CRITERIA FOR IRRIGATION SYSTEM DESIGN AND MANAGEMENT: SELECTED RESEARCH FINDINGS

Sadiqul I. Bhuiyan

Water use in an irrigated farm is the end result of a complexity of operations carried out at different points in the irrigation system, starting from the source of water and ending at the point of delivery for farmer use. Generally, the bigger the system, the more complicated these operations. In public irrigation systems, most of these operations are carried out by the agency personnel following prescribed guidelines which ideally should conform to certain design specifications. However, a crucial role in the ultimate use of the water is played by the farmers through their individual or group actions in attempts to adequately irrigate their lands. The significance of that role is often underestimated.

Sound design and construction of major structures at the headworks -- dams, reservoirs, spillways, tube wells, pumps, etc. -- are undoubtedly of great importance. In most cases, however, there is a tendency to underrate the importance of facilities other than the major system structures and the need for their proper use in the beginning of a project is typically underestimated. This trend, historically, has led to the neglect of good design and construction of water control facilities at the tertiary level and absence of proper facilities at the main farm-ditch level and beyond for equitable and timely delivery of the water to all farmers. The criteria currently used for distribution and allocation of irrigation water at the tertiary or farm-ditch level can be best described as unclear and inadequate; better identification of these criteria can be of tremendous help for new irrigation development schemes as well as those to be rehabilitated.

Although the water delivery requirement at the farm level can be estimated with relative ease, it is not easy to accurately

Associate agricultural engineer, Irrigation Water Management Department, International Rice Research Institute, Los Baños, Philippines.

predict the efficiency of water distribution and use for the whole or part of the area served by an irrigation system. The total amount of water delivered, the extent of control structures present in the distribution network, and the nature of their use largely determine the status of water allocation and availability at the farm level. Unsystematic and uncontrolled use by farmers of the water conveyance, distribution, and delivery facilities introduces a highly unpredictable element into the system. These practices are presumably influenced by farmers' past experience with water availability and water sharing, and the existing degree of agency control on water allocation. Surprisingly little studies have been made of the advantages and disadvantages of alternative models of water distribution for farmers in an area served by a common turnout or offtake.

I discuss results of a number of selected past researches and the methodological approach to a current research at IRRI that are related to the problems of irrigation system design and management criteria for the farm level water use, water application rate and stress effects on rice yields, and water allocation and distribution in a small diversion-type irrigation system. Research information on such issues are vital to proper design and efficient use of irrigation water.

## WATER DISTRIBUTION METHODS AND ON-FARM FACILITIES

### Rotational vs continuous irrigation

Rotational irrigation, as practiced in Japan and Taiwan, provides each small section of an area served by a turnout the total flow over a predetermined period of time so that the section stores water that will be needed until it has its next turn of irrigation. The flow is thus rotated among a number of sections, which constitute the total service area of the turnout. The volume of water to be applied and the irrigation interval are determined on the basis of the size of the unit, evapotranspiration, seepage and percolation requirements, and conveyance losses.

Experiments in Taiwan indicate that rotational irrigation can achieve water savings of about 20 to 30% without any reduction in rice yield. The method was also found favorable to plant growth and effective in fertilizer savings, labor savings, and elimination of disputes over water, especially during drought (Wen 1977). Rotational irrigation in Taiwan is also credited with significant extensions of irrigated areas and, in some cases, with higher grain yield.

A joint IRRI-Philippine National Irrigation Administration (NIA) study in the Upper Pampanga River Project in Nueva Ecija investigated in the 1974 dry season the relative advantage of rotational irrigation over the prevalent continuous method in which the whole service area of the turnout received water simultaneously and continuously. The study was at three sites within Nueva Ecija province. A key element in the study was the distribution of equal amounts of water to each of a pair of 50-ha side-by-side blocks in which the 2 water distribution treatments were applied. The block receiving the rotational method of distribution was divided into 5 equal rotation units of 10 ha and each unit received enough water over a 24-hour period for 5 days' use -- a 5-day rotation cycle. In the other block, the same total amount of water was applied but simultaneously and continuously over the whole 50-ha area. Because of an insufficient water supply in the whole system, there was no significant surface drainage from the area.

There was essentially no difference in duration of and total amount of water used for land preparation between the two methods of irrigation. The mean duration to complete land preparation of the whole area was about 7 weeks and water used by that time was about 775 mm in both methods (IRRI 1975).

The study showed slightly, but not significantly, higher mean grain yields and yield per unit of water added (Table 1) for rotational method of irrigation. The insignificant difference was not surprising, because essentially no difference was observed in the occurrence of drought between the two areas throughout the season. The additional cost involved for the construction of on-farm facilities to implement rotational method was about $83/ha, including the cost of right-of-way and construction supervision. Also, additional costs were incurred in the rotational method because of production losses from the land used up by the supplementary farm ditches constructed and personnel costs to implement the rotation system, which added to about $70/ha.

Because measured water delivery was made in both treatment plots, a high water-use efficiency of about 90% could be achieved. This was possible because almost no surface drainage from the areas was allowed.

No significant yield advantage could be proven for rotational irrigation under the conditions of the study. Moreover, the costs of construction and operational supervision required of the NIA field personnel to implement the rotational system appeared substantial. However, different results might have appeared if the supply of water had been substantially lower than that required for normal crop growth.

Table 1. Mean rice yield and yield efficiency at six pilot areas, Nueva Ecija, Philippines, 1974 dry season.

| | Observations (no.) | Yield (t/ha) | Yield Efficiency[a] (kg rice/$m^3$ water) | |
|---|---|---|---|---|
| | | | Water for crop growth only | Water for land preparation and crop growth |
| Kaliwanagan Site | | | | |
| Rotational | 32 | 3.67 | 0.22 | 0.13 |
| Continuous | 35 | 3.66 | 0.20 | 0.12 |
| Gomez Site | | | | |
| Rotational | 35 | 3.45 | 0.41 | 0.23 |
| Continuous | 29 | 3.11 | 0.36 | 0.21 |
| Santa Arcadia Site | | | | |
| Rotational | 22 | 3.14 | 0.46 | 0.24 |
| Continuous | 19 | 2.97 | 0.43 | 0.21 |
| Means | | | | |
| Rotational | 89 | 3.42 | 0.36 | 0.18 |
| Continuous | 83 | 3.25 | 0.33 | 0.16 |

[a] There were no significant differences at the 5% level for any location or their means. Source: IRRI 1975.

## Optimum intensity of on-farm facilities

The degree of intensity of on-farm facilities that should be provided for most efficient water allocation and distribution within the area served by a turnout has hardly been investigated. The prevalent practice of deciding on a level of development that appears to be reasonable, conforms to past experience or follows rules of thumb, can certainly be improved and irrigation performance increased if comparative potentials of different alternative models can be established. An IRRI study to assess the performance of seven alternative models of on-farm infrastructure development in the Philippines is currently under way in collaboration with the National Irrigation Administration.

Five of these models ($T_1$ to $T_5$) are developed in both the Upper Pampanga River Integrated Irrigation System (UPRIIS),

representing a storage-type system, and the Camiling River Irrigation System (CamRIS), which represents a diversion type system. Three land classes -- flat rice land, rice land with moderate slope, and dual class land (lighter soil) -- with farm holdings of about 1.5 ha, have been included for further stratification of the 2 systems for development of the treatments. CamRIS does not have any dual class land; therefore, only the first two land classes are relevant there. Each treatment is being replicated three times in each land class for either type of system.

Treatment $T_1$, which has the least infrastructure development, is an improved traditional model in which the 40- to 50-ha irrigation block is provided with a gated turnout, a flow-measuring device, and limited main farm ditches as required to irrigate the distant paddies in a continuous flow method. Treatment $T_2$ is the present UPRIIS model in which the irrigation block, or *rotational area,* is divided into 5 *rotation units,* each about 10 ha in size, and water is delivered to each unit through a supplementary farm ditch that receives water every 5th day on the basis of a 5-day rotation cycle. Structures required to implement this treatment model include a gated turnout with a measuring device and division boxes to allocate water to the supplementary farm ditches from the main farm ditch. Treatment $T_5$ is the same as $T_2$, with the exception that in $T_5$ water allocation is made on a simultaneous and continuous basis. Treatment $T_3$ is identical to $T_2$ in all respects except that it has a rotational area of about 30 ha, divided into 5 equal units. Treatment $T_4$ has the most intensive infrastructure and is identical to T3 in all respects except that it has additional internal farm ditches receiving water from the supplementary farm ditches to provide direct water access to individual farms.

In addition to the five treatments described, two more treatments already existing in the UPRIIS pilot land consolidation area, i.e. land consolidation with land leveling ($T_6$) and land consolidation without leveling ($T_7$), were added. Rotational areas of $T_6$ and $T_7$ are about 30 ha and 40 ha in size, respectively.

Benchmark information on the water flow, distribution, and use were gathered for the 1978 wet and 1978-79 dry seasons. A benchmark economic survey of cost and return for the past two seasons and a sociological survey to document farmer attitude and response to the new development proposal, their willingness to cooperate, present use or abuse of facilities, etc., were conducted in the study areas before the start of the 1979 wet season. The physical infrastructure developments were done during the same time. During the following four seasons, the treatment models are to be monitored through collection of data

on technical water-related factors as well as social and economic factors for evaluation of the performance as well as practicability of each treatment model.

Specific expected outputs from the study include:

- estimation of costs and benefits accruing to the farmers as well as the irrigation agency from each development model;
- design criteria that are critical for successful implementation of equitable water distribution for farmers sharing a common turnout;
- information on the management requirements of each model; and
- assessment of farmers' acceptance criteria and their understanding of the usefulness of the different models of development and the expected level of their participation in operating and maintaining the facilities that they find suitable to their needs.

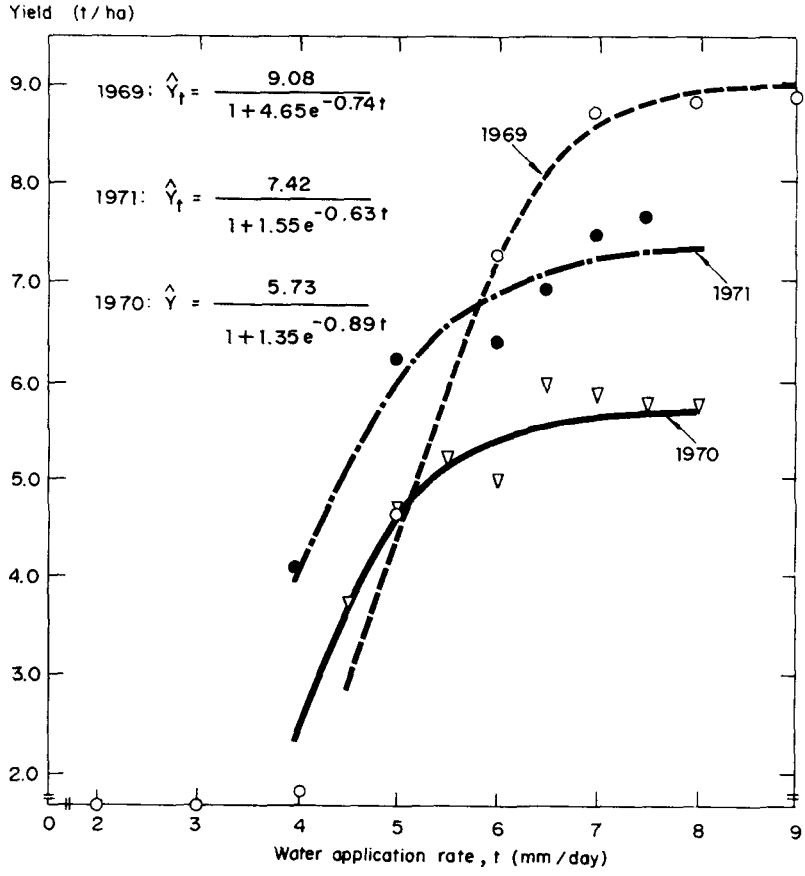
## Effects of water depth and application rate on yield

Experiments at IRRI with IR8 in metal tanks installed in the field have shown that there is no significant difference in the yield of rice for water depths maintained between 1 cm and 15 cm. Shallow flooding, however, gave higher grain yield per unit of water used, mainly because of relatively lower percolation losses. Temporary drainage at maximum tillering alone, and at maximum tillering plus at panicle initiation did not cause any significant yield difference in the heavy clay soil. It was concluded that, although continual flooding is not essential to obtain high grain yield, continuous submergence to 5-7 cm of water in the paddy is probably the best practice considering the beneficial effects of submergence, such as better weed control and higher efficiency of fertilizer (De Datta et al 1973a).

Another IRRI experiment over three consecutive dry seasons studied the effects on yield of different water application rates ranging from 2 to 9 mm/day (Reyes 1973). Three different levels of nitrogen fertilizer (0, 50, and 100 kg N/ha) and three varieties (IR5, IR8, and IR773) were used. The experiment showed that response from water status can vary substantially among varieties. The average benefits obtained for the three varieties from the first 50 kg N/ha increment was about the same for all levels of water input. At 100 kg N/ha, however, the yield increase due to the second 50 kg of nitrogen decreased at lower

levels of water input. Thus, with poor irrigation supply, it is less profitable to apply high levels of nitrogen fertilizer.

Another major finding of that study was that there is apparently a water application rate below which the yield is sharply reduced. For IR8 with 100 kg of nitrogen, this threshold value was about 6.5 mm/day in 1969 and 5.5 mm/day in the 1970 and 1971 dry seasons (Fig. 1) for the IRRI experimental farm; the difference was caused by the effect of higher evaporative demand due to higher solar radiation in 1969 compared with the other two seasons. Water supply in excess of these rates did not produce proportionally higher yield up to a peak value of 7 mm/day for




**1.** The relationship between rice yield and water application rates for 3 IR8 crops with 100 kg N/ha. IRRI, 1969, 1970, and 1971 dry seasons.

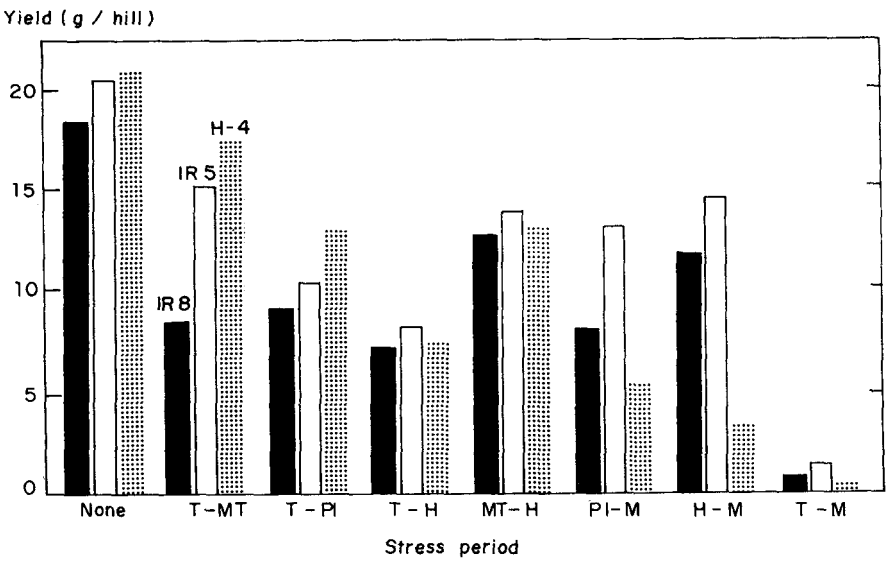
1970 and 1971, beyond which no benefits could be achieved from additional water. The peak point for 1969 was found at about 9 mm/day.

Such experimental results are useful in setting target rates that should be met at the paddy level for obtaining high returns from irrigation, particularly with limited water supply.

## Effects of water stress on yield

The next logical question is: how is water stress related to yield?

The effect of water stress on yield has been found to vary according to stress duration, crop growth stage, and rice variety. A 1969 experiment (Krupp et al 1971) on IRRI montmorillonitic clay soil showed that water stress imposed during different growth stages of IR8, IR5, and H-4 rice varieties produced different grain yields. For all varieties, the grain yield was found highest for no stress and lowest where the plants were kept stressed throughout the growing period but not allowed to undergo permanent wilting. The grain yield of IR8 was found to be less affected by moisture stress from maximum tillering to heading stages than at other growth periods (Fig. 2). For IR5, no growth stage was found more critical than others for susceptibility to moisture stress.




**2.** Grain yield of three rice varieties as affected by moisture stress at various physiological growth stages (T = transplanting, MT = maximum tillering, PI = panicle initiation, H = heading, M = maturity).

But the tall variety H-4 was found more sensitive to moisture stress during the reproductive and ripening stages than at others. A 1972 experiment with 30 rice varieties indicated that the relationships between moisture stress and stage of growth of the crop may depend on, among other factors, the growth duration of the variety. IR5 variety, for example, recovered faster from low moisture stress of short duration than IR20 (De Datta et al 1973b).

In an IRRI experiment with IR20, yield was reduced by about 66% when no irrigation was applied from 63 to 102 days after seeding (DAS), i.e. during the reproductive period (Reyes and Wickham 1973). In contrast, about an equal period of no irrigation during the early growth period, i.e. 43 to 81 DAS, reduced the yield by only 30% of the potential yield (Table 2). When the later stress was continued to harvest time, yield was reduced by about 92%. A plausible explanation for this difference in yield reduction given by the authors was that the plants have time to partly recover from stress in the early or vegetative period. When substantial stress occurs in the reproductive period, the recovery opportunity is less. Recent studies of Stansel and Fries (1980) also concluded that in contrast to vegetative stress, stress during the reproductive stage causes very drastic effects on yields because the potential recovery of the plant is very low.

Table 2. Water use and grain yield of IR20 under four different water treatments. IRRI, 1972 dry season.

| Water treatments[a] | Days drained (no.) | Average yield (t/ha) | Water use[b] (mm) | Yield productivity of water (kg/mm) |
|---|---|---|---|---|
| No stress | 0 | 6.2 | 773 | 8.1 |
| Early stress | 38 | 4.4 | 788 | 5.6 |
| Late stress | 39 | 2.0 | 806 | 2.5 |
| Late stress to harvest | 54 | 0.5 | 338 | 1.5 |

[a]No stress = flooded throughout crop growth. Early stress = no irrigation from 43 to 81 days after seeding. Late stress = no irrigation from 63 to 102 days after seeding. Late stress to harvest = no irrigation from 63 days after seeding to harvest.
[b]From transplanting to about a week before harvest. Includes all rainfall.

The above results indicate that if water supply is not sufficient for a whole system, preference for water allocation should be given to areas with crops at critically sensitive growth periods. The studies also suggest the need for further investigation with different levels of water stress and their possible interactions with management of other inputs.

## Degrees of water inadequacy and interaction with other inputs

As a logical follow-up from the earlier studies reported, a randomized and replicated experiment with split-plot design was conducted in the dry seasons of 1978 and 1979 with IR36 to determine the yield from five different degrees of irrigation inadequacy during the reproductive stage interacting with three different levels of management of other inputs, i.e. fertilizer, weed control, and insect control. The 5 water treatments represent a range of paddy-water regime conditions from adequately irrigated ($T_1$) to no water between panicle initiation and 50% flowering period ($T_5$). The other inputs are considered in package treatments, which include farmer level (FL), intermediate level (IL), and high level (HL) management treatments -- all applied in subplots (6 m x 3 m) within each water treatment area, or the main plot (15 m x 10 m size). The HL and IL subplots were each replicated twice within a main plot.

The main plots were hydrologically separated from each other and adjoining boundaries by use of plastic sheets which were installed around them. The sheets were embedded below the tilled soil and extended to the top of the paddy dike. The experiment was conducted in Nueva Ecija Province in the farmer's field having loamy soil in the top 30 cm layer.

Water treatment $T_5$ had the severest water shortage with consecutive 33 days of no standing water beginning at panicle initiation and ending at 50% flowering time. The number of consecutive days of no standing water for $T_4$, $T_3$, and $T_2$ treatments were 26, 19, and 12, respectively. Water stress in all treatment plots ended simultaneously at 50% flowering time. Continuous standing water was then maintained in them until they were terminally drained about 2 weeks before harvesting.

The FL management of inputs followed what the cooperator farmer practiced in the *comparative paddy.* In both the seasons, HL plots received 153.2 kg N/ha, 40.1 kg P/ha, and 29.7 kg K/ha. The corresponding inputs used in IL plots were 102.1, 30.1, and 19.8. All P and K were applied as basal and incorporated with soil during last harrowing for both HL and IL. Fifty percent

of N of these two management levels was incorporated with the last harrowing and the remaining applied 5 to 7 days before panicle initiation. Weed control for both the higher level management treatments included application of 2,4-D weedicide 4 days after transplanting and one hand weeding 25 days after transplanting, which gave almost a weed-free condition. Insecticide application for these two inputs management treatments varied in quantity, but both received application of Diazinon and Furadan; the IL plot received an additional Lindane application.

As expected, the FL input use varied between the 2 years. In the 1978 dry season, the farmer applied very high quantity of N, about 170 kg N/ha, and 40 kg P/ha.[1] No K or insect control measure was applied. In the next dry season, the farmer applied 44 kg N/ha, 55 kg P/ha and no K. He, however, had two applications of Brodan spray for insect control this season. In both years, weed control was at less than weed-free condition.

Table 3 shows the comparison of mean yields from the different treatments in two different matrix orientations. Although all water stress treatments decreased yield relative to the control for each inputs management level, the higher management levels, i.e. HL and IL, showed greater sensitivity to water stress. Yield reduction due to 33 consecutive days of no standing water (treatment $T_5$) was 2.08, 1.30, and 0.87 t/ha for HL, LL, and FL plots. The yield advantage, in absolute values, of HL over both IL and FL declined substantially as water stress became more severe at $T_4$ and $T_5$ treatments (Table 3). This finding for IR36 is in general agreement with what Reyes (1973) obtained for IR5, IR8, and IR773 varieties of rice. The behavior of the yield reduction phenomenon in IR36 with increasing water stress is shown in Figure 3.

The yields of IR36 rice variety obtained with different water stress conditions and inputs management levels are depicted by the response surface curve and the corresponding multiple regression model shown in Figure 4. A similar relationship between the yield of IR36 rice variety and stress days has been found by Padilla and O'Toole (1980) for different amounts of N application. To use the general regression model in Figure 4

[1] The yield obtained by this farmer, however, was very close to what other neighboring farmers obtained with less than 50 kg N/ha.

Table 3. Mean[a] rice yields (t/ha) with different water and inputs management treatments shown in two different matrix orientations. Gapan, Philippines, 1978 and 1979 dry Seasons.

| Management treatments | Water Treatments | | | | |
|---|---|---|---|---|---|
| | $T_1$ (0)[b] | $T_2$ (12) | $T_3$ (19) | $T_4$ (26) | $T_5$ (33) |
| HL | 4.978 a | 4.666 a | 4.621 a | 3.079 a | 2.899 a |
| IL | 4.096 b | 3.611 b | 3.753 b | 2.840 a | 2.797 a |
| FL | 2.414 c | 2.237 c | 2.483 c | 1.725 b | 1.536 b |

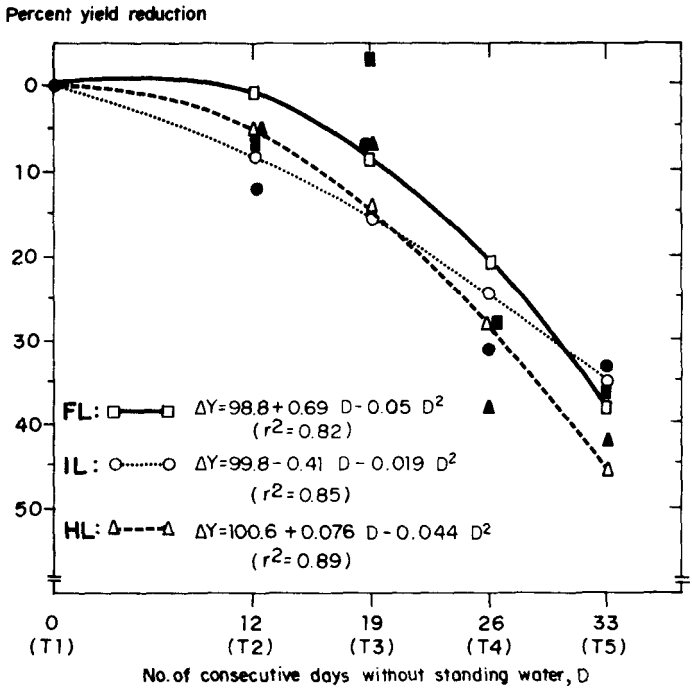
| Water treatments | Management Treatments | | |
|---|---|---|---|
| | HL | IL | FL |
| $T_1$ (0) | 4.978 a | 4.096 a | 2.414 a |
| $T_2$ (12) | 4.666 a | 3.611 ab | 2.237 a |
| $T_3$ (19) | 4.621 a | 3.753 ab | 2.483 a |
| $T_4$ (26) | 3.079 b | 2.840 b | 1.725 a |
| $T_5$ (33) | 2.899 b | 2.797 b | 1.536 a |

[a]Means in the same column followed by the same letter are not significantly different at the 5% level. [b]Figures within parentheses are the number of consecutive days without standing water for the corresponding water treatment.

for estimation of yield for a specific inputs management level (say HL), the value of that management index should be set at 1.0 (i.e. use HL = 1.0) and the other management indices must be set at 0.0 (i.e. use IL = FL = 0.0).

Water allocation and distribution patterns in a small diversion system

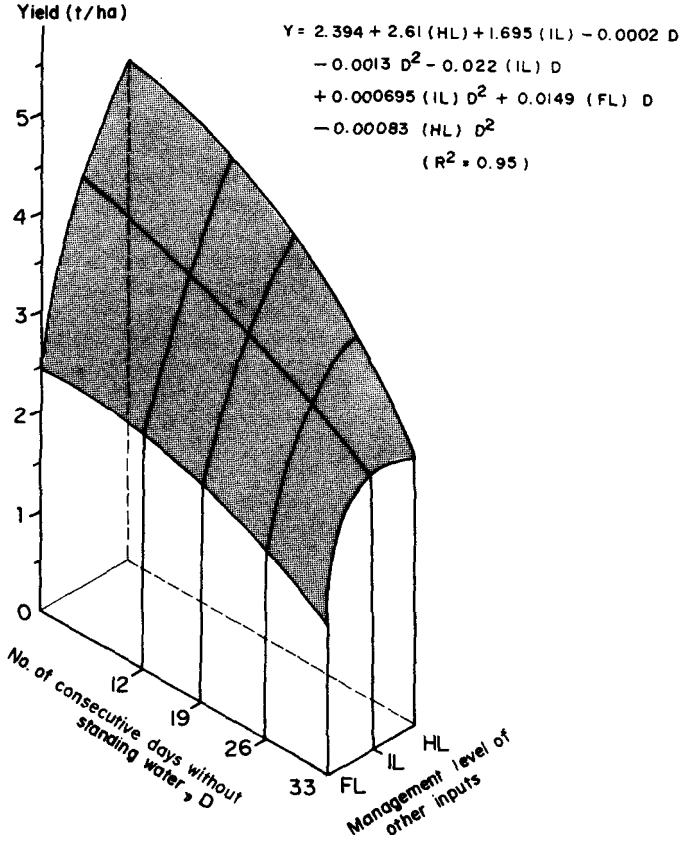
Many diversion systems are characterized by their inability to serve all farms within the service area. Recent studies have established a direct relationship between the incidence




**3.** Yield reduction pattern for IR36 due to water stress for three different input management treatments. FL = farmer level, IL = intermediate level, HL = high level.

of water shortage to the distance from the water source for large-scale gravity irrigation systems (Tabbal 1975, Khan 1978; Islam 1978). During the period of 1976-77, we took a close look at the water availability, allocation, and its distribution in the 506-ha service area of the Sagnay communal Irrigation System in Camarines Sur Province, Philippines. Communal systems, which are owned and operated by the farmer community on a self-supporting basis, served a total of about 790,000 hectares in the Philippines in 1975 (IRRI 1976) and the increase in the area irrigated by these systems during 1975-78 has been dramatic, about 149,000 hectares (Bagadion and Korten 1979). These systems of the Philippines can be likened to the *Sederhana* or simple irrigation projects of Indonesia.

The Sagnay system has a concrete dam on a perennial river and two other small dams on smaller creeks to supplement water supply to parts of the service area distant from the main dam. The total service area is divided into five sectors of different sizes on the basis of natural topography and drainage waterways.




**4.** Response surface curve and general regression model relating yield with degree of water stress and input management treatments. FL = farmer level, IL = intermediate level, HL = high level.

There is no definite scheduling of water delivery among the different sectors. Irrigation water in the main canal flows continuously. Checking to head up water level is not generally allowed. But as the main canal bed is above the service area level and all turnouts on the main are at the canal bed level, the prevalent practice of farmers with access to the main canal is to take as much water as their turnouts would allow even at times of lean flow in the main canal. Farmers away from the main canal obtain their water either from a farm ditch receiving water from main canal or by excess flow from upstream farms through paddy – to – paddydistribution.

Table 4. Area irrigated, farm ditch density and water diverted per ha, by sector. Sagnay Communal Irrigation System, Camarines Sur, Philippines, 1976 and 1977 dry seasons.

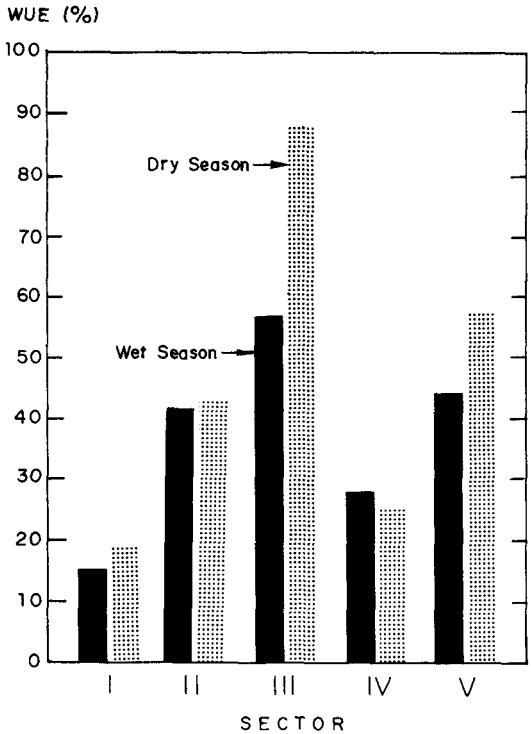
| Sector | Area (ha) | Farm ditch density (m/ha) | Av flow diverted per ha | | | |
|---|---|---|---|---|---|---|
| | | | Wet | | Dry | |
| | | | mm/day | % of total | mm/day | % of total |
| I | 47.8 | 69 | 80.7 | 55 | 59.7 | 53 |
| II | 144.5 | 98 | 21.4 | 15 | 21.0 | 19 |
| III | 75.0 | 73 | 14.8 | 10 | 8.4 | 8 |
| IV | 112.0 | 62 | 18.3 | 13 | 17.1 | 15 |
| V | 127.2 | 44 | 10.6 | 7 | 5.7 | 5 |
| Total | 506.5 | | | | | |
| Weighted Av | | 70 | | | | |

The first three sectors, which are to use the river water from the dam alone, received water amounts in inverse relationship to their distance from the dam (Table 4). Sector I, which was the first sector after the dam and constituted only 9% of the total service area, received an average of 54% of the total available flow. Other sectors, therefore, received much less canal water than they needed.

The performance of the system was evaluated in terms of its water use efficiency (WUE) estimated by the equation

$$WUE = \frac{ET + S\&P}{Ir + Rn}$$

where ET is the evapotranspiration requirement of the crop, S&P is the seepage and percolation rate in the soil, and Ir and Rn are the water supply from irrigation and effective rainfall, respectively. As expected there was a great difference in the WUE in different sectors of the system. Sector I had the lowest WUE because it consumed about 6 times more water than was actually required, Sectors III and V, being supplied with the least amount of irrigation water, achieved highest WUE values (Fig. 5). The high WUE of 88% in the dry season in Sector III was possible because of low irrigation water supply and more or less regular, but not excessive, rainfall that occurred in that season.




**5.** Water use efficiency (WUE) at the different sectors, Sagnay Communal Irrigation System, Camarines Sur, Philippines, 1976 wet and 1977 dry seasons.

The 506-ha Sagnay Communal Irrigation System study shows that severe inequity in water allocation and distribution existed in this small diversion system, although the total water availability in the system as a whole may be adequate. The reasons for this inequity are basically the same as earlier found for large-scale gravity systems; that is, overuse of water in sections closer to the source because of lack of adequate control and implementation of strict delivery schedules in the system by the management. The Sagnay system could greatly benefit from a number of improvement measures, such as controlling discharges in existing turnouts, reducing the number of turnouts in the main canal, and implementing a well-planned layout of farm ditches to replace the existing high-density (about 70 m/ha) but haphazardly constructed farm ditches. These improved facilities should be helpful in implementing scheduled water allocation to the different sections of the service area according to their actual needs, which should improve not only the WUE in all sectors

of the system but also enable expansion of the project's service area. It is estimated that if the WUE of sectors I and II were improved to 60% from their present values, the resulting water savings would be sufficient to meet the irrigation requirements of more than 150 additional hectares of land.

## CONCLUSION

I have cited selected examples of IRRI research findings that have bearing on irrigation system design and management and ultimately on the productive use of the available water.

It is perhaps evident that our concerns for design and management improvement are not at the primary headworks level of a system, e.g. dam, reservoir, spillway or main canal structures in the case of a reservoir irrigation system. We believe that there are great scopes for making significant contributions by concentrating research efforts on problems that exist in the reaches downstream of the primary headworks, with the parts of the system the day-to-day operation and management of which are crucial to the availability of water to different sections of the system's service area. Such efforts should not exclude researching problems at the farm level, where the results of all plans, designs, and implementations are ultimately tested. The primary goal of the research efforts is to develop technology or management tools to help achieve more efficient utilization of the available water resources in irrigation systems and thus help increase rice production as well as returns from irrigation development.

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# WORKSHOP RECOMMENDATIONS

WORKSHOP RECOMMENDATIONS

These recommendations, developed during the workshop, identify priorities for the development of directions for research in irrigation water management. After the presentation of each paper in the general session, which covered selected issues and IRRI's water management research program, there was considerable discussion relevant to the topic and to the objectives of the workshop. Those discussions were the forerunners, and naturally influenced later discussions to pinpoint the problems and priorities for research attention.

After the general session, the workshop participants separated into three groups to formulate recommendations. Each group had a specific research area to consider during a half-day session. The general session reconvened after the group discussion to review each group's approach and contribute to the deliberations made. Group deliberation later resumed and recommendations were prepared by each group for final discussion by the general body. That final general session provided the recommendations -- and the criteria used to make them -- that are presented here.

*Grour I. Engineering- and management-related research*

Convenor: Dr. T. H. Wickham
Reporter: Engr . Leonardo Lucero

The engineering and management group outlined the following criteria to recommend priority research activities:

- The problem should be generally applicable to countries in the region. The humid tropical region of South and Southeast Asia is the primary geographical focus for the recommended activities.

- The activity should contribute to an optimum use of total resources in irrigated agriculture.

- The activity should have an impact on decision – making in lending institutions and governments.

- Problem areas that have linkage with other research programs at IRRI should be selected.

- Basic research for guidance in irrigation design and management is important.

The group classified the recommended research issues into two categories:

1. research activities relating to irrigation systems taken as a whole, and

2. research on individual elements of systems, or on specific technological problems.

The group recognized that, based on the needs of the region and on relevance to IRRI's basic interest, the first category is more important and should, therefore, receive greater priority. It also recognized, however, the difficulty of closely linking research in the first category with the Institute's main stream of research.

Recommendations:

On activities relating to irrigation systems as a whole, there is need for research to

- identify and characterize critical data required to effectively improve irrigation system design and management;

- determine the efficacy of alternative methods of management in meeting various objectives, e.g. irrigation water savings, distribution equity, etc.;

- find the appropriate points or levels in irrigation systems that divide responsibility between agency personnel and farmers in systems of different types and scales;

- identify the problems in given irrigation systems and the hierarchal levels at which they occur, and develop a methodology for broader application in the region;

- examine interaction effects of irrigation design and management on other farming parameters, e.g. mechanization,

adoption of modern varieties (interpreted to apply to interactions within the system command area, and not to much larger regional areas); and

- identify engineering, economic, and institutional factors that affect farmers' use of water -- to determine the factors that explain relative ease or difficulty in farmers' handling of water.

On activities relating to individual elements of system or specific technological problems, there is need to:

- study relative benefits and costs (interpreted broadly) of small, medium, and large systems;
- develop diagnostic tools aimed at providing hydrologic information for evaluating the suitability of small watersheds for irrigation for which conventional hydrologic data are not available;
- find irrigation practices that are suitable for conditions of irrigated dryland crops grown in rotation with wetland rice;
- determine better water management practices for rainfed culture with no irrigation, e.g. paddy bund management;
- determine the value and costs of land consolidation and land leveling in irrigation;
- develop and disseminate efficient and inexpensive equipment, instruments, and methods for building or managing irrigation systems, e.g. inexpensive farm ditch trenchers, flow meters, assessment of water adequacy; and
- determine the interactions of fertilizer use and water.

The group recognized the importance of and need for *strong training component* parallel to research advancement in the recommended areas.

*Group II. Social and institutional research*

Convenor: Dr. M. K. Lowdermilk
Reporter : Dr. Roger Cuyno

The group selected four criteria for selection of research priorities:

- provision of information required by designers, developers, and managers;
- provision of data for increasing crop production;
- provision of information on ways and means to provide increased equity; and
- identification of issues where findings are generalizable to a region.

Recommendations :

Three major practical problem areas were identified as priority research issues:

- effectiveness of alternative methods of redistribution or denial of water in irrigation systems;
- effectiveness of alternative modes of local involvement in irrigation systems, specifically in system design, rehabilitation, operation, and maintenance; and
- alternative approaches for optimizing the synchronization of farming activities dependent on irrigation water availability with special emphasis on land preparation, cropping schedules, and rice-based cropping patterns.

The group's recommendations related to research approaches and transfer of findings were for:

- increased emphasis to improve coordination of research and training efforts with other IRRI departments that have natural overlap and complementarities in interest;
- continued high priority for on-the-job training in research and use of research findings for training programs in the countries of the region;
- development of research methodologies for the region that relate to cost-effective approaches to improving irrigation system management;
- continued testing and refining of research methods outside the Philippines and continued efforts to develop a comparative data base;

- increased focus on a water management information network for individuals and organizations interested and involved in water management research as well as for specific audiences such as policy makers, technical-engineering groups, and other professionals involved in irrigation planning and implementation;

- consideration of research in IRRI's economic consequences program, in conjunction with the water management program to determine consequences of irrigation especially with regard to the support of future population growth in rural areas, the man-land ratio, employment generation in farming activities and in processing farm products, social and environmental impact of irrigation, and increased inequities between rainfed and irrigated areas; and

- utilization of IRRI's existing resources to invite social scientists from the region to assist the water management program in designing and implementing social and institutional research and training.

*Group III. Economics- and investment-related research*

Convenor: Dr. Rudolf Sinaga
Reporter: Dr. Juan Zapata

The group considered several factors:

- The comparative advantage, resources, and specific research strengths of IRRI have not been specifically considered. Activities that can more appropriately be undertaken by national research institutes or local government agencies are excluded from the recommendations.

- Areas that are researchable and have direct policy and implementation implications are given greater consideration in the determination of priority.

- Research leading to better approaches to solving problems, rather than to specific results valid only for specific areas, is a more useful course of action for an institution such as IRRI.

- Recommendations should focus on goals rather than on procedures of research.

- The water management program at IRRI can often work most productively by collaborating with other international and national research or development bodies.

Recommendations:

The group's recommendations were for:

- the preparation of a handbook outlining procedures for postproject evaluations (the evaluations should consider the direct and indirect returns to project investment and distribution of project benefits with supplemental attention to the institutions that were developed to support irrigation in the project and would include applications of the procedure to selected irrigation projects in the region);

- the development of methodologies for determining, within a given irrigation system, the main problems of water distribution, and evaluating the alternative solutions using improved infrastructure, management, and farmers' participation;

- the development of methodologies for estimating employment and income effects of irrigation projects, specially regarding distribution of irrigation benefits and repayment criteria;

- the evaluation of costs and benefits of different types of distributional and on-farm irrigation facilities, with particular attention to conditions existing in rural areas with regard to repairability, farmers' understanding of the structures, and their income level;

- development of methods of appraisal of the true potential for expansion and improvement of different types of irrigation projects; and

- development of a procedure for determining the economic and operational factors for conjunctive use of surface and ground water.

## CONCLUDING REMARKS

D. J. Greenland

It is both difficult and perhaps unrewarding to attempt to summarize the work of a meeting such as this. The results of the workshop are contained in the recommendations of the working groups, which are wide ranging. In his paper at the start of the workshop, Dr. Chambers emphasized that we should not oversimplify our objectives, and where the recommended activities are many and diverse, there is inevitably a tendency to do so.

Undoubtedly better use of irrigation water can lead to the production of more rice and the elimination of hunger, and an increase in employment and reduction of poverty. To attain these objectives water resources need to be better used in relation to increased rice production, and more equitably distributed. This requires that water supplies be managed more efficiently and more economically to meet the farmers' needs. Not only must we understand better the ways in which too little and too much water affect rice production, but we also need to develop a better understanding of the technical, social, and economic factors involved in the management of irrigation systems.

From the discussions during the meeting three themes relating to IRRI's role in studies of this type were repeatedly emphasized:

- What is most needed is an established methodology to determine the efficiency of an irrigation system, in physical, economic, and social terms as well as in terms of water use, and to show how the efficiency can be improved.

- IRRI has a strong comparative advantage in the close association of its Department of Irrigation Water

Deputy director general, International Rice Research Institute, Los Baños, Philippines.

Management with other departments at IRRI concerned with the agronomic, economic, and biological factors which determine rice yield, and it should utilize that advantage in the studies it develops.

- IRRI can only study irrigation water management problems effectively by collaboration with the various national agencies which have the responsibility for the management of irrigation, and must therefore seek to strengthen further its relationships with those agencies in developing its research program.

In considering and endeavoring to implement the recommendations of this meeting, these themes will be borne in mind. IRRI can actively study very few irrigation systems, but in selecting those where it will work, their suitability in terms of methodology development will be a prime consideration. Linkages of the studies to the work of other departments at IRRI, and their involvement in the studies, will be increased. This should help to ensure that rice production is brought to an optimum economic level.

IRRI already has close links with the National Irrigation Administration in the Philippines, which it appreciates and hopes to maintain and strengthen. It will seek to develop further and where necessary establish new relationships with other irrigation agencies in the rice-growing countries, to broaden its involvement with water management and to ensure that the methodologies developed are examined in a range of physical, social, and organizational conditions.

The importance of studies on small, and community-managed, systems, as well as large systems should also be mentioned. The need for IRRI to be aware of farmers' perceptions of what is efficient water management is well recognized. The importance of direct contacts between farmers and researchers, managers, and engineers is undoubtedly essential to the development of efficient management of irrigation water.

The importance of training in water management is another theme that has recurred during the meeting. IRRI will seek to fulfill a role in this respect, and to develop and improve its training programs concerned with irrigation water management. In this respect, as well as in its research activities, we can be successful only through close collaboration with various national agencies.

I would like to close this meeting by expressing the

warm thanks of IRRI to all of you for giving us the benefit of your time and wisdom during this workshop. Many of you have particularly heavy workloads, and we appreciate the time you have taken to be with us. We hope that the deliberations and discussions may have been valuable to you, as much as they have been to IRRI. And we very much hope that this workshop has helped to lay the foundations for future collaboration in the improvement of the efficiency of irrigation systems, the production of more rice, and the alleviation of poverty.

## PARTICIPANTS

Syed Hashim Ali, Command Area Development Department, Government of Andhra Pradesh, Secretariat, Hyderabad, A. P., India

N. C. Brady, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Sadiqul I. Bhuiyan, Department of Irrigation Water Management, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Gelia Castillo, Department of Agricultural Education, University of the Philippines at Los Baños, College, Laguna, Philippines

Robert Chambers, The Institute of Development Studies at the University of Sussex, Brighton, Sussex BN1 9RE, England

Roger Cuyno, Center for Policy and Development Studies, University of the Philippines at Los Baños, College, Laguna, Philippines

Oesman Djojoadinato, Department of Public Works and Power, Kebayoran Baru, Jakarta, Indonesia

Alan C. Early, Department of Irrigation and Water Management, International Rice Research Institute, P.O. Box 933, Manila, Philippines

John C. Flinn, Department of Agricultural Economics, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Jose Galvez, National Irrigation Administration, EDSA, Diliman, Quezon City, Philippines

Grace Goodell, Department of Agricultural Economics, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Dennis J. Greenland, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Majibul Haque, Directorate of Land and Water Use, Bangladesh Water Development Board, Motijheel Commercial Area, Dacca, Bangladesh

L. Dale Haws, Rice Production Training and Research, International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Robert W. Herdt, Department of Agricultural Economics, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Carlos Isles, National Irrigation Administration, EDSA, Diliman, Quezon City, Philippines

Sam Johnson, The Ford Foundation, P.O. Box 436, Bangkok, Thailand

Prasert Kanoksing, Operation and Maintenance Division, Royal Irrigation Department, Sam Sen Road, Bangkok, Thailand

G. N. Kathpalia, Department of Agriculture, New Delhi, India

Frances Korten, The Ford Foundation, 6th Floor, Doña Narcisa Bldg., Paseo de Roxas Ave., Makati, Metro Manila, Philippines

Roberto Lenton, The Ford Foundation, 55 Lodi Estate, New Delhi 110003, India

Gil Levine, Center for Environmental Research, Cornell University, Ithaca, New York 14853, USA

Max K. Lowdermilk, Colorado State University, Ft. Collins, Colorado 80521, USA

Leonardo Lucero, National Irrigation Administration, EDSA, Diliman, Quezon City, Philippines

A. M. Michael, Water Technology Center, IARI, New Delhi-110012, India

Senen Miranda, Philippine Council for Agriculture and Resources Research, Los Baños, Laguna, Philippines

Richard A. Morris, Multiple Cropping Department, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Charles J. Moss, Department of Agricultural Engineering, International Rice Research Institute, P.O. Box 933, Manila, Philippines

D. Nangju, Agriculture Department, Asian Development Bank, P.O. Box 789, Manila, Philippines

Hashim Noor, Malaysian Agricultural Research and Development Institute, Serdang, Selarngor, Malaysia

Affifuddin Hj. Omar, Muda Agricultural Development Authority, Teluk Chengai, Alor Setar, Kedah, Malaysia

Petronio Ongkingco, Institute of Agricultural Engineering and Technology, University of the Philippines at Los Baños, College, Laguna, Philippines

Effendi Pasandaran, Direktorate Perlindungan Tanaman Pangan, Jalan Raguna, Pasarminggu, Jakarta, Indonesia

Mano D. Pathak, Research and Training Coordination, International Rice Research Institute, P.O. Box 933, Manila, Philippines

K. D. P. Perera, Irrigation Department, Colombo 7, Sri Lanka

Shamsur Rahman, Bangladesh Water Development Board, Motijheel Commercial Area, Dacca, Bangladesh

Jose Remulla, Farm Systems Development Corporation, 18th Floor, Pacific Bank Bldg., Ayala Ave., Makati, Metro Manila, Philippines

Romana delos Reyes, Institute of Philippine Culture, Ateneo de Manila University, Quezon City, Philippines

Rudolf Sinaga, Department of Agricultural Economics, Bogor University of Agriculture (Indonesia), Bogor, Indonesia

Donald Taylor, Agricultural Development Council, Inc., 20th Floor, Cangkat Damansara, Kuala Lumpur 10-05, Malaysia

Thanya Teerasart, North East Agricultural Center, Traphra, Khon Kaen, Thailand

Nukul Thongtawee, RID Nong Wai Region Office, Nong Wai, Khon Kaen, Thailand

Odelon Ventura, Farm Systems Development Corporation, 18th Floor, Pacific Bank Bldg., Ayala Avenue, Makati, Metro Manila, Philippines

Thomas Wickham, Wickham's Fruit Farm, Cutchogue, Long Island, New York 11935, USA

Hubert G. Zandstra, Multiple Cropping Department, International Rice Research Institute, P.O. Box 933, Manila, Philippines

Juan Zapata, International Food Policy Research Institute, 1776 Massachusetts Ave., N.W., Washington D. C. 20036, USA