ECONOMIC REPORT

ER83-5 APRIL 1983

SOCIOECONOMIC ISSUES IN IRRIGATION DEVELOPMENT AND DISTRIBUTION

K. WILLIAM EASTER AND DELANE E. WELSCH

Department of Agricultural and Applied Economics

University of Minnesota
Institute of Agriculture, Forestry and Home Economics
St. Paul, Minnesota 55108

TABLE OF CONTENTS

PREFACE

This report is part of the work done by the University of Minnesota and Colorado State University for the U.S. Agency for International Development under the Cooperative Agreement for Economic Planning and Policy Analysis for Irrigation. The studies have been concentrated in Asia and North Africa with special emphasis on South India, Northeastern Thailand, Egypt, and Pakistan. The work in Thailand and India is focusing on small scale irrigation while that in Egypt and Pakistan is concerned with water allocation in large scale projects.

The purpose of this report is to provide a summary of what we have learned through review of the research literature concerning socioeconomic problems in irrigation faced by developing countries. The emphasis in this review is on Asia and on what we feel to be three critical problem areas of water allocation, irrigation institutions, and investment alternatives. While we have not cited all the literature, what we include is representative of research completed in these three problem areas.

For further information about the research in Thailand and India, contact K. William Easter, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, MN 55108, and for Egypt and Pakistan write Robert Young, Department of Economics, Colorado State University, Fort Collins, CO 80523.

SOCIOECONOMIC ISSUES IN IRRIGATION DEVELOPMENT AND DISTRIBUTION*

K. William Easter and Delane E. Welsch**

The basic problem in most irrigation schemes is the failure to reach expected levels and distribution of output and income. Water allocation, operation and management procedures are major contributors to poor project performance both in terms of income and its distribution. A fundamental concern is the capacity of countries to properly evaluate complex water resource development and to design and implement appropriate projects and policies. In many cases expectations in terms of output and its distribution may be unrealistic.

This paper seeks to spell out what is known about the socioeconomic problems facing irrigation planners and managers. It will also highlight some of the important socioeconomic research issues that need to be addressed. The review will be organized around three topics:

(1) Water allocation procedures and policies

(2) Institutional arrangements for irrigation management

(3) Irrigation investment alternatives

The first two topics are closely related in that water allocation or distribution is central to irrigation management. In addition, the institutional arrangements for management can determine the success or failure of water allocation procedures. Even the design and scale

---

*The authors are indebted to Drs. Edward Sparling, Dick Suttor, Donald Taylor, Leslie Small, Charles Howe, Sam Johnson and K. Palanisami for their extensive comments on earlier drafts and their help in covering this extensive topic. Errors and omissions, however, remain the responsibility of the authors.

** The authors are professors in the Department of Agricultural and Applied Economics at the University of Minnesota.

issues are difficult to separate from management. Many irrigation problems arise out of failures to jointly plan project design and management. Too many times project management has not been considered until the project is almost complete.

WATER ALLOCATION PROCEDURES AND POLICIES

Bottrall (1981) in his recent World Bank report on Management and Organization of Irrigation Projects terms water allocation or distribution as one of the astonishingly neglected areas of research that has a high potential payoff. "Water distribution was accorded its central place in the Terms of Reference for several reasons. In contrast with other activities mentioned, it is an activity peculiar to irrigated agriculture and it has not been widely studied - indeed, until very recently, it has been astonishingly neglected, both by academic researchers and professional practitioners. But the overriding reason was that there was recognized to be an immense potential, so far largely untapped, for improving current water distribution practices" (Bottrall, 1981, p. 2).

Bottrall goes on to suggest that there are two important dimensions to water distribution. First is the technical dimension relating to the appropriateness of the water distribution methods. Second is the social and political dimension which concerns the ability and willingness of irrigation officials to allocate water equitably and resist powerful pressure to misallocate water. "Good water distribution thus requires not only a high order of technical skill but also a management system which will make it rational for irrigation officials to deny extra water to the more powerful and better located" (Bottrall, 1981, pp. 122-123).

Indeed, the potential payoff from improving irrigation systems is large. As will become clear, water distribution involves complex technical, institutional and investment questions. In order to simplify the discussion of research findings and future areas of work, this section is divided into three parts based on location in the system: water allocation among farmers, transmission water losses and water source allocation. Although this is somewhat an artificial division, it helps emphasize the key role which physical design has in determining the allocation alternatives open to management.

Water Allocation Among Farmers

A wide range of procedures can be used to allocate water among farmers. These include: (1) no formal allocation procedure -- water flows continuously, (2) rotation -- water is available for irrigation every 7, 10, or 14 days depending on the length of rotation, (3) farm priorities -- farms are served in order of priority based on time of settlement, (4) market -- water users bid each period for water shares needed to irrigate their crops or buy water shares for the whole crop season, (5) demand -- water supply for the full season is stored and each farm is allotted a fixed quantity for the season which can be obtained on demand.

Although there are rules for selecting the appropriate design for a canal there are no comparable rules for selecting the method for allocation of irrigation water. What criteria should be used to determine whether a rotation system or a demand system should be used? Maass and Anderson (1978) suggest that five objectives are important in deciding how to allocate water at the farm level: equity, efficiency, growth, justice and local control. The weight given each objective is likely to be different among water managers, farmers and politicians. This complicates the problem of establishing criteria for selecting the appropriate method for water allocation. It is also likely that the method of allocation should change over time as farmers gain experience and can take more responsibility. For example, one may start out on a strict rotation system and change to a demand system. However, to make such a change the design capacity must be adequate to handle changes in allocation procedures. It will be possible to change from a continuous flow system to a rotation system only if there are adequate control structures.

Seagraves and Easter (1982) suggest that some combination of regulations and prices will be used to allocate water and help pay for the system. The particular mix of rules and prices depends on a number of factors including: the value of water, the ability to collect fees, dependability of supply, cropping patterns, control structure, project objectives, etc. The specific weights given to these factors for selecting the appropriate combination of regulations and prices will vary among countries and projects. They suggest that the possibilities for achieving an efficient and equitable distribution of water are enhanced if some form of variable pricing is used (see the section on Water Pricing for further discussion).

Reidinger (1974) and Malhotra (1980) both studied the rotational system (Warabundi) used on canal systems in northern India. They both found that this system often prevents the distribution of water to areas of highest need because the times reserved for water allocation to individual farms are non-transferable among farmers. One possible way to resolve this inefficiency would be to sanction intra-watercourse markets which allow trading of water turns or shares to take place among farmers.[1/] In contrast to Reidinger, Malhotra concludes that, given the size of the system it operates fairly well. Malhotra seems to ignore the problem inherent in most Indian irrigation, which is the failure to involve farmers and agronomists in decisions on water allocation (Bottrall, 1981). Still a well-operated Warabundi has the potential for increasing the output from some irrigation systems in India.

These studies all point to the need for additional research which will provide comparisons between the different methods of water allocation so that suitable criteria can be developed for selecting the allocation procedure best suited to meeting the project objectives and conditions of specific irrigation systems. Such future studies should emphasize the dynamic aspects of irrigation, which is important in today's rapidly changing agriculture. Research should be patterned after Maass and Anderson's (1978) studies in Spain and the U.S. where they evaluated water allocation changes as water availability conditions changed from year to year, and as farmers adopted new and more complex irrigation methods. Future studies should also determine what the impacts of various allocation procedures (including water pricing) are on output and income distribution. Do certain procedures lead to higher levels of production while others foster a more equal distribution of benefits?

1/ However, in Pakistan under the Warabundi system, water trading used to be allowed but farmers petitioned the government to switch to a less flexible system. The few remaining watercourses that allow trading are small and have extraordinary intra-watercourse cooperatives. A water market requires coordination of turns which tends to be a difficult task when a system is abused by the powerful farmers (Mirza, Freeman, and Eckert, 1975).

In addition, do certain allocation procedures create externalities such as water logging and salinity problems?

The social and political dimensions of water allocation suggest several additional research questions. Irrigation systems have been called behavior systems because their performance is so dependent on the many people involved. Since incentives influence people's behavior, it is important to understand the incentives provided by an irrigation system to all groups involved in that system (Small, 1982). This leads to several important allocation questions which concern the compatibility of incentives.

First, there are many sub-groups within irrigation agencies, each with different motives and responsibilities. Little work has been done on how incentives can be used to influence each of these groups. Small speculates that the basic organization of many irrigation agencies may lead to inappropriate incentives. "The improved system layout resulting from farmer input in the design and construction stages causes better system performance ... and fewer operation and maintenance problems ... This would appear to be a potential incentive for the irrigation agency to incorporate farmers in the design process. But given the usual organization of irrigation agencies into separate divisions for design and construction on the one hand; and operation and maintenance on the other, the incentives to incorporate farmers may exist only at the very highest levels within the irrigation agency" (Small, 1982, p. 7).

In addition, where excessive water use by upstream farmers deprives downstream farmers of water, a real conflict in objectives may occur. Only the irrigation official may see the potential for redistributing the water while the individual farmers can only see their own direct losses or gains. However, there is a potential for redistributing water, in a number of cases, without reducing production upstream. These potentials need to be identified and demonstrated to farmers.

Second, are the incentives for irrigation system managers and the farmers compatible with the efficient and equitable allocation of water? If not, how might they be altered to increase the compatibility? For example, Gopalakrishnagya argues that India's Command Area Development (CAD) fails to meet the compatibility of objectives test. "When CAD officials determine land localization/water distribution policy and cropping pattern solely based on soil, climate and the availability of water for maximizing cropwise production, the objectives of the CAD and the farmer do not fully coincide," (Golpalakrishnagya, p. 75). He finds that the CAD "objective has to be modified to allow the participation of the farming community as an integral part of the program. This can be achieved when the objectives of the farming community are also taken into consideration along with the objectives of the government," (Gopalakrishnagya, p. 76). He suggests that a reasonable return to farmers should be included as an objective.

Finally, how can farmers be organized to help in water allocation so that when they serve their own self-interest they also serve the overall interests of the project? The answer will involve study and evaluation of existing systems of allocating water which include farmer inputs at different stages of the allocation process. A more detailed discussion of farmer organization must wait until the section on Organizations for Water Distribution.

Transmission Water Losses

Water losses as high as 70 percent have occurred during transmission of water to the farmer's fields. The seepage of water through the banks of canals accounts for much of the loss. If water is being transmitted over a vast area, the problem of water losses is aggravated. Therefore, an important question in transmission is how large an area should be served? This question involves a trade-off between efficiency and equity. Three things generally happen when the area irrigated is expanded. More farmers can irrigate, the transmission losses increase and the certainty of water supply decreases. We need to know the cost in income foregone (due to water losses and decrease dependability) from expanding the irrigated area and the benefits from expanding the number of farm families receiving irrigation.

Palanisami (1980) reviews the development of a large scale irrigation project in Tamil Nadu, in which the command area was expanded from 251,000 acres to 366,000 acres during the late seventies. This expansion was approved despite the fact that 61,000 acres in the original command area had never been irrigated. After the expansion farmers received, on the average, enough water to irrigate one crop every 2 years as compared to water for a crop every 1-1/2 years before the expansion. In addition, the expansion was concentrated on two of the six major canals. Because of the limited and uncertain canal water supply, the area irrigated by wells increased significantly. However, little is known about the groundwater supply and the recharge provided by the irrigation project.

In another large South Indian irrigation system, Palanisami (1981) found that the pattern of water allocation from reservoir to fields had to be changed to accommodate an expanded command area. Due to inadequacy of water, a "zonal system" of irrigation was introduced in 1959. The command area was divided into odd and even miles along the main canal. All distributaries along the odd numbered miles received a continuous supply of water for a rice crop during August 15 to December 15, 1959. The distributaries along the even numbered miles obtained water for dry crops on weekly intervals during December 16, 1959 through April 15, 1960. In 1960-61, the sequence changed so that the even numbered miles obtained water August 15 through December 15 while the odd numbered miles received water December 16 through April 15. The "zonal system" was an attempt to serve as many farmers as possible given the political decision to have a command area larger than could be served, at one time, by the irrigation system.

Roy and Singh (1979) used a linear programming model to determine the optimum command area for small private tubewells. This is a much easier problem to model than the large flood irrigation systems since there is little or no transmission loss or trade-off among farmers (assuming no groundwater constraint). The main questions to be decided are the cropping patterns and the acres irrigated given the pumping capacity and rainfall.

One option for large irrigation projects is to start with a relatively compact irrigation system and collect fees for the full cost of providing the irrigation water. The system could then be expanded as new investments in storage capacity, canal linings, other water saving improvements, etc., make water available for irrigating additional land. The criteria for this step-by-step expansion of the irrigated area would be to equate the marginal cost of delivery to the marginal revenue from irrigation expansion. This assumes that the water delivered to the new area is surplus water, i.e., the value of water at the margin is close to zero in the existing irrigated area. Expansion of the irrigated area would continue as long as the marginal cost of delivery is less than the expected marginal return from new irrigation.

The more likely and difficult problem occurs when the transfer of water to a new area involves a loss of income to farmers in the existing irrigated area. In this case, the following information should guide the decision makers: (1) the loss in income to farmers in the existing irrigated area, (2) the cost of delivery to the new area including water lost in delivery, (3) the net returns to irrigation in the new area, (4) the levels and distribution of income in both areas, and (5) the environmental impacts of the increase in irrigated area. At best, decision makers usually have a little information concerning net returns and the cost of delivery.

Within a compact irrigated area, transmission losses can be further reduced by several water conservation procedures. However, research is needed to determine the highest return water conservation methods. One of the most frequently proposed methods is canal lining. Yet current technologies for lining, particularly concrete lining, tend to be high in cost. Studies of concrete lining do not give clear-cut conclusions concerning profitability (Taylor, 1981, p. 157). Other materials need to be tried and evaluated in terms of cost of installation, maintenance required, speed of installation, land used and water saved.

Gupta, et.al. (1973) studied several cases in India where there had been a change from ordinary canals to concrete lined ones. They found that such changes reduced water losses due to seepage and evaporation and increased the cropping intensity, and provided an assured supply of irrigation water to a larger area. Hafid and Hayami (1979) discovered similar results from canal lining in the rehabilitation of the Subsidi Desa scheme in Indonesia. There is no doubt that lined canals can reduce the variability and uncertainty of the water supply, but how much is added to the costs of providing water and what are the benefits? Cheaper alternatives are often available to assure a water supply. One possibility is partial lining of the canals or watercourses.[2/] Johnson, et.al. (1978) evaluated several methods of watercourse improvement including concrete and masonry linings and simple earthen improvements of the ditches with concrete control structures, junctions and turnouts. They found that the earthen improvements with concrete structures were the best investment in Pakistan where labor costs were low. Recent studies, however, suggest that the life of earthen improvements may be substantially shorter than assumed by Johnson, et.al. Improved watercourses in Pakistan's Punjab tend to reach their previous state of neglect in one to three years (Renfro, 1982).

Ali (1980) assumed a life of three years for earthen improvements in Pakistan and used programming techniques to find that lining the upper reaches of improved watercourses was just on the verge of being profitable under 1977 prices. This lining was done on the most heavily used and most porous sections of the watercourses. Higher energy prices or procedures for increasing the life expectancies of the earthen improvements would make improvements profitable.

Pang (1979) found that fiberglass-reinforced polyester (FRP) flumes to carry water above ground were superior to earthen channels in Malaysia. The flumes could be installed more rapidly and required less land and

---

2/ Watercourses are generally maintained by the farmers while the canals are the responsibility of a government agency.

maintenance. These cost savings plus the savings in water more than offset the capital costs which were two and a half times the cost of earthen channels.

Similar studies need to be done in other countries to determine returns from alternative canal and watercourse linings under varying soils, climate, prices, etc. In fact, more work should also be done with alternative methods of water conveyance at the watercourse level. For example, Lenton and Seckler (1978) and Gisselquist (1979) have suggested alternative ways of using pipe.

Probably the cheapest method of reducing transmission losses, where labor costs are low, is by proper and timely maintenance of the canals. Johnson, et.al. (1978) cite inadequate organization of the users as the major reason for the lack of maintenance and resulting losses. Lowdermilk, et.al. (1977) also believe that this problem can be alleviated by effectively organizing the users to maintain and improve their watercourses. Sparling (1981a) suggests that the problem of irrigation canal maintenance is a particularly thorny collective goods problem. He contends that this problem is characterized by "... externalities resulting from individual action; and vulnerability to opportunistic behavior (i.e., water theft) by other farmers". He also demonstrates the organizational difficulties of maintenance and provides theoretical arguments and empirical evidence in support of his proposition that the watercourse maintenance problem is an important cause of divisiveness among Pakistani farmers.

Maintenance is also a basic investment problem. Little or no funds are generally allocated for system maintenance when budgets and designs are made for irrigation projects. In fact, countries may find that they have constructed more irrigation projects than can be adequately maintained. Both funds and trained manpower can be constraints to adequate maintenance of irrigation projects. When these constraints exist, new projects may have to be curtailed. In addition, maintenance should be included as a specific item in all project plans.

Singh and Bhargava (1977) emphasize the need for conservation of run-off water during periods of heavy rainfall. They suggest the construction of small reservoirs with devices to slow evaporation. Chambers (1978) also recognize the need for conservation and proposes research into devices that will reduce the evaporation from open bodies of water. Such devices include windbreaks, shade, vegetation and chemical films.

Another aspect of transmission that has been all but neglected in the literature is the economics of irrigation scheduling. Taylor and Tantigate, 1981, in one of the few papers on the subject showed that non-adherence to the scheduling was associated with lower yields and profitability. They found that farmers lost the most time relative to the gazetted schedule in transplanting and harvesting. The labor supply was inadequate for the two-week time specified in the gazetted schedule for each operation. The gazetted schedule calls for irrigation water to be supplied to all farmers simultaneously which is not possible. They concluded that the schedules should be reformulated to phase in irrigation water across schemes. To make a phased scheduling possible would require investments in irrigation infrastructure, training of staff, changing of staff incentives, increasing the tractor supply, irrigation extension programs for farmers and farmer incentives to follow irrigation schedules.

The research on ways to reduce transmission losses has certainly improved during the 1970's and 1980's. However, much action research is still needed in the heavily irrigated areas of Asia where different alternatives can be tried and tested. Research is needed on alternative methods for reducing water losses during transmission to farmers' fields. Different methods for improving canal maintenance need to be tried and tested. More analysis is needed to determine the optimum size of command areas under different resource conditions and trade-offs between efficiency and equity. Finally, the technical and economic effects of alternative irrigation schedules deserves further attention.

Water Source Allocation

A number of problems arise with regard to the allocation of irrigation water from its source. One such problem involves the allocation of water over time, both within a season and between seasons. Water in a reservoir or a groundwater aquifer represents a source of income generation in the current period as well as in future years. Evaporation losses impose a penalty on water stored in reservoirs for future use, encouraging large releases as does the existence of a discount rate. In contrast, the diminishing productivity of water and the uncertainty of next year's water supply both encourage water storage. This problem has been dealt with by Cummings (1974) in his case study in Mexico but has been largely neglected in the literature of Asia.

Another question concerns the allocation of water among different uses. For example, if water is withdrawn for irrigation, what does this mean for other users? Maass and Anderson (1978) consider the question in terms of downstream users in both the U.S. and Spain. This appears to be a fairly common externality in parts of Asia such as the Philippines where upstream farmers use excessive quantities of water. The result is water shortages for downstream farmers. Return flows reduce this externality somewhat. The same externality exists in tank irrigation in South India where tanks are arranged in a series with the overflow from one tank going into the next tank. Palanisami and Easter (1983) found that farmers served by upper tanks used excessive water and double cropping, resulting in water shortages for the one crop grown under the lower tanks. It will take action by the government irrigation agency to internalize this externality. Kelso, et.al. (1973) address the problem in terms of the low value of irrigation water in Arizona when compared to alternative uses, i.e., industrial and commercial.

Finally, what procedures can lead to an economically efficient joint allocation of groundwater and surface water supplies (conjunctive use)? Maass and Anderson (1978) studied the conjunctive water distribution to farms in the Kings River service area of central California. There, surface water prices are kept low as long as there is an adequate river flow. When surface water supplies drop, the price for the surface water is raised above the marginal cost of pumping. Young (1970) and Bredehoeft and Young (1970) used mathematical programming and simulation techniques to model the release of groundwater from aquifers. Their models provide valuable insights into the questions associated with conjunctive water management. Burt (1963) derived an inventory model for the optimal management of water over time, under conditions of conjunctive use of ground and surface water. His analysis was done for the same area in California as the Maass and Anderson study. These studies indicate the type of work that is needed in many LDC's. Their techniques need to be applied to the specific resource and cultural situations found in countries such as India, Thailand and Bangladesh. In addition, much more research should be done on these water allocation problems using less sophisticated approaches such as the equi-marginal principle (the last unit of water in each use should have the same value).

INSTITUTIONAL ARRANGEMENTS FOR IRRIGATION MANAGEMENT

Tukase (1982) says that Asia has experienced three phases in irrigation development over the past 15 years. The first phase was the construction of large dams and main canals during the 1960's. This was followed by a second phase of on-farm water management in the 1970's. The third phase is the concern for "institutional aspects and human management skills, cost effectiveness, socio-economic benefits and project implementation" (Tukase, 1982, p. 8). These issues, he feels, will be a major concern throughout the 1980's.

Governments in Asia have also shown a growing concern for the institutional aspects of irrigation.[3/] Levine (1980) suggests that government attitudes towards irrigation have gone through the same three phase evolution. In the earliest stage, the emphasis is on the capture and conveyance of water. This is followed by a concern for agricultural water use and the agronomic aspects of irrigation. In the final stage government finally recognizes that the farmer is an active participant in irrigation and that farmer's needs, as well as crops and soils must be taken into account in the system design, construction and operation. When governments finally reach this third stage the importance of institutional arrangements comes to the fore. What kinds of institutions will facilitate farmer participation and high levels of produciton? Also, what institutions have farmers already developed to better utilize their irrigation water?

Although there are at least three levels of institutions involved, the most important for direct farmer involvement are those dealing with distribution

---

3/ Institutions is broadly defined in this paper to include ways of doing things as well as legal and contractual arrangements for organizing activities and distributing property.

of irrigation water and maintenance of the irrigation system. Geographically these institutions are usually at the local or regional level. Generally they involve farmers, possibly in a water user's association. An irrigation department or bureau office in charge of a particular sub-project is another example. The success or failure of "management" is likely to be determined at the level where the farmer-user and the system interact.

A second set of institutions are those that directly affect distribution of benefits. These include both customary and legal institutions that deal with land tenure, crop tenure, access to resources, division of production, access to water, rights to water, etc. This level of institutions has considerable influence on the attainment of management objectives in an irrigation system and the eventual distribution of benefits. In fact, if one is to influence the distribution of irrigation benefits, decisions concerning these institutions have to be made at the design stage of the project.

A third set of institutions is at the national level. It consists both of organizational structures, such as a ministry of irrigation or a national planning authority, and of "rules" or ways of doing things. This includes such things as how the central government decides to go ahead with an irrigation project, how the Ministry of power and irrigation decides to allocate water to irrigation rather than to power generation and whether all signals come from the top down or some come from the bottom up.

The study of institutions and their problems, with institutions as defined above, leads directly to questions of efficiency and equity in the delivery of services, which may be the most crucial or critical irrigation issue facing many countries. How to reform or revitalize institutions which are having a negative effect on income and how to start new institutions which are needed to improve irrigation efficiency and to achieve a better distribution of gains are crucial and unanswered questions for most countries.

Bromley, et.al. (1980) suggest the following general principles for designing irrigation institutions borrowed from Rawls, (1971): (1) compatible liberty -- each participant in the irrigation system should possess an equal right to the most extensive liberty compatible with similar liberty for others; (2) knowledge and participation - any institutional system must be widely understood by all of the participants; (3) shared concept of justice -- there must be a shared concept of what is just and what is unjust; (4) formal system of justice -- there must exist a system of formal justice in which there is impartial and consistent administration of the rules; (5) rational rules -- rules should be designed so that the predominant self-interests of individuals leads people to act in ways which further desirable social ends.

Application of these principles however, depends on the basic "norms" of the society. Rawls' principles tend to come out of the norms of Northern Europe. But, in this paper, we are dealing mainly with societies which have different traditions and they may find Rawls' principles rather strange. Thus one must be careful when judging or recommending institutions for areas which have very different traditions than those found in developed countries.

At best we may be able to suggest a set of questions or criteria which should be satisfied concerning the institutional setting for irrigation development. For example, is the disparity in land ownership and the underlining power structure such that most of the benefits will go to the high income groups? What changes in institutions are necessary if an irrigation project is to achieve both equity and efficiency objectives? Do farmers have a record of being able to work together to solve local problems? These and other questions concerning institutions should be part of the overall evaluation of project feasibility. Even if the benefit-cost ratio appears satisfactory, the lack of appropriate institutions may spell project failure.

National Water Institutions

One important question with regard to institutions at the national level is: How should authority over water project formulation and implementation be delegated? A number of authors, including Abel (1976), Hutapea, et.al. (1976), and Thornton (1975) have found that the most efficient form of administration was one in which all of the development activities within an irrigation project were coordinated by a single agency. In cases where separate departments exist whose authorities overlap, for example, a department of irrigation and a department of agriculture, conflicts arise and blame is placed on one for shortfalls perceived by the other. Delegation of responsibilities is a source of conflict between two such departments. This has led to recommendations that where both departments exist, one overseeing agricultural activities and one concerned with irrigation, they should be combined or, at the very least, one should be given overall responsibility. However, such a merger can have serious consequences for existing government agencies and will be strongly resisted.

Abel (1976) takes his analysis one step farther and finds that the efficiency of irrigation systems management in Taiwan depends on the legal administrative basis for centralized planning of irrigation investment but decentralized management of irrigation systems. Research is needed to explore ways in which other countries can achieve integrated regional and national planning while at the same time have decentralized management of irrigation project. Abel also concludes that government recognition that water is a scarce agricultural input, is an important factor influencing the efficiency of irrigation management. For irrigation to be efficiently developed and used, water use must have a high national priority.

If irrigation development activities are to be coordinated, the coordination should start at the national level. The existence of a national agency for overall coordination is crucial, especially with regard to the planning and evaluation of irrigation projects. In setting up such a unit, care must be taken to keep the planning and evaluation agency separate from the construction agencies. The U.S. experience with the Bureau of Reclamation and the U.S. Army Corps of Engineers is enough to highlight the problems created when a construction agency also does the planning and evaluation. These are separate jobs with different incentives and should not be placed in the same agency (Easter and Waelti, 1980).

Although it may not be clear what type of national water planning and evaluation system is best, there is no doubt that such an institution should be established. Research can help shed some additional light on the effectiveness of various systems, such as the U.S. Water Resources Council.[4/] Analysis can also help establish guidelines for project evaluation. However, the first job that needs to be completed is to establish a national agency with

---

4/ The Water Resources Council is an example of an agency established to coordinate water development across several powerful agencies involved in water development. Their record should help make the point that it is almost impossible to effectively coordinate water development spread over numerous agencies. The real solution is to have the irrigation development as part of a department or ministry of agriculture. But, as we all know, this requires some difficult political decisions.

authority over water planning and evaluation. The agency will make decisions about the feasibility of projects and the allocation of funds among projects and geographic areas of the country. The actual project proposals must come from the provincial or district level. The centralized agency does not have the data and information to develop projects for specific parts of the country. The proposals must come from the regional or local level where the resource endowments, bottlenecks, and physical and social conditions are known.

Organizations for Water Distribution

It is widely agreed that effective organization and management of irrigation systems by informal or formal cooperative water user organizations will increase the efficiency, equity and productivity of irrigation projects (Abel, 1976; Andreou, 1979; Bottrall, 1977; Oh, 1978; Nickum,1977; Lowdermilk, et.al., 1978). The question is how to establish effective user organizations to meet the project objectives and at the same time be adaptable to local conditions. In many cases, this may mean making use of informal water user organizations that farmers have already developed. Throughout Asia we find effective water user organizations that have been ignored by central governments (Poffenberger, 1980).

Bottrall (1977) provides a description of the decentralized approach to irrigation administration followed by the Irrigation Associations of Taiwan. With this system much of the responsibility for decisions about water allocation and system maintenance is delegated to the users themselves. Although this is an institution that was developed in a specific environment and is not widely applicable, Bottrall feels that the knowledge gained from the sequence of developments that took place in Taiwan may be useful in devising such successful water user cooperatives elsewhere.

One of the conditions under which these cooperatives developed in Taiwan was that of strict enforcement. At the time of their implementation, Taiwan was subject to colonial rule by Japan. User cooperatives were implemented by official decree and their rules were enforced by police power. Although this is a condition which may be undesirable to emulate, it does not rule out the possibility of using the Taiwan example as one possible pattern of water user cooperatives. It does, however, point out that, without strict control or strong leadership, successful water user cooperatives may be difficult to formally establish in areas which do not have a history of successful cooperatives (Duewel, 1981, p. 15).

In his analysis of ten watercourses in Pakistan, Sparling (1981a) found that a history of cooperation had a positive impact on the quality of maintenance. This supported his hypothesis that a group which has organized, and is providing collective goods, has more at stake and the members are more likely to understand the degenerative effects of "free rider" behavior. Past cooperative activities can be expected to reduce the difficulties involved with establishing watercourse organizations.

A related major concern is how far control by a national agency should extend down the irrigation system. At what point in time and space can the farmers take charge of the water? In the case of large systems constructed by the government, farmer cooperation in irrigation may be restricted to their own immediate communities. The day-to-day management of the main system is probably best in the hands of the technically capable and impartial government or quasi-government agency. Ideally, this agency should be responsive to farmers' needs. In fact, farmer representatives should participate in the development of each season's water allocation and in the evaluation of the agency's day-to-day performance. The farmer representatives should include a majority of tail-enders and small scale farmers (Bottrall, p. 202).

In smaller systems and in places where the farmers' management and technical capacities are well developed, the level of farmer cooperation in irrigation is much higher. The existence of irrigation associations of farmers is a key asset in improving farmer cooperation in irrigation. In fact, a system could be developed to a stage where the government turns the water over to the irrigation association at some point in the system. It is likely to be difficult for farmers to take over much responsibility without an organization which can internalize the individual externalities involved in water allocation and canal maintenance. This externality problem will be highlighted in the next section in the discussion of the distribution of irrigation benefits among head-end and tail-end farmers.

De los Reyes (1981) conducted a study of the organization and management of Philippine communal gravity irrigation systems. She discovered that the nature of groupings which farmers adopt, and the ways in which they managed the irrigation, vary with system size. The smaller the system, the more loosely organized was the organization managing it. In addition, the methods of management vary with system size. Allocation procedures and system maintenance are greater tasks for larger schemes. Therefore, more complex methods are required to handle these tasks in larger irrigation projects.

The most frequently cited reason for the failure of communal associations was financial mismanagement (De los Reyes, 1981). Tubpun's study (1981) of tanks in Northeast Thailand found that a lack of funds was preventing farmer organizations from playing a more important role. Radosevich and Kirkwood (1975) recommended that farmer organizations in Pakistan be allowed to levy assessments for the operation and maintenance of watercourses. Duewel (1981) found in two lowland irrigation systems of central Java that a variety of sources were used to finance irrigation. Membership fees, water charges, special levies on land owners, village funds and revenues from village lands were all used to improve, maintain and operate their irrigation systems. Both villages made major efforts to establish a sound financial footing for their irrigation. This whole question of methods for financing and financial management needs to be addressed if farmer organizations are to be effective on a wide scale.

As mentioned earlier, compatibility of the incentives for the managers of the irrigation systems and the farmers can be an important factor in efficient and equitable allocation of water. Abel (1976) concluded from his study of canal irrigation in Taiwan that one of the important factors upon which the efficiency of the irrigation depended was the use of management incentives. In Taiwan's case the irrigation associations were made up of the farmers who operated the irrigation system themselves. The irrigation associations hired and fired managers at their discretion. As a result of this relationship, good managers were usually rewarded whereas poor managers were penalized. This added to their management efficiency which resulted in better irrigation service. This, in turn, enhanced the users' willingness to pay water charges and to contribute labor to the maintenance of the system.

Svendsen (1981) suggests that two considerations are necessary for farmers to organize and manage their water collectively at the tertiary level. First, the water supply at the tertiary level must be scarce or limited. Second, the supply must be fixed in that it cannot be increased by appeals for more water by local irrigators to government officials. These finds are consistent with what Palanisami and Easter, 1983, found in their study of ten tanks (small reservoirs) in South India.

Hutapea, et.al. (1976) reviewed the historical development of four farm level irrigation management systems in Indonesia. They found that the nature of village values and leadership and the extent of economic and social disparity within villages influenced the effectiveness of farm level irrigation services. Local organizations in communities with wide economic and social disparities were less effective. It seems that in cases with wide disparities, there is a danger of conflicts of interest among village leaders who seek to improve their personal welfare at the expense of the community. They suggest that to attenuate some of these problems local officials should be elected rather than appointed. Also, they should be paid by means other than compensation from the harvest of village owned land. If we follow Abel's suggestion, they should be paid by the farmers who receive the water.

Hutapea, et.al. found that command areas often do not coincide with village boundaries because of topographical features. In cases where these boundaries do coincide, irrigation systems are easier to manage and conflicts are less likely. Therefore, it appears best to establish irrigator groups so that their jurisdiction approaches that of both the village government and the command area as nearly as possible. The question is how to do this and what are the cost implications of such restructuring? In many cases restructuring is not feasible and one must concentrate on creating institutions which can function with two sets of boundaries.

Coward (1977b) discusses irrigation management alternatives based on cases of indigenous irrigation systems which exist around the world. He identified several factors common to successful management organization. In building organizations for the terminal irrigation unit, identifying and keeping adequate leaders is often a problem. According to Coward, traditional irrigation leaders serve relatively small groups of water users, are selected by the local group which they serve, and receive compensation directly from those they serve. Another factor, which was common to successful indigenous organizations, was that many of these small systems were further divided into smaller sub units with their own set of local leaders to operate them. Finally, Coward found that irrigation associations in these indigenous systems were established along the lines of the irrigation community which was not necessarily one and the same as the village community.

Lowdermilk, et.al. (1975) recommend that farmers be given incentives to organize for improving water delivery. These incentives would range from special assistance to farmers who have organized and made improvements to legal institutional changes. Both the irrigation and agricultural departments should be involved in providing the incentives.

Numerous authors have found that a major constraint to the efficient and equitable distribution of water is the absence of knowledge about irrigation technology (Abel, 1976; Johnson, et.al., 1977; Lowdermilk, et.al., 1975; Khuspe and Sawant, 1979; Sam and Chaubey, 1975; Thornton, 1975; Wade and Chambers, 1980). They emphasize the need for effective information systems that will permit the exchange of agronomic and water availability information between the users of water and the managers of the system. In most cases this requires an agricultural extension service and regular training sessions for farmers and agents about water use technology. Extension provides a way of combining some of the information disseminating efficiency of centralized control with the efficiency of decentralized decisions concerning special local situations. In addition, there must be some way of integrating and coordinating the activities of the agricultural extension service and those managing the irrigation system. Without the institutions for coordination, irrigation improvement will be hard to achieve.

The literature is quite consistent in identifying farmer involvement and decentralized decision making as the two major issues. How do we get information and technology to the farmers and how can the farmers' management ability be used in distributing water? One of the preconditions for farmer cooperation and organization is water scarcity. Small units within large systems or small projects seem to be better able to develop cooperative irrigation. A past history of cooperation is also helpful as is a reasonably equal distribution of economic resources among irrigators. Village or group leaders and some continued source of finance are important to the success of a farmer's organiztion. Finally, different methods for involving farmers and disseminating technical information need to be tried and tested under a variety of cultural and physical conditions.

Distribution of Benefits

The final level of institutions to be considered are those which directly affect the distribution of irrigation benefits. Factors that directly affect the distribution of irrigation benefits include the location of a farmer's fields along the irrigation watercourse, the nature of land ownership water rights and land tenure as it affects water users.

A number of studies have found that farmers whose fields are most distant from the source of water frequently have the least secure water supplies. As the distance between water source and field increases, there is a greater cumulative effect of seepage and evaporation losses from delivery channels. There is also greater possibility for intervening irrigators to disturb intended water distribution as water flows from head-end to tail-end fields. The solutions suggested to alleviate this problem of location include strict water control, rotations, better maintenance practices, canal lining, land leveling, land reform and measuring devices at the end of canals and ditches.

Bromley, et.al. (1980) reported that with many large irrigation systems in Asia, the pattern of water distribution favors the farmers at the head-end of the system. Farmers successively more distant from the main intake receive correspondingly less water. Decreases in water availability also occur along branch canals and distribution canals (Wolfe, et.al., 1979, Wickham and Valera, 1979; Tabbal and Wickham, 1977). The reasons are numerous: poor canal maintenance, too large a command area for water available, water stealing, etc. "Conclusions drawn from the field study areas fully support evidence from elsewhere that serious deficiencies in water distribution practices are widespread in developing countries. In most cases a substantial proportion of overall inefficiency of water use could be attributed to shortcoming in main system management. Head-reach farmers were taking far more than their share of water on canals of area two and three, leaving tail-reach farmers with insufficient and unpredictable supplies" (Bottrall, 1981, p. 13).[5/]

5/ There are several studies that have failed to find any yield differences between farmers at the head-end and at the tail-end of the canals (Taylor, 1981; Tubpun, 1981). Tubpun felt that differences in soil quality may have masked the locational differences. Taylor found that infrastructure intensity did not necessarily improve water distribution equity.

Bottrall (1978) believes that radical changes in the structure of land ownership would have to accompany improvements in management and design so that benefits of development could reach the poorest farmers. Case studies of areas that have experienced land reform are needed so that their influence on irrigation can be determined. Knowledge derived from such study could be used to design and implement land reform programs before projects are constructed.

Another aspect of the distribution of benefits which has been missing from the literature on irrigation is the impact on landless labor and input suppliers. Work done by Adriano (1981) in the Philippines is an exception. She estimated the income distribution among four classes of earners: landlords, hired labor, farm operator, and input suppliers. When she compared their income shares for rainfed and irrigated farms, she found that hired labor had a decreased relative share but an increased absolute income on irrigated farms. The input suppliers and farm operators had increased relative shares while landowners had decreased relative shares. Also, there was a decrease in family labor on the irrigated farms but an increase in hired labor.

She concludes that "commonly cited direct beneficiaries of irrigation infrastructure, the small rice farmers and the landless hired laborers, are truly beneficiaries in terms of absolute income shares. Such increases in absolute income shares would not have occurred in the absence of an increase in output due to irrigation. In total, the substantial increase in the absolute share of the income of labor should not be over-shadowed by the decrease in the relative income share of labor" (Adriano, 1981, p. 26).

Lazaro, et.al. (1977) reported that if equity is an important objective in irrigation, it will require deliberate attention. They identified three approaches that emerged from the seminar discussions. First, concentrate new irrigation in areas where farms are small and farmers are poor. "A strategy that emphasizes small-scale irrigation development would seem to contribute towards this end. Small-scale projects are usually found in rather remotely located areas where economic differences among farmers tend to be small and where economic development efforts usually receive low priority. Indonesia's program of small-scale sederhana irrigation may provide a contemporary illustration of such an approach ..."

Second, ensure "that the views of disadvantaged irrigators receive recognition in irrigation decision-making ... Identifying precisely who the most disadvantaged are, and exploring ways of guaranteeing their rights in decisions on the design of further infrastructure or allocation could contribute to ensuring greater equity in the distribution of water ..."

Third, analyze "the distribution of benefits from alternative irrigation strategies. Relatively little emphasis seems to have been given to examining the effects of irrigation development on income distribution. Since such effects are of growing national concern in Southeast Asia, their empirical examination would seem of high priority" (Lazaro, et.al., 1977, p. 11).

Although the research findings suggest that location, water rights and land ownership can adversely or positively influence water distribution, additional analysis is needed to impress upon decision makers the importance of these institutions and to show where changes are needed. Poorly managed systems will have tail-enders short of water. Irrigation projects with large differences in farm sizes will have an unequal distribution of benefits. Uncertain land or water rights will prevent farmers from making investments to improve their irrigation. Yet, it is difficult to change institutions once the project is completed. The trick is to make the needed changes before water is delivered.

Water Pricing

Rules and procedures for water prices or charges on institutions will affect both the distribution of water and benefits. Charges for water can serve as instruments to resolve some of the conflicts related to the equitable distribution of irrigation services. In addition, water prices can help improve the efficiency of water distribution. A number of authors, including Patel (1977), Neghassi and Seagraves (1978), Doppler (1977), Easter (1980), Dhawan (1974), Asopa (1977), and Torres (1973), defend the need for water charges to meet the objectives set forth by the government or agency responsible for implementing and operating irrigation schemes. Government objectives for levying water charges usually include recovering some or all of the cost of providing water and influencing the allocation of water over time and among farmers.

There are at least six general methods by which water charges can be levied to cover the fixed and/or variable costs of the system: (1) direct charges based on measured volume of water; (2) direct charges per share of the stream or canal flow, or per irrigation; (3) direct charges per acre irrigated; (4) indirect charges on crop outputs marketed or on inputs purchased such as fertilizer; (5) development rebates or promotional water charges; and (6) a general land or property tax. Each method has its own set of appropriate conditions (Seagraves and Easter, 1982).

Volumetric charges are only possible if water delivered to farmers can be measured. Charges based on shares received is best suited for rotating irrigations where water is delivered to the users along a canal in turns according to some prearranged schedule. Charges per acre irrigated are best suited for continuous flow irrigation, where water flows continually in the main canal and farmers are free to take whatever quantity they need. Indirect charges are used when ease of collection is an important objective. Development or promotional fees are used to encourage greater water utilization with lower fees at the start of a project. Finally, taxes or fees levied on all lands and property in the irrigated area are used when the objective is to distribute the cost of the project among all direct beneficiaries. The idea behind this tax is that irrigation increases economic activity throughout the area and, therefore, everyone should pay for the benefits (Easter, 1980).

Distribution systems for services such as water are often described as natural monopolies because larger volumes result in lower unit costs and it would be wasteful to have competing systems serving the same customers. Many economists argue that society should regulate the prices of such natural monopolies using marginal cost pricing. The water price should be set to equal the long run marginal cost (the average total cost of the newest project) when the demand for water is expanding and the present facilities are fully utilized. A short run marginal cost should be used if facilities are used below capacity. In this case the price should be equal to the short run marginal costs of delivering water which includes only the operating and maintenance costs (Seagraves and Easter, 1982).

Both national governments and international agencies are deeply concerned about policies for pricing irrigation water particularly in terms of repayment. Yet many problems exist in implementing a system of water charges. Official rates of irrigation assessments do not reflect actual payments. Water charges cannot be expected to provide incentives for more efficient water use unless they are assessed in relationship to the quantity of water used. Policies for financing irrigation projects should take into account the full range of irrigation beneficiaries from land owners to local businessmen. Water rates need to be decided within the context of overall government agricultural development policy which may involve food subsidies or taxes on farmers (Lazaro, Taylor and Wickham, 1977).

Small (1981) reports that farmers are more likely to pay specific fees for specific purposes rather than general water fees. This, he argues, suggests a strategy of local collection and utilization of fees. "In some communal irrigation systems, several different fees for specific purposes have been established. Although this adds complexity to the process of collecting and accounting for the funds for irrigation, the farmers involved apparently feel that the benefits associated with the greater incentives for payment outweigh these problems" (Small, 1981, p. 7).

Doppler, 1977, suggests fitting the pricing system to the conditions facing a particular country and project. He argues that the pricing system should change with development. Indirect water charges coupled with close administrative control over water distribution should be used in the initial phase of a project when farmers are inexperienced in irrigation. As farmers gain more experience, the system could be converted to a system of fixed and variable water charges. In more highly industrialized countries, water prices can be based on equilibrium prices. He thinks that variable water charges should be based on the benefit pricing principle. This, however, ignores the difficulties caused by the high variability of irrigation benefits among farmers and, therefore, the possibility of large price differences among farmers.

Taylor, 1976, argues that both the direct and indirect beneficiaries should help pay for irrigation projects. He feels that project repayment ought to be envisioned in terms of a package approach for extracting benefits from various beneficiaries. "For example, direct taxes may want to be assessed against direct beneficiaries and production-related indirect beneficiaries, and indirect taxes against the general consuming public who enjoy larger quantities of cheaper food as a result of irrigation (Taylor, p. 81). He strongly believes that any search for a set of general financial policies for irrigation in Asia will always remain an enigma.

Although there is much support by economists for the use of some form of water charge to ensure the efficient and equitable distribution of water, such a charge is impractical without the necessary infrastructure to accompany it. Rules have to be made and the prices for water and irrigation services estimated. An organization is required to determine and enforce these regulations and collect the charges. The inability to collect water charges from higher income farmers has led many to argue against water charges of any kind in developing countries. Some type of volumetric measure of water delivered is also necessary if water pricing is to help improve water allocation, which requires devices that are often expensive and thus prohibitive in many schemes. A possible solution to this dilemma is to locate measuring devices at the head of each branch canal and to charge a "branch canal water users' association" an aggregate fee for water delivered to that point. This would necessitate strong leadership and effective organization in the form of a formal or informal water user association. They would be responsible for delivering the water in the branch canal and for collecting the fees from each user.

Research is needed to determine what types of pricing systems are feasible and what impact they have on water use, i.e., the price elasticity of demand for water. Under what conditions would an aggregate fee charged to water users' associations improve water use efficiency? Are there other methods of reducing water measurement costs and giving more responsibility to farmers? In many cases the best that can be achieved is to collect enough fees to cover operation and maintenance costs.

IRRIGATION INVESTMENT ALTERNATIVES

The literature on the evaluation of irrigation investment is more extensive than any other area of economic investigation of irrigation. However, this literature focuses on individual project selection, i.e., cost-benefit analysis. A number of the broader questions concerning irrigation investment have not received the same attention. These broader questions involve trade-offs among different types of investment.

Levine (1980) suggests five such choices: government vs. private irrigation projects; wet-season irrigation vs. year-round irrigation; irrigation vs. rainfed production; expansion vs. intensification (rehabilitation) of irrigation; and large scale vs. small scale irrigation. Of these five choices, the first three are of lesser importance than the last two for future research. In the first question, the case of government vs. private irrigation development, optimum use of water usually requires some government involvement. This may range from credit for private tubewells to actual construction of canals and dams. The most important question is what mix of private and government involvement is best for a given project? In the case of tubewells, research findings suggest continued heavy private involvement. The major exception is when there are problems of overpumping and well interference, which may require government regulation of well spacing and/or pumping rates. It is also possible that water user organizations could be established to regulate use. For large reservoir projects, there is no doubt that government must take the lead in construction and management. But interaction among farmers and the government both in design and management of projects is the critical issue. Currently, in much of South and Southeast Asia there is too little farmer involvement in design and management.

In the second question, the trade-off between wet season irrigation and year-round irrigation is not as important an issue as it once was. With the development of high yielding varieties and improved farming practices, the returns to dry season irrigation have jumped. Although wet season irrigation once was the only way to provide insurance against droughts, other methods are now available, i.e., short-term food distribution programs and reserve stocks. In much of South Asia, after a large intensive irrigation project with numerous canals and tertiary channels has been constructed, it is an economic waste not to grow at least two crops per year in the irrigated area. Returns in the dry season will tend to be higher than in the wet season because of generally lower pest damage, higher solar radiation, etc. With two crops per year the irrigation system is likely to have a high rate of return while with one wet season crop the project will likely be marginal at best.

Unless the size is dictated by physical considerations, the question still remains of how large should the irrigated area be. Although economics may favor a small area with two crops per year, a case can be made on an equity basis for larger irrigated areas and one season irrigation. Thus, the question of wet season vs. year-round irrigation is partly a concern for the trade-off between economic efficiency and equity.

A related question is that of the intensity of irrigation water application. As pointed out above, many farmers, particularly those at the head end of irrigation systems, tend to use too much water. The last cubic meter of water yields very little in crop production. In addition, these farmers grow high water using crops such as rice and sugarcane. Thus, there is substantial potential for considering less intensive water applications (Taylor, 1980, p. 57). This could allow either the expansion of the command area or the irrigation of a second crop.

To determine what the water application intensity should be will require extensive research. "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 vs. from upland crop production" (Taylor, 1980, p. 57). Once this research is completed, the findings can be used to help design, rehabilitate and manage irrigation systems. For to be able to reduce water intensity in many existing systems will require better water control.

The third question, concerning irrigation vs. rainfed agriculture, carries with it the same implied efficiency-equity trade-off as the wet season vs. year-round cropping. The argument is that we should be investing more to help the poor rainfed farmers and less to help the higher income irrigated farmers. This is an issue when a government is allocating its budget between crops research and large scale irrigation projects. The answer seems clear, that governments in general have already invested too much on large irrigation schemes relative to agricultural research. On the other hand, there are many areas of the world which will not be able to increase agricultural production without improving existing irrigation or building new irrigation projects. The investment problem is a micro one of comparing alternative investments in a given agro-climatic and cultural situation (Abel and Easter, 1971). The question is how best to invest in both irrigation and rainfed agriculture.

This will require continued planning and evaluation of agricultural production alternatives.

The two remaining issues are the most important for researchers trying to make a contribution in irrigation investment policy. Governments and international lending agencies are asking whether irrigation investment should be large scale or small scale and whether the emphasis should be on new projects (expansion) or on rehabilitation (intensification) including development of drainage and terminal infrastructure.

New Irrigation vs. Rehabilitation

Levine points out that expansion of irrigation through new systems has its special appeal. "New systems present a sign of progress that has strong political appeal, both internally and externally; and which may have a more general psychological value. Potential benefits may be more easily identified and the requisite technical skills more easily mobilized than in the improvement of existing systems, particularly when new means larger scale and external resources, both financial and technical, are available. High quality central design teams can be obtained and concentrated construction operations can be managed more easily" (Levine, 1980).

Although rehabilitation will improve the water use efficiency within each scheme that is rehabilitated, the benefits from such rehabilitation will be felt mainly by those farmers within the scheme. If the rehabilitation results in greater water delivery, the command area of the scheme could be enlarged which would benefit more farmers. There are also positive secondary impacts which might be felt in the local economy from rehabilitation but most of the benefits will be received by the farmers in the scheme targeted for rehabilitation.

Yet deterioration of physical irrigation infrastructure is one of the key constraints preventing many past investments in irrigation from reaching their full potential. The returns from rehabilitation appear to be high enough so that they can no longer be ignored (Bottrall, 1981). Investments in canal lining, land leveling, control structures, field ditches, measurement devices, etc. increase the water delivered to the fields and provide for a more efficient water utilization. Also as suggested above rehabilitation will be necessary in many systems if water use intensity is to be reduced.

Hayami and Kikuchi (1978) found that the spread of high-yielding varieties in the Philippines increased the relative advantage of improving the irrigation infrastructure over opening new land because high-yielding varieties perform better under controlled irrigation. In contrast, under poorly controlled irrigation, local varieties were superior.

Few studies deal directly with the rehabilitation vs. new projects issue. Most consider only the value of individual programs or alternative types of rehabilitation. Kandiah (1978) criticizes the practice of the Sri Lanka government of investing huge capital outlays exclusively in large development projects with little or no attention given to the individual farmers' management practices He contends that part of the investment for irrigation must be devoted to teaching the farmers improved management practices and another part to the leveling, terracing, bunding, and drainage at the field level.

Sharma (1972) agrees with Kandiah and suggests four key means of improving farm irrigation efficiencies. The first is the creation and improvement of physical facilities, including land leveling, improving the water conveyance system, providing water measuring devices, installing control and distribution structures, and developing the water source to provide a more assured water supply. The second is adopting suitable methods of water application, such as adapting the irrigation method (sprinkler, surface, or subsurface) to the crops, soil and slope of the land. The third is management improvement by proper operation of the system, or more specifically, the application of water at a rate determined by the water holding capacity of the soil and crop needs. The fourth is the extension of scientific techniques of water management, including up-to-date information on the frequency of irrigation, crop varieties, fertilizer application rates, and pest and disease problems.

Johnson, Hussain, et.al. (1977) evaluated the economic returns to investments in land leveling in Pakistan. Their study showed a benefit-cost ratio of 1.62 for investment to upgrade traditional land leveling to a precision level. Their findings implied increasing returns to added investments in land leveling.

Khattak, et.al. (1981) studied the effect of land leveling and application of fertilizers on the physico-chemical properties of soil, water use and yield of wheat. They found that leveling significantly increased phosphorus, exchangeable potassium and the infiltration capacity of soil. They also attributed a saving of 34 to 47 percent of irrigation water to leveling.

Some of the problems associated with inefficiencies due to a lack of water control at the field level may be alleviated by investments in system redesign and control structures. Easter (1977) and Kumar (1977) evaluated a pilot program in India designed to improve existing flood irrigation systems by constructing farm ditches. The design enabled each farmer to control the flow of water onto his fields without affecting the flow to his neighbors' fields. The program was found to be highly successful in increasing the area under irrigation, the cropping intensity, the production per acre, and the returns per acre.

Returns on investment in terminal systems will depend on the number of farmers served by an outlet. If only one or two are served from each outlet, the farmers can be expected to adequately allocate the water beyond the outlet. They will benefit directly from improved allocation and government investments in terminal system improvement is likely to have low returns. However, if 5 to 20 farmers are served by the same outlet, as Easter and Kumar found, individual farmers do not receive all the benefits from improved water allocation. Farmers impose externalities on other farmers served from the same outlet. In such cases outside assistance and funds may be necessary to improve the terminal system and should offer high pay-offs. Because of conflicting interests, it is likely to be difficult to get farmers to build their own terminal system below the outlet. Water will tend to be distributed unevenly among farmers and some farmers will benefit more than others from terminal system improvements.

Other studies evaluating the rehabilitation of existing infrastructure in Asia include Hafid and Hayami (1979) and Taylor (1979). Hafid and Hayami examined the impact of national subsidies for rehabilitation on two small-scale, river diversion irrigation projects in Indonesia. The rehabilitation involved the repair and raising of the height of diversion dams and the lining of some canals. Their study shows that the subsidies were substantial inducements to the mobilization of local resources, and that as a result, high rates of return were achieved from the rehabilitation.

Taylor studied the rehabilitation of the 274,000 ha. river-diversion Pekalen Sampean irrigation project in East Java, Indonesia. This rehabilitation primarily emphasized desilting of channels and the repair of water control structures rather than the restoration of original water-diversion capabilities. In this case there was no immediately observable impact of the rehabilitation on production, perhaps because the rehabilitation did not improve the project's water supply by increasing its water-diversion capacity. There was a shift in cropping patterns towards growing more rice which substantially increased employment. In addition, one has to question the estimated net returns for irrigated crops which were lower than the non-irrigated returns for three out of the four crops considered. If farming conditions were truly comparable then why would farmers irrigate if it lowered their net returns?

Another question is the frequency of project rehabilitation. Could periodic rehabilitation effectively substitute for a more frequent scheme of annual maintenance? A major rehabilitation every ten years might allow project redesign which would make it more suitable to current farming conditions. An irrigation system designed to provide only supplementary irrigation might be redesigned to better meet the demands of high yielding crop varieties. The benefits gained from such a redesign must be weighted against both rehabilitation cost and net income losses during the 10-year period of inadequate annual maintenance. The net income losses should be adjusted for the cost savings from the reduced maintenance expenditures.

The trade-off between new irrigation schemes and rehabilitating existing schemes is another in the series of equity/efficiency trade-offs inherent in irrigation development.[6/] The literature suggests that we have probably errored

---

6/ New irrigation projects means that additional farmers will receive irrigation benefits while rehabilitation primarily improves the income of farmers who are already obtaining some irrigation water.

errored on the side of building too many large irrigation systems too fast. More now needs to be invested in rehabilitation and improved management. However, research is needed to help guide the planners in these investments. The work of Taylor, Johnson, Easter and Kumar needs to be repeated in other areas and under different conditions. In addition, other investments in system rehabilitation need to be analyzed in the same manner as the above authors analyzed canal lining and construction of farm ditches. For example, what are the net returns from investing in alternative types of on-farm water development programs?

Large vs. Small Scale Projects

Many countries must make choices as a matter of policy between large and small scale irrigation systems and concentrated vs. dispersed systems. Most countries cannot develop all viable irrigation supplies at once. Choices must be made between concentration of investments in limited areas, as is often the case with large scale projects, and investment in small or medium scale projects scattered throughout the country. Often, some aspects of a system can be large scale (diversion, storage and main canal), while other aspects can be small scale (service distribution, control and management systems).

The Asia Development Bank has identified small irrigation projects as a high priority. The Deputy Director says, "the Bank has been particularly interested in irrigation projects which are small in size, quick in yielding economic benefits and which use appropriate technology suited to local conditions, rather than costly and more time-consuming projects requiring high technology — such as large dams" (Takase, 1982, p. 8).

In some countries or regions there are relatively few sites for large multi-purpose dams and the best ones have already been used. In addition, irrigation agencies may not consider these few large projects to be alternatives to a series of small scale projects. "It does seem likely, however, that in the long run the availability of funds for these large projects will be influenced by their expected performance relative to the likely performance of smaller projects" (Small, 1982, p. 3). Even in countries with little potential for large projects, there will be a concern for the performance of smaller projects relative to medium sized projects.

Many countries as a matter of policy may opt for small irrigation projects in order to spread irrigation investment throughout the country. Smaller irrigation systems can be more rapidly developed and utilized. Local capital and labor resources can be more fully mobilized with small projects. Small projects minimize adverse environmental impacts and allow for adjustments when it becomes apparent that there are unforeseen impacts and costs. The potential for involvement of the local community in system operation and maintenance is greater with small projects (De los Reyes, 1981).

Large projects are likely to involve irreversible changes which mean investments should be postponed while more information is collected concerning likely outcomes. In other words, quasi-option values are involved due to irreversibilities and uncertainties concerning the project.[7/] This

---

7/ There is a quasi-option value to refraining from development even on the assumption that there is no risk aversion, and only expected values matter. The passage of time results in new information about benefits of alternative uses of an environment, which can in turn be taken into account if a decision to development is deferred.

suggests that a more conservative decision rule should be used to select large projects as compared to small projects (Krutilla and Fisher, 1975). However, there is little or no research to guide decision makers concerning what the decision rule should be.

On the other hand, large projects hold several advantages. (1) Large projects frequently may be necessary for the effective utilization of a relatively large but variable water supply. (2) Large projects may permit more efficient and effective use of limited managerial and technical skills by drawing these people together to work on the same project. This advantage could be quite different if farmers are heavily involved in the operation and maintenance of the small scale projects. (3) Large projects permit more economical use of physical elements of the system such as storage, diversion, and conveyance capacities. In other words, economies to scale are likely to be present. (4) Large projects are more easily financed because it is easier to obtain external financing for large projects than for small ones. (5) Large projects generate major benefits such as employment for skilled and unskilled workers during the construction period. Yet this employment is only temporary and can also cause problems if it disrupts wages and occupational choices. Governments have tended to choose the large project route to irrigation development. However, there is a growing feeling that small projects provide greater opportunities for equitable distribution of benefits, and a greater return per hectare or cubic meter of water available. They also involve less resettlement.

One method of modifying the adverse impacts of large scale projects is to stage the development. Different parts of the projects are added as funds and information become available or the need for more irrigation increases. Howe (1971) suggests that there are three conflicting factors that enter into the decision on staging: "(1) It pays to build large increments to the system because there usually are cost savings (economies of scale) involved in increasing project size. (2) The commitment of resources to a capacity that will not be used for a long time is costly. It pays to defer investments as long as possible since future costs are more heavily discounted than present costs. (3) Maintenance of flexibility is important" (Howe, 1971).

"What is desired is the timing and sizes of additions to the system that will meet the demands at a minimum present value of all costs. In some problems, permitting shortages to occur but attaching a penalty to any shortage makes sense. In general, an optimum solution to these sequencing problems is difficult to determine" (Howe, 1971, p. 91). The solutions involve estimating the present value of the entire sequence of costs and benefits which are tested under different assumptions. Unfortunately, large projects must be evaluated under significant degrees of ignorance. Therefore, there is a real potential for sizable unintended consequences which is another reason to favor the staging of projects or small projects. Finally, staging allows a process of incremental learning to take place, leaving more time for training of irrigation personnel and farmers.

In many cases, large irrigation projects are completed in stages but not always by design. For example, the Chao Phya River Basin was developed in three phases. "The first involved the construction of the Chainat diversion dam and the primary distribution network; the second, the construction of the Bhumiphal and Sirikit dams and reservoirs to provide dry-season irrigation; and the third, localized on-farm consolidation and development" (Trung, 1976, p. 155).

Puttaswamaiah (1977) conducted an economic analysis of major and minor irrigation projects in India. He found that large projects often require large public investment in selected areas which benefit relatively few people. Minor irrigation schemes generally involve lower investment costs per hectare and are favored because they have relatively slower depreciation and lower operating expenses than large projects. He also found that the time gap between creation and utilization of irrigation potential is substantially less for minor works than for major and medium projects. Finally, he determined that because of the inefficiencies in water delivery, actual irrigated areas in many of the larger projects are substantially less than the potential supposedly created by the irrigation system. This results in cost per hectare actually irrigated higher than the planned cost per hectare based on the assumed full irrigation potential of the system.

Results of a Bangladesh government benefit-cost analysis showed that smaller projects with low investment cost per hectare appeared to offer higher average benefit-cost ratios than medium and large irrigation projects. Large scale gravity irrigation and flood control projects tended to have high unit costs as well as longer gestation periods. The benefits from large scale projects were found to be much below expectations (Bangladesh Planning Commission, 1980).

Analysis of a wide range of irrigation projects in the Philippines suggests that communal run-of-the-river systems have had the highest pay-off. National systems and surface pumps have had good returns but somewhat lower than the communal irrigation. Finally, deepwell pumps have been too expensive and have resulted in benefit cost ratios below one (Maya, 1981). None of the systems analyzed could be considered large scale irrigation, as even the national system was only 2,700 hectares.

In Sparling's (1981b) review of studies of Sahelian irrigation projects, he found "that 'small' perimeters are more efficient than 'large' perimeters." He argues "that the labels 'large' and 'small' are misleading because important differences are organizational. Funds of 'social capital' and 'human capital' peculiar to each area have real economic value which can be harnessed to develop irrigation perimeters. But because these funds of capital are peculiar to each place, it is important that perimeters be developed incrementally -- without displacing farmers or requiring farmers to surrender existing agricultural practices."

"The decentralization of control of agriculture leads to more efficient agriculture, but it makes extension services especially important ... The organizations which surrender control of perimeters to farmers should be reoriented toward a combined extension-research and development service function" (Sparling, 1981b, p. 25-26). Waldstein (1978) and Scudder (1973) arrive at similar conclusions but from the perspective of another discipline.

Contrary to the studies listed above, Taylor and Tantigate (1979) and Taylor (1981) found that economies-to-scale exist in the construction of gravity-diversion irrigation schemes in Malaysia. They found that larger schemes also have higher annual yields per unit of water than smaller schemes. Their costs suggest that diversion headworks are generally less costly than pumping facilities. They advocate caution in policies to encourage small-scale irrigation. However, it should be pointed out that the schemes involved little or no resettlement and since it was supplementary irrigation, there was no wholesale switch in cropping.

There are three general types of small scale systems. The first is the pump or groundwater system, which has seen tremendous expansion during the 1970's. Although there have been a number of studies of tubewell expansion, there are still important areas for research. These include the question of regulating pumping under conditions of a rapidly decreasing groundwater stock, the impact of higher energy costs on pump irrigation and, as discussed above, the potential for conjunctive use of groundwater and surface water for irrigation.

The second type of system is river diversion schemes. Many of these diversions are indigenous systems which are either locally managed or receive only limited government assistance. These have been favorite objects of study by anthropologists and sociologists (Bottrall, 1981, p. 222). The literature is fairly rich in descriptions of how these systems work effectively and the problems which occur when government tries to take them over (Coward, 1977b). Coward found three particularly important principles common to indigenous systems: accountable leadership, the use of small sub-groups within each scheme and the channel-based character of the sub-groups. More recently, another example of government interference occurred in the Senegal River Valley where the government agency, SAED, attempted to "help" a spontaneous irrigation scheme at Bakel (Sparling, 1981b).

Further research is needed to determine ways of managing conflicts among farmers over irrigation. The containment of conflict is a prerequisite for successful system operation. The communal systems may provide some answers (De los Reyes, 1981). In addition, studies are needed of the operations of small government run schemes since few studies exist today. How do they differ from communal systems in terms of returns, management of conflict and allocation rules?

The third type of small system includes tank schemes (small reservoirs) which are both indigenous and government controlled. South India and Sri Lanka have had, for many decades, a large number of both types of tanks . In Northeast Thailand the government has built over 500 new tanks during the past 20 years. The unpredictability of rainfall introduces major operational complexities into the decisions concerning water releases and the size of command area. Another major problem is the silt accumulation and damages caused by heavy rains and flooding. In many cases the latter problem is beyond the means of farmers to repair. The case for technical advice and support from government to overcome these problems appears to be extremely strong (Bottrall, 1981).

The success of existing tanks in Northeastern Thailand has been much below expectations in terms of increasing production and income. Although water seems to be available, little or no dry season production occurs. The Thai government as well as donor agencies would like to know why they have not reached expectations. One of the basic problems seems to be that the tanks were originally built for political or local military reasons with little concern for cost or potential irrigation benefits.

These projects also tend to serve a number of purposes besides crop irrigation such as fish production and water for livestock, household use, and gardens.

What practices and policies make some small scale projects highly beneficial and others not? Operation and water handling should be easier on small scale projects as compared to large scale projects since the distance between water source and irrigated farms is much shorter. However, there may be such a diversity of operating procedures involved with small scale irrigation that it may be very difficult to generalize.

Tubpun's (1981) study of five tanks in Northeastern Thailand found that benefits from fish culture and domestic water use were very important. With fish and domestic water use benefits included the real rates of return for the tanks ranged from 8 to 24 percent depending on the rice price and the area irrigated. Judging from the large magnitude of the admittedly rough estimates of fish and domestic water use benefits, they deserve special research attention. This is particularly true since the Government of Thailand is emphasizing the construction of small tanks which are primarily for domestic water uses. A good approach to the problem would be to use the travel cost method which has been applied to the analysis of recreation benefits. This methodology could be adopted to value domestic water uses without much difficulty.

There are several other possible reasons why design expectations are above actual performance. It is probable that estimation procedures followed and/or assumptions made concerning expected benefits and costs were in error. An ex post analysis of alternative projects such as Tubpun's help identify the procedures and assumptions in the *ex ante* analysis that lead to forecasting errors concerning project benefits and costs. In addition, they provide a basis for comparison with other investments including large scale irrigation and lift irrigation schemes. The distribution of benefits from the small projects should also be estimated. Do small scale irrigation projects help the small farms as Tubpun (1981) found in Thailand or do the benefits go to the larger more politically powerful farmer as Easter (1975) found in one tank irrigated village in eastern India?

There also may be unexpected constraints to achieving planned performance. This might involve lack of markets, seasonal labor shortages or limited credit. The *ex post* analysis should be designed to collect information concerning these constraints so that realistic assumptions can be formulated. The next step would be to determine if these constraints can be eliminated and at what cost. For example, if markets are not available and cannot be developed for vegetables, then the project analysis should not include vegetables as a potential output.

Bottrall (1981) recommends two further areas of research on small-scale irrigation. The first is on existing patterns of organization and management, particularly for government constructed projects. The second is on the potential for developing more effective ways of assisting and supervising small scattered irrigation projects of any kind (Bottrall, 1981, p. 241). For example, is a special technical assistance cadre needed to help improve the performance of small scale reservoir projects? Two closely related issues are: (1) Under what physical and social conditions can irrigation be operated and managed in small scale units? and (2) Are there fewer socioeconomic problems associated with the development of small irrigation projects as compared to large projects?

SUMMARY AND CONCLUSION

A number of important research issues have been highlighted, ranging from the evaluation of returns to small government irrigation projects to the analysis of alternative procedures for allocating irrigation water. Many of the research issues involve both a concern for the efficiency of water use and for an equitable distribution of benefits. It is important to realize that many of the irrigation problems are difficult to resolve once a project has been designed and constructed. Management and water allocation procedures should be included in the planning stage of projects. The project design will determine what allocation and management options are possible. This is particularly true of the distribution of project benefits.

Another important theme which comes out of the literature on irrigation development and distribution is the concern for decentralized decision making. At what level can the farmers be effectively used in operating the irrigation system? This is one of the basic issues involved in the choice of small scale vs. large scale projects. It is also important in determining the relative share of public vs. government involvement in irrigation development. In the past, except for tubewell irrigation and some river diversion projects, developing countries have tended to error on the side of not involving farmers. More needs to be done to develop incentives training programs and institutions which will make better use of management talent available among farmers.

Finally, it appears that the evaluation of irrigation investments needs to be strengthened in several respects. First a consistent and uniform procedure of evaluating government projects must be established. This means an agency independent of the traditional construction agencies should have responsibility for the project evaluation and planning. Second, a criteria needs to be developed for selecting the appropriate procedures for allocating water among farmers i.e. rotation vs. continuous flow. This should be part of the decision concerning project scale and design. Third, a criteria should be included in the project evaluation to determine if the institutional set-up is adequate for implementing the irrigation project. For example, if the water is delivered to an outlet serving 100 farmers, will they be able to organize adequately to allocate the water equitably among themselves?

In summary, the section on water allocation procedures and policies raises numerous issues concerning the distribution of irrigation water. These include: (1) the optimum allocation of water over time and among end uses; (2) the conjunctive use of groundwater and surface water; (3) the optimum size of irrigated area and distribution system; (4) the returns from alternative investments to reduce transmission water losses and improve distribution (control structure, lining materials, etc.); (5) the impact of allocation procedures on water logging and salinity; and (6) alternatives for improving the compatibility of incentives and objectives among farmers and system managers for the efficient allocation of water.

Some of the same issues occur in the section on institutional arrangements for irrigation management. This is particularly true with regard to incentives. One of the important aspects of institutional research is to help find ways to devise institutions that make incentives more compatible among individuals and society. To do this will require an understanding of the underlying power structure and how it affects incentives.

The new issues raised in the institutions section include: (1) alternative institutions to facilitate farmer participation in irrigation management; (2) institutions for coordinating government involvement in irrigation development, evaluation and management; (3) institutions to internalize the externalities involved in water allocation and canal maintenance; (4) procedures for financing farmer water user associations; (5) the impact of land tenure and water rights on the level and distribution of project benefits; and (6) the impact of water rights and project financing procedures on project performance.

The final set of issues revolve around two important investment questions. The first is the trade-off between new irrigation projects and rehabilitation of old systems. Most of the investment questions raised under the water allocation sections are directly related to the rehabilitation issue. Second is the trade-off between small and large scale projects. Many of the questions in this section relate closely to the sections on water allocation among farmers and organizations for water distribution.

The new investment issues include: (1) the opimum frequency and type of maintenance and rehabilitation investments including on-farm water management; (2) alternative means of preventing overuse of groundwater and the impacts of higher energy costs on groundwater use; (3) comparisons between communal and government operated and managed irrigation systems; (4) ex-post analysis of tank projects including an evaluation of the distribution of benefits and of the fishery and domestic water use benefits; (5) alternative size management units for operating irrigation projects; (6) socioeconomic problems associated with different sized irrigation projects; (7) economic returns for alternative small scale irrigation investments; (8) the returns from different levels of water application intensity; and (9) the timing and level of development of drainage and terminal infrastructure.

Many of these issues will be of major concern to developing countries and lending agencies during the 1980's. It is important to note that there is very little literature on the returns from drainage investments even though a number of studies have pointed this out as a major constraint to increasing crop production. Our guess is that investments in small scale irrigation, farmer participation in management, investments in project rehabilitation (including drainage) and incentives for efficient allocation of irrigation water will continue to be major concerns during the rest of the decade. With the current level of investment in irrigation researchers and policy makers cannot ignore these questions.

REFERENCES

Abel, Martin E. (1976). "Irrigation Systems in Taiwan: Management of a Decentralized Public Enterprise," Water Resources Research 12, pp. 341-348.

Abel, Martin and K. William Easter (1971). "Agricultural Planning: Focus on Regional Constraints," Economic and Political Weekly, Vol. VI, No. 30-32, pp. 1577-1596.

Adriano, Marietta S. (1981). "Impact of Labor Intensity and Income Distribution of the Sibalom Irrigation Project," A/D/C Workshop, Bangkok.

Aiyasamy, P. K., K. Palanisami and A. F. Bottrall (1979). Problems in the Planning and Management of Large-Scale Surface Irrigation Projects in Tamil Nadu: The Case of the Lower Bhavani Project, Workshop on Management of Water Resources for Agriculture in Bhavanai River Basin College of Agricultural Engineering, Tamil Nadu Agricultural University, Coimbatore, India.

Ali, Barkat (1980). "Optimal Watercourse Improvements," M.S. Thesis, Department of Economics, Colorado State University, Fort Collins.

Andreou, P. (1979). "Economic Appraisal of Irrigation Cooperatives in Agricultural Development in Ganges-Kobadak Project, Bangladesh," Agricultural Administration 6(2), pp. 111-122.

Asopa, V. N. (1977). "Pricing Irrigation Water," Artha-Vikas 13(1), pp. 51-64.

Bangladesh Planning Commission (1980). The Second Five Year Plan 1980-1985, Dacca.

Binnie and Partners (1976). Feasibility Study of Krueng Jreue and Krueng Baro Projects, Aceh, North Sumatra, Vol. V. pp. 100ff.

Birkelback, A. W. (1973). "The Subak Association," Indonesia 16, pp. 1953-1969.

Bottrall, Anthony F. (1981). Comparative Study of the Management and Organization of Irrigation Projects, World Bank Staff Working Paper No. 458.

__________ (1977). "Evolution of Irrigation Associations in Taiwan," Agricultural Administration 4(4), pp. 245-250.

__________ (1978). "Technology and Management in Irrigated Agriculture," O.D.I. Review 2, pp. 22-50.

Bredehoeft, John D. and Robert Young (1970). "The Temporal Allocation of Groundwater: A Simulation Approach," Water Resources Research 6(1), pp. 3-20.

Bromley, Daniel W., Donald C. Taylor and Donald E. Parker (1980). "Water Reform and Economic Development: Institutional Aspects of Water Management in the Developing Countries," Economic Development and Cultural Change 28(2), pp. 365-387.

Burt, Oscar R. (1963). "The Economics of Conjunctive Use of Ground and Surface Water," Hilgardia 36(2), pp. 31-111.

Chambers, R. (1977). "Men and Water: The Organization and Operation of Irrigation," Green Revolution?, Technology and Change in Rice-growing Areas of Tamil Nadu and Sri Lanka, Westview Press, Boulder, Colorado, pp. 357-360.

Coward, E. W. (1977a). Irrigation Institutions and Organizations: An International Bibliography, Department of Rural Sociology, Cornell University.

__________ (1977b). "Irrigation Management Alternatives: Themes from Indigenous Irrigation Systems," Agricultual Administration 4(3), pp. 223-237.

Cummings, Ronald G. (1974). Interbasin Water Transfers, The Johns Hopkins University Press, Baltimore.

Dastane, W. G. (1974). "Economic and Efficient Use of Irrigation Water," Proceedings of the First FAO/SIDA Seminar on Improvement and Production of Field Food Crops for Plant Scientists from Africa and the Near East, FAO, Rome, Italy, pp. 388-398.

De los Reyes, Ramona P. (1981). "Managing Communal Gravity Systems: Farmer's Approaches and Implications for Program Planning," A/D/C Workshop, Bangkok.

Dhawan, B. D. (1974). "Utilization of Groundwater Resources--Public vs. Private Tubewells," Economic and Political Weekly 9(39), pp. A75-A81.

Doppler, W. (1977). "Towards a General Guidelines of Irrigation Water Charging Policy," Agricultural Administration 4(2), pp. 121-129.

Duewel, John (1981). Promoting Participatory Approaches to Cultivating Water Users Associations: Two Case Studies from Java, A/D/C Workshop, Bangkok.

Easter, K. William (1980). "Issues in Irrigation Planning and Development," Staff Paper P80-5, Department of Agricultural and Applied Economics, University of Minnesota.

Easter, K. William (1980). "Capturing the Economic Surplus Created by Irrigation," Staff Paper P80-14, Department of Agricultural and Applied Economics, University of Minnesota.

__________ (1977). "Improving Village Irrigation Systems: An Example from India," Land Economics 53(1), pp. 56-66.

Easter, K. William and John J. Waelti (1980). The Application of Project Analysis to Natural Resource Decisions, WRRC Bulletin 103, University of Minnesota, Chapter 2.

Geertz, C. (1967). "Tihingan: A Balinese Village," Villages in Indonesia, Cornell University.

Gisselquist, David (1979). "Designs for a Low Pressure Pipe Distribution System for Tubewells to Give a Measured Supply of Water to Individual Plots," mimeo, Ford Foundation, Bangladesh.

Gopalakrishnayya, K. (1979). "An Integrated Approach to Command Area Development Programme," Indian Journal of Public Administration 25(1), pp. 74-85.

Gupta, D. D., A. Singh, and M. V. George (1973). "Water Management Practices in Sandy Arid Zones," Agriculture and Agro-Industries Journal 6(6), pp. 34-38.

Hafid, A. and Hayami (1979). "Mobilizing Local Resources for Irrigation Development: The Subsidi Desa Case of Indonesia," Irrigation Policy and Management in Southeast Asia, A/D/C, Bangkok, pp. 123-133.

Hayami, Yujiro and Masao Kikuchi (1978). "Investment Inducements to Public Infrastructure: Irrigation in the Philippines," The Review of Economics and Statistics LX(1), pp. 70-77.

Howe, Charles W. (1971). Benefit-Cost Analysis for Water System Planning, American Geophysical Union, Washington, D.C., Water Resources Monograph 2.

Howe, Charles W. and K. William Easter (1971). Interbasin Transfers of Water: Economic Issues and Impacts, The Johns Hopkins University Press, Baltimore.

Hutapea, R., Prajarta Dirjasanyata, and N. G. S. Nordholt (1979). "The Organization of Farm-Level Irrigation in Indonesia," Irrigation Policy and Management in Southeast Asia, A/D/C, Bangkok, pp. 167-174.

Johnson, Sam H. III, Alan C. Early, and Max K. Lowdermilk (1977). "Water Problems in the Indus Food Machine," Water Resources Bulletin 13(6), pp. 1253-1268.

Johnson, Sam H. III, M. Hussain, Z. Khan, and Ch. B. Ali (1977). "The Economics of Precision Land Leveling in Pakistan," Agricultural Water Management, Vol. 1, No. 4.

Johnson, Sam III, W. Doral Kemper, and Max K. Lowdermilk (1978). "Improving Irrigation Water Management in the Indus Basin," Water Resources Bulletin 15(2), pp. 473-495.

Johnson, Sam III (1979). "Major Policy Issues in the Development of Irrigation in Thailand." Agricultural Economics Society of Thailand, Kasetsart University, Bangkok.

Kandiah, A. (1978). "Some Technical and Social Problems in the Irrigation Projects of Sri Lanka," Agricultural Mechanization in Asia 9(4), pp. 49-53.

Kelso, Maurice M., William E. Martin, and Lawrence E. Mack (1973). Water Supplies and Economic Growth in an Arid Environment, The University of Arizona Press, Tucson.

Khattak, Jehangin K., Abdur Rashid, S. U. Khan, Kermit E. Larson, and Riaz A. Khattak (1981). "Effect of Land Leveling and Irrigation on Wheat Yield," Agricultural Mechanization in Asia, Africa, and Latin America XII(1), pp. 11-14.

Khuspe, T. E., and G. K. Sawant (1979). "Constraints in Utilization of Canal Irrigation Water," Agricultural Situation in India 34(6), pp. 381-384.

Krutilla, John V. and Anthony C. Fisher (1975). The Economics of Natural Environments (Studies in the Valuation of Commodity and Amenity Resources), The Johns Hopkins University Press, Baltimore, Chapters 3 and 4.

Kumar, Praduman (1977). Economics of Water Management: A Study of Field Channels, Heritage Publishers, New Delhi.

Lazaro, Rogelio, D. C. Taylor and T. H. Wickham (1977). "Irrigation Systems in Southeast Asia Policy and Management Issues," Teaching and Research Forum Seminar Report #6, A/D/C, Singapore.

Lenton, Robert and David Seckler (1978). "Choice of Irrigation Techniques Under Alternative Physical and Socio-Economic Conditions," Ford Foundation, New Delhi.

Levine, Gilbert (1980). "Irrigation Development and Stragegy Issues for the Asian Region," draft of Issues paper submitted to USAID, Cornell University.

Lowdermilk, M. D., Alan C. Early, and David M. Freeman (1978). "Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan," Water Management Technical Report No. 48, Colorado State University, Fort Collins.

Lowdermilk, M. K., D. M. Freeman, A. C. Early, G. Radosevich and D. Kemper (1977). "Organizing Farmers to Improve Irrigation Water Delivery: The Problems and Prospects for Solutions in Pakistan," Pakistan Economic and Social Review 15(3/4), pp. 152-173.

Lowdermilk, M. K., Wayne Clyma, and Alan C. Early (1975). "Physical and Socioeconomic Dynamics of a Watercourse in Pakistan's Punjab: System Constraints and Farmers' Responses," Technical Report No. 42, Colorado State University, Fort Collins.

Maass, Arthur and Raymond L. Anderson (1978). ... and the Desert Shall Rejoice, The M.I.T. Press, Cambridge, Massachusetts.

Malhotra, S. P. (1981). "The Warabandi System and Its Infrastructure," Central Board of Irrigation and Power, Pub. No. 157, New Delhi.

Mirza, Ashaq H., David M. Freeman and Jerry B. Eckert, (1974). Village Organization Factors Affecting Water Management Decision-Making Among Punjabi Farmers, Water Management Tech. Report No. 35, Colorado State University, Fort Collins.

Moya, Piedad F. (1981). "Benefit Cost Analysis of the Different Types of Irrigation Systems in Central Luzon Philippines," A/D/C Workshop, Bangkok.

Neghassi, H. M. and J. A. Seagraves (1978). "Efficiency in the Use of Water for Irrigation: The Role of Prices and Regulations," Natural Resources Forum 3(1), pp. 53-72.

Nickum, J. E. (1977). "An Instance of Local Irrigation Management in China," Economic and Political Weekly 12(40), pp. 1714-1716.

Oh, H. S. (1978). "Customary Rules of Water Management for Small Irrigation Reservoirs in Korea," Journal of Rural Development 1(1), pp. 96-110.

Palanisami, K. and K. William Easter (1983). The Tanks of South India (A Potential for Future Expansion in Irrigation), Draft Economic Report, Department of Agricultural and Applied Economics, University of Minnesota.

Palanisami, K. (1981). "Problems of Water Distribution and Management at Outlet Level: A Case of Lower Bhawani Project, Coimbatore District," Workshop on Problems and Research Methods in Irrigation Systems Related to the Chak (Outlet) Requirements, Gandhian Institute of Studies, Rajghat-Varanasi, India.

Palanisami, K. (1980). An Economic Evaluation of the Working of the Major Surface Irrigation Systems in Tamil Nadu: A Case of Parambikulam Aliyar Project, Research Report, Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore, India.

Palanisami, K. and D. S. Thornton (1981). "Research Methodologies for Improved Irrigation Systems Management: Some Reflections Based on Experience in Tamil Nadu, India," International Seminar on Field Research Methodologies for Improved Irrigation Systems Management in Collaboration with Ford Foundation, College of Agricultural Engineering, Tamil Nadu Agricultural University, Coimbatore, India.

Pang, L. H. (1979). "Fiberglass-Reinforced Polyester Flumes as Tertiary Channels in Malaysian Irrigation Development," Irrigation Policy and the Management of Irrigation Systems in Southeast Asia, A/D/C, Bangkok, pp. 39-44.

Pasternak, B. (1972). "The Sociology of Irrigation: Two Taiwanese Villages," Economic Organization in Chinese Society, Stanford University Press, pp. 193-213.

Patel, S. M. (1977). "Need for Establishing Model Water Cooperatives in India," Artha-Vikas 13(1), pp. 65-75.

Poffenberger, Mark (1980). "A Feasibility Study for a Beneficiary Evaluation of the Sederhana Irrigation Program," Counterpart Consultants, Inc., for USAID Jakarta.

Puttaswamaiah, K. (1977). Irrigation Projects in India: Towards a New Policy, Nrusimha Publications, Bangalore, India.

Radosevich, George E. and Craig Kirkwood (1975). "Organizational Alternatives to Improve On-Farm Water Management in Pakistan," Water Management Technical Report No. 36, Colorado State University, Fort Collins.

Rawls, John (1971). A Theory of Justice, Harvard University Press, Cambridge, Massachusetts.

Reidinger, Richard B. (1974). "Institutional Rationing of Canal Water in Northern India: Conflict Between Traditional Patterns and Modern Needs," Economic Development and Cultural Change 23, pp. 79-104.

Renfro, R. Z. H. (1982). "Economics of Local Control of Irrigation Water in Pakistan: A Pilot Study," Ph.D thesis, Department of Economics, Colorado State University.

Roy, S. and L. R. Singh (1977). "An Assessment of Optimum Command Area and Economic Feasibility of Private Tubewell Installation in Lucknow District of Uttar Pradesh," Financing Agriculture, Vol. 9, No. 2, pp. 20-23.

Sagardoy, J. S. (1976). "Associations of Irrigation Water Users," ODI Workshop on Irrigation Management, Canterbury.

Sam, M. J. and B. K. Chaubey (1975). "An Analysis of Causes Associated with the Non-Utilization of High Level Canal Irrigation from Tungabhadra Project," Mysore Journal of Agricultural Sciences 9(4), pp. 663-670.

Scudder, T. (1973). "The Human Ecology of Big Projects: River Basin Development and Resettlement," Annual Review of Anthropology 2, pp. 45-61.

Seagraves, J. A. and K. William Easter (1982). Pricing for Irrigation Water, Economic Report ER82-5, Department of Agricultural and Applied Economics, University of Minnesota.

Sharma, T. C. (1972). "On Improving the Efficiency of Farm Irrigation," Indian Farmers' Digest 5(8), pp. 50-52.

Singh, D. and P. N. Bhargava (1977). "Conservation of Water and Its Utilization," Indian Society of Agricultural Statistics: Journal 29(2), pp. 66-75.

Small, Leslie E. (1982) "Investment Decisions for the Development and Utilization of Irrigation Resources in Southeast Asia," Teaching and Research Forum Workshop Report #26, A/D/C, New York.

Sparling, Edward W. (1981a). "Collective Goods and Conflict: An Example of a Positive Feedback Mechanism at Work in Rural Pakistan," Department of Economics, Colorado State University, Fort Collins.

__________ (1981b). Consulting Report: A Survey and Analysis of Ex-Post Cost-Benefit Studies of Sahelian Irrigation Projects, Department of Economics, Colorado State University, Fort Collins.

Svendsen, Mark (1981). Irrigator Collective Behavior in Three Philippine Irrigation Systems, A/D/C Workshop, Bangkok.

Tabbal, D. F. and T. H. Wickham (1979). "Effects of Location and Water Supply on Water Shortages in an Irrigated Area," Irrigation Policy and the Management of Irrigation Systems in Southeast Asia, A/D/C, Bangkok, pp. 93-101.

Tagarino, R. N. and R. D. Torres (1977). "Potential Farm Value and Equitable Pricing of Irrigation Water: A Case Study of the Upper Pampanga River Project," Journal of Agricultural Economics and Development 7(1), pp. 1-21.

Takase, Kunio (1982). "Food Production and Irrigation Development in Asia," ADB Quarterly Review.

Taylor, D. C. (1979). "Financing Irrigation Services in the Pekalen Sampean Irrigation Project, East Java, Indonesia," Irrigation Policy and the Management of Irrigation Systems in Southeast Asia, A/D/C, Bangkok, pp. 111-122.

__________ (1980). "Economic Analysis to Support Irrigation Investment and Management Decisions," Irrigation Water Management, IRRI, Manila.

__________ (1981). The Economics of Malaysian Paddy Production and Irrigation, A/D/C Workshop, Bangkok.

Taylor, D. C. and Kanaengnid Tantigate (1979). "Alternative Strategies for Developing Malaysia's Irrigation Resources," Kajian Ekonomic Malaysia XVI (1&2).

__________ (1981). The Economics of Irrigation Scheduling the Kemubu Agricultural Development Project, Malaysia, A/D/C Workshop, Bangkok.

Thornton, D. S. (1975). "Some Aspects of the Organization of Irrigated Areas," Agricultural Administration 2(3), pp. 179-194.

Torres, R. D. (1973). "Pricing Irrigation Water," Water Management in Philippine Irrigation Systems: Research and Operations, Water Management Workshop, IRRI, Los Banos, Philippines, pp. 183-194.

Trung, Ngo Quoc (1979). "Economic Analysis of Irrigation Development in Deltaic Regions of Asia: The Case of Central Thailand," Irrigation Policy and the Management of Irrigation Systems in Southeast Asia, A/D/C, Bangkok, pp. 155-164.

Tubpun, Yuavares (1981). "Economics of Tank Irrigation Projects in Northeastern Thailand," Ph.D. thesis, Department of Agricultural and Applied Economics, University of Minnesota.

Wade, Robert and Robert Chambers (1980). "Managing the Main System: Canal Irrigation's Blind Spot," Economic and Political Weekly 15(37), pp. A107-A112.

Waldstein, A. (1978). "Government Sponsored Agricultural Intensification Schemes in the Sahel: Development for Whom?" Paper done for USAID, REDSO/WA.

Wickham, T. H. and A. Valera (1979). "Practices and Accountability for Better Water Management," Irrigation Policy and the Management of Irrigation Systems in Southeast Asia, A/D/C, Bangkok, pp. 61-75.

Wolfe, John, F. Shaheen, and Saif Issa (1979). Preliminary Evaluation of Monsouria Canal System in Giza Governate, Egypt, EWVP Technical Report No. 3, Cairo.

Young, Robert A. (1970). "Safe Yield of Aquifers: An Economic Reformation," Journal of the Irrigation and Drainage Division, A.S.C.E. 96(IR4) Proc. Paper 7719, pp. 377-385.