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## ISSUES IN IRRIGATION PLANNING AND DEVELOPMENT

by

K. William Easter

**Department of Agricultural and Applied Economics**

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

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TABLE OF CONTENTS

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## I. Introduction

A useful starting point in delineating irrigation issues is to recognize the importance of natural and human diversity. Climate, soil, topography and vegetation can vary widely within countries and even within subdivisions of countries. One area may receive little or no rain while another has a surplus. Human diversity can also be substantial, particularly between countries and regions within countries. Water users' organizations may work in one part of the country but not another. The difference in natural and human factors means that one is usually faced with a wide range of water use patterns. Thus, any water resource planning effort must recognize these differences and consider the nation's water problems in the context of agro-climatic regions or river basins. If possible, internal political subdivisions should not be allowed to prevent the planning for an optimum use of a country's water resources. Water resources should be planned from a national point of view even though management of the various water systems is decentralized.

If one is planning water use in a developing country the major concern is generally irrigation. Irrigation usually accounts for 80 to 90 percent of the consumptive use of water. Electricity production, flood control, transportation and domestic water use can also be important, particularly in some of the large multi-purpose projects. However, the main focus of this paper is on irrigation water use. The emphasis is also on irrigation issues important to developing countries.

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*The author is professor of Agricultural and Applied Economics at the University of Minnesota. The author wishes to thank Delane Welsch for his helpful comments particularly his ideas on levels of institutions.

There are a wide range of irrigation issues that could be researched. These issues involve problems both of making existing systems work better and of designing systems that better contribute to the efficiency and equity goals of society. The following list of issues is not all inclusive but gives an idea of the range of questions facing water policy decision makers and researchers.

A. Water allocation rules, methods, and customs

1. How do the procedures for irrigation water allocations, including water pricing and rotation methods, affect output and its distribution?
2. What procedures can lead to an economically efficient allocation of groundwater and surface water supplies? How much flexibility is needed in these procedures to respond to changing natural and economic conditions?
3. What government policies affect the allocation or distribution of costs and benefits of irrigation?
4. Are the incentives for both the managers of the irrigation systems and the farmers compatible with the efficient and equitable allocation of water within the irrigation system both in the short run and the long run?

B. Institutional and managerial arrangements for irrigation project implementation and rehabilitation

1. What impacts do tenure and legal structures have on irrigation project implementation and on the level and distribution of benefits?

2. How important are national level water institutions in water project formulation and implementation?
3. What institutional changes are required to improve the efficiency with which groundwater is exploited over time?
4. What are the impacts of increasing land fragmentation on irrigation efficiency?
5. How much flexibility exists in irrigation institutional arrangements and management procedures? What degree of flexibility is required to achieve the efficient and equitable use of water over time?
6. How do local water distribution and maintenance institutions or lack of them affect water use efficiency and equity?
7. What is the trade-off between more infrastructure investment and improving the human managerial input?
8. How can groundwater and surface water supplies be managed to provide economically efficient water use over time?

C. Alternatives for design, scale, and geographic distribution of irrigation investments

1. Are small scale irrigation projects a viable means for developing water resources?
2. Can large scale irrigation projects be operated and managed in small scale units?
3. How does the size of the terminal management unit affect project performance?
4. Are there fewer socio-cultural and economic problems associated with the development of small irrigation projects as compared to large projects?
5. What is the optimum life of irrigation structures?

6. Can socio-cultural and economic constraints be overcome by staging irrigation development?
7. What should be the mix of irrigation investments between intensive vs. extensive irrigation projects?
8. What are the economic and distributional gains from building more flexibility into an irrigation project in terms of water delivery, area served, etc.?
9. What gains in economic efficiency can be obtained from a systematic central planning of a nation's water resources?

D. The selection of irrigation projects and the timing of irrigation development relative to other alternatives for achieving agricultural and rural development

1. Do government policies favor capital intensive irrigation projects over programs to improve agricultural research or to supply other inputs?
2. What are the relative multiplier effects of various types of irrigation investments? Are secondary benefits directly related to the size and concentration of economic surpluses created by an irrigation project?
3. How does the availability of efficient biochemical technology affect the optimum timing of irrigation investments? What are the complementarities between investments in research to develop biochemical technology and in irrigation?

E. Information systems for improving water resource decisions

1. What type of water resource inventory information is needed for research and decision making?

2. What is needed to develop an information and planning system based on river basins or agroclimatic regions that provides a continuous flow of information to decision makers?
3. Given a country's resource base, what is the best information system for the exchange of agronomic and engineering information between irrigators and system managers?

F. Water use allocation between irrigation and alternative uses

1. What are the economic trade-offs among irrigation, hydroelectric power, flood control and other nonfarm water uses?
2. How much flexibility among alternative uses should be built into water projects?

G. Improving system-wide performance

1. At what level in the system, sector, project or farm, can performance best be improved?
2. Can system performance be best improved through introducing new technology, decentralized management or government policy changes?
3. What is the trade-off between system maintenance and rehabilitation?
4. How does the government's policy (or lack of) concerning the scarcity of water resources affect the use of water resources?
5. Do government subsidies on credit, commodity prices and electricity rates encourage an inefficient use of either groundwater or surface water?

Clearly, one University or irrigation department cannot solve or even address all of the above problems associated with irrigation. However, it is informative to indicate the scope of the problems before selecting the ones for specific attention. Another way to visualize the scope of irrigation problems is to think in terms of a matrix (see Figure 1). Across the top are different types of physical systems, such as privately operated pump irrigation, large scale government operated gravity flow systems, small scale gravity flow systems with storage and small scale systems dependent on the river flow (no storage). On the left-hand side of the matrix are possible options for changing the performance of each type of system. This would include such things as allocation procedures, management and operation alternatives, repayment methods, government investment strategies and types of information and planning systems.

Performance would be measured in terms of impacts on farm income and its distribution among farmers. Other measures of performance might include employment of landless labor, impact on regional growth, migration rates, incomes of small scale farmers, mobilization of local resource (labor and savings) and regional consumption levels.

As one begins the process of filling in the cells of the matrix, it becomes clear that analysis to complete one cell can also provide answers in another. In other words, research projects can answer more than one question and the measures of performance will be common across many problems. Also on certain issues work may already be completed or underway which will provide answers to help fill in cells.

Of the issues listed above the following four areas seem to be especially important: (1) water allocation rules, methods and customs, (2) institutional and managerial arrangements for irrigation project implementation and rehabilitation, (3) alternatives for the design, scale, and geographic distribution of irrigation investments, and (4) improving

FIGURE 1. Matrix of Irrigation Systems and Alternative Policies, Procedures and Investments

| | TYPES OR IRRIGATION SYSTEMS | | | | | |
|---|---|---|---|---|---|---|
| | Large Scale Gravity Flow | | | | Private Pump | Tank Irrigation |
| | Variance of Income | Investment per hec. | Net income per farm | Average farm size | | |
| **Allocation procedures** | | | | | | |
| 1) No formal allocation | | | | | | |
| 2) Market allocation | | | | | | |
| 3) Constant share, etc. | | | | | | |
| **Operation and management (O&M)** | | | | | | |
| 1) O&M provided by government | | | | | | |
| 2) O&M by farmers | | | | | | |
| 3) No M, etc. | | | | | | |
| **Repayment methods** | | | | | | |
| 1) Average or marginal cost | | | | | | |
| 2) Base on income or acreage | | | | | | |
| 3) Nominal land tax, etc. | | | | | | |
| **Institutional setting** | | | | | | |
| 1) Tenure system favoring large land owners | | | | | | |
| 2) Tenure system neutral | | | | | | |
| 3) Water consider free resource, etc. | | | | | | |
| **Government investments** | | | | | | |
| 1) Field channels investment | | | | | | |
| 2) Govt. investment in roads | | | | | | |
| 3) Govt. investment in markets, etc. | | | | | | |

system-wide performance. Thus, the remainder of the paper is devoted to suggesting specific types of research that might be done in each of these issue areas.

## II. Water Allocation Rules, Methods and Customs

The methods used to allocate water may be as important as the project design since water lost in allocation can reach 70 percent of the total available. Methods should be designed to fit the culture and the operational abilities of the farmers and may require special organizations and institutional arrangements. In addition, the allocation procedures should fit the design of the irrigation systems as well as the water supply conditions and the character of the production systems.

Most irrigation systems are designed to reduce the variability and uncertainty of water supply. However, the methods used to allocate water, if not properly designed and implemented, can actually decrease the certainty and predictability of water supplies (Reidinger, 1974).

### A. Levels of Allocation

There are generally three levels that should be considered in water allocation: (1) the water source (reservoir, river, or well), (2) the transmission of water to the farmer's fields, and (3) the allocation among farmers. Each level can be important in the success or failure of a project. What happens at one level may well limit what is possible at the others.

#### 1. Water source allocation

Source allocation can involve several types of decisions. First in a reservoir system the question is that of allocation 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.

The common property nature of ground water forces farmers to put very little value on water left in storage. Instead they will pump water to the point where the returns generated at the margin are equal to the pumping cost unless there are public restrictions on pumping. This can lead to a rapidly dropping groundwater table and continued pressure on farmers to deepen their wells. The problem is amplified by government subsidies which reduce pumping costs.

Second, a different type of decision is faced in run of the river systems where management must make allocation decisions concerning upstream and downstream users. If more water is withdrawn for irrigation, what does this do to downstream users? In Spain and the U.S., these allocations are specified in water rights [Maass and Anderson, 1978].

2. Transmission allocation

Water losses tend to be very high during transmission. One reason for high transmission losses is the dispersed nature of irrigation activities which may be partly due to overly expanded command areas. One important transmission decision is how large of an area should be served. The larger the area served, the more farmers that will receive water. But the larger the area the larger the water losses. This leads to the question: What is the cost in income foregone from expanding a command area and what are the improvements in income distribution? Answers to the latter question depend very much on land ownership patterns.

There may also be some important transmission decisions concerning how often a given part of the system gets water. Is water provided on a continuous flow basis or is it rotated on a five to ten day schedule? The amount provided at different times of the year will be an important decision in the water rotation as will be the length of each rotation.

### 3. Farm allocation

The final level of water allocation is the farm level. Here a wide variety of procedures have been used to distribute water ranging from the agronomist's notion of water requirements to the economist's notion of markets for water shares. Moreover, there will be an interaction between all three levels of the irrigation system. What is done at the reservoir level will effect both the transmission of water and its distribution among farmers. In fact, the distribution rules used at the farm level depend in part on the amount delivered from the main water sources.

In deciding on how to allocate water at the farm level five objectives are usually important: equity, efficiency, growth, justice, and local control [Maass and Anderson, 1978]. The particular weights given to each objective will vary among projects and countries; some, if not all, are important in every irrigation project. In addition the weights given to these objectives may well vary widely among the water managers, farmers and politicians. This usually leads to a conflict among these three groups as to how water should be allocated.

## B. Methods of Allocation

Some of the more common methods of allocating water are briefly described below:

1. No formal allocation procedure. Water is allowed to flow continuously in the channels. Those at the head of the system get all the water they need (sometimes even more than they want) while those at the tail of the system are usually short of water and will receive water so late that land preparation and planting will be late. This type of system essentially allocates water based on location on the canal. It may not be too bad a system when water has very low value (wet season irrigation).
2. Shares. Each farm received in each period a fixed percentage of water available for the period. A farmer's percentage is based on ownership of shares which in turn is normally based on farm size. If a farmer does not want his share it is passed on to others and may even be wasted during times of plentiful water. Unless shares can be sold the system does not allow for use of water on farms of highest need.
3. Turn. Each farm is served in order of location along the canal. When water reaches a farmer, he takes all he needs before the next farmer is served. Water distribution in any period usually begins where it stopped in the previous period, otherwise those at the tail would be disadvantaged and may never get water during droughts. During drought periods the time between irrigations or turns is increased. This procedure tends to be inefficient during drought periods since water cannot be used in areas of highest need. It also leads to over-irrigation as farmers attempt to take enough water to carry them over until the next irrigation or turn.

4. Rotation. Farmers have a reserved or set time in which they can irrigate in each period. The quantity of water delivered will vary in each time period depending on flow in the ditch. The time assigned is normally based on farm size. If a farmer does not use the water in his assigned time, the water is available to other irrigators. The set time usually does not allow farmers enough time to overirrigate. In addition, unless the reserved times are transferable among farms or farmers the system does not allow water to be allocated to areas of highest need. Finally, if little or no water is in the ditch during a farmer's reserved time, he will not get water until the next irrigation period.

5. Farm priorities. Farms are served in an order of priority based on time of settlement. When water reaches a farmer, he takes all he needs before the farmer next in order of priority is served. This is similar to the turn system except that water distribution in any period starts with first-priority farms or farmers. During periods of drought the first-priority farms are the only ones to obtain a crop. This method does not rank high in terms of equity but will allow for some production in dry periods while other methods may not.

6. Crop priorities. Crops are assigned orders of priority which are normally based on the crops' economic value or importance to a country. When water is in short supply, priority crops receive water first. If water remains after irrigating priority crops then it

is distributed to non-priority crops. Allocation by crop can be fairly equitable and efficient in drought periods if all farmers grow some priority crops. It basically allows some crops to be saved during drought periods.

7. Market. Water users bid each period for water needed to irrigate their crops or buy water shares for future irrigation. Thus, water is allocated to the highest value uses in each period. Only part of the water may be marketed since farmer may own a certain base amount of water. Some losses may occur because of lack of knowledge about seasonal water supply. Crops may be planted that cannot be irrigated due to imperfect knowledge about the seasonal water supplies. The market will also fail to account for the impact on other farmers of return flows.

8. Demand. Water supply for the full season is stored and available at the beginning of the season and each farm is allotted a fixed quantity for the season. A farm receives, in each irrigation period, the quantity of water that the farmer requests (demands). Farmers, knowing at the beginning of the season what their seasonal water supplies will be, can plan the areas of their crops to get the highest return for the available water. This tends to produce the highest returns for the area. It is an equitable system if farms are of about equal size. A demand system would not produce the highest return if soils and other natural conditions made some farms more productive. One could achieve increased

returns by allocating or selling more water to farms with the highest productivity.

C. <u>The Impact of Alternative Methods for Water Allocation</u>

Because improving the operation of existing systems can be as important as project design, guidelines for selecting water allocation methods deserve special attention. What criteria should be used to select the method for allocating irrigation water to farmers and under what conditions does each tend to perform best in terms of efficiency, equity, etc.?

One of the questions would be: "To what degree can the market be used to allocate irrigation water as compared to administrative allocation?" Ideally this decision should be made before a project is designed. The differences in design requirements and cost would be compared with the efficiency and distributional advantages of market versus alternative allocation procedures.

In addition, if the primary objective of an irrigation system is to provide irrigation for small farms, then this must be considered at the design stage. The size of land holdings to which water will be delivered, tenure systems either in operation or to be implemented and the methods of water delivery will all be important in determining whether or not the primary beneficiaries are small scale operators. After the system has been built and the water is being delivered it then becomes very difficult to break up and redistribute land. The redistribution of land should be an integral part of the design of any irrigation project in which viable small farms is an important project objective.

Many irrigation systems are designed to deliver water by the least cost method and to collect a fixed charge from farmers to pay some or all of the project costs. Under such systems, the possibilities for using water pricing is very limited without a major project rehabilitation. However, other options can be considered that might improve water allocation, such as crop charges or charges based on the flow of water or number of hours a farm receives water.

There are numerous pros and cons concerning whether or not the water charges should cover the operating and capital costs. On the one side some people argue that irrigation only lowers farm prices, which means the main beneficiaries are the consumers. Therefore consumers should pay the cost through a government subsidy of irrigation projects. In contrast, others argue that the farmers obtain a large income transfer from government financed irrigation projects which increase land values and displace tenant farmers. The actual impact of the project will depend on size of land holdings, the size of the project, tenure arrangements, crops grown, markets, etc. The final decision on how much of operating and capital cost should be repaid will depend on the weights given to efficiency, equity, economic growth and the particular resource and economic situation in the area where the project is built.

Based on economic efficiency one would argue that the water charge should at least cover the marginal cost of operating the irrigation system. The contribution to capital costs would depend on the demand for water. If demand for water is high then the charge for water can be raised to cover some or all of the capital costs. The contribution to capital costs can be reinvested and again contribute to the country's growth and development.

Water charges could also depend on the certainty of water supply. This would include both the certainty in quantity and timing. Farmers who obtain a certain water supply throughout the season would have the highest charge. Those at the edge of the project area or at the tail end of the distribution system, with uncertain water deliveries, would have the lowest charge. Another option available would be to vary the charge by season of the year. Since the value of water is higher in the dry season, the charge would be higher. This could be done even without measuring the volume delivered to each farm. The charge could be based on the canal flow rates, the number of irrigations received, or the acres irrigated in the dry season.

The first step in any analysis of water allocation policies is to collect secondary information and study the existing water allocation. This would be followed by a comparison of alternative methods for allocating water. The analysis should include an investigation of how different allocation procedures influence water distribution, crop production and the distribution of irrigation benefits. Another aspect of such a study would be to determine how well the procedures could be adjusted to changing economic conditions. Under what conditions are allocation procedures non-responsive to the requirements of a changed agriculture? What government policies facilitate the adjustment of allocation methods?

The research could then be followed by seminars designed to inform government officials about the rationale and effects of alternative water allocation policies. The seminars would facilitate the two-way communication and feedback between researchers and administrators. The primary objective would be to help improve the economic efficiency and the equity with which irrigation water is allocated.

# III. Institutional and Managerial Arrangements for Irrigation Project Implementation and Rehabilitation

## A. Levels of Institution

Institutional questions can be divided into three levels. The first consists of institutions that directly affect the level and distribution of benefits. These include both customary (as well as traditional) 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.

The second level consists of institutions in the sense of organizations or organizational structures that deal with distribution of irrigation water, maintenance of irrigation systems, etc. Locationally these institutions are usually at the local or regional level, i.e. not at the national level. They usually deal directly with farmers at the field level. A water user's association is one example. An irrigation department or bureau office in charge of a particular sub-project is another example. It is at this level, where the farmer-user and the system interact, that the success or failure of "management" is determined.

The third level 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. For example, what are the "rules" for the national budget staff to decide among various irrigation and hydroelectric power projects. Also included is the legal administrative bases for centralized planning of irrigation investments. The strengths of each of the institutions are important. For example, after a project has been constructed and is in operation, does it then operate more or less independently, or is it still strongly controlled from the national level?

The study of institutions and their problems, with institutions as defined above, leads directly to the question of efficiency and equity in irrigation system operation, which may be the most crucial or critical issue facing irrigation in many countries. How to reform or revitalize institutions that are having a negative effect on irrigation efficiency, how to start new institutions that are needed to achieve efficiency, and how to manage each part of the system, are crucial and unanswered questions for many countries.

There is a fourth level of institutions that should also be mentioned. This is the kind or type of institution that deals with providing inputs and services at the local level that will enhance the productivity made possible by irrigation. For example, suppose that a small irrigation system has been constructed and put into operation. Assume that the size and scale of the distribution system is ideal for achieving high technical efficiency of water use. In addition the management of the system is enlightened, and is very bottom up oriented, i.e., signals from farmer-users are strong and management hears them. Yet, if an institutional infrastructure, consisting of distribution channels for farm inputs and a farm marketing system is not in place, then the impact of the system will be minimal.

In dealing with the various management issues related to irrigation schemes it is helpful to think in terms of three aspects: (1) the <u>physical infrastructure</u> of the water delivery system; (2) the <u>people</u> directly responsible for agricultural development within the area irrigable by that system (scheme managers, their staff, the farmers); and (3) the overall framework of government policy within which the managers and farmers operate. The extent to which the poor performance can be related to management will depend on deficiencies in technology, the adequacies of the physical structure and the overall policy. It is difficult to operate and manage an irrigation system efficiently when water is not recognized by the national government as a scarce resource in agricultural production. In some cases significant improvements in performance can be achieved without immediate recourse to major capital investments while in others physical changes will be required.

## B. Conjunctive Water Management

One of the important management problems facing a number of LDC's is how to best utilize surface and groundwater supplies. For optimum use the two sources of supply should be managed jointly (conjunctively). There are a number of options for accomplishing conjunctive use. Water charges can be used to encourage the use of either surface water or groundwater throughout the season. The charge for surface water would be set below the pumping cost to encourage surface water use during periods of plentiful surface supplies. When surface supplies are low the charge would be raised above pumping costs to encourage groundwater use. Such a pricing system allows one to regulate pumping without actually owning the groundwater.

Who has the rights to the water can complicate the planning and management of surface water and groundwater supplies. If, as in many countries, groundwater belongs to the landowners, it is very difficult to directly regulate use. The same is true in situations where surface water is owned by landowners. Thus, one may have to plan and manage the use of one water source such that the desired use from the other source is also achieved.

If the government controls both sources of water the management problem can be easier. In fact, one would have the option of using a strict centralized management system with state tubewells, reservoirs, and ditches. The government would provide the optimum amount of surface and groundwater as determined by a programming model. However, successful centralized management systems are hard to find. Not only is management control and accountability a problem but determining what is the optimal level of groundwater and surface water use is not an easy task.

The following situations would require the joint management of surface and groundwater for optimum use of water supplies:

1. Pumping is used during the dry season to be replenished during the rainy season or non-growing season. The pumped water is combined with surface flows to provide adequate crop irrigation and surface flows are important for groundwater recharge.
2. Groundwater is only slowly recharged or not recharged at all and, therefore, it is essentially a stock resource. Under these conditions groundwater is best used as a reserve for very dry years when the reservoir or river supplies are very low. There may also be some special cases where the groundwater is used up and irrigated agriculture abandoned when the pumping costs become too high. Such use of a stock of groundwater must be carefully

planned. Otherwise when irrigated agriculture is abandoned there may be significant losses in returns to immobile capital and labor or the government will be asked to import large quantities of high cost irrigation water to "save agriculture." Northern Mexico and parts of the southwestern United States are examples of areas faced with a declining stock groundwater resource.

3. Pumping is used around the edge of a command area. This reduces the length of canals needed to irrigate the area. Many flood irrigation systems could consider such a use of pumps. This has been shown to be desirable in parts of the Indian Punjab.

4. Pumping is used to extend the irrigation period by allowing for earlier planting. Groundwater is used until the surface flows become available. Surface flows are dependent on the start of the monsoon rains. This is the situation in the Cauvery system in southern India where pumping allows earlier planting and harvesting for the summer rice crop. The early harvesting avoids the November rains and allows the planting of two rice crops.

5. Pumping provides drainage by drawing down the water table. This drawdown may be used for extra storage during periods of high river levels and thus help in flood control. The pumped water is also an additional source of water to be used for irrigation. This type of pumping is being suggested along the Ganges River of Northern India.

## IV. Alternatives for Design, Scale and Distribution of Irrigation Investments

One of the first questions that needs to be addressed is the viability and desirability of small scale irrigation projects. In many regions natural conditions are not suited for large irrigation projects. In addition, many countries want to spread the irrigation investments throughout the country which means small irrigation projects.

What practices and policies make some small scale projects highly beneficial and others not? Operation and water distribution should be easier on small scale projects as compared to large scale projects. Information about on-farm water needs should be easier to obtain in a small scale project. In addition, the distance between water source and irrigated farms should be 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.

As a first step in looking at the scale of irrigation investment, one needs to investigate small scale irrigation in a number of areas. We know a great deal more about large scale irrigation and pump irrigation than we do about small scale reservoir (tank) irrigation. Thus, several specific studies are badly needed to provide basic information about the performance and operation of tank irrigation projects.

### A. Tank Irrigation

A wide range of tank irrigation projects seem possible in many countries. Because of the climate and the topography, tanks may be the primary means for improving irrigation in many semi-arid areas. In general the success of existing tanks has been below expectations in terms of increasing production and income. However, little is known about the potential for increasing production and income from improving old tanks or building new ones.

The first part of a study of tanks would be to work with government officials to identify tanks for study. One would want to study the tanks that appeared to be performing well along with those with a poor performance. An important aspect of the study would be to compare the organization, operation and management among different types of tanks. What is the impact of the reservoir, operation and management on the efficiency and the equity with which water is distributed?

A second part of the study would be a benefit-cost analysis of selected tanks to determine the return on investment. This would provide some basis of comparison with other potential investments including large irrigation projects and other agricultural inputs. In conjunction with this analysis, the distribution of benefits from the project should be estimated. Do small scale irrigation projects really reach the smallest farmers or, as found in eastern India, do the benefits go to the larger land owners and the more politically powerful farmers? [Easter, 1975]

The final part of the study would be to help government officials develop better procedures for planning and operating tank projects. Clearly, this may mean new institutions or the adopting of institutions that have worked elsewhere. Too many times it appears that tanks have been built only to be forgotten in terms of maintenance and operating. This is much like passing legislation but forgetting to implement the program.

## V. Improving System-wide Performance

It is fairly clear that irrigation by itself is not going to solve the world's food problems. Irrigation should be considered as just one of the alternatives for increasing production and farm income. In fact, new large scale irrigation systems established in a country with limited trained people and capital may cause more problems than it solves. An effective large scale irrigation project requires a wide range of services besides the physical irrigation structures. Are the management resources trained and available to operate the system? Do the farmers receive technical assistance on how to use irrigation water? Are roads and markets available to move inputs and outputs? Can input supplies meet farmers' demands in the irrigated area without increasing prices? Is domestic demand adequate to use the products produced in the project without driving down prices? If not, is there an export market for the products that the country can effectively penetrate? Are farmers organized to maintain the irrigation ditches and distribute the water among themselves? All of these questions and many more need to be answered before an effective large scale irrigation system is established.

An irrigation system can be thought of as (1) a large reservoir and its service area, (2) a series of small interconnected tanks or reservoirs serving the same area, (3) a series of wells that are drawing from the same groundwater pool, or (4) a combination of reservoirs and wells serving the same area. The system may or may not be managed as one unit. In fact, most likely wells pumping from the same groundwater aquafier will be privately owned and not be managed as a unit.

A large number of government policies can influence the performance of an irrigation system. These policies include the pricing and allocation of inputs, commodity price support programs and credit programs. Import and export policies can also directly affect crops grown and inputs used.

## A. Groundwater Systems

All the wells drawing from the same groundwater source should be considered as part of the same irrigation system. One of the first steps would be to identify the different groundwater sources through a survey of existing wells and additional test drilling as needed. A number of research projects could then be started on any one of the identifiable systems of wells drawing from the same water source. when one is dealing with the classic case of a stock common property resource that is rapidly declining the first question should involve methods for changing the situation. What alternatives might be used to increase the groundwater recharge or what alternatives are possible for regulating pumping and the installation of new wells? In most cases the alternatives will require some type of government action such as taxes, assigning water rights or outright controls. A research project could be designed to measure the impact of each of the alternative government actions. The research results could then be discussed, at a seminar, with government officials to encourage them to take some action.

Certain government programs or policies are also influencing the rate at which the groundwater is being drawn down. These include cheap credit policies that allow farmers to borrow money to deepen wells and buy pump sets. Price support programs also raise farm prices and encourage the more rapid use of groundwater for irrigation. Finally, subsidized electricity rates reduce pumping cost and increase pumping and groundwater use. One could study any one of these policies to determine the impact on groundwater use, income and adjustment costs over time. The amount of income lost to society can be used to show government the indirect cost of these programs and possibly help bring about changes.

In cases where the drawdown of the groundwater cannot be stopped or slowed down short of the point where the marginal pumping costs (MPC) equals the marginal value of irrigation water (MVP) the important questions is how should farmers adjust to this situation. A study should be made of selected farms to determine how farmers are likely to adjust to future declines in the water table. One should estimate the impacts on cropping patterns, acres of irrigation (intensively and extensively), investments in well deepening and the use of water conserving practices. The study should also determine the likely outcome with the groundwater used optimally over time.

Another aspect of the study would be to determine the loss to resources during the adjustment period. The biggest losses are likely to be the adjustment costs for farm labor. Clearly as farming declines due to the dropping groundwater table, employment in farming will drop. There would be a loss in income and employment for family labor, at least, in the short run. In addition, the families may have to move to find employment. The moving cost is another adjustment cost to society. If the family must turn to crime in order to survive this would also be an adjustment cost to society.

Farm owners would experience a drop in land values as the water table is pumped lower and lower. Capital expenditures in housing and wells may also be lost with the loss of water if owners are forced to move elsewhere. One of the interesting questions is how fast does the capital and labor move to more profitable uses? The longer the lag period involved in this adjustment the higher the adjustment costs will be.

Government should be appraised of these likely outcomes. Actions can then be suggested for shortening the adjustment period and lowering the adjustment costs such as training of displaced farm labor. Public works projects that can increase future agricultural production such as land and water conservation structures, small tank construction and irrigation rehabilitation should all be considered.

## VI. Conclusion

Although the irrigation problems tend to be numerous and there are strong political forces working against change, one of the positive forces for change can be research. Through research that determines what actually exists, what is possible, and what is preventing improvement, policy makers can better see the need for change in irrigation systems. Many institutions are not adapted to making the necessary adjustments when natural and socio-economic conditions change. Thus, as researchers we must do a better job of pointing out where the necessary changes are not being made to improve income and its distribution. Research should suggest alternatives for improving irrigation systems and indicate the likely effects of these alternatives.

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# APPENDIX

## A. Conjunctive Use in the Cauvery Basin

The Cauvery Basin in south India provides a good example of the type of conjunctive water use studies that might be done. The Cauvery River has been irrigating parts of Tanjavur district for centuries. Water is usually available for irrigation in the second week of July which means that harvesting of short duration rice varieties must come during the heaviest rainfall month, November. This subjects the crop to extensive damage in years of heavy November rainfall.

Tanjavur district also appears to have sizeable quantities of groundwater which is only being used at a very modest level. The groundwater supplies could be considered as another reservoir to be used when the lower cost surface flows are not available. The use of groundwater could have three beneficial impacts: (1) earlier planting and harvesting would avoid rainfall damage during harvesting, (2) earlier planting would mean more sunny days and higher yields, and (3) increased yields and reduced damage would encourage more farmers to plant the shorter duration rice and grow two rice crops.

The important control variables would be location and capacity of wells and the reservoir stock and release time. Recharge and withdrawals may also be important if groundwater pumping increases greatly. Finally, water rights on the old irrigation area may mean that the largest benefits from pumping will come in the newer irrigated areas.

One of the key questions would be how large an investment in tube wells, if any, is justified based on the additional benefits from: reduced damages, increased yields and a large acreage planted to a second crop? The timing and amount of reservoir supplies available from year to year would be important in determining the average level of benefits. November rainfall would also be an important determinant of benefits from pumping. Well development should be expanded to the point where the additional cost is equal to the additional benefits. Another benefit, not mentioned above, might occur because of reduced flooding and improved drainage in low areas due to pumping.

To start with, the model of the Cauvery might be simplified. Since there appears to be a large groundwater supply and excellent recharge, no hydrologic model may be necessary. Groundwater can be considered as another reservoir with no evaporation but with a higher price (cost of pumping water) that could increase with pumping. An example of a model for the conjunctive management on the Cauver is the following:

$$V_n(S_i^1, S_j^2) = \max_{k,m} [B(W^K, Y^M, S_i^1, S_j^2)]$$

k, m = release and pumping levels

$$S_i^1 (n-1) = S_i(n) + e - W^K - E \left[\frac{S_i (n-1) + S(n)}{2}\right]$$

$$S_j^2 (n-1) = S_j^2(n) + \text{recharge} - Y^M$$

$S_i^1$ = reservoir stock

$S_j^2$ = groundwater stock

e = water receipts in reservoir

E = evaporation from reservoir

$W^K$ = water release from reservoir

$Y^M$ = groundwater pumped

i = 1 ... I different stock levels in the reservoir

j = 1 ... J different groundwater stock levels

n = number of years remaining in period

One can assume $S_j^2$ is constant if recharge is high enough. Thus the major random variable is reservoir level and release date. The benefit function could be calculated for different pumping levels. For example, assume an average reservoir level and water release date and then estimate how much would be gained by pumping.

The final phase of the analysis would be to consider different institutional arrangements for providing pump irrigation. Due to capital constraints and small farm size many farmers cannot install pumps. Thus, alternatives such as cooperatives, government subsidies, etc. should be considered as methods for getting well water to small farms. This will not be an easy task since past attempts such as state operated tube wells have not worked.