BANGLADESH AGRICULTURAL RESEARCH PROJECT PHASE-II

A Framework for Economics Research on Water Management in Bangladesh

A CONSULTANCY REPORT

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A FRAMEWORK FOR ECONOMICS RESEARCH ON WATER MANAGEMENT IN BANGLADESH

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A Framework for Economics Research on Water Management in Bangladesh:

Executive Summary

The focus of the consultancy was to develop a framework of agro-economic research that can enhance the IMP command area development program in two ways. Research output coordinated under BARC can contribute directly to the IMP by identifying critical areas of technology improvement, by helping program leaders to better understand the constraints to command area improvement, and to suggest what policy changes can best enhance command area development. The research program can also contribute indirectly to IMP by making inputs to the BARD National Water Management Training Centre at Bogra. Positive research aimed at understanding existing water management practices can provide valuable feed-back to trainers by showing which recommendations are appropriate for specific local conditions and which require further adaptation.

The task of the team was not to identify new problems on which to develop research programs. There has been much insightful problem identification by keen observers of the Bangladesh agricultural economy. Rather the charge was to conceptualize a coordinated agro-economic research program for irrig ated agriculture which would expose the fundamental causes of the perceived problems. The output of the research could be expected to assist policy makers in the understanding and development of policies for achieving the objectives of government. It can not be overemphasized that the conclusions and output of this report are recommendations for research programs and methodologies. They are not policy recommendations. The contribution of research is severely debited if hypotheses are confused as recommendations.

I. Technology Development for Pumpsets and Conveyance Systems

The components of pump sets are commonly mismatched and inappropriate for their present sites. The objectives of the proposed research on pumping equipment are to determine the most efficient pump sets for various site characteristics, to determine priorities in generating new design, and to evaluate alternative policy instruments for promoting appropriate pump technology.

We propose that pump set efficiency be evaluated according to the criterion of minimum cost of water delivery taking account of the head, discharge, and tolerance (to fluctuating water table) requirements of alternative sites. This information can be used by banks in their evaluation of pump loans and by engineers in determining design priorities. Complementary policy needs to be fashioned to encourage domestic industry to play an appropriate role in pump set supply without undue protection that penalizes pump users. In the policy section, we propose that alternative policy strategies for pump technology development be evaluated according to their economic effects and total cost.

Conveyance systems can also be evaluated according to the cost of delivering water to various locations in the command area. A simplification in the system analysis is proposed whereby delivery costs can be approximated without reference to the specific cropping pattern. By describing the relationship between water loss and recharge, delivery costs can be related directly to the pumping costs as estimated in the first part of the study.

Costs of both pumping and conveyance can then be combined to get the costs of delivery to various points in a specified area. The framework proposed is thus capable of not only evaluating pump sets and conveyance alternatives independently but as integrated systems. This facilitates, for example, explicit analysis of the trade offs between improved conveyance systems and an increased number of tubewells.

II. Constraints to Command Area Development

There is a widespread belief that installed irrigati capacity is being greatly underutilized, with actual comman areas significantly less than physical potential, and that substantial economic gains can be achieved by policies to increase existing command areas to nearer the physical potential. We propose research designed to assess the difference between actual and potential command area, analyz the constraints which cause the gap between actual and physically achievable command areas, and estimate the costs and benefits of interventions designed to increase the effective command area.

A research design is described which provides an integrated analysis of (1) agro-climatic and physical constraints, including potential evapotranspiration, soil texture, rainfall distributions, and topography; (2) technica and operational constraints, including pump and canal design and maintenance, water distribution methods, and siting of irrigation systems; (3) economic and agronomic constraints such as the price of irrigation water and other inputs, crop water requirements, crop yield response to water and other inputs, crop prices, and the pattern of delivery of water; an (4) organization and management constraints, including the cost and effectiveness of organizational mechanisms for sharing financial costs, allocating water, maintenance, and other responsibilities, and enforcing implicit contracts.

The research design includes primary data collection and analysis, case studies, and development of a computer simulation model of irrigation systems. Research activities include classification and mapping of regions by agro-climatic characteristics; design and implementation of a sample survey of systems, and farms within systems, stratified by size, type, and organization of system and agro-climatic zone; estimation of production functions incorporating water and fertilizer for potentially irrigable crops; development of case studies of the impact of organizations on water delivery and cropping patterns; and action research on extension of innovative types of organizational arrangements.

The simulation model of irrigation systems is described in some detail. The model consists of three main components: (1) a model of the irrigation system itself, which generates the distribution of water to the farm level as a function of the configuration and management of the delivery system, the type of canal infrastructure, the water management and allocation system and the agro-climatic environment; (2) a farm level water balance model which estimates daily water availability and crop stress at the farm level, based on the daily distribution of irrigation water, rainfall, evapotranspiration, and seepage and percolation; and (3) a farm decision/crop production model, which estimates farm input use and crop production as a function of water availability, input prices, and other factors.

The simulation model permits estimation of the impact of the important agro-climatic/physical, technical/operational, economic/agronomic, and organization/management variables on command area irrigated, crop yields and production, and farm income.

III. An Ecological System Approach to Water Resource Development

Optimal water resource development requires an integrated model of all competing and complementary water uses. Failure to recognize these often complex interactions can result in substantial misallocation of resources. Section III suggests two partial resource use models which would examine these interactions. The first assesses the relationship among pumping of groundwater, saltwater intrusion and surface water diversion for irrigation. In this case, water diversion can be evaluated as a source of groundwater recharge. The second framework is suggested for examination of the competition between water for irrigation and water for both fresh and saltwater fish production.

IV. The Role of Government Policy

It is apparent that many of the present inefficiencies of water management in Bangladesh are partly a consequence of subsidies and other policies encouraged by donor agencies. The new thrust towards privatization may be an over-simplified counter reaction to mistakes of the past. Section IV of the proposal discusses research strategies for understanding the nature and consequences of the past and present policies and for evaluating policy alternatives.

Section IV concludes with a proposal for integrating the various components of the research framework. Section I provides the cost of delivering water to various points (in place and time) in a target area. Section II shows how the optimization problem can be extended to incorporate the dynamics of water loss and recovery and the economics of cropping systems. Section III discusses method for incorporating environmental and other social costs which are external to the cropping system. Section IV incorporates the public sector as a major actor in the total water management picture. The principles of managing renewable resources can, with some extension, provide a basis for integrating both the private and social cost components and for generating policy prescriptions that are compatible with socially efficient management.

The body of the report is divided into four sections:

I) Technology Development (pp. 3-14).

II) Constraints to Command Area Development (pp. 15-34)

III) The Role of Government Policy (pp. 35-37) and

IV) An Ecological Systems Approach to Water (pp. 38-45)

A Framework for Water Management Research in Bangladesh

Introduction

The terms of reference for this consultancy were:

1. Assist BARC in identifying issues, topics, and methodologies for the water management component of the BARC Contract Research Program.

2. Assist BARC in identifying specific areas for water management short term consultancies within the water.

3. Assist BARC and participating institutes in articulating priority topics under three general areas:

   a. economic assessment of irrigation alternatives: cost effectiveness, system efficiency, and project evaluation for predominant agro-climatic and hydrological zones;

   b. the role of rural institutions in irrigation system design and water management; and

   c. a framework for an integrated irrigation policy.

In addition, IADS requested the team to look at conditions issues, and policies related to (1) ownership and management of irrigation equipment and distribution of benefits from irrigation and (2) irrigation water distribution systems for STW's, DTW's and LLP's.

The Consultancy:

The focus of the consultancy was to develop a framework of research that can enhance the IMP command area development program in two ways. Research output coordinated under BARC can contribute directly to the IMP by identifying critical areas of technology improvement, by helping program leaders to better understand the constraints to command area improvement, and to suggest what policy changes can best enhance command area development. The research program can also contribute indirectly to IMP by making inputs to the BARD National Water Management Training Centre at Bogra. Positive research aimed at understanding existing water management practices can provide valuable feedback to trainers by showing which recommendations are appropriate for specific local conditions and which require further adaptation.

It is well recognized, and important to remember that any plan, set of policies and research agenda must be under constant review and reformulation as new information becomes available. Only in this way can the objectives of government be achieved. The Ministry of Agriculture has recognized this in its Master Planning Organization. The project documents clearly state that the planning effort should be a continuous process that is responsive to development progress and short comings, increased knowledge of resources and understanding of problems, changing economic and financial conditions and changing objectives and priorities.

All of the research suggestions outlined in this report can come under the broad umbrella of socio-economic research in irrigation recommended by the economic sub-committee of the Priorities for Research in Irrig ation and Water Management Workshop held by BARC in October of 1983.

I. Technology development: Pumpsets and Conveyance Systems

Introduction

The team believes there is rather conclusive evidence which suggests that farmers are economic optimizers, both individually and collectively. Therefore, irrigated agricultural development is typically driven in the direction of economic opportunism as conceived by the farmers from their perspective. With years of experience, they already know the value of good soil, water, seed and fertility and are sensitive to the market realities and their own financial constraints. Adding modern pumping plants significantly alters their productive environment but perhaps not to the extent envisioned by the planners.

Along with increasing hydro-agricultural potential, irrigation also increases: the complexity of the required infrastructures, the needed amount of labor and financial backing; the need for new knowledge and techniques; and perhaps most difficult of all, the essential amount and intensity of interaction needed between farmers who are somewhat accidently thrown together into essential relationships which are dictated by the physical hydraulic realities of their irrigation system. Standard benefit/cost analysis does not take into account the fringe or hidden costs of the above realities; furthermore, neither does the analysis consider the real probabilities of realizing anticipated benefits.

To design effective interventions for improving irrigated agricultural performance, we must first understand how well the system is now working in terms of the real economic incentives as viewed from the farmers individual and collective perspective. This understanding must consider all of the hidden costs and constraints on production as indicated earlier as well as the more obvious ones normally considered. We then must design rational cost effective interventions which hopefully will reduce these hidden costs. These interventions must then be treated through action research.

Action Research

Carefully planned action research to test the comparative performance of various interventions designed to improve irrigated agricultural performance would be appropriate in several areas at this time. The interventions tested can be ones which are already actively underway, such as the IMP, CARE, and MAWTS programs, or new interventions, such as the yet to be implemented 40 experimental DTW distribution systems in the WB/DTW II project. The most opportune action research areas include:

1. Economic optimization of pump-engine selection, maintenance, and rehabilitation needs for meeting annual irrigation requirements taking into account annual and perinnial water level fluctuations in the various important agro-climatic and physical environments. Consideration should also be given to the critical need for deep pumping during extended drought periods when the marginal value of water is the highest.

2. Micro-economic constraints to expanding pumped irrigation command areas and an analysis of optimum economic command area sizes for various pumping plants considering: topography, soils, climate, cropping patterns, socio-economic circumstances, land fragmentation, management modes, infrastructural support, and credit availability.

3. Economics of various technological and managerial interventions designed to more fully realize the potential-command-areas of pumped irrigation systems.

Pumping Plant Optimization

The foreign exchange and local costs associated with pumped irrigation is dependent upon both invested capital and operating costs. Thus it is not prudent to operate low efficiency locally manufactured equipment with high priced imported fuel. This should not rule out local manufacture, but it does imply that ample assistance and quality control regulation should be provided to obtain high standards of equipment.

Fortunately pumping lifts in Bangladesh are relatively low, thus, high efficiency operation is not so critical. The initial efficiency of the pumping plant is dependent on: the efficiency of the engine; on the efficiency of the pump operating at the actual lift encountered; and the relative match between the engine and pump. The same total life cycle cost can be achieved over a relatively wide range of options including low first cost (inefficient) pumping plants requiring high operating costs and high first cost (efficient) plants which have lower operating (fuel and maintenance) costs.

Typical pump lifts of both surface and groundwater vary from 2 m to 4 or 5 m throughout the year. Furthermore, at more and more locations, the groundwater reservoir is being slowly depleted, especially during long droughts; in other words, annual recharge is insufficient to replenish withdrawals. Therefore, the pumping lift varies throughout the year and in some cases between years. In addition, crop irrigation requirements vary throughout the year depending on the cropping sequence, weather conditions, and the performance of the irrigation conveyence and application system.

A final variable relative to pumping plant optimization is the change in mechanical efficiency of the pump set with time. As both the engine and pumps become older, their respective and combined performance useually deteriorates. The relative rate of deterioration of the engines depends on the quality of: installat fuels and lubricants, routine service, repairs, and spare parts. The rate of deterioration of the pumps is mostly dependent on the quality of installation and the water pumped. Some attention must be given to lubrication and repair but this is relatively minor. More importantly, impellers are eroded by sand in the water and cavitation. The amount of sand is dependent on the aquifer conditions, the well screen and well installation. Cavitation occurs when the suction lift exceeds specific limits for the pump (usually 6 to 8 m for centrifugal pumps) while the pump is operating. Quite naturally, erosion of the impeller alters the pump performance proportionately. Since the pumping plant characteristics and lift charge over time, rehabilitation is eventually required.

Careful analysis is required to determine:

1. the optimum initial system design options for the various conditions through the country,

2. the relative merits of various management and maintenance programs,

3. the optimum schedule for rehabilating existing and yet to be installed pumping plants.

A considerable variety of pumps are manufactured locally. Furthermore, some engines and motors are partially manufactured locally. First priority should be given to evaluating the suitability of these locally manufactured products along with likely candidates for expanding the list. Assistance should be considered to help manufactures make improvements in the quality of castings and impeller designs to improve pump performance.

Output. Field studies should be carried out to determine the actual performance of existing pumping plants under different operating conditions and management schemes. Thus, based on life-cycle-costing (both in terms of local and foreign exchange criteria) a set of engine (motor) pump combinations should be selected which meet the various pumping demands found throughout Bangladesh. This set of engine (motor) pump combinations should account for the total lift, variation in lift and irrigation requirements throughout the year, and the deterioration of the pump set with time. The outcome of the research will be a menu of engine (motor) - pump combinations that minimize costs under alternative environmental configurations. The information can be summarized by graphing regions of dominance using discharge (cusecs) and head (feed) on the axes. A table can then be prepared showing the user costs for the pump sets in each region of dominance.

By summarizing user-cost information in this manner, gaps in technical design will be readily revealed and priorities for new designs can be established. Continuity of the pump-set spectrum and harmoney with the repair and rehabilitation objective can be simultaneously assessed. This will also facilitate policy evaluation for promoting the appropriate role for the domestic pump industry.

Even aside from policy formulation to encourage appropriate patterns of investment in the future, there is a critical need to develop a maintenance, service and repair and rehabilitation program for the capital stock of pumping equipment already in use. Life cycle costing analysis can also be applied in this case to evaluate repair and replacement options. In view of the large number of pump sets which have recently been put into service and the lack of spare parts and repair service available, development of a repair and maintenance strategy is urgently needed. Pumped irrigation throughout the country may be suddenly jeopordized by what might be called a "time bomb explosion of repair needs" relentlessly ticking away!

Alternative Distribution Systems

Unquestionably water losses along the distribution systems from DTW's, LLP's and STW's limit the potential command areas. It is well documented that losses from the main canals are very large—often exceeding 50% of the water pumped when delivering to the fields at the extremities of the commanded areas. Much of the loss is leakage through various holes in the canal banks (such as rat holes) rather than seepage through the soil. When the canals run through irrigated rice paddies, most of the water lost from the canal is part of the irrigation supply to adjacent fields. While stopping these losses may appear to benefit users at the extremities of the system, it would not necessarily improve or increase the irrigation capacity of a unit of water pumped for paddy irrigation. However, this is not the case when irrigating upland crops.

Canal Improvements

Of course all farmers would like some external agency to improve their water delivery system. The ideal distribution systems being a piped main distribution system which would have minimum seepage losses; present no obstacle to cross, require minimum maintenance, and minimize loss of land for the conveyence systems. The next choice might be a low maintenance lined canal with functional diversion boxes and outlets. With limited losses all users would receive almost equal access to water no matter how far their plots were from the pump set. It is as though all land parcels in the command area were adjacent to the pump. Losses and main canal maintenance are the same for all. Thus, constructing a pucca distribution system should logically result in reducing required outside management inputs and expanding the irrigation capacity from a given water source.

The question is, will it pay to improve the distribution system and who is responsible for financing and maintaining it? It is usually considered unrealistic to expect the farmers to pay for the improvement but they are typically expected to maintain it. Therefore, no external provision is made for maintenance. But naturally the farmers acting as individuals don't respond and unless there is some (usually external) discipline imposed to assure collective action, canal (or pipeline) maintenance is not done. (Pipelines maintenance may induce more collective action because a major break at least affects all downstream users equally !) With the above in mind, if canal improvement is undertaken as a public enterprise, then some rational mechanism for maintenance must also be imposed (set up).

Benefit/cost factors. Under the geological conditions in Bangladesh, where the canal seepage returns to the same aquifer for almost immediate reuse, the benefits of conveyance system improvements can be measured, for the most part, in terms of the effect on the overall cost of delivering water. In other words, the productive value of the water is not important in the decision process, given that existing systems are already in use and considered profitable by the users (even though highly subsidized).

As for the cost analysis, two decision processes are in order: (1) the operational and ownership cost as viewed by the farmers (in which the pumping plants and certain other inputs to the system are highly subsidized); and (2) the real toral cost which include the full cost of all hard and software inputs both by the public agencies and the farmers themselves.

The benefits derived from improving a unit length of conveyence system depend upon: 1) the difference in the rate of water loss before and after the improvement; 2) the length of time each unit length of the system is expected to the conveying water; and 3) the annual cost of pumping each unit of water.

The loss in a traditional channel is a function of the size and shape of the channel and the type of soil and topography it traverses. Through field investigations on existing systems, it should be possible to categorieze losses for different sites in the important irrigated areas. Sufficient research may already be available to categorize losses from potential improved conveyence systems; however, further applied and action research may be needed.

The length of time a given section of the conveyence system will be in operation depends on: 1) the system layout and the position of the section in the layout; 2) the climatic conditions; and 3) the cropping pattern.

The benefit (cost savings) afforded by the lining is dependent on the reduced amount (volume) of water to be pumped. This is equal to the difference in the loss rate times the length of time the section is expected to be carrying water. The cost savings per unit volume of water saved is dependent on: the pumping lift, efficiency, and operating time throughout the year; pumping plant capital and maintenance costs; and fuel costs and engine (motor) efficiency.

Estimating the cost per unit length of improved conveyence system is a rather straight forward process. In the case of open channels, it is the cost per unit length of providing the improved section capilized over its life plus the cost of the required maintenance. In addition, for pipelines, the cost of supplying the required pressure (addition lift) to overcome

pipe function losses must be added. Since pipe friction loss is a function of pipe diameter and flow rate, an optimization procedure is need to minimize the sum of operational and fixed costs in selecting pipe diameters.

Output. Based on the above, a conveyance improvement decision program (computer model) can be developed for guiding decision making. The output of the program can be put into tabular form for convenient field use. Tables can be developed for different climatic and hydrologic regions, soil types, cropping (rice and/or upland) programs, fuel sources (diesel or electric), types of systems, and types of canal linings and pipe.

Pipelines have unique place in affording a means for expanding potential command areas of DTW's and LLP's by providing a means to conveniently convey water to higher ground. For example, many DTW's are sited at relatively low points where the installation of a few hundred meters of pipe will allow the well to serve a much larger potential command area. Obviously LLP's are located at low points because that's where the surface water is- so here again pipe can be very useful.

A point to remember is that improving the efficiency of the main distribution system by adding some improved canal sections is not an "all or nothing" proposition. Only the critical areas such as those sections which convey water most of the time the pump is operating, or channels through high seepage areas may warrant improvement. Furthermore, under many conditions simple compaction of existing channel sections (which can be done by the farmers themselves as part of a maintenance program) affords the most cost effective means for conserving water.

Irrigation of Industrial and Perennial Crops

The record of successful industrial and pernnial crop production around the world clearly shows pattern of heavy investment in research in yield increasing and cost reducing technology. Irrigation has been shown to be an important and critical element of that technology in many locations. Such adaptive research is location specific and must be carried out within Bangladesh.

It is probably a mistake to assume that the new irrigation technologies have no place in a developing agricultu economy. Cost reducing technologies are lowering the cost of plastic pipes and hardware is being developed and can be selecte which will function in adverse situations. It is very predictal that irrigation will be utilized by competing producers of expo commodities if it will lower the average unit costs of productic When the economic circumstances are appropriate irrigation is likely a necessary condition for maintaining a position in today competative export markets.

Objective

To investigate the benefit from increasing the production of industrial and pernnial crops with the new irrigation techniques.

The net-economic benefits to the irrigation of at least tea, jute, and sugarcane within agro-climatic regions of the country, could be investigated. Such systems as drip, and surge might be considered.

The experimental design should recognize topagraphical variation and the source of irrigation water available.

Methodology

A centerpivot and or lined source irrigation system may be used at an experiment station to develop a responsive surface for water and fertilizer. The water treatment variation is obtained by varying sprinkler heads across the pivot arm and the fertilizer trials and crops variety dimension are incorporated within the irrigated circle by water treatment.

Given information on the crop response to water by type and variety under various fertilizer schedules, the cost benefit ratios under alternative system designs can be calculated. These budgets can be subjected to sensitivity analysis to identify critical variables in the investment decision under various technology senarious.

II. Constraints to Command Area Development

Perhaps the most prominent issue in irrigation and wat management policy in Bangladesh is how to achieve the physica optimal command area for each type of irrigation system (low lift pump, deep tubewell, shallow tubewell, and diversi n dam gravity systems). Estimates of achievable command area vary widely. The World Bank has estimated potential command areas of 30 to 50 acres per cusec of installed capacity, while other estimates are as high as 40 to 80 acres per cusec. Actual command areas achieved are also highly variable, and estimates of actual average command areas range from 20 to 30 acres per Whatever the actual figures, there is a widespread perception that installed capacity is being grossly underutilized and that substantial economic gains can be achieved by increasing existing command areas toward the physical maximum. Here we suggest research designed to assess the constraints to command area development in Bangladesh. The objectives of the research can be divided into three sections.

1. Estimation of the physically achievable and actually achieved command area for alternative types of irrigation systems and cropping systems in different agro-climatic zones and estimation of the difference between actual and physically achievable command areas.

2. Analysis of the constraints which cause the divergence of gap between actual command areas and physically achievable command areas.

3. Analysis of the impact and cost effectiveness of interventions designed to increase the effective command area.

The determination of both physically obtainable and actual command areas is a function of the complex interaction of a number of factors, which can be divided into at least four areas, agro-climatic and physical, technical and operational, economic and agronomic, and organization and management. We propose to assess the following constraints on command area development in order to estimate the relative importance of each in determining the gap between actual and potential command area for each type of system.

1. Agro-climatic and physical constraints

It is generally recognized that the potential command area of irrigation systems varies according to the agro-climatic and physical environment of the system. A large body of work has been completed which quantifies the important agro-climatic factors by region, including potential evapotranspiration, soil texture and seepage and percolation rates, rainfall distributions, river discharge, patterns of residual moisture retention, and topography. We propose to build upon this substantial foundation of work to develop a generalizable classification of relevant environments to assess the impact of these environments on potential and actual command area.

2. Technical and operational constraints

Many technical and operational constraints on command area development are cited in the literature on irrigation and water management in Bangladesh, including shortfalls in actual pump discharge due to difficulties in design and installation of pumps; problems in design and maintenance in canals and turnouts; methods of pumping and distribution of water within the canal system; the siting of systems such that there is overlapping of command areas and insufficient area commanded; and the appropriateness of different environmental conditions. These technical and operational constraints on command area development are discussed in detail in Section I of this report.

3. Economic and agronomic constraints

The role of economic and agronomic constraints and fa decision making on water use has received relatively little attention. Operation of pumps is costly, and farmers pay for operation through either flat rate charges per unit of la or through direct payment of operations and maintenano costs. The benefits to the farmer from irrigation are the marginal profits achieved from increased yield from use of the irrigati water. If these benefits are less than the cost of the farmer of using the irrigation water the farmer will choose not to irrigate his crops.

The cost of irrigation water tends to increase, the further the farmer is from the source, due to conveyance losse and additional effort on the part by the farmers to maintain the larger system of channels. In addition, the expected benefits to farmers may decline as the distance from the sourc increases due to increased variability in the delivery of wate as the distance increases. Thus, with costs of water tending t increase and benefits decline with the distance from the sour a point may be reached in the system where farmers choose not t irrigate, despite the physical potential, because it is unprofitable to irrigate.

The marginal net benefits of irrigaion water to the far are a function of many things, including the agro-climatic environment described above and economic and agronomic factors, such as the yield response of the different crops to water and other inputs, the price of irrigation water and other inputs, t price of alternative crops, added labor and management require and the pattern of delivery of water. We propose to attempt th sort out these complex interactions using the methodology described below.

4. Organization and management constraints

There are numerous accounts of organizational failures in Bangladesh water management. Usually these focus on the inability of the farmers to make the system work according to t engineering design. This biases the whole perception of organizations and renders the research of dubious scientific va A methodology is needed which is capable of evaluating the efficiency and equity of organizational performance relative to optimal performance for the members of the community, not relative to an artificial ideal.

A related problem is that research too often focuses on cooperatives or quasi-formal organizations. Complementary research is needed that focuses on the functions of collective action. In water management, it may not be necessary to have a formal organization with officers, elections and the other of government but rather a collective contract with specification of the necessary rights, obligations, and sanctions.

The specific research objectives relative to organization and management constraints are:

a) To compare the efficiency of water management organizations in alternative environments.

b) To compare actual performance with estimated optimal (not designed) performance.

c) To assess the extent of monopoly rents of "waterlords."

d) To document relatively successful institutional arrangements for assessing and enforcing water use charges and other obligations.

System interventions for command area development

Following estimation of the gap between actual and potential command area and analysis of the relative importance of the various constraints on command area development, we will evaluate the possible interventions into the systems which may increase the command area. Among the interventions which will be assessed are the following:

1) Improvement and extension of organization and management of systems.

2) Improved canal maintenance.

3) Improvement of canal systems through alternative types of linings.

4) Use of various quantities of pipes in place of canals for conveyance of water.

5) Alternative water pricing policies.

6) Alternative crop and input pricing policies.

7) Modification of water distribution rules, including rotational and demand based distribution.

8) Modification of pumping operation.

Research Design

In order to carry out this research, we propose a combination of primary data collection and analysis, case studies, and simulation modeling of irrigation systems. The first two activities will provide independently useful results as well as providing required inputs for the modeling analysis. The following activities will be included:

1) Delineation of potential arable area into agro-climatic zones, stratified by rainfall pattern, soil texture, potential evapotranspiration, slope, and elevation. Mapping and estimation of number of acres of arable land within each strata.

2) Design, implementation, and analysis of a sample survey of irrigation systems, stratified by size, type, and organization of the systems and agro-climatic zone. Types of systems to be covered include diversion gravity systems, low lift pumps, manually operated tubewells, shallow tubewells and deep tubewells. Data to be collected include actual discharge at the source, hours of operation and maintenance costs, canal length and design parameters, area planted and harvested by crop, farmer input use and yields, water charges, and soil texture within the command area. Each system in the sample should be visited at least three times to collect data for each crop season (or potential crop season). Analysis of the data will include assessment of relative economic efficiency of the different types of systems in different agro-climatic zones and assessment of the importance of the other factors described above in determining effective command area.

3) Estimation of production functions which incorporate water and fertilizer for the major potentially irrigated crops, including rice, wheat and mustard. Production functions can utilize either the relative evapotranspiration approach or water stress index approaches, but will probably be constrained by availability of existing data. However, if a 2 year research program is feasible a combination of experiments and field surveys could be designed to develop more systematic data on the water/crop yield relationship.

4) Collection of available time series of daily rainfall and estimation of potential evapotranspiration by agro-climatic zones (or collection of data where these estimates are available).

5) Estimation of the private economic returns to farmers for different crops in the identified agro-climatic zones under rainfed and irrigated conditions using the irrigation and farmer survey above together with other available data. Estimation of the social costs and domestic resource cost of production of the different crops taking account of explicit and implicit subsidies and shadow prices of inputs.

6) Documentation of stylized history of water delivery and cropping patterns. For this purpose it is not necessary to measure actual water flow but to develop proxies to distinguish major discrepancies (in e.g. head vs. tail timing and delivery) from relatively minor ones. Explain the observed patterns with reference to technical variables (e.g. pump capacity and reliability, conveyance losses), and organizational constraints. This requires assessing the relative agency costs of available institutional arrangements. Mechanisms will be compared for sharing the financial costs, allocating maintenance and other responsibilities, and enforcing the implicit contracts. Our hypothesis is that where equal sharing rules are close to optimal sharing, then the organization remains viable.

Where an equitable distribution of costs according to benefits implies unequal sharing, the agency (transaction) costs inhibit organizational viability. These organizations are characterized by higher conflict, lower compliance and smaller command areas.

7) The conventional assertion that tubewell owners charge monopoly rents appears to be at odds with the difficulty of collecting user fees from all farmers in the command area, the case of water theft and the various alternative cropping patterns. Fragmentation and the possibility of other water sources also mitigate against monopoly rents. A study is needed that actually calibrates return to tubewell investment in excess of the costs of enforcement and the opportunity cost of capital. The hypothesis is that these returns are higher, the lower are substitution possibilities and the higher are barriers of entry to other sources of water supply.

8) By understanding the relationship of successful institutions for water management, one can better tailor recommended organizational forms to the underlying physical, environmental, and economic conditions. Innovative group contracts, especially these allowing unequal costs sharing in accordance with unequal benefits, may be tried in action research programs on organizational extension. These can be compared to technical options for enhancing the physical reliability of water systems so as to render conventional sharing arrangements more appropriate.

9) An integrated approach to modelling of irrigation systems. The set of research activities described in points (1-8) will provide independently valuable research results. However, to integrate the various thrusts of the research, a framework is needed which can systematically assess the impact of the complex set of agro-climatic/physical, technical/operational, economic/agronomic, and organization/management constraints on determination of command area, yields, and income in the different types of irrigation systems.

It would be very difficult to derive generalizable conclusions about the relative impact of the various constraints on command area development from the set of surveys and case studies alone. The usual difficulties in generalizing from case studies are compounded in the case of irrigation. The complexity of both cross-sectional variation and variation over time in the crop/water environment make it very difficult to analyze the important variables described above. We therefore propose development and application of a simulation model of irrigation systems to assess the constraints on command area

A Simulation Model of Irrigation Systems

In the remainder of this section we describe the analytical structure of the simulation model of irrigation systems. The analytical framework incorporates three main components linking the irrigation system to final farm production:

1) A model of the irrigation system which permits estimation of the daily distribution of water during each season to farms (or blocks of farms) at different locations in the system as a function of the configuration and management of the delivery system at the source, type of canal infrastructure and delivery system specified by design parameters, the water management/ allocation system, and the agro-climatic environment specified by rainfall distribution, soil type and evapotranspiration rate.

2) A farm level water balance model which estimates daily water availability and crop stress for the farms at each location in the system, based on the daily distribution of irrigation water, rainfall, evapotranspiration and seepage and percolation.

3) Production functions for the relevant crops (rice, wheat, mustard, and any other specified) which incorporate the crop stress index, permitting estimation of yields as a function of water availability and other inputs for each farm.

Simulation of a number of seasons for any type of irrigation system using the model provides estimates of the mean and variability of seasonal command area harvested, crop yield, production, and farm income. By systematically varying the canal design parameters, water management methods at the source and in the canal and farms, cropping patterns, price of water, other inputs and crops organizational efficiency, and agro-climatic parameters within the model, it is possible to assess the impact of each of these on water distribution, command area, yields, and income.

Irrigation system model. The irrigation system model in turn has three primary sub-components, water discharge at the source; computation of flows and water losses through the canal system; and distribution of water among main, secondary, tertiary and farm turnouts. Figure 1 gives a simple schematic of the model of the irrigation system. The actual layout depends on specification of system parameters.

Discharge at the source. Treatment of the discharge at the source varies depending on the type of system. Release of water at the diversion dams is treated as a function of streamflow and the discharge capacity of the dam.

For pump systems, more complex rules are specified. Pump discharge rules can be specified based on marginal productivity/marginal cost principles, and on alternatives, such as crop water requirements, fixed rates of pumping per unit of area, or other rules to be tested.

Canal discharge and losses. The model considers three sources of loss from canals: seepage and percolation, evaporation, and spillage, and permits additions to water flows from rainfall. Seepage and percolation losses from each section of canal (i.e., between B_1 and B_2 in figure 1) are computed as a function of wetted perimeter of the canal.

In order to compute the wetted perimeter, Manning's equation is used to characterize daily flows through the canal. This equation (see Table 1) permits computation of depth of water and wetted perimeter in the canal section based on initial discharge in the section, the bottom width of the canal, side slope, hydraulic gradient, and roughness coefficient. These parameters are specified separately for each section of canal. The computed wetted perimeter is then multiplied by the rate of seepage and percolation per unit of wetted perimeter to get actual seepage and percolation loss. The loss rate is determined by soil type in unlined canals or by type of lining in lined canals.

Evaporation losses are computed similarly to seepage and percolation, using Manning's equation to compute surface area of the water in each section. Evaporation per unit area is determined by regional location of the system.

Rainfall additions to the flow are computed based on daily rainfall and the surface area of the water. Spillage is computed as a function of the depth of water above full supply depth, with all water above freeboard lost.

Following computation of these losses, computation of daily discharge at the end of a canal section is straightforward; with the discharge at the B_2, for example computed as

$$QB_{2t} = QB_{1t} + R_t - SP_t - EV_t - S_t$$

Where QB_{2t}, QB_{1t} = discharge at B_2 and B_1, respectively in time t

R_t = rainfall

SP_t = seepage and percolation

EV_t = evaporation

S_t = spillage

Water distribution. The model permits separate specification of water distribution rules at turnouts at each level of the system (i.e. A_1, B_j, C_k in figure 1). Each turnout is specified by size (for example, diameter of a circular orifice turnout) and head at full supply depth. This specification permits computation of discharge through the turnout at any depth of water in the canal serving the turnout. Discharge in the canal, together with the water distribution rule determines the depth of water.

Three distribution rules have been specified thus far. The first is simultaneous irrigation without checking, in which water is permitted to flow continuously through the system. Second is simultaneous irrigation with checking. With this rule, checking of water at turnouts to raise the water level is begun when the depth of water in the canal falls below is specified proportion of full supply depth. The third rule is rotational irrigation, where available water is rotated among different sections of the canal network at scheduled periods during the crop season.

Each rule can be implemented throughout all levels of the system or combinations of rules can be designated. For example, simultaneous distribution could be utilized at turnouts to secondary and tertiary canals, with rotational irrigation among turnouts to farms along a single tertiary canal.

Farm level water balance model. The water balance model converts discharge to the farm as simulated by the irrigation system model to depth of flooding over the size of the block of farms, and utilizes this as one input to the water balance in the field. The daily water balance is then used to compute the number of days of moisture stress in the paddy. The water balance is defined as

$$WD_t = WD_{t-1} + IR_t + R_t - SP_t - ET_t - DR_t$$

Where WD_t = water depth, time t

IR_t = irrigation water applied

R_t = rainfall

SP_t = seepage and percolation

ET_t = evapotranspiration

DR_t = drainage

Irrigation is determined by the distribution of water throu the system as described above. Rainfall is generated from long te time series from rainfall stations in the different agro-climatic zones so that different types of rainfall distributions can be simulated (see parts 1 and 4 in Research Design). Drainage occurs when the water depth is greater than the bund or spillway height o the paddy.

Seepage and percolation. Seepage and percolation of water is primarily a function of soil texture. Three soil textures, lig medium, and heavy, can be designated, depending on percentage clay content. Each soil type determines a seepage and percolation index and volume of water in the soil at field capacity, wilt point, and saturation point. Actual daily seepage and percolation is then a function of the actual water depth relative to these factors and accumulated seepage and percolation. Table 2 presents the set of equations describing computation of seepage and percolation. The equations indicate that at the start of the season, when seepage an percolation has not accumulated, daily SP is high. As water is applied, the index and daily loss decline (Eq. 1). Actual seepage is also a function of amount of water in the soil, decreasing relative to the index as the amount of water in and on the soil decreases (Eqs. 2 and 3) and reaching zero as water volume reaches the wilt point.

Evapotranspiration. Potential daily evapotranspiration for any given location in Bangladesh will be based on computations usin the Penman method for as many weather stations and agro-climatic zones as is feasible. Maximum evapotranspiration is then computed as potential evapotranspiration times the crop efficient, which varies by stage of growth for each crop. Finally, actual evapotranspiration is computed as a function of maximum transpiratio and the volume of water in the soil. Actual daily evapotranspiratio decline as soil moisture content declines below saturation.

Farm decision/crop production model. Simulation of a ful season of irrigation flows and farm-level water balance generates a daily vlaue of water level in farm blocks at each turnout in the system. Based on these values, the farm decision/crop production model determines land preparation start and duration, date to transplanting, moisture stress days during the relevant growth stages, input use and crop production for each farm block.

Land preparation/transplanting. The model determines the date of beginning of land preparation based on soil moisture status. Land preparation start and duration rules will be based on existing farm methods in relationship to soil moisture status.

Crop growth period. When the date of planting or transplanting is set, the remaining stages of crop growth are determined based on typical growing seasons of the specified crop and vareity. In order to assess the impact of water on crop yield during the growth process, a proxy variable for water adequacy is utilized.

The proxy variable used for rice production in the model can be stress days or crop relative evapotranspiration indices. The moisture stress index is computed in the model based on the daily water balance in the field.

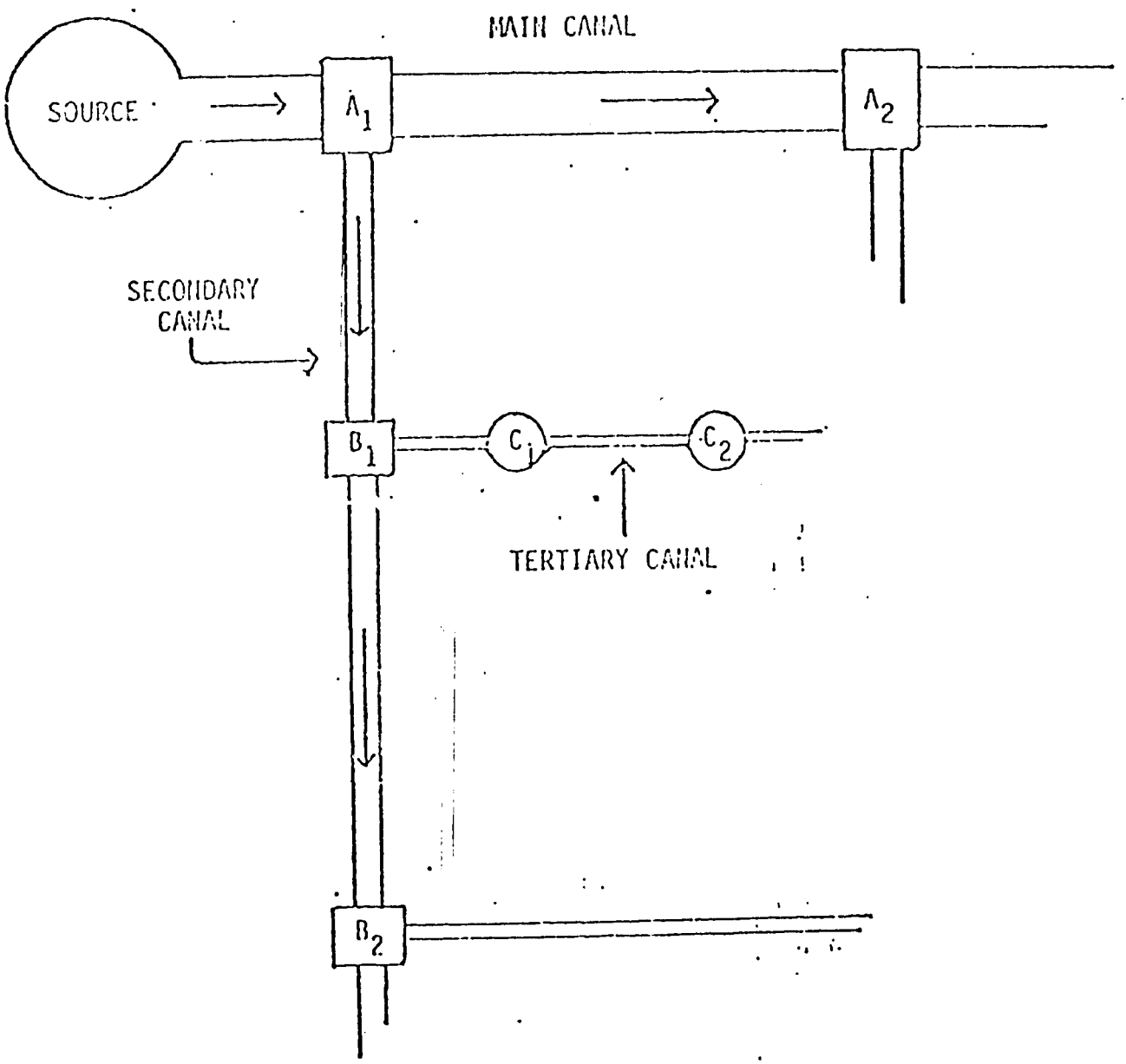
Crop production function. The impact of stress on yields is then computed using an estimated production function, which would ideally include both managed inputs such as nitrogen, phosphorous and insecticide, and agro-climatic variables such as solar radiation and soil texture (see part 3 of Research Design). Operation of the water balance model together with the farm decision/crop production model thus provides the link between the daily flow of irrigation water to the farm and crop production. Irrigation determines,

together with seepage and percolation, evapotranspiration, rainfa and drainage, the daily depth of water in the paddy; the daily water depth determines date of land preparation and transplantin crop growth stages, and water adequacy as measured by stress day and the number of stress days determines the crop yield in combination with the managed inputs and other agro-climatic variables in the production function.

Summary of model input and output. The combined irrigatio system/water balance/farm decision/crop production model can be briefly summarized in terms of its input and output. Input is broadly defined to include the parameters and behavioral rules whi can be specified and varied within the model to assess their impac upon model outputs. At the system level these include storage an or discharge capacity and water allocation rules at the source; li requirements, if any; discharge capacity, bottom width, side slo hydraulic gradient, and roughness coefficient by canal section a all levels; size and head of turnouts and water allocation and rul at the turnouts; soil texture in canals; potential evaporation; a time series of streamflow, reservoir inflow, and rainfall. At the water balance/crop production level, input includes crop and input prices; decision rules for choosing crop plantings, purchased inpu use, and water use; rainfall; potential evapotranspiration and seepage and percolation.

The output of the model is a set of performance measures, including conveyance efficiency of the canal system by section a water use demand and efficiency at the farm, by farm location and crop stage. Final performance measures include total command area irrigated per crop season and crop year; area planted to rice and other crops per season and year; cropping intensity; input use per hectare, per crop, by farm location; yield and income per hectare, per crop, by farm location; and total crop production and income per crop year for the irrigation system as a whole.

Figure 1. Schematic Layout Of A Section Of An Irrigation System



OUTLETS TO:

1. Secondary Canal (A_1,A_2)
2. Tertiary Canal (B_1,B_2)
3. Farms (C_1,C_2)

Table 1. Manning's equation for computation of depth (
water for any discharge level.

$$Q = 1/n\ AR^{2/3}H^{\frac{1}{2}}$$

Where Q = discharge, cubic meters per second (cm/s)

n = roughness coefficient

A = cross sectional area of flowing water, m^2

R = hydraulic radius (A divided by wetted perim

H = hydraulic gradient

Table 2. Computation of daily seepage and percolation.

(1) SP = 10 (SPX + 1.0) - SSP/2.0, bound by SP $\geq$ SPX

(2) SPA = SP + 2.0 SPA (WD/50.0) for WV $\geq$ SAT

(3) SPA = SP (WV - WILT)/(SAT - WILT) for WILT < WV < SAT

(4) SPA = 0.0 for WILT $\geq$ WV

where

SPX = Inital seepage and percolation index

SP = Modified seepage and percolation index

SSP = Accumulated seepage and percolation

SPA = Actual daily seepage and percolation

WD = Water depth in paddy

SAT = Saturation point

WV = Water volume in soil

WILT = Wilt point

Large Scale Surface Irrigation Systems

Large scale surface rice irrigation systems with field to field water distribution are frequently found to be incapable of irrigating design acreage. This failure is most often attributed to (1) faulty main system management and (2) poor on-farm water management practices. Those who subscribe to these views have advocated rather massive investment in rehabilitation efforts. In fact, there has been no systematic line of research which has established with any degree of certainty either of these two conditions.

There are other possibilities besides water management which may provide an explanation of the shortfalls in irrigated acreage. One is that the original designs were faulty and that design capacity never existed, not a surprising outcome when designers are working with an inaccurate data base. A complimentary observation may be that in fact, given the opportunity for a water reuse system to develop, so called illegal cultivation may account for a greater irrigated acreage than the difference between the area irrigated and design acreage.

The implicit assumption behind this suggestion is that a system of cultivators does not waste water if the marginal value of that water is greater than the cost of saving it even if there is no relation between water fees and the quantity used. In other words any water wasted by one farmer will be captured and saved by another neighbouring farmer if the capture returns justify the cost. If this hypothesis is true, then few if any production gains can be achieved by only improving both main and farm system water management. However, redistribution can be accomplished and so called tail-enders, as defined under the original system design can be supplied with water at the expense of the reusers. It is expected that the forgoing hypothesis will hold as a function of the age of the project. The younger the project, the less likely that farmers have had sufficient experience with the availability of "wasted water" for a pattern of reuse to be established. On older systems, one

total unnecessary losses from the system will be minimal.

The preceeding discussion suggests that there is much to be learned concerning the operational efficiency of large scale surface irrigation system. If surface water is to be utilized in Bangladesh, it would be well to carry out research on existing systems to establish the actual irrigation efficiency of the systems given any existing reuse pattern. This would require a total system approach. First, a hydrologic model is needed to (1) account for water into the system from water sources and rainfall, (2) establish total drainage from the system under varying circumstance of water stress. The marginal benefit from irrigation along with the costs of irrigation would need to be established if it were found that water losses from the total system were greater than what might be expected under reasonable assumption of obtainable irrigation efficiency. The marginal cost and benefit data would provide a basic understanding when water would be allowed to be wasted and not be picked up by reuse systems.

Quantification of the marginal benefits of water applied to the irrigated cropping patterns should also be used to evaluate water saving measures such as canal lining. Canal lining costs, especially of surface diversion systems, must be evaluated against the benefits obtained from canal seepage in ground water recharge.

When surface irrigation system (as is also true for well systems) are used to irrigate crops other than paddy, water seepage and canal losses become much more critical. Water reuse systems can no longer be expected to utilized "wasted" water. Canal lining may then be a economically viable option for extending command areas. On large systems, lining may vary as a function of the soil type in given section of the command area and of the cropping

patterns. The research needed for decision making requires the determination of (1) the cost of lining and (2) the value of the water saved in the production of irrigated crops.

There is ample information in Bangladesh and elsewhere to determine crop water requirements on food grains. Given price information and detailed data on lining costs, there is no difficulty in evaluating the canal lining alternative. Also, in some circumstances, if organizational and management costs are considered in the calculus, canal lining may be preferable to irrigation rotation. Additionally, as noted elsewhere in this report, where groundwater conditions permit, well water may be an alternative to canal lining. The relative economics of these alternatives could be included in the research program.

III. An Ecological systems approach to water resource development

The farming patterns which develop before irrigation and a modern agriculture are generally in tune with the ecological system. After irrigation begins, changes in that system irrevitably occur. These changes most often go unnoticed until the emergence of undesirable economic consequences. For example falling groundwater levels may dramatically increase the cost of pumping water. Supply may be exhausted or salt water intrusion foul the wells. Other production systems, such as for fresh water fish, or brakish water marine spawning grounds may be affected. The optimal development path for water resource use requires a holistic view which recognizes the competeing and complimentary dimensions of water use.

The ideal model would recognize the value of water for navigation the net benefits of flood control, recognizing hat flood control changes natural ecosystems in ways that may create negative economic impacts, the value of water in agriculture and fish production and in domestic and industrial use. A fully specified model would include the negative impacts of pollution associated with industrial growth.

Because international development agencies are involved in the development of water resources in India which effect water resource use and the ecological balance in Bangladesh, it is important that the impact of this development be seen in its totality. It seems inappropriate for donor agencies to subsidize water development projects in one country which impose negative externalities on neighbouring countries.

A complete model for a country with the water resources of Bangladesh is a massive undertaking. Useful policy guidelines may be developed initially by attacking the total problem incrementally while retaining appreciation of the need for a holistic overview.

The objective of this research would to be to develop water use models which incorporate water demand and supply factors in recognizable ecological regions of the country. The models would have the following forms:

A. Recognition of the complimentarity between surface water storage and diversion and groundwater recharge. A minimum cost irrigation network which maintained the integrity of the system thru time would be developed. Saltwater intrusion, for example, would be avoided by establishing permissible irrigation levels both within and between seasons and/or by infusions of ground water through seepage- from surface irrigation system which might utilize a combination of river diversion and reservoir storage.

There is work to be done in the development of the theoretical concepts for evaluating these systems. The optimizing framework which would specify the optimal number of pumps, pumping depth and cropping patterns would need to recognize among other things (1) The relationship between depth and size of well and per unit pumping costs. (2) The relative cost of large compared to small distribution systems. (Generally given an equal area, a series of small distribution system from multiple point sources is less costly than a larger system from a single point source). (3) The effect on pumping costs of tapping multiple aquifers such as perched water tables and deeper water. (4) The natural rate of system recharge from rainfall and flood waters. (5) The cost of surface irrigation per unit of ground water recharge from this source. (6) Operational transaction costs under different system designs and (7) The opportunity cost of surface water diverted into the area for irrigation use.

This type of research would best be initiated as a case study. An area of the country which had the following circumstances should be selected (1) known depletion of groundwater under current well systems, (2) the availability of surface water for diversion and (3) the possibility or existence of saltwater intrusion. The research output would provide policy guidelines for investment in irrigation, and for the control of groundwater pumping.

B. Recognition of the effects of the development of irrigation flood control and navigation on fish production. The diversion of rivers and the pumping of water for irrigation from natural and man made impoundments reduces the habitat available for fish production. Alternatively, reservoirs create fish production potential. Alteration in the water environments necessarily effect production and have income effects on fisherman. These effects may result in either increased or decreased net benefits from water resource development. Recognition of the fisheries component of water resource development allows for better estimates of the real benefits from the development.

The possibility exists that river development in Bangladesh and India would alter the brakish water regions of the coastal zone in such a way as to significantly effect that resource which is the breeding ground for a very significant marine fishery. A loss of that resource would be economically significant to the country.

The development of a simultation model based on hydrologic interaction and relative economic values of competing water uses would be useful for formulating policies to guide holistic water resource development.

There is considerable anecdotal information on the effect of water resource development on fisheries development in Bangladesh. There is no systematic line of research which has established the significance of the problem. A base line case study should be carried out in an area known to have competition between fishing and water resource development. A methodology for data collection and evaluation of small scale fisheries has recently been developed by Stevenson, Pollnack and Logan (1982) which is applicable for estimating the net value of the fishery in a given resource area.

The evaluation of the economic consequences of changes in the brakish water coastal zone requires an understanding of the biological system and the value of production. Incremental changes in the productivity of the system need to be weighed against the return from the development activities which are creating those changes.

IV. The role of government policy

The perceived problems with water management in Bangladesh range from reliability of pumping equipment to organizational performance in water distribution and utilization.

As in any country, some problems in resource allocation arise in conjuction with unanticipated consequences of well intentioned public policy. In order to achieve the goals of efficient water resource utilization for improvements in levels of living, a better understanding is needed of the role of government policy in various water management choices. This analysis can facilitate appropriate modification of government policy.

As with the bulk of the other studies proposed, the policy analysis component is envisioned to focus primarily on tubewells. Specific objectives for positive studies of irrigation and related aspects of public policy include:

1. To guage the effect of government subsidies on the rate of tubewell investment, the composition of tubewells (by pump size, type, and depth), placement of tubewells, ownership patterns, rate of explitation of the water resources, and cropping patterns.

2. To indicate the potential response to selected policy reforms.

Heavy subsidies on rental charges of tubewell equipment and interest rates render inefficient placement, inappropriate pump equipment and socially inefficient conveyance and utilization systemsall financially feasible.

Over-exploitation of water resources, known as the "tragedy of the commons," is accelerated by policies that subsidize the cost of pumping water and reduce levels of waterways and water tables.

In order to guage the effects of these policies, a case study is proposed to compare actual investment and water management policies with optimal techniques. The latter will be estimated using the methods proposed in part II above on command area constraints.

Particular emphasis is needed on the recent policy reforms in the direction of privatization. While small tubewells are sold directly to farmers and cooperatives, a number of subsidies and distortions remain in the water supply industry. Tubewell investors are subsidized directly via interest rates lower than the real shadow price of credit, tubewell importers are regulated via licenses and may face increased taxation through import tariffs. Tubewell investment is affected directly by water-use law and indirectly by pricing policies of outputs and farm inputs.

It is important to assess how this mix of policies is influencing the levels and composition of tubewell investment and water use. It is plausible for example that subsidies and import protection to local pump producers can actually increase the total import bill by inducing farmers to operate less fuel-efficient engines. More specifically, an "impact of privatization" study would estimate:

- The effect on the rate of investment in shallow tubewells.
- The effect on command area development under private well ownership.
- The effect on distribution of benefits to farmers of varying economic circumstances. Are poor farmers being excluded from access to irrigation ?

Are private wells developed to serve family, kinship or other natural functioning social groups? It there a natural pattern of cooperation which is utilized with private well development? How does privatization affect contractual arrangements between well operators and water users and to what extent is distributional efficiency enhanced?

Methodology: Determine the following by surveys of tubewell owner/operators.

a) Cost of operators of the irrigation equipment including capital costs, (2) operation and maintenance, (3 depreciation, (4) debt service and (5) rate of default by water users.

b) Contractual arrangements with water users. These contracts may vary by season, crop irrigated, distance from the well-head and other characteristics of the physical and economic environment. It should not be assumed that the contractual arrangement between well-owners and water users is a money charge or percentage of the crop. Labor or other barter exchanges are possibilities. Additionally, well owners may serve as sources of credit for farmers. These linkages between contractual arrangements for water, credit, and labor should be documented.

c) Cropping pattern, production costs, and yields.

It might be expected that the value of irrigation water would vary between regions, crops, seasons and years and that contracts might reflect these differences. The sample of wells studies should reflect these sources of variation. The study should likely be planned for a three year time period to capture between years variation if it develops.

It is very likely that within Bangladesh, relational banking could play an important role in the privatizing of S.T.W. and any other production systems which may be turned over to the private sector. Under this relationship banks would provide expertise in well location, pump matching and distribution system design and layout. A

willingness to follow the approved plan would be condition of receiving the loan. Payment to suppliers would be made throug line of credit established by the farmer after demonstration tl siting and distribution had been met. The bank might als be asked, and it would be in their interest, to provide training farmers on engine use and care and on such items as operating temperatures, selection of lubricants, running schedules most likely to minimize repair costs and so on. These cost reducing practices should decrease the per unit costs of pumping water a increase the total and net return from well operation. Competit between banking institutions could foster the provision of thes training services as banks compete to make loans to farmers.

An action research program of relational banking in a selected case study area would be developed for comparison of tl net return to irrigation in other areas. The compared areas wou need to be in the same agro-climatic region (same soils, climate and access to groundwater) with similar cropping patterns. To t extent that other environmental variables cannot be adequately controlled through the sampling design, proxy variables need to be developed to avoid biased estimates in the statistical analys

The methodology proposed for policy evaluation needs furtl development. Policies can be usefully described and summarized using statisitcal constructs such as nominal protection rates (NPR's), effective protection rates (EPR's), and domestic resour costs (DRC's). Effects of policies can be roughly indicated usir partial equilibrium analysis but further work would be required t develop methodologies capable of properly handling the simultaneo impact of multiple distortions and other general equilibrium effects.

Additional policy analysis is needed in support of the oth sections of this proposal. In technology development, existing methods supporting the local pump industry need to be assessed relative to promising policy reforms. Casual inspection of local produced centrifugal pumps suggest that fuel efficiency could be markedly improved by better casting. Some improvements can be mad through training activities, not only in care and maintenance of pumps and engines but in indicated improvements (eg. filing the rough spots off the impeller blades).

Competition among dealers of pump engines appears to be limited by licensing requirements. The benefits of licensing need to be assessed relative to the costs of higher engine prices and the resources spent on obtaining the political favours associated with obtaining a license. Some observers believe that licenses are necessary to conserve scarce foreign exchange. But since the offic exchange rate is close to the market clearing rate, it is not clear that licenses have a substantial impact on foreign exchange requirements and quite likely that whatever modest savings are achieved are not worth the deadweight loss associated with price distortions and rent-seeking. The methodology developed by Arnold Harberger as extended by Suthad Setboonsarng (for agricultural poli in Thailand) is appropriate for the evaluation of these issues.

Alternative policy proposals for reforming lending policies for tubewells also need to be evaluated. Existing policies subsidiz borrowers both by setting effective interest rates below the shadow price of credit and by selection and enforcement policies which permit a high default rate. The new international thrust towards relational banking is one promising alternative. By expanding and training the technical assistance staff in selected financial institutions, it may be possible to improve the pumping and conveyan technology set in place and thus improve the financial viability of the project. Government can facilitate this process by providing a set of recommended pumps and engines for different types of wells. This reduces the cost to bankks of developing their own criteria for the approval of loans.

Other complementary policy modifications require estimating the divergence between market prices and opportunity costs (shadow prices). Where the policy in question has substantial effects on the use of foreign exchange, the shadow exchange rate becomes especially important. This may warrant special taxes, subsidies or other policies to partially correct for existing distortions. For example, if the shadow exchange rate exceeds the official exchange rate, a subsidy on electric motors (or a tax on diesel engines) may be justified to conserve on imported fuel.

Pricing policies also affect cropping patterns and water use In regions and seasons where the social cost of water is greater than the private cost, it may be prudent to lower the procurement price of rice and to raise the price of wheat and other crops which are supply-side substitutes but have relatively low water requirements. Such adjustments should be modest however, to avoid inefficient transportation of grain and inventory adjustments.

Another area for complementary policy analysis is in the agricultural processing industry. Manufactured products which use agricultural commodities as inputs are twice penalized by existing policy. Non-protected industries are penalized relative to import-substituting industries, which are protected by import tariffs. Exports in general are penalized by import tariffs and other policies that defend an exchange rate which undervalues foreign exchange relative to the undistorted equilibrium.

Several observers have suggested that irrigation development is not conducive to improvements in income distribution. Irrigation allegedly helps richer farmer, leads to land consolidation, converts marginal farmers into landless workers, fosters "waterlordism" and fails to "trickle down" to landless workers. None of these claims has been properly developed either conceptually or empirically.

The recent framework developed by Robert Evenson and Han Binswanger in the Indian context can be adapted to the Bangladesh situation to estimate the income distribution consequences of irrigation. The results from the Indian case are instructive as irrigation helps the poor in two important ways. First, it increases employment and provides upward pressure on the wage rate. Second, it increases food security and real levels of living by decreasing the relative price of rice and other irrigated crops.

Optimal control of groundwater resources: an integration

Spacing requirements in water-use policy and policy instrumer affecting pump capacity, frequency of use and cropping patterns can in principal be used to promote optimal control of groundwater resources. However the optimal control profile depends on a complex interaction involving the nature of the aquifer and recharge mechani the technology available for extracting and conveying water, and the range of choices in water utilization.

Calculating the optimal use profile requires first adapting and extending the principles of renewable resource economics and the applying the principles in selected sites.

Rather than mount a huge modelling and planning effort from the outset, we recommend that optimal use be calculated for one or two specific sites. By actually calculating optimal use patterns and the appropriate instruments for efficient resource management, one can evaluate the utility of this approach and simultaneously provide an example of how the methodology should be applied.

The optimal control framework would draw from all aspects of the research described above. The economic assessment of pumping and conveyance technology is needed to estimate the cost of water delivery under alternative policy regimes. Optimal cropping patterns and expected farmer practices (from section II) are needed to estimate actual draw-down. The ecological aspects of water management (from section III) should be incorporated to expand private cost estimates to reflect the more inclusive social costs. The response to indicated policy changes (from section IV) should be used to sketch the sensivity of draw-down to possible policy adjustments. Accordingly the resource economics approach, even if implemented for a selected region, can illustrate how all aspects of water management can be incorporated to generate a unified policy package.

TRIP REPORT

The following contacts and field visits were made by members of the team:

10 January	Meeting with Ms. Joanne Hale, USAID
11 January	Meetings with Dr. D.M. Daugherty and Dr. Carlos Garcès, IADS, Dr. Corey, Bogor Training Institute, Dr. M.A. Mannan and Dr. Ekramul Ahsan, BARC, Mr. Basset, BRDB, Team Members gave briefing on the assignment to BARC and IADS.
12 January	Meeetings with Dr. Laumark, CARE, Dr. A. Bottral, Ford Foundation, Mr. M. Hyland, UNDP, Mr. H. Brammer, FAO, Dr. G.J. Gill, ADC.
13 January	Meeting with Dr. F. Sheppard, BRRI, Dr. Hannan, BUET. Visit to Deep Tubewell Site.
14 January	Meeting with Dr. C. Garces, Dr. David Gisselquist, IADS.
15 January	Meetings with Dr. Garvey, Dr. Schuy, Dr. Pitman, MPO, Dr. Haque, BRRI.
16 January	Meeting with A.K.M. Jamaluddin, Md. Muzaffor Ahmed, CARE. Visit to tubewell sites. Meeting with Mr. Kader, CARE, Mr. A.M. Anisuzzaman, Secretary, Ministry of Agriculture.

17 January	Meetings with Dr. S.M.H. Zaman, BINA, Dr. D. Cantor and Dr. Miller, IRRI, Mr. M. Taramullah, MANWs, Dr. Boyd Wennerger, USAID.
18 January	Meetings with Dr. M.R. Biswas, Dr. A. Ali, Dr. S. Mandal, Dr. Karim, Bangladesh Agricultural University.
19 January	Debriefing BARC.