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Planning and Policy Analysis for Irrigation with Technical Assistance in Irrigation Economics

by

University of Minnesota
and
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for

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FINAL REPORT TO USAID ON THE
IRRIGATION ECONOMICS PROJECT

The four year project on the economics of irrigation was concluded in September 1983 with a three-day workshop in Khon Kaen, Thailand. Over 50 people attended the workshop from countries throughout Asia. The first two days were devoted to a review of the studies done in India, Thailand, Egypt, and Pakistan. The final day was reserved for papers and discussions concerning future research directions in irrigation.

India

The two-year study of tank irrigation was completed in September 1983. The first year of the study occurred in a normal rainfall year while the second year was a drought year. Only 40 of the 200 irrigated farms sampled in 1981 were able to irrigate in 1982. The 1982 survey was expanded to include 41 additional tanks and raise the total sample to 51 tanks in 1982. However, detailed farm level data was not collected in the 41 tanks. Only secondary data was collected to provide a basis for selecting tanks for rehabilitation.

The survey work was done by Dr. Palanisami from Tamil Nadu Agricultural University. The project supported Dr. Palanisami for a year during the project. He also had a Fulbright Fellowship for six months while at the University of Minnesota and Tamil Nadu Agricultural University supported him during the first year of survey work. He plans to collect another year of data in March 1984. Although the project is no longer funded, we hope to put the three years of data together and analyze the tanks under

three different rainfall conditions. The third year appears to be one of relatively high rainfall.

Rice is the crop grown under irrigation except in very dry years. Yield is very dependent on the amount of irrigation available during the cropping season January-March. In tanks with a dependable supply of water from a river or large reservoir the farmers obtain one or two good rice crops each year. In contrast, farmers served by tanks that are dependent on run-off from the watershed area are lucky to obtain one average crop of rice and in dry years they receive no irrigation water. Thus, ways need to be found to extend the water supply for many tanks.

The detailed analysis of irrigation in ten tanks provided insights into the returns of different investments in tank rehabilitation and management. In tanks that are faced with a shortage of tank water, farmers have organized to more efficiently allocate the limited water supply. In addition, a combination of private and community wells have been used to irrigate after the tank water is exhausted.

A number of key issues have been identified as important for improving tank irrigation. These issues include encroachment of farmers in the water storage area, tank siltation, water user organization, farm size variation, the number of wells, and returns on investments in tank rehabilitation.

Three types of analysis were completed in the study. First, production functions were estimated which included variables for encroachment, condition of channels, water user organizations, etc. Second, the rates of return were estimated for investments in channel lining and community wells. Third, a procedure was developed for selecting tanks to rehabilitate based on tank characteristics.

Results

1. At the margin there are high returns to additional tank water and well water. The price charged for well water was substantially below the marginal value product for well water. Since the charge for tank water was nominal it was also much lower than the marginal value product for tank water. In contrast the analysis indicated that the farmers may be using too much fertilizer. Both findings suggest that farmers need better information concerning water availability and management of their inputs such as water and fertilizer. Technical assistance on water management would be one component.

2. Encroachment of farmers on land that is part of the tank storage area (foreshore area) is a serious problem for many tanks. This became a more serious problem after the sanction of "Kulamlorvai Patta" by the government in 1971 which confirmed the right of farmers to cultivate the foreshore area. Approximately 30 to 50 percent of the water holding area of the tanks are encroached on resulting in a substantial drop in tank storage capacity. In addition, the encroachers illegally release water from the tanks to avoid flooding of their crops. The penalty system to discourage encroachment is not effective. The charges are less than the cost of well water. The conflict between command area farmers and encroachers results in poor management of the tank water.

3. Due to poor tank maintenance silt has accumulated and seriously restricts water availability particularly to the upper outlets (sluices) of the tanks. In several tanks, in the sample, the upper sluices are not functioning or are functioning at less than 50 percent of their original water storage capacity. Hence, there is a large disparity in water supply among farmers served by the different outlets.

4. Water user organizations only exist in tanks with serious water shortage problems. The organizations may be formal (government officials involved) or informal. The operation and water distribution among farmers is more efficient in tanks with water user organizations. They have established rules and procedures for rationing their short water supplies. The maintenance of the tanks and channel structures is also better. Since the water is also more uniformly distributed with water user organizations, conflicts are reduced among farmers. The main purpose of one or two water user organizations was to bring additional water to the tank. This causes a negative externality, in most cases, because the water would have been used by other farmers. In one case, the farmers are being taken to court for water stealing. During drought years such as 1982, tank irrigated farmers, who in normal years have abundant supplies, activated rules and procedures for allocating the scarce water supplies.

5. Normally tanks are classified as system and non-system tanks. However, we found that this classification is not appropriate for studying tank performance. Many non-system tanks have adequate water supplies while system tanks may have inadequate water. Therefore, a new classification is recommended to facilitate tank selection for rehabilitation, that of dependent and independent tanks. Dependent tanks are those with assured water supplies from rivers or other reservoirs during most years while independent tanks are ones which are faced by a wide fluctuation in water supplies. In an average year, tank water in an independent tank will not be adequate to irrigate one crop of rice. The dependent tanks tend to receive more water than is required and farmers over-irrigate their

paddy crop. Many times they obtain two crops. Farmers irrigated by the independent tanks under-irrigate their paddy crop and use wells to supplement the tank water.

Investments to improve tank irrigation must be fitted to the type of tank involved. For the independent tanks, the emphasis should be on saving water and increasing water supplies. For the dependent tanks, ways need to be found for transferring excess supplies to other areas.

6. Several new tanks were constructed in the last decade, two of which were in our ten tank sample. The economic feasibility of these investments was justified by high benefit-cost ratios. However, after construction, these tanks did not provide water to the full command area. At least 20 to 40 percent of the lands in the commanded area were not irrigated because the lands were higher than the reservoir outlets. Under such conditions, the entire command area cannot be irrigated without lifting water with pumps. Consequently, the returns for these new tank investments are much lower than originally estimated and may be too low to justify the projects. This suggests that construction of new tanks is not as good an investment as improving existing tanks.

7. The rehabilitation measures include a wide range of possible investments. In the ten tank sample, two types of investments have been tried. One is to construct community wells and the other is to line channels with concrete slabs. Water saved by lining in one tank was about 20 percent, while the community well irrigated 40 to 50 acres in another tank. The analyses of these two investments shows that the channel lining has a higher pay-off for big tanks while community wells are better suited to small tanks (100 acre command area). Investment priorities need

to be set by individual location and tank. Independent tanks should be given priority as should tanks with farmers who are willing to organize or are organized to improve tank maintenance and water allocation.

8. Given the large number of tanks which could be rehabilitated, a criteria was developed to identify which tanks should be given first consideration for modernization. Six factors were identified as the most important in determining tank performance. These are depth of tank water, farm size variation in command area, encroachment, tank location, tank size, and the number of wells in the command area. Only tank depth and tank location had positive effects on performance while the other four factors had negative impacts. An index was developed based on these six factors which showed that 10 to 12 tanks, out of 48 tanks, should be given high priority for rehabilitation. The next step would be to study these tanks to determine how they should be improved and what the pay-off would be.

Extensions

In South India, there are many possibilities for further work. Given the wide variation in rainfall from year to year, it is important to study irrigation practices over a period of at least five years. At best, we will be able to obtain three years of data. Further analyses that could be done include the following:

1. Study the impact, under different rainfall conditions, of rescheduling tank water deliveries so that they are coordinated with well water use. This should reduce the cost of irrigation and increase the area effectively irrigated. Currently, tank water is applied first and

when it is gone well water is used to finish irrigating. This does not appear to be the optimum method of combining the tank and well irrigation capacities.

2. Study the relative differences in effectiveness of alternative institutions for operating cleaning and maintaining tanks. Several different institutions are used for tank maintenance and these could be compared to determine their relative effectiveness.

3. A study is needed of the effect of government rice and fertilizer policy on tanks irrigated. Some of the inefficiencies we observed in our analysis may be due to the uncertainty concerning government policies which effect both rice and input prices.

4. An analysis should also be made concerning alternative tank water release alternatives. Under different rainfall patterns and tank water rotation schedules, what are the trade-offs between higher production and uniform water distribution among farmers.

5. Further test the criteria developed for selecting tanks for rehabilitation to determine its effectiveness and consistency. Are the weights used for each of the six factors appropriate? Are there other factors that have been left out which should be included? A study of the 12 tanks determined as high priority for rehabilitation would be a key part of the test.

Thailand

In Thailand, the 1983 study focused on estimating the benefits from three small tanks. This was combined with our 1981 studies of larger tanks and river pump systems to provide a better picture of irrigation in Northeastern Thailand. The 1981 field survey of irrigation included four

tanks, constructed and operated by the Royal Irrigation Department, and two river pump schemes, established and operated by the NEA (National Electricity Authority). Three Thai faculty members from three different Thai universities were involved in the project as collaborators and co-leaders of the project. Dr. Jerachone Sriswasdilek is an agricultural economist in the Department of Agricultural Economics at Kasetsart University in Bangkok. Dr. Adul Apinantara is in the Department of Agricultural Extension in Khon Kaen University. Although his Ph.D. is in communications, he has had some coursework in sociology and has considerable rural sociology field research skills. The third member of the group is Dr. Yuavares Tubpun, an Agricultural Economist who is on the Faculty of Economics at Thammasat University. All three of our collaborators spent a short time at the University of Minnesota during the period of May to July, 1983. During this period, which was too short, they finished their computer processing and data analysis. We also planned the September 1983 workshop which Dr. Adul so graciously hosted at Khon Kaen, and held a workshop at the University of Minnesota on "Small Scale Irrigation in Northeastern Thailand."

1981 Study

The projects selected for study were from three different provinces and appeared to have different levels of performance. The farm sample size and projects are listed in Table 1. A questionnaire was administered to each sample farmer. The questionnaire was divided into two parts. The first part dealt with farm management economic information such as crop area planted and harvested, use of inputs, credit, labor, location of land relative to source of irrigation water, method of obtaining irrigation water, and use of irrigation water.

TABLE 1. Irrigation Projects Surveyed in October-November 1981 in Northeast Thailand (numbers of sample farmers in parentheses).

Province	Tanks	Pump
Khon Kaen	Hai Sai (17) Hui Yang (35)	Nong Bua Dee Mee (20)
Roi Et	Hui Aeng (40)	Tha Sub Baeng (22)
Mahasarakham	Hui Kaw (40)	

The second part dealt with sociological and interpersonal behavioral information such as the farmers' perceptions of the adequacy of water, water based problems and conflicts, organizational membership and participation, water charges, cleaning and repair of irrigation structures, farmers' perceptions and opinions on responsibilities and regulations, and interpersonal interactions.

Ms. Kanda Paranakian, a faculty member in Rural Sociology from Kasetsart University who is studying for a Ph.D. at Colorado State University, will be using this data as part of her Ph.D. thesis. A new graduate student at Minnesota, Mr. Keith Fuglie, is also using some of the data to analyze labor use patterns.

Results

1. The degree of water utilization, as measured by cropping intensity index, during the dry season was relatively low and varied considerably among the six projects.

2. Rice yields in wet season in pump projects were much lower than those in tank projects. Therefore, net incomes from rice production in pump projects were lower than those in tank projects.

3. The two main factors causing negative net income from dry season crop production were low yield and high labor costs.

4. Delivery schedules were adopted by most farmers for water allocation.

5. Pump projects were inefficient from economic point of view while the tank projects were economically efficient.

6. The majority of the members of water user organizations (WUO) reported that they derived many benefits from being members, especially in securing water for their crops. Most of them also understood the purposes of establishing WUO.

7. One-half of the farmers participated regularly in cleaning and repairing the irrigation canals, but some participated only occasionally and seldomly. The findings revealed no sanction against nonparticipation in these activities. It is noted that a large number of the farmers in pump projects had never participated in such activities, because they thought they were not necessary since the irrigation canals were "concrete lining". The farmers perceived a high level of benefits from cleaning and repairing the irrigation channels but their contribution to project maintenance either in terms of money or labor was very low.

8. Almost three-fourths of the farmers stated they did not set rules for restricting water use.

9. Generally the farmers rated the level of water supply in the wet season as adequate, but for the dry season inadequate, except for farmers served by the high performance pump project. Those who reported "inadequate water" were the ones whose farms were at the tail-end or far from the canals or were in the upland areas.

10. Regarding the irrigation agent-farmers interaction, it appeared that three-fifths of the farmers had high frequencies of approach to the irrigation agent. Most of the farmers reported high and medium frequencies of contacting with the irrigation agent. The higher the interaction between the farmers and the irrigation officer, the better the knowledge and performance on irrigation practices of the farmers themselves.

11. More than one-half of the farmers practiced dry season cropping, but on a small scale, to supplement incomes and home consumptions. In Tha Sub Baeng pump and Huai Sai tank, the farmers planted dry season crops, mostly for marketing or commercial purposes.

12. There were some problems and conflicts among the farmers in using irrigation water. The major problem was water stealing especially during the first period of rice cultivation in tank irrigation systems. However, the problems and conflicts were few in pump projects. The farmers thought that these problems and conflicts could be solved by cooperation among themselves.

13. The WUO should meet as often and as regularly as necessary, especially before each cropping season. When the members have agreed on a set of rules and regulations, there should be a follow-up in implementation. Since the WUO is only an association for the farmers in the whole command area of irrigation systems, the WUO should be divided into sub-units called Chaek or area served by a farm ditch and a farm turn-out. Chaek group will be responsible for control of water, water distribution and maintenance within the respective sub-unit. The Chaek leader will represent the members in WUO management committee for the whole command area both in pump and tank systems.

Responsibilities and authority of the WUO officers and Chaek leaders, rules and regulations of the WUO should be specifically determined, including sanctions for violators of the rules and destroyers of the system structure.

14. Farmers or the WUO members should have a good knowledge and understanding of proper use of irrigation water for agricultural production and their responsibilities as members of the association. Therefore, training of the water users must be done. Moreover, the farm-level irrigation officers must be well-trained in water management practices to advise farmers on water use procedures.

15. Dry season cropping should be encouraged to fully utilize the water and increase the irrigated area. A closely planned effort for cropping systems and water management should be implemented by the water authorities and WUOs. A two-way exchange of information between farmers and water authorities is needed. To achieve these purposes, all government agencies concerned such as RID, NEA, Department of Agricultural Extension, etc., must share these responsibilities and fully cooperate.

16. An adequate supply of inputs and marketing facilities should be made available to farmers.

17. Although the farmers can improve water deliveries by cleaning and repairing the irrigation channels, either as in groups or as individuals, the water authorities should give technical and financial assistance whenever WUOs express those needs. In the pump project, a stand-by pump should be available at the center in order to replace some out-of-order pumps. In addition, land leveling should be adopted, especially on the undulating and sloping command areas.

Extensions

1. The causes of low rice yields in wet season in pump projects need further investigation. Is flood damage the problem or is it poor management of water supplies? If pest damage or poor cultivation is a cause, then more farmer education is needed.

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2. The reasons for the low dry season rice yield is not known. If it is pest damage then pest control programs should be evaluated. Are there special problems involved with pest control when only a small area is planted. Low yields of other crops may be due to lack of experience or knowledge of improved farming practices. If so, more extension education is needed. The appropriateness of crops planted and the farming systems used need to be examined.

1983 Study

Dr. Adul and Dr. Yuavares have studied three very small tanks in the Khon Kaen area. They are "very small" in that they have less than 1 million M^3 of storage. Tanks of this size do not have an RID staff member stationed at them and, therefore, are truly "communal" systems. The study of these three tanks was in two parts. The focus was estimating the benefits from the tanks in meeting "basic needs". The basic needs include five benefits.

1. Household domestic consumption - drinking water.
2. Household domestic consumption - bathing and laundry.
3. Use for farm animals.
4. Fish production.
5. Irrigating a kitchen garden in a dry season or starting a rice seedling nursery in the late dry or early wet season.

Fisheries faculty members at Khon Kaen University have been very active in promoting fish production in small tanks throughout the northeast and the government is attempting to provide villages with basic water needs.

Students visited each tank one time per week from the first of November through the end of April. They spend one full day each week at each tank. Data was collected at the tank sites on how many villagers come to take water from the tanks, which villages they come from, how often they come, how much water they take each trip, how far it is to their house, how many villagers come to catch fish, what kind of fishing equipment do they use, how many fish do they catch, etc.

In addition, a sample of 128 villagers were interviewed to determine water use within the village and estimate the impact of water on agricultural production. The sample included 45 villagers from control villages which had no tank water supply. The remaining 83 sample villagers were from the three villages next to the three tanks. Forty-two villagers were members of a water user organization (WUO) while 41 were not.

Two approaches were used to measure benefits. The first was based on the change in productivity and/or utility and market values are assigned to these changes. The second approach is based on how much villagers are willing to pay for the water supply.

Results

At least two major conclusions can be drawn from this study. First, benefits from domestic use alone did not meet the economic efficiency criterion for any of the three tanks studied. This suggests that

the government goal of constructing these very small tanks just for storing and providing water for human and animal consumption, with irrigation benefit as a by-product, should be reconsidered. Water supply for domestic use only might be provided cheaper by other means, such as wells. If groundwater is not available, then small tanks may be the only means available. In that case, to be able to pass the economic efficiency test, irrigation should be one of the main objectives, even for tanks as small as 100,000 cubic meter storage capacity. However, having irrigation as a main goal in designing and constructing a tank is a necessary but not sufficient condition for economic justification of the investment. The sufficient condition is that the irrigation water has to be effectively and fully utilized.

This leads to our second general conclusion, that to gain full benefit from irrigation the following four factors are necessary: (1) leadership, (2) cooperative spirit, (3) location, and (4) market and price incentives. At this stage of the research, no single factor can definitely be said to be the most important. The general impression is however, that in the presence of strong leadership, the other conditions can be brought about or their absence compensated for if leadership is strong. Certainly in the three tanks studied, leadership made the difference. A strong leader will also encourage cooperative spirit among the members of the WUO. Examples include the need for owners of the land that will be submerged or used for canals to voluntarily give up the land, the owners of land in the command area to "loan" or rent others use of that land for dry season crops, and the general willingness to cooperate in operation and maintenance that is so important in irrigation.

Location was important in Tank 1 in preventing damage to structure from animals, in enforcing fishing rules, etc. The location of the tanks away from the villages and from personal supervision around the clock seemed to be a drawback in Tanks 2 and 3.

There is no avoiding the fact that a good market, with strong price incentives to produce is crucial in encouraging dry season irrigation.

If the first three conditions are not present then the government should seriously consider not constructing a tank at that location. What can be done then if any of the four conditions are not present in a village or a large group of villages? First, a leadership training program could be initiated. Special educational efforts could also be made to teach or convince villagers of the value of cooperation. Second, marketing advice needs to be made more readily available. The government, possibly with assistance from Khon Kaen University, should conduct marketing studies and price forecasts for dry season crops in the Northeast.

Extensions

1. More work is needed to refine the methods for estimating the benefits from fish production and domestic water use. Long-term visits may be necessary to actually determine the full domestic water use. The one day a week visits failed to capture as much of the water use as we had hoped for.

2. New methods for estimating domestic water use such as willingness to pay surveys should be tried. The results from our study suggest that such methods can be used but needs further modification and refinement.

The results from willingness to pay studies need to be compared with benefit estimates based on market values.

Pakistan

Two types of efforts were directed toward problems of irrigation in Pakistan: direct policy analysis for USAID or the World Bank, and research aimed at a better understanding of Pakistan's irrigation system.

Direct Policy Analysis

Both Young and Nobe were involved in direct policy analysis. During a 1981 trip to Pakistan, Young was part of an interdisciplinary team which helped USAID's mission define priorities for improving irrigation. Nobe's involvement stemmed from his "Overview of Pakistan's Current Agricultural Policy Options," which he wrote for USAID/Pakistan in December, 1982. That experience and his writings on "Management by Results" has resulted in Nobe's current involvement with the World Bank/USAID joint effort to design a comprehensive improvement program for Pakistan's irrigation system.

Young's 1981 trip to Pakistan was part of a team effort, along with Wayne Clyma and Max Lowdermilk, to prioritize USAID's alternatives for aiding Pakistan's efforts to improve on farm water management. Young's contribution to the team's reports and recommendations were memoranda relating to irrigation water pricing and to the proposed privatization of government tubewells.

Nobe's policy analysis work in Pakistan was funded primarily from other projects. However, the Water Policy project did fund Nobe's writing of

papers which detail the "management by results" framework which Nobe and Seckler have formulated as a result of their combined experiences with irrigation systems of the Asian Sub-Continent.

Results

1. A general statement of the "management by results" framework was published as a chapter in a book, Nobe and Seckler (1983). In that paper, Nobe and Seckler argue that development projects often founder from lack of a feedback from end results back to those with overall responsibility for the project. They suggest that projects be designed with a monitoring mechanism which emphasizes end results, de-emphasizing attention to formal relationships between echelons of organization.

2. An application of these ideas to India is given in a 1982 article in the Indian Journal, VIKALPA, Nobe (1982). There, Nobe addresses the need to populate organizations which administer irrigation systems with persons having skills appropriate to their levels of responsibility. The nature of those skills varies with the level of officials in the organization -- the higher the level, the more the skills become management skills, akin to those taught in MBA programs. Because irrigation systems of the Asian Sub-continent are so large, the number of personnel requiring training are on the order of tens of thousands. Although this number seems staggering, Nobe points out that it is unlikely that farmers will be willing to make massive investments in irrigation when the organizations which deliver the water cannot respond to the farmers' needs.

3. These ideas are currently finding direct application in the design of a proposed USAID/World Bank Command Water Management Project for which Nobe was retailed to design the "institutional" component. In particular,

the project objectives include "development of replicable water management techniques ..." and "building within [Pakistan's] provincial [irrigation] agencies ..." (World Bank/USAID Appraisal Mission) a management capacity such as that described in the above papers.

The Research Component

Four lines of research were pursued relative to Pakistan's irrigation system: (1) Hussain's thesis research which included a statistical valuation of water on farms in Pakistan's Sind, N.W.F.P. and Punjab provinces (2) Hussain and Young's study of the costs to farmers of different timing and periods of canal closure for maintenance, (3) Sparling and Renfro's study of water trading on watercourses in Pakistan's Punjab province, and (4) Renfro's statistical analysis of Pakistan's watercourse improvement program. The last topic has, in turn, resulted in methodological work in which Sampath and others have re-examined the production function meth-odology used both in Renfro's work and in previous works dealing with evaluation of similar projects. Sampath has also used a theoretical model to characterize the distribution of benefits from watercourse improvement among farmers belonging to a particular watercourse.

Irrigation Water Values

Two water productivity studies were undertaken. One studied the pro-ductivity of irrigation water from a large sample of Pakistan's farmers, while the other attempted to identify the role of salinity in affecting crop production.

Value productivity estimates for irrigation water are a useful aid in diagnosing the efficiencies in allocating the resource. In cases where

the marginal value productivity is higher than the opportunity cost of supply an additional investment in irrigation supply promises high returns. Since market prices for irrigation water are not observable in Pakistan (or, except in a few cases, elsewhere) information on the economic scarcity of the resource must be derived from other means.

Through the helpful cooperation of the Pakistan Water and Power Development Authority (WAPDA) and the World Bank, we obtained farm survey data from 2,000 interviews with irrigated crop farmers in Pakistan for the 1976-77 crop year. Every eighth farmer on 402 watercourses in the three major provinces was interviewed.

These data were subject to econometric analysis. Various forms of production functions were fit to the data via regression procedures to determine the value productivity of water and other inputs (labor, land, chemicals, etc.).

Results

The results of the analysis from the Punjab and the Northwest Frontier Province show the value productivity of water for the mean levels of application were eight to ten times as large as the cost of obtaining new water from wells. However, in the Sind Province, marginal value was not different from pumping cost (a result hypothesized to arise from the presence of waterlogged and/or salinized soils in that region).

The principal policy conclusion is that additional good quality water supplies (from groundwater, surface water or controlling systems losses) would have important positive impacts on agricultural production.

(It should be noted that the data for this analysis was collected prior to the general availability of new water supplies from Tarbela Dam,

so that the rate of return to new water would be substantially less than the figures reported above.)

A subset of the same data base employed in the above analysis included observations on soil salinity. Production function analysis on these 170 farms yielded estimates of crop yield reduction as related to salinity, when other inputs (water, land, labor, chemicals, machinery) were controlled.

A statistically significant but not overly large crop loss for salinity on the sample farms was identified. A draft report has been prepared, and is being revised prior to circulation for external comment (Hussain and Young, 1983b).

The Economic Costs of Canal Closure

Conveyance systems must be closed periodically for maintenance and rehabilitation. The timing and length of such closures impose production losses on farmers, particularly in areas such as the Indus Basin where water can be usefully applied throughout the year.

A linear programming model of irrigated crop production in the Punjab was developed from farm survey data and secondary sources. Each crop was represented by several alternative irrigation practices, each incorporating alternative dates of water supply. Monthly water supply limits were varied to model different maintenance periods, so as to determine the cost (in foregone production) of alternative closure regulations.

Results

Changes from the present system appear desirable from the user's perspective since net farm income could be improved by changing closure schedules. A draft report summarizing this analysis has been prepared

(Hussain and Young, 1983c). It is undergoing additional revision prior to circulation for external review.

Extensions

Hussain has returned to his post with the Faculty of Agricultural Economics at the University of Agriculture, Faisalabad. His research assignment includes studies of irrigation water economics and he teaches a course each year on the subject of "Economics of Water Resource Planning."

Intra-Watercourse Water Trading

Pakistan's On-Farm Water Management (OFWM) project incorporates several elements including precision land leveling and agronomic extension, but it has become strongly identified with its watercourse improvement program. This program was originally designed cooperatively by USAID and the Government of Pakistan, with Colorado State University and WAPDA (Water and Power Development Authority of Pakistan) as principal agents. From the outset there was concern with effective collective action by farmers -- each watercourse improvement was to be a cooperative undertaking involving farmers served by the watercourse as one entity and the OFWM employees as another. After watercourse improvement, it was expected that farmers would be sufficiently organized to maintain their watercourse in good repair. The importance of farmer cooperation was a central theme of work done by Mirza and Merrey (1979), in which they expressed concern that the Pakistan Punjabi culture was predisposed to conflict rather than cooperation.

Starting with the Mirza-Merrey paper, Sparling set about characterizing the backdrop or private incentives before which farmers in each watercourse play out their particular collective action. Sparling (1981) shows that

cooperation is especially difficult because it embodies asymmetries with respect to the ways in which upstream farmers and downstream farmers view the benefits of watercourse maintenance. It is suggested that, whatever the cultural setting, the asymmetrical collective good problem is intractable because it tends to inhibit agreements based on reciprocity. An unexpected conclusion of this analysis was that asymmetries would be eased by the presence of multiple private tubewells on a watercourse. It is reasoned that tubewell owners typically depend on rental of services from their well to cover the considerable overhead required. Since such transactions are reciprocal in nature, and since the upstream tubewell owner depends upon both the downstream users and the downstream watercourse, he has incentives to cultivate good will by participating in maintenance of the watercourse. Sparling noted that presence of multiple private tubewells on the ten watercourses analyzed by Mirza and Merrey seemed to be associated with better than average cooperation and less than average conflict among farmers.

Sparling hypothesized that watercourses with substantial water trading would tend to have greater success in watercourse maintenance, and in collective action in general. These were hypotheses which Raymond Renfro set out to test in his Ph.D. research in Punjab.

After reaching Pakistan, Renfro amended his dissertation plan to include a statistical valuation of the benefits of an on-going watercourse improvement program. His study covered 20 watercourses and 130 farmers. Although the number of watercourses was twice that used by Mirza and Merrey, it was smaller than originally hoped. This compromise was made in order to accommodate questions needed for valuation of the watercourse improvement program.

Results

1. Renfro's dissertation contains a detailed description of the ways in which the Warabundi system functions in the Faisalabad District of Punjab Province. Included in this description is a discussion of the distinction between two kinds of internal Warabundis: formal (pukka) and informal (katcha).

2. Renfro found that, in spite of formal illegality, farmers were willing to trade turns of canal water -- consistent with the findings of Freeman, et.al. The feasibility of trading was most often limited by willingness of intervening farmers to accommodate to the necessary adjustments in their schedules.

3. It was found that trading of canal turns was more common among farmers who were purchasers of tubewell water than by farmers who did not use tubewell water.

4. There was evidence that frequency of water trading was positively correlated to the number of collective projects undertaken by the farmers belonging to the watercourse (a measure of general cooperation).

Valuation of Benefits from Watercourse Improvement

In order to estimate the impact of watercourse improvement on farmers' incomes, Renfro employed a production function approach similar to that used by Hussain. Gross income per acre was specified to be a function of various per acre inputs, then separate estimates of function parameters were made for various parts of the 130 farm sample: improved versus unimproved watercourses, tubewell users versus nonusers, head versus middle versus tail of the watercourse, etc. Statistical tests were employed to suggest whether watercourse improvement changed the production function.

Absent such changes, it is possible that added water supplies act through the original production function to achieve hoped for increases in farmer income. Evidence of the latter effects was sought in comparison of means and standard deviations in various inputs between improved and unimproved watercourses. In addition, analysis of variance was used to test for complex interactions between variables, and to display gross income per acre for the various partitionings of the 130 farmers.

Results

1. Analysis of Renfro's data revealed consistent evidence that watercourse improvement had a positive effect on gross incomes of farmers on the participating watercourses. There was, however, a general lack of statistical significance attached to these results -- giving room for some concern about the magnitude of benefits enjoyed by participating farmers.

2. There is a possibility that the lack of statistical significance may have been due to the fact that improved watercourses had more private tubewells than did unimproved watercourses. Analysis of variance results indicate that watercourse improvement benefits farmers who do not have access to tubewells proportionately more than tubewell users -- not a surprising result if one accepts the premise that increased water supply is the chief cause of benefits from watercourse improvement. This result was "significant" at the .19 level.

3. The above result would suggest that officials administering the watercourse improvement program should choose those watercourses with fewest tubewells in order to maximize returns to resources used to improve each watercourse. This, however, runs counter to the counsel of Mirza and

Merrey who emphasize choosing watercourses most likely to cooperate successfully: first in improving their watercourse, then in maintaining it. This is not to suggest that OFWM officials consciously choose watercourses based on numbers of private tubewells, rather it is possible that watercourses lacking cohesiveness are simply less likely to "get organized" to petition for inclusion in the OFWM program.

4. Estimated production functions consistently showed insignificant coefficients for canal water and significant coefficients for tubewell water. This result is consistent with findings of Papanek and Mujahid (1983) whose statistical sample covered both time series and a cross-section of agricultural statistics from both Indian and Pakistani Punjab. In that study an aggregate linear model of relating inputs to gross value per hectare was estimated using pooled cross sectional data from the two Punjabs. Interestingly, coefficients of canal irrigation are "negative and almost significant" (p. 428), while the coefficient of tubewell irrigation is positive and significant. While Papenek and Mujahid suggest that their measure of canal irrigation may not have corresponded to per acre water use, they also suggest that the difference between canal and tubewell water responses may be due to the far better control by farmers over their water supplies.

Since Renfro's canal water variables was per acre water delivered to farmers' fields, it is felt that a considerable efficiency premium should be placed on farmer control of irrigation water supplies in Pakistan's Punjab.

5. Renfro's results also showed that the mean gross income per acre for tubewell users was significantly higher than that of nonusers. Further, if the class of tubewell users was partitioned into those who used private

tubewells versus those who used cooperatively owned tubewells, it was found that users of privately owned tubewells were significantly better off. Finally, owners of private tubewells were predictably most advantaged.

Methodological Problems

During the course of analysis it became evident that the method of production function analysis which we had used suffered from either multicolinearity or model misspecification. This directly concerns only those who use the particular statistical methodology employed in Renfro's study. The method has, however, had fairly widespread use and, therefore, the problems we have recognized have indirect implications for persons interested in evaluating projects like Pakistan's watercourse improvement project. Therefore, R. K. Sampath has undertaken a systematic review of the method -- his results are reported in preliminary form in Sampath, et.al. (1983). In addition to identifying inconsistencies in previous use of the production function approach, the paper examines the case for using economic surplus to measure benefits of large irrigation projects.

Results

1. Sampath's investigation of the economic surplus method of valuing irrigation project benefits results in a note published in the American Journal of Agricultural Economics, Sampath (1983a), more detail is given in Sampath and Nobe (1983).

2. Sampath used a similar framework to analyze infrawatercourse distribution of benefits from watercourse improvement. This work is reported in the Water Resources Bulletin, Sampath (1983b).

Extensions

Tubewells seem to be important both as timely suppliers of supplemental irrigation water and as catalysts for cooperation among farmers sharing a watercourse. There would seem to be an argument in favor of examining alternative policies affecting farmer investment in private tubewells. The issue is not clear cut; while it appears that non-owners also benefit from presence of private tubewells on their watercourse, the greatest benefits accrue to tubewell owners. Consequently, there are potentially adverse income distribution effects due to a policy to encourage private investment in tubewells. It appears that research into fractional tubewel technology may be warranted.

Meanwhile, it is also clear that local water storage has a significant payoff -- at least when farmers are able to "store" water underground. Consequently, farmers in regions with saline groundwater are at a significant disadvantage relative to farmers in areas with sweet groundwater. Development of techniques to increase farmer control of irrigation timing in saline areas is, therefore, likely to make significant contributions both to agricultural production and to interregional equity. Research on such techniques should be placed high on Pakistan's agenda of irrigation investment.

Methodological problems uncovered during the course of our study suggest a need to formulate alternative functional forms which allow for a stage I of water production functions. As a first step in this direction we have begun investigation of a generalized exponential production function.

West Africa

Our research on West African irrigation was limited to a survey of ex-post evaluations of irrigation projects for USAID's Africa Bureau, Sparling (1981). Most of the literature available dealt with rice production in Senegal or Mali. The Senegal River Basin does, however, present an interesting comparison between "small" and "large" perimeters. In his literature review of these irrigation schemes, Sparling concludes that "small perimeter" projects were more profitable than large perimeter projects.

In seeking to explain this difference, Sparling suggests that small perimeters were more viable because they were incremental, allowing farmers autonomy to adapt new water supplies to their existing farming systems. In contrast, large perimeters were essentially land resettlement schemes which uproot farmers from their familiar milieu, rendering their previous experience ineffective for making informed decisions on resource allocation. Furthermore, since irrigation projects most often have a common property infrastructure which requires continuous attention to maintenance and operation, uprooting farmers from familiar community ties precludes use of existing social networks for organizing and sanctioning collective action.

The seriousness of the collective maintenance problem in West African irrigation should not be overlooked. It is attested by the large study of recurrent costs recently completed by HIID (1981). Irrigation projects are especially vulnerable to recurrent cost problems because their infrastructure tends to be capital intensive, and because it is vulnerable to

constant deterioration due to the energy and corrosive power of water. The effect of inadequate maintenance can be easily appreciated by cost-benefit practitioners since it is easily possible to cut the life of expensive capital structures by more than one-half.

Extensions

F.A.O. is already conducting studies of small scale irrigation in Africa, and is seeking to establish an infrastructure for training extension personnel in the fundamentals of establishing small irrigation projects. Sparling attended an FAO meeting in Rome during November of 1982 as a representative of USAID. At that time it was suggested that the Water Management Synthesis II project lend support to this endeavor.

Egypt

The research in Egypt was motivated by a request from that nation's Ministry of Irrigation for information on the potential of pricing systems for financing the maintenance and operation of the irrigation infrastructure and for efficiently allocating irrigation water. In order to respond to such a question, it is necessary to first have an empirical model of the effects on farmers' alternative quantities and changing mechanisms for water. Data and research resource limitations precluded a national study of this question, so a case study was chosen. The analysis dealt first with the calculation of marginal benefits and second with the effects of various pricing and revenue-raising schemes.

Marginal, Average, and Total Net Economics Benefit Functions

A linear programming model of farming in the Kafr El Sheikh region in Egypt's Nile Delta was developed and operated for the purpose of estimating

irrigation net benefit functions. (Net economic benefit functions measure willingness to pay for irrigation water supply, and are useful for evaluating supply, reallocation and pricing policies.) The model incorporated a range of potential water use levels for each of the typical crops and adjustments in water use efficiency in order to provide measures of the total, average, and marginal net benefit functions for irrigation water in the region. In the absence of more satisfactory ways of reflecting crop response to alternative water supplies, generalized response functions (from FAO) were adapted to Egyptian conditions. The results were expressed in both social benefits (international prices) and private benefits (governmental prices).

Results

1. The Egyptian government's revenue and pricing policies lower farmer's valuations of water. A high tax burden lowers willingness to pay for production inputs. Long-run efficiency concerns are probably much more important than the short-run distortions in allocative efficiency produced by current pricing policy. The transfer of much of the farmers' surplus out of agriculture reduces the ability of farmers to invest in productivity improvements, including investments in improving water management technologies.

2. Irrigation water in the Northern Delta study area has a high average social economic benefit but a low marginal benefit. Social net benefits may differ from other areas due to regional differences in productivity of the land and cropping patterns. For instance, returns to water in many of the newly reclaimed lands are far less than the estimates in this study. The low marginal value of water is generalizable since aggregate water supply in Egypt is generally considered to be adequate to meet

all present needs. Ongoing water development projects, primarily on the Upper Nile in the Sudan, are expected to keep supply abreast of perceived needs for many years.

3. The marginal social net benefit function can be interpreted as an opportunity cost function when read from right (full supply) to left (reduced supply). This function measures the social opportunity cost of reduced water supply to the study area, which might occur due to increased scarcity. Such a function can be useful in decision-making regarding the relative desirability of the alternative policies of developing new water supply or reallocating existing supply from existing irrigated lands to lands planned for reclamation.

Pricing for Cost Recovery and Efficient and Equitable Water Allocation

Our research effort on water pricing was aimed in determining which of several cost recovery instruments would be appropriate for Egyptian conditions, as evaluated under the concerns for allocative efficiency and equity in income distribution. The full range of instruments that could be considered is quite large, consisting of different combinations of allocative rules, quotas, water charges, and water markets. We have evaluated two broad types of water charges: area-based taxes and volumetric prices. Of these, only the "dual" form of volumetric prices employs the use of water supply quotas in addition to a water charge.

Since the analytical results and price policy implications of the government and market models were similar, the subsequent discussion reports only the findings derived from the market model.

Two levels of cost recovery were evaluated. One level recovers all budget operating and capital costs of providing irrigation water plus the

estimated cost of administering a water pricing system. The other level recovers budget operating costs only. These costs are estimated to be 20 L.E. and 10 L.E. per feddan per crop for area-based charges and 25-37 L.E. and 10-22 L.E. per feddan per crop for volumetric charges.

Single charge instruments (area-based taxes and flat volumetric charges) can usually only guarantee the attainment of one objective. In this analysis, cost recovery is the presumed objective. Dual volumetric charges can be adjusted to pursue two objectives, which are assumed to be cost recovery and allocative efficiency.

The optimal pricing instrument, judged by the efficiency criterion, is the instrument that maximizes returns to land and water in the study area, net of social costs incurred in providing and charging for the irrigation water.

Unlike the efficiency objective, there is no agreed-upon basis for defining an "optimal" equity position. The equity concerns considered here are the distribution of farm income along the watercourses and the differences in per capita income among farms of varying size.

Results

1. An economically efficient water pricing system will equate the marginal value of water in all its uses. When the marginal value of water is zero, then the marginal price should also be zero. It is not surprising then that the results of this study show pricing systems with a zero marginal charge to be most efficient under nonscarce supply.

2. Because of lower administrative cost, area-based charges are more efficient than volumetric charges under current water supply. The flat land tax is the least expensive instrument and has the advantage of

being allocatively neutral. Although crop taxes theoretically can produce allocative distortions, no misallocations were predicted by the model under the range of conditions tested. This result follows from the fact that demand for water in the linear programming model is a step function. In this case, the demand was perfectly inelastic with respect to price (or price proxies) within the range of water charges examined.

3. There were also no differences among the water charging instruments under current water supply according to the measure of income equity. Income equality along the branch canals was achieved by all the instruments. Under constant returns to scale, distribution of income per unit of land will be equal when water is not limiting.

4. The analysis has shown area-based water charges to be more efficient and just as equitable as volumetric charges under the plentiful water supply conditions that are expected for Egypt in the next few decades. In particular, the flat land tax is the highest ranked instrument, using both efficiency and equity criteria. This recommendation rests upon the proposition that water charges will not add to the current agricultural tax burden in Egypt but will be balanced by tax reductions elsewhere. Taxes on farmers in the Northern Delta study area were shown to be high and further increases would worsen long-run distortions in agricultural incentives.

5. Our results show that water supply per irrigable acre in Egypt would need to decline substantially to warrant volumetric pricing. Small farm size is an important factor in the high transactions cost of measuring water and providing it on a demand basis. Land taxes would continue to be an appropriate method of raising revenue but would need to be supplemented with administrative rules for allocating water under conditions of scarcity.

Extensions

The research findings have generated considerable interest in Egypt. Dr. Young has been invited to participate in further studies relating to water valuation and pricing underway at Cairo University. They have supported his expenses for two further trips to Egypt (August 1982 and December 1983) to discuss this work.

A useful further research step would be to confirm the generality of the findings with regard to both valuation and pricing in case studies for other production and cropping situations in Egypt.

Since the administrative cost of a pricing system was found to be relatively high as compared to the immediate gains in water use efficiency, non-price rationing systems deserve further investigation.

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