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ECONOMIC ASPECTS OF MINOR PUMP IRRIGATION DEVELOPMENT IN BANGLADESH

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PREFACE

This report is the result of a 3-week consultancy for USAID from June 24 - July 15, 1983. The general purpose of the consultancy was to assist Dr. Hammond Murray-Rust in the ultimate development of a project identification document dealing with irrigation water management issues in Bangladesh.

I wish to express my thanks to Dr. Murray-Rust and his assistant, Mr. Latifur Rahman for their most helpful assistance and support in providing background materials, arranging for meetings with people in many organizations, and arranging for field visits to Bogra, Rajshahi and Mymensingh.

At the end of three weeks, I am overwhelmed by the complexity of the issues and problems in the area of irrigation water management in Bangladesh, and by an awareness of how very limited my knowledge of these matters is. The purpose of this report is therefore certainly not to provide a definitive discussion of the economics of irrigation water management in Bangladesh. Rather, I have tried to identify what appear to me to be some of the important problems and issues, to suggest questions and possible ways of thinking about these issues, and to indicate, where appropriate, the tentative opinions that I have formed in light of the information available to me at the present time.

INTRODUCTION

This report deals with what may be referred to as the "modern" minor irrigation sector in Bangladesh. Basically, this means relatively small-scale pump irrigation projects. Four types of pumps are generally distinguished in Bangladesh: manually-operated tubewells (MTW), shallow tubewells (STW), deep tubewells (DTW), and low-lift pumps for surface water (LLP). This report does not deal with major irrigation projects (large gravity schemes run by the Bangladesh Water Development Board, which may involve lifting water from rivers into the distribution network by very large low-lift pumps), nor with "traditional" minor irrigation methods (such as the swing basket and the doon).

Manually operated tubewells rely on human energy for pumping water. Most of the pumps that have been fielded to date are hand-operated pitcher-type pumps; however, some work is being done with developing other types of hand or foot powered pumps that would make better use of human energy. Shallow tubewells, as I define them, are operated by surface-mounted centrifugal suction pumps run by either diesel engines or electric motors. Although the actual well may be quite deep (I saw one that was being drilled to a depth of 140 feet), STW are "shallow" in the sense that they are limited to conditions where the static water table is close enough to the surface (generally less than 30 feet) to permit suction pumping. Deep tubewells have submersible turbine-type pumps mounted below the water surface, and thus can be effective at locations where the depth to the ground water is much greater than 30 feet. As in the case of STW, they may be powered by either diesel engines or electric

motors. In contrast to the three types of tubewells, low-lift pumps are used to pump surface water, rather than ground water.

In recent years Bangladesh has experienced a very rapid growth in the minor pump irrigation sector. In the early 1960s, what is now the Bangladesh Agricultural Development Corporation (BADC) fielded a small number of LLP. By 1965 the number of such pumps had reached approximately 3,000. The following decade saw a rapid growth in LLP, with the number reaching 20,000 by 1970, and about 36,000 by 1975 (World Bank 1983, Table 7.23). Since 1975, the number of LLP has remained relatively stable (Table 1). STW and DTW experienced rates of growth roughly similar to each other during the period from 1972 to 1979. In both cases the number of wells in operation rose from about 1,000 in 1972 to around 9,000 in 1979 (Table 1). Since 1979, however, while the number of DTW has continued to increased at a moderate pace, the number of STW has virtually exploded, reaching approximately 43,000 in 1982.

Manually-operated tubewells have also increased dramatically in number in recent years. Small numbers of these pumps were originally installed to provide supplies of household drinking water in rural areas. Farmers, however, were found to begin using these pumps for irrigation purposes. This led to projects specifically designed to make these pumps available for irrigation purposes. From 1975-1980 a joint IRDP/UNICEF project distributed approximately 87,000 MTW (World Bank 1983, Table 7.26); however, a subsequent evaluation study indicated that approximately 60 percent of these MTW were used for drinking water

only, with the remaining 40 percent being used for irrigation (Miyan et al 1980), pp 74-75). Subsequently, a joint BADC/USAID project was established to sell MTW for irrigation purposes. Sales were very limited prior to the 1980-1981 dry season; however, by February 1982 approximately 104,000 MTW had been sold under this program (USAID 1983, p 3).

Data on the area irrigated in the minor pump irrigation sector are neither very reliable nor consistent. "Official" figures on the area irrigated by LLP in 1980/81 range from 1.38 to 1.65 million acres (World Bank 1983, Tables 7.21, 7.22, 7.24, 7.25). Of the total acreage irrigated by tubewells, MTW account for only around 5 percent. Official statistics for the 1980/81 season suggest that about 67 percent of the tubewell area is accounted for by DTW, and about 27 percent by STW (see World Bank 1983, Tables 7.24 and 7.25, and World Bank 1982, p 3); however it seems likely that the figures are biased in the direction of overestimating the relative importance of the acreage of DTW. It appears that in many cases acreages are obtained by multiplying nominal discharge capacity by nominal command area per cusec, rather than by direct measurement of acreage in the field.

Underlying the efforts to promote the expansion of the minor irrigation sector is a concern for increasing food production in Bangladesh, and the concept that a strategy focused on small-scale irrigation investments would provide a quick pay-off in terms of food production. From this concern emerges the general issues of identifying policies and strategies which most effectively utilize the resources

devoted to irrigation. I should emphasize here that consideration needs to be given to the productivity of all resources used in the irrigation process, and not just to the productivity of water.

It seems clear that while rapid increases in production have been possible in recent years simply by the expansion of the number of tubewells, this source of increased production will of necessity become less important in the future, as the potential area suitable for new tubewells diminishes. This again indicates the importance of identifying methods of increasing resource productivity in the future.

One important caveat is in order at this point. In this report I do not consider the question of the appropriate mix of resources which should be devoted to increasing production by irrigation as compared to resources used to increase production in rainfed areas. Although this question goes beyond the scope of this report, it is a significant question, given the importance of rainfed areas in Bangladesh. Any overall strategy towards irrigation needs to take into consideration the relative returns to the resources devoted to increasing productivity in both the irrigated and non-irrigated areas.

Perspectives on Farmer Behavior and the National Economy

Before discussion of several important issues associated with irrigation development in Bangladesh, it is appropriate to outline the frame of reference from which the discussion proceeds. A basic assumption is that in making decisions about their agricultural operations, farmers attempt to optimize. By this I mean that they attempt to achieve as much satisfaction as possible, given the resources available to them, the constraints which they face, and the prices which prevail in their local economy. I am not suggesting, however, that farmers are always successful in their attempts to optimize, and it is important to recognize that when changes in conditions occur, there is likely to be a period (which is sometimes protracted) of trial-and-error learning as farmers attempt to adapt to the altered conditions.

The second point in the frame of reference is a presumption that, with certain important exceptions, the cumulative or aggregate effect of the attempts of farmers to optimize leads to generally desirable outcomes in the national agricultural sector. The exceptions are basically of two types. The first type involves situations where the prices that the farmers face are distorted from their national opportunity costs. This could arise because of government policies; because of market imperfections; or because of externalities in production (i.e., situations where decisions by one individual impose costs on (or provide benefits to) other individuals, but which are not reflected in the prices faced by the first individual). The second type of situation in which the aggregate effect

of individual farmers may not lead to nationally desirable outcomes occurs when the resulting distribution of income is deemed undesirable.

Given this framework, three general approaches to considering how to improve the performance of the minor irrigation sector in Bangladesh can be identified from a national perspective. The first approach involves identifying possibilities for efforts to offset the undesirable consequences of inappropriate prices. The second approach is to identify possibilities for activities which are likely to make individual farmer decisions lead to income distribution consequences that are more in line with national income distribution objectives. The third approach is to identify possibilities for activities designed to remove constraints which limit the productivity of the resources devoted to irrigation and irrigated agriculture.

Important Issues of Minor Pump Irrigation in Bangladesh

Listed below are what I perceive to be significant issues that either are being or should be considered in planning for future directions of activities designed to enhance the minor pump irrigation sector in Bangladesh. Although I have listed them separately, there is a considerable amount of overlap among the issues, which is reflected in the subsequent discussion of them.

A. Utilization of Existing Irrigation Equipment and Infrastructure

B. Institutional Issues

1. Government and Private Sector Roles

   - equipment sales and service

   - management services

2. Allocation of Groundwater Supplies

C. Income Distribution Issues

1. Distribution of the Economic Surplus Created by Irrigation Water

2. Employment Effects

D. Input Supply Issues

1. Mix of Irrigation Technology (LLP, MTW, STW, DTW)

2. Equipment Pricing

3. Source of Power (diesel vs electricity)

4. Credit

E. Agronomic Issues

1. Cropping Patterns

2. Supplemental Irrigation

3. Water Application Rates

F. Data Sources for Economic Evaluation of Irrigation

A. UTILIZATION OF EXISTING IRRIGATION EQUIPMENT AND INFRASTRUCTURE

Perhaps no issue in the development of the minor pump irrigation sector in Bangladesh has received more attention than this one. Typically, the issue is framed in terms of the following question: "How can the command area be increased to a size commensurate with the capability of the equipment which has been installed?" "Capability" is usually defined in terms of a certain number of acres that can be irrigated per cusec of installed pump capacity. One problem with this approach is that there are considerable differences among the quantitative estimates of this "capability." For example, a World Bank report identified "potential" command areas of 30 to 50 acres per cusec of nominal installed capacity, depending on cropping patterns and soil types (World Bank 1982a, p 14). On the other hand, in a report prepared for USAID, comparable figures given were 40 to 80 acres per cusec (Keller et al 1980, p iii). One government official I talked with complained about the confusion created by different sets of numbers being used by various people as the appropriate "norm."

But the more fundamental problem with this formulation of the issue is the inherent technical bias involved. It is presumed that technical capability (perhaps adjusted in some mysterious way for certain human limitations) determines the ideal or optimal utilization of the capital equipment. But there is no more reason to presume that it is economically desirable to utilize equipment to its technical capacity than there is to presume that it is economic to utilize land to its

agronomic capacity (in terms of maximum yields per acre). Just as there are costs associated with achieving maximum yields which may be greater than the value of the increased yield, so too there are costs associated with achieving maximum utilization of equipment which may be greater than the benefit of increased utilization. Thus the question of the optimal level of utilization of irrigation equipment is ultimately an economic question, and needs to be framed in economic rather than in purely technical terms.

Once the economic nature of the problem is recognized, it becomes possible to re-formulate the issue, utilizing the conceptual framework outlined in the previous section of this report, as follows. For a substantial period of time, farmers have been utilizing irrigation equipment at levels that are considerably below the expectations of those involved in national irrigation sector planning. This suggests that under current farm-level conditions, what is apparently optimal from the perspective of individual farmers is much less that what the planners had believed would or should be the case. The issue then becomes one of first identifying whether or not the conditions creating this farm-level optimum imply a divergence from the optimal situation for the nation. To the extent that there is divergence, then questions of how to bring the national and individual perspectives more in line with each other need to be addressed. To the extent that there is no divergence, there is a need to develop an understanding of the conditions which result in the current optimal, but low, levels of productivity. Once this understanding has been achieved, it may then be possible to identify activities that

could be undertaken to change conditions that currently limit the productivity of the investments being made in irrigation.

First I will deal with the question of the possible divergence between the individual and the national perspectives on the issue. Perhaps the most obvious distortion of prices is that resulting from the subsidies on the equipment itself. These subsidies have been particularly large in the case of LLP and DTW. For example, in 1975/76, BADC accounts indicated that the actual payments by farmers for the utilization of LLP amounted to 12 percent of the cost to BADC. For DTW the figure was a mere 2 percent (World Bank, 1982a, p 11). Current arrangements for selling tubewells (as opposed to the earlier policy of renting them) result in prices for STW that are nominally unsubsidized, while DTW continue to be heavily subsidized, with a recommended sale price amounting to only 43 percent of the full cost (World Bank 1982a, p 74). In addition to the nominal price of the tubewells, provisions for the sale of all tubewells involve subsidized credit arrangements which further reduce the effective price paid. For example, for a STW being sold for Tk.30,000, a farmer pays Tk.2,000 as a down payment, and receives a 6-year loan for the balance, paying a nominal rate of interest of 12 percent per year. Not only is this rate of interest much lower than in the traditional (non-subsidized) credit sector, but at recent rates of inflation, it amounts to a zero or negative real rate of interest. (See the section below on credit for a fuller discussion of this matter). Furthermore, repayment of agricultural credit has generally not been satisfactory, with usually less than 60 percent of the loans paid when due, and ultimate repayments tending to range from 60 to 70 percent (World Bank 1983, pp 328-329).

Perhaps less obvious than the subsidy on irrigation equipment is the subsidy that exists on the implicit sale of water rights. Although the right to pump groundwater has substantial economic value, this right is, in effect, given away free to any individual or group who purchases a tubewell. Once individuals or groups have purchased and installed a tubewell, they have in effect obtained the right to pump as much water as they can, paying only for the cost of pumping. Anyone without a pump, or who is unable to become part of a cooperative which has a pump, has no claim to water at the cost of pumping; rather, if he is able to purchase water from some other tubewell owner, he can expect to pay a considerably higher price for the water, reflecting to some extent its economic value in production.

Given the existence of these substantial subsidies on the purchase of irrigation equipment and on the implicit purchase of water rights, what is the likely impact on farmer decisions regarding the utilization of irrigation equipment? Certainly the subsidy can be expected to have a substantial positive impact on the total number of tubewells sold. Although this does not necessarily imply that the utilization of individual tubewells will be reduced, the likelihood of two pumps being installed in an area that could be served by one is increased. To examine the question more carefully, we need to consider the effect on both an individual who is considering the purchase of a tubewell and an individual who already owns one. For a farmer who is considering the alternatives of purchasing a tubewell vs purchasing water from a neighboring farmer, the subsidy reduces the cost of water obtained by purchasing a STW. It is possible

that the subsidy would also reduce the price that he might have to pay for the purchase of water from another STW owner (because that individual also paid a lower cost for the equipment), but this is not certain because of the possibility that the price of the water will be determined more by its value in crop production than by the pumping cost. Thus it seems likely that the subsidy gives a considerable incentive to a potential purchaser of a STW acquire the tubewell rather than rely on the purchase of water from a neighbor. Considering the situation of a farmer who has purchased a tubewell, the subsidy certainly puts less economic pressure on him to expand the command area by selling water, since he may be able to finance the purchase of the subsidized equipment without resorting to selling water. On the other hand, to the extent that there is an economic return to be earned by selling water to cover an expanded area, the subsidy in no way reduces the desirability of earning this return. In fact, by increasing the differential between the value of water in its use in crop production, and the cost of obtaining the water from the ground, the potential for profit from the sale of water is increased.

In the case of a cooperative group operating a DTW, the issue is not the price at which water would be sold, but the cost of water as the area is expanded. The subsidy on the DTW means that if the area served is expanded, the per acre cost of water to the group will be reduced by less than would be the case in the absence of the subsidy.

I suspect that the overall impact of the equipment-cum-water right subsidy has been to reduce the farm-level optimum command area size below the level

optimal from a national perspective. However, we really know very little about the extent to which tubewells have been sited so close to each other that the potential command areas are reduced. Gathering information on this matter would provide a more concrete empirical basis for judging the impact of equipment subsidies on tubewell utilization.

In addition to the price distortion created by the equipment subsidy, the nature of the land market may lead to distortions that result in a difference between the optimum utilization of irrigation equipment at the individual and national levels. The distortion results from the fact that whereas one of the characteristics of a well-functioning market, which leads to the establishment of an "appropriate" price, is mobility of the item traded, land is completely immobile. The result is that a farmer who may desire to purchase additional land in the future can only effectively consider purchasing land located in close proximity to his existing operation. Thus if a tubewell cooperative group decides to expand the command area, they are in effect giving away water rights whose value will translate into a rise in the value of the very parcels of land that members of the original group might be most interested in eventually purchasing. The same consideration would apply to an individual owner of a STW if he decides to sell water but is unable to charge a price high enough to capture the entire economic surplus generated by the water.

Although one hears anecdotal reports -- or simply speculation -- about cases such as this, their empirical importance remains uncertain. Furthermore, it is not easy to see how this particular problem can be overcome, since it appears to be inherent in the way in which implied water rights are issued.

Having dealt with questions of the possible divergence between what is desirable from the individual and national perspectives, it is now appropriate to turn to an examination of the factors which may result in the optimum level of utilization of irrigation equipment, even when viewed from a national perspective, to be relatively low. The first factor to be examined is the relationship between the cost per unit of water delivered to the field and the size of the area served. It is commonly assumed that because of economies of scale and the spreading of fixed costs over a larger area, the costs of water decline as the size of the area increases. Some of the analysis and reasoning on this matter appears to be faulty, however, and it is not clear that costs will be reduced as area increases.

First of all, depreciation — the rate at which the capital cost of the equipment is used up — is largely related to the number of hours of pumping. And since the number of hours of pumping needed per acre is likely to rise somewhat with an increase in area (due to greater conveyance losses in the longer channels needed to serve the larger area), it is not clear that beyond a modest sized command area there are any significant economies of scale associated with the capital cost of irrigation. As far as capital costs are concerned, the major advantage of a larger command area would appear to be that it permits the spreading of the cost of financing the equipment.

Secondly, most of the operating costs are likely to be largely a function of the number of hours of pumping. Fuel and repairs are obvious cases, but other expenses such as the cost of a pump operator and labor

for distributing the water are likely to be roughly proportional to the area served. Thus, for example, if the pump is run 16 hours a day instead of 8 hours, additional labor will have to be hired to operate the system.

To clarify and investigate the points made above, some crude illustrative calculations are presented for STW in Table 2 and for DTW in Tables 3 and 4. As indicated in the footnotes to the tables, the calculations are based on reasonable estimates of capital and operating cost components taken from World Bank (1982a) and Hanratty (1983). One critical point which has not been taken into consideration in other reports I have been able to find is that the length of life of the pump and engine will be related to the number of hours it runs. In the calculations I have assumed that doubling the number of acres served by a pump (which more than doubles the number of hours of pumping per season) will result in reducing the number of years of life of the pump and engine by half. I have also assumed that all operating costs (including such things as the wages for the pump operator) will vary in direct proportion to the number of hours that the pump is run. This assumption may not be entirely valid, and it would be useful to obtain some additional empirical information on this question. (It seems possible that data that CARE has gathered in its project could be useful).

Finally, I have added a critical assumption that as the area served by a single pump increases, the proportion of the water pumped that actually reaches the fields is reduced, due to the increased conveyance losses through the longer channels. Little empirical information on conveyance losses exists, and this is another area where it would be useful

to collect more information. For purposes of the calculations in Tables 2 - 4, I have assumed that 10 percent of the water pumped is lost in conveyance when 10 acres are served (i.e., a conveyance efficiency of 90 percent). Each doubling of the area beyond 10 acres is assumed to reduce the conveyance efficiency by approximately the square root of 2. Thus the conveyance efficiency is assumed to drop to 0.8 when 20 acres are served by the STW. For the DTW serving 40 acres I have used a conveyance efficiency of 70 percent, which then drops to 50 percent when the area is expanded to 80 acres.

Two sets of calculations are presented for the DTW. In Table 3 the capital cost of the DTW is based on the estimated full economic cost of the equipment, as reported in the World Bank report (World Bank 1982a). But since the government subsidizes the cost of DTW, the calculations in Table 4 are based on an assumed 57 percent subsidy of the capital cost. This figure is based on a recommendation that a 57 percent subsidy be given in order to equalize the estimated cost of water from STW and DTW (World Bank 1982a).

Although these calculations are illustrative and not definitive, they do suggests that there may be very little cost advantage to increasing the utilization of STW and DTW. For STW, the calculated cost per acre served (in terms of the present value of all capital and operating costs incurred over a 12 year period) is virtually identical for command areas of 10 and 20 acres. The same is true for the DTW at full cost. In the case of the DTW with 57 percent of the equipment cost subsidized, the calculated cost per acre for a command area of 80 acres is about 15

percent greater than for a command area of 40 acres. The reason for this result is that the subsidy, by reducing the financing cost, reduces the benefit of spreading the cost of financing over a larger number of acres. As a result, the benefits of spreading the financing cost are no longer great enough to outweigh the increase in the per acre operating costs.

It is thus not at all clear to me that either from the perspective of an individual farmer, or from a national perspective there is any substantial cost saving associated with the utilization of irrigation equipment at a level approaching its technical capacity. The importance of this point cannot be overemphasized. If there are no substantial cost savings to be realized from efforts to expand command areas from their current typical levels, then the substantial expenditures being made in this direction may be ill-advised. I therefore strongly recommend that additional information permitting better quantification of the factors involved in this issue be obtained.

Another consideration in understanding the economics of low rates of equipment utilization is the risk of yield loss or crop failure due to mechanical breakdowns. The more hours the pump is run, the greater will be the expected rate of mechanical failure per season. If repairs are difficult to obtain, and delays in obtaining them are common (as apparently has been true in the case of BADC-owned DTW), then from both the individual and national perspectives it may be economic to keep the area served lower than would otherwise be optimal. The relevant consideration in this case is to maximize the expected returns after deducting the expected losses due to mechanical failure. In this regard, it would also be noted

that the greater the number of hours per day that the pump must be run under normal conditions, the less is the ability to "make up" for a period of down time by extra pumping after the repairs have been made, and therefore the greater will be the yield losses that can be expected from any given amount of down time.

Another factor in understanding the economic logic of low utilization of irrigation equipment has to do with the costs of organizing and operating a tubewell to cover a large area. It seems likely that these "transactions costs" associated with an expanded command area are quite high. Given the small average farm size, expanding the command area requires dealing with a large number of individuals. Not only is this time-consuming, but the larger the number of individuals to be included in the command area, the greater the likelihood that there will be serious conflicts (stemming from both irrigation-related and non-irrigation-related matters) among these individuals. Negotiations over the location of the increased number and length of channels to convey the water will be difficult, and considerations related to the pattern of land-holding boundaries may increase costs by making it difficult or impossible to lay out straight channels. Another component of these transactions costs involves the management effort. As the number of farmers and the size of the area to be managed increased, the complexity of the management input increases. Communication becomes a greater problem as both distances and the number of farmers increases. All of these transactions costs are, in a sense, "hidden", in that they are generally not included in financial cost calculations such as those presented in Tables 2 - 4. Yet they are

real costs, both to the individuals who must organize and operate the expanded command area, and to the nation as a whole.

It should be pointed out that from the perspective of individuals, the economics of equipment utilization will be influenced in a very important way by the institutional arrangement associated with ownership of tubewells (and thus, by implication, ownership of water rights). If the ownership of the tubewell is communal, in the form of a cooperative, then cooperative members will be influenced in their decisions about expanding the command area by the impact of such expansion on their costs of water. If, as suggested in the above discussion, there is little or no cost reduction on a per acre basis, then the coop members have little or no economic incentive to expand the command area, especially as they are the ones who are likely to have to bear the transactions costs of organizing the expanded area. On the other hand, if the ownership of the well is individual (as appears to be the case for many STW and may also be the de facto case for some of the DTW), then the relevant economic consideration is not simply the impact of the expansion on the cost of water, but rather is the differential between the cost of water and what it could be sold for. It would appear that irrigation water is a valuable commodity on which an economic surplus (i.e., a return above the cost of production) can be earned. Thus an individual owner of a tubewell may find it attractive to sell water to neighboring farmers at a price which is far enough above his costs (including his transactions costs) to make it worth his while to do so.

Unfortunately, we know relatively little about the private water market. Some information on the water market was reported by Hamid et al 1982, and in conversations with Professor Mandal at BAU I learned of some information of a related nature that he had gathered in connection with a LLP scheme. It would be very useful to have more systematic information about the private water market, and perhaps studies of it could be encouraged. Such studies should focus on the cost of water to the seller; the value of water to the purchaser; and the price for which the water is sold.

Having considered the economic factors underlying current rates of utilization of irrigation equipment, I now turn to consideration of possible approaches to changing some of the conditions which result in low productivity of resources devoted to irrigation. In this regard, a distinction needs to be made between areas where STW are feasible and areas where the depth to the water table is such that only DTW are feasible. In the former area, STW can be considered as a potential substitute for DTW. (In fact, it seems unfortunate that DTW were ever installed in areas that are suitable for STW, considering their considerably higher costs of producing water). Thus, in these areas, any effort to increase the utilization of DTW must, if it is to be economically viable, result in water which is provided to additional areas at a lower cost per acre than water could be provided by the installation of additional STW.

I have identified four general categories of approaches to increasing the productivity of the resources used for irrigation. These are physical, technical, management and market approaches.

Physical. Two physical approaches that are being considered in Bangladesh are buried pipes and channel lining. The attraction of the buried pipe approach is that by making water available at various specified points in the command area of the tubewell, the number of farmers who are served by a single point of access to water is limited. This reduces the organizational efforts necessary for the distribution of the water. In fact, the system would appear to mimic the situation that would exist with a series of STW. But it would appear that the costs of such a system are very great — certainly much greater than the cost of installing additional STW. Thus this system would not be appropriate in areas where STW are a viable alternative. Even in areas where STW cannot be utilized, the capital costs are likely to be too great to make the approach viable.

Channel lining is also quite expensive, although if it is done with low-cost materials, and on a selective basis, the costs can be reduced substantially. Some recent work at BAU reported to us by Professor Biswas at a meeting with him and his colleagues suggests that in the area in which they conducted their study, brick channels with cement linking are not economic when compared to the alternative of compacted earthen channels.

A third physical approach which might be mentioned is that of "land consolidation". As undertaken in Thailand, where the approach has been used fairly extensively and apparently with considerable success, land consolidation involves land levelling, the construction of a network of distribution channels, and consolidation and realignment of

land holdings. This approach, as it is done in Thailand, is also very expensive -- particularly because of the land levelling component -- and probably would not be economic in areas where STW are a viable alternative. (In Thailand the approach is used in areas which are served by large gravity-fed irrigation systems). Under the conditions in Thailand, approximately 4 percent of the total land area is taken for channels, and because of the realignment of property boundaries, this land cost is spread evenly among all the farmers, with each farmer receiving approximately 96 percent of the amount of land he previously held. Surprisingly, the program has apparently been popular enough in Thailand that groups of farmers have come to the government requesting that their areas be targeted for land consolidation.

It seems quite possible that land consolidation -- particularly in the precise form used in Thailand -- would not be politically or socially viable in Bangladesh; however, it might be an approach worth some investigation. One of its attractions is that if it is acceptable to the farmers, it can be a method of relieving the constraints imposed by small scattered parcels. It would also allow for a network of irrigation channels to be built without the burden of the cost of the land used for the channels falling only on those who happen to own land in the locations where the channels are needed. If land levelling were to be done, it would seem appropriate to consider using human and animal labor, rather than mechanical equipment as is done in Thailand. This would have the added attraction of providing some rural employment. I must emphasize, however, that this can be expensive approach to irrigation,

and I seriously doubt that it could be economically justified in Bangladesh.

Technical. It would appear from what little information is available that in many cases the actual pump discharges are considerably below the expected or rated amounts. Thana reports on the CARE projects for the 1981/82 boro crop report the average discharges of nominally 2 cusec DTW as follows: for 75 DTW in Dhamrai, 1.66 cusecs; for 51 DTW in Joydebpur, 1.53 cusecs; for 10 DTW in Rajshahi, 2.11 cusecs; and for 44 DTW in Parbatipur, 1.61 cusecs (USAID Files). In work done by the Bangladesh Rice Research Institute, the measured discharge of 5 DTW in the Joydebpur area, each with a 2 cusec rated capacity, averaged 1.39 cusec at the time of measurement in the 1978/79 boro season (BRRI 1982, p 25). In another experiment conducted by BRRI in the 1979/80 boro season in the command area of a single DTW, the measured discharge was 1.2 cusec for a pump nominally rated at 2 cusecs (BRRI 1982, pp 55-56). The average discharge in 11 DTW in Dhamrai measured by Islam in the 1978/79 season was 1.74 cusecs (Islam, 1980). Finally, as a part of the recent Diagnostic Analysis Training Course in Bangladesh measurements of discharge were made on 5 DTW with a nominal rating of 2 cusecs. The actual measured discharges ranged from 1.0 to 1.3 cusecs (Oad 1983, p 5). The reasons for the discharges being low relative to the rated capacity are not clear; nor is it clear whether it would be economically feasible to take whatever action would be necessary to bring the discharges closer to the rated levels. But it certainly would be useful to identify the causes of the low discharges, so that the nature and cost of possible remedies could be evaluated.

Management. Under this approach, an attempt is made to provide management services to assist the farmers in overcoming some of the organizational and other constraints to increasing the area served by a tubewell. This approach is best typified by the work that CARE is doing in coordination with BADC and the Bangladesh Krishi Bank (BKB) under the Deep Tubewell Irrigation and Credit Program (DTICP). The approach includes among other things the provision of general agricultural extension assistance to the farmers; careful cost accounting of both individual and group water costs; and provision of assistance in the management of the distribution of the water.

The DTICP appears to have been quite effective; however, the provision of such management services is also costly. Although CARE is now charging, in at least some of its projects, Tk.100 per acre for the management services, the total costs are greater than this. It would be useful to develop estimates of the cost of such services, and I presume that from the data which CARE could provide, some reasonably careful estimates of the cost of such services could be made.

Any evaluation of the costs and benefits of this management approach to the better utilization of irrigation resources will be complicated by the fact that some of the services provided are general agricultural extension type services which presumably could be reasonably effective in increasing yields even under non-irrigated conditions. Another complication in evaluating the costs and benefits of such an approach has to do with the question of what portion of the costs can be considered to be an investment in "human capital" as opposed to being simply an annual

cost of management. To the extent that these services are developing the ability of the farmers to undertake some of these management functions themselves, then at some point it should be possible to reduce the expenditures being made without a reduction in the benefits flowing from the improved management.

I should also point out that part of the success of DTICP is undoubtedly due to the ability of those in charge of the project to "go to the top" and get action at high levels within BADC and BKB when problems arise at the field level. This is a type of "management service" which must be regarded as unique to the situation of a foreign-based organization working on what is essentially a pilot project. Given that it is unlikely that this aspect of the management service could be duplicated in a larger regional or nation-wide project, it is to be expected that the results of efforts to duplicate the project on a large scale will be less satisfactory than the results which CARE has achieved.

Market. It is commonly pointed out be economists that one of the reasons that the resource such as water is used at a low productivity level is because the users do not pay an appropriate price for the resource. To the extent that water has a value in production which, at the margin, is considerably higher than the cost of obtaining it by pumping, farmers who pay only for the cost of pumping the water wil tend to fail to use the resource as economically as desirable. If, however, a private market for water can be developed, then a farmer who owns a tubewell has, in addition to the ability to use water on his own farm, the alternative of selling water to neighboring farmers. This is

likely to raise the effective price of water toward its marginal value in production. For the farmer who owns a tubewell, the water now has an opportunity cost to him which is equal to the price for which he could sell it. One can expect that this will encourage all farmers to use water more economically.

Although there may be some troublesome equity issues associated with this approach, they are more a result of the way in which implicit water rights have been distributed than they are the result of the existence of a water market. The very limited information available suggests that water markets are developing among some users of STW (Hamid et al 1982).

B. INSTITUTIONAL ISSUES

B.1. Government and Private Sector Roles. The decision of the government to permit and encourage more active involvement of the private sector in providing equipment sales and service is a significant one. In general, given the well-known bureaucratic difficulties associated with the provision of these services by the government, the decision seems well-advised from the point of view of encouraging the rapid expansion of irrigation. However, important roles for the government remain.

In the area of equipment sales, it seems that the private sector is well-equipped to provide the needed services as long as government policies permit economic viability. There is some concern about distorted incentives resulting from inappropriate government policies. For example, it appears that government tariff policies have the effect of economically discriminating against the domestic manufacture of irrigation equipment. Certainly an examination of the tariff structure and its rationalization to avoid this type of situation should be undertaken. It is my understanding that within the Planning Commission such a review is currently being undertaken with assistance from the Harvard Development Advisory Group.

There is a greater concern about the ability of the private sector to perform adequately in the area of equipment service. The problem of service is compounded by the large number of different types of equipment (particularly engines and motors) which are being sold.

One company (Bangladesh Deutz) has recently established a service center for the Northwest region of the country, where some 50 to 60 of its engines have reportedly been sold. It seems likely that about such a number of pump sets is necessary before it becomes economic for a company to provide this type of service. When a large number of different makes are allowed to be imported and sold, it is possible that in a given area the total number of pumpsets in use would be enough to warrant the provision of a service center, but the number of pumpsets of any single make is too small to justify any single company providing this service. This would appear to be an area where it might be useful for the government to consider taking some policy action to try to limit, to a reasonably small number, the types of pumpsets allowed.

Given the rapid increase in the number of tubewells that are being installed, one can expect that there will be some shortages of trained mechanics. Although this may not be a severe problem at the present time, at least in parts of the country, it may become a greater problem in the near future as the pumpsets become older and are in need of more frequent repair, and eventually of more complete overhaul. Consideration should be given to studying the supply of mechanics, and of the anticipated demand for their services. Training programs, including arrangements for apprenticeships, could be developed. Educational and training materials could be prepared and distributed to existing as well as to newly-trained mechanics. The training program should emphasize the teaching of skills needed for repair of several different types of commonly-used pumps. By doing so, the

training program would increase availability of competent mechanics especially in those parts of the country where no company had yet found it feasible to establish a service center for the type of pumps that it sells.

The supply of spare parts is an important consideration in evaluating how well the private market can support the irrigation sector. It appears that there is a considerable potential for the manufacture of spare parts locally, and we were told in several locations that farmers can buy many locally-made parts in the market. Some concern about the quality of these parts was expressed by some people; however, I am not qualified to judge the importance of the quality issue. If it is a serious problem, it might be possible to arrange to provide some technical assistance to the manufacturers of the spare parts in order to upgrade the quality. I would point out, however, that it should not automatically be assumed that poor quality is economically undesirable. If a locally manufactured part that will last only 75 percent as long as its top-quality imported counterpart costs only one-third as much, it may be economically desirable for the farmer to use the lower quality part.

In addition to the sales and service of equipment, there are significant questions about the roles of the government and private sectors in the provision of management services to farmers and groups of farmers irrigating from pumps. It appears to me that this is an important area that needs to be developed over the next five years. It is also

probably an area where it is appropriate for both the government and the private sector to be involved.

Some work in this area is, of course, already being done. The Integrated Rural Development Board (IRDB) through its Integrated Management Program (IMP) apparently provides some aspects of what might be included in such management services, but its approach seems to be limited mostly to administrative and organizational questions, particularly in relationship to cooperatives. I have no clear picture of the effectiveness of this service; however, one serious weakness appears to be the lack of expertise to deal with technical management questions. Another potential problem is that the IRDB activities appear to be closely tied to cooperatives, while it appears that many of the tubewell operations are basically in private hands. For example, in a study of 41 STW it was found that only one was owned by a group of farmers, and even in that case the cooperating farmers were closely related (Hamid et al, 1982, pp 170-171).

Related to the IRDB activities is the approach used by the Rural Development Academy at Bogra for training for the provision of services for management. This approach appears to put great emphasis on the development of a detailed plan of physical and organizational structure with minimal input on the part of the farmers. For example, in the training manual used at Bogra, a 7-step procedure for command area development is identified. "Meet the Farmers" is step number 4, which comes after the completion of development planning of step 3 (which includes planning for channel construction, cropping systems, and the

organization of the farmers). Experience from the Philippines suggests that great success is likely if the farmers are brought into the process much sooner. (See Bagadion et. al., 1980 for a discussion of this experience).

An alternative approach to the provision of management services is that used by DTICP, discussed above. It would be useful to have a careful documentation of exactly what services are being provided under this project.

There also appears to be a potential role for the private sector in the provision of management services. Although information is very limited, it appears that in at least some areas, this is occurring. Dr. Mandal of Bangladesh Agricultural University (BAU) informed us that he had investigated an area served by a LLP where the farmers had contracted with an outside entrepreneural group to provide a total management package that included the operation and maintenance of the pumps. The management group agreed to provide the farmers with adequate water for the crop (which was boro rice) and to pay for all of the costs of doing this. In turn, the farmers agreed to pay from 6 to 7 maunds of paddy per acre. Hamid also reports on some arrangements for the sale of water in the case of STW where it appears that the seller agrees to provide a package of services by contracting to provide the water necessary for the crop, in exchange for either a fixed payment for the services, or a share of the crop (Hamid et al 1982).

It should be noted in passing that a payment arrangement that involves a share of the crop rather than a fixed payment is not necessarily inequitable, although I presume it is the specter of such

an arrangement which leads to the concern about "waterlords" expressed by various people. The advantage, from the perspective of the farmer, of the share arrangement is that it gives the provider of the management services an economic stake in the quality of the services provided. This may lead to better service and fewer disputes between the farmers and the providers of the service than in situations of fixed payment. Although Hamid reports that in the pumps he studied, farmers paying a share of the crop generally paid more for water than those who paid a fixed amount (Hamid et al 1982, pp 172-174), there is no reason to think that in general there would be any significant difference in the amount paid relative to the services performed. (Obviously, to the extent that a crop share arrangement involves the provision of credit services not included in a cash sale arrangement, the payment required will reflect the cost of this service).

B.2. Allocation of Groundwater Supplies. Of all the aspects of irrigation development in Bangladesh, probably the clearest example of an externality leading to divergence between the perspectives of the individual farmer and the government regarding what is optimal involves the utilization of groundwater, and its effective allocation through the siting of tubewells. The present situation is one that might be characterized as both private and public anarchy. Although there are rules supposedly prohibiting the siting of a new tubewell within a certain distance of an existing well, there is no effective mechanism in place for the enforcement of such rules. This is particularly true

in the case of STW, where the move to private sector sales has virtually eliminated any potential for government control over, or even knowledge of, the siting of wells. Casual field observations suggest that the rules regarding tubewell siting are not being observed.

Although there is not enough groundwater to allow all of the land to be irrigated, the ability to allocate the available water in any rational way through limiting the number of wells permitted in an area, and the ability to enforce such an allocating seem nonexistant. Furthermore, although most people seem to agree that it would be technically rational for the government to avoid siting DTW in areas which are suited for STW, examples of STW and DTW in close proximity to each other are numerous. Studies of groundwater supplies are underway; however it seems clear that any policy decision to limit DTW to certain portions of the country would be difficult politically.

The likely result of this state of affairs is that unless some changes are made, in a few years many of the STW that have been and are currently being sunk will suffer from a drastically curtailed output of water due to declining depths of the water table. Already there are scattered reports that the water table is declining in some areas, although there is little systematic knowledge of the actual situation. A significant drop in the water table could have widespread economic consequences, both on farmers irrigating from tubewells and on others. Many farmers may find their tubewells useless, or severely curtailed in both their physical and economic ability to support irrigated cropping. People who installed tubewells with manually operated handpumps may find their source of drinking water eliminated. (Again,

there are some reports of this having happened). People who rely surface water ponds for irrigation or for other purposes may find these water sources shrinking in response to the change in the water table.

Unfortunately, I see no easy solution to this problem. Even if the government could come up with an enforceable system of allocating rights to sink tubewells, then the allocation process itself would become a focal point for the capture of a part of the economic surplus generated by water. As a result, it is likely that the surplus would in part be shifted to the government, and away from the farmers. This might not be bad if the resulting revenue could be used for development activities. This could happen if, for example, the government established a system of public auction of tubewell permits. It is more likely, however, that a set of policies would be established which an individual could circumvent for the payment of an informal fee. Thus the revenue would accrue to government bureaucrats.

Perhaps the best that can be hoped for is the establishment of a monitoring system whereby the government could keep track both of the number of tubewells in various parts of the country, and the situation with respect to changes in the groundwater table in the different regions of the country. Such a system might enable the government to respond to an impending problem before the situation reaches crisis proportions.

C. INCOME DISTRIBUTION ISSUES

C.1. Economic Surplus. By creating value in production greater than the cost of pumping, irrigation water generates an economic surplus which will be distributed among various individuals and groups in the economy. The critical factors determining the initial distribution of this surplus are access to land and ownership of effective rights to pump ground water.

Early attempts to limit tubewell acquisition to cooperative groups represented an attempt to give effective water rights to as large a group of people as possible. As noted above, however, these efforts appear not to have been very successful, particularly in the case of STW. Even where cooperative groups have been established, there are, as noted previously, incentives to keep the group small, rather than to expand the group and dilute the water rights of the existing members. It would thus appear that it is likely that most of the initial economic surplus generated from irrigation will go to the larger farmers who have the financial ability to obtain a tubewell.

Not only do owners of tubewells have the ability to capture the economic surplus from irrigation by using the water on their own farm, they have the potential to sell water and capture at least a part of the surplus that this water generates on the land of the purchaser of the water. To what extent the surplus is shared between the seller and the purchaser of the water will depend on the relative bargaining positions of the two parties, and will be reflected in the price of the water. While selling water may, by definition, make the owner of

a tubewell a "waterlord," any prohibition on the sale of water can only worsen the position of the potential buyers of water, since it removes an option which they might find more attractive than being totally unable to obtain water. The inequities associated with the "waterlord" issue arise, not because the individual is selling water, but rather because the individual has been given, through the sale of the tubewell, the right to pump water.

In this context it is worth pointing out that there is a potential conflict between production objectives and equity objectives. To the extent that rapid increases in production are desired, individual ownership of tubewells and a private market for water is likely to be a more successful approach then the cooperative ownership approach. On the other hand, the cooperative approach (if it can be effectively implemented) implies a more widespread distribution of effective water rights, so that more farmers are able to earn more of the economic surplus generated by water.

There are a couple of interesting possibilities for making more of this surplus available to the proper farmers with less access to land. One of these involves an attempt by a private organization, PROSHIKA, to arrange for tubewells to be provided to landless individuals, who would then sell water. Although it is an interesting concept, there are several potential problems. A number of organizational and management problems would have to be addressed. Then the question of a satisfactory location for the well (which presumably would have to be next to the house of one of the landless individuals in the group) would have to be addressed, with adequate consideration given to the

location and topography of the lands to be irrigated. Finally, the question of prohibiting potential buyers of water from purchasing their own individual tubewells would have to be dealt with.

To me, the most promising approach to making more of the surplus available to the small farmer has to do with the types of technology made available. As is discussed more fully in the section on the mix of irrigation technology, manually operated tubewells (MTW) represent a type of technology which is not likely to be attractive to large farmers because of the high cost of water if labor must be hired. But to the very small farmer with surplus family labor available, MTW may be economically attractive. Thus if the government continues to make this type of technology available to those who find it attractive, it will probably automatically result in a more widespread distribution of the benefits of irrigation. The beauty of this approach lies in its ability to achieve desired income distribution goals without the imposition of complex, but generally unenforceable, and perhaps self-defeating, government regulations. (For additional discussion on this point in the context of an evaluation of the USAID-supported hand tubewell program, see USAID 1983).

C.2. Employment Effects. Although the income distribution verdict of the previous section is not particularly encouraging, it should be noted that the initial distribution of the economic surplus created by irrigation water is not the whole story. There is considerable evidence, particularly from the Philippines and Indonesia that new

agricultural technology, especially that associated with the production of modern varieties using complementary inputs of irrigation and fertilizer, results in increased employment opportunities for agricultural labor. Often the cropping intensity increases, thus increasing the demand for hired labor. Demand for labor for crop care activities, such as weeding, frequently increases. Also, in many cases there is a shift away from family labor toward hired labor. Thus small farmers and landless laborers are likely to benefit in absolute terms from the changes brought about by irrigation, and even in relative terms may not be any worse off as a result of these changes. (For a detailed discussion of several Indonesian and Philippine case studies, see Hayami and Kikuchi, 198?).

D. INPUT SUPPLY ISSUES

D.1. Mix of Irrigation Technology. Four general types of pump irrigation technology are available: LLP, STW, DTW and MTW. One question that arises is what mix of these four types of technology should be made available to the farmers of Bangladesh.

Excluding for the moment the MTW, it appears fairly clear that in terms of the cost of water, LLP are the lowest and DTW are the highest. This immediately suggests that LLP be used wherever possible, and DTW not be used whenever another alternative exists. Investigations into the supply of surface water suggest, however, that current abstractions by existing LLP may be approaching the recommended limit. Thus it appears that there is only limited possibility for further expansion of LLP irrigation, for minimum flows have to be maintained in many rivers for purposes of navigation, water supply, water quality and minimization of salt water incursions.

Given the continued emphasis on DTW, and their siting in areas where STW are also being sunk, it is worth reviewing the estimates of the relative costs of these two types of technology. The World Bank has estimated the 1981 cost of one acre-inch of water at the pumphead to be approximately Tk. 29 for water pumped by STW, and Tk. 44 for water pumped by DTW (Table 5). Thus water at the pump costs approximately 50 percent more when pumped by a DTW. In addition, it must be remembered that because the area served by a DTW is likely to be

considerably larger than that of a STW, a smaller proportion of the water pumped is actually delivered to the fields in the case of DTW. Thus the differential in the cost of water delivered to the farms is even greater than 50 percent. The siting of DTW in areas of the country where STW can be used thus appears to be a clear case of economic inefficiency from a national perspective.

Even in areas where STW cannot be used, there is some question about the economic viability of DTW. Hanratty's estimates suggest that in some situations, DTW may yield a benefit-cost ratio of less than 1.0 (based on a 12 percent discount rate) (Hanratty 1983, p 36). This suggests that technology involving rainfed agriculture should receive serious consideration as an alternative to DTW in such areas.

The other type of pump technology available is manually operated tubewells (MTW). Although in the past most of these have been hand-operated pitcher-type pumps, other types of manually operated pumps (such as the rower pump and the treadle pump) which are easier to use have been developed.

As can be seen from Table 5, the calculations done by the World Bank indicate that the cost of water pumped by MTW is about the same as that of STW. But calculations of the cost of water pumped by MTW are heavily dependent on the assumption used regarding the cost of labor. If average market wage rates for labor are used, the cost of water is considerably greater than the cost of water pumped by STW. If, on the other hand, the cost of labor is taken to be zero (on the grounds that family labor which otherwise would be unemployed is used), then the cost of water becomes less than for STW. (For some calculations of these costs, see Hannah 1978).

What is the appropriate price of labor to use? Obviously there is no single answer to this question. For some farmers with a substantial amount of family labor available with few alternative productive opportunities, the relevant figure may be close to zero. On the other hand, for a farmer who has a fairly large farm and has to hire labor for pumping, the going wage rate may be the appropriate figure. Because the relative economics of MTW and STW are so heavily dependent on the cost of labor, it appears likely that smaller farmers with little land and a substantial amount of labor would find the MTW economically attractive, while larger farmers would find it unattractive. Thus, as already noted in the section on income distribution, the MTW technology nicely complements the STW in that it makes an irrigation technology available to a group of farmers who may not be able to afford the capital investment of the STW technology.

In a very important sense, one has only to look at what is happening in the market to evaluate the economics of MTW. These tube-wells, which have been sold with little or no subsidy (other than the implicit subsidy associated with subsidized credit), have been very popular in the market, with large numbers of them having been sold for irrigation purposes. The fact that MTW are selling well in competition with STW and subsidized DTW is an important market signal of their economic viability to a significant group of farmers.

An alternative, more academic, approach to examining the economic viability of these pumps is to consider the cost of water pumped when labor is valued at the cost of the additional food required to provide

the physical energy used to pump the water. Although there are a number of uncertainities in making such an estimate, an attempt at such a calculation is given in Appendix 1. These estimates suggest that the energy requirement to produce one acre-inch of water is equivalent to approximately 5.7 kg of milled rice. Using an estimated 1981 farm-level price of rice of Tk.3.6 per kg (estimated from World Bank 1983, Table 9.7), the cost of labor is thus equivalent (in 1981 prices) to Tk.20.5 per acre-inch, which is an increase of Tk.13.0 over the figure used in the derivation of the 1981 cost figure presented in Table 5. This would then bring the total cost of water using MTW to Tk.39.5 per acre inch, as compared with 28.8 for STW and 43.6 for DTW.

It seems quite clear that MTW should be made available in the market so that farmers who find it attractive to purchase them for irrigation purposes are able to do so. Not only do they find it economic to irrigate using these pumps, it may be the only way that effective rights to underground water can be given to many of them. For these reasons, I strongly recommend that efforts to improve the types of MTW available in the market be encouraged. The treadle pump appears to be a particularly attractive alternative to the hand pump, although I have not obtained comparative cost figures. I suggest that a comparative cost analysis be undertaken.

D.2. Equipment Pricing. Current policy on equipment pricing essentially makes the price of STW and MTW unsubsidized. Furthermore, as a result of a joint review of the minor irrigation sector by the

World Bank and the Government of Bangladesh, it has been recommended to end the roughly 40 percent subsidy on the price of LLP as soon as possible (World Bank 1982a, p 36). For DTW, the recommendation of the joint review is to gradually reduce the subsidy, and to stabilize it at a level that would make the calculated cost of water at the pumphead equal for DTW and STW (World Bank 1982a, p 35). (The World Bank recommended that DTW be sold at a 20 percent premium over the STW-equivalent cost, but this recommendation was not accepted by the Government of Bangladesh. See World Bank 1982a, p 36).

Although the policy of gradually reducing the subsidy on DTW is a step in the right direction, the intent to make the cost of water from STW and DTW equivalent to the farmer seems economically misguided for three reasons. First, in the areas that should be using STW, prices that the farmers face will not clearly favor the STW technology. Not only is this uneconomic from the point of view of the cost of the equipment, but it encourages an undesirable externality, in that the installation of a DTW may draw down the water levels enough to reduce or eliminate the economic viability of nearby STW. Second, in areas where STW are not feasible, farmers will be encouraged to over-rely on DTW irrigation as a means of increasing crop production, as opposed to alternative approaches based on rainfed agriculture. Finally, this over-emphasis on irrigation in these areas where it is very expensive may also have the undesirable side effect of discouraging research efforts to develop improved technology appropriate to rainfed areas.

To the extent that the Hayami-Ruttan (1971?) induced innovation model is applicable, the subsidy on DTW may thus not only be uneconomic in the short run, but it may have a negative long-run effect by reducing incentives to find better rainfed technology.

D.3. Source of Power. Many tubewells are operated by a diesel engine, but some use electric motors. Thus the question of the relative merits of these two alternative power sources arises. One economic advantage of electric motors is the reduced requirement for repairs. There is also currently an economic incentive operating at the farm level in the form of a considerably lower power cost. One comparative study estimated that for DTW, electric motors would reduce power costs paid by the farmers by about 19 percent. Comparable figures for LLP and STW were 22 and 52 percent, respectively (Ahmed 1981). Another report on the actual performance of 5 diesel-operated DTW and 5 electric DTW indicated an average reduction in fuel costs per acre of 28 percent for the electric DTW, while overall operating costs per acre were 36 percent lower for the electric DTW (Adeeb n.d.)

But electricity rates are highly subsidized (World Bank 1982b, p 161), so that it is not clear that these are real cost savings to the nation. What is needed are estimates of the economic cost, to the nation, of electricity. Similar figures are needed for diesel, which is apparently taxed. Undoubtedly the World Bank has developed such figures, but I was unable to meet with the appropriate people during my visit.

Some indications of the economics of the electric power subsidy are given in a World Bank study which noted that the average electricity rates of Tk. 0.70 per kWh would need to be raised to Tk.1.20 per kWh to achieve satisfactory targets of financial performance (World Bank 1982b, p 161). Ahmed's study of comparative costs, which was based on the Tk. 0.70 rate, indicated that at a rate of Tk. 1.20 there would be only a 3 percent power savings over diesel of DTW and LLP, and a 21 percent savings for STW. If the rate is raised to Tk.1.30, diesel becomes cheaper for all except the STW (Ahmed 1981, p 7).

A major drawback to the use of electric power for tubewells is its unreliability. Adeeb reports on a case of a DTW in Dinajpur where the farmers had no power supply for two months during the irrigation season (Adeeb n.d.). Other cases of substantial down time due to lack of power have been reported. Voltage fluctuations have also been reported to be a problem (World Bank 1982, p 16). It has been reported that some farmers who have electric motors feel it necessary to have a diesel engine as a standby. This is certainly not an efficient arrangement.

It is difficult to evaluate the seriousness of the power supply situation. An analysis of the experience of the electric DTW in the DTICP project in which CARE is working might be useful, at least for evaluating the power situation in the districts covered by that project.

D.4. Credit. The agricultural credit system is a very important element in the irrigation picture. Most of the sales of tubewells involve agricultural credit either through BKB or some other bank.

Critical to the whole system is the ability of the various banks to obtain refinancing from the Bangladesh Bank. Although there are some differences in the rates that have been charged for tubewell loans under various programs, in general, the loans that are made to farmers for the purchase of tubewells carry a 12 percent interest rate.

As previously noted, this government credit is made available to the farmers at a substantial subsidy. There appear to be two components to the subsidy. On the one hand, a nominal rate of interest of 12 percent per year implies a very low or negative real rate of interest. Using the daily wages of agricultural labor as a proxy measure of inflation in rural areas of the country, the average rate of inflation from 1970/71 to 1981/82 was 15.6 percent per year. For the more recent years (1977/78 to 1981/82), the comparable figure is 11.6 percent. Very similar results are obtained if one uses the consumer price index for industrial workers as the measure of inflation (World Bank 1983), Tables 9.3 and 9.10). The second component of the subsidy comes from the low repayment rates. As previously noted, the general repayment rates for agricultural credit appear to be only 60 to 70 percent. Current reports indicate a significant recent effort to move additional credit into the countryside with little concern about repayment. The result has been that many farmers do not feel a strong obligation to repay the loans they obtain. This problem has become so severe in the last couple of years that under the DTICP program, CARE has substantially reduced the number of DTW that it is working with since they refuse to work with groups that default on their loans.

It should be pointed out that it is quite difficult to get a very accurate picture of the extent to which the failure to repay loans exists, because it appears that a common way to deal with deliquent loans is to "roll them over" — i.e., the bank engages in a paper transaction that creates a "new" loan which is used to "repay" the original loan.

Although it would probably be very difficult to ever obtain a very reliable and complete picture of the extent of the repayment probelm for tubewells, my feeling is that the potential subsidy represented by this "soft" form of credit may have a significant impact on the economics of irrigation faced by the farmers.

E. AGRONOMIC ISSUES

E.1. Cropping Patterns. The cropping patterns that exist in various parts of the country are very complex, making any evaluation of the potential impact of irrigation both extremely difficult and very site specific. Various types of changes in cropping patterns have been reported by researchers (e.g., Hamid et al 1982, Christopher et al 1982, Hussain, 1982, Hossain 1982c). Some of the changes that are occurring seem to be reducing the usefulness of some of traditional categories used to report statistics on crop production (such as boro, aus and aman). Although it is safe to assume that farmers will continue to experiment with changes in their cropping patterns as a result of irrigation, it is not clear to me to what extent this process can be enhanced by outside assistance.

The complexity of cropping patterns that exists in many areas has implications for the management of the tubewells. It is obvious that the management decisions regarding the operation of the pump and the distribution of the water are more complex in a situation where a complicated combination of crops is being grown than in a situation of monoculture. Although I have seen no study of the matter, I would hypothesize that in situations with more complex cropping patterns, smaller numbers of farmers will be sharing water from a single tubewell.

There is another issue associated with the change in cropping patterns that merits attention. As the distinctiveness of the seasonal cropping patterns decreases, and it becomes more common to find crops in various stages of growth at any time of the year, the environ-

ment for pest populations will be changed in ways that may result in an increase in pest problems. There is thus a danger that the production gains being achieved now, in the early years of irrigation expansion, will not be sustainable in the future due to pest problems. There is also the danger that pests, such as malaria-carrying mosquitoes, may increase with adverse effects on human health. It seems desirable to develop a system to monitor for the possible emergency of such problems, and perhaps encourage cropping patterns that will minimize the problems.

E.2. Supplemental Irrigation. Although there seems to have been a tendency to think of irrigation in Bangladesh primarily in terms of dry season irrigation, it is obvious from field trips that supplemental irrigation does exist. Part of the change in cropping patterns probably is associated with farmers' ability to engage in supplemental irrigation.

It would appear that there have been some institutional constraints in the past to supplemental irrigation, particularly in situations where equipment was rented from BADC on a seasonal basis. As the change toward farmer ownership of irrigation equipment proceeds, these institutional constraints can be expected to become of less importance. I expect that it will prove easier to develop patterns of supplemental irrigation when the water is supplied by STW rather than DTW, simply because it is easier for an individual who owns a pump to make decisions about when to irrigate than it is for a group of individuals cooperating

together on a DTW to come to an agreement about the use of the pump for supplemental irrigation.

Although it would be difficult to estimate the average returns that could be expected from supplemental irrigation without undertaking an analysis of rainfall probability distributions, it seems clear that in some years, the potential returns to supplemental irrigation should be very high. And yet one hears reports of cases of farmers failing to irrigate a severely stressed crop, or irrigating only after a substantial amount of yield loss has occurred. It would be useful to study such situations to try to obtain a better understanding of the factors affecting the farmers' decisions. To some extent, the farmers may postpone irrigating in the hopes that rain will come and eliminate the need to incur the expense of irrigating. It is possible that, at least when viewed in retrospect, the farmers simply made a bad economic decision in such a case. (See Small 1982 for discussion of a similar situation in a pump irrigation project in the Philippines). Perhaps the problem is just one of lack of experience; or perhaps there are other less obvious constraints affecting the decisions. A careful study might help identify factors that could be changed to remove some of the constraints limiting the ability of the farmers to take advantage of opportunities for supplemental irrigation.

E.3. Rates of Water Application. This is a traditional area of investigation, and studies of this type have been conducted at BRRI (BRRI 1982). The one point which I wish to make here is the importance of including economic considerations in the interpretation of the results.

There is frequently a tendency in such studies to assume that the treatment that gives the greatest amount of yield per unit of water is the one to be preferred. But in situations where cost of obtaining additional water is relatively low, maximizing the yield per unit of water may be very uneconomic.

F. DATA SOURCES FOR ECONOMIC EVALUATION OF IRRIGATION

National agricultural statistics are published annually by the Government of Bangladesh (Ministry of Planning). Due to a variety of problems common to this type of information, the figures tend not to be particularly reliable, and are subject to a variety of sources of inconsistency and error. (See Pray 1980 for a discussion of some of the problems and peculiarities of the national agricultural statistics).

An important source of information on economic aspects of irrigation that is becoming available stems from the BARC-supported study of the Agro-Economic Research group in the Ministry of Agriculture on "Economics of Irrigation in Bangladesh." This a very ambitious 2-year project designed to give nation-wide information on irrigation. The sample for the first year's survey involved over 2,200 interviews. To date, 3 working papers have been published (Hossain et al 1982a, 1982b, 1982c). Although as a general rule, I tend to be skeptical of the quality of data that results from such large surveys, I have been told that more than the usual amount of effort was put into the collection of the data. Still, it is very hard to have the type of quality control needed at the enumerator level when such a large number of interviews must be conducted. However, there should be a good deal of useful information resulting from this study.

Useful data for constructing the type of crop budgets used in comparative-type analyses of returns to irrigation are available from a number of sources. The Agro-Economic Research unit of the Ministry of Agriculture, in cooperation with USAID, has published a number of

costs and returns studies (Ministry of Agriculture 1979 and 1980). CARE and USAID cooperated to publish a study on costs and returns of rabi crops in 1979 (Rahman et al 1979). The Division of Agricultural Economics of BRRI, in cooperation with USAID has put out a series of cost and returns studies for rice and wheat (Hossain et al 1981a, 1981b, 1982a, 1982b, 1982c). For crops other than rice, the Bangladesh Agricultural Research Institute (BARI) has published a number of reports containing cost and return information (Elias et al 1980a, 1982a, 1982b, 1982c, 1982d, 1982e). Furthermore, I understand that Dr. G. Gill of the Agricultural Development Council has been involved with a number of cost of production studies. Unfortunately, Dr. Gill was ill, and I was unable to meet him.

It was not possible within the time frame of my stay in Bangladesh for me to attempt to compare and evaluate these various studies. A simple comparison of the cost data across the various studies could be made fairly easily to get a feel for the degree of consistency among the studies.

I should also point out that the World Bank regularly develops crop budgets for use in their various project reports. Again, as I was unable to meet with the appropriate people in the World Bank, I do not know what their source of data is. Depending on the purpose at hand, the crop budgets developed in these reports may be perfectly adequate for the kinds of analyses that might be needed by USAID.

Finally, I should mention that in the course of the DTICP project, CARE has systematically and carefully collected a great deal of economic data on a large number of tubewells. It would appear that the data are comprehensive and of high quality. It appears that CARE would be interested in receiving assistance in doing some analysis of these data. This seems a promising possibility which should be pursued.

Table 1. Development of Minor Power Pump Irrigation in Bangladesh, 1972/73 through 1981/82

Year	Number of Pumps		
	LLP[a]	STW[b]	DTW[c]
1972/73	33,000	1,000	1,200
1973/74	35,000	1,000	1,500
1974/75	36,000	1,000	2,700
1975/76	36,000	2,200	3,800
1976/77	28,000	3,000	4,500
1977/78	37,000	6,500	7,500
1978/79	36,000	8,400	9,300
1979/80	37,000	11,000	9,800
1980/81	36,000	21,000	10,100
1981/82	38,000	43,000	11,500

[a] BADC pumps only. Excludes the relatively small number of LLP fielded by BWDB.

[b] Wells in operation, BADC program. Any STW sold outside of the BADC program are not included.

[c] BADC wells in operation. Excludes DTW installed by BWDB.

Source: World Bank 1983, Table 7.23 - 7.25;
World Bank 1982, p 3.

Table 2. Illustrative Calculation of Relationship Between Size of Area Served by a STW and Water Cost Per Acre (Taka)

	10 Acre Command Area	20 Acre Command Area
Initial Capital Cost[a]	24,000	24,000
Capital Cost in 7th Year[b]	0	22,400[c]
Annual Operating Cost, Years 1-12	7,440[d]	16,740[e]
Present Value of Capital Costs[f]	24,000	35,300
Present Value of Operating Costs[f]	46,100	103,700
Present Value of Total Costs	70,100	139,000
Present Value of Total Costs per Acre	7,010	6,950

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[a] From World Bank 1982a, p 68.

[b] Assumes 12 year life of pump and engine when used for 10 acres; 6 year life when used for 20 acres.

[c] Equal to initial capital cost minus the cost of drilling and installation.

[d] From Hanratty 1983, Table A5.1, model II, based on 395 hours of pumping.

[e] Assumes all operating costs are proportional to hours of pumping. Based on 890 hours of pumping, assuming that distribution efficiency decreases from 90% for 10 acres to 80% for 20 acres.

[f] Discounted at 12 percent.

Table 3. Illustrative Calculation of Relationship Between Size of Area Served by a DTW and Water Cost Per Acre: No Government Subsidy (Taka)

	40 Acre Command Area	80 Acre Command Area
Initial Capital Cost[a]	223,000	223,000
Capital Cost in 7th Year[b]	0	148,000[c]
Annual Operating Costs, Years 1-12	30,400[d]	85,100[e]
Present Value of Capital Costs[f]	223,000	298,000
Present Value of Operating Cost[f]	188,000	527,000
Present Value of Total Costs	411,000	825,000
Present Value of Total Costs Per Acre	10,275	10,310

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[a] From World Bank 1982a, p 69.

[b] Assume 12 year life for pump and engine when used for 40 acres; 6 year life when used for 80 acres

[c] Equal to initial capital cost less the cost of drilling and installation.

[d] From Hanratty 1983, Table A5.0, Model II, based on 600 hours of pumping.

[e] Assumes all operating costs are proportional to hours of pumping. Based on 1680 hours of pumping, assuming that distribution efficiency is 70% for 40 acres, and 50% for 80 acres.

[f] Discounted at 12 percent.

Table 4. Illustrative Calculation of Relationship between Size of Acre Served by a DTW and Water Cost per Acre: With Government Subsidy (Taka)

	40 Acre Command Area	80 Acre Command Area
Initial Capital Cost[a]	95,000	95,000
Capital Cost in 7th Year[b]	0	63,000[c]
Annual Operating Costs, Years 1-12	30,400[d]	85,100[e]
Present Value of Capital Cost[f]	95,000	127,000
Present Value of Operating Cost[f]	188,000	527,000
Present Value of Total Cost	283,000	654,000
Present Value of Total Costs per Acre	7,075	8,175

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[a] From World Bank 1982a, p.74, assuming the government subsidy to be 57 percent of capital costs, based on the recommendation in World Bank 1982a, p 74.

[b] See note b, Table 3.

[c] Equal to the initial capital cost less the subsidized cost of drilling and installation.

[d] See note d, Table 3.

[e] See note e, Table 3.

[f] Discounted at 12 percent.

Table 5. Estimated Cost of Water Using Different Types of Irrigation Equipment, 1981 (Tk. per acre-inch of water pumped)

	STW[a] (6 hp)	DTW[a] (22 hp)	MTW[a] (hand operated)
Annualized Capital Cost[b]	8.7	23.3	12.0
O and M Costs	20.1	20.3	14.5[c]
Total Cost	28.8	43.6	26.5[c]

[a] Assumes 800 hours of operations per year.

[b] Assumes full financial cost (i.e., with no subsidies), excluding import duties. Capitalization rate is 13 percent.

[c] Includes Tk. 7.5 for labor for pumping.

Source: Adapted from World Bank 1982a, p.73.

Estimation of the Rice-Equivalent of the Human Energy Used in Manual Pumping of Irrigation Water

In making these calculations, I was assisted by Professor Joe Campbell, Agricultural Engineer and co-member with me on the consulting team. A more detailed discussion of the calculations can be found in his consultancy report.

It is assumed that two men trading off (each working one hour and resting one hour) can generate 0.18 horsepower on a steady basis. Assuming that the water is being lifted 10 feet, and that the pump is 20 percent efficient, it would require approximately 0.15 horsepower to deliver 1.7 cubic feet of water per minute, which is equivalent to 0.028 acre-inches of water per hour. Thus approximately 35.7 hours are required to pump one acre-inch of water.

Assuming that the pump operator is generating the full 0.18 horsepower to pump this water, and assuming that the energy efficiency of man is 20 percent, then for each hour of pumping, the energy requirement will be equivalent to 0.9 horsepower-hours (0.18 divided by the efficiency rate of 0.2), which is equal to 1,782,000 foot-pounds. At 3,088 foot-pounds per kilocalorie, this translates into a calorie requirement of 577 kilocalories per hour of pumping.

Using a figure of approximately 3600 kilocalories per kilogram of milled rice, the "fuel" requirements for the pump operator would thus be 0.160 kilograms of rice per hour of pumping. For the 35.7 hours required to pump an acre-inch of water, a total of 5.7 kilograms of milled rice would be needed to provide the energy used in pumping.

List of Individuals Contacted

1. Dr. H.R. Khan, Northwest Hydraulic Consultants
2. Mr. M. Ekramullah, Project Manager, Mirpur Agricultural Workshop and Training School
3. Mr. Erich Baumann, Advisor, Mirpur Agricultural Workshop and Training School
4. Dr. Golam Kibria, Manager, Milnars Pumps Limited, KSB Pumps
5. Dr. Brook Green, Agricultural Economist, IADS/BARC.
6. Mr. Akbar Ali, Agro-Economic Research group, Ministry of Agriculture
7. Mr. Mahbub Ahmed, Agro-Economic Research group, Ministry of Agriculture
8. Dr. Roger Montgomery, USAID Food and Agriculture Office
9. Dr. H. Sherry Plunkett, USAID Program Office
10. Charles H. Antholt, Chief, Food and Agriculture Office, USAID
11. Boyd Wennergren, Food and Agriculture Office, USAID (Utah State)
12. Dr. S.M. Elias, Chief Economist, Bangladesh Agricultural Research Institute
13. Dr. Mohammad Mukarram Hossain, Economist, Bangladesh Rice Research Institute
14. Dr. M.A. Mannan, Member Director for Water Management, Bangladesh Agricultural Research Council
15. Dr. David Gisselquist, Agricultural Economist, IADS/BARC
16. Mr. A.F.M. Fariduddin, Deputy General Manager, Bangladesh Krishi Bank
17. Dr. Gerrard S.M. Schokman, Irrigation Engineer, World Bank
18. Mr. Shafiullah, Businessman
19. Mr. Nazmul Alam, Member Director for Irrigation, Bangladesh Agricultural Development Corporation

20. Dr. Sandra Laumark, Coordinator, Deep Tubewell Irrigation and Credit Program, CARE

21. Dr. Keith Gorey, FAO Team Leader, Rural Development Academy, Bogra

22. Mechanic at Deutz Service Center, Bogra

23. Commercial pump and engine dealer, Bogra

24. Dr. M.A. Hamid, Professor of Economics, Rajshahi University

25. Dr. M.R. Biswas, Professor of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh

26. Mr. M.A. Baset, Joint Director, Integrated Management Project, Bangladesh Rural Development Board

27. Mr. Nurul Haq Mian, Chief Evaluation and Minotoring Section, Ministry of Agriculture

28. Dr. M.A.S. Mandal, Professor, Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh

29. Dr. S.M. Altaf Hossain, Professor, Department of Agronomy, Bangladesh Agricultural University, Mymensingh

30. Dr. Ekramul Ahsan, Member Director for Agricultural Economics and Social Science, Bangladesh Agricultural Research Council

31. Dr. Anthony Bottrall, The Ford Foundation

32. Dr. Walter Koch, Senior Agriculturalist, World Bank

In addition to these contacts, I worked closely with the team leader for the Cornell/USAID Water Management Synthesis II project, Dr. Hammond Murray-Rust, and his assistant in USAID, Mr. Latifur Rahman. During the field trips, and in many of the meetings I was with two other members of the team, Joe Campbell, agricultural engineer from Cornell University, and Susan Turnquist, rural sociologist, Cornell University.

Schedule of Field Trips

1. July 3-5: Drove to Bogra, where we visited the Rural Development Academy and commercial pump dealers. On July 4 we drove to Rajshahi, where we met with Dr. Hamid of Rajshahi University. On July 5 we drove to Ishurdi, and then flew back to Dhaka about noon.

2. July 10: We drove to Mymensingh where we visited the Bangladesh Agricultural University. We then visited a DTW field site where the irrigation group at the University have been working. We then drove back to Dhaka via Tangail.

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