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THE DEVELOPMENT OF TUBEWELL IRRIGATION IN BANGLADESH:

AN ANALYSIS OF ALTERNATIVES

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THE DEVELOPMENT OF TUBEWELL IRRIGATION IN BANGLADESH: AN ANALYSIS OF ALTERNATIVES*

"Water, water every where and all the boards did shrink.
Water, water every where nor any drop to drink."

It would take only a slight paraphrase of Coleridge's famous lines uttered by the becalmed mariner to describe the conditions of agricultural land in Bangladesh annually from November through April. It is ironic that during this hot dry season it is impossible to grow anything despite the major rivers which flow through this deltaic area into the Bay of Bengal. If the plentiful supplies of surface and underground water could be brought to the potentially productive agricultural lands, the area could greatly increase its agricultural output.

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*Research for this study of tubewell irrigation alternatives took place primarily in 1970; initial drafts were prepared in 1971, and the final version was completed early in 1972. During this period, the area of East Bengal has undergone a civil war which transformed the former Province of East Pakistan into the new nation of Bangladesh.

Although this study is based on arrangements and institutions existing in the area when it was East Pakistan, it attempts, whenever possible, to take into account the changing situation. During this period of transition, many governing and administrative institutions are being altered; nevertheless, the fundamental economic and physical conditions relating to tubewells will remain constant. This study should be interpreted accordingly by those concerned with the development of Bangladesh.

The author is particularly grateful to Eric Griffel, Stephen V. Allison, Edwin H. Smith, and Walter P. Falcon for their support and for their comments which have helped to make this a more objective and concise study.

I. Agriculture, Irrigation and Development

The necessity for raising incomes in Bangladesh is clear. Rapid population growth, combined with a generally stagnant economy, has resulted in growing annual requirements for food imports and unacceptable levels of subsistence for many people. Recognition that the area is one of the poorest in the world has focused increasing attention on methods for accelerating development.

The population was estimated at 75 million at the end of 1970. Over 90 percent[1/] live in rural areas, and most of these derive their income from agricultural activities. Eighty-five percent of the labor force is in the agricultural sector.[2/] The economy of the region is based on agriculture, and there are no important natural resources other than water and land. Since 57 percent[3/] of Gross Domestic Product is derived from agriculture and 95 percent[4/] of the area's export earnings are from the agricultural sector, the dominant role of agriculture in the economy is clear. If economic growth is to take place, it must, in the short run at least, come from agriculture.

[1/] The 1961 Census of Pakistan indicated that 94.6 percent of East Pakistan's population was rural. This is assumed to have declined somewhat in the intervening ten years.

[2/] Government of East Pakistan, Statistical Digest of East Pakistan, (Dacca: 1968), Table 3.3, p. 40.

[3/] Government of East Pakistan, Economic Survey of East Pakistan, (Dacca: 1969-1970), Table I, pp. 102-3.

[4/] Ibid., Table 19, p. 24.

Facilities for irrigation would permit substantial increases of agricultural production in Bangladesh. Only with irrigation is a boro (November-May) crop in the six-month dry season possible. With its continual sunshine and the absence of the recurring floods and storms that damage crops in other seasons, this period is potentially the most productive season of the year.[5/] In addition to making a third crop possible, facilities for supplemental irrigation allow marginal shifts in the planting and harvest times of the other rice crops thereby reducing the risk of crop loss in the peak flood season in August and the loss of productivity due to drought at the end of August to November (amon) season.

Expansion of irrigated cultivation in the boro season is only one of several ways to increase agricultural production. Efforts are being made to improve the varieties of rice grown in all seasons and to expand the use of other modern agricultural inputs. Important as these efforts are, the first generation of improved rice varieties, such as IR-5 and IR-8 which had great impact on production elsewhere, did not produce similar results in the wet and highly variable conditions that exist in the aus

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[5/] During the period 1965 to 1970 boro (November-May) rice averaged 18.2 maunds (1 maund = 82.3 pounds) per acre. Aus (May-July) harvests yielded 10.1 maunds and amon (August-November) production averaged 12.4 maunds per acre. <u>Agricultural Production Statistics</u>, Department of Agriculture, (Dacca: mimeo issued annually).

(summer) and amon (autumn) seasons. Fertilizer and pesticides have also proved of limited value in growing seasons typified by heavy rains and overland flooding.

There is evidence that second generation, improved varieties selected specifically for conditions in East Bengal can substantially increase per-acre production in the aus and amon seasons. These efforts deserve high priority. However, increases in irrigation bringing large areas under cultivation in the boro season offer a more sure, but costlier, way to increase rice production. It is estimated that between 10 and 15 million acres are suitable for dry season production if water is available.[6/]

Since 1954 there have been continuous attempts to increase agricultural production through irrigation. These can be classified in three categories. First, there have been the large multi-purpose projects generally including flood control, irrigation and drainage systems. These have been carried out by the Water and Power Development Authority (WAPDA) at high cost, frequently incorporating technically complex engineering designs and operating systems, planned and constructed with the assistance of foreign consultants and financed by external aid. In most of these projects, such as Ganges-Kobadak, Brahmaputra Right Embankment, Coastal Embankments, Dacca-Demra, and Chandpur, the ratio of benefits to costs has been negative. Despite an average

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[6/] Recent estimates by the Harvard Center for Population Studies Group on the Ganges, Brahmaputra Basin suggest that as much as 15 million acres or 75% of the total crop land may be suitable for irrigated winter cultivation.

allocation of 17.7 percent of total development funds to WADPA for water development projects during the 1960's,[7] these projects have brought 175,000[8] additional acres under irrigated cultivation -- an increase of only .008 percent in total irrigated land. The highly complex nature of water management in the world's largest river delta, the designs provided by foreign engineers which have frequently been inappropriate for conditions in Bangladesh, and the neglect of water delivery and farm management aspects of the schemes have all contributed to the problems that have plagued WAPDA projects. Much has been learned from the experience of the 1960's and future projects will undoubtedly avoid many of these mistakes. Nevertheless, the WAPDA projects are large and have long gestation periods so that projects presently underway or about to begin will not yield benefits until the late 1970's.

A second approach to irrigation has been the exploitation of surface water by low-lift pumping. A pump and diesel engine which can lift water a few feet from rivers, channels, and ponds to adjacent agricultural land is the most economic of the power irrigation techniques, but it is limited by the availability of surface water. Low-lift pumping began in 1956 with the Mechanized

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[7] Calculated from Government of East Pakistan, Approved Development Programme of the East Pakistan Government for the years 1960-61 through 1969-70.

[8] Government of East Pakistan, Economic Survey of East Pakistan 1969-70, (Dacca, 1970), p. 47.

Cultivation and Power Pump Irrigation Program (MCPPI). From 1956 to 1967 a total of 3,990 low-lift pumps were fielded.[9/] The number of pumps did not approach the potential because the MCPPI program never established an effective means of organizing farmers to share water from a single pump or to ensure the delivery of water at the critical intervals for crop production.

In 1968 the Thana Irrigation Program (TIP) replaced the MCPPI scheme. This low-lift pump irrigation program placed emphasis on organizing farmers to share and utilize water before water was provided. Pumps were allocated only to irrigation groups formed by farmers holding contiguous plots totaling 50 acres. To form a group the constituent farmers agreed to pay a rental fee for the pump and its operating costs, elected a group chairman, a pump driver to be trained to operate the pump, and a model farmer who would spend one day a week undergoing training. The number of low-lift pumps in operation under the Thana Irrigation Program has expanded rapidly. By the 1969-70 irrigation season, 18,000 pumps were in operation, irrigating about 700,000 acres.[10/] Under-utilization of water and maintenance of engines and pumps were becoming important problems partially as a result of the rapid expansion of the TIP. However, the most serious constraint on low-lift pump irrigation is the availability of surface water. Present estimates are that there is enough

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[9/] East Pakistan Agricultural Development Corporation, Annual Report, 1966-67, (Dacca, 1968), p. 17.

[10/] Economic Survey of East Pakistan 1969-70, p. 46.

water to supply only 35,000 to 40,000 pumps. This means that low lift pump irrigation will be fully exploited in a few years with only 20 percent of the irrigable land under cultivation.

The third category of irrigation is groundwater exploitation through tubewells. This is the least tested of the three alternatives. Two tubewell projects were begun in the early 1960's, with a total of 591 wells. These two efforts must be considered pilot projects for each was limited to a small area, and each represented radically different approaches to tubewell development. Neither experience was expanded on a Province-wide basis. In Thakurgaon in the north-west of the Province, WAPDA sponsored the sinking of 380 wells by German contractors under a German supplier's credit. In Comilla on the eastern border, 211 wells have been sunk by the Academy for Rural Development and the Comilla Kotwali Thana Central Cooperative Association (KTCCA) primarily with East Pakistan Government funds. These two efforts will be discussed in more detail later, but both indicate the presence of a good groundwater supply as well as the substantial economic benefits resulting from its exploitation.

II. Priorities for Irrigation Development in the 1970's

If agricultural production is to be increased rapidly in the 1970's by irrigation, it will be necessary to exploit groundwater by means of tubewells. Tubewells have important advantages over alternative means of providing irrigation. With less than 1,000 wells in the Province at the beginning of 1971, the potential for expansion is obvious. A well with a two cusec yield ranges in cost from Rs. 25,000 to Rs. 75,000 (Rs. 4.75 = U.S. $1). The estimated net annual benefit from such a well is Rs. 38,000 (see Appendix C, Table 3). The life of the well is estimated to be eight to twenty years, depending on specifications; sinking can take one to four weeks time depending on technique; and once installed, assuming the field channels have been prepared in advance, irrigation can begin at once. This means the numbers can be rapidly expanded and that long lags in obtaining returns on capital invested are avoided. The divisibility of a well construction program means that a variety of technologies may be attempted and those proving most suitable can subsequently be utilized. It also means that the size of the program can be expanded or contracted as priorities or available alternatives change. There is flexibility in locating wells. Assuming groundwater availability, location is not limited by the necessity to be near major rivers. Wells can be located in areas away from regular flooding or at sites with favorable groundwater levels. They can also be disbursed according to land characteristics to take advantage of soils best suited to irrigated farming. Finally, wells can be scattered throughout the country with a resulting distribution of benefits that is more equitable than that offered by large projects.

The ability to vary location allows farmer demand for water to be a prerequisite for well installation. The underutilization of water in large multi-purpose projects has resulted in part because physical conditions rather than farmer demand determined location. Once the multi-purpose project is constructed, all farmers in the area are expected to participate. Arrangements for water distribution are frequently determined by bureaucratic convenience rather than agreement of farmers. When provision of water can be based on farmer demand, the beneficiaries may be required to help construct the distribution system, help pay for water and undergo training in the techniques of irrigated agriculture. In these circumstances they are less likely to undervalue and therefore underutilize the water being provided.

A tubewell development program is obviously dependent on adequate groundwater resources. Definitive information on the extent of groundwater is not yet available. However, initial investigations which indicate that groundwater exists in substantial quantities, and is recharged annually by monsoon rains, provide a basis for planning further exploitation of this resource.[11/]

This view is shared by experienced engineers and hydrologists who visited East Pakistan as World Bank consultants in

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[11/] Center for Population Studies, Harvard University, Progress Report: Ganges-Brahmaputra Basin Studies, (Cambridge: September 1969), mimeo. Section IIa, Rainfall Recharge, pp. IIa, 1-10; Section IIa, Groundwater Potential, pp. IIc, 1-14.

1969. After examination of drilling and operating records of existing wells they concluded that planning for groundwater exploitation should proceed. One of them observed that Bangladesh's acquifer is constituted of medium to coarse sand which is both continuous and deep and as good or better than West Pakistan's, which has so far been considered the best in the world.[12]

Another Bank consultant on groundwater hydrology drew similarly optimistic conclusions when he stated, "East Pakistan has truly enormous groundwater resources."[13] He also indicated that tubewell development could proceed before the completion of a comprehensive groundwater survey if wells were spaced at least one mile apart.[14]

In late 1970 a groundwater resource investigation team from the U.S. Geological Survey began work in East Pakistan. This was interrupted by the civil war; completion of such a study remains a high priority. However, given the evidence, thus far, concerning the availability of groundwater and given the length of time needed to organize and finance a tubewell installation program, there is full justification for proceeding with planning and with initial implementation of a program to take advantage of the area's presumably extensive groundwater resources.

12/ Roy Stoner, McDonald and Partners, Consultant to the World Bank Tubewell Appraisal Mission, December, 1969.

13/ Harris R. McDonald, Evaluation of Tubewell Projects in East Pakistan, June 26, 1969, mimeo., p. 10.

14/ *Ibid.*, p. 12.

The development of tubewell irrigation over the next five to ten years should be an essential part of the overall development plans of Bangladesh. The technology of well installation and operation which is selected has important bearing on the extent of tubewell development and on other policy goals of the nation. Before the civil war, financing for tubewells was offered by external sources which were willing to support the installation of wells, usually according to their own specifications. Presumably much of this assistance will be made available again. Before tubewell development policy is established by external financers' preferences, it is essential to compare alternative tubewell technologies and draw some conclusions as to the appropriateness of each for Bangladesh's development.

This paper attempts to initiate such an examination of tubewell technology by examining East Pakistan's tubewell experience, comparing the available alternatives and reaching some conclusions as to an appropriate set of techniques to insure that Bangladesh's tubewell program is consistent with her other development priorities and objectives.

III. East Pakistan's Initial Tubewell Experience

East Pakistan's two tubewell projects during the 1960's provide good examples of the range of alternatives available for tubewell development.

In Thakurgaon, Dinajpur District, in the northwest part of the Province, a tubewell field was constructed under the auspices of WAPDA. The feasibility study, design, including the choice of well location, and construction were done by German engineers under a German supplies credit loan of DM. 22.2 million. The project was located in an area known to have excellent groundwater supplies. Agricultural benefits were anticipated from the production of sugarcane and rice on the irrigated land. Three hundred eighty wells were installed, each with a design capacity of 4 cusecs. An electric generating plant was constructed solely for the purpose of electrifying the tubewells. The wells, which were sunk by power drilling rigs, utilize mild steel filters and turbine pumps, all imported from West Germany. Although the engineering and installation work on the wells was completed in two years, the construction of the electric generating plant and the transmission system delayed their operation another three years, until 1965.

Of the wells installed, 362 are being used for agricultural purposes. Four are being utilized to cool the electric generating plant, and the remaining 14 failed. The wells have averaged 3 to 3.5 cusecs output. The cost of these wells was very high, approximately Rs. 260,000 per well or Rs. 87,000 per cusec of water. Just over half the cost went in generation of electricity and facilities for transmission. The wells installed have proven technically excellent.

Major problems have arisen in Thakurgaon from location of wells and inadequate utilization of water by farmers. Not only was the area chosen one of porous soils, in addition, the wells were located on high ground along a ridge so that the location proved inefficient for irrigation.

There was no provision in the project for preparing, organizing, or training farmers in the techniques of irrigated agriculture. As a result, in 1965, the year the project was completed, according to a WAPDA study only 6.5 percent[15] of the total water capacity of the wells was utilized. In 1966 performance did not improve appreciably. Early the next year WAPDA brought in organizers trained at the Academy for Rural Development in Comilla to organize the farmers into cooperatives and to train them in irrigated rice cultivation. By 1969, the area under irrigated winter cultivation increased to 20,994 acres out of an irrigable area of 71,000 acres.[16] Because of the reluctance of the farmers to utilize water for irrigation, WAPDA has never been able to charge the farmers for any of the installation or operating costs of the wells. In light of the gaps in planning and the initial dimensions of the problems, the present results of the projects are encouraging. Given thethe total costs, however, it is clear that the overall cost-benefit ratio is negative.

The other pilot project was in Kotwali Thana, Comilla District, in the east-central portion of East Bengal. In that area 211 wells have been sunk by the Kotwali Thana Central Co-operative Association, (KTCCA) which adapted for local conditions

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[15] EPWAPDA, Economic Study of Groundwater and Low Lift Pump Irrigation Projects in the Northern Districts, EPWAPDA, 1966, Chart II, p. 16.

[16] EPWAPDA, Irrigation Extension Activities in Thakurgaon Tubewell Project, 1969, mimeo., Appendix A, pp. i-v.

two low-cost techniques for installing wells: percussion and jet drilling. Percussion drilling utilizes unskilled labor to raise and lower a sludger manually which slowly bites through the earth (see Figure 1). Slightly less costly is jet drilling utilizing the same drilling rig plus a small pump which forces water down a casing pipe causing a scouring action cutting the ground away beneath the pipe flushing earth up to the surface between inner and outer casing pipes. In this work, the Comilla KTCCA was assisted by Majid Hassan Khan who had initiated a program for sinking low-cost wells in West Pakistan. (The West Pakistan low-cost well program is described in detail in Appendix A.)

The 211 wells, of two-cusec output design, were installed between 1962 and 1969. All were initially diesel powered, although some have been converted to electricity as connections became available through the regular expansion of the electric system. The cost of all the installations was Rs. 5 million, provided jointly by KTCCA and the East Pakistan Government. Mild steel was used for strainers in 22 of the wells and brass in the remainder.

Of the wells installed, 200 are now operating. Four wells were never operational, one because of breakage in the pipes in installation and three because of poor acquifer. The other seven failures were caused by incrustation on the mild steel strainers. As a result, mild steel is no longer used in irrigation tubewell strainers in the Comilla area. The average

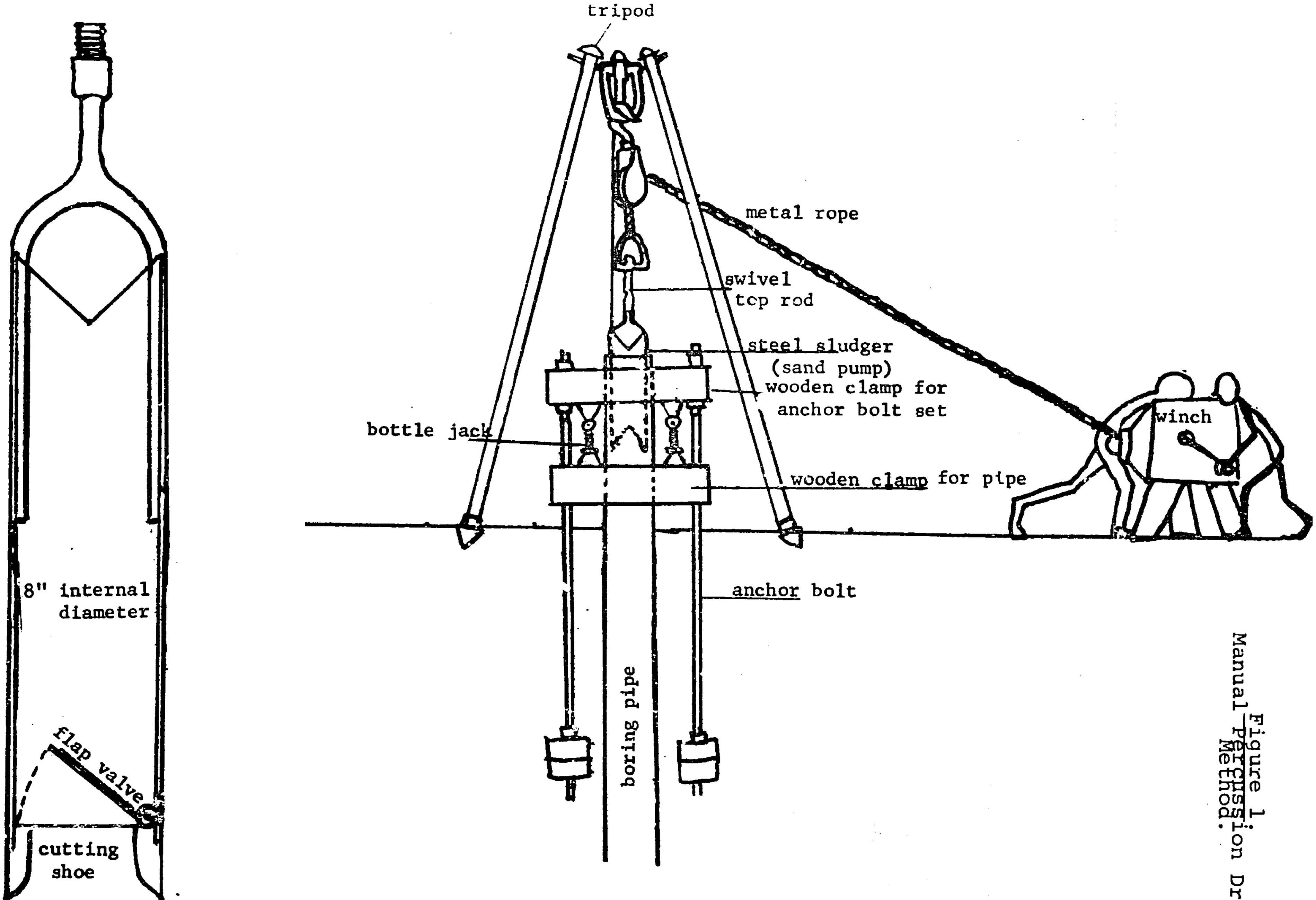

Figure 1.
Manual Percussion Drilling
Method.

Figure 1 (continued)

Explanation of Manual Percussion Drilling

The metal rope imparts a circular movement to the sludger as it is worked up and down.

The method of forcing the casing or boring pipe downward illustrated in the drawing is called the Anchor Bolt Method. The upper clamp is secured tightly to the two anchor bolts, whose lower ends have been buried 7 - 10' under ground. (The square at the bottom of each anchor bolt is a cross-sectional drawing of a rail piece 6" x 4" x 6'.) The bottom wooden clamp is secured to the pipe itself. It is held in place on the anchor bolts but can move up or down along them.

Bottle jacks are placed between the two bolts. When they are unscrewed, pressure is exerted between the two clamps. As the upper one is stationary, the lower bolt is forced downward, carrying the casing pipe with it. As each new length of casing pipe is lowered into the well, it is screwed to the top of the one beneath it.

When the digging is completed, blind pipe and strainer are lowered through the casing pipe and shrouded with gravel. To remove the casing pipe, the action of the clamps is reversed, so that the lower one is held tightly to the anchor bolts and the upper to the pipe itself, and the bottle jacks then worked between them.

cost per well was Rs. 27,000.[17] Installation by percussion takes four weeks in dry weather and eight weeks in the wet months, June through September. The process of jet drilling takes two weeks in dry weather and cannot be done during monsoon.

Water utilization has averaged 29 acres per cusec, slightly higher than the Provincial average, but in Comilla as elsewhere it has been inefficient. Water utilization, and thus benefits, began almost immediately after installation. The KTCCA methods for organizing and training farmers for irrigated agriculture became the basis for the Thana Irrigation Program and under these procedures farmers in Comilla have met approximately 40 percent of operation and maintenance costs.

Although a high rate of return to tubewell irrigation was demonstrated, it did not spread rapidly in the 1960's.[18] The Government of East Pakistan committed its water development resources to WAPDA multi-purpose projects. Although there was a complex variety of reasons for this decision, it was frequently justified by the absence of comprehensive knowledge about groundwater resources.

Despite the profitability of irrigation in Comilla, there was little private investment in tubewells. The general level of rural poverty has meant that only a very small proportion of the farmers have an investable surplus and there are reasons

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[17] Because of controversy over Comilla well costs, a separate discussion of this is contained in Appendix B.

[18] Farmers benefits from a 2-cusec well are estimated at Rs. 38,000 annually, enough to pay the full costs of well installation in one to two years. See Appendix C, page 6.

why even these few well-to-do farmers have not invested in tubewells:

1. Government subsidy policies have prevented private tubewell development, even where the value of water is understood. Data from the Comilla area document this. The average cost of wells (without pump and engine) has been Rs. 20,000. The market cost of pump and engine in the area was Rs. 12,500 in 1970, while the Agricultural Development Corporation (ADC) was obtaining them at a budget cost of Rs. 5,000. The ADC was (through KTCCA) providing the well at no cost, and renting pump and engine to irrigation groups on a sliding scale that begins at Rs. 300 for the first year and reaches a maximum of Rs. 1,400 in the fourth year. Under these circumstances, there are rational economic reasons for not investing Rs. 32,500 in a well when one may be obtained in a year or two from the Government at a fraction of this cost.

2. A second reason is that costs for pioneers in sinking tubewells would be much higher than the average cost. Until there is an entire infrastructure of facilities for well installation the private sector cannot operate efficiently. People skilled in tubewell installation techniques are located only in Dacca and Comilla. Assuming labor could be hired locally, the master driller and driller and rig would have to be transported to the drilling area. The farmer would have to arrange privately for the supply of pipes, screen, pump and engine, presumably from Dacca, and arrange transportation to his farm. It is highly improbable that he could obtain all the needed supplies and time their arrival so as to avoid extensive delays and the

resultant excess cost. Once installed, there would be no service or maintenance facilities immediately available. Under these circumstances, before drilling capacity, a supply system and repair and maintenance facilities for low-cost tubewells is established, private investment would prove uneconomic.

IV. Tubewell Development: Plans and Alternatives

East Pakistan established a target of 20,000 tubewells for the five-year period 1970-75. It budgeted Rs. 1,400 million (or Rs. 70,000 per well) for this purpose. To meet this target more than half the funds would have to have been obtained from external sources. There was considerable foreign interest in providing assistance for tubewells. However, aid donors frequently had strong preferences as to the technology to be utilized in well installation. It is instructive to examine the well proposals prepared by the Government of East Pakistan and the commitments of foreign aid donors.

Under ADC (Agricultural Development Corporation) sponsorship:

1. World Bank support for 3,000 tubewells was requested in an application to the World Bank. Two thousand were to be drilled by contractors, 1,000 to be drilled by ADC using labor intensive methods. All were to be powered by diesel engines, but half were to have turbine pumps and fiberglass screens, and half

centrifugal pumps with brass screens.

The World Bank decided to finance 3,000 wells but 2,100 were to be drilled by foreign contractors and 900 by local contractors all by power drilling primarily reverse rotary techniques. All the wells were to have fiberglass screens and to have diesel powered turbine pumps. The wells were to be located primarily in the five districts of North Bengal. The total cost of the IDA project was $44.6 million. Each well to cost about Rs. 67,000 with a foreign exchange component for the project of 51 percent. An agreement for the wells was signed, bids let but few if any wells drilled before the outbreak of civil war.

2. Under a General Electric Corporation (G.E.C.) British supplier credit, 5,000 wells of 2-cusec capacity were to be installed by local contractors using power drilling techniques, supervised by the G.E.C. and with materials supplied by them. Details were not available but presumably the wells would have been diesel powered, with turbine pumps and fiberglass screens and costing approximately Rs. 80,000 per well. An agreement was signed but work never began.

3. A barter agreement with Yugoslavia would have provided 1,000 wells of 2-cusec capacity diesel powered, presumably with turbine pumps, and screen material unknown. They were to be installed by Geotechnica, a Yugoslav firm, exclusively in North Bengal where heavy rigs can operate. The cost is difficult to determine under barter arrangements but was estimated at Rs. 75,000 per well.

Under WAPDA sponsorship:

1. The World Bank proposed financing an extension of the Thakurgaon Project. This project was to consist of 285 large (3 cusec) wells and 600 small (1/2 cusec) wells, all to be electrically powered. The large wells would use fiberglass screens, the small wells, PVC (polyvinyl chloride) screens. The large wells were to be equipped with turbine pumps and the small wells with a new design floating centrifugal pump. They were all to be electrically powered, at an average installation cost of Rs. 106,233 per cusec of capacity.

2. Another 1,110 wells were proposed by WAPDA in three tubewell fields located in Dinajpur, Rangpur and Mymensingh Districts. Feasibility studies were carried out for all of these. All would have been contractor installed (presumably foreign contractor) electrified and of a capacity ranging from (2 to 4 cusecs); financing was never obtained for these.

The trend of tubewell development up to the outbreak of war was clear -- the foreign aid donors indicated their preference for high quality, high cost foreign contractor drilled wells. The agencies of the East Pakistan Government concerned with tubewell installation either shared or acquiesced to this preference for high cost wells.

B. Alternatives

Despite the preponderance of support for high cost wells, there is a wide range of options in well design and installation technique. Economic comparisons of benefits of wells of alternative specifications can be made by utilizing costs per unit of output, since the product of wells is standard and only the quantity varies. (Output will generally be measured in cusecs and abbreviation of cubic feet per second.) Cost alternatives fall in five general categories: (1) Drilling technique, (2) Driller, (3) Type of pump and engine, (4) Type of materials installed, and (5) Well Specifications. Figure 2 illustrates the component parts of a tubewell. The details of alternative techniques are as follows:

(1) Drilling technique. There are three main drilling techniques used in East Pakistan. Most contractors and some Government agencies use mechanically powered rotary or reverse rotary rigs mounted on truck bodies. This is the most expensive and least mobile, but produces the most vertical and uniform well in the least time. In Comilla, KTCCA has used cable percussion drilling primarily. The technique is simple and slow but produces a well of good verticality and uniformity KTCCA has also used water jet drilling. This technique is the least expensive and is slower than power but faster than cable drilling. It produces the least uniform well.

BASIC TUBEWELL DESIGN - BANGLADESH

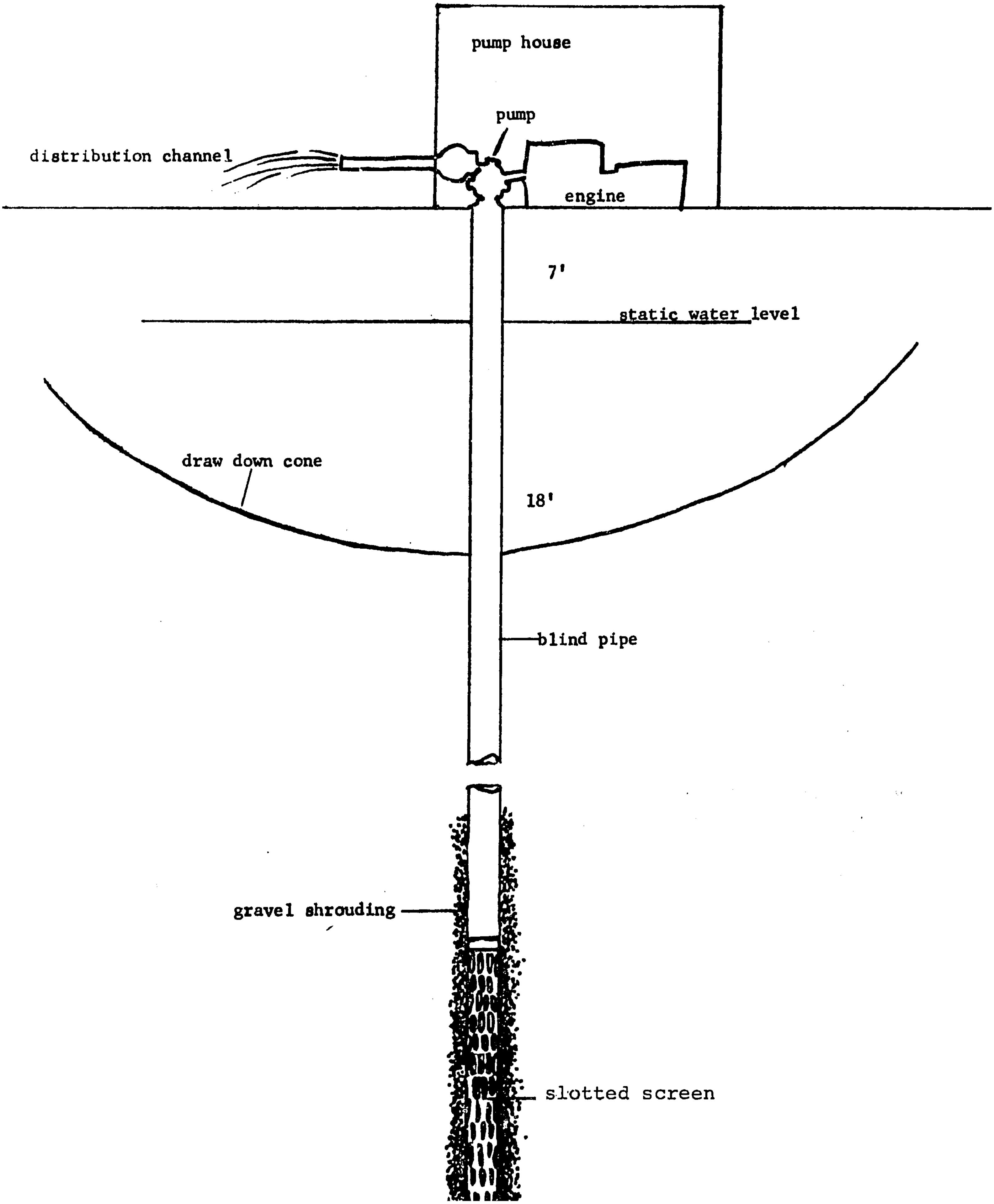

TABLE 1.

Comparison of Tubewell Drilling Techniques

	Cost of Rig	Foreign Exchange	Drilling Cost Per Foot	Drilling Time 300 Feet	Drilling Season	Mobility of Rig	Uniformity of Well
Power drilling	Rs.560,000	100%	Rs. 47.50	1 day	Nov. to April	10-15 tons moves only over road or dry field unless specially adapted for other conditions	Excellent
Manual percussion drilling	Rs. 38,500	50%	Rs. 10	4-6 weeks	Oct. to May	1,000 lbs. can be moved anywhere	Good
Jet drilling	Rs. 70,000	65%	Rs. 7	1-2 weeks	Oct. to May	1,500 lbs. can be moved anywhere	Fair

There has been controversy over whether percussion and jet drilling methods produce wells of sufficient alignment and verticality for the installation and operation of turbine pumps. Turbine pumps have been used without problems in a few percussion drilled wells in Bangladesh. Beco, the Pakistani manufacturer of pumps will not guarantee their turbine pumps installed in wells that vary more than 1% from true vertical which percussion and jet drilled wells frequently do; however, U.S. manufacturers of pumps indicate that verticality is irrelevant to performance or durability of turbine pumps. It appears, therefore, that drilling methods do not impose any rigid limits on type of pump to be utilized.

(2) Drillers. There are four categories of tubewell drillers: foreign contractors, domestic contractors, government agencies and local government bodies or cooperatives. It is difficult to distinguish among these on the basis of cost. Bids received by the ADC from domestic contractors do not show profit rates or administrative costs. However, examination of these by item suggests that the overhead and profit are included in the drilling cost. Bids to ADC have averaged about Rs. 45 per running foot for a 12-inch hole.[19/] This substantially exceeds a normal international standard which would be more typically Rs. 25 to Rs. 30. It therefore is possible to assume that at least Rs. 15 per foot or about Rs. 4,500 for the average

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[19/] ADC, Project Loan Application for 3,000 Deep Tubewells, Dacca, August 1969, p. 91.

300-foot wells is administrative overhead and profit. The ADC , however, specifies that management and staff costs for the wells they sink amount to Rs. 2,500 per well. If the administrative costs of domestic contractors' are presumed to be the same, this reduces profit to Rs. 2,000 per well. Estimates of costs for materials are frequently higher in contractors' bids than the current market rates, suggesting that some additional profits may be concealed in these items, but it is impossible to draw any definite conclusions from this source.

Another basis of comparison is cost estimates by ADC and contractors for sinking identical wells. For 12-inch diameter, 300-foot identical wells, ADC's costs were Rs. 5,265 lower than the charges of domestic contractors.[20] One can conclude, therefore, that profit rates for domestic contractors are in the range of Rs. 2,000 to 5,000 per well.

There is no basis for estimating the profits of foreign contractors. Clearly, however, their costs are much higher in actual cost terms and foreign exchange. They must pay their foreign employees at international salary scales and support them while resident in the area. They must import much of their equipment and then repatriate profits. Foreign contractors will prove the most expensive means of installing any given type of well; domestic contractors are next in cost. The local government or cooperative, operating without profit and employing local residents, will be at the other end of the

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[20] _Op. cit._, pp. 94-96.

cost scale.

One very serious problem of utilizing foreign and domestic contractors is their inevitable and rational preference for machinery over human labor when selecting technology. If local currency is overvalued as the Pakistan rupee was, imported machinery and spare parts may be obtained for as little as half their true cost to the economy. By the same terms, interest rates have generally not reflected the opportunity cost of capital in the economy. This results in a large subsidy on capital goods which contractors are eager to accept. In addition, recruitment and supervision is frequently difficult. As a result, contractors will generally adopt capital intensive methods of work despite the fact that this may be inconsistent with the priorities of the economy.

The advantage of contractors and particularly foreign contractors is that existing expertise and capacity for implementation can be bought. The engineering quality of the resulting well can be relatively assured. With Bengali national or local agencies, there is little residual knowledge or skill. Capacity to install wells must be created over time and knowledge must be acquired with experience. Both time and the acquisition of knowledge have substantial costs that partially offset the higher costs per well charged by contractors.

The various drilling agents prefer different drilling techniques. Foreign contractors have decided preferences for power drilling. Local level agencies would have capacity for only percussion or jet drilling. Local contractors and government agencies, however, could and would, depending on demand, install wells by any of these three techniques.

(3) Type of power, pump, and engine.

(a) Power. Electrically powered engines are more reliable than diesel engines if the power supply is reliable. They also have fewer maintenance requirements. Operating costs to the farmer are lower if, as has been the case in the past, power is subsidized and an electric distribution system is already available in the area. To install generating capacity and transmission lines just to power a tubewell field is prohibitively expensive. In the Thakurgaon Tubewell Project one half the cost of the project, or Rs. 130,000 per well, was for electrification.[21/]

Electric generating capacity, considerably in excess of demand, existed in East Pakistan. If this condition holds in Bangladesh, electrification in areas close to existing transmission lines and where a high concentration of wells is planned would appear justified. Yet it is also necessary to remember that the government bears much of the cost of transmission lines and also subsidizes the cost of electric power. Thus the farmers' savings in installation and operating cost are in fact not a real saving to the economy. This fact suggests that it would be wise to make charges for electricity or electrified

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[21/] IBRD Thakurgaon Tubewells Project Extension Appendix 1, p. 1.

wells at least as high as the operating costs for diesel wells.[22/] Given the few transmission and distribution lines presently available, it appears that for the time being tubewells in Bangladesh, with a few exceptions, will be powered by diesel engines.

(b) Reliability in provision of irrigation water is essential. The failure of water supply in the middle of an irrigated growing season means the loss of investment in all the inputs. Farmers will not be willing to make this investment unless they are confident their water supply is reliable. Minimizing maintenance requirements associated with the supply of a given quantity of water is a high priority objective.

The engine is the most delicate component of the well. It is very important to find the most reliable engine and the one that can be repaired most rapidly in the event of a breakdown. In the past, most tubewells and low-lift pumps have been powered by imported high speed diesel engines. This choice was justified because of their theoretically greater reliability and lighter weight which makes them more mobile. It was reinforced by the fact that the exchange rate, duty and tax structure made the

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[22/] In West Pakistan, many private wells are electrified. From the perspective of the investor they are cheaper than the diesel powered wells, Rs. 7,000 to Rs. 9,000 plus payment to local officials to obtain a connection. This is because the provision of electric power is heavily subsidized by the Government and none of the capital costs of generating and transmission facilities are passed on to the farmer.

high speed engine cheaper than the slow speed, despite the fact that the latter is much less expensive to produce.[23/] A third reason was that the high speed engines were made available under British and German suppliers' credits which made them attractive to ADC officials not particularly concerned with debt obligations. The experience with the high speed engines driving low lift pumps suggests that high speed engines are not entirely satisfactory in the conditions of Bangladesh. High speed engines are complex machines which are manufactured to precise specifications and have proven susceptible to breakdowns when operated and maintained by the minimally trained operators who can be obtained for village work of this type. Neglect of standard operating procedures, poor or no maintenance, and the use of kerosene rather than high speed diesel fuel has greatly increased the frequency of breakdowns and reduced the time between overhauls considerably. Repairs and overhaul can only be carried out at costly, well-equipped service centers with supplies of imported spare parts. The Thana level maintenance shops established by ADC under the Thana Irrigation Program have mechanics who have received only limited training and frequently cannot service and overhaul the high speed engines adequately. The result is that these engines are being overhauled after one or two years rather than five

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[23/] This was the case because high speed engines were purchased or supplied on credit at the official exchange rate Rs. 4.75 = $1 and imported free of duties and taxes while materials for domestic production of engines were purchased at the bonus voucher rate of approximately Rs. 9.50 = $1 and sales tax was levied on the final product.

which is the normal period, and the anticipated lifetime of the engines may be reduced from the expected 10-15 years to as little as five years.

Low speed diesel engines have been used very little in the past and not at all in East Pakistan Government programs. Yet, if exchange rates and duty strictures are rationalized, low speed engines will be cheaper. They operate on any kerosene or diesel fuel. They compare favorably with high speed engines in tolerance to carelessness in operation and neglect of maintenance. Major repairs including overhaul can be done at lower cost with much less equipment and in small workshops close to the operating site. In West Pakistan, where slow speed diesel engines have been extensively used and are preferred to high speed diesels for tubewell operation, they have an average life of 15-20 years.

The slow speed engines also could be manufactured in Bangladesh. Their maintenance, repair, the production of spare parts, and eventually the engines themselves could easily become an important rural small industry as it has in West Pakistan.[24/]

(c) Pumps. There are two types of pumps generally used for tubewells. The centrifugal, vacuum pump, easily produced in Bangladesh cost Rs. 750 in 1970. The limitation on the centrifugal pump is that if the drawdown cone drops below

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[24/] Edwin H. Smith, Jr., The Diesel Engine Industry of Daska, Sialkot District, Reprint Paper No. 20, Planning and Development Department, Lahore, 1969.

about 18 feet, it begins to lose efficiency, and it stops pumping entirely below about 25 to 27 feet. The second type, the turbine pump, is submerged in the well and can operate at lower levels of water. Its cost was Rs. 5,500 in 1970,[25/] but there are corresponding savings in that the efficiency of the pump means less well depth is required.

Differential costs can be calculated from Table 4, alternatives 1 and 2. The only difference between these is the use of a turbine pump in alternative 2. The differential cost of the turbine is Rs. 6,600. If a more realistic value than the official exchange rate were placed on the Rupee, such as Rs. 9.50 = $1, the gap between the imported turbine pump and the locally produced (but with imported components) centrifugal would increase to almost Rs. 11,000.

The offsetting fact is that under pumping conditions, when water levels in the well begin to drop, the centrifugal pump may lose efficiency and output drop to 1.5 or 1.25 cusecs while the turbine pump still delivers the rated two cusecs.

Given these differentials in cost and performance between pumps, the critical question becomes what determines the critical limits of performance of the centrifugal pump. In brief the answer is static water level in the well before pumping and the drawdown during pumping. Table 2 indicates the performance of a typical 2-cusec rated centrifugal pump.

[25/] Pump costs are estimates made by the World Bank in 1970.

TABLE 2.

Performance of a Centrifugal under Conditions of Increasing Suction Lift.

Suction Lift (feet)	Discharge (U.S. gpm)	Discharge (cusecs)
0	1310	2.88
5	1280	2.84
10	1230	2.73
15	1170	2.60
20	1090	2.24
23	995	2.21
25	890	1.98
26	700	1.56

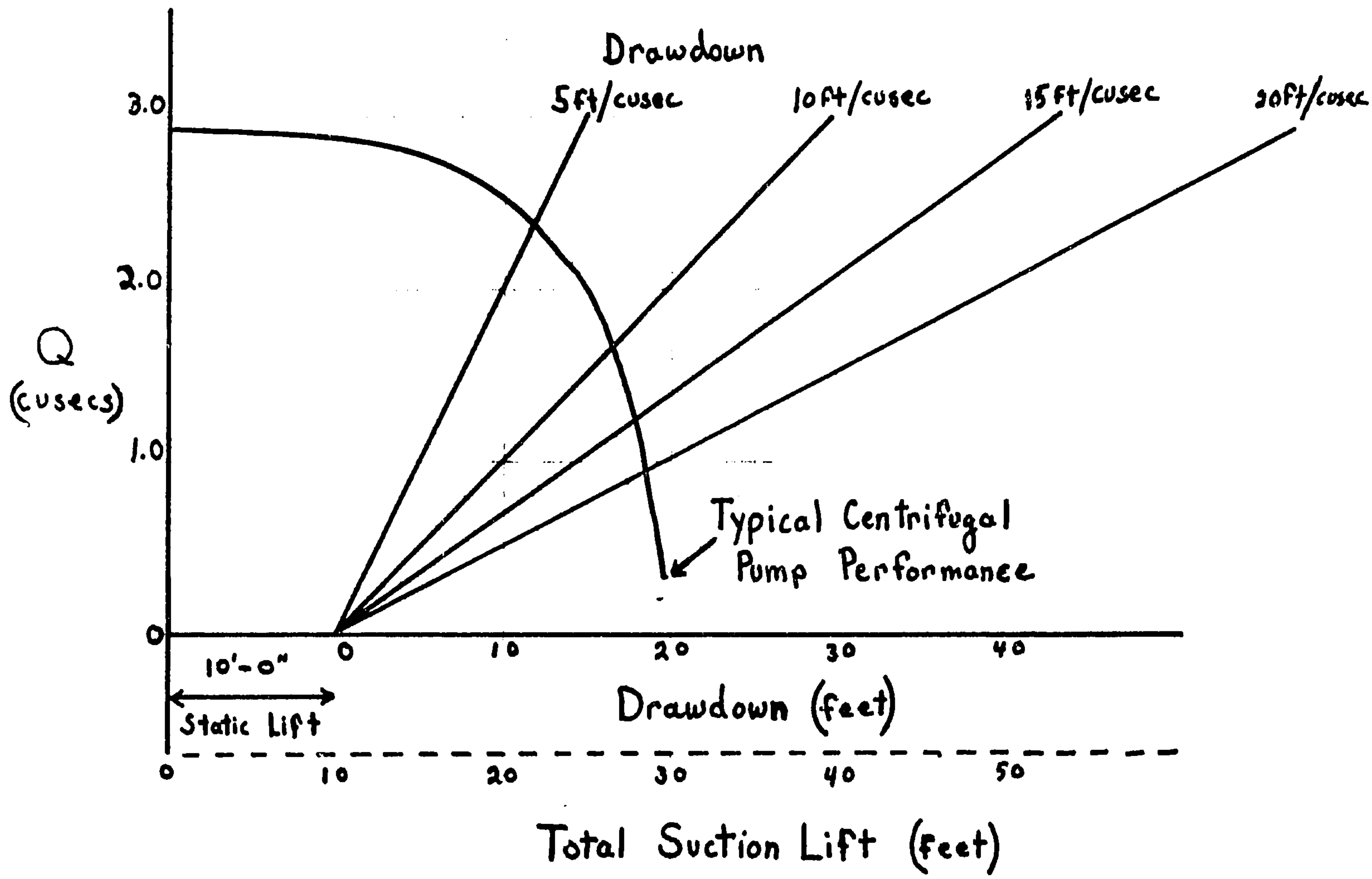
Source: Stephen V. Allison, Special Projects Division, IBRD.

Static water levels in Thakurgaon and Comilla have averaged about 10 feet.[26/] What it may be in other areas of Bangladesh is unknown. However, assuming ten feet to be average, the performance of a typical pump is charted in Figure 3.

[26/] Comilla data provided to author by KTCCA. Thakurgaon data from Harvard Center for Population Studies, East Pakistan Land and Water Studies, Progress Report, December, 1969. Section 1d p. 4.

FIGURE 3.

Typical Centrifugal Pump Performance Under Differing Levels of Suction Lift



Source: Stephen V. Allison, Special Projects Department, I.B.R.D.

Under these conditions if drawdown drops below about seven to eight feet per cusec, the centrifugal pump becomes quite ineffective. For both Comilla and Thakurgaon, where ground water levels are good, drawdown is about seven feet per cusec, the outside edge of the centrifugal pump's capacity. Under these conditions it also means that the centrifugal, pumps 25 percent less water than the turbine pump, with the related reduction in benefits.

Attempts have also been made to extend the range of centrifugal pumps. For this, electric motors provide important additional options not available with diesel power. In the extension of the Thakurgaon project, the World Bank proposes using a small floating pump. This technique if successful will represent a useful innovation, but it is applicable only where electricity is available. In drier areas centrifugal pumps have been placed in pits below the level of surrounding ground to extend the depth of the pump by an equal amount. The very rapid rise of ground water levels at the start of the monsoon season in East Bengal makes this a hazardous proposition in the area. However, there is great need for additional innovation to extend the potential use of the lower cost centrifugal pump.

(4) Type of materials installed. Most of the materials used in a tubewell are relatively standard -- only the choice of well filter screen material provides important alternatives.

(a) Screen. Screens are the most expensive component of the well. The three most commonly considered materials are fiberglass, brass and polyvinyl chloride (PVC). Mild steel which has been tried in Comilla and Thakurgaon is not considered because of its unreliable performance and the availability of better alternatives. The characteristics of these are compared in Table 3. The relative attractiveness of these alternatives in economic terms are expressed in rates of return in Table 3. These show PVC to be slightly preferable in economic terms and fiberglass and brass to be very similar.

Brass is moderately priced and durable in installation but subject to corrosion, resulting in the shortest anticipated lifespan. Its greatest advantage is that for some time in East Bengal it has been fabricated from scrap or sheet brass with only simple equipment. As a result, if widely used, there would be potential for local small industry to fabricate brass strainers.

The basic manufactured cost of fiberglass is less than brass. The price c.i.f. Chittagong is U.S. $11.25. Duties and internal transportation would be additional. There was discussion of establishing a domestic plant to produce fiberglass. If this were done it would lower the price, but it would probably only be done if a decision were made to use fiberglass screen exclusively, insuring adequate demand to justify a

TABLE 3.

Comparison of Tubewell Screen Materials
(prices in rupees)

	Cost Per Foot	Foreign Exchange Component	Shadow Price	Antici-pated life (yrs.)	Compara-tive Rate of Return[1]	Rate at Shadow Price
Fiber-glass	53.50	80%	96.30	20	.38	.29
Brass	50.00	70%	85.00	10	.35	.29
PVC	34.50	10%	38.00	15	.44	.43

Sources of cost data listed in Table 4.

[1] These rates of return should be treated as ordinal numbers for comparison of screen materials only. For ease of calculation, a round number was used to approximate all other costs, and only screen costs and the resulting anticipated well life were varied. Real rates of return for tubewells are shown in Tables 4 and 5.

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factory. In this case it would be a single large firm operating with imported equipment and technology in a single location and would not have the potential for establishing local small industry. The price of fiberglass screen could be somewhat lowered if the slotting were done domestically. This is a simple process but would require special equipment, limiting the number of firms that could undertake it.

PVC is the lowest cost strainer material. The c.i.f. price is $7.25 per foot. PVC could be produced at even lower cost in Bangladesh, either using imported resins, or utilizing domestic natural gas to produce it.[27/] While PVC could be produced domestically, it would have to be done with imported equipment and technology. For this reason it would be confined to a central manufacturing installation. The price of PVC could be further reduced if it were slotted domestically, a process simpler than slotting brass which would be done in small shops in the rural areas.

PVC has not yet been tried in irrigation tubewells, although it has been used extensively in smaller wells installed for drinking water supplies by the Department of Public Health Engineering. PVC can be damaged by heat or rough handling, both of which may occur in Bangladesh. As a result, it would be necessary to experiment with PVC on a small scale before adopting it for widespread use. Nevertheless, its low cost, light weight for shipping and potential for local production lead to the presumption that PVC will prove the most desirable screen material for the area.

One other material that should be listed is the coir or coconut fiber screen, used successfully in West Pakistan (see Appendix A). This is very cheap to produce, Rs. 1-2 per

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[27/] The potential for local production is discussed in detail in Camp Dresser and McKee, Analysis of loc al Procurement Development Potentials - DPHE, November 1965, pp. 3-40.

foot in West Pakistan, and has a short life of three to five years. It is possible that the finer acquifer of East Bengal would make the coir filter inappropriate, but it at least deserves testing. The other limitation on its use is that it must be replaced at intervals of three to five years. This is not too costly but requires at least the percussion drilling type tripod and wrench and a trained supervisor to direct the work. Until these are available in sufficient numbers that they can be obtained on short notice when the coir screen fails, this type of screen should not be installed except on an experimental basis.

In summary, the best estimates of costs of well components are compared in Table 4. While these are all subject to change they accurately reflect the relative cost of the options in tubewell installation.

(5) Well specifications. Well discharge of 1.5 to 2 cusecs has been generally established as the most desirable for East Bengal's conditions. Smaller wells have proven satisfactory for some conditions, but generally smaller or fractional wells (less than one cusec) irrigate an area that is of a size that one large farmer takes a major portion of its water and can dominate water usage but cannot use all the water so must find a way to sell or provide water to neighboring farmers on some basis. Such arrangements have generally not worked satisfactorily. Furthermore, the smaller the well, the less economic it becomes.

TABLE 4.

Costs of Major Variable Items in Tubewells
(in Rupees)

	Units	Costs	Foreign Exchange Component	Shadow Price	Source
Engine	20 h.p. engine				
Low speed diesel		4,500	50%	6,750	Author's estimate (assume domestic production).
High speed diesel		6,000	100%	12,000	I.B.R.D. estimate 1970.
Electric		5,000	100%	10,000	Dacca market price 1970.
Screen	8" diam. per foot				
PVC		34.50	10%	38.00	(Prices based on IBRD esti- (mates 1971. Foreign exchange
Fiberglass		53.50	80%	96.30	(assume local production.
Brass		50.00	70%	85.00	Dacca market price 1970.
Pumps	per pump	(See Table 2 for more complete comparison)			
Centrifugal		750	50%	1,125	Dacca market price 1970.
Turbine (inc.r. angle gear)		7,000	100%	14,000	IBRD estimate 1970.
Drilling	foot				
Water jet		8	25%	10	KTCCA cost 1970.
Manual percussion		10	5%	10.50	KTCCA/ADC cost 1970.
Power (by contractor)		47.50	75%	83.12	IBRD estimate 1970.

Within any given technology economies of scale can be obtained by increasing the design output; however, these tend to be offset by diseconomies due to increasing distribution losses largely due to soil conditions and social factors. There is probably a minimum point in the cost per acre irrigated calculations somewhere near two cusecs of output.

Lining primary distribution channels with PVC would undoubtedly lower irrigation costs per acre. This would necessitate a change in the present system where the beneficiary farmers are responsible for constructing all distribution channels. Although this would raise the budget cost of irrigation, it would lower the economic cost. Larger wells of 3.5, 4 cusecs or more have a sufficiently large output to cover over 100 acres, but losses in distribution and the difficulties of organizing the 75 to 100 farmers who can be served by such a well on a basis for mutual trust and cooperation in sharing the water has proven difficult. As a result, experience has shown that the 1.5 to 2 cusec well is the most manageable under East Bengal conditions.

One item of expense generally included in well cost is the pump house. Estimates of these range from Rs. 3,500 to Rs. 4,000, and the product is of high quality brick or cement construction. While a good quality cement base is needed, brick or cement walls are less essential. Therefore, it would appear sensible to produce pump houses of local materials, either thatch or mud, and thereby reduce the cost by as much as one half.

Some have suggested that the centrifugal versus turbine pump controversy can be resolved by using 10" diameter blind pipe in the top 80 feet of a well equipped with a centrifugal pump to allow it to be replaced by a turbine if water levels drop below the efficient levels for the centrifugal. The additional cost of expanding the top 80 feet is Rs. 5,000. In addition, to operate the centrifugal pump, 160 feet of screen are needed so a well with an expanded top and 80 feet of blind pipe at the top must be 240 feet deep to accommodate 160 feet of screen, or 60 feet deeper than the regular well for a centrifugal pump. This brings the additional cost of the expanded top to Rs. 7,500. Since this is greater than the cost difference between centrifugal and turbine pumps, it is clear that the turbine should be installed if there is any serious question about the suitability of a centrifugal pump in a particular well location.

The project appraisal report of the World Bank[28/] poses a trade-off between strainer length (capital cost) which reduces drawdown and operating cost, (the greater the drawdown, the higher are pumping costs) and notes correctly that the implication of this trade-off is who will pay; the Government (for capital costs) or the farmer (for operating costs). Where there is such a trade-off, East Bengal conditions would seem to indicate the desirability of reducing initial investment and increasing operating costs. This encourages and extends

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[28/] IBRD, Tubewell Project Report, June, 1970, Appendix 5.

the installation of wells in an area where investment capital is in exceedingly short supply and allows farmers to share well cost as their income rises as a result of benefits produced by the well. For this reason minimum well depths have been chosen in this study.

V. The Objectives of Irrigated Agriculture in Bangladesh

Increases in agricultural production are the primary objective of groundwater development. While increases in output are necessary, they are not a sufficient condition for overcoming the manifold problems of rural East Pakistan. This constellation of problems and the objectives of programs seeking to meet them must be understood before effective decisions can be made about tubewell development.

The population of the rural areas is large, and small farmers with holdings of seven acres or less hold 62 percent of the total cropped land. There will be no major increase in agricultural output without their involvement, and any tubewell program must have this group as its primary target. Agricultural landholdings which average 2.6 acres per owner are also fragmented, 69 percent are subdivided into four or more parcels.[29/]

It is clear that the poverty and fragmented nature of landholdings of the vast majority of the farmers effectively eliminates much scope for private investment in tubewells.

[29/] Government of Pakistan, Census of Agriculture, A Summary of East Pakistan Data, Lahore, 1960, p. 11.

If private investment were relied upon as the primary means of installing tubewells the 10 percent of farmers who are large enough to invest could quickly increase their incomes, and if traditional patterns hold, would use this new wealth to buy land from small farmers thus increasing the number of landless. Furthermore, the number of farmers with sufficient capital to invest are few and the total increase in output would be small. As a result, substantial reliance on the private sector would increase inequities, exacerbate the employment problem and generally prove counter-productive.

Private investment should be encouraged, only if the Government's primary effort is directed toward making wells available to small farmers who do not have personal funds to invest. This must be done through farmers' organizations such as the Thana Irrigation Program which brings small farmers together to share the water available from a well. In the Comilla cooperative system and the East Pakistan Integrated Rural Development Program there is a basis for organizing farmer cooperatives and concentrating rural development activities at the Thana level. The more tubewell development can be integrated with this effort, the more successful will it be in reaching the small farmers, the primary clientele for agricultural development.

In considering tubewell alternatives, primary importance must be attached to the objectives of distributing benefits broadly among small farmers, creating employment opportunities and creating new rural small industries. These factors must be considered along with more standard calculations such as economic return and engineering efficiency.

VI. An Evaluation of Alternative Tubewell Technologies

(a) Economic return. The evaluation of tubewell technologies must proceed from the fact that the physical conditions differ to an important degree in various parts of Bangladesh. As a result, no single prescription can be made for the entire region. Differing levels of static groundwater will dictate the type of pump that can be used. The availability of electricity or the frequency of flooding will mean that a particular source of power or type of engine is suitable for use in one area but not in another. A particular combination of drilling techniques and equipment may be more suited to one area than to another.

Similarly, the most appropriate technologies may differ over time. In the first few years the returns to irrigated agriculture may justify use of local and foreign contractors to install wells, while equal cost may be unjustified at a later stage when greater capacity to do the same work at much lower cost exists. Groundwater level may also change over time thus requiring changes in technology. Rural electrification or other developments may change the comparative advantage of one technique over another. Knowledge of the suitability of a particular type of equipment may also vary, necessitating changes in accordance with new experience.

What follows is an attempt to evaluate the existing tubewell alternatives, to present and clarify the background information necessary for making decisions regarding tubewells, and outline the conditions under which each alternative may be suitable.

The alternatives listed in Table 4 provide numerous possible specifications for tubewells. It is impossible to compare all potential combinations here. However, five possible combinations which might be commonly used are listed in Table 5. Other combinations are also possible. The purpose of this comparison is to show the approximate rates of return on variously priced alternatives. The details are contained in Table 5.

Having established the cost of these five alternatives, it is possible to calculate the rate of return for each well. The benefits used in the rates of return given below are conservatively calculated on the basis of the international market price for rice, rather than domestic price. They also assume a one year lag between investment and production on irrigated land, a lag which will not exist in some cases. They also assume that the output of a two-cusec centrifugal pump is only 75 percent of the output of a turbine. In calculating these rates of return, it was assumed that PVC would prove a feasible strainer material with an estimated lifetime of 15 years. Low speed diesel engines have lower operating and maintenance costs and a life expectancy estimated at 15

TABLE 5.

Comparison of Costs of Five Tubewells of Varying Specifications (in Rupees)

	(1)	(2)	(3)	(4)	(5)
Drilling	Jet	Jet	Percussion	Percussion	Contractor,power
Screen	PVC	PVC	Brass	Fiberglass	Fiberglass
Pump	Centrifugal	Turbine	Centrifugal	Turbine	Turbine
Engine	Low speed diesel	Low speed diesel	Low speed diesel	High speed diesel	High speed diesel
Move in and out	300	300	300	300	4,500
Drilling cost 160 feet 180 feet	1,440	1,280	1,800	1,600	7,600
Pumphousing 10" diam. 80 feet at Rs.60		4,800		4,800	4,800
Blind pipe 8" diam. 20 feet at Rs. 40	800		800		
Screen 8" diam. 80 feet 140 feet	4,830	2,760	7,000	4,280	4,280
Bail plug and reducer	500	500	500	500	500
Gravel pack 80 feet Rs. 15 160 feet	2,400	1,200	2,400	1,200	1,200
Install well hardware 160 feet Rs. 12 ft. 180 feet	2,160	1,920	2,160	1,920	1,920
Develop and Test Well	1,500	1,500	1,500	1,500	1,500
Pump	750	5,500	750	5,500	5,500
Engine 20 h.p.	4,500	4,500	4,500	6,000	6,000
Right angle gear drive		1,500		1,500	1,500

(continued)

TABLE 5 (continued)

	(1)	(2)	(3)	(4)	(5)
Drilling -	Jet	Jet	Percussion	Percussion	Contractor, power
Screen -	PVC	PVC	Brass	Fiberglass	Fiberglass
Pump -	Centrifugal	Turbine	Centrifugal	Turbine	Turbine
Engine -	Low speed diesel	Low speed diesel	Low speed diesel	High speed diesel	High speed diesel
Install pump and engine	750	750	750	750	750
Pump House	3,500	3,500	3,500	3,500	3,500
Sub total	23,430	30,010	25,960	33,350	43,550
Contingency	2,343	3,001	2,596	3,335	4,355
Total	25,430	33,011	29,556	36,685	47,905
Rate of return	.32	.39	.28	.30	.22

years as opposed to the high speed engines with an estimated life of seven years. All turbine pumps are assumed to last seven years. The rates of return are as follows: (Details of the calculations are given in Appendix C.)

alternative 1-- .32	alternative 4-- .30
alternative 2-- .39	alternative 5-- .22
alternative 3-- .28	

These rates represent the return to the economy. The return to the farmers who benefit at the market price of rice, which is approximately double the international price, proved to be over 1.0 for alternatives one through four and about .75 for alternative five. This serves to reconfirm the original assumption that tubewell irrigation is extremely profitable.

After calculating rates of return at the official exchange rate, it is useful to re-do the exercise at a more realistic value of the rupee (and one closer to the present value of the Bangladesh Taka). The rate of Rs. 9.50 = $1, the rate commonly employed by the World Bank as the rate most closely approximating the real value of the Rupee, is used in Table 4 to calculate a shadow cost of tubewell components. The rates are used in Table 6 to shadow price the same well alternatives that are listed in Table 5. On this basis, the rates of return are:

TABLE 6.

Comparison of Cost of Five Tubewells of Varying Specification in Shadow Prices
(in Rupees at Rs. 9.50 = $1)

	(1)	(2)	(3)	(4)	(5)
Drilling -	Jet	Jet	Percussion	Percussion	Contractor, power
Screen -	PVC	PVC	Brass	Fiberglass	Fiberglass
Pump -	Centrifugal	Turbine	Centrifugal	Turbine	Turbine
Engine -	Low speed diesel	Low speed diesel	Low speed diesel	High speed diesel	High speed diesel
Move in and out	300	300	300	300	4,500
Drilling cost					
160 feet		1,600		1,680	13,300
180 feet	1,800		1,800		
Pumphousing 10" diam.					
80 feet		9,600		9,600	9,000
Blind pipe 8" diam.					
20 feet	1,600		1,600		
Screen					
80 feet		3,040		13,482	
140 feet	5,320		11,900		
Bail plug and reducer	1,000	1,000	1,000	1,000	1,000
Gravel pack					
80 feet		1,200		1,200	1,200
140 feet	2,400		2,400		
Install well hardware					
160 feet		1,920		1,920	1,920
180 feet	2,160		2,160		

(continued)

TABLE 6 (continued)

		(1)	(2)	(3)	(4)	(5)
	Drilling -	Jet	Jet	Percussion	Percussion	Contractor, power
	Screen -	PVC	PVC	Brass	Fiberglass	Fiberglass
	Pump -	Centrifugal	Turbine	Centrifugal	Turbine	Turbine
	Engine -	Low speed diesel	Low speed diesel	Low speed diesel	High speed diesel	High speed diesel
Develop and Test Well		1,500	1,500	1,500	1,500	1,500
Pump		1,125	11,000	1,125	11,000	11,000
Engine		6,750	6,750	6,750	12,000	12,000
Right angle gear drive			3,000		3,000	3,000
Pumphouse		3,500	3,500	3,500	3,500	3,500
Sub-total		27,455	44,410	34,350	60,182	69,624
Contingency		2,745	4,441	3,435	6,018	6,962
Total		30,200	48,851	37,470	66,200	76,586
Rate of return		.25	.19	.18	less than .10	

alternative 1-- .25	alternative 4	less than .10
alternative 2-- .19	alternative 5	
alternative 3-- .18		

These calculations suggest that the two most expensive wells appear not particularly attractive from a national economic perspective although they remain highly profitable for the individual farmers. The turbine and centrifugal wells both yield good returns, with the turbine having the better return at market prices, while the centrifugal is preferable at shadow prices. Under the circumstances, it appears justified to use the centrifugal where there is no question of an adequate water level, while in all cases where there is reasonable doubt, the turbine appears justified. There are other low cost alternatives that have a good economic justification, but if price rises above about Rs. 40,000 for a 1.5 to 2 cusec well, then it becomes a poor investment in economic terms. Future tubewell installations should experiment with all three screen types. All can be used in low cost wells. Likewise, changes in engines and pumps are possible. The five alternatives listed here are only a few of numerous economically attractive low-cost well alternatives. Experiments should not be limited to these alternatives. What these do show is that low-cost combinations have a high pay-off while more expensive wells are decidedly less attractive.

(b) Time sequence of well development. The preceding calculations of returns to different types of wells assumes that wells can be installed at the same rate and are subject to the same time constraints. Most advocates of the foreign contractor drilled wells claim that their much higher cost is justified by much more rapid rates of installation, which gives the more expensive wells a higher present value. One adviser to WAPDA suggested this is an official report. "The question is whether or not local contractors can cope with the great number of wells which must be installed in East Pakistan in the next 5 to 10 years. If the capacity is not available and foreign contractors must be brought in, the cost price per unit is likely to increase considerably. However, the increase in cost price may be offset by the total return in the larger number of units which can be installed with the aid of foreign contractors."30/

There is considerable international capacity for well sinking which can be attracted rapidly at an appropriate price. To obtain this capacity, foreign firms would have to be guaranteed substantial profitable business before they would bring their equipment to the area. Although no such commitments have yet been made, for purposes of this analysis, it is assumed that all the equipment necessary to drill 20,000 wells in a five-year period would be imported.

There is always a lead time of six months to a year or more between the time contracts can be signed and the time it

30/ Peter Mulder, ILLACO, General Consultants to EPWAPDA, Socio-economic Cost of Irrigation by Tubewells and Low Lift Pumps, Dacca, 1970, mimeo., p. 6.

takes to import drilling equipment and supplies and bring personnel to operate the equipment. Once in place, wells can be installed by a single power drilling rig in about a week. Given the monsoon climate, however, it is possible to drill only about 5 to 6 months of the year, or 24 to 25 wells by one rig per year.

In any situation, and particularly so in the case of Bangladesh, it is necessary to assume that resources represent some constraint. Therefore, for purposes of this analysis let us assume that the generous East Pakistan Fourth Plan budget of Rs. 1,400 million, or Rs. 70,000 per well, represents the financial limit of resources for investment in tubewells and that with this guarantee foreign firms can be attracted to install wells at the rate of 4,000 per year to achieve the target of 20,000 wells in five years.

This must then be compared with the rate of development of capacity to install low-cost tubewells. The Comilla KTCCA wells are installed by two-man teams of a Driller and assistant Driller who hire and direct a group of 10 to 20 local, unskilled laborers. One Foreman supervises the work of five rigs. In addition to this group, it is necessary to have a good supply system which can provide materials for each rig as they are needed so that progress is not delayed because of the non-availability of materials. The KTCCA has worked out an efficient system with a tubewell supply warehouse located at the Thana headquarters. The Foreman, who travels daily between each of his rigs and the Thana Center, is personally responsible for seeing that there is never a shortage of supplies at the drilling site.

A team of this type can drill a well by percussion methods in approximately four weeks or jet drill a well in one to two weeks. It can also drill by percussion but not by water jet through the monsoon season, although installation time doubles in the rainy months. It is conservatively estimated that one rig using either low cost method can drill about six wells per year.

In order to compare the rates of installation of wells, it is necessary to analyze how rapidly the capacity to install low-cost wells can be developed. Drilling rigs are simple and can be fabricated more rapidly than men trained to operate them, so the constraint is the rapidity with which crews to operate them can be trained. In Comilla, six months of apprenticeship on a drilling rig was the time needed to train assistant drillers. After an additional half year's work, an assistant driller is promoted to a driller and is given charge of a rig. Foremen are selected from among the drillers on the basis of aptitude, knowledge, and organizational ability.

As of the end of 1970 ADC had in its employment 80 drilling crews which had been trained at Comilla. In addition, Comilla KTCCA had seven crews. There are enough foremen and drillers to begin operating 85 rigs immediately. In addition to this, there are at least 14 local contractors with capacity to drill percussion wells. However, to be conservative, private contractor capacity will not be included in these calculations.

Since drilling can be done with efficiency in only nine months of the year, it is possible to train only three men on each rig each year. (In other words, one 2-man team in six months and half the training of a 2-man team in the remaining three months.) If you begin from the existing 85 rigs and calculate that each one trains three men per year, it is possible to have 3,312 rigs with an annual installation capacity of approximately 19,000 wells operational in five years.

Table 7 shows the maximum rate of expansion of the capacity to install percussion-drilled wells over a five year period.

It is then possible to compare the installation capacity of low-cost wells with foreign contractor drilled wells. Figure 4 shows the rate of development of foreign contractor wells, assuming the cost limit of Rs. 1,400 million. As the figure indicates, more wells can be installed in the first four years by foreign contractors, but by the end of the fifth year, capacity to install wells by low cost methods will have vastly exceeded foreign contractor capacity.

The question that must next be answered is this: Does the slower initial capacity to install percussion wells off-set the cost advantage in a rate of return comparison? To

TABLE 7.

Rate of Increase of Well Installation Capacity by Low Cost Methods

Year	1	2	3	4	5
Rigs operating	85	212	530	1,325	3,312
Annual capacity	510	1,272	3,180	7,950	19,872
Cumulative instal.	510	1,782	4,962	12,912	32,784

determine this, it was assumed that 20,000 wells would be installed in a five year period by each technique. For this calculation a combination of jet and percussions drilled, centrifugal and turbine pumped wells with an average cost of Rs. 30,000 per well utilizing PVC screen, were compared with 20,000 contractor-drilled wells costing Rs. 45,000 with fiberglass strainers and turbine pumps. The two alternatives were compared with installation for the low cost wells at the rate indicated in Table 7 above except that in year five the installation was stopped at 20,000 rather than proceeding to the theoretic maximum of 32,784.

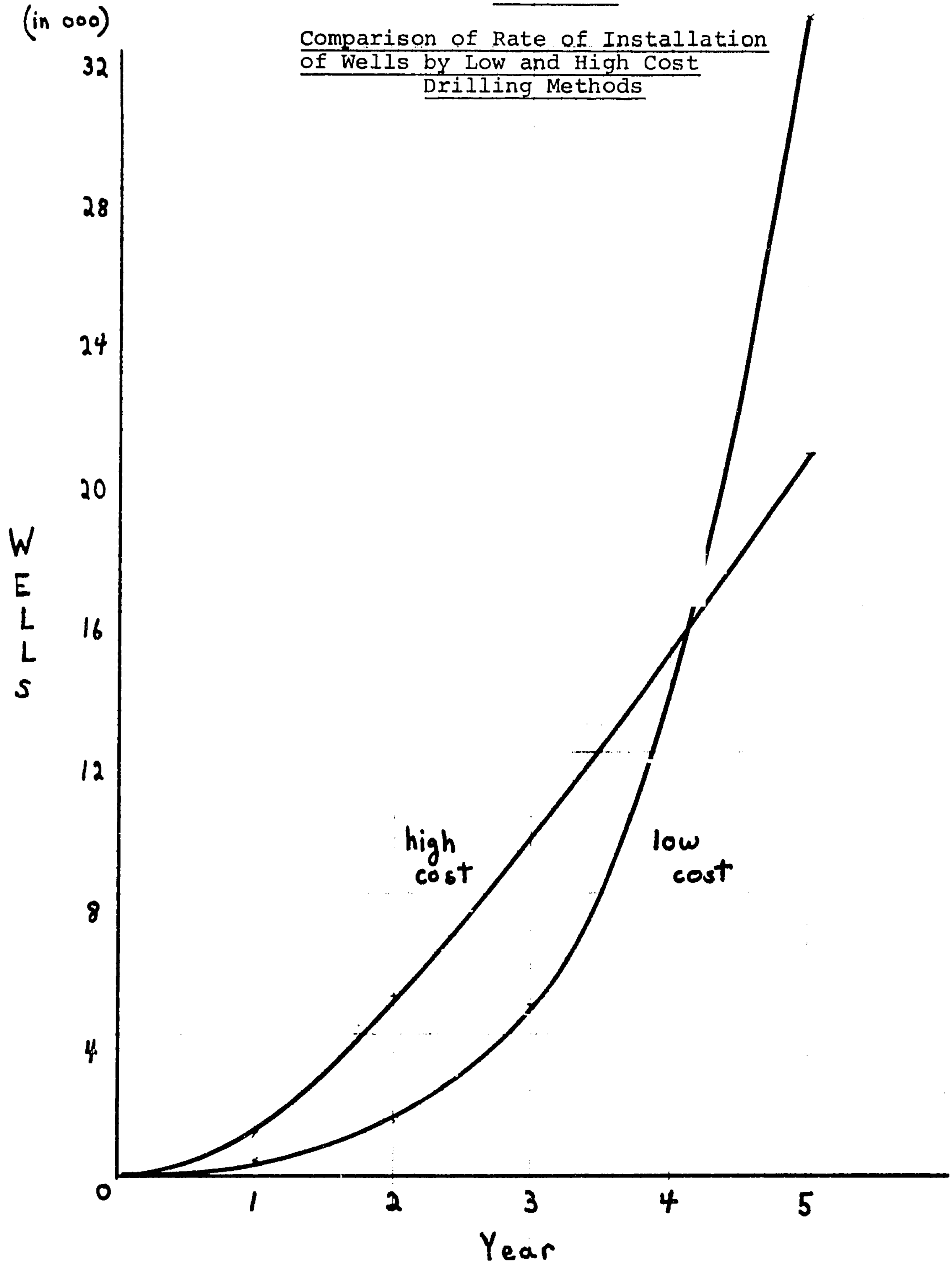
Compared in this manner the rates of return were as follows:

Jet and percussion-drilled wells	.31
Contractor, power-drilled wells	.18

From this, one must conclude that the economic return on the low cost wells, despite lower initial rate of installation,

FIGURE 4.

Comparison of Rate of Installation of Wells by Low and High Cost Drilling Methods



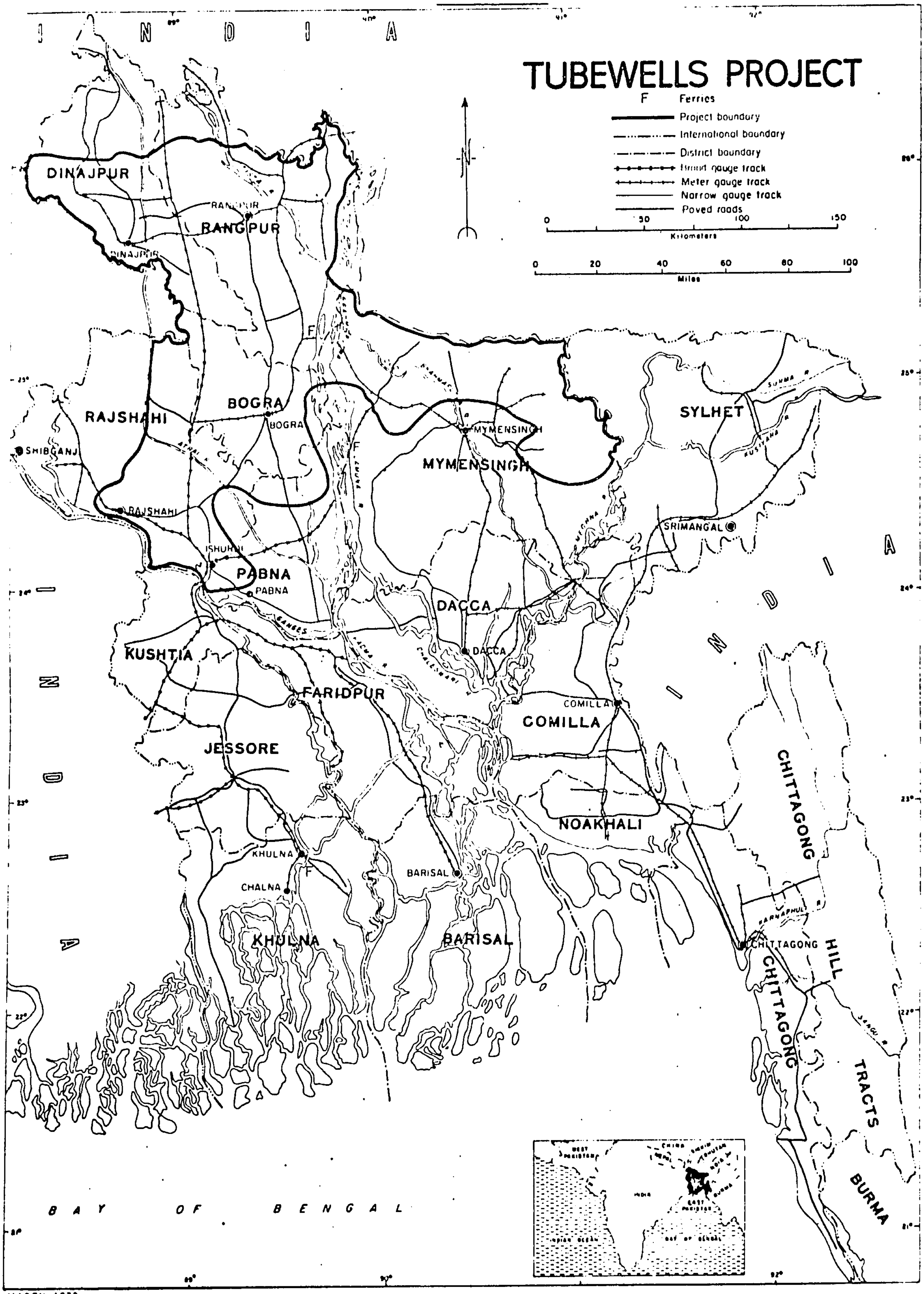
is substantially higher. Anything that can be done to improve these wells or cut their costs, will increase the return, but the low cost drilling method is clearly the more economic alternative.

The installation of 20,000 wells in five years by either of these methods is a theoretical maximum figure. In practice neither would probably be achievable. For a foreign contractor, commitments of expensive drilling equipment and personnel to Bangladesh without a long-term guarantee would be impossible. The complexities in mounting and supplying such a large operation would also be substantial. The difficulties in agreeing on the 1,000-well project under the Yugoslav barter agreement illustrates the dimension of the problem. Geotechnica has been negotiating for almost two years trying to establish the areas of well sinking, the supply system and other details that they consider necessary prerequisites for initiating operations.

The same difficulties confronting foreign contractors in supplying such a large organization would confront the low cost drilling operation. Training drillers in low-cost methods and actual installation of wells would doubtlessly present problems. However, it is impossible to estimate how much each operation would be diminished by the various difficulties encountered. Therefore, for purposes of this calculation, since there is no way of arriving at more realistic estimates of performance, the computations are done at these theoretical maximums. In interpreting the results, it is important to remember that these are valid for comparing the effect of time on the two alternative techniques, but they are not valid for projecting the actual rate of well installation. Rate of return calculations have very severe limitations where employment and equity are major goals of development projects as well as economic profitability. In the preceding test of tubewell alternatives, the rate of return is used purely to show economic profitability. The effects of the various alternatives on employment and equity are considered separately. They must be weighed along with the rate of return in the final determination of technology.

(c) Location. Both the World Bank and the Yugoslavs (presumably GEC too, although details of the agreement are not known), have limited their drilling sites to the five Districts of North Bengal and to northern Mymensingh District (see Figure 5). These have been selected partly because of the known groundwater supply in the area and partly because it is only in these areas that the heavy 10-15 ton power rigs mounted on trucks can be moved from one drilling site to another easily. In other areas, mobility of heavy truck-borne power rigs is limited by the absence of roads and bridges and specially adapted rigs must be obtained. However, the jet and percussion drilling rigs are relatively light weight, easily taken apart and reassembled. As a result they can be transported from one site to another by almost any means from tractor-drawn wagon or boat to animal cart or men's shoulders. This means they can be moved almost any place and can operate and

FIGURE 5.


TUBEWELLS PROJECT
F Ferries
Project boundary
International boundary
District boundary
Broad gauge track
Meter gauge track
Narrow gauge track
Paved roads
Kilometers
Miles
I N D I A
DINAJPUR
RANGPUR
RAJSHAHI
BOGRA
SHIBGANJ
MYMENSINGH
SYLHET
SRIMANGAL
PABNA
ISHURDI
DACCA
KUSHTIA
FARIDPUR
COMILLA
JESSORE
NOAKHALI
KHULNA
CHALNA
BARISAL
CHITTAGONG
CHITTAGONG HILL TRACTS
BURMA
B A Y O F B E N G A L
MARCH 1970

be moved in all seasons. This mobility makes the low-cost drilling equipment much more versatile and much cheaper to move into the many areas of Bangladesh where it is difficult to transport heavy equipment.

The distribution of benefits of the installation process vary according to the type of installation technique employed. The low-cost wells provide a broader distribution of employment, training and financial benefits most of which are retained in the rural areas. They also create the potential for rural small repair and manufacturing industry. Alternatively, the benefits from power-drilled wells go to city based contractors or foreign contractors, and the installation itself provides almost no benefit to the location in which it takes place.

(d) Irrigation water utilization. The failure of past irrigation projects in East Pakistan has resulted in large part from an absence of farmer demand for water. Until the Thana Irrigation Program, irrigation projects focused on the supply side and neglected demand for water. The Thana Irrigation Program, which made demand a prerequisite for supply, has succeeded in solving this difficult problem.

The organizational framework of the Thana Irrigation Program has already been described briefly. It focuses on organizing farmers into irrigation groups to jointly manage, utilize and pay for water. After they have formed a group, they can apply for a water supply. Once water has been received, they also select a pump or well operator and a model farmer who receives training in pump or well operation and the use of irrigation water respectively. The model farmer is, in turn, responsible for teaching new techniques of irrigation farming to the other members of the group. It is essential that any tubewell program, no matter what installation technique is used, be deployed within the framework of the Thana Irrigation Program, or a similar organization structure.

The issue of demand and the capacity of the Thana Irrigation Program to organize irrigation groups will be the critical determinant of the rate at which the number of tubewells can be expanded. If installation capacity surpasses demand, then the rate of installation must be slowed because wells sunk in excess of demand will be only partially utilized.

It is difficult to determine in advance the rate at which demand for water will expand. It is clear that once available and utilized, irrigation water becomes a highly prized commodity which villages will fight to retain.[31/]

[31/] The East Pakistan newspapers occasionally carried reports of clashes over water. One report from Mymensingh reads, "On the morning of May 9 two groups of people clashed with each other over water pumped out from an irrigation pump in an IRRI paddy field in village Hoglakandi under Hossainpur Police Station. As a result two persons of the locality, Abdul Hai and Abdul Mojeed, lost their lives, it is learnt (sic)." Dacca Morning News, May 26, 1970.

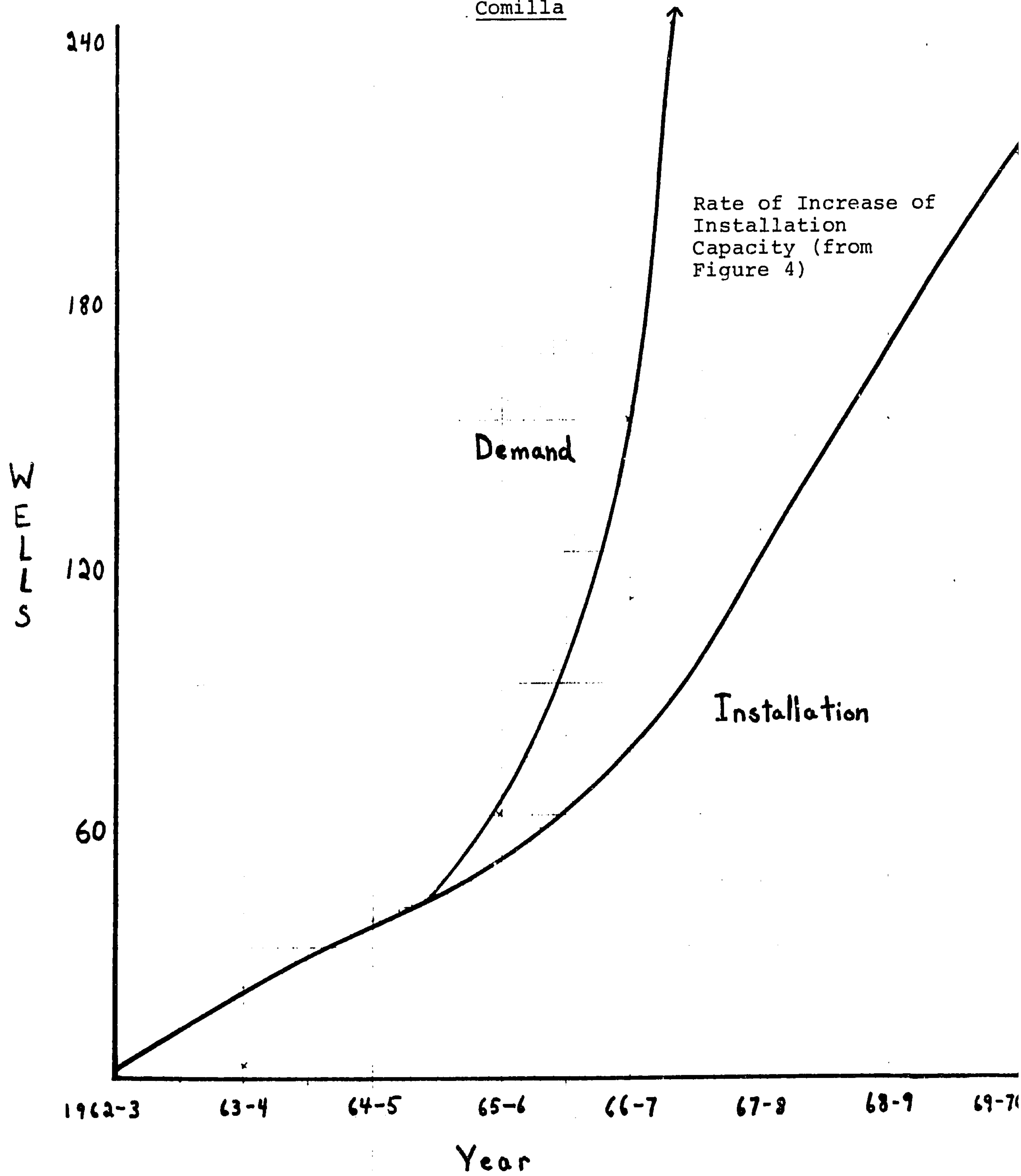
Judging from the pattern of demand at Comilla, there is an important demonstration effect governing demand. It is useful to examine the experience of Comilla once again, for demand did much to regulate the rate of expansion. Figure 6 shows the cumulative rate of expansion. After year four, the rate of demand and installation approximately doubled. It is useful to compare Figure 4 with Figure 6. They suggest that the demonstration effect causes a lag in demand and that the installation of wells at a high rate in the early years may not be desirable. The lag in demand may well fit with the time needed to develop capacity for installation of wells by low cost techniques.

The most critical point, however, is that installation schedules be sufficiently flexible that they can be geared to demand as shown by the formation of irrigation groups under the Thana Irrigation Program. If installation schedules replace farmer demand as the determinant of the rate of well sinking, the tubewell program will be destined for serious problems of underutilization.

It is also quite probable that installation techniques will have some influence on both farmer utilization and operation and maintenance. Although there is no way to quantify this psychological aspect, farmers who have participated in the installation of a well, perhaps even have spent four weeks working on it, will have a much greater understanding of well operations as well as a feeling of personal investment in it.

FIGURE 6.

Demand and Rate of Installation for Wells by K.T.C.C.A., Comilla



As a result, they may be much more aware of its potential benefit. If the process is one of bringing in heavy equipment which they do not understand and which in one or two days installs the well and then departs, they will not understand how the well works or feel it is anything with which they are associated. The process of participation will provide the farmers a comprehension of the principles of a well and its operation. As a result of this, they will have much more capacity to use it correctly, maintain it and make minor repairs. Despite the vagueness of these psychological factors, they will have a bearing on the ultimate use and maintenance of the well.

(e) Employment. In Bangladesh, with its labor surplus, capital short economy, the creation of new employment opportunities and the conservation of capital are high priorities. The low cost drilling techniques create far more jobs while requiring only a fraction of the capital investment necessitated by using foreign contractors. It is important to calculate the employment potential. During sinking of a well by percussion or water jet methods, two shifts of eight unskilled laborers are employed for a four-week period, a total of 16 man-months or 1 1/3 man-years. If 20,000 wells of this type are installed, 26,000 man-years of employment for unskilled labor will be created. In addition to this, employment is created for the drillers and assistant drillers. This would amount to 8,990 man-years employment. The total for the program would be 34,000 man-years. By contrast, the power-drilled wells have a very small employment component. The 160 power rigs needed to drill 4,000 wells annually would employ two men each. This would amount to 1,605 man-years' employment for 20,000 wells. The 32,400 additional man-years of employment created by percussion drilling mean that this form of well sinking is definitely preferable from the employment perspective.

(f) Training. In a society in which the absence of skilled manpower serves as a severe constraint on development, a program of tubewell development that would train 7,286 foremen and drillers is preferable to employing foreign contractors whose operations would provide a little training to only a few hundred Bengalis. In addition, percussion and jet drilling would provide 524,500 laborers with two to four weeks' experience in drilling operations. This is not an immediately marketable skill, but it is an exposure to simple mechanical principles and skills which can be quickly and profitably applied to well operation and maintenance and other agricultural operations. In terms of training, the low cost system is clearly preferable.

Foreign contractors can make an important contribution to the general knowledge of tubewell technology particularly in the early stages of the program. They bring much greater experience and greater engineering knowledge and they can impart important training in the techniques and skills of well installation. Such training is a benefit in depth in that it increases the capacity of local well technicians rather than providing broad training in simple mechanics and well technology as do the other wells.

(g) Quality control and supervision. It is assumed that a large portion of the cost of any major tubewell program will have to be financed by external aid donors. Foreign donors are more likely to be attracted if the tubewell development program is consistent with their mode of operation. This will usually mean a centralized administrative system for installation and an emphasis on engineering quality. The GEC supplier's credit and the Yugoslavian commitment, for intance, were made on the understanding that contractors utilizing power rigs would do the installation, and that the donor country would provide the well materials according to their own preferences. Given the high return on any well, it may be desirable to accept this type of foreign financing on a small scale, recognizing that the technology of wells provided is probably not the most suited to provide Bangladesh's development.

There were also strong pressures from the East Pakistan Government agencies to maintain maximum control over a large and important program. For many of the same reasons as foreign aid donors, these agencies preferred to maintain control in their own hands. These interests, no more than the donor, should stand in the way of the nation's needs.

Finally, an assurance of quality is considered important by some in the early stages of any new and critical program and any risks in performance should be avoided. Given the demonstration effect in creating new demand for water, well failures and sub-standard performance could have a negative psychological impact on farmers. Power drilled wells, with turbine pumps, are the surest way to obtain engineering quality. This, however, is one of many related considerations, as illustrated by the fact that the 360 high quality wells in Thakurgaon have irrigated much less land than the 200 low cost wells in Comilla.

(h) Potential for non-governmental installation. Potential for private sector investment in tubewells is limited in Bangladesh. Despite the poverty of the area there is some scope for private investment. It is important that this demand be met despite the fact that the government must put much higher priority on other forms of tubewell development. If a few private contractors can become sufficiently proficient that they can drill wells for a cost between the Rs. 20,000 to Rs. 30,000, this potential market which is probably limited to the 10 percent large landholders (a total of 1.3 million individuals) should be met.

The Bangladesh Government can probably finance a maximum of 10,000 high-cost wells in a five-year period with its own resources supplemented by external aid. However, at this rate it would take them thirty years to install the number of wells West Pakistan installed in the decade of the sixties.

If this rate is to be accelerated, it will be necessary for Bangladesh to find a third alternative, beyond private investment and Central Government investment. The best hope for this would appear to be local government or Thana cooperative federations.

In the 1960's the competence of local government and particularly that of the Thana Councils, increased through its primary administrative responsibilities for the Rural Works Program and the Thana Irrigation Program. Simultaneously the model for an effective two-tier system of farmers' cooperatives based at the village level with supporting Thana-level federations was developed at Comilla. Before the Civil War, this system was scheduled for expansion as the Integrated Rural Development Program. If these plans are carried out, each Thana Council or Thana Cooperative Federation could obtain a number of drilling rigs on the basis of local conditions, demand and the necessary personnel to operate them. They could then assume responsibility for tubewell sinking in their Thana. Heavy subsidies from the Government would be necessary particularly in the early stages. Over time, with cooperative financing and the pooled resources of beneficiary irrigation group members, local demand could be met by a program increasingly administered and financed at the local level. It is clear that such a program would depend very much upon a well of minimum cost. Neither local institutions nor private farmers would find a high-cost well an economic proposition. Furthermore, local agencies could not easily acquire the competence to install wells with rotary drilling rigs and complex equipment. The parallel to West Pakistan is clear, the low-cost, technically simple wells could be attractive to non-governmental investment while the high-cost complex wells could not.

(i) Creating rural small industry. Development of small rural industry would be an important fringe benefit of the tubewell development program. With some encouragement from the ~~Provincial~~ Government, the number of private domestic contractors installing wells will inevitably increase. These will develop either from those trained by the public sector program or directly in response to private demand. In addition to these, the important question is what local small industries would be developed by alternative techniques. This has been considered very specifically in terms of actual equipment.

Rigs. Power rigs must be imported in final form. The components of up to 3,000 percussion drilling rigs, tripods, hand winches, pulleys and the sludger or bit can all be fabricated in Bangladesh with a minimum of machinery and technical skill. Their fabrication and maintenance would provide the basis for one or more small firms.

Pipe and strainer. If 20,000 wells are to be drilled in the five-year period and the average well is 170 feet, the demand for blind pipe and strainer is clear. Using the estimate of 40 feet of blind pipe and 120 feet of screen for a 170 foot well, the demand for pipe would amount to 2.4 million feet of screen and 800,000 feet of blind pipe. In financial terms it would mean an expenditure of Rs. 120 million on screen and Rs. 40 million on blind pipe. Blind pipe is not difficult to manufacture, and with the demand generated by a large tubewell program it could be produced in Bangladesh. Brass strainer has been produced for some time in Bangladesh in a relatively simple process which could be expanded to additional small workshops around the country. PVC is a complex process which can be carried out at a large plant so has little potential for widespread duplication, however slotting could be done in local workshops. If the once planned petro-chemical complex were developed, resin for production of PVC would be available at low cost. There was also discussion of constructing a fiberglass plant in East Pakistan; this could easily be done, but raw material would have to be imported. Such an industry should not be established unless fiberglass were demonstrated to be the best screen material. Fiberglass, like PVC, production would be a process carried out only in one large plant. Brass strainers are more attractive than PVC or fiberglass for their potential for encouraging local small industry.

Pumps and Engines. Centrifugal pumps and low-speed diesel engines have been manufactured in Bangladesh. Turbine pumps could also be manufactured there but are more complicated than centrifugal pumps. Once again, the experience of West Pakistan suggests that if a large number of tubewells are installed, local fabrication, manufacturing, and maintenance industries will follow rapidly.[32/] If percussion and jet drilling methods are used, with PVC or brass filters, centrifugal and turbine pumps with low speed diesel engines, it is evident that the potential for local fabrication, repair and maintenance will be particularly high. The development of local industry will have two benefits, first the stimulus to the economy of additional manufacturing, and second, the provision of a readily available supply of spare parts and maintenance facilities, both of which are essential to the effective operation of a large number of tubewells.

VII. Future Directions for Tubewell Development

Despite the obvious desirability of a variety of low cost wells, East Pakistan had been moving toward the installation of high cost wells, with much less attention to the low cost alternatives, primarily because of aid donor preferences. This analysis suggests that the past trend should be reversed by the Government of Bangladesh. Emphasis should be given to experimentation and to creating capacity to produce and install low cost wells. Foreign assistance which is available only for high cost wells could be used in the short run while low cost well installation capacity is being created. Nevertheless, high cost wells can be fully justified only as a temporary expedient while giving time to develop knowledge and capacity for another type of tubewell irrigation. In the future, Bangladesh and its aid donors must follow a pattern of well installation more closely correlated with the objectives of the nation's development.

[32/] Edwin H. Smith, _op_. _cit_.

This review of tubewell alternatives for Bangladesh indicates that there is no single well design appropriate for all circumstances. There are a variety of options available and it will be critical to select the well specifications suitable for the specific area of installation. It is also important in the early stages of a major tubewell program, to experiment as widely as possible with various techniques and specifications.

As part of the tubewell development program, certain areas of research and experimentation deserve high priority. The need to carry out a comprehensive groundwater survey as soon as possible has already been mentioned. As part of this survey it will be important to obtain detailed information on the depth of groundwater from ground surface. This information is vital to determining where centrifugal pumps can safely be used. The land classification prepared by the East Pakistan soil survey must also be analyzed to determine the probability of flooding and range of flood depth. This is needed to judge which areas can be irrigated by tubewell, the elevation at which pumphouses must be built to avoid inundation and areas where flood is inevitable and portable high speed engines must be used.

Although all the evidence suggests that PVC will prove to be the most appropriate well screen material, it needs extensive field testing, as does fiberglass to determine its performance in transportation, installation and in well operation. Final judgement on the most appropriate screen material and decision on local production must await this testing process. Other materials like coir (coconut fiber) should be tested if they appear to have any promise.

Considerable experimentation on well depth is needed. This analysis has made optimistic assumptions about depth. Existing wells have been somewhat deeper, but have had the same footage of screen. Experiments are needed to determine optimum well depth, screen length combinations and whether variations are needed in different parts of the country.

Finally, more experimentation is needed with fractional (less than one cusec capacity) wells. Thus far, primarily for the organizational reasons cited these have not proved attractive. If tubewell irrigation becomes popular and installation capacity grows as is probable, there may be considerable private demand for fractional wells.

When a major tubewell program is undertaken it should follow the model of the Thana Irrigation Program and be implemented through a structure that focuses on farmer demand and organization for water utilization. Training of selected farmers from each well group in the techniques of irrigated farming and introducing complementary agricultural inputs will be essential to the productivity of the tubewell program.

A planning system similar to that developed under the Thana Irrigation Program should be used to determine the number of wells to be located in a particular Thana. The expansion of wells should be closely coordinated with the expansion of rural development system of cooperatives if one is planned in the Comilla and Rangunia patterns, since the two programs would be mutually supportive. The cooperatives in Comilla have proven most successful when their existence is supported by substantial increases in production resulting from irrigation. Rising incomes equip farmers to participate in the monetized sector of the economy. This facilitates credit programs and helps bring the kinds of economic increases that provide a fertile ground for institutions which can help the farmer deal with these changes. The existence of cooperatives has also provided a cohesive, disciplined unit around which to build the irrigation group. Cooperatives can also contribute by helping to process, store and market the increased production that will result from the availability of irrigation. As a result, phasing and locating tubewells should be coordinated with the expansion of other rural development and cooperative programs.

If the type of tubewell irrigation suggested here is put into operation, it will orient Bangladesh's tubewell development efforts in directions which could result in a rapid expansion of irrigation and agricultural production. The returns to irrigation are sufficiently high to provide a substantial incentive for its rapid expansion. To accomplish this, the public sector must create the technology that is appropriate for the needs of the country and the capacity to respond to the demand for irrigation once it is created. The result would be a major stimulus to the agricultural development of Bangladesh.

APPENDIX A

Tubewell Development in West Pakistan

Irrigation has always made a critical contribution to the prosperity of West Pakistan. Traditionally, canal irrigation fed by the Indus and its tributaries provided the prosperity of the Punjab and the Sind. However, beginning in the 1950's, tubewell irrigation expanded. Tubewells were attractive because of their locational flexibility and the relatively small investment needed per unit. In 1956, the Agricultural Engineering Department of the West Pakistan Department of Agriculture under the direction of Majid Hassan Khan, a trained agricultural engineer, designed a simple, low-cost tubewell that cost between Rs. 7,000 and 9,000. The most expensive part of the well is the screen, the lower portion of the well pipe that is perforated with small slots to let water into the well and filter out the sand and gravel of the aquifer in which it is placed. To reduce costs to a minimum, iron strips were welded into 6-inch iron rings and coconut fiber or coir string wound around the strip to form a strainer rather than using slotted pipes. Locally manufactured diesel engines were employed to drive the pump. In addition to the low cost of these wells, their components could be manufactured and serviced in the small workshops of the towns in the area of their use. The result was a low-cost well which could be installed and serviced by local people, which made engineers skeptical but was to prove highly popular among farmers.

The Department of Agricultural Engineering, which initiated the low-cost tubewell program, only installed about 750 of the low-cost wells. After that public funds were no longer available for this type of well development and the program was dropped. However, the popularity of low-cost tubewells installed by farmers with their own funds grew rapidly in the late 1950's and early 1960's although there was little knowledge of this phenomenon. Public investment in wells also grew during the period. However, most public wells were of a large capacity, constructed to specifications that made them very expensive and were concentrated in the large salinity control and reclamation projects.

By 1965 West Pakistan began to witness spectacular growth in agricultural production. Initially, it was assumed that this was derived from efforts to improve the technology of agriculture with fertilizer, new seed varieties and pesticides. However, analysts of West Pakistan's agricultural success concluded that "water is the key input in the [Indus] basin region, which produces about 80 percent of the total provincial [agricultural] output."[1/] Much of this water was produced by low-cost, private tubewells. These increased from about 7,000 in 1960 to 55,760 in 1969,[2/] while over the same period public tubewells increased from an unknown number

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[1/] W.P. Falcon and C.H. Gotsch, "Lessons in Agricultural Development -- Pakistan", in Gustav F. Papanek, ed., Development Policy: Theory and Practice, Cambridge, 1968, p. 273.

[2/] Projected 1970 figures from U.S. A.I.D., Division of Economic Analysis, Statistical Fact Book, (Rawalpindi, 1968), Table 6.17.

in 1960, to 10,353 in 1970,[3/] at a cost of approximately Rs. 72,000 per 2-cusec well.

Of irrigation tubewells operating in West Pakistan at the end of the 1960's, 93 percent were private and provided 79 percent of the total well irrigation water. This large impetus to West Pakistan's development from private investment in tubewells of the magnitude of Rs. 502 million during the 1960's was an important if unanticipated stimulus to development.

The fact that the low-cost private tubewells provided 79 percent of the tubewell irrigation water in the 1960's when almost all public investment in irrigation was in expensive, high-cost tubewells means that the simple technology of private tubewells provided the incentive that brought forth a major and unanticipated private investment in West Pakistan's agricultural output. Although the Department of Agricultural Engineering drilled only a few wells and invested approximately Rs. 7.5 million, its initiative established the technology, and the private sector took advantage of it.

It is interesting to look at the controversy which surrounded low-cost wells in West Pakistan, particularly in light of the contribution which they made to agricultural output. The arguments used in West Pakistan are frequently cited to persuade against the use of technically simple installations.

[3/] Projected 1970 figures from U.S. A.I.D., Division of Economic Analysis, Statistical Fact Book, (Rawalpindi, 1968), Table 6.17.

When the idea of low-cost wells was suggested, engineers were skeptical. Aloys Michel in his major study of the Indus Basin development states that the large public wells, exclusive of power to drive the pump, cost $11,000, while low-cost wells, exclusive of power, using a coir filter, cost about $3,500 (in fact the average cost was $1,700 or Rs. 8,000). Noting that the high-cost public wells have "greater efficiency, lower consumption of fuel per cusec and longevity,"[4/] he goes on to conclude that the low-cost wells "seem to have little technical validity."[5/] While even the technical validity point seems debatable, it proved to be irrelevant. The low-cost well proved to be of a cost and specification that made it economic and efficient for conditions existing in West Pakistan. As Falcon and Gotsch state, "The private tubewells installed were of various shapes and sizes. From a technical engineering point of view many were not very efficient, but they had one point in common: they were extraordinarily profitable."[6/] It was this suitability for the needs of farmers that proved to be the critical criterion for judging the appropriateness of alternative techniques for rapid expansion of irrigated agricultural output.

4/ Aloys Michel, The Indus Rivers, (New Haven: Yale University Press, 1967, p. 472).

5/ Ibid., p. 471.

6/ Op. cit., p. 274.

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The lesson of West Pakistan is that wells that were inferior in technical and engineering terms proved more economic for the farmer and suitable for the conditions in which he operates. As a result, low-cost wells proved more efficient in their ultimate objective, increasing total agricultural output. What many technicians failed to see was the step beyond the efficient production of water, the dissemination of the wells throughout the countryside. West Pakistan's experience suggests that the critical issue is what type of well produces water at an acceptable technical efficiency but also has the mixture of cost and performance characteristics and maintenance potential that make it suitable for the area in which it is to be used.

APPENDIX B

Cost of Tubewells Installed in Comilla Area by KTCCA

There has been controversy over the costs of Comilla wells. This has arisen partly because of differences of opinion between the Agricultural Development Corporation which has been contracting with KTCCA to install wells and KTCCA over the pricing of wells. This dispute does not bring into question the actual cost of the wells but only the amount KTCCA is to be reimbursed. The detailed costs of wells sunk is available and is summarized here. Table B-1 gives the number of wells installed annually and the average costs.

Table B-1

Number and Average Cost of Wells Sunk in Comilla Area by KTCCA

Year	Wells Sunk*[1]	Average Cost*[2]
62-63	3	--
63-64	17	Rs. 20,757.38
64-65	15	24,378.26
65-66	11	26,042.15
66-67	24	25,854.15
67-68	54	25,343.26
68-69	45	27,020.49
69-70	42	26,973.85*[3]
	211	

*[1]Taken from the records of KTCCA, Tubewell Division, Comilla.

*[2]Financial Statement on Tubewell Grants Received by KTCCA Ltd., Director Budget, KTCCA Ltd., Comilla, 1969.

*[3]Estimated by the author from data in Table B-2.

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The cost of these wells includes pump and engine costs. Except for two turbines, the pumps are centrifugal, 21 strainers are mild steel, the remainder brass. All are hand percussion or water jet drilled. The wells are 6" in diameter and have an average output of 1.5 cusecs. These figures, taken directly from KTCCA records, indicate a slowly rising cost which has averaged Rs. 27,000 in recent years. From 1962 through December, 1967, KTCCA well drilling operations were financed by grants from the Basic Democracies and Local Government Department. After that time, EPADC paid for wells on a contract basis.

In order to get more specific details of the components of tubewell cost, six wells drilled in 1969-70 were selected for closer study. These included the highest and lowest cost well and four others selected at random. The results are contained in Table B-2.

It is useful to note the wide variation in costs of well drilling in approximately the same area. It is also useful to see that materials represent about half the cost of the well and that the labor component is 16 percent. The Comilla cost would presumably be representative of cost for sinking this type of well in other areas.

Table B-2

Details of Costs of Six Wells Sunk by KTCCA in 1969-70

(excluding costs of pump and engine)

	Well #1	Well #2	Well #3	Well #4	Well #5	Well #6	Percent of Total Cost
Materials	Rs. 7,380.00	7,715.00	8,070.00	16,898.00	11,050.00	9,370.00	.49
Boring (labor cost)	955.35	1,084.70	1,646.00	9,407.90	3,370.00	6,325.90	.16
Incidental	1,019.26	1,043.80	335.80	1,228.06	1,121.40	784.00	.04
Pump house	2,106.00	1,932.00	1,595.93	1,874.22	2,002.30	1,967.50	.10
KTCCA overhead*[1]	4,000.00	4,000.00	4,000.00	4,000.00	4,000.00	4,000.00	.21
TOTAL	Rs. 15,460.61	15,775.50	15,647.73	33,408.18	21,543.70	22,447.40	= Average Cost Rs. 20,713.85
Well depth (feet)	235	248	261	536	392	342	= Average Depth 336 feet
Boring cost per foot	Rs. 4.07	4.37	6.31	17.55	8.60	18.49	= Average Rs. 9.90

Source: Data taken from KTCCA records.

*[1] Includes the following fixed charges:

1.	Supervision	Rs. 1,000
2.	Test drilling and dry holes	Rs. 1,000
3.	Depreciation of rigs	Rs. 500
4.	Transportation	Rs. 500
5.	Fittings	Rs. 1,000

APPENDIX C

Rate of Return on Tubewells

The estimate of benefits from irrigation is very conservative. First, it is difficult to estimate benefits from supplemental irrigation of aus and amon rice crops although these may be substantial. Therefore, possible benefits from this use of irrigation are not included. Second, rice is probably the most expensive possible crop to grow on irrigated land because of its high rate of water consumption. It can be assumed that as irrigation becomes more widespread and as rice production increases toward levels of self-sufficiency, cropping patterns will change and higher value crops will be grown in the irrigating season. This change will result in considerably higher returns on fixed units of land and water. Third, presumably within the next few years, all farmers planting winter rice will be using new high-yielding varieties. However, because of difficulties in finding a variety that is entirely appropriate to the conditions of the season, the irrigated crops are now planted partially in new varieties and partially in traditional varieties, and these benefit calculations are based on present practices.

Benefits

In calculating benefits the experience in Comilla Thana will be utilized since this is the only area from which detailed information as to production under irrigation is available. Table C-3 below indicates the cropping patterns observed under irrigated agriculture in Comilla.

TABLE C - 1

Cropping Patterns in Areas Under Tubewell Irrigation

Category of Crop	Percent of Land Under Crop
Improved variety rice	84.8
Local variety rice	4.2
Non-rice crop	11.0

Source: M. Solaiman, "Winter Crop Survey in Comilla Kotwali Thana 1969-70," Comilla, Pakistan Academy for Rural Development, p. 5.

From the calculation of areas under different crops, it is necessary to calculate the net benefit per acre for each of the above crops. To do this it is necessary to establish the price of rice. Prices vary widely in different parts of the Province and for different types of rice. Therefore, the established price for which the Government sells rice in ration shops throughout the Province is very close to or a little below the average wholesale price which is Rs. 30.80 per maund (82.2 pounds) and which will be taken as the standard value of rice. Table C - 2 contains the calculation of benefits from irrigated land.

Assuming that one 2-cusec tubewell will irrigate 45 acres, which is the Provincial average for a 2-cusec water source, it is then possible to calculate the net annual benefit accruing from a 2-cusec tubewell, assuming the cropping pattern that exists in Comilla. Table C - 3 summarizes these calculations.

TABLE C - 2

Calculation of Net Benefit per Acre of Tubewell Irrigated Crops*

Improved Varieties of Rice

Costs per acre

Input cost (labor, power, fertilizer, seeds, insecticides, except irrigation) . . . . Rs. 343.00

Overhead costs (interest on land and credit, land and sales tax) . . . . Rs. 110.43

Total cost per acre . . . . Rs. 453.43

Benefits per acre

	Yield (mds.)	Price per md.	Return per acre
Grain	41.3	30.80	1272.04
Straw	19.4	3.00	58.20
			1330.24

Net benefits per acre: Rs. 879.81

Local Varieties of Rice

Costs per acre

Input costs . . . . Rs. 236.53

Overhead costs . . . . Rs. 84.38

Total cost per acre . . . . Rs. 320.91

Benefits per acre

	Yield (mds.)	Price per md.	Return per acre
Grain	21.8	30.80	671.44
Straw	13.7	3.00	41.10
			712.54

Net benefits per acre: Rs. 391.63

TABLE C - 2 cont.

Other Crops

	Net benefit per acre
Watermelon	650.55*[1]
Potatoes	886.52*[2]

Average net benefit per acre . . . Rs. 768.53

*[1] Anwarul Hoque, ibid, pp.53, 65.

*[2] Statistical Digest, Comilla, P. A. R. D., 1968, p. 56, Table 25.

* Source: Anwarul Hoque, Cost and Returns, Comilla, Pakistan Academy for Rural Development, 1968.

TABLE C - 3

Calculation of Benefits Accruing From One Tubewell

Crop	% of total area	Net benefit per acre (in Rs.)	No. acres per 45-acre pump group	Net annual benefit per tubewell
Improved variety rice	84.8	879.81	38.1	33,520.76
Traditional variety rice	4.2	391.63	1.9	744.10
Other crops	11.0	768.53	5.0	3,842.65

Net annual farmer's benefit Rs. 38,107.51
(excluding irrigation costs)

On this basis the farmer's annual benefit from a tubewell would be about Rs. 38,000. This calculation is important because it suggests the profitability of a tubewell to the water users, which is sufficiently high to repay the investment cost of a low- or medium-cost well in one year or even a high cost well in two years! Obviously tubewells are a highly profitable investment.

However, this calculation must be tempered somewhat when examined from the perspective of the benefits to the economy. The real value of rice to the economy is not that price at which the farmer can sell in the local market. Rather, it is the international market price at which the nation must purchase rice to make up its annual food deficit. Or stated differently, the amount of foreign exchange saved by the domestic production of each additional ton of rice. Or alternatively, if Bangladesh produced a surplus, the amount it could command in the international market. Rice has recently been imported from Burma, and for this calculation the current export price for Burmese rice, $103 per ton, is used.[1]

Calculated at this price, the benefit from one tubewell (with a centrifugal pump) is reduced to Rs. 17,483.34 per well, and it is this benefit calculation that will be used in the rate of return calculation. However, where turbine pumps are used, a 25% increase in output is assumed and the benefit rises to Rs. 21,854.17.

<u>Comparison of wells of alternative specifications.</u> The calculations are a comparison of the rate of return on tubewells with five alternative specifications. The costs of these well alternatives at market and

[1]F.A.O. <u>Monthly Bulletin of Agricultural Economics and Statistics</u>, No. 9, Vol. 19, (Rome, 1970) p. 46.

shadow prices are contained in Tables 5 and 6 in the text. These calculations are made to compare the profitability of these five types of wells and are done on the basis of one well of each type only. The time streams of benefits and cost and the resulting rate of return are shown in Table C-4.

Rate of return for alternative time sequences of installation. The previous calculation compares five well alternatives open to Bangladesh in a static situation. The following calculations attempt to compare two more realistic alternatives and include a time dimension. For purposes of this calculation, it is assumed that the percussion or jet-drilled wells have brass screens with a ten-year life, and a combination of centrifugal and turbine pumps. The contractor-sunk, power-drilled well is assumed to have a fiberglass screen with a twenty-year life, and turbine pumps. The installation of power-drilled wells is to take place at the rate of 4,000 per year and the percussion-drilled well, according to the schedule in Table C-4. The results of these calculations are shown in Table C-5.

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TABLE C-4

Comparison of Rate of Return on Five Alternative Tubewells of Varying Specifications

Year	Benefits	Costs	Benefits	Costs	Benefits	Costs	Benefits	Costs	Benefits	Costs
1	0	25,430	0	33,011	0	28,555	0	36,685	0	47,905
2	17,483.17	6,500 1/	21,854.17	6,500 1/	17,483.17	6,500 1/	21,854.17	8,000 2/	21,854.17	8,000 2/
3	"	"	"	"	"	"	"	"	"	"
4	"	"	"	"	"	"	"	"	"	"
5	"	"	"	"	"	"	"	"	"	"
6	"	"	"	"	"	"	"	"	"	"
7	"	"	"	"	"	"	"	"	"	"
8	"	"	"	13,500 3/	"	"	"	21,000 4/	"	21,000 4/
9	"	"	"	6,500	"	"	"	8,000	"	8,000
10	"	"	"	"	"	"	"	"	"	"
11	"	"	"	"	"	"	"	"	"	"
12	"	"	"	"			"	"	"	"
13	"	"	"	"			"	"	"	"
14	"	"	"	"			"	"	"	"
15	"	"	"	"			"	"	"	"
16	"	"	"	"			"	21,000 4/	"	21,000 4/
17							"	8,000	"	8,000
19							"	"	"	"
19							"	"	"	"
20							"	"	"	"
21							"	"	"	"
22										
Rate of Return		.33		.40		.29		.31		.23

1/ Annual operation and maintenance cost, low speed diesel engine (estimated life 15 years)

2/ Annual operation and maintenance cost, high speed diesel engine (estimated life 7 years)

3/ Replacements of turbine pump and operating costs

4/ Replacement costs of pump and engine plus operating cost
(Operating and maintenance costs from A.D.C., Tubewell Loan Application, p. 113)

Shadow Costs	30,200	49,851	37,470	66,200	76,586
Rate of Return	.26	.20	.19	less than .10	

TABLE C-5

Comparison of Rate of Return on 20,000 Wells, Jet or Percussion and Contractor Power Drilled
(in Rupees millions)

Jet and Percussion Drilled Well, Rs. 30,000

Year	Operating Wells	Benefits	Operation and Maintenance	Total Cost
1	510	0		
2	1,780	8.9	4.1	15.3
3	4,960	31.1	14.2	42.2
4	12,910	86.7	39.7	109.6
5	20,000	225.1	103.3	278.2
6		349.7	160.0	316.0
7		"	"	160.0
8		"	"	160.0
9		"	"	160.0
10		"	"	162.4
11		"	"	166.0
12	19,490	340.8	155.9	174.9
13	18,220	318.5	145.8	193.2
14	15,040	262.9	120.3	179.1
15	7,090	124.0	57.7	120.3
16				57.7
17				
18				
19				
20				
21				
22				
23				
24				
25				

Rate of Return .31

TABLE C-5 (continued)

Year	Operating Wells	Benefits	Operation & Maintenance	Replacement	Capital Cost	Total Cost
1	4,000	0			180.	168.
2	8,000	69.9	32.0		180.	212.
3	12,000	139.9	64.0		180.	244.
4	16,000	209.8	96.0		180.	276.
5	20,000	279.7	128.0		180.	308.
6		349.7	160.0			160.
7		"	"			160.
8		"	"			160.
9		"	"	60.0		220.
10		"	"	60.0		220.
11		"	"	60.0		220.
12		"	"	60.0		220.
13		"	"	60.0		220.
14		"	"			160.
15		"	"			160.
16		"	"	60.0		220.
17		"	"	60.0		220.
18		"	"	60.0		220.
19		"	"	60.0		220.
20		"	"	60.0		220.
21		"	"			160.
22	16,000	279.7	128.0			128.
23	12,000	209.8	96.0			96.
24	8,000	139.9	64.0			64.
25	4,000	69.9	32.0			32.

Rate of Return .18

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