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BANGLADESH AGRICULTURAL RESEARCH PROJECT PHASE-II

Economic and Technical Criteria for Location of Deep and Shallow Tubewells

Sam H. Johnson III

BANGLADESH AGRICULTURAL RESEARCH COUNCIL
INTERNATIONAL AGRICULTURAL DEVELOPMENT SERVICE
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A Consultancy Report

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Department of Agricultural Economics

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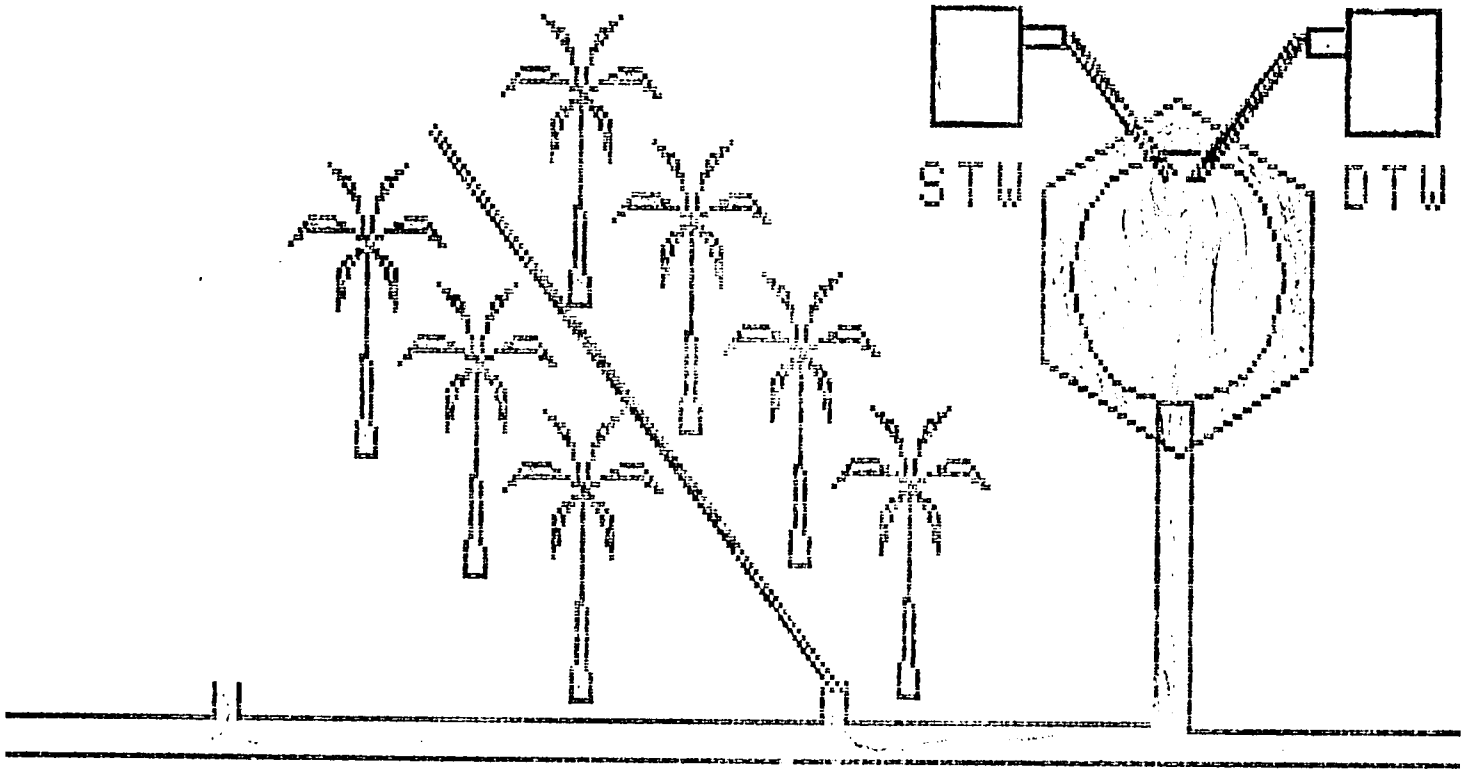
Tubewells in Bangladesh

Deep or Shallow ?



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Preface

This work is a continuation of research on tubewells in Bangladesh that was started in 1984 when the author was asked to study the Deep Tubewell Irrigation and Credit Program (DTICP) under the auspices of the Irrigation Water Management Program of the Bangladesh Agricultural Research Council (BARC) and the International Agricultural Development Service (IADS). Published results of that study are available from BARC-IADS. One conclusion the author drew from the previous research was that a study of tubewells had to include shallow (STWs), hand operated (HTWs), and deep (DTWs) tubewells in order to address the full range of policy issues. Consequently, the author was pleased when BARC and IADS asked him to return to Bangladesh to explore the question of criteria for location of various types of tubewells.

During his research, the author has been assisted by a number of individuals. Drs. Kh. Azharul Haq and Ekramul Ahsan, BARC Member-Directors of Agricultural Engineering and in-charge Soils and Irrigation and Agricultural Economics and Social Sciences and Acting Chairman, respectively, have both offered challenging suggestions and have been supportive of the research. Similarly, Drs. David Gisselquist and Carlos Garces of the IWM Program have raised important questions and forced the author to sharpen the focus of his analysis. At the Master Planning Organization (MPO), Drs. Md. Sazzad Hossain and Monirul Haque have provided invaluable assistance and are to be commended for their excellent work. Almost in abstensia, Dr. G. T. K. Pitman at Harza-MPO needs to be recognized as the author is very familiar with him through his work, although, unfortunately has only had two chances to have short, but very productive, meetings. Another individual that influenced the author's thinking and provided insight into STW problems in the Northwest Region is Mr. M. Asaduzzaman of BADC, Rajshahi. He is a prolific writer and has published some of the best papers on groundwater in Bangladesh. The author was honored to meet him and felt that the meeting contributed significantly to the research effort. Last, but certainly no least, Dr. and Mrs. Daugherty were their usual gracious selves, even though twenty other consultants and the ARP-II Evaluation Team were in town at the same time. Finally, the author wishes to thank the elves at Silicon Valley without which none of the data could have been crunched.

It is hoped that concerned policy makers within the Government of Bangladesh will read this paper and the other reports by organizations such as MPO and use the information provided to better develop the water resources of Bangladesh. This is critical both for the well-being of the country and to improve the condition of the vast population in the rural areas of Bangladesh.

Glossary of Abbreviations

BADC	Bangladesh Agricultural Development Corporation
BBS	Bangladesh Bureau of Statistics
BWDB	Bangladesh Water Development Board
boro	Rice crop grown in Bangladesh from December to May
CARE	Congress for American Relief Everywhere
DSSTWs	Deep sunk shallow tubewells
DTWs	Deep tubewells
GOB	Government of Bangladesh
HTWs	Hand tubewells
HYVs	High yielding varieties
LLPs	Low lift pumps
MPO	Master Planning Organization
MTFPP	Medium Term Foodgrain Production Plan
STWs	Shallow tubewells
thana	Former name for *upazila*
Tk	*Taka*, Bangladesh currency unit
UNDP	United Nations Development Programme
upazila	Sub-district level basic administrative unit

ECONOMIC AND TECHNICAL CRITERIA FOR LOCATION OF DEEP AND SHALLOW TUBEWELLS IN BANGLADESH

As a consequence of high birth rates and declining death rates, Bangladesh is in a chronic, food deficit situation. One obvious solution to this problem is to produce more food domestically. Yet, with a population of 93 million and a maxim cultivated acreage of 23 million acres, Bangladesh has a land-m ratio of 0.25, one of the lowest in the world. Given its limit land base, in order to significantly increase production of foc Bangladesh must intensify crop production. Possessing large areas of fertile, deltaic soils with temperature suitable for year-round cropping, the potential exists throughout the countr for multiple cropping. However, annual rainfall, which varies from 60 to 120 inches, falls mainly during the monsoon season (May to September). Therefore, during the rest of the year irrigation is required for successful crop production.

While Bangladesh is a country rich in rivers and surface water supplies, its topography is such that it is both technical complicated and extremely expensive to build large-scale surface irrigation systems. Consequently, once the full development of available water supplies using traditional water lifting devices and low lift pumps (LLP's) was reached in the late 1960's. the Government of Bangladesh (GOB) made a deliberate decision to develop its vast groundwater resources for irrigation. However, while there is considerable agreement within Bangladesh that investment in devices to extract groundwater for irrigation is

needed, there is wide disagreement about what form that investment should take.

The purpose of this paper is to explore the range of issues pertaining to investment in groundwater development. In particular, the paper details the economic and technical criteria that determines the most efficient location of different types of groundwater extraction devices. For the purpose of this study four types of tubewells are considered: deep tubewells (DTWs), hand tubewells (HTWs); shallow tubewells (STWs); and deep sunk shallow tubewells (DSSTWs). These four types represent the range of tubewells currently in use in Bangladesh. While this paper does not attempt to resolve all the issues related to the complex question of groundwater development, it does attempt to put the issues in perspective and, thus, offer policy level guidance for GOB decision makers, researchers and donor agencies.

PRESENT SITUATION

As detailed earlier this report is primarily concerned with shallow tubewells (both surface mounted and deep set ones sunk in a pit) and deep tubewells. However, there are, in fact, three different major types of groundwater extraction devices in commercial use in Bangladesh. These are:

Deep Tubewells (DTWs) are wells drilled by direct jetting or reverse circulation to a depth of 250-350 feet. The well is developed with a gravel pack around the 6" - 10" well screen and utilizes an upper casing of sufficient length and diameter to install a lineshaft turbine pump. DTWs are either electrically or diesal powered and normally have a design discharge of 2 cusecs (60 lit/sec) for DTWs installed by BADC and 3-4 cusecs (90 lit/sec) for BWDB DTWs.

Shallow Tubewells (STWs) are wells drilled with jetting or bailing methods, utilizing a section of the casing string to facilitate drilling, these wells are developed with sawcut or gauge wrapped screen and normally do not use a gravel pack. The depth of STWs varies depending upon the aquifer, the area and the contractor, but they are usually around 90 to 120 feet deep. However, they normally use a centrifugal pump connected directly to the top length of the blind casing and, thus, the effective pumping lift is restricted to a maximum of 25-28 feet. Most STWs are driven by small diesel engines but more and more are switching to electrical motors where electicity is available. STWs are generally designed to have a discharge of .5 cusecs (15 lit/sec).

Hand Tubewells (HTWs) or manually operated shallow tubewells for irrigation (MOSTIs) are widely need in Bangladesh both for drinking water and for irrigation. These are installed using traditional bailing methods which utilize the well components in the process. Unsually, HTWs use 1.5 inch (40 mm) pipe with brass or sawcut screen and are installed to a depth of 80-100 feet. There are a number of different types of manual pumps used; hand, treadle and rower but the discharge is generally low, approximately 0.01-0.02 cusecs (0.3-0.6 litre/sec)

Under its 1980-85 Medium-Term Food Production Plan (MTFPP) Bangladesh planned to increase land irrigated to more than 7 million acres with approximately half of that being irrigated from groundwater. The major element of irrigation growth in the two decades prior to the MTFPP was the rapid expansion of low lift pumps (LLPs) to harvest available surface water supplies. After 1980, the major element of irrigation growth shifted from LLPs to groundwater. Under the Third Five Year Plan (TFYP), groundwater irrigation is expected to contribute 5.57 million acres or 57 percent of the total irrigated area (Pitman and Haque, 1984).

Table 1 presents an estimate of the number of tubewells installed through the first quarter of 1985. These numbers, although compiled using the best data available, are still only

estimates due to the large number of agencies that are involved, particularly with respect to the development of STWs and HTWs.

Table 1: Estimated Number of Tubewells and Areas Served
Bangladesh, February, 1985

Tubewell Type	Approximate Number Available ('000)	Approximate Area Irrigated ('000 acres)	GOB Estimated Area Irrigated ('000 acres)
DTWs	18.2 1/	728.0	1096.9
STWs	150.8 2/	1508.0	1899.6
HTWs	285.0 3/	94.1	112.6
Total		2246.1	3109.1

1/ Data from Central Coordination Committee for Irrigation Management.
2/ Data from BADC Shallow Tubewell Division
3/ Data from various sources

As can be seen in Table 1, GOB estimated areas irrigated, based assumed command areas of 60 acres for DTWs, 12.5 acres for STWs and 0.5 acres for HTWs, tend to oerstate actual groundwater irrigated acreage. This is particularly obvious when comparing statistics from BADC and the BBS. It is difficult to obtain the conect, figures but it is apparant that actual command areas of tubewells are much smaller than BADC data indicate.

In addition to problems of low command areas, tubewells in Bangladesh also have problems with maintenance and repair. Most tables, such as Table 1, present the number of tubewells commissioned and assume a 100 percent operational status. Yet, the limited available records show that this is not correct.

BADC's own records for 1982-83 revealed that in Rajshahi, Pabna, Bogra, Rangpur and Dinajpur Districts, of 6745 existing DTWs, only 4556 were operating (Asaduzzaman, 1984). Similar data for STWs and HTWs is not available, but it is unlikely that the percentage of these actually in operation is much more than that of DTWs.

In certain areas, particularly in the Northwest, STWs have been having problems. This has resulted primarily from the rapid, uncontrolled installation. No attempt has been made to match STW numbers to available recharge or to restrict the numbers, and consequently, localized overexploitation has occured (Alam, 1984). DTWs have been troubled more by mechanical problems with the power units, but in some schemes such as Thakurgaon, crustation and improper screening, have led to reduced discharge and even well failure. (Bhuiyan, 1984).

CRITERIA FOR LOCATION

Criteria for developing a proper mix of tubewells in Bangladesh must address economic, social and technical considerations. In some areas of the country, due to unique environmental and/or social conditions, these considerations will be hierarchial, but in most areas there is a wide range of alternatives that can be pursued. Obviously, in these cases the mix of tubewells that are developed will be as much a function of existing policy as it is a function of either economic, social or technical considerations.

I. Social and Economic Considerations

As in the case of any investment, the GOB wishes to maximize its return from groundwater development. This requires that they obtain the largest possible increase in human well being subject to the physical, technical and management constraints that restrict this type of investment. However, it should be emphasized that increased human well being is not necessarily synonymous with maximum economic return. For example, the GOB may believe that development of HTWs is more beneficial to small or landless farmers and deliberately decide to follow this path; among alternate development programs this may be the most equitable, but it is not necessarily the one that provides the maximum economic return on the government's investment. Yet, equity is a valid policy objective and one that the GOB may wish to follow.

In the case of selection of tubewell technology, initially the GOB opted for DTWs. This decision was made not necessarily because DTWs offered the highest return but primarily based on the argument that DTWs can be oriented toward small farmers (Asaduzzaman, 1984) This was done to avoid the situation where large farmers can afford to purchase the tubewells and become water lords, controlling the water supply. However, the situation in the field has failed to justify this decision and, based on current data, indicates that small farmers are often at the mercy of large farmers that gain control of the the DTWs. (Johnson, 1984). In recent years, similar arguments have been

made for HTWs over STWs and DTWs as they are affordable by small and landless farmers. Yet, HTWs have both technical and practical limits that restrict both the total numbers and the areas of the country that can be irrigated using this technology.

A. Economic Factors

Given no extraordinary technical or social constraints it is most economic to invest in groundwater extraction technology that can provide the most water for the least cost. In the case of a developing country like Bangladesh this cost has two considerations, total costs and foreign exchange costs as a percent of total cost. Clearly, given the shortage of foreign exchange, it is best as much as possible, to minimize the required foreign exchange and, under certain circumstances, may be most economic to use a technology that actually costs slightly more if it can be purchased locally rather than be imported. In the case of tubewells, DTWs require large amounts of foreign exchange as they are developed primarily using imported components. STWs require a much smaller percentage of imported components and, in stark contrast, HTWs are almost completely made from local materials.

Fortunately, in Bangladesh, STWs and HTWs are able to deliver water at a cost less than DTWs. In light of the fact that they also require less foreign exchange and create domestic production of components, these technologies are economically best in the areas where there are no technical or social constraints. These cost comparisons are presented in Table 2.

Table 2: Coefficients and Computations to Compare DTWs, STWs and HTW Irrigation Systems.

	DTW	STW	HTW
Pump Capacity (cusecs)			
Typical 3/	1.5	0.40	0.02
Design	2.0	0.5-.75	.02-.04
Command Area (acres)			
Typical 3/	40.0	10.0	0.3
Planned	60-80	15-20	.25-1.0
Pump Hours/Acre	30	90	1800
Waters Costs/Acre			
(Taka) 1/	3884	1556	1484
(Taka) 2/	1210	-	-

1/ Adapted from Loyd Johnson (1983)
2/ Based on BADC rental rates of Tk. 3500 per DTW per year
3/ Based on the consultant s experiences and numerous studies

However, all of the mechanical lifting devices in Bangladesh have been sold with a subsidy. These subsidies have been particularly large in the case of LLPs and DTWs. In the late 1970's BADC accounts indicated that actual payments by farmers for LLPs amounted to 12 percent of the cost to BADC, while for DTWs the figure was less than 10 percent Current arrange- ments for selling STWs result in prices that are nominally unsub- sidized. However, DTW's continue to be heavily subsidized with a 1985 selling price amounting to only about 40 percent of the cost to BADC (Hanratty, 1983)

In addition to the nominal price of tubewells, provisions for the sale of all tubewells involve subsidized credit arrangements which reduce the effective price paid. For example, for a STW sold for Tk 35,000 a farmer has only to pay Tk 2000 as a down payment and receives a 6-year loan for the balance, paying a reduced rate of interest (10-13 percent, depending upon the source of the loan) on the balance. For DTWs, the down payment is Tk 26,000 for an individual or Tk 13,000 for an official farmer cooperative. Furthermore, repayment of agricultural credit has generally not been very satisfactory, with repayment rates for tubewells being particularly poor (CARE, 1984).

Farmers are utilizing tubewells at levels that are considerably below the expectations of those involved in national planning. This suggests that under current farm-level conditions there is a divergence such that what is perceived optimal by farmers is much less than what national planners believed would or should be the case. Probably the most obvious distortion that leads to a possible divergence between farm-level and national-level optimum is the distortion of prices resulting from the various subsidies on the STWs and DTWs. As illustrated in Figures 1 and 2, the higher the rate of subsidy the smaller the command area required to reach a point where there is no further cost advantage to increased utilization of the tubewell. This is particularly obvious with the DTWs under the annual rental program. After 40 acres there is effectively no economic incentive to expanding the command area as the rental subsidy has

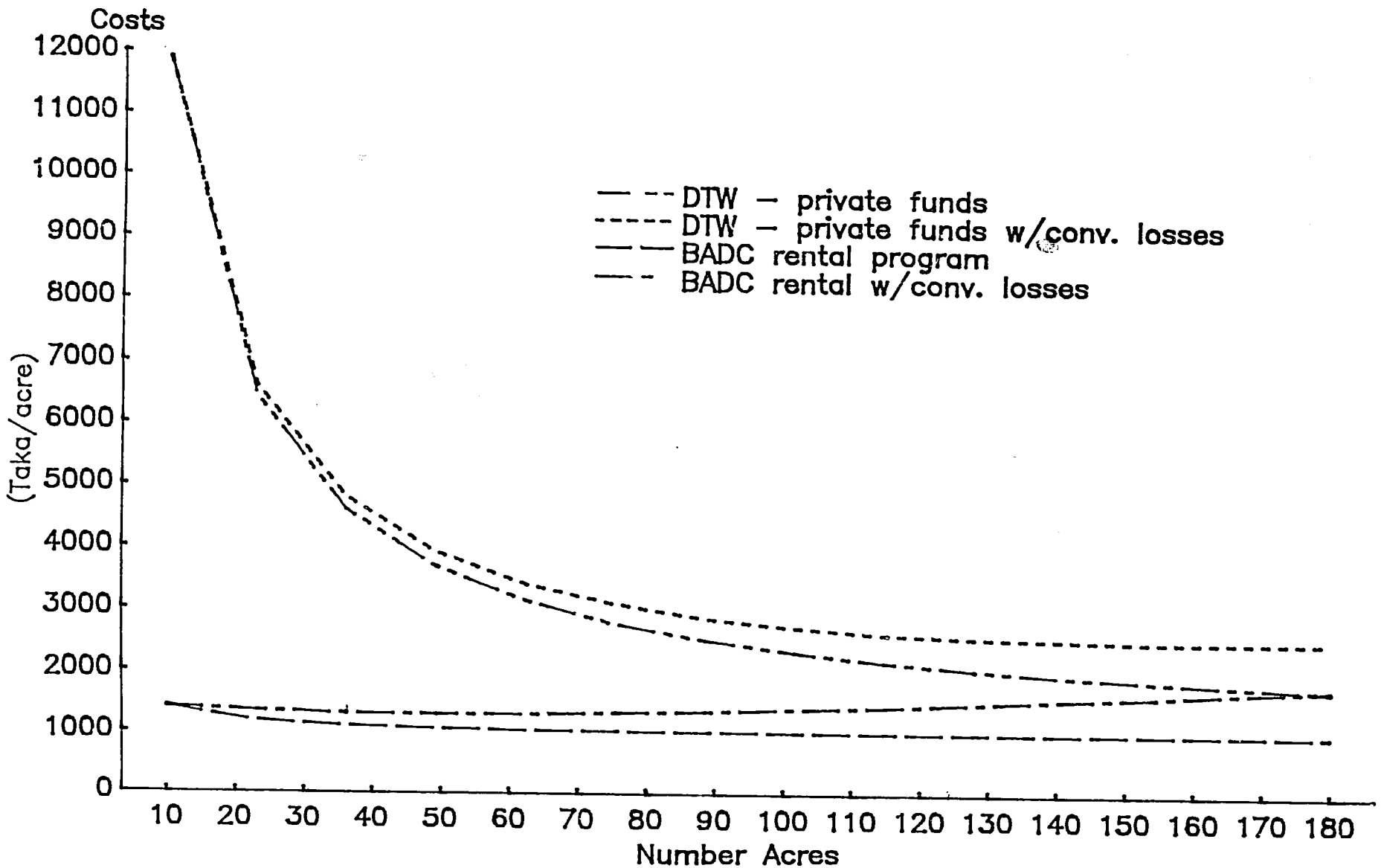


Fig. 1. Costs of DTW water with and without conveyance losses.

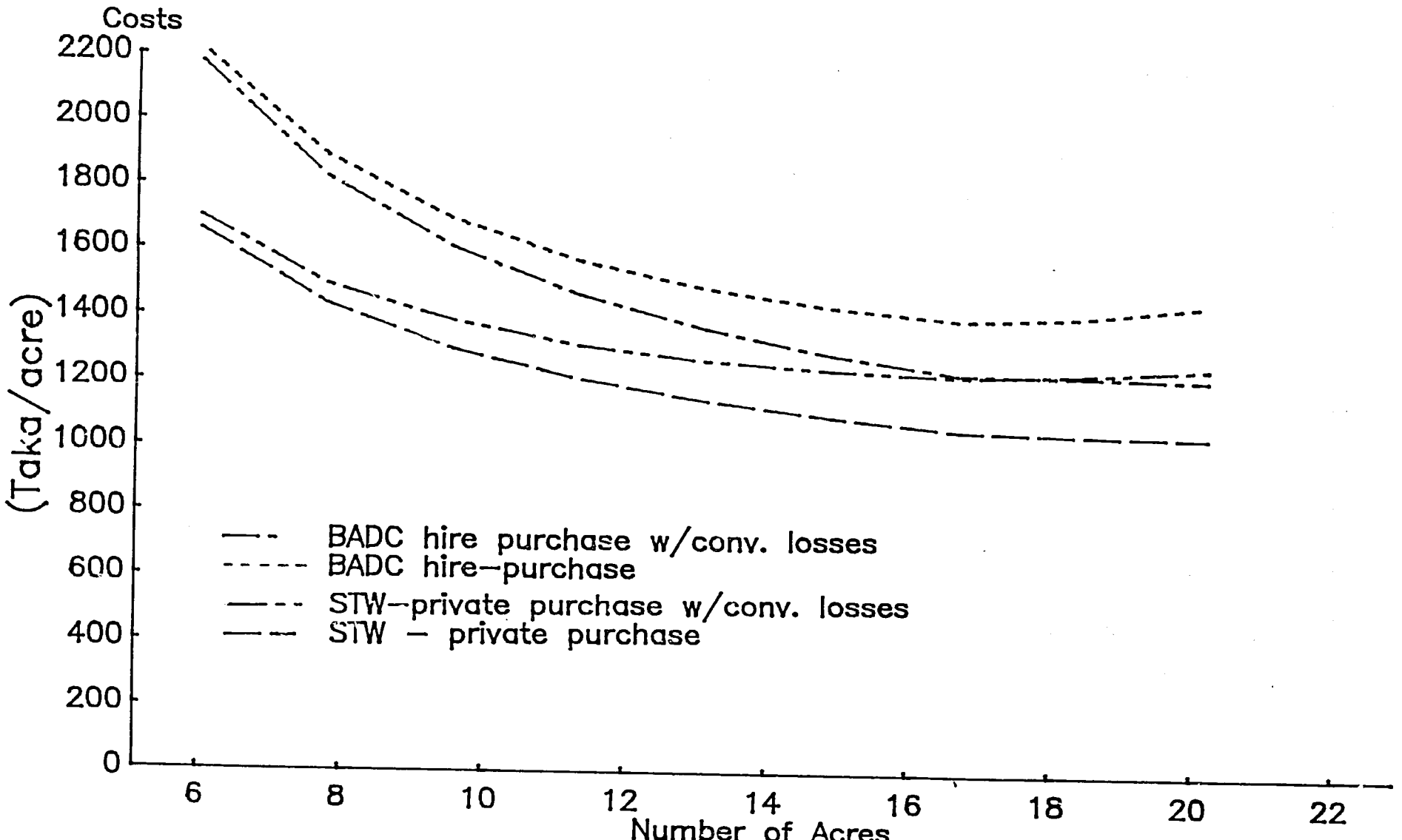


Fig. 2. Costs of STW water with and without conveyance losses.

practically eliminated, the benefits of spreading capital costs over a larger number of acres.

Compounding the impact of subsidies are the additional distributional losses resulting from expansion of the command area and consequent utilization of a larger network of distribution channels. These losses may vary by location, by soil type and by degree of maintenance, but research has shown that the losses are in almost all cases a function of length of channel from the water source (Karim, et al. 1983). As illustrated in Figures 1 and 2, when conveyance losses are taken into account, the results also serve to discourage expansion of command area.

B. Social Factors

In selecting the type of groundwater extraction technology, a number of social factors are also critical. One of the most important one is that of control. As mentioned earlier public DTWs were initially favoured over private DTWs and STWs as it was argued that they would be less subject to control by larger farmers. However, as pointed out by Hamid (1982), a critical consideration in the installation of DTWs is the pressure that is brought to bear on concerned officials to control the location of the tubewell. In the case of the DTW this usually results in the well being located near the house or fields of an influential farmer. Data from 170 BADC DTWs collected in Bangladesh in 1984 indicates that mislocation of these tubewells is a common occurence. Based on this data, mislocation resulted in a

reduction of total potential command area by an average of 11 acres (Johnson, 1984).

Associated with these same issues of control are the "transactions costs" related to managing and expanding the command area. With average farm size within any single command area of less than an acres, expanding the area of land served and number of users increases management effort and potential for conflict. Using details from Hanratty (1983) it is possible to estimate per acre organization costs. Based on this information, it appears that organization costs per acre commanded are constant between 10-30 acres, decline until 40 acres are served and then start to increase rapidly as the command area expands beyond 50 acres. Given this situation, and the lack of economic incentive to serve a larger command area, it is not surprising that a number of DTWs are found to be controlled by a few large, powerful farmers and are only serving 20-30 acres.

Another major critical social factor in selecting the type of groundwater extraction technology is the impact on village level drinking water supplies. Generally village level HTWs are installed on the village mound and, therefore, are 3-6 feet above the irrigated areas. Consequently, even a STW has the potential to lower the groundwater beneath a HTW, although it is the DTW that is likely to have major negative impacts on drinking HTWs. Already in areas of Rajshahi and Dhaka Divisions some surface mounted HTWs are not able to lift water from the prevailing depths.

DANIDA and MPO have delineated those areas where deep set hand pumps are now, or will soon be, required because of a general lowering of groundwater levels below 25 feet (7.8) m from the surface. This has resulted primarily from excessive competition from the irrigation sector. Table 3 details the areas and the population affected.

Table 3: Areas and Populations Requiring Deep Set HTWs for Potable Water.

District	Upazilas		Population (1981)		
	Total	Affected	Total	Affected ('000)	%
Rajshahi	32	27	5,263	2,634	50
Dhaka (part) 1/	30	6		639	
Pabna	18	12	3,420	970	28
Bogra	16	11	2,717	818	30
Tangail	11	5	2,444	726	30
Kushtia	12	7	2,273	471	21
Jamalpur	13	6	2,445	454	19
Faridpur	26	4	4,768	322	7
Jessore	26	4	4,016	239	6
Comilla	26	1	6,880	209	3
Sylhet	37	6	5,650	186	3
Dinajpur	23	2	3,198	59	2
Noakhali	16	1	3,813	49	1
Mymensingh	35	1	1,543	27	1
Total	321	93	53,470	7,804	14.6%

1/ Dhaka Sadar not included

Source: Pitman and M. Haque, 1984

II. Technical Considerations

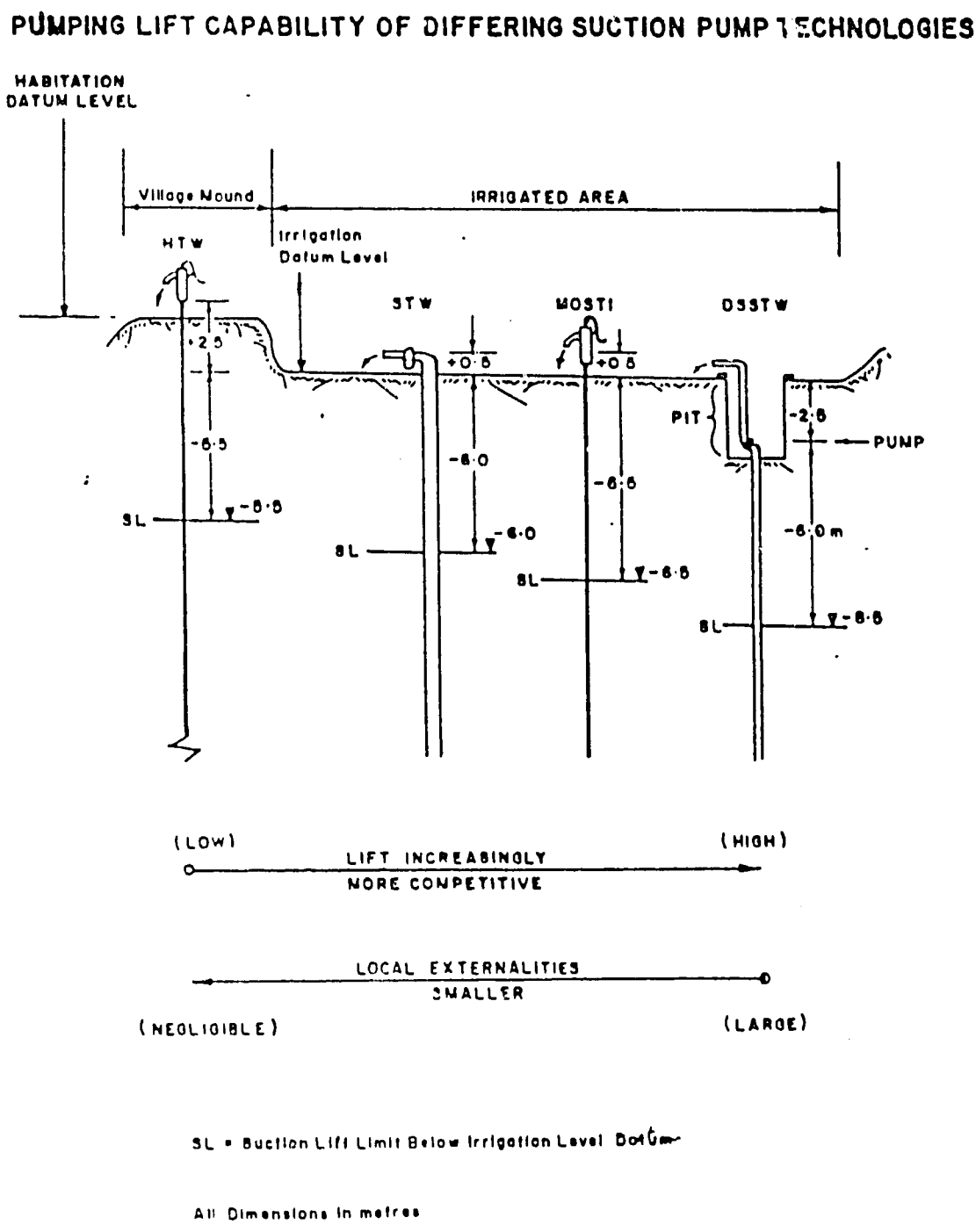
In general, in most regions of Bangladesh, an area that is suitable for installing STWs is always feasible for installing DTWs, but an area which is considered suitable for DTWs may not be feasible for STWs or even for DSSTWs. The main differentiating factor is the static water level in the well. As illustrated in Figure 3, the effective lift for the other technologies is less than 30 feet for DSSTWs and around 20 feet for STWs and HTWs. In contrast, the effective limit for DTWs is determined by the depth of the turbine pump within the well. Consequently, if STWs and HTWs are to be located in an area, the effective depth to groundwater from the surface cannot be allowed to go below 20-30 feet. However, if DTWs are to be the sole device installed, then the water table can be pulled down below the effective limit of 30 feet. Yet, if a decision is made to avoid mining the groundwater resource, then the effective limit to pumping is the amount of usable recharge, whether or not it is above or below the effective level for STWs. Thus, the availability of groundwater may be constrained in two ways:

(a) The water level may fall below the depth from which it may physically be pumped

(b) the recharge limit may be exceeded

In addition to pumping depths and recharge, the thickness of the upper clay layer and silt formation are major determinates of the development potential of the aquifer system. Where these layers are relatively thick the potential for STWs is limited;

Fig. 3. Lift capability of different suction pump technologies



Source: Pitman and Haque, 1984

although often in low-lying areas STWs can be successfully installed. However, some areas such as the Eastern Piedmont Water Basin that is located in the most northern parts of Jamalpur and Mymensingh Districts, surface clays that vary from 25-125 feet in thickness effectively eliminate the potential for STWs. Figures 4 and 5 detail the thickness of the upper clay layers for the Northwest and Northeast Regions of Bangladesh.

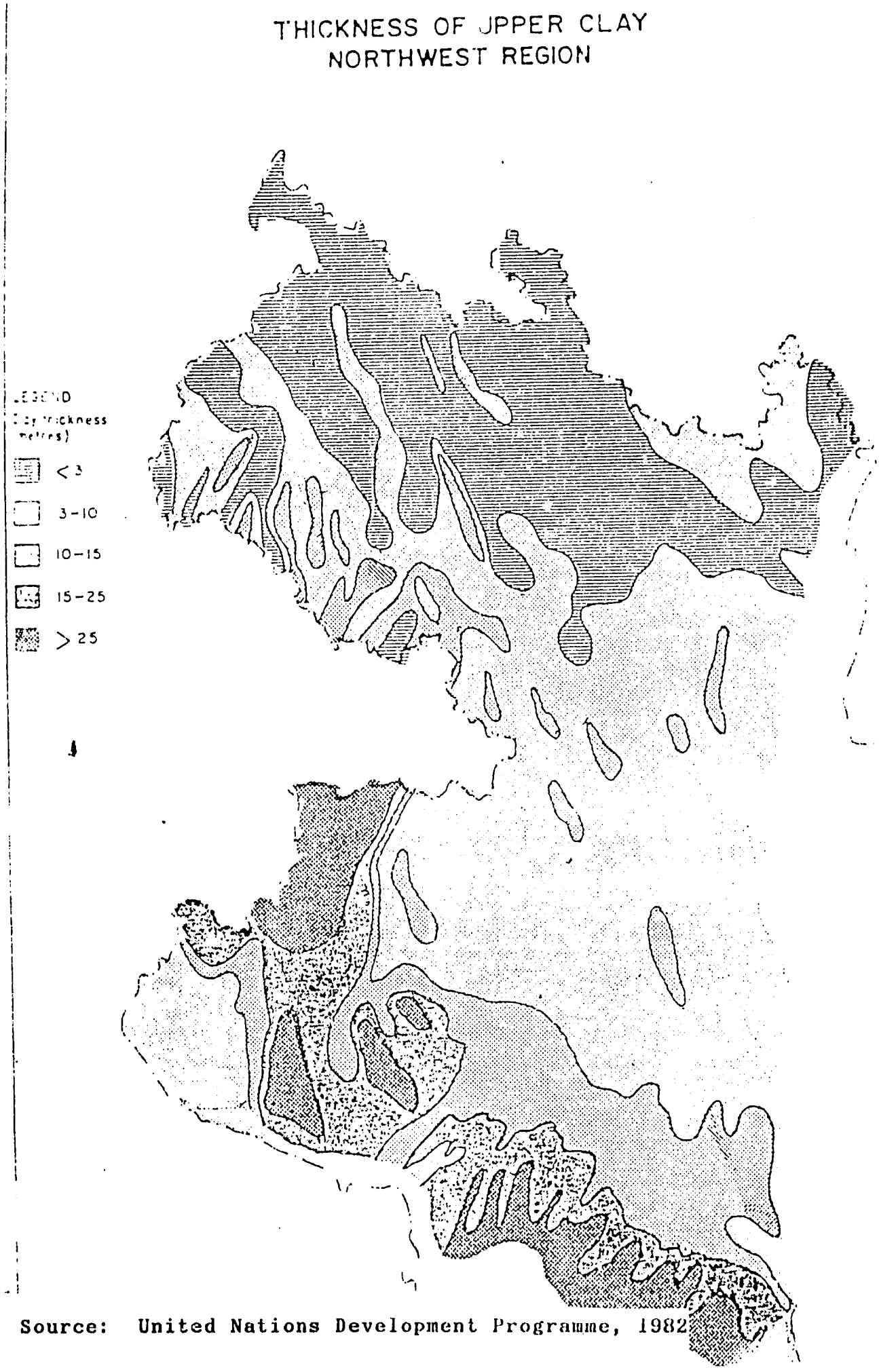
Another consideration is the amount of irrigable land. It is possible to have some cases where the amount of irrigable land is the limiting factor rather than the quantity of available groundwater. This case is not the norm but may occur in some areas of Bangladesh and, therefore, must be included as a technical consideration.

Finally, it must be recognized that there is a zone of influence created by any tubewell, either DTW, STW or DSSTW. This zone varies widely depending upon aquifer characteristics and is certainly not uniform across a country such as Bangladesh. Well tests in the Northwest Region have shown that the radius of influence for DTWs varies from 600 to 8000 feet. Therefore, spacing of wells, as well as the type and number, is also a major consideration.

A. Scenarios

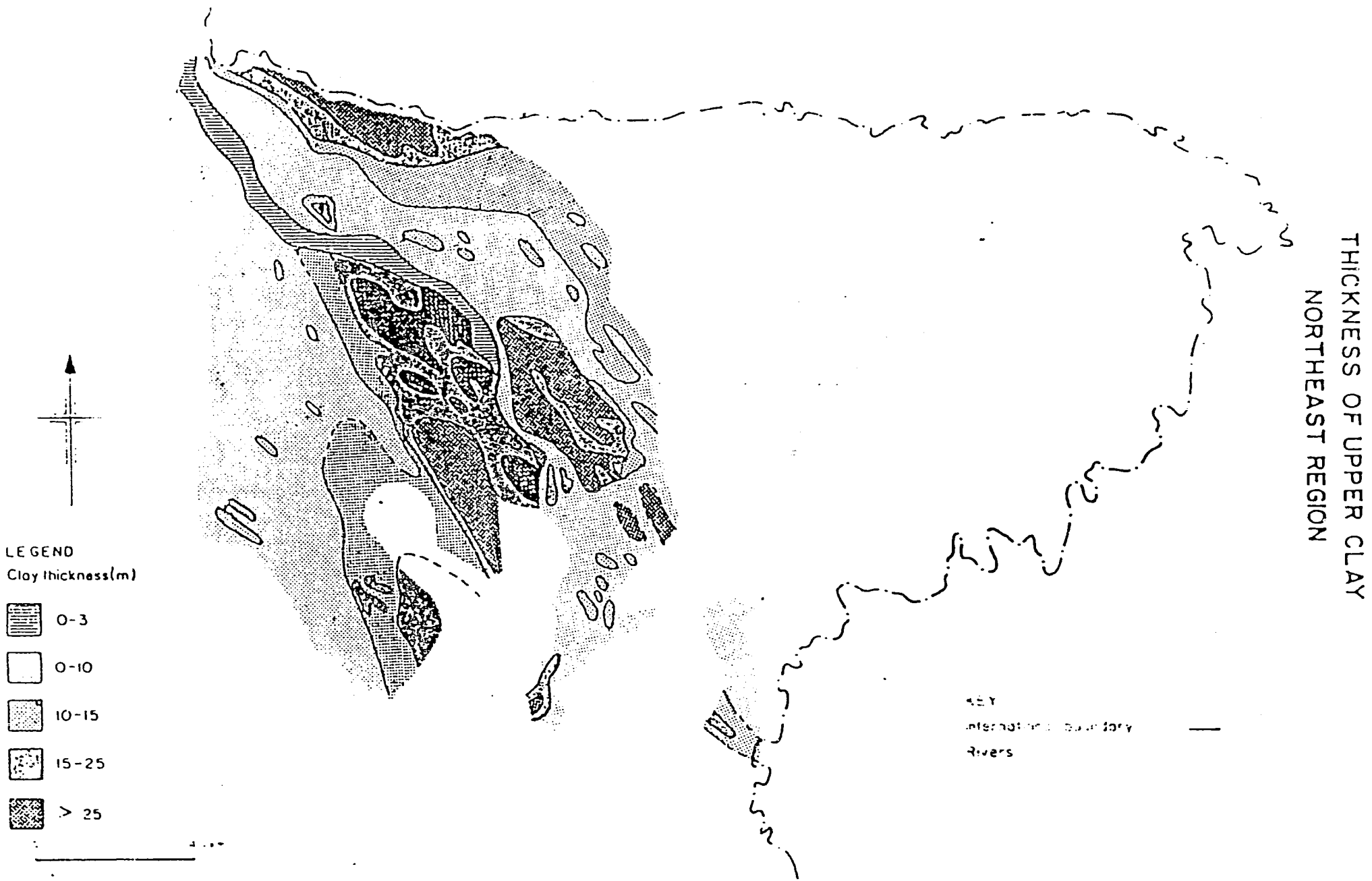
If a decision is made not to mine the groundwater, there can then be two scenarios: (1) the available recharge can support pumping at a depth greater than 20-30 feet and (2) available

Fig. 4. Thickness of upper clay in Northwest Region



Source: United Nations Development Programme, 1982

Fig. 5. Thickness of upper clay in Northeast Region



Source: United Nations Development Programme, 1982

recharge is insufficient to provide enough water to pump the water table below 20-30 feet. In the latter case, recharge is the obvious dominant constraint and, hence, dictates the development potential, and to some extent, the type of technology as well. In the former case, in order to capture all of the recharge, a deliberate decision will have to be made to exceed the 20-30 foot limit if all of the recharge is to be captured and used for productive purposes. Where the decline in groundwater level needed to capture all of the recharge is rather small, for example from 20 to 28 feet, the use of DSSTWs may be considered as a viable alternative. Producing water at a cost estimated to be 20-30 percent more than that of STWs (depending upon the depth of the pit and depth to groundwater), DSSTWs are still less expensive than DTWs for this type situation.

Using data from the UNDP Groundwater Modelling Study (1982), it is possible to compare the impacts of a criterion that constrains the reduction of groundwater depth to an effective limit for STWs (here 25 feet) and a criterion that constrains the reduction of groundwater depth to an effective limit for STWs plus the total recharge quantity (whichever occurs first). Data for Bogra District are presented in Table 4. From this table it can be seen that in all but two of the upazilas thanas recharge is the dominant constraint and, consequently, a criterion related to depth to groundwater is not active in this district. This district can, in most upazilas, develop all the available recharge using only STWs and, therefore, should not be developed using DTWs.

Table 4: STW Numbers Based on Different Criteria for Bogra District

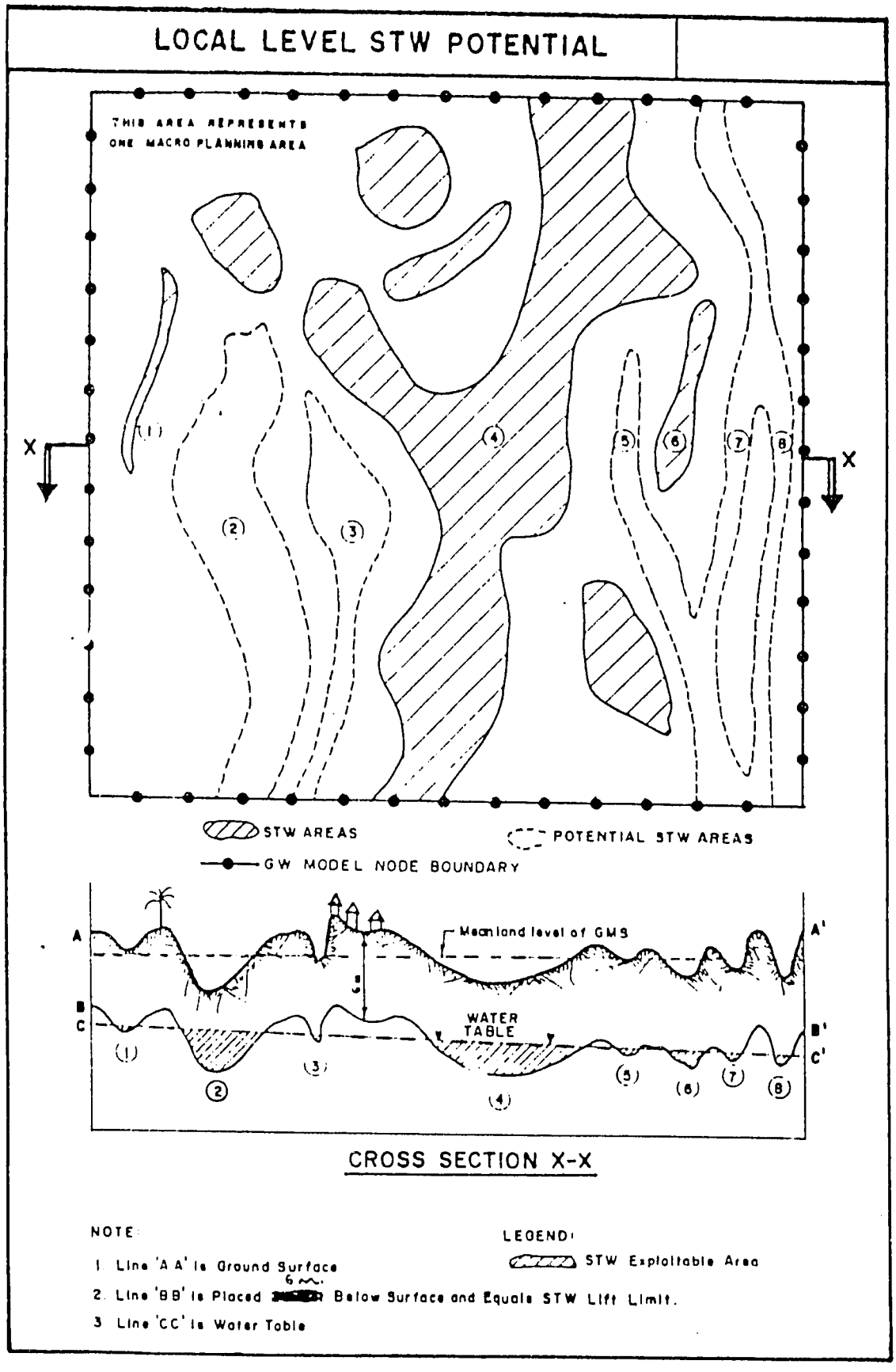
Thana	Criterion		Actual % Land Irrigated Within Recharge Limit
	25 Foot GWL Limit	25 Foot GWL Limit Plus Recharge Constraint	
	No. STWs	No. STWs	%
Adamdighi	540	519*	26
Akkelpur	479	388*	21
Bogra	2120	1707*	35
Dhunat	1647	1647	53
Dupchanchia	350	338*	18
Gabtali	3661	3257*	69
Jaipurhat	1230	928*	29
Kahaloo	561	509*	17
Khetlal	945	876*	22
Nandigram	809	681*	22
Panchbibi	871	871	23
Shariakandi	1486	1261*	66
Sherpur	1753	1622*	43
Shibgonj	2029	1291*	30
Total	18,481	15,895	35

* Recharge is the dominant constraint

Source: Tables 7.7, 7.8, 7.9 Groundwater Modeling Study, 1982

While Bogra District appears to be relatively straightforward, even here, due to localized variation in topography, there are areas that may not be reachable by STWs. As illustrated in Figure 6, local variation can shift the appropriate technology from a STW to a DSSTW or even a DTW. Thus, even studies such as this have to be balanced off with good, local-level data.

Fig. 6. Variation in STW potential



Source: Pitman and Haque, 1984

III. Combined Considerations

By combining social, economic and technical considerations it is possible to develop a suggested set of criteria for locating different type of tubewells in Bangladesh. As mentioned earlier, in some cases, due to unique circumstances, these criteria are hierarchical (i.e. the thickness of the clay layer dictates DTWs over the more economic STWs) but in many others they are not. A suggested set of criteria follows:

(1) In areas where the groundwater is abundant and all the available land can be irrigated using the groundwater within the first 20 feet of the aquifer, only STWs should be installed.

(2) In areas where all the available land can be irrigated using the groundwater within the first 30 feet of the aquifer, STWs should be installed but with a mechanism in place to change them to DSSTWs as necessary.

(3) In areas where all of the available recharge can be pumped by STWs from the first 20 feet of the aquifer, only STWs should be installed.

(4) In areas where all of the available recharge can be pumped from the first 30 feet of the aquifer, only STWs with a mechanism to move them down to become DSSTWs should be installed.

(5) In areas where the clay layer and/or silt formation is too thick for STWs, DTWs are the main alternative to be considered. However, localized variation must be recognized and procedures developed to install STWs where they have access to a dependable aquifer.

(6) In areas where available recharge exceeds what can be pumped from the upper 30 feet of the aquifer (a rare case but possible in some regions of Bangladesh), a decision has to be made whether or not to install both STWs and DTWs, recognizing that the DTWs have the potential to pull the groundwater below the pumping depth of the STWs. One possible mechanism in this case is to install both STWs and DTWs but to stop pumping STWs during the months of April and May, which is the time when the water table is at its maximum depth.

(7) *In those areas where the natural watertable and/or drawdown is below the lift capability of STWs and DSSTWs, to capture the available recharge, it is necessary to install DTWs.

(8) *In the coastal regions, where saline water is found in the upper aquifer, it is necessary to install DTWs to reach the freshwater in the lower quifer.

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* In both of these cases it must be explicitly recognized that, while DTWs are technically feasible, the water from these DTWs will be much more expensive than groundwater obtained from the other areas due primarily to the pumping depths.

CRITERIA APPLIED

Based on the criteria presented in the previous section it is posible to use available groundwater and tubewell installation data to see how well current development is progressing and to determine if it is consistant with the criteria. Gill (1983) carried out such a study for STWs for the Northwest Region of Bangladesh but his comparison was based on the optimum number of STWs as defined in the UNDP Groundwater Modelling Study (1982). This optimum was based on a 45 percent development level and did not take into account available recharge (Pitman, 1984).

For this excercise, recent upazila (thana) level data are required. Such data are available in the excellent report by the Groundwater Investigation Circle and are used for this study (Karim, 1984). MPO is currently revising these estimates, using a much larger sample of well points, but for the purpose of this report the data contained in the report by Karim (1984) are considered to be adequate (see Appendix I for details of the upazilas and Appendix II for a listing of the data used). As additional data on groundwater conditions and other technical coefficients are only readily available for the Northwest and Northeast Regions, this study is limited to these two areas. However, this is almost 70 percent of the entire country and, thus, is an extremely significant area. In addition to using the upazila level data, the two regions were also divided into groundwater basins (see Appendix III) based on the Bangladesh Water Balance Studies carried out by the United Nations (1983).

Unfortunately, the quantity of groundwater available for recharge is not a clear cut number that can, at this time, be easily defined and calculated. It is known, for example, that in some areas increased groundwater withdrawal will increase the amount of recharge without leading to a situation of mining the groundwater. As clearly stated by Asaduzzaman (1984), the safe yield (which is defined as the annual extraction from a groundwater unit which will not, or does not, exceed the annual recharge or lower the water table so that the permissible cost of pumping is exceeded) relates to a particular set of conditions. Hence, the safe yield is not a constant, and the value needs to be revised over time.

I. Results

The data used for this study cover the majority of Bangladesh including most of the tubewells installed in the country. General statistics for the area are presented in Table 5. From this table it can be seen that total pumping, across the entire area, is only slightly more than half of the estimated available recharge. This, however, varies from area to area and therefore cannot be generalized. However, the average available recharge per cultivated unit area (.220 m/ha) is not sufficient water to plant all of the cultivated area in rice. In fact, in most areas even if wheat is planted, there is not sufficient water to cultivate all the land using only groundwater.

Table 5: Description of Study Area: NE and NW Bangladesh, 1983-84 1/

	Total Area	Cultivated Area	Number Tubewells			Total Recharge	Total 2/ Pumping	Average Available Recharge/ha
Area	('000 ha)	('000 ha)	DTWs	STWs	HTWs	(MCM)	(MCM)	(m/ha)
NW	3444.7	2524.4	6812	62002	173549	7000.5	3341.45	.196
NE	3324.9	2183.0	6638	31255	142990	4673.6	2192.95	.107
Total	6769.6	4707.4	13450	93257	316539	11674.1	5534.4	.153

1/ After Karim (1984) data are presented in metric units. They can be converted to English units by using the following conversion factors: 1 ha = 2.41 acres 1 m = 3.281 feet 1 MCM = 810.71 acre feet.

2/ Total pumping is, in contrast to most studies including Karim's (1984), based on typical discharge rates, hours, and number of tubewells in operation (see table 2)

Using the data available it is possible to examine the frequency of occurences where total pumping exceeds available recharge. In Figure 7 it can be seen that in 220, or 88 percent of the upazilas, recharge exceeds pumping. However, in 30 or 12 percent of the upazilas, pumping is more than the recharge rate. It would seem that in these areas installation of additional tubewells would not only be uneconomic, it would also be technically unwise. However, as documented recently by Asaduzzaman (1985), even in upazilas where STW installation has been stopped, there are pockets where additional STWs can be installed. Yet, even in these cases it is difficult to control exactly where STWs are actually installed.

Fig. 7. Depth of pumping to available recharge

---------- FREQUENCY DISTRIBUTIONS ----------

HEADER DATA FOR: B:BGGWDTOT LABEL: NE & NW GROUND WATER DATA AFTER KAPOM
NUMBER OF CASES: 250 NUMBER OF VARIABLES: 33

VARIABLE: 24. DPR/AVRE

FREQUENCY ANALYSIS OF DEPTH OF PUMPING TO AVAILABLE RECHARGE

=====CLASS LIMITS====		FREQUENCY	PERCENT	....CUMULATIVE... FREQUENCY	PERCENT
.00 <	.20	42	16.80	42	16.80
.20 <	.40	52	20.80	94	37.60
.40 <	.60	52	20.80	146	58.40
.60 <	.80	42	16.80	188	75.20
.80 <	1.00	32	12.80	220	88.00
1.00 <	1.20	17	6.80	237	94.80
1.20 <	1.40	8	3.20	245	98.00
1.40 <	1.60	2	.80	247	98.80
1.60 <	1.80	0	.00	247	98.80
1.80 <	2.00	0	.00	247	98.80
2.00 <	2.20	0	.00	247	98.80
2.20 <	2.40	0	.00	247	98.80
2.40 <	2.60	0	.00	247	98.80
2.60 <	2.80	2	.80	249	99.60
2.80 <	3.00	0	.00	249	99.60
3.00 <	3.20	1	.40	250	100.00
	TOTAL	250	100.00		

27 MISSING DATA CASES ENCOUNTERED.

=====CLASS LIMITS====		FREQUENCY	.....
.00 <	.20	42	
.20 <	.40	52	
.40 <	.60	52	
.60 <	.80	42	
.80 <	1.00	32	
1.00 <	1.20	17	
1.20 <	1.40	8	
1.40 <	1.60	2	
1.60 <	1.80	0	
1.80 <	2.00	0	
2.00 <	2.20	0	
2.20 <	2.40	0	
2.40 <	2.60	0	
2.60 <	2.80	2	
2.80 <	3.00	0	
3.00 <	3.20	1	

Based on the recommended zones (Appendix 4) for STWs and DTWs (United Nations, 1983) it is possible to examine the current situation in the country. Information related to STWs in the NW and NE is presented in Table 6.

Table 6: Potential of STW Designated Areas - 1984

Area	Available Recharge (MCM)	Present STW Pumping3/ (MCM)	Present Number STWs	Maximum Possible No. STWs1/	Potential Area Irrigatable ('000 ha) High1/	Low2/
NW	3798.7	1002.5	27088	102667	411(34%)	616(51%)
NE	2330.2	662.6	17905	62978	252(27%)	378(41%)
Total	6128.9	1665.1	44993	165645	663	994

1/ High water demand crops (1000 mm/ha)
2/ Low water demand crops (500 mm/ha) - 6 ha. command area
3/ Assumes discharge of 0.4 cusecs and 900 hours pumping. Excludes pumping of DTWs and HTWs. Number in parentheses indicates percentage of presently cultivated land.

Similar information concerning DTWs in the NW and NE is, presented in Table 7.

Table 7: Potential of DTW Designated Areas - 1984

Area	Available Recharge (MCM)	Present DTW Pumping3/ (MCM)	Present No. DTWs	Maximum Possible No. DTWs1/	Potential Area Irrigatable ('000 ha) High1/	Low2/
NW	3201.8	559.0	3774	17307	280(22%)	421(33%)
NE	2343.4	520.6	3560	12667	151(12%)	308(24%)
Total	5545.2	1079.6	7334	29974	431	729

1/ High water demand crops (1000 mm/ha)
2/ Low water demand crops (500 mm/ha) - 24.3 ha. command area
3/ Assumes discharge of 1.5 cusecs and 1200 hous pumping. Excludes pumping of STWs and HTWs. Number in parentheses indicates percentage of presently cultivated land.

From Tables 6 and 7 it is possible to explore the potential possibility in the NW and NE Regions for STWs and DTWs, respectively, assuming that the only limits are available recharge. The maximum possible number of STWs and DTWs may be over optimistic but they do provide some estimates on the number of tubewells that could be installed (assuming it was possible to distribute all the tubewells homogeneously throughout the country) within the limits of available recharge. However, as pointed out by a number of researchers, the types of tubewells installed are not well correlated with the clasification of the area (Gill, 1983), nor are the wells evenly distributed (Assaduzzaman, 1985). Table 8 details how poorly the types of wells installed match with the designation of the particular areas. From this table it can be seen that there are 48,264 STWs in areas designated for DTWs and 6116 DTWs in areas designated for STWs. Obviously these designations are not ironclad, and most of the tubewells were installed prior to the studies that developed the designation, yet the wide discrepancy between designation and type of installed tubewells goes far to explain why the groundwater irrigation system is not working as well as planned. Proper equipment installed in the correct areas is required to obtain maximum social return from the water resources of the country.

II. Economic Costs

It is difficult to determine exactly the costs of installing DTWs in STW designated areas and STWs in DTW designated areas but

Table 8: Comparison of Types of Wells in STW and DTW Designated Area, 1984

Designation of Area by Technology	Number of STWs	Number of DTWs	Number of HTWs	Present Rate of Pumping: STW or DTW (MCM) 1/
NW - STWs	27088	3038	85436	450.2 (DTW)
NE - STWs	17905	3078	55518	458.9 (DTW)
NW - DTWs	34914	3774	88113	1291.2 (STW)
NE - DTWs	13350	3560	87472	494.4 (STW)
Total	93257	13450	316539	2694.7

1/ Pumping by tubewell type that not the designated one.

it is certain that it is a very large amount. If it is assumed, for example, that all of the DTWs that are installed in STWs designated areas are incorrectly located, it is possible to estimate the GOB subsidy that was provided unnecessarily. With 6116 DTWs at an average price of approximately Tk 250,000 and a rate of subsidy varying from 40 to 90 percent, the total cost to the GOB ranges from Tk 6116.6 million to Tk 1376 million. These figures have to be prefaced with a number of assumptions, but they do reflect the magnitude of the costs of incorrectly locating equipment in areas where other technologies, in this case unsubsidized STWs, could serve the same purpose more economically.

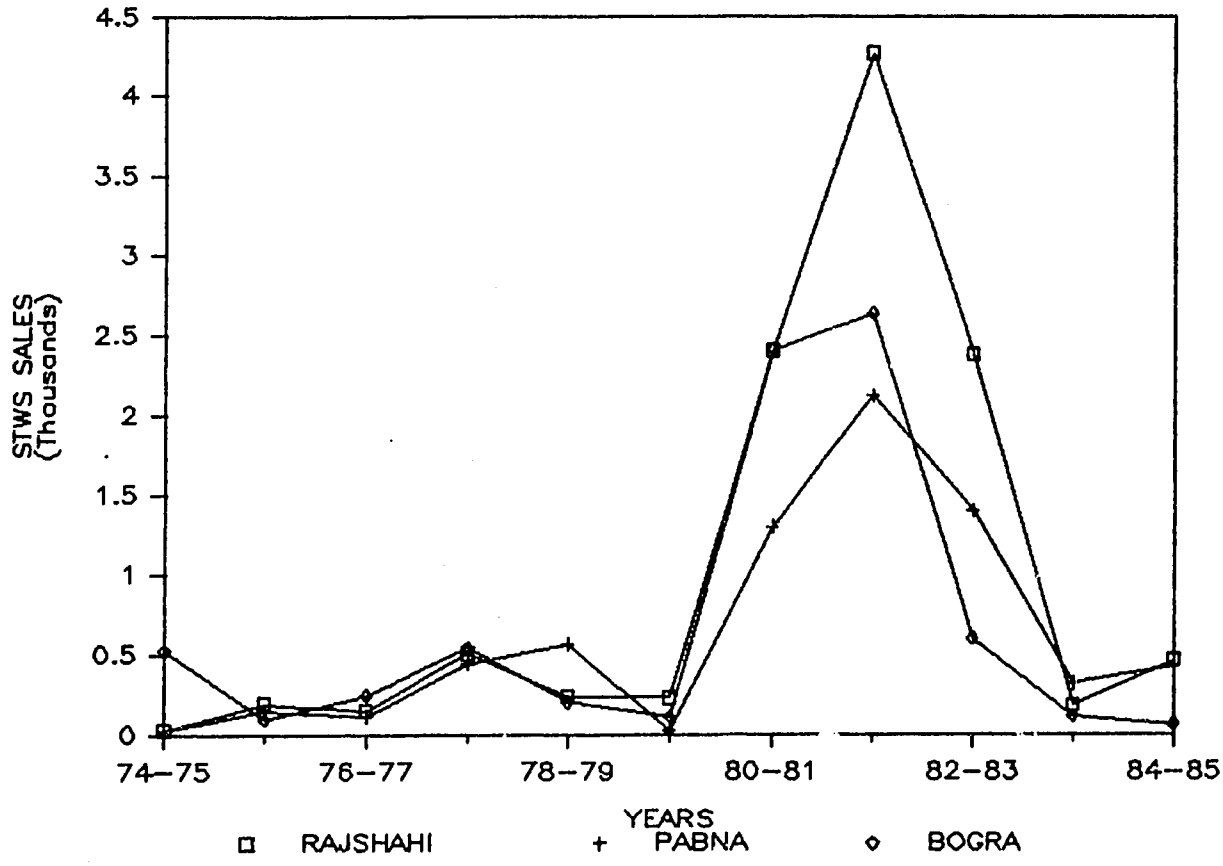
Some GOB officials have expressed concern about areas of the country where STWs have problems. This is a valid concern, but their suggestions for solving the problem, by barring STWs and

installing DTWs, are not logical. In many of these areas there are already more tubewells and more potential extraction capacity than the available recharge. Installing additional tubewells, particularly DTWs, will simply exascerbate the problem.

It is interesting to examine these areas, as the self regulating aspects of STWs have become obvious. Farmers have in some areas such as Tanore in Rajshahi District modified their STWs to become DSSTWs. At the same time they have made a major shift to wheat away from boro rice as they know that boro rice requires maximum water in late March and April, which is exactly when the groundwater level is the deepest and, therefore, most likely to be below 30 feet from the STW pump. In addition, farmers have come to realize that STWs are not the high paying investments they were a few years ago. Consequently, STW sales in the problem areas have fallen drastically. This is dramatically illustrated in the line chart in Figure 8. Farmers in the problem areas have become much more conservative and are only buying STWs if or when they are certain they will make a fair return on their investment.

Both as a consequence of the changed pumping practices and of better rainfall, groundwater levels in the problem areas, that were low in 1982-83, came back up to normal level in 1984. This indicates that, at least to date, the aquifer is not being mined. However, while groundwater investment patterns to date are history, future patterns are extremely important. Given the results of the analysis presented in the previous section, it is difficult to understand how the GOB can be actively involved in

Fig. 8. Sales of STWs in Rajshahi, Pabna, and Bogra Districts 1974-1984



Source: Data from BADC, Shallow Tubewell Division

planning additional tubewell investments that are counter to the recommendations of all the groundwater modelling studies to date. Two such projects, the Thakurgaon DTW Project funded by ADB and the IDA DTW-II Project are to install 960 and 1100 DTWs, respectively. The bulk of these DTWs are to be placed in some of the best STW areas in the country. In general, there is not even a major disagreement about these locations; they are excellent for STWs and have been designated so by all of the major groundwater studies. This kind of investment is not only economically difficult to justify but eventually will lead to more significant problems of competition as STWs will continue to be installed in these areas until restricted by law or falling groundwater levels.

III. Future Requirements

Projections of future population and foodgrain requirements, carried out as part of the long-range planning exercise by MPO, have indicated that it is not possible to meet the future foodgrain requirements of Bangladesh without drawing down watertable levels throughout the country. This will result in some degree of short-term mining of groundwater, but in the long-term as this frees up storage space in the aquifer it is expected that this will create additional groundwater recharge.

The analysis carried out in the previous sections was restricted to available recharge and, therefore, excluded even limited mining. However, the data set used provides a set of estimates for the situation where the groundwater is exploited to a

greater depth. This data can be used to evaluate the impacts of a general lowering of the watertable. An example from this analysis is presented in Table. 9.

Table 9: Development of STW Designated Areas at Potential Recharge Levels

Area	Potential Recharge (MCM)	Possible STWs with Available Recharge[1]	Possible STWs with Potential Recharge[2]	Potential Area Irrigatable ('000 ha) High[3]	Low[4]
NW	8536.5	102667	230716	923(75%)	1384(100%
NE	4849.6	62978	131070	524(57%)	786 (84%
Total	13386.1	165645	361,786	1447	2170

[1] From Table 6, Column number 5
[2] Assumes that the water table is drawn down to the limits of STWs pumping lift
[3] High water demand crops (1000 mm/ha)
[4] Low water demand crops (500 mm/ha) - 6 ha command area
[5] Actually exceeds 100%

From this table it can be seen that, even when planting rice, using only STWs it is possible to irrigate 75 percent of the presently cultivated land in the NW and 57 percent of the presently irrigated land in the NE. If the farmers in these regions change to lower water requiring crops such as wheat, in the NW 100 percent of the presently cultivated land can be irrigated from groundwater and 84 percent of the presently cultivated land can be irrigated in the NE. In practice, due to local variations in groundwater availability, it is not actually possible to irrigate 100 percent of the presently irrigated land in the NW, except for certain upazilas in districts such as Rangpur and Dinajpur. However, it is

certainly possible to irrigate 90 plus percent throughout the entire region.

It should be emphasized that this scenario does not pull the average watertable level below the effective lift of STWs, although, due again to local variability it maybe necessary in certain identified areas to install DSSTWs. This point is important as it means that more expensive, imported DTWs are not required in these regions even to meet future projected foodgrain requirements. Of course, the presence in the area already of more than 6000 DTWs which are presently pumping almost 1000 MCM of groundwater means that there must be a proportional reduction of the number of STWs. However, as these DTWs age and need replacement, such as the BWDB Thakurgaon DTWs, they should not be replaced with DTWs but instead STWs should be installed in their place.

DISCUSSION

This paper has presented a criteria for location of STWs and DTWs and, using available data, has compared the actual situation against the criteria. Based on the results of analysis it can be concluded that present location of STWs and DTWs, and even planned future developments, do not agree very closely with the suggested criteria. There are a number of explanation for this situation but one of the main reasons is the fact that excessive subsidies on DTWs have encouraged them to be installed in areas where, judged from groundwater conditions, they are not required and,

consequently, they are more expensive to operate than STWs. Only massive subsidies by the GOB have made this situation possible. Economic theory argues that if owners of DTWs had to pay the true cost of installing them, DTWs would be installed, if at all, only in areas where they can provide water at less cost than the next best alternative. GOB subsidies have drastically changed market conditions and, thus, have encouraged inefficient investment practices.

As noted in the discussion on criteria for location, DTWs that are required in areas with a deep watertable, excessive drawdown, shallow saline aquifers and/or extremely thick clay layers are going to be both more expensive to install and to operate. Yet, it is in these areas where STWs and DSSTWs are not technically feasible that DTWs provide the next best alternative source of water for irrigation. Given the desire of the GOB to make certain that economic activities in these less well endowed areas continue to grow, and keep abreast of the other regions, there may be a welfare argument for providing subsidized DTWs. This will be provided from the point of regional equity rather than economics and has to be recognized as such. Such a case is in sharp contrast to the situation where the GOB is installing DTWs at 40-90 percent subsidy in some of the best water resource endowed areas in the country; a process that serves to further skew regional income disparities.

Bangladesh is rapidly approaching a point where uncontrolled installation of groundwater extraction devices has to cease. Already STW sales have been restricted in eight upazilas in Rajshahi, Pabna, and Bogra districts. Consultants of the IDA

DTW-II project have recommended to ban further STW development in 15 upazilas and to discourage development of STWs in an additional four upazilas. This recommendation was made, primarily, in order to minimize encroachment of STWs within the command areas of DTWs.

Some individuals within the GOB believe that the only way to solve this problem is to pass very strict installation and pumping laws. Yet, this suggested solution goes directly against the GOB's stated position of moving away from government ownership. This committment toward 'privatization,' while significantly reducing the financial burden of subsidies on the GOB, also reduces the ability to control pumping and, to some extent, location of installation.

Given that the trend toward privatization is likely to continue and even accelerate, the GOB's ability to control groundwater development at the micro level is going to be significantly reduced. If this is correct, then what is most likely to work best are regulations that work at a very macro level. An example of such a regulation is a zoning rule that zones an area for only one type of extraction device. This type of regulation is easy for everyone to understand, does not require complicated interpretation and tends to minimize (but of course does not eliminate) the potential for corruption.

With the vast areas of Bangladesh that can be irrigated with STWs at a cost (both total and in foreign exchange) much less than the cost of using DTWs, it is recommended that all areas capable of being developed with STWs and DSSTWs be zoned for STWs and, as such, no DTWs would be installed. In those limited areas that,

because of unique aquifer conditions, require DTWs, the GOB would have to decide if it was justified to install DTWs. If this decision is made on an economic basis, then DTWs would not be subsidized. Only when the decision to install DTWs is based on an income transfer argument should subsidies for DTWs be considered.

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APPENDIX I

SERNO	FLUCGWL	KARIMNO	UPPAZILLA	DISTRICT
1	2.17	1	TETULIA	DINAJPUR
2	2.82	2	PANCHAGHAR	
3	2.41	3	ATWARI	
4	3.12	4	BEDA	
5	2.54	9	DEBIGANJ	
6	2.38	5	THAKURGAON	
7	2.14	6	BALIADANGI	
8	2.09	21	HARIPUR	
9	2.10	7	RANISANKAIL	
10	1.70	14	PIRGANJ	
11	2.41	8	BIRGANJ	
12	1.82	13	BOCHAGANJ	
13	2.26	11	KAHOROLE	
14	1.37	46	KISHORGANJ	RANGPUR
15	2.10	38	DOMAR	
16	2.18	37	DIMLA	
17	2.06	40	JALDHAKA	
18	2.65	41	NILPHAMARI	
19	4.67	15	KHANSAMA	DINAJPUR
20	1.66	45	SYEDPUR	RANGPUR
21	2.38	43	KOTWALI	
22	2.03	44	GANGACHARA	
23	2.18	36	POTGRAM	
24	2.23	39	HATIBANDHA	
25	2.04	42	KALIGANJ	
26	2.89	19	BIROL	DINAJPUR
27	2.38	43	KOTWALI	RANGPUR
28	1.93	12	CHIRIBANDHA	DINAJPUR
29	2.00	16	PARBATIPUR	
30			BHURUNGAM	RANGPUR
31	2.07	25	NAGEWAR	
32	1.46	48	PHULBARI	
33	3.19	26	KURIGRAM	
35	1.92	50	LALMANIRHAT	
37	1.24	17	FULBARI	DINAJPUR
38	3.50	20	NABALGANJ	
40	3.21	18	HAKIMPUR	
41	1.80	22	GHORAGHAT	
42	1.86	32	PIRGANJ	RANGPUR
43	2.43	31	MITHAPUKUR	
44	1.60	33	PALASHBARI	
45	2.30	34	SADULAPUR	
46	2.19	28	GAIBANDHA	
47	2.43	31	MITHAPUKUR	
48	2.09	49	BADARGANJ	
49	1.90	23	PIRGACHA	
50	2.03	447	KANNIA	
51	1.66	45	SYEDPUR	
52	1.80	24	SANDARGANJ	
53	1.26	35	CHILMARI	
54	2.02	27	ULIPUR	
55	2.19	28	GAIBANDHA	
56			FULCHARI	
57	2.46	29	SHAGATHA	
59	2.54	60	SHARIAKANDI	BOGRA

60	3.72	80	KAZIPUR	PABNA
61	2.95	75	SIRAJGANJ	
62	4.00	78	BELKUCHI	
63	3.48	74	SHAHJAPUR	
64	1.00	58	GABTALI	BOGRA
65	2.54	60	SHARIAKANDI	
66	3.72	59	DHUNAT	
67	3.72	80	KAZIPUR	PABNA
68	2.98	56	SHERPUR	
69	2.70	57	BOGRA	
70	3.00	76	ROYGANJ	
71	2.95	75	SIRAJGANJ	
72	1.80	30	GOBINDAGANJ	RANGPUR
73	2.07	61	PANCHBIBI	BOGRA
75	2.85	62	KHETTAL	
76	2.15	53	SHIBGANJ	
77	1.00	58	GABTALI	
78	2.70	57	BOGRA	
79	1.66	52	DUPCHACHIA	
80	1.50	54	KAKALU	
82	1.50	55	NANDIGRAM	
83	2.85	85	SINGRA	RAJSHAHI
84	3.80	77	TARASH	PABNA
85	1.40	63	JOYPURHAT	BOGRA
86	2.07	61	PANCHBIBI	
87	2.85	62	KHETTAK	
88	1.50	64	AKKELPUR	
89	1.50	51	ADAMDIGHI	
90	1.50	103	RANINAGAR	
91	1.80	101	ATRAI	RAJSHAHI
92	1.60	94	BAGMARA	
93	2.22	92	DURGAPUR	
94			PUTHIA	
95	2.00	82	NATONE	
96	2.85	85	SINGRA	
98	2.20	83	BAGATIPARA	
99	3.80	77	TARASH	PABNA
100	2.37	65	CHATMOHAR	
102	1.80	101	ATRAI	RAJSHAHI
103	2.90	73	ULLAPARA	PABNA
104	3.48	74	AHAHJAPUR	
105	4.00	78	BELKUCHI	
106	3.00	79	KAMARKANDA	
107	2.00	99	BHOLAHAT	RAJSHAHI
108	5.90	98	GOMASTAPUR	
109	4.56	97	NACHOLI	
110	1.70	95	NABABGANJ	
111	1.90	96	SHIBGANJ	
112	3.50	91	GODAGORI	
113	1.80	89	TANORE	
115	3.50	106	DAMURHAT	
116			PORSHA	
117	3.10	107	PATNITOLA	
118	1.88	105	MOHADAPUR	
119	2.82	108	BADALGACHI	
120	2.20	104	NIAMATPUR	

121	1.28	102	MANDA	
122	1.20	100	NOOGAON	
124	1.40	63	JOYPURHAT	BOGRA
125	1.80	89	TANORE	RAJSHAHI
126	2.60	88	PABA	
127	1.88	105	MOHORPUR	
128	1.61	94	BAGMARA	
129	2.22	92	DURGAPUR	
132	1.89	93	CHARGHAT	
133	2.20	83	BAGATIPARA	
134	3.94	87	LALPUR	
135	1.80	84	BARAIGRAM	
136	2.12	67	ISHURDI	PABNA
137	1.87	66	ATGHARIA	
138	2.12	68	PABNA	
139	2.68	72	FARIDPUR	
140	3.29	71	SATHIA	
142	4.10	69	SUJANAGAR	
143	5.56	70	BERA	
144	2.37	65	CHATMOKAR	
145	1.65	302	DEWANGANJ	JAWALPUR
146			JHENAIGATI	
147	2.68	309	NALITBARI	
148	2.07	210	HALUGHAT	MYMENSINGH
150	2.22	92	DURGAPUR	
151	2.50	3.12	PURBAHALA	NETROKONA
152			ROUMARI	RANGPUR
153			CHARIJIBPUR	
154			FULCHARI	
155	1.83	303	ISLAMPUR	JAMALPUR
156	2.00	304	MARLANDA	
157	2.97	205	MUKTIAGACHA	MYMENSINGH
158	1.82	209	TRESHAL	
159	1.27	213	ISWANGANJ	
160			ROUMARI	
161			CHARIJIBPUR	
162			FULCHARI	
163	1.65	302	DEWANGANJ	JAMAL
164	2.58	308	SRIBUNDI	
165			JHINAIGATI	
166	2.68	309	NALITABARI	
167	2.10	307	SHERPUR	
168	2.00	304	MALADA	
169	2.65	310	NAKLA	
170	2.68	309	NALITABARI	
171	2.20	211	PULPUR	MYMENSINGH
172	2.07	210	HALHALUGHAT	
173	2.5	312	PURBADHALA	NETRAKONA
174	2.54	313	NETRAKONA	
175	2.21	314	KENDUA	
176	2.35	318	ATPARA	
177	3.50	224	TARAIL	
178	2.50	320	KAMALKANDA	
179	2.00	319	BARHALTA	
180	2.35	318	ATPARA	
181	2.00	315	MADAN	NETROKONA

182	2.54	317	MOHANGANJ	
183	2.12	316	KHILIPURIKHILIPURI	
185	3.66	248	TAHIRPUR	SYLHET
186			JAMALGANJ	
187			DARAMPASSA	
188	2.30	240	DERAI	
189			SALLA	
190	2.12	316	KAHLIJURI	
191	2.00	315	MADAN	
192			SALLA	
193	1.30	241	JAGANNATHUR	
194	1.89	223	KARIMGANJ	KISHOREGANJ
195	3.5	224	TARAIL	
196	1.89	225	ITNA	
197	1.80	221	NIKLI	
198	2.45	226	ASTRAGRAM	
199	2.50	227	BAJITPUR	
200	2.00	219	KULIACHARA	
201	3.50	224	TARAIL	
202	2.00	182	RAIPURA	DHAKA
203	1.54	233	ADJMIRIGANJ	SYLHET
204	1.27	234	BANIACHANG	
205			HOBIGANJ	
206	1.52	236	MADHAPUR	
207			BRAHAMBARIA	COMILLA
208	1.19	261	SARAIL	
209			AKHAURA	
210	0.92	260	NASINAGAR	
211	1.83	214	NANDAIL	MYMENSINGH
212	1.70	216	HOSSAINPUR	
213	1.89	223	KARIMGANJ	
214	2.62	222	KISHARGANJ	
215	2.50	217	PAKUNDIA	
216	2.24	218	KATIADI	
217	2.00	219	KULIARCHAR	
218	3.50	224	TARAIL	KISHOREGANJ
219	2.00	182	RAIPURA	DHAKA
220	3	183	NARSINGDI	
221	2.17	186	ARAIHAZAR	
225	4.53	181	SHIBPUR	
227	3.35	171	KAPASIA	
228	2.12	207	BHALUKA	MYMENSINGH
229	2.30	208	GARFARGAON	
230	2.84	169	SREEPUR	DHAKA
231	4.02	170	KALIAKOIR	
232	3.35	171	KAPASIA	
233	2.76	172	KALIGANJ	
235	3.90	168	JOYDEPUR	
236			SHAKHIPUR	TANGAIL
237	2.00	199	GHATAIL	
238	1.65	203	MIRZAPUR	
239	3.47	167	DHAMRAI	DHAKA
240	4.18	166	SAVAR	
241	1.50	111	MIRPUR	
242	2.62	165	KERIGANJ	
243	2.64	179	SINGAIR	

244	2.02	301	JAMALPUR	JAMALPUR
245	2.00	304	MALANDA	
246	1.50	306	SARISHABARI	
247	1.80	196	MODHUPUR	TANGAIL
248	2.00	199	GHATAIL	
249	2.00	197	GOPALPUR	
250	1.32	198	BHUAPUR	
251	1.60	200	KALIHATI	
252	2.00	201	TANGAIL	
253	3.47	167	DHAMRAI	DHAKA
254	1.65	203	MIRZAPUR	TANGAIL
256	1.40	202	NAGARPUR	
257	2.46	204	BASAIL	
258	3.40	176	SATURIA	DHAKA
259	2.92	177	MANIKGANJ	
260			FULCHARIA	RANGPUR
261	1.83	303	ISLAMPUR	JAMALPUR
262	1.73	305	MADANGANJ	
263	1.50	306	SARISHABARI	
264	2.00	304	MALANDA	
265	1.32	198	BHUAPUR	TANGAIL
266	2.00	201	TANGAIL	
267	1.40	202	NAGARPUR	
268	2.02	301	JAMALPUR	JAMALPUR
269	1.80	196	MADHOPUR	TANGAIL
270	2.97	205	MUKTAGACHA	MYMENSINGH
271	1.84	206	PHULBARIA	
272	1.82	209	TRISHAL	
273	2.12	207	BHULUKA	
274	1.27	213	ISWARGANJ	
275	1.83	214	NANDAIL	
276	1.78	215	GOURIPUR	
277	2.59	212	KOTWALI	
278	2.30	208	GARFARGAON	
279			NABIGANJ	SYLHET
280	1.88	238	BAHUBAL	
281			HOBIGANJ	
282	1.52	237	CHANARIGHAT	
283	2.17	229	SRIMANGAL	
284	1.60	230	KAMALGANJ	
285	1.71	231	KULAURA	
286	1.64	232	BARALOKHE	
287	3.05	173	DHULATPUR	DHAKA
288	3.03	174	GHIOR	
289			SHIVALAYA	
291	2.90	178	HARIANPUR	
292	2.64	179	SINGAIR	
293	2.88	164	NAWABGANJ	
295	2.23	188	FATULLA	
296	2.27	163	DOHAR	
297	2.23	191	SRINAGAR	
298	2.02	190	SRIAJDIKAR	
299	1.90	193	TONGIBARI	
300	1.92	194	MUNISHGANJ	

DATA FROM GROUNDWATER INVESTIGATION CIRCLE AFTER KARIM 1984

HEADER DATA FOR: B:KARIMFOR LABEL: BANGLADESH GRD WATER DATA FROM KARIM E
NUMBER OF CASES: 277 NUMBER OF VARIABLES: 15

	SERNO	KARIMNO	WATBASIN	TOTAREA	CULTAREA	NO-DTWS	NO-STWS
1	1	1	1	19180	11984	0	20
2	2	2	1	26670	14372	14	49
3	3	3	1	20960	15182	29	26
4	4	4	1	42980	34170	20	65
5	5	9	1	30840	22713	23	179
6	6	5	1	64510	34939	190	253
7	7	6	1	28730	20972	56	55
8	8	21	1	19950	15263	38	86
9	9	7	1	28490	21741	76	141
10	10	14	1	39380	29555	80	274
11	11	8	1	40670	29150	71	313
12	12	13	1	35730	17004	55	297
13	13	11	1	20720	14818	59	167
14	14	46	2	26500	19352	16	225
15	15	38	2	25090	18623	41	229
16	16	37	2	32860	23077	5	103
17	17	40	2	32570	22915	27	89
18	18	41	2	35080	25749	49	314
19	19	15	2	17850	14372	2	50
20	20	45	2	6090	4453	21	66
21	21	43	2	31880	23887	111	523
22	22	44	2	21200	15506	52	256
23	23	36	2	25890	20648	46	125
24	24	39	2	28770	21134	33	62
25	25	42	2	43220	32348	27	200
26	26	19	3	35730	20243	64	595
27	27	43	3	36020	29959	88	809
28	28	12	3	31320	25061	73	401
29	29	16	3	43260	33198	92	460
30	30	MISSING	4	23643	17814	27	353
31	31	25	4	41190	31376	65	335
32	32	48	4	16316	11741	18	83
33	33	26	4	27110	20648	26	187
34	35	50	4	33990	27854	46	125
35	37	17	5	31850	23806	31	301
36	38	20	5	39380	27935	66	204
37	40	18	5	20190	15425	39	187
38	41	22	5	14770	10162	37	165
39	42	32	5	41110	29959	138	367
40	43	31	5	26300	17409	80	246
41	44	33	5	19100	14575	83	618
42	45	34	5	23300	16923	81	798
43	46	28	5	16050	11741	48	484
44	47	31	6	25300	17409	80	245
45	48	49	6	42980	31579	80	214
46	49	23	6	25490	20040	111	625
47	50	47	6	14810	9190	58	163
48	51	45	6	6090	4453	21	66
49	52	24	6	41800	29393	73	431
50	53	35	6	28170	19838	20	130

51	54	27	6	54670	40081	62	302
52	55	28	6	16450	11741	48	484
53	56	MISSING	6	31420	22794	29	175
54	57	29	6	22860	17409	51	1139
55	59	60	6	23430	12146	20	480
56	60	80	6	18530	15182	83	49
57	61	75	6	16830	12955	102	90
58	62	78	6	8160	6883	0	295
59	63	74	6	16000	12955	13	771
60	64	58	7	17720	14980	38	800
61	65	60	7	23430	12146	20	480
62	66	59	7	24830	19150	23	2561
63	67	80	7	18530	15182	83	49
64	68	56	7	29670	23482	73	1051
65	69	57	7	20380	15789	48	1038
66	70	76	7	26670	24696	201	511
67	71	75	7	16830	12955	102	90
68	72	30	8	46060	34737	151	1207
69	73	61	8	14120	11741	53	207
70	75	62	8	15440	11336	43	139
71	76	53	8	31520	26316	260	982
72	77	58	8	17720	14980	38	800
73	78	57	8	20380	15789	48	1038
74	79	52	8	16260	13765	127	814
75	80	54	8	24160	21053	202	556
76	82	55	8	26870	19433	118	1156
77	83	85	8	26230	18219	13	1601
78	84	77	8	15010	13158	0	470
79	85	63	9	23840	19838	112	616
80	86	61	9	14120	11741	53	207
81	87	62	9	15440	11336	43	139
82	88	64	9	14240	11336	79	732
83	89	51	9	16830	12753	106	1262
84	90	103	9	24610	20850	60	1582
85	91	101	9	26060	12146	0	765
86	92	94	10	18300	12551	35	487
87	93	92	10	9980	7692	14	163
88	94	MISSING	10	19433	8097	40	289
89	95	82	10	40470	29879	87	894
90	96	85	10	26230	18219	13	1601
91	98	83	10	7000	6478	14	57
92	99	77	10	15010	12955	0	470
93	100	65	10	18560	14980	9	456
94	102	101	10	26060	10526	0	756
95	103	73	11	41440	36842	302	1104
96	104	74	11	31850	25506	25	1542
97	105	78	11	8160	6883	0	295
98	106	79	11	9350	8097	9	174
99	107	99	12	12950	10081	0	90
100	108	98	12	31850	20972	0	427
101	109	97	12	27960	22672	0	162
102	110	95	12	48160	26316	0	348
103	111	96	12	52570	36842	17	484
104	112	91	12	44800	31174	17	549
105	113	89	12	14970	12146	33	439
106	115	106	13	29780	21255	10	706
107	116	MISSING	13	50530	35223	1	348
108	117	107	13	38820	29352	2	757
109	118	105	13	39380	33603	18	1155
110	119	108	13	21490	18866	59	577

111	120	104	13	44800	35628	8	865
112	121	102	13	41200	32389	45	861
113	122	100	13	27440	21457	58	1530
114	124	63	13	23840	20243	140	710
115	125	89	13	14970	12146	33	439
116	126	88	13	26140	8907	65	424
117	127	105	13	16310	6073	35	313
118	128	94	13	18300	12551	35	487
119	129	92	13	9980	7692	14	163
120	132	93	14	37030	27449	19	113
121	133	83	14	7000	6479	14	67
122	134	87	14	32980	27328	52	85
123	135	84	14	15340	10526	49	625
124	136	67	14	26750	22267	84	178
125	137	66	14	18650	14980	59	550
126	138	68	14	37550	28138	141	602
127	139	72	14	21490	14777	5	616
128	140	71	14	33140	26518	35	843
129	142	69	14	34960	27571	20	224
130	143	70	14	26670	16356	4	99
131	144	65	14	18560	14980	9	456
132	145	302	15	21230	17045	9	115
133	146	MISSING	15	12440	8907	14	20
134	147	309	15	26720	19231	45	185
135	148	210	15	21370	16599	54	373
136	150	92	15	42980	25547	0	590
137	151	312	15	17360	8502	37	218
138	152	MISSING	16	9890	8502	0	122
139	153	MISSING	16	11350	5294	0	0
140	154	MISSING	16	15710	11336	15	88
141	155	303	16	18490	15385	21	508
142	156	304	16	12180	10526	50	753
143	157	205	16	15810	10729	140	42
144	158	209	16	12650	10526	70	19
145	159	213	16	13920	10931	24	34
146	160	MISSING	17	9890	8502	0	122
147	161	MISSING	17	11350	5294	0	0
148	162	MISSING	17	15710	1134	15	88
149	163	302	17	21330	17045	9	115
150	164	308	17	31360	20243	64	283
151	165	MISSING	17	12440	8907	14	20
152	166	309	17	26720	19231	45	185
153	167	307	17	35730	28745	109	393
154	168	304	17	12180	10526	50	753
155	169	310	17	17360	13968	102	273
156	170	309	17	26720	19231	45	185
157	171	211	18	66570	54656	164	1135
158	172	210	18	21370	16599	54	373
159	173	312	18	17360	8502	37	218
160	174	313	18	31320	17895	70	516
161	175	314	18	33420	24656	71	202
162	176	318	18	9640	4858	12	32
163	177	224	18	7120	4980	1	82
164	178	320	19	38320	18947	0	618
165	179	319	19	22010	13198	30	236
166	180	318	19	9640	4858	12	32
167	181	315	19	11700	8300	5	43
168	182	317	19	29840	16599	0	12
169	183	316	19	14440	11984	0	2
170	185	248	19	36790	23279	0	7

171	186	MISSING	19	50780	11741	0	0
172	187	MISSING	19	36270	26721	0	9
173	188	240	19	41680	26518	0	0
174	189	MISSING	19	12960	6478	0	0
175	190	316	20	14440	11984	0	2
176	191	315	20	11470	8300	5	43
177	192	MISSING	20	12960	6478	0	0
178	193	241	20	18270	11781	0	0
179	194	223	20	9980	7692	22	95
180	195	224	20	14240	9838	21	164
181	196	225	20	57540	34372	0	18
182	197	221	20	30310	18542	3	244
183	198	226	20	30020	20283	0	50
184	199	227	20	18890	13765	55	236
185	200	219	20	10360	6478	60	354
186	201	224	20	12180	7287	11	173
187	202	182	20	19040	10162	25	499
188	203	233	20	21490	9636	0	2
189	204	234	20	49490	30000	1	3
190	205	MISSING	20	12310	7287	1	3
191	206	236	20	27960	17895	52	159
192	207	MISSING	20	48440	34818	143	398
193	208	261	20	24580	20648	64	140
194	209	MISSING	20	MISSING	24696	0	22
195	210	260	20	37350	26721	9	21
196	211	214	21	16310	13158	37	64
197	212	216	21	11900	9312	52	3
198	213	223	21	9980	7692	22	95
199	214	222	21	17890	13522	67	29
200	215	217	21	17890	11781	48	38
201	216	218	21	22250	14534	57	195
202	217	219	21	5180	6883	30	172
203	218	224	21	7120	4980	10	82
204	219	182	21	38080	20243	24	499
205	220	183	21	21210	14368	121	358
206	221	186	21	18370	11611	80	226
207	225	181	21	22540	17625	118	423
208	227	171	21	18010	13283	0	104
209	228	207	22	22130	14980	28	38
210	229	208	22	19950	16194	104	105
211	230	169	22	46380	26566	230	22
212	231	170	22	30110	15866	227	177
213	232	171	22	18010	13283	0	104
214	233	172	22	28440	22604	94	26
215	235	168	22	36010	25289	219	8
216	236	MISSING	22	MISSING	MISSING	150	154
217	237	199	22	22520	15170	90	736
218	238	203	22	18630	15267	95	340
219	239	167	22	15160	14271	125	401
220	240	166	22	34440	26328	271	115
221	241	111	22	32370	18547	1	120
222	242	165	22	18370	13738	0	231
223	243	179	22	11380	7827	0	176
224	244	301	23	23960	19028	129	703
225	245	304	23	12180	10526	50	754
226	246	306	23	13980	10931	35	301
227	247	196	23	23960	13846	126	556
228	248	199	23	22520	15170	90	736
229	249	197	23	25130	21281	165	1297
230	250	198	23	9590	14694	15	195

231	251	200	23	48440	28138	91	1217
232	252	201	23	20770	16619	89	181
233	253	167	23	15160	14271	125	401
234	254	203	23	18630	15267	95	340
235	256	202	23	14840	14038	7	50
236	257	204	23	42730	15471	94	991
237	258	176	23	16070	12265	22	357
238	259	177	23	19670	13198	46	255
239	260	MISSING	24	15710	MISSING	15	88
240	261	303	24	18490	15385	21	508
241	262	305	24	23300	18421	0	904
242	263	306	24	13470	10931	35	301
243	264	304	24	12180	10526	50	753
244	265	198	24	9590	14694	15	195
245	266	201	24	20770	16619	89	181
246	267	202	24	14840	14038	7	50
247	268	301	25	23910	19028	123	703
248	269	196	25	23960	13846	126	556
249	270	205	25	15660	10729	140	42
250	271	206	25	42200	33198	279	118
251	272	209	25	12560	10526	70	19
252	273	207	25	22130	14980	28	38
253	274	213	25	13920	10931	24	34
254	275	214	25	16310	13158	37	64
255	276	215	25	25000	20972	37	82
256	277	212	25	27840	29838	47	68
257	278	208	25	19950	16194	104	55
258	279	MISSING	26	41460	7085	1	8
259	280	238	26	23070	10688	0	1
260	281	MISSING	26	24620	7287	1	3
261	282	237	26	49740	26721	5	19
262	283	229	26	40390	22267	6	4
263	284	230	26	48680	22308	5	8
264	285	231	26	67870	27854	6	5
265	286	232	26	22430	10121	0	0
266	287	173	27	21770	15535	0	382
267	288	174	27	14490	11419	1	200
268	289	MISSING	27	19950	9577	0	134
269	291	178	27	24320	15023	0	185
270	292	179	27	10870	7827	0	176
271	293	164	27	28250	18421	0	259
272	295	188	27	8010	6559	1	3
273	296	163	27	9340	7745	5	63
274	297	191	27	20190	15605	0	30
275	298	190	27	18130	13387	0	16
276	299	193	27	11900	7692	0	7
277	300	194	27	20700	14413	0	1

	NO-HTWS	DEPTHGWL	MAX-GWL	MAX-FLUC	FLUC-GWL	SP-YIELD	ACTULREC
1	700	4.15	6.20	5.10	2.17	14.000	.714
2	500	4.10	5.50	4.50	2.82	14.000	.630
3	700	3.38	8.50	4.50	2.41	12.000	.540
4	1350	4.03	5.05	5.10	3.12	14.000	.714
5	1350	3.41	4.33	4.10	2.54	12.000	.492
6	2100	3.42	4.24	4.20	2.38	10.000	.420
7	850	3.73	4.32	4.30	2.14	14.000	.602
8	400	4.34	5.15	3.35	2.09	12.000	.402
9	900	2.72	4.28	2.96	2.10	15.000	.444
10	1300	3.24	4.09	3.24	1.70	12.000	.389
11	1500	3.41	4.63	3.85	2.41	12.000	.462
12	1300	3.85	4.14	3.93	1.82	12.000	.472
13	1300	2.72	4.42	3.94	2.26	15.000	.591
14	1550	4.73	3.59	2.79	1.37	8.000	.223
15	1200	3.68	3.68	3.42	2.10	15.000	.513
16	900	3.66	3.66	3.31	2.18	15.000	.497
17	2300	3.66	3.67	3.15	2.06	10.000	.315
18	1700	4.66	4.66	3.93	2.65	10.000	.393
19	1100	4.51	5.01	5.00	4.67	10.000	.500
20	500	4.86	3.61	3.66	1.66	8.000	.293
21	2200	4.77	4.87	3.86	2.38	10.000	.386
22	1750	4.48	4.48	3.30	2.03	12.000	.396
23	1500	3.56	3.56	3.46	2.18	15.000	.519
24	800	3.81	3.81	3.44	2.23	15.000	.516
25	2100	4.12	4.12	3.05	2.04	10.000	.305
26	1700	3.48	4.60	4.17	2.89	8.000	.334
27	1850	3.58	4.87	3.42	2.38	10.000	.342
28	1900	3.23	3.94	3.39	1.93	9.000	.305
29	2100	3.56	5.06	4.03	2.00	7.000	.282
30	300	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
31	1700	4.89	4.89	3.63	2.07	20.000	.726
32	100	MISSING	4.23	MISSING	1.46	MISSING	MISSING
33	1450	6.12	6.12	4.27	3.19	20.000	.854
34	1500	3.89	4.25	3.24	1.92	20.000	.648
35	1300	2.84	4.63	4.15	1.24	7.000	.291
36	1700	4.99	5.25	1.47	3.50	8.000	.118
37	800	2.99	5.01	4.80	3.21	8.000	.384
38	1100	3.13	7.01	5.18	1.80	8.000	.414
39	1600	5.47	5.47	3.33	1.86	15.000	.500
40	850	4.65	4.65	3.91	2.43	8.000	.313
41	1750	7.40	7.40	3.94	1.60	15.000	.591
42	1950	5.48	5.48	3.60	2.30	20.000	.720
43	1150	4.82	4.82	4.07	2.19	20.000	.814
44	800	4.65	4.65	3.91	2.43	8.000	.313
45	1450	5.04	5.04	3.18	2.09	8.000	.254
46	1800	5.03	5.03	4.10	1.90	18.000	.738
47	1200	4.24	4.24	3.40	2.03	20.000	.680
48	500	4.86	4.86	3.66	1.66	8.000	.293
49	2600	4.87	4.87	3.28	1.80	20.000	.656
50	1300	4.98	4.98	3.22	1.26	20.000	.644
51	3000	4.09	4.16	3.45	2.02	20.000	.690
52	1100	4.82	4.82	4.07	2.19	20.000	.814
53	900	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
54	2000	5.54	5.54	4.50	2.46	20.000	.900
55	850	5.96	5.96	3.72	2.54	20.000	.744
56	900	5.80	6.20	4.93	3.72	10.000	.493
57	1000	6.10	6.10	4.30	2.95	9.000	.387
58	900	6.20	6.90	5.60	4.00	12.000	.672
59	1300	6.80	6.85	6.00	3.48	10.000	.600
60	900	4.81	5.62	4.15	1.00	15.000	.623

61	850	5.96	5.96	3.72	2.54	20.000	.744
62	1600	7.84	7.84	5.90	3.72	12.000	.708
63	900	5.80	6.20	4.93	3.72	10.000	.493
64	500	7.54	7.54	6.00	2.98	10.000	.600
65	1400	7.27	7.27	4.70	2.70	14.000	.658
66	1500	5.10	5.63	5.40	3.00	10.000	.540
67	1000	6.10	6.10	4.30	2.95	9.000	.387
68	2700	5.55	5.55	3.46	1.80	15.000	.519
69	650	4.86	4.86	4.36	2.07	9.000	.392
70	520	8.28	8.28	4.83	2.85	9.000	.435
71	1950	6.09	6.09	4.73	2.15	9.000	.426
72	900	4.81	5.62	4.15	1.00	15.000	.623
73	1400	7.27	7.27	4.70	2.70	14.000	.658
74	800	4.85	6.05	5.18	1.66	8.000	.414
75	950	7.75	7.75	4.08	1.50	9.000	.367
76	1300	7.77	7.77	5.50	1.50	10.000	.550
77	1300	5.81	5.89	5.85	2.85	7.000	.410
78	450	5.70	7.00	5.10	3.80	8.000	.408
79	2400	4.49	6.00	5.40	1.40	8.000	.432
80	650	4.86	4.86	4.36	2.07	9.000	.392
81	520	8.28	8.28	4.83	2.85	9.000	.435
82	1100	3.86	4.50	3.00	1.50	6.000	.180
83	700	7.17	7.17	6.13	1.50	7.000	.429
84	2400	8.70	8.70	8.00	1.50	5.000	.400
85	950	6.02	6.20	5.00	1.80	5.000	.250
86	1100	5.21	5.53	3.76	1.60	7.000	.263
87	600	3.29	5.14	6.00	2.22	6.000	.360
88	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
89	3800	6.16	7.76	6.00	2.00	6.000	.360
90	1300	5.81	5.89	5.85	2.85	7.000	.410
91	820	5.89	5.89	5.30	2.20	6.000	.318
92	450	5.70	7.00	5.10	3.80	8.000	.408
93	650	5.70	6.00	4.90	2.37	9.000	.441
94	950	6.02	6.20	5.00	1.80	5.000	.250
95	2300	6.60	7.00	5.30	2.90	10.000	.530
96	2550	6.80	6.85	6.00	3.48	10.000	.600
97	1750	6.20	6.90	5.60	4.00	12.000	.672
98	850	6.00	6.00	4.72	3.00	12.000	.566
99	720	10.06	10.86	5.50	2.00	5.000	.275
100	1100	19.50	10.23	11.80	5.90	3.000	.354
101	600	12.86	12.86	8.20	4.56	3.000	.246
102	1000	11.69	11.69	5.08	1.70	5.000	.254
103	2700	4.93	5.11	5.72	1.90	5.000	.286
104	1200	7.01	7.15	6.78	3.50	5.000	.339
105	1150	9.19	9.19	4.76	1.80	5.000	.230
106	950	4.90	8.84	6.14	3.50	5.000	.307
107	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
108	850	7.23	7.23	5.50	3.10	5.000	.275
109	1250	7.00	7.00	5.23	1.88	5.000	.262
110	1250	6.48	6.48	6.20	2.82	5.000	.310
111	1800	7.04	7.04	6.60	2.20	5.000	.330
112	2550	4.20	4.24	3.94	1.28	5.000	.197
113	2650	8.50	8.50	6.20	1.20	5.000	.310
114	2400	4.49	6.00	5.40	1.40	8.000	.432
115	1150	9.19	9.19	4.76	1.80	5.000	.230
116	1650	4.84	6.52	5.70	2.60	6.000	.342
117	1100	5.86	7.00	5.62	1.88	5.000	.281
118	1100	5.21	5.53	3.76	1.61	7.000	.263
119	600	3.29	5.14	6.00	2.22	6.000	.360
120	2000	2.46	6.14	5.18	1.89	8.000	.414

121	850	5.89	5.89	5.50	2.20	6.000	.330
122	1650	6.48	7.08	6.32	3.94	7.000	.442
123	1500	5.11	5.56	4.50	1.80	6.000	.270
124	1350	6.10	6.40	5.08	2.12	8.000	.406
125	800	6.00	6.10	4.46	1.87	9.000	.401
126	2000	6.00	6.10	5.05	2.12	8.000	.404
127	1800	6.50	6.78	6.78	2.68	8.000	.542
128	1550	6.50	7.05	5.75	3.29	8.000	.460
129	1925	6.10	7.42	6.10	4.10	7.000	.427
130	1450	7.00	7.42	6.10	5.56	8.000	.488
131	650	5.70	6.09	4.90	2.37	9.000	.441
132	1300	6.70	6.70	4.40	1.65	20.000	.880
133	350	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
134	900	4.22	4.22	3.05	2.68	9.000	.275
135	600	4.73	5.03	4.65	2.07	4.000	.186
136	900	4.52	6.00	5.56	2.22	5.000	.278
137	630	5.00	6.15	5.52	2.50	5.000	.276
138	300	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
139	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
140	450	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
141	1150	6.14	6.14	4.10	1.83	20.000	.820
142	704	5.77	5.77	5.30	2.00	15.000	.795
143	800	4.44	7.66	4.29	2.97	5.000	.215
144	950	4.20	4.66	4.29	1.82	4.000	.172
145	850	2.80	5.45	3.00	1.27	5.000	.150
146	300	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
147	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
148	450	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
149	1300	6.70	6.70	4.40	1.65	20.000	.880
150	1450	4.85	4.85	4.85	2.58	12.000	.582
151	350	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
152	900	4.22	4.22	3.05	2.68	9.000	.275
153	1600	6.69	6.69	4.34	2.10	10.000	.434
154	704	5.77	5.77	5.30	2.00	15.000	.795
155	950	3.71	3.71	3.71	2.65	8.000	.297
156	900	4.22	4.22	3.05	2.68	9.000	.275
157	2800	5.62	6.09	5.10	2.20	5.000	.255
158	600	4.73	5.03	4.65	2.07	4.000	.186
159	630	5.00	6.15	5.52	2.50	5.000	.276
160	1200	4.40	6.20	2.57	2.54	4.000	.103
161	2500	4.50	5.70	3.80	2.21	3.000	.114
162	324	3.00	3.20	2.50	2.35	3.000	.075
163	375	4.91	4.93	4.45	3.50	3.000	.134
164	1300	4.70	5.33	4.80	2.50	4.000	.192
165	750	6.50	6.57	2.30	2.00	4.000	.092
166	324	3.00	3.20	2.50	2.35	3.000	.075
167	750	4.80	5.37	4.41	2.00	3.000	.132
168	650	2.80	5.25	4.40	2.54	3.000	.132
169	400	4.30	5.00	4.42	2.12	2.000	.088
170	440	2.35	5.44	3.65	3.66	3.000	.110
171	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
172	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
173	670	2.37	2.41	2.30	2.30	3.000	.069
174	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
175	400	4.30	5.00	4.42	2.12	2.000	.088
176	750	4.80	5.37	4.41	2.00	3.000	.132
177	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
178	0	MISSING	2.41	MISSING	1.30	MISSING	MISSING
179	650	2.30	3.61	2.83	1.89	3.000	.085
180	750	4.91	4.93	4.45	3.50	3.000	.134

181	600	4.37	4.65	4.25	1.89	3.000	.128
182	600	4.10	4.35	3.23	1.80	3.000	.097
183	600	4.00	4.67	4.09	2.45	3.000	.123
184	900	6.39	6.78	3.00	2.50	3.000	.090
185	1100	4.31	5.13	3.00	2.00	4.000	.120
186	780	5.00	4.93	3.07	3.50	4.000	.123
187	1300	5.36	5.36	4.60	2.00	4.000	.184
188	530	4.13	4.13	MISSING	1.54	3.000	MISSING
189	1300	3.71	3.89	3.10	1.27	3.000	.093
190	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
191	1300	3.37	4.28	3.36	1.52	4.000	.134
192	3000	4.91	MISSING	4.52	MISSING	5.000	.226
193	1600	3.03	4.93	2.65	1.19	5.000	.133
194	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
195	2000	2.87	5.00	4.35	.92	4.000	.174
196	950	4.54	5.17	3.88	1.83	4.000	.155
197	800	5.37	6.34	4.30	1.70	4.000	.172
198	650	2.30	3.61	2.83	1.89	3.000	.085
199	1400	4.90	5.86	3.02	2.62	3.000	.091
200	1100	4.50	6.34	4.68	2.50	4.000	.187
201	1300	4.50	4.50	2.67	2.24	3.000	.080
202	550	4.31	5.13	3.00	2.00	4.000	.120
203	375	4.91	4.93	4.45	3.50	3.000	.134
204	1300	5.36	5.36	4.60	2.00	4.000	.184
205	2100	5.81	5.81	3.43	3.00	5.000	.172
206	1800	3.87	3.87	3.48	2.17	4.000	139
207	1850	4.93	6.80	6.00	4.53	4.000	240
208	1320	6.36	6.36	4.95	3.35	3.000	149
209	620	6.56	6.50	4.67	2.12	4.000	.187
210	1310	6.00	6.72	3.11	2.30	4.[illegible]	24
211	2350	8.19	8.19	4.11	2.84	4.000	.164
212	1600	7.75	7.75	5.80	4.02	5.000	290
213	1320	6.36	6.36	4.95	3.35	3.000	49
214	1300	6.87	6.87	4.05	2.76	4.000	.162
215	1600	8.19	8.19	5.00	3.90	4.000	.200
216	450	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
217	850	4.82	6.00	4.00	2.00	8.000	.320
218	1020	6.14	11.53	5.26	1.65	8.000	.421
219	882	7.13	7.13	4.75	3.47	8.000	.380
220	1600	6.24	6.24	5.58	4.18	5.000	.279
221	1600	4.15	4.50	2.60	1.50	8.000	.208
222	2100	5.55	5.55	4.29	2.62	5.000	.215
223	725	5.15	6.15	6.00	2.64	8.000	.480
224	1200	5.55	5.55	3.72	2.02	15.000	.558
225	704	5.77	5.77	5.30	2.00	15.000	.795
226	714	4.53	4.53	4.50	1.50	20.000	.900
227	1000	6.90	7.00	3.90	1.80	7.000	.273
228	900	4.82	6.00	4.00	2.00	8.000	.320
229	1900	5.30	5.30	4.40	2.00	15.000	.660
230	60	3.83	6.02	5.00	1.32	10.000	.500
231	2200	5.40	6.07	4.47	1.60	10.000	.447
232	1050	4.00	5.50	4.40	2.00	10.000	.440
233	882	7.13	7.13	4.75	3.47	8.000	.380
234	1020	6.14	11.53	5.26	1.65	8.000	.421
235	950	5.00	5.51	4.50	1.40	10.000	.450
236	1250	MISSING	6.14	4.29	2.46	7.000	.300
237	1300	9.11	9.11	5.56	3.40	8.000	.445
238	1200	6.97	6.97	5.84	2.92	7.000	.409
239	450	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
240	1100	6.14	6.14	4.10	1.83	20.000	.820

241	1100	5.31	5.31	3.48	1.73	20.000	.696
242	720	4.53	4.53	4.50	1.50	20.000	.900
243	700	5.77	5.77	5.30	2.00	15.000	.795
244	60	3.83	6.02	5.00	1.32	10.000	.500
245	1050	4.00	5.50	4.40	2.00	10.000	.440
246	950	5.00	5.51	4.50	1.40	10.000	.450
247	1200	5.55	5.55	3.72	2.02	15.000	.558
248	1000	6.90	7.00	3.90	1.80	7.000	.273
249	800	4.44	7.66	4.29	2.97	5.000	.215
250	2100	4.74	5.76	4.81	1.84	5.000	.241
251	950	4.20	4.66	4.29	1.82	4.000	.172
252	620	6.56	6.45	4.67	2.12	4.000	.187
253	804	2.80	5.46	3.00	1.27	5.000	.150
254	930	4.54	5.17	3.88	1.83	4.000	.155
255	2200	4.60	5.14	4.50	1.78	4.000	.180
256	1600	2.60	5.05	3.00	2.59	5.000	.150
257	1300	6.00	6.72	3.11	2.30	4.000	.124
258	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
259	881	4.07	3.30	3.30	1.88	3.000	.099
260	0	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
261	1300	3.89	4.97	2.65	1.52	4.000	.106
262	650	4.70	4.70	4.24	2.17	3.000	.127
263	1100	3.61	5.45	2.96	1.60	3.000	.089
264	1500	4.47	4.47	3.25	1.71	3.000	.098
265	800	4.37	5.08	3.31	1.64	3.000	.099
266	1800	5.69	5.69	4.52	3.05	8.000	.362
267	1000	7.68	7.68	5.41	3.03	8.000	.433
268	750	MISSING	MISSING	MISSING	MISSING	MISSING	MISSING
269	.300	5.66	6.66	6.00	2.90	8.000	.480
270	720	5.15	6.15	6.00	2.64	8.000	.480
271	1600	5.63	5.63	4.41	2.88	5.000	.221
272	800	4.17	4.17	2.64	2.23	4.000	.106
273	1050	4.73	4.73	4.91	2.27	5.000	.246
274	2500	5.31	5.31	2.68	2.23	6.000	.161
275	1300	4.80	4.80	3.73	2.02	5.000	.187
276	1400	2.24	2.24	2.06	1.90	5.000	.103
277	1600	4.78	4.78	2.50	1.92	6.000	.150

Data Notes

Definition of Data Fields

SERNO - Serial number for internal identification

KARIMNO - Number used to identify data from Karim (1984)

WATBASIN - Water basin based on UNDP divisions (Appendix III)

TOTAREA - Total area of upazila in hectares

CULTAREA - Total area presently cultivated in hectares

NO-DTWS - Number of DTWs

NO-STWS - Number of STWs

NO-HTWS - Number of HTWs

DEPTHGWL - Depth to GWL from average ground level - April-May, 1983 (meters)

MAX-GWL - Maximum GWL ever recorded

MAX-FLUC - Maximum fluctuation between the highest GWL ever recorded and the lowest GWL (meters)

FLUC-GWL - The fluctuation between the highest GWL and that of the water level in the last week of December. For the districts of Dhaka, Mymensingh, Kishoreganj, Moulavibazar, Sunamganj, Sylhet, Comilla, Brahmanbaria and Chandpur, FLUC-GWL is the maximum fluctuation between GWL in the last week of December and the lowest GWL in the months of April to June (meters)

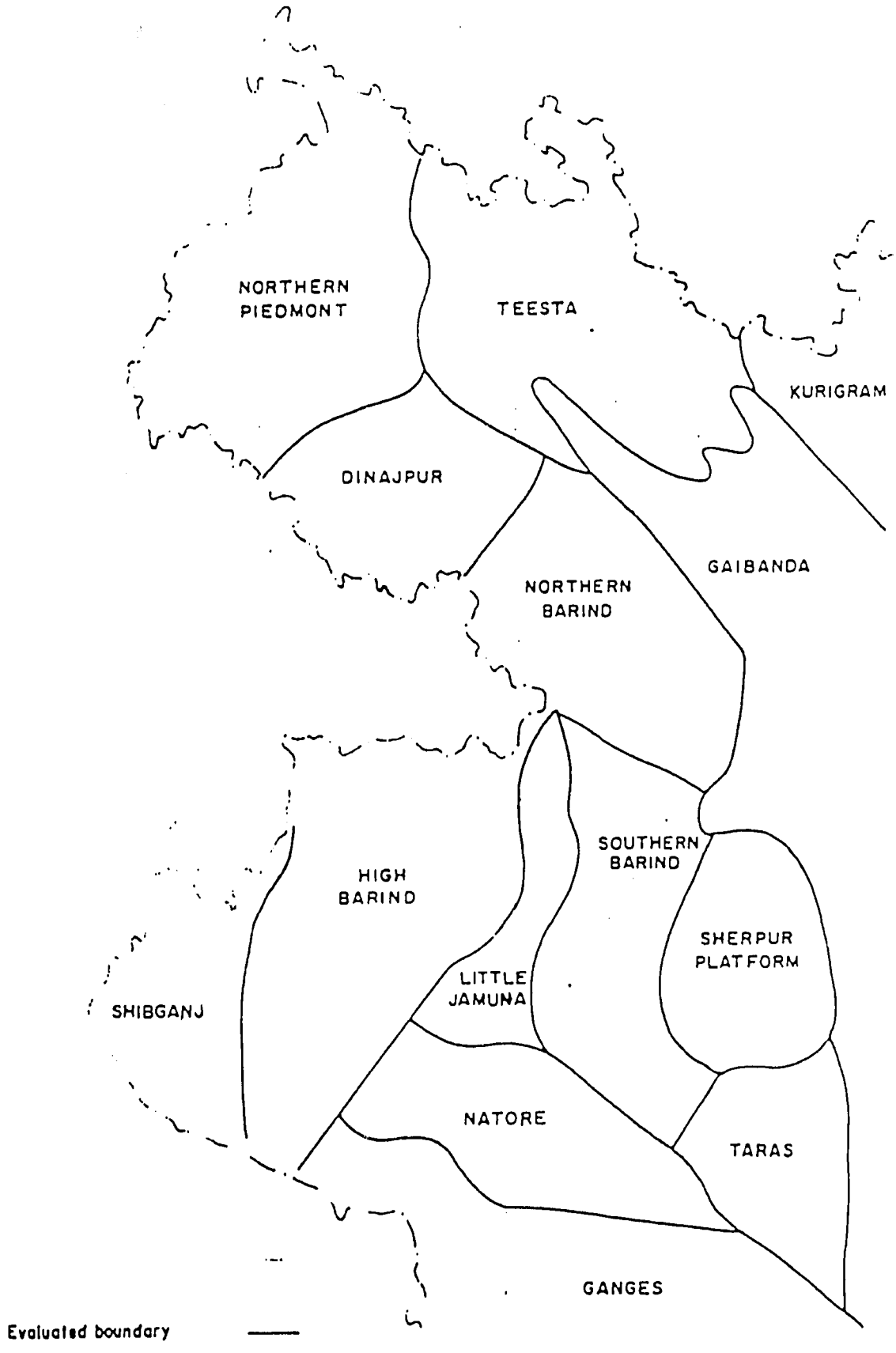
SP-YIELD - The specific yield in percent (%)

ACTULREC - Actual recharge is the specific yield converted to decimals multiplied by the MAX-FLUX (meters)

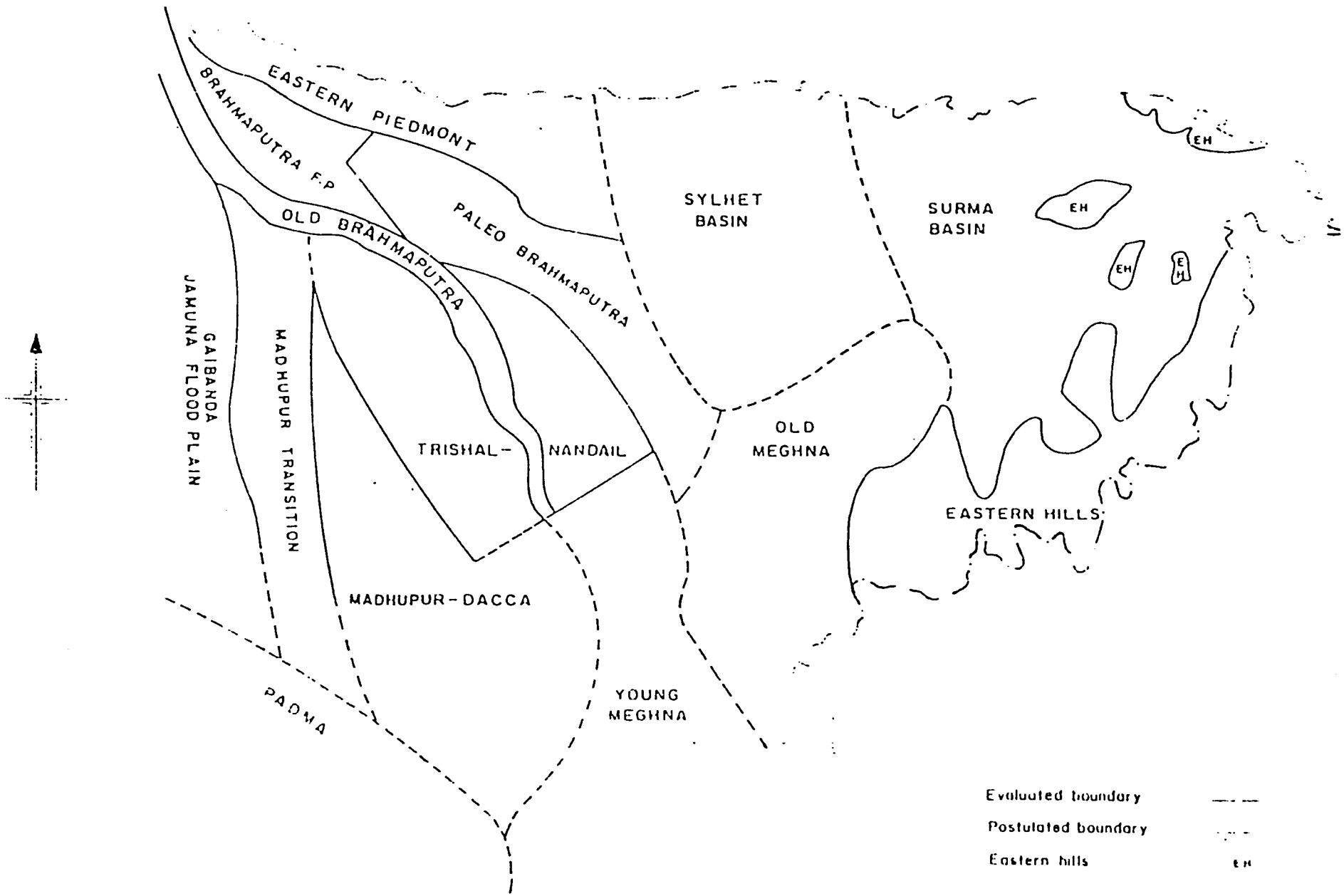
AVAILREC - Available recharge can be calculated by multiplying the specific yield converted to decimals times FLUC-GWL and subtracting from ACTULREC. However, for the above mentioned districts, Karim calculated available recharge by multiplying specific yield in decimals by FLUC-GWL. (meters)

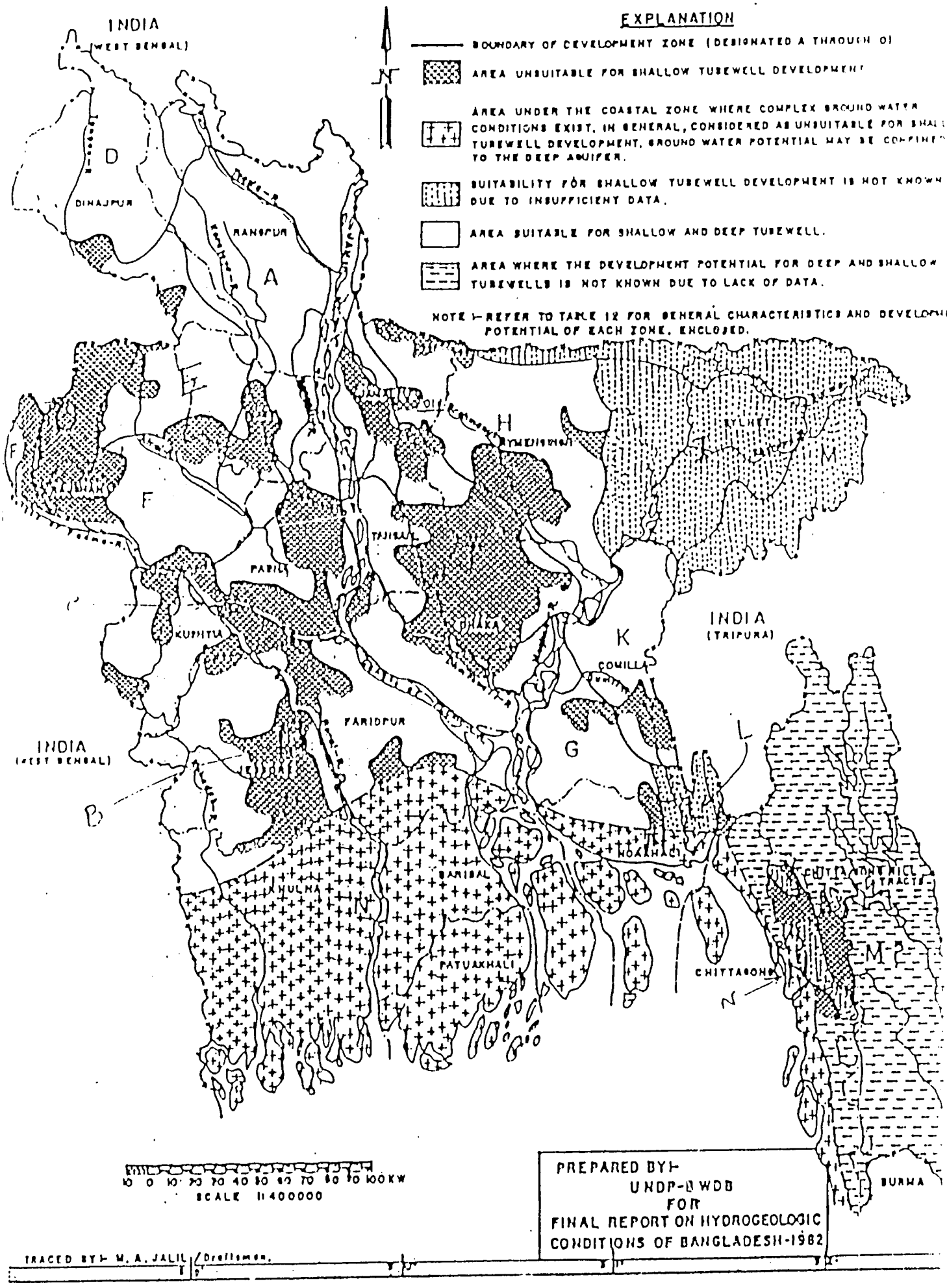
Some upazilas, where appropriate, have been split in half to reflect the fact that half the area is good for STWs and half for DTWs. However, depending upon the location of the observation well, the technical coefficients are biased toward one or the other.

AQUIFER UNITS
NORTHWEST REGION



NORTHEAST REGION




EXPLANATION
BOUNDARY OF DEVELOPMENT ZONE (DESIGNATED A THROUGH O)
AREA UNSUITABLE FOR SHALLOW TUBEWELL DEVELOPMENT
AREA UNDER THE COASTAL ZONE WHERE COMPLEX GROUND WATER CONDITIONS EXIST, IN GENERAL, CONSIDERED AS UNSUITABLE FOR SHALLOW TUBEWELL DEVELOPMENT. GROUND WATER POTENTIAL MAY BE CONFINED TO THE DEEP AQUIFER.
SUITABILITY FOR SHALLOW TUBEWELL DEVELOPMENT IS NOT KNOWN DUE TO INSUFFICIENT DATA.
AREA SUITABLE FOR SHALLOW AND DEEP TUBEWELL.
AREA WHERE THE DEVELOPMENT POTENTIAL FOR DEEP AND SHALLOW TUBEWELLS IS NOT KNOWN DUE TO LACK OF DATA.
NOTE :- REFER TO TABLE 12 FOR GENERAL CHARACTERISTICS AND DEVELOPMENT POTENTIAL OF EACH ZONE, ENCLOSED.
INDIA
(WEST BENGAL)
INDIA
(TRIPURA)
INDIA
(WEST BENGAL)
BURMA
DINAJPUR
RANGPUR
TAJIRHAT
PABNA
KUSHTIA
DHAKA
COMILLA
FARIDPUR
KHULNA
BARISAL
PATUAKHALI
NOAKHALI
CHITTAGONG
SYLHET
D
A
E
F
H
K
G
L
M
B
N
10 0 10 20 30 40 50 60 70 80 90 100 KM
SCALE 1:400000
PREPARED BY:-
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