BANGLADESH RURAL WATER SUPPLY
AND
ENVIRONMENTAL SANITATION PROGRAMME

THE BRIDGING OPERATION
DPHE/UNICEF/DANIDA

FINAL REPORT
HYDROGEOLOGICAL STUDIES

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1. INTRODUCTION AND ACKNOWLEDGEMENTS.

As a part of governmental co-operation agreement between Bangladesh and Denmark a DANIDA team consisting of a Water Engineer a Sociologist and Hydrogeologist (the writer of this report) was selected to assist DPHE and UNICEF in a number of activities relevant for development of strategies for the Third Five Years Plan within the field of rural water supply.

This report describes the Hydrogeological Studies carried out from January 1984 until December 1985.

The emphasis in this report is placed on the major task of the Hydrogeologist - Mapping of Deepset Areas.

The other large task - investigations of the sline belt, has already been described in "Pilot Study on fresh water resources in the coastal belt of Bangladesh", September 1985, a report prepared jointly by J.S. Rus, IWACO hydrogeologist and the writer.

One Inception Report and two Bi-Annual Reports have been prepared during January 1984 - February 1985 period where progress of work and revised work plans have been presented.

One technical note: "TARA Pump, Bangladesh Type, Evaluation of Limiting Conditions" was submitted in July 1984.

It is assumed, that the reader of the Final Report is either familiar with the above mentioned documents of can refer to them if needed; therefore unnecessary repetitions were avoided.

The writer greatly appreciate the invaluable assistance provided by the DPHE personnel at all levels, and the UNICEF's contribution mainly with respect to logistic support and technical assistance. Without the good spirit of co-operation between DPHE, UNICEF and DANIDA the Hydrogeologist's work would be much more difficult and definitely less enjoyable.

The positive role of MPO, has to be emphasized. The writer had practically unlimited access to MPO's computer facilities until the DPHE's computer was procured. The deepset area maps were drawn by MPO's draftsmen on the MPO's base map. The major part of input data was either directly copied from the MPO's data base or based on MPO's files.
The close co-operation primarily with the Groundwater Section of MPO had definitely positive impact on the outcome of the Hydrogeological Studies.

The last major contribution to the Hydrogeological Studies was the Ground Water Investigation Circle of BWDB. Without their water level Hydrographs the whole task would be much more difficult, if not impossible.

2. HYDROGEOLOGICAL STUDIES: OBJECTIVES, STATUS AND FUTURE.

2.1 TERMS OF REFERENCE.

The Terms of Reference for the Hydrogeologist specifies, that his major task is: "to collect and collate data to determine which areas of Bangladesh will require handpumps needing to operate near or beyond the barometric limit"; these areas are in the report called deepset areas.

The other duties listed in the TOR were:

- assessment of groundwater resources available for drinking water supply,

- investigation of groundwater quality,

- assistance in pollution studies,

- creation of data bank at DPHE,

- examination of need for laboratories and trained laboratory staff.

It was understood from the beginning, that TOR provides a framework and that an adjustment and alteration of duties can be made if the need arises.

The comments to the duties specified in the TOR for Hydrogeologist in relation to the work actually done are summarized below.

Deepset areas.

In agreement with the TOR this has been the major task for the Hydrogeologist and a major part of time was devoted to it.

Assessment of groundwater resources.

Groundwater resources for drinking water supply can be limited in three cases:

- if fresh groundwater is not available within accessible depth (coastal belt),

- if the quality of groundwater is poor or unacceptable (iron problem) or

- if the pump technology is inappropriate for a deep water table (deepset areas).

In agreement with the TOR, major effort was directed toward assessment of two out of these limitations: salinity in the coastal belt and depth to water table (deepset area).

Investigation of groundwater quality.

It was agreed to give this task lower priority because the only water quality problem of regional extent - the iron problem - was dealt with under R&D activities. Other water quality problems are either restricted to few pocket areas or are not regarded as major ones.

Pollution study.

No assistance was requested for this task.

DPHE's data bank.

Considerable amount of data is already stored on the computer and it is planned to extend the data bank to include new types of data.

Need for laboratories.

This subject is adequately covered within Bangladesh - Netherlands co-operation.

2.2 MAJOR TASKS.

The major part of time of the Hydrogeologist was devoted to two tasks: deepset area mapping and coastal belt investigations (salinity problem).

It is not easy to decide which one of these problems is more serious. Normally, scarcity of drinking water of acceptable quality in the coastal areas is regarded as a main cause of water-borne diseases. However, the problems connected with lowering of the water table and drying-up of the HTWs may be even more serious for two reasons: it is a new phenomenon and the affected people are not accustomed to deal with it and, in many places, no alternative water sources are available within reasonable distance; the ponds are not so common in the present and the future deepset areas as it is the case in the coastal belt.

It is widely agreed (DPHE, UNICEF and DANIDA) that both tasks should have top priority.

It is the writer's opinion, that in spite of the substantial progress made during the last two years toward solution to both problems, there is still a lot of work to be done.

2.2.1 Deepset areas.

An estimate of the magnitude of this problem (geographically and population-wise) for the present situation and for the future is made. This estimate gives planners the possibility to determine the targets for TARA pump production figures and helps to determine which areas of Bangladesh are already within the deepset category and which areas will fall into this category in the future.

The results of Hydrogeological Studies are well suited for macro-planning, but their usefulness for micro-planning, like for example establishing priorities with regard to deployment of TARA pump to individual Upazillas and within these Upazillas, is limited. This limitation is caused by:

- varying quality of data used for the mapping,
- uncertainty with regard to future projection of groundwater withdrawal and
- the degree of resolution of the result.

The map of the present and the future deepset areas should be verified when new (or improved) data become available. Particularly monitoring of water level on a permanent basis would be extremely valuable.

2.2.2 Coastal belt.

An assessment of fresh water resourced and solution of drinking water supply problem in the coastal belt is at preliminary stage.

Unlike the major part of Bangladesh, where good quality groundwater is easily accessible within shallow depth, the coastal belt is a difficult area from water supply point of view.

The difficulty is caused by poor bacteriological quality, as unprotected ponds are the most common sources of drinking water, rather than fresh water availability.

To fulfill the objective - safe water for all - considerable efforts have to be made in the coastal area.

Three tasks need to be carried out in order to achieve an improvement of drinking water supply in the coastal belt:

- development of methodology for investigations and mapping of fresh water resources,

- assessment of water resources and preparation of proposals for optimal water supply systems for the individual coastal Upazillas,

- technologies appropriate for different hydrogeological conditions.

At present, the first task - development of methodology - is finished and DPHE is in the process of carrying out the two remaining tasks.

It should be expected, that 3 years from now a clear picture of the water supply situation in the coastal belt will be available. Already now it can be predicted, that the cost of safe drinking water in these areas will be substantially higher than for the rest of Bangladesh; therefore careful analysis of alternative sulutions is necessary.

3. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.

A summary of the results of the Hydrogeological Studies (including some of the essential assumptions) together with the derived conclusions and recommended future activities are presented under three headings:

- Deepset Areas
- Coastal Belt and
- DPHE's Computer Centre

3.1 DEEPSET AREAS.

Summary and conclusions.

1.1 Delineation of the deepset areas of Bangladesh - areas where suction mode handpumps are not adequate to ensure dry season domestic water supply for the rural population - was made; 14 out of the 20 old districts were analysed.

1.2 Two deepset area maps were produced: the first (November 1984) drawn on the basis of the BWDB's hydrogeological network and the second (December 1985) on the basis of the same network, but using an Upazilla as a basic unit. The first map was based primary on these observation wells for which correct coordinates were available while the second map is based on all usable observation wells.

1.3 The second map shows both the present deepset areas and the areas which may/will become deepset in the future.

1.4 The predictions regarding extent of the future deepset areas are based on computer modelling of the effect, which an expected increase of groundwater withdrawal for irrigation will have on the water table.

1.5 It is assumed, that the expansion of irrigated areas will take place in three five-year periods: 1985-90, 1990-1995 and 1995-2000.
At the end of the last period, the percentage of irrigated areas will become 75 - 85 as compared to present 10 - 50%.

1.6 The extent of deepset areas and the number of people affected (1985 population figures) were calculated for each phase of irrigation development:

1985 - 7 million people affected
1990 - 17 " " "
1995 - 50 " " "
2000 - 66 " " "

If the expansion of irrigated areas is carried out as assumed, practically all the districts without salinity constrains will fall into the deepset area category by the year 2000 (except for parts of Rangpur and Dinajpur).

1.7 For a number of Upazillas there is a certain amount of data inconsistency, which reduces confidence to future deepset area predictions for these Upazillas.
A procedure is described for adjustment of the inconsistent data.

N.B. For most of the country it will not be possible to achieve the close to maximum percentage of irrigated areas (phase 3, 1995 - 2000), without severe reduction of dry season river flow. Therefore it is unlikely, that phase 3 will be implemented.

Regarding continuation of the deepset area-related activities it is <u>recommended</u> that:

1.8 The Upazillas for which data inconsistency has been dicovered are screened for input errors.

1.9 The data inconsistency is removed by using the procedure described in the report.

1.10 The computer model is re-run with the consistent input data.

N.B. Activities proposed under 1.8 -1.10 should be coordinated with organizations providing the input data (MPO and agricultural organizations).

1.11 DPHE establishes groundwater level monitoring network with the purpose to provide in early warning about lowering of the water table and to check and verify the predictions of the computer model.

1.12 DPHE maintains groundwater level data base and publishes these data.

1.13 DPHE coordinates water level monitoring activities with BWDB. Regular exchange of data between DPHE and BWDB would be beneficial for both parties and additional work involved in this excercise would be minimal, as both organizations use the same type of computer for data storage and processing.

3.2. COASTAL BELT

The investigations of the coastal belt of Bangladesh, initiated in February 1985, are described in several progress reports and summarized and evaluated in the "Pilot Study on fresh water resources in the coastal belt of Bangladesh", IWACO, September 1985. The IWACO report was prepared by J.S. Rus - IWACO's hydrogeologist and by the writer of this report. For a comprehensive description of these investigations a reference to the IWACO report has to be made.

In this report, only short summary of events related to the Hydrogeological Studies within the Bridging Operation and selected general conclusions and recommendations will be given.

<ins>Summary.</ins>

2.1 The need for conducting special invèstigations in the unserved/underserved coastal Upazillas was recognized long time ago. A pilot study of groundwater supply system was proposed in March 1984: "R&D Activity, VSST and Estimation of the Groundwater Resources in the Coastal Zone", E. Gosk, 21.3.1984.

2.2 Launching of such a pilot study was postponed until evaluation of two "Crash Programmes on VSSTs" (Very Shallow Shrouded Tubewells) selected coastal Upazillas.

2.3 The Crash Programmes provided valuable information about the investigated areas but did not give guide-lines for investigations of the saline belt. The need for an alternative approach was recognized.

2.4 In February/March 1985 a study with the primary objective to indentify suitable methods for mapping of VSST-feasible areas was initiated by the R&D Committee. The proposal for this investigation and the field work was done by a team consisting of DPHE engineers, IWACO consultant and the writer.

Considerable support and assitance during project formulation and mainly during field work was provided by UNICEF. The field work continued from the end of February until the beginning of May and the Final Report was made in September 1985.

Conclusions.

2.5 The hydrogeological conditions in the coastal areas varies considerably within short distance.

2.6 A wide range of investigation methods is required for an evaluation of fresh water resources in these areas.

2.7 A large amount of information is already available, but there is a need to organize this information in a way suitable for an essessment of drinking water resources.

2.8 An assessment of drinking water resources should consist of desk study and field investigations.

2.9 The major components of desk study should consist of preparation of Upazilla maps - topographical maps 1:50,000 with Upazilla and Union boundaries and with tubewell information added to the map. There should be one map for every coastal Upazilla. The desk study should end with formulation of a number of questions which have to be answered through field investigations and the field investigations should be planned accordingly.

2.10 The field investigations should consist of:

- inspection of characteristic parts of Upazilla (old and new areas, lower and higher lying areas, flooded and non-flooded areas, tubewell successful and tubewell unsuccessful areas, etc.).

- collecting information about water use pattern,

- conducting geoelectrical surface measurements at selected locations,

- collecting representative number of conductivity measurements, both for surface and groundwater,

- drilling of shallow and/or very shallow test tubewells for verification of the geoelectrical measurements and for groundwater quality determination.

2.11 The information obtained during field investigations should be added to the previously prepared Upazilla Maps.

2.12 Following alternative water supply systems for coastal Upazillas should be analyzed: VSSTs, sand filters, deep tubewells, protected/ unprotected ponds and artificial tanks for rain water collection. A catalog describing these water supply systems with respect to price, number of users, quality of water, reliability, maintenance etc. should be prepared.

2.13 The assesment of fresh water resources together with the above mentioned catalog of alternative solution should be used to propose the optimal type of drinking water supply system for each Upazilla.

<u>Recommendations</u> .

2.14 The work initiated by the recent Coastal Belt Investigation should continue along the guide-lines described in this report and the "Pilot Study" report.

2.15 An attempt to finish the mapping excersise within the next 2 - 3 years using the expertise available at DPHE (at least for the major part of work) will require almost full time involvement of 2 - 3 engineers (preferably familiar with this work). Therefore it is recommended, that the necessary personnel is assigned for this task.

3.3 DPHE's COMPUTER CENTER

Summary and conclusions.

3.1 The computer centre was inaugurated by the Minister on October 1st, 1985.

3.2 The centre was created on request from the management of DPHE with support from UNICEF/DANIDA.

3.3 The computer equipment was taken over from the Hydrogeological Study task.

3.4 There are three main objectives for the computer centre:

- to improve the quality of periodical reports to the government,
- to establish and maintain DPHE's data base and,
- to enable DPHE to perform new tasks requiring use of computers (continuation of deepset area task, piped water supply calculations, DPHE's Hydrogeological Monitoring Network, etc.).

3.5 An introductory computer training (3 months) for ten DPHE's engineers was conducted at BUET.

3.6 A three month intermediate level training for 5-7 persons was provided by an individual trainer at DPHE's computer centre.

3.7 An additional course of 3 months duration, primarily for two system managers, is being carried out by an individual trainer.

3.8 It can be concluded, that DPHE's computer centre has been started in a proper way and the necessary conditions for an efficient running of the centre are created.

Recommendations.

3.9 The positive attitude of the management toward training of the younger engineers should continue.

3.10 One of the two system managers should alway be present at the centre to prevent an unauthorized use of the facilities and reduce possibility for damage of the equipment.

3.11 Further software development should be encouraged.

3.12 Closer co-operation with other organizations, particularly those using the same type of computer - MPO, BWDB -- should be established.

3.13 A permanent information channel to the senior staff of DPHE should be established.
A monthly "Newsletter", describing recent software development, would enable the management to judge the centre's ability and give guide-lines for future development. The system manager(s) should be in charge of this task.

4. DEEPSET AREA MAPPING

Deepset Areas can be defined as areas where hand tubewells of suction type can not be used as means of water supply for the rural population.

It was chosen to select an Upazilla as the basic unit and all calculations refer to the Upazillas. Only one value of each parameter is chosen as valid for the Upazilla.

An Upazilla is included in the deepset category if one or more of the Water Level Hydrographs (WLH) show more than 8m to water table; therefore it should be expected that the extent of deepset areas is overestimated.

An attempt was made to predict the future extent of deepset areas by assuming an increase of groundwater withdrawal in three phases:

- phase 1 where 25% of the Net Cropped Area (NCA) which presently is not irrigated is brought under irrigation,
- phase 2 where this percentage is 50 and,
- phase 3 where this percentage is 75.

The coastal areas of Bangladesh consisting of Khulna, Barisal, Patuakhali, Noakhali and Chittagong (old districts) are not included in the mapping exercise for two reasons:

- it is unlikely that these areas may become deepset areas due to salinity constraint on irrigation development,
- the model applied for prediction of the future deepset areas is not valid if deep aquifer (the only substantial groundwater source in these districts) is used for irrigation.

The last district not included in the analysis is Chittagong Hill Tracks. The topography of this district precludes any meaningfull mapping without an adequate contour map. It may be assumed that, except the valleys and locations close to and at the level of permanent water bodies, the district can be regarded as deepset area.

The description of the deepset area mapping exercise is divided into 6 parts:

- chapter 4.1 where the purpose is outlined,

- chapter 4.2 where principles for delineation of the present deepset areas are given,

- chapter 4.3 where the methodology for calculation of the future water table are described,

- chapter 4.4 where the results of calculations are presented,

- chapter 4.5 where all the data used in analysis are described and characterized and,

- chapter 4.6 where ways of improvement of the future deepset area map are suggested.

Chap. 4.1, 4.2 and 4.4 are of general interest, while chap. 4.3, 4.5 and 4.6 contain details essential for an understanding of the applied methodology and for future work with deepset areas.

4.1 PURPOSE

The main purpose of the mapping excercise was to provide DPHE and UNICEF with an assessment of the present deepset areas and with prediction about future increase of these areas. A lot of resources have to be mobilize and it requires good ahead planning to meet the demand of rural population facing severe water supply problems caused by lowering of the dry season water table.

Therefore it is necessary to have an estimate of the present and the future deepset areas.

4.2 PRESENT SITUATION.

In November 1984 a map showing the extent of Present Deepset Areas was prepared (Annex 1). The criterion for classifying an area as deepset type (Annex 1) was minimum water level of more than 7.75 m.b.s. occurring within the whole period for which the Water Level Hydrograph (WLH) was recorded; erroneous and unexplainable records were excluded from the analysis.

The approach in this report is different. An Upazilla is chosen as a basic unit and one set of parameters is assumed to be valid for the whole Upazilla. The most unfavourable water table conditions (maximum depth to water) are assumed representative for Upazilla, provided that the most unfavourable WLH is not significantly different from the other WLHs of this Upazilla.

The Upazilla is classified as deepset if the assigned maximum depth to water table is greater than 8m.

For Upazilla without any reliable WLHs, an interpolation based on values from the surrounding Upazillas and the knowledge of the hydrogeological situation was made.

The extent of present deepset areas on the Upazilla basis is shown on the Map, Annex 2.

4.3 FUTURE DEEPSET AREAS, METHODOLOGY.

Prediction of the future extent of deepset areas is dependent on the development of agriculture. An increase of irrigated areas will create increased withdrawal of groundwater and lowering of the dry season water table.

In this chapter the principles for transferring the increased water withdrawal into expected water table maps is described.

As always, when the hydrogeological modeling is concerned, the quality of the data is essential for the confidence to the simulation results. The discussion of data quality and representativeness is done in chapter 4.5 and here only the principles of the model are presented

4.3.1 Water balance.

Setting up a water balance is a widely used method for analysis of hydrogeological systems.

The components of the water balance are shown on fig.4.1 and are described by equations 1-4.

The general form of the water balance equation is:

water in = water out + change of storage(1)

Using the symbols defined on fig.4.1, the water balance equations for different times of the year becomes:

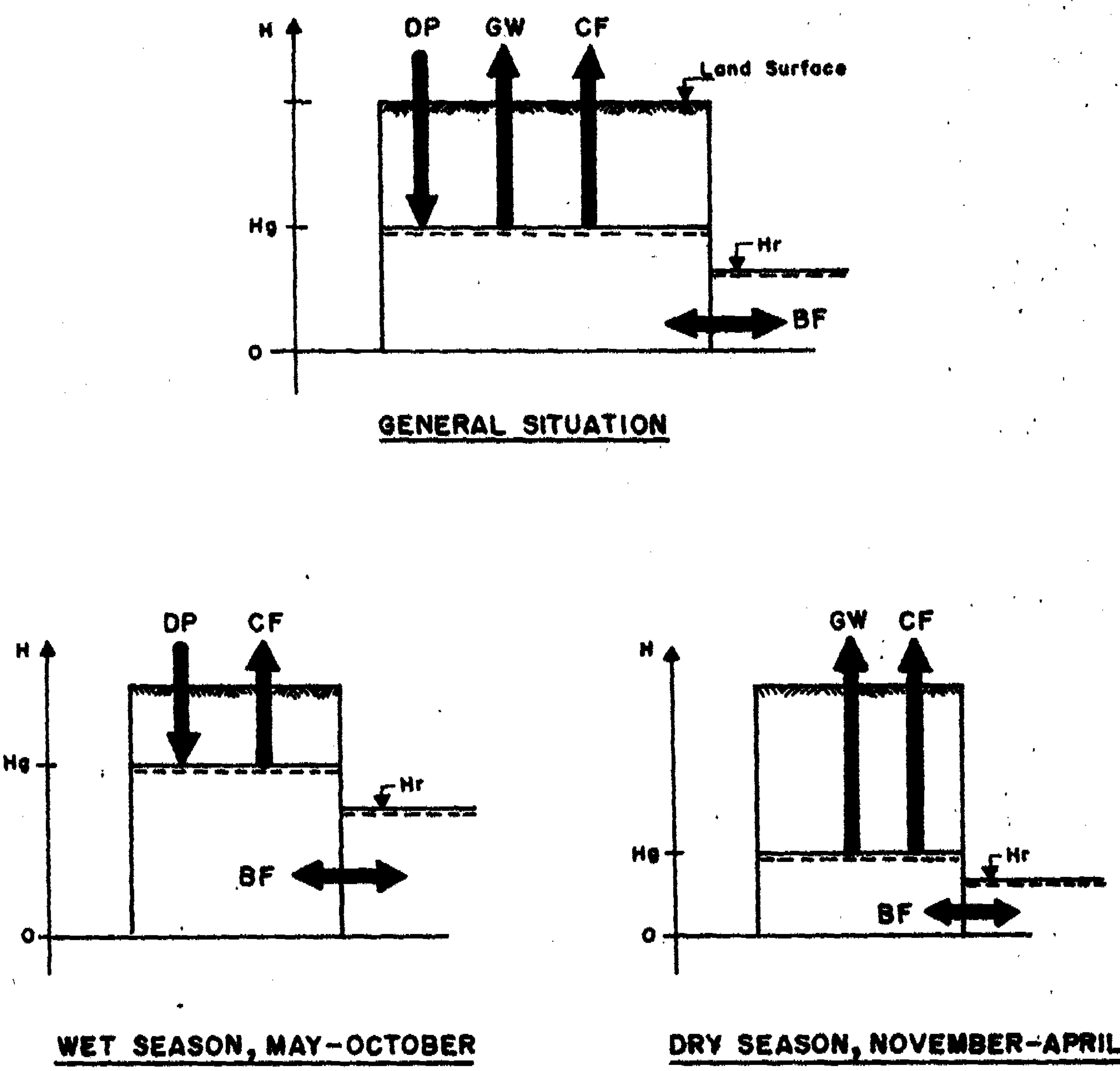
$$DP = CF + BF + (dH/dt) \times SY, \quad \text{May-Oct.} \quad (2)$$

$$0 = CF + BF + (dH/dt) \times SY, \quad \text{Nov.-Dec.} \quad (3)$$

$$0 = GW + BF + (dH/dt) \times SY, \quad \text{Jan.-April} \quad (4)$$

FIGURE 4.1

SKETCH OF THE COMPONENTS OF WATER BALANCE; UNITS: LENGTH / TIME



SYMBOLS:

Hg = Groundwater Level

Hr = River Level

Dp = Deep Percolation

GW = Groundwater Withdrawal

CF = Capillary Flux

BF = Base Flow

where:

DP = deep percolation
CF = capilary flux
BF = a part of the base flow of the river which comes from the aquifer. In most cases the BF value will be positive - the aquifer contributes with water, but situations may occur, where BF value becomes (periodically) negative.
dH/dt = change of the aquifer head (water table) per unit time.
SY = specific yield
GW = (rate of) groundwater withdrawal per unit area.

Comments to the equations:

- the water balance can be expressed in any convenient length/time - units. Normally one would choose mm/day or mm/week.

- the change of aquifer storage is represented by (dH/dt) x SY.

- the equations 2-4 are good approximation for the conditions occurring in an average (typical) year but an unusual rainfall distribution may change the periods of validity for these equations.

Definition of the water balance components.

Deep percolation expresses the rate at which the saturated part of the aquifer is recharged by water infiltrating through the unsaturated zone. This component can not be negative.

Capilary flux expresses the rate at which groundwater is removed from the saturated part of the aquifer due to capilary action of silt-containing sediments. This component becomes negligible if water table falls below the capilary suction limit (up to 2-3m). It is assumed that capilary flux becomes zero by the end of December.

Base flow expresses the rate at which the saturated part of the aquifer is exchanging water with rivers and canals. Base flow is positive if there is an outflow from the aquifer and negative in case of inflow. The head (water table) difference between aquifer and river determines the sign and the magnitude of the base flow. This component of the water balance equation is present during the entire year.

Change of storage expresses the rate at which the volume of groundwater in the aquifer is increasing (rise in water table) or decreasing (fall in water table). This component of water balance is positive if groundwater level is rising and negative if groundwater level is falling.

Groundwater withdrawal expresses the rate at which groundwater is removed from the saturated part of the aquifer through pumping (DTW, STW, HTW and MOSTIs). LLPs do not remove groundwater directly but cause lowering of the water level in rivers and by that an increase of groundwater outflow towards the rivers (increase of base flow).
For the purpose of calculations it was assumed that 20% of LLPs withdrawal comes from groundwater.

Groundwater withdrawal is positive for the January-April period and is assumed to be zero for the remaining part of the year.

This simplification is justified by calculations showing that groundwater withdrawal for irrigation is several times greater than the withdrawal for domestic use - HTWs withdrawal.

The water balance equations.

There are five components of the water balance equation: deep percolation (DP), capilary flux(CF), base flow (BF), groundwater withdrawal (GW) and change of storage ((dH/dt)xSY).

In our case, the period of interest is January-April and two of the components becomes zero: deep percolation and capilary flux.

Furthermore the value of GW and dH/dt can be, relatively easy, obtained from the files of argricultural organizations (GW) and from DWDBs water level monitoring network (dH/dt).

The value of specific yield (SY) can be estimated from bore-log data and from literature.

In theory the only unknown left is the base flow, which is difficult to measure with sufficient degree of accuracy.

In practice, however, there are several problems caused by:

- variation of hydrogeological conditions within Upazilla (water levels and SY),

- inhomogenous distribution of irrigation wells within Upazilla,

- insufficient or/and wrong data.

Therefore the solution of the water balance equations may not always provide reliable results.

4.3.2 Future water table.

To determine the future water table it is necessary to assume the present water table and calculate how much this water table will be affected by a change or water balance equation components.

<u>Water level Hydrographs (WLH).</u>

The present water table is estimated from analysis of 808 WLHs from 14 districts. There were several Upazillas where no WHLs were available and for some Upazillas there were as many as 10 (in one case 15 usable WLHs).

In most cases there was a moderate variation of the maximum depth to water table-values for the different WLHs and choice of a representative value did not create problems.

In few cases the variation was large and it was difficult to assign one depth-to-water value which would be representative for the whole Upazilla.

The WLHs showing the deepest water table was chosen as representative if the data quality was acceptable and if other hydrographs from this Upazilla did not show significantly higher water table.

If no WHLs were available for an Upazilla, interpolation between neighbouring Upazillas were made.

An important conclusion from the analysis of the WLHs is that the dramatically increased groundwater withdrawal for irrigation, since late seventies, did not cause mining of the aquifers (groundwater mining is understood as a situation where both dry and wet season water level is decreasing).

Table 4.1 summarizes the Upazilla-wise trend situation of WLHs.

District	No of Upazillas		
	Total	Trend	Indication of trend
Bogra	16	4	4
Comilla	27	4	2
Dhaka	35	9	1
Dinajpur	23	0	0
Faridpur	27	0	0
Jamalpur	13	0	1
Jessore	21	2	2
Kushtia	12	1	1
Hymensingh	35	2	3
Pabna	18	5	1
Rajshahi	32	12	7
Rangpur	35	2	2
Sylhet	37	3	0
Tangail	11	7	1

Table 4.1: Upazilla-wise summary of the groundwater level trend situation.

In spite of the fact that the dry season water level in quite a large number of Upazilla is becoming lower from year to year, the aquifer is still being filled up during the monsoon.

For most of the country, the increased groundwater withdrawal for irrigation can not even be detected on the WHLs and, from equation 3, it can be concluded that (in this case)the increased groundwater withdrawal can only be absorbed by reduction of the Jan.-April base-flow.

4.3.2.1 Estimation of the future groundwater withdrawal.

If the groundwater withdrawal remained unchanged, the dry season water table would be dependent on the rainfall variation and changes in drainage base (river levels).

An increase of agricultural production requires however an increase of the irrigated areas.

Therefore our model is based on the assumption that the irrigated area will increase until, practically, all the cropped area is brougt under irrigation.

From calculation point of view it was convenient to relate the increase of the irrigated area to the fraction of the Net Cropped Area which presently is not irrigated.

In our model it was assumed that the non-irrigated part of the NCA will be reduced in three phases and within each phase 25% of the presently non-irrigated areas will be brought under irrigation.

The groundwater withdrawal is proportional to the area which is irrigated and to the irrigation demand - amount of water needed for irrigation of a particular combination of crops.

For the calculations of future situations it was assumed, that the future irrigation demand will remain the same as it is now and that the future withdrawal can be calculated as a sum of the present withdrawal and the additional withdrawal caused by an increase of the irrigated areas.

4.3.2.2 Calculation of future drawdowns.

Calculations of the future water table situation is a difficult task and it was necessary to make a number of assumptions based on analysis of the Water Level Hydrographs (WLHs) and on evaluation of groundwater withdrawal figures.

It is assumed that:

- the present withdrawal is in balance with the groundwater storage and the base flow, which means that in absence of an increase in withdrawal, the dry season water level will remain on the present level,

- an increase in groundwater withdrawal will be compensated by depletion of the storage and reduction of the base flow.

The first asumption is equivalent to saying that the groundwater resources are equal or larger than the present withdrawal and that the limitation to groundwater utilization is imposed by pump technologies and consequences for domestic water supply rather than by the size of the resource.

This is confirmed by analysis of the WLHs; except for few wells, the present monsoon water table remains at the same level as water table from the period where no substantial irrigation withdrawal took place.

The second assumption requires that percentages of the increased groundwater withdrawal which will affect water table (depletion of the storage) and base flow are known.

Again, the WHLs were used to decide how much of the extra withdrawal will result in lowering of the water table and how much as reduced base flow. Three situations were defined where:

- the patterns of the past and the present water level fluctuations are similar and no effect of irrigation withdrawal can be detected,

- the present situation seems to be influenced by the withdrawal, but no definite prove of lowering of the water table exists (either due to short observation period or small changes of water level),

- there is a well defined increase in the depth to water table.

It is obvious, that an increase of the groundwater withdrawal above the present level will have different effects for the above mentioned situations. In the first case it was assumed that 50% of the additional withdrawal will result in depletion of the aquifer and 50% in reduction of the dry season base flow. In the second and third case these percentages were assumed to be 70/30 and 90/10 respectively.

With further increase of groundwater withdrawal (as decribed in chapter 4.3.2.1) it may be expected, that relatively larger part of the withdrawal will affect the water levels and smaller part the base flow.

As a consequence of these considerations, a parameter called drawdown factor was introduced. The drawdown factor defines what fraction of the increased withdrawal will result in lowering of the water table.

Depending on the situation, the drawdown factor can take values equal 0.5, 0.7 or 0.9 for the first phase of future development of groundwater resources (reduction of the non-irrigated part of the NCA by 25%) and 0.7 or 0.9 for the second phase (reduction of the non-irrigated part of NCA by 50%).

For the third phase (reduction of the non-irrigated part of NCA by 75%) it is assumed that all withdrawal will be counterbalanced by lowering of the water table (drawdown factor = 1.0).

With the drawdown factor defined according to the rules described above the expected drawdowns for phase 1,2 and 3 are calculated by multiplying the respective additional withdrawals by this factor.

The resulting depth to water table values are then obtained by adding the calculated drawdowns to the present depth to water table.

4.4. RESULTS OF SIMULATION.

This chapter gives a summary of the large number of figures contained in the computer print-outs, Annex 3.

The discussion regarding methodology, data quality and consistency of results is done in chapter 4.3, 4.5 and 4.6, respectively and will not be repeated here.
Therefore, the reader who is interested in this essential background information, is referred to these chapters.

All the variables from Appendix 3 are described in chapter 4.5 in order of appearance.

From the point of view of DPHE the following questions are to be answered:

1. Which Upazillas have to be regarded as deepset already now?

2. Which Upazillas will fall into this category in the future?

3. When will it happen?

4. How many people are presently affected and how many people will be affected in the future by the lowering or the water table?

5. Which Upazillas can not be served by the locally produced deepset TARA pump (max. lift around 15m)?

This report tries to give answers to all these questions.

4.4.1 Country-wide summary.

One table (Table 4.2) and two drawings, based on the data from this table, (fig. 4.2 and 4.3) were prepared to illustrate the most important aspects of the simulation model.
Comments to the summary contained in Table 4.2 are given in chapters 4.4.1.1 - 4.4.1.3

4.4.1.1 Net Cropped Area, irrigated area and irrigation demand. (table 4.2, fig. 4.2).

For Bangladesh the percentage of NCA is fairly constant (70-80%), except Sylhet where this percent is only 56, (fig. 4.2).

There are three districts (Tangail, Bogra and Jamalpur) where between 1/3 and 1/2 of the NCA is already irrigated, while for the other districts the percentage varies between 9 and 27.

If it was possible in some districts to achieve rather high irrigation coverage within one decade it should be technically possible to achieve close to full irrigation coverage by the end of the century. It can be mentioned, that quite substantial increase of the irrigated areas could be obtained without increasing the number of irrigation wells. Better management and sharing of tubewells by more users could improve utilization and increase command areas.

The constrains to the increase of irrigated areas are therefore defined by groundwater availability, groundwater abstraction technology and groundwater withdrawal's effect on the river flow.

An evaluation of these contrains is not a part of this report and therefore an alternative way to define the future expansion of irrigated areas was adopted: it was assumed, that the irrigated areas will increase in three periods in such a way that for every five years there will be an increase of irrigated areas equal to 25% of presently non-irrigated part of NCA.

District Name	% NCA	% NCA irrigated	Irrigation demand, mm	Potential recharge, mm	Groundwater storage, mm	Present groundwater withdrawal: Total, mm	%, HTW	%, STW	%, DTW	%, other	Deepset area population in %: Present	1990	1995	2000
Bogra	76	43	681	534	283	210	3	58	28	11	0	38	38	79
Comilla	77	22	630	585	153	69	13	25	41	21	11	16	81	100
Dhaka	68	25	791	596	233	104	8	36	40	16	18	41	93	98
Dinajpur	72	14	460	688	361	55	8	41	44	7	0	2	9	46
Faridpur	71	12	642	531	141	37	17	46	16	21	0	1	87	100
Jamalpur	79	35	674	847	250	169	3	60	28	9	0	17	44	94
Jessore	77	10	529	257	172	53	11	40	43	6	0	13	63	100
Kushtia	71	23	328	241	221	62	10	43	41	6	17	30	38	82
Mymensingh	72	27	715	694	141	97	6	33	46	15	6	27	87	100
Pabna	75	22	725	617	273	128	5	51	37	7	6	38	80	96
Rajshahi	72	18	628	414	286	72	7	66	13	14	51	75	100	100
Rangpur	71	17	507	755	242	71	8	56	28	8	0	0	0	42
Sylhet (*)	56	9	575	693	153	3	0	9	15	76	5	7	38	78
Tangail	74	48	753	686	429	222	3	56	32	9	40	40	85	91

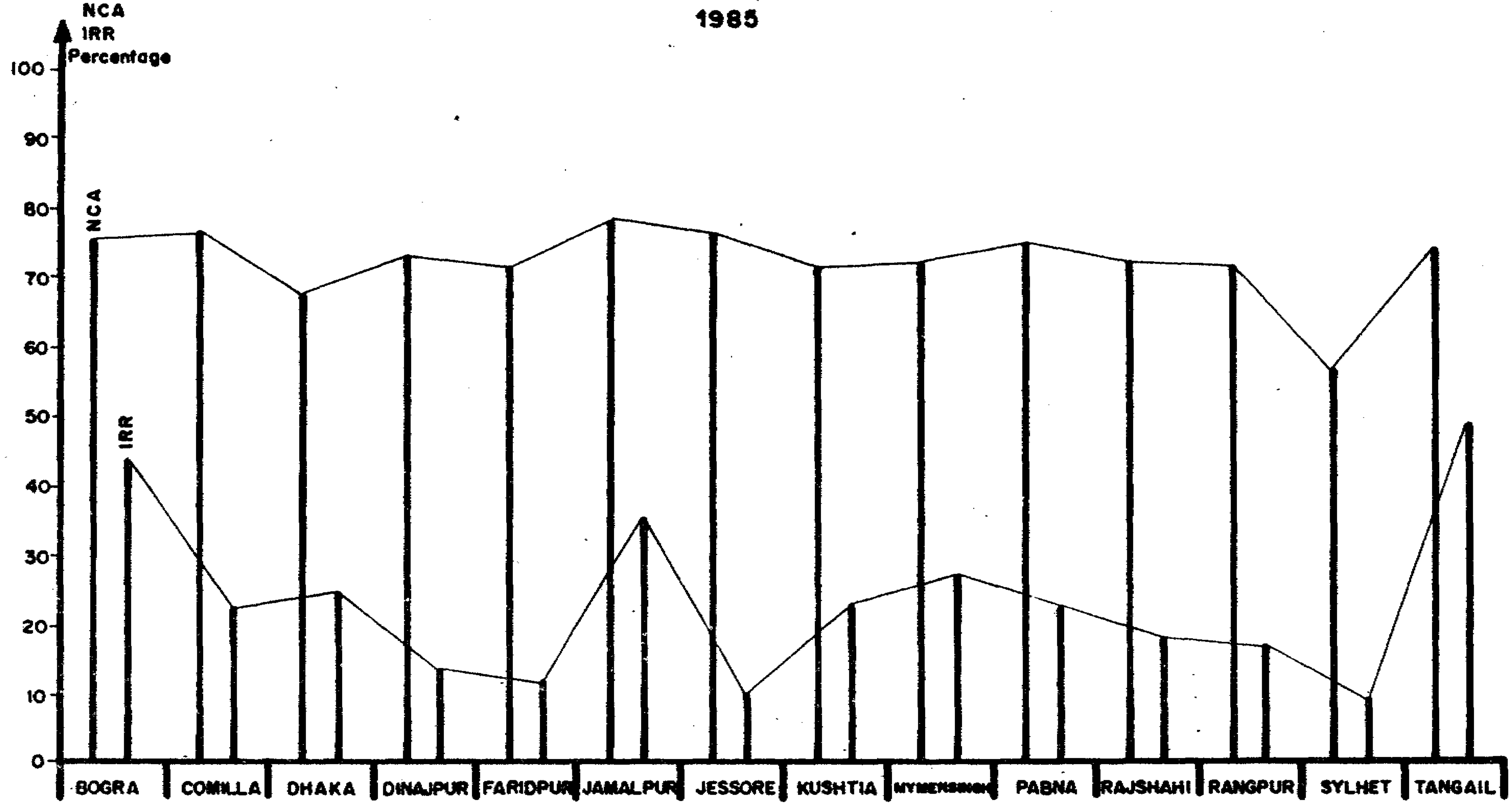
Table 4.2 District summaries.

(*) = data for Sylhet incomplete : number of HTWs and MOSTIs not available at the time of calculations.

DPHE/UNICEF/DANIDA, Dec, 1985

-4.17-

DISTRICT SUMMARY (DATA FROM TABLE 4.2) NET CROPPED AREA AND IRRIGATED AREA 1985



% NCA = Percentage of the Net Cropped Area (NCA / Total Area) x100

% IRR = Percentage of NCA Presently Irrigateted

FIGURE 4.2

For the major part of Bangladesh it will not be possible to increase the irrigated area beyond around 60% of NCA due to the constrains mentioned above and water table conditions corresponding to the last phase of development are highly hypothetical.

The typical irrigation demand is around 500 - 700mm, except for Kushtia district where relatively large percentage of wheat is cultivated and the irrigation demand is slightly above 300mm.

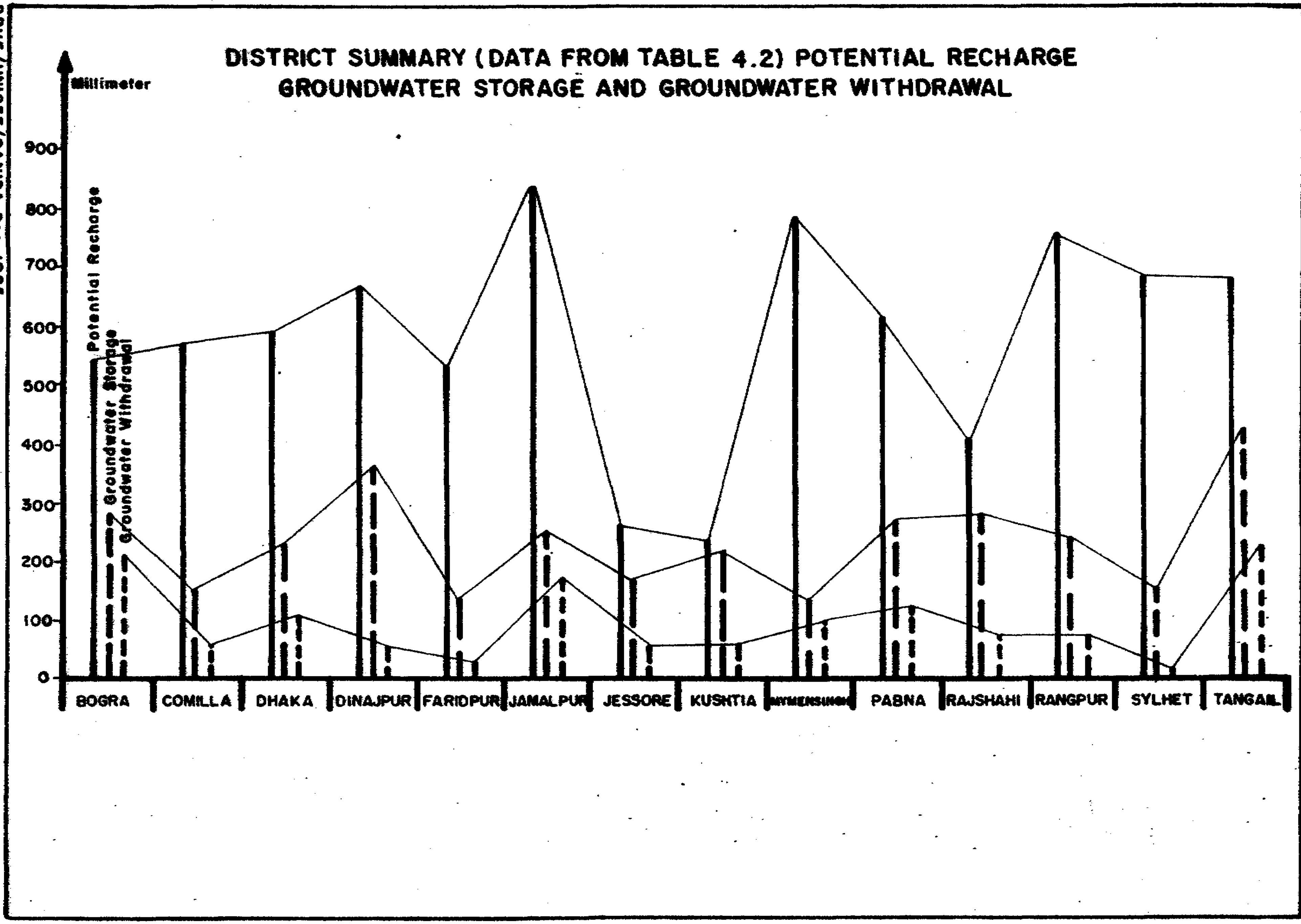
Simple calculations, see the example below, charaterize a situation which would occur with full irrigation and high irrigation demand.

Example:

If the NCA is 75%, irrigated area covers 90% of the NCA and irrigation demand is 700mm, it is required that the aquifer provides up to 400mm in the January - April period for irrigation alone; with specific yield of 0.05 it corresponds to lowering of the water table by 8m.

As the groundwater level in January is typically few meters below surface, the lift by the end of the dry season would be far beyond the suction limit.

These calculations are done under assumption, that the groundwater storage is not depleted by aquifer's contribution to the base flow in the January - April period. In fact, lowering of the water table of that magnitude may result in a situation where river level becomes higher than groundwater level. This will, in most cases, reverse the flow and cause removal of water from rivers. Taking into account that the dry season flow in rivers is already insufficient, it is easy to imagine the severe problems which will be created for navigation and fisheries.



DISTRICT SUMMARY (DATA FROM TABLE 4.2) POTENTIAL RECHARGE GROUNDWATER STORAGE AND GROUNDWATER WITHDRAWAL
Millimeter
900
800
700
600
500
400
300
200
100
0
Potential Recharge
Groundwater Storage
Groundwater Withdrawal
BOGRA
COMILLA
DHAKA
DINAJPUR
FARIDPUR
JAMALPUR
JESSORE
KUSHTIA
PABNA
RAJSHAHI
RANGPUR
SYLHET
TANGAIL
DPHE/UNICEF/DANIDA, Dec, 1985

FIGURE 4.3

4.4.1.2 Potential recharge, groundwater storage and present groundwater withdrawal (table 4.2, fig. 4.3).

The potential recharge - maximum amount of water which can infiltrate down to the aquifer under present rainfall conditions - varies from 240mm for Kushtia to 850mm for Jamalpur.
Normally, a part of recharge is rejected due to insufficient storage capability of the aquifer.

Groundwater storage - amount of water stored during monsoon and utilized during dry season - varies between 140mm in Faridpur and Kushtia and 430 in Tangail.

The present groundwater withdrawal varies from more than 200mm in Bogra and Tangail to less than 10mm in Sylhet and the typical withdrawal value is around 100mm. STWs are normally responsible for the major part of withdrawal, while HTWs take normally less than 10%.

For a balanced hydrogeological system the following relations between potential recharge (PR), groundwater storage (GS) and groundwater withdrawal (GW) should be expected:

$$PR \geq 2 \times GS$$
$$GS \geq 1.5 \times GW$$

The first relation is not valid for Kushtia (where GS almost equals PR), Rajshahi, Jessore, Tangail, Bogra and Dinajpur. Probable reasons: overestimated storage for Rajshahi and underestimated potential recharge for the other districts.

The second relation is not valid for Bogra, Mymensingh and Jamalpur. If the withdrawal is correct, the storage should be increased.
For all the other districts both relations are fulfilled.

4.4.1.3 Population of deepset areas (fig 4.4).

The deepset area population is calculated to:

- 7 million (1985)
- 17 million (1990)
- 50 million (1995)
- 66 million (2000)

The population figures refer to the year 1985 (1981 census with an addition of 10%). Each Upazilla is classified either as non-deepset or belonging 100% to the deepset category.

The percentages of population within the 1985 deepset areas are highest in Rajshahi and Tangail (50 and 40% respectively).

None of Upazillas within 6 districts were classified as deepset.

From 1990 13 out of the 14 analysed districts, except Rangpur, will have deepset areas.

From the year 2000, practically all Upazillas would become deepset.

Here again it should be stressed, that phase 3 (1995-2000) is highly hypothetical and the constrains outlined in chapter 4.4.1.1 will prevent the full development of irrigated areas.

The population figures are summarized in table 4.3 and vizualized on fig. 4.4.

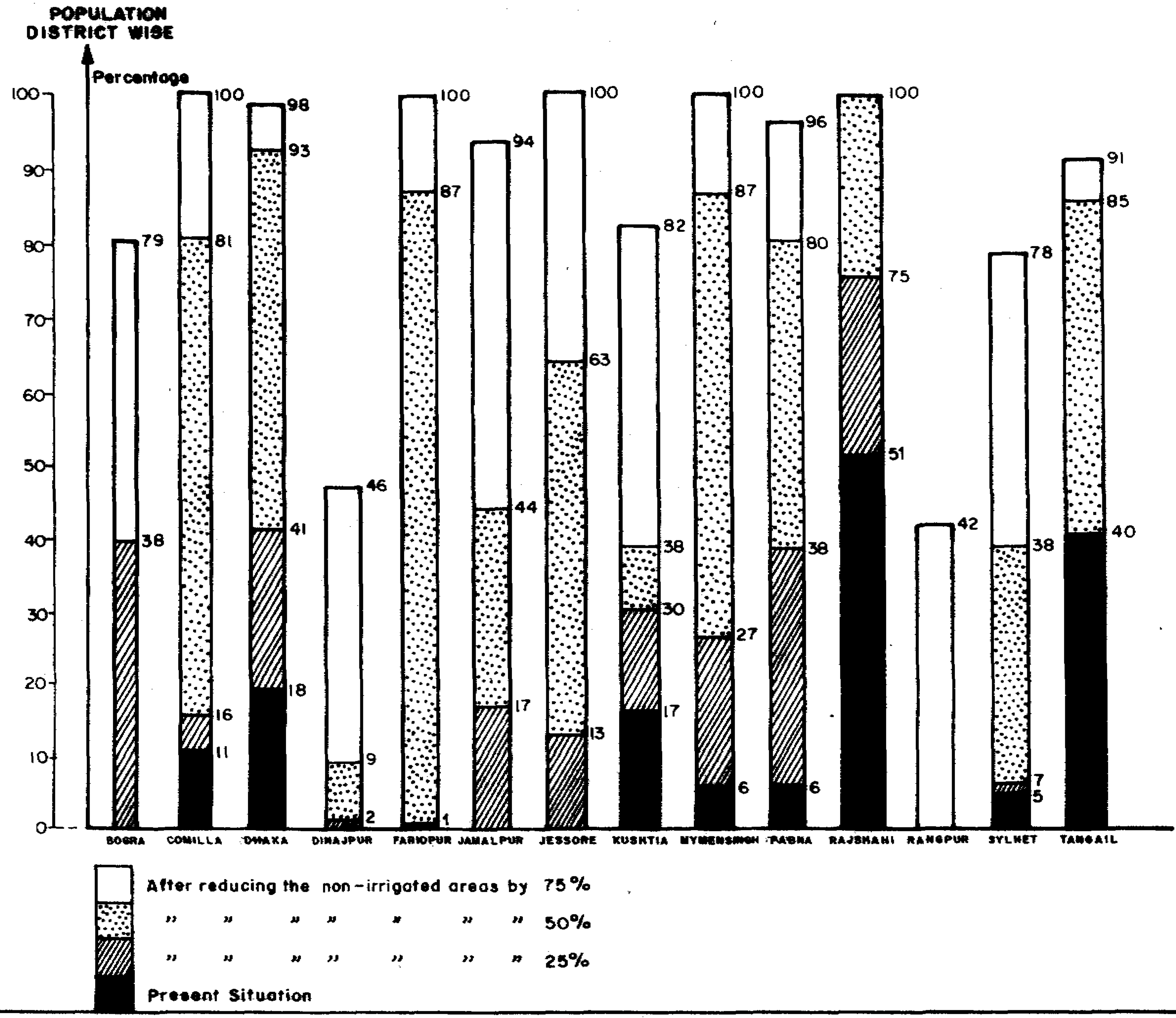
District	Total Popul.	Deepset areas population			
		1985	1990	1995	2000
Bogra	3.0	–	1.1	1.1	2.4
Comilla	7.6	0.9	1.3	6.2	7.6
Dhaka	7.7	1.4	3.2	7.2	7.6
Dinajpur	3.4	–	–	0.3	1.6
Faridpur	5.2	–	–	4.6	5.2
Jamalpur	2.7	–	0.5	1.2	2.5
Jessore	4.7	–	0.6	3.0	4.7
Kushtia	2.5	0.4	0.8	1.0	2.1
Mymensingh	7.2	0.5	2.0	6.3	7.2
Pabna	3.7	0.2	1.4	3.0	3.6
Rajshahi	5.8	3.0	4.4	5.8	5.8
Rangpur	7.1	–	–	–	3.0
Sylhet	6.2	0.3	0.5	2.4	4.9
Tangail	2.7	1.1	1.1	2.3	2.5
total	69.5	6.8	16.9	50.4	65.7

Table 4:3 Present and future population within deepset areas;

year 1990 – 25% of NCA, presently not irrigated is brought under irrigation.
year 1995 – 50%
year 2000 – 75%

FIGURE 4.4

POPULATION OF PRESENT AND FUTURE DEEPSET AREAS(OLD DISTRICTS) COASTAL DISTRICTS AND CTG. H. T. NOT INCLUDED



DPHE/UNICEF/DANIDA, Dec, 1985

4.5 INPUT AND OUTPUT, COMPUTER CALCULATIONS.

The result of computer calculations are presented in Annex 3. There are four pages of print-out for each district (Table 1-3).

As mentioned before, all the calculations are done using Upazilla as a basic unit, which implies that only one value of each parameter is used to characterize the required property for the entire Upazilla.

The quality of predictions about the extent of deepset areas depends heavily on:

- the accuracy of mathematical description of the situation,
- the representativeness of input data,
- the reliability of input data.

The mathematical model is described in chapter 4.3, the results in chapter 4.4 and here an evaluation of data reliability and representativeness will be made.

The data representativeness is understood as an ability of the particular type of data to express the required properties or conditions for the Upazilla by a single number.

Examples, representativeness:

- for an Upazilla with the minimum water level varying from 3 to 9 m.b.s., for two different wells, it is difficult to choose one representative minimum water level value.
- number of deep - or shallow tubewells in the Upazilla may not be representative if these tubewells are concentrated in specific parts of the Upazilla.

With other words, the data may be accurate, but not necessarily representative.

The data reliability express the level of confidence to the accuracy of the data. The data may not be reliable either due to inadequate data collection procedure (erroneous measurements, insufficient care, etc.) or due to difficulties in transferring the measured values to the required parameter.

Examples, reliability:

- relatively large number of water level hydrographs has to be regarded as unreliable either due to wrong measurements or errors in data processing procedures.

- specific yield values may be unreliable because it is not possible to determine these numbers in the field or calculate by other means with sufficiently high degree of accuracy.

To make a judgement of the predictions regarding future deepset areas, it is necessary to define representativeness and reliability of the input data and sensitivity of the model for changes in the input data.

The following chapters 4.5.1 - 4.5.17 describe all the input data and the calculated values in a sequence corresponding to the computer print-out (Annex 3, Table 1-3).

4.5.1 MPO Code and Upazila Name.

Upazilas in MPO's database are arranged alphabetically and a number (ranging from 1 to 501) is assigned for each Upazilla.

Advantages with this system are following:

- searching for a number is easy and errors associated with rather arbitrary spelling of many Upazilla names are avoided,

- arranging of Upazillas in alphabetic order makes transfer of data from computer print-out to maps much faster.

There are some disadvantages with the present system:

- the numbering system is adopted with reference to the whole country. Majority of tasks refer to districts and therefore it would be more convenient to have an alphabetic ordering scheme within each district. The present numbering system does not give the possibility to locate Upazillas geographically based on the MPO Code Number,

- the numbering system does not take into account the possibility of administrative changes (creation of new Upazillas); if a new Upazilla is created, the number assigned to it would be either higher than 501 or the new Upazilla's code number would correspond to the new alphabetic order which would change the code numbers for all the following Upazillas.

4.5.2 Population data, (POPUL(000) in the print-out).

type of data	:	input
source	:	Statistical Pocket Book of B'desh 1982
influence on deepset area prediction	:	none
representativeness	:	good
reliability	:	good
improvement	:	practically not possible

The population figures are based on 1981 population census. For the purpose of calculation it was assumed that 1985 figures are 10% higher than the 1981 figures.

For some of the Upazillas the population figures are not yet available.

4.5.3 Tubewell information.

type of data	: input
source	: MPO, DPHE
influence on deepset area prediction	: substantial
representativeness	: varying,depending on conditons
reliability	: medium
improvement	: possible

This section of input data contains three types of information:

- about the *number of* tubewells (NHTW, NMOS, NSTW, NDTW),
- about the percentage of STWs and DTWs in operation (%OS, %OD) and
- about average area irrigated by one and one DTW (UAS and UAD).

It is assumed that 80% of HTWs and MOSTIs are in operation.

For the LLPs, the data about number of pumps in operation were readily abvailable; in this connection it has to be mentioned, that LLP data may not be fully correct, as number of operating pumps equals number of installed pumps in most of the cases, while for some districts none or very few of the hundreds installed pumps are listed as being in operation.

Fortunately the influence of an error in number of LLPs will have only limited effect on groundwater level calculations. As the LLPs take water directly from the rivers and canals, it is assumed that the indirect groundwater abstraction equals 20% of the yield of the LLP (due to increased outflow from the aquifer caused by water withdrawal from the rivers).

It is not unlikely, that the net effect at the LLP on the groundwater is close to zero.

4.5.4 Area irrigated.

type of data	: output
source	: DPHE's calculations
influence on deepset area prediction	: substantial
representativeness	: depending on Tubewell Information, chapter 4.5.3
reliability	: depending on Tubewell Information, chapter 4.5.3
improvement	: depending on Tubewell Information, chapter 4.5.3

For MOSTIs it is assumed that 80% of these are in operation, and that each unit irrigates 0.2 ha (personal communication, MPO):

area irrigated, MOSTIs = NMOS x 0.8 x 0.2

For DTWs, STWs and LLPs the irrigated area is calculated by multiplying the number of tubewells by percentage of tubewells in operation and unit area irrigated by one tubewell:

area irrigated, DTWs = NDTW x %OD x UAD

area irrigated, STWs = NSTW x %OS x UAS

area irrigated, LLPs = NLLP x 1.0 x 16

For the LLPs the number of pumps in operation is given as input data and the area irrigated by one LLP is assumed to be 16 ha (personal communication, MPO).

4.5.5 Irrigation demand.

type of data	:	input
source	:	MPO's Data Base
influence on deepset area prediction	:	moderate
representiveness	:	good
reliability	:	good
improvement	:	possible,particularly if cropping pattern will change in the future.

Actually, this data are not directly input data but rather a result of manipulation of the duty values.

Irrigation demand expresses the average amount of water needed for irrigation. Irrigation demand will be higher for Upazillas with high percentage of rice cultivated areas and lower for Upazillas with high percentage of wheat cultivated areas. The MPOs Data Base provided "duty" - values (number of hectars which can be irrigated, an average for the Upazilla, by one million m3). The inverse of this value multiplied by a unit conversion factor (100,000) provides irrigation demand in mm of water.If various development strategies are considered, the irrigation demand has to be re-calculated.

4.5.6 Groundwater withdrawal.

type of data	: output
source	: DPHE's calculations
influence on deepset area prediction	: substantial
representativeness	: depending on tubewell data
reliability	: depending on tubewell data
improvement	: depending on tubewell data

Groundwater withdrawal is calculated in two types of units: million m3 and mm. These two figures are related through the total area of the Upazilla.

Groundwater withdrawal consists of two parts:

- groundwater withdrawn for irrigation which equals total irrigated area multiplied by irrigation demand and
- groundwater withdrawal for domestic purposes which equals NHTW x 0.8 x 700 x 0.5 x 3.6/1,000,000; it is assumed that 80% of HTWs is in operation for 700 hours per year at a pumping rate of 0.5 l/sec (the factor 3.6/1,000,000 is used to express withdrawal in millions m3).

4.5.7 Recharge estimates.

The three numbers presented under this heading are not directly comparable and are listed mainly for reference purposes.

4.5.7.1 Recharge estimates. UNDP

type of data	: input
source	: Groundwater Survey, the Hydrogeological Conditions of B'desh UNDP report, 1982
influence on deepset area prediction	: none
representativeness	: poor
reliability	: poor
improvement	: not applicable

UNDP estimates are one of the first attempts to describe the potential recharge districtwise. Recharge figures are based on infiltration properties of the top-soil and the available rainfall.

Prescribed percentages of the rainfall were routed as surface run-off and as base flow while the rest was called "recharge".

Taking into account the distribution or rainfall within the year, the variation of depth to water table and variation of the specific yield it is clear that direct proportionality between the total rainfall and recharge can only be regarded as a first step approximation.

4.5.7.2 Recharge estimates, MPO

type of data	: input
source	: MPO
influence on deepset area prediction	: limited
representativeness	: moderate
reliability	: high
improvement	: possible

MPO's potential recharge figures are based on computer modeling of the hydrogeological processes taking place in the nature. A very large amount of information is incorporated in the model (see table 4.4) and the methodology is appropriate. However, the recharge figures can not always be regarded as final until more field measurements and cross checking of the data is made. Field measurements of infiltration capacity, determination of transmissivity and head distribution in the aquifers, soil moisture profiles measurements and base flow measurements can be combined to calibrate and verify the model and improve the quality of recharge estimates.

Table 4.4 : CHECK LIST OF THE VARIABLES REQUIRED AND USED FOR GROUNDWATER RECHARGE CALCULATION.

Recharge Assessment Variables and Procedure	Variables Quantified and Used		
	MPO's Analysis	UNDP-BWDB 1982	GWC-BWDB 1984-1985
1. Meteorological Data	Yes	Yes	No
2. Mean Annual Rainfall	Yes	Yes	
3. 10 day Rainfall variation over a 20 year period	Yes		No
4. Evaporation	Yes	Yes	
5. Evapotranspiration	Yes	Yes	
6. Interception of rainfall by vegetation	Yes	Yes	
7. Effective runoff	Yes	Yes	
8. Vegetation and Land Use	Yes		
9. Variability over Bangladesh for 160 catchments	Yes		
10. 10 day daily croping patterns	Yes		
11. Un cultivated land	Yes		
12. Homestead areas	Yes		
13. Urban areas	Yes		
14. Tea gardens	Yes		
15. Forests	Yes		
16. Water Bodies - Static (Beels, haors)	Yes		
17. Water Bodies - Rivers	Yes		
18. 10 day daily flood depth	Yes		
19. Land Soil Data	Yes	Yes	Yes
20. Land - 15 Physiographic Units	Yes	Yes	Yes
21. Land - For all 828 Soil Associations	Yes		
22. Flood phases	Yes		
23. Cultivation practice wet land rice	Yes		
24. Cultivation practice dry land crops	Yes		
25 Field bunds to hold standing waters	Yes		
26 Soil infiltration rate	Yes		Yes
27 Soil storage capacity	Yes		
28. Full saturation	Yes	Yes a	
29. Field capacity	Yes	constant value	
30. Wilting point	Yes		
31. Presence or absence of plough pan	Yes		
32. Ploughpan deep percolation rate	Yes		Yes
33. Subsoil clay	Yes		Yes
34. Thickness	Yes		
35. Vertical permeability	Yes		
36. Calibration	Yes	No	No
37. Special study areas	Yes	Yes	
38. Daily rainfall	Yes		
39. Daily groundwater levels	Yes		
40. Crop inventory to verify	Yes		
BBS cropping patterns	Yes		
41. Water use inventory to establish actual withdrawals	Yes		
42. Mapping at 16" to 1 mile location of wells and areas irrigated			
43. Prediction of groundwater levels	Yes		
44. Verification of groundwater level prediction	Yes		
45. Independent Checks	Yes	No	No
46. Check to see predicted results correlate with national water balance of surface and groundwater	Yes		
47. Back-check using observed groundwater levels and specific yield data	Yes		Yes
48. Constant specific yield	No		Yes
49. Depth variable specific yield	Yes		
50. Response of groundwater levels to groundwater development	Yes		
Total =	49	8	7
Percentage of variables Quantified	98%	16%	14%

Source : MPO.

4.5.7.3 Recharge estimates, Ground Water Investigation Circle, BWDB (GWC).

type of data	:	input
source	:	M.A. Karim, Upazillwise Groundwater Recharge Conditions of B'desh, BWDB.
influence on deepset area prediction	:	none
representativeness	:	good
reliability	:	moderate
improvement	:	not applicable

These recharge figures called "actual recharge" are calculated by multipying groundwater level fluctuations by specific yield values and represent the amount of water stored in the aquifer during the monsoon season.

The Groundwater Storage (chapter 4.5.8) is calculated in a similar way and these two numbers should be directly comparable. The differences are caused by different estimates of specific yield and (in some cases) different fluctuations representative for the Upazilla.

4.5.8 Groundwater Storage (GWST).

type of data	: output
source	: DPHE's calculations
influence on deepset area prediction	: limited
representativeness	: good
reliability	: moderate
improvement	: possible

The detailed discussion of this parameter was already done in chapter 4.3 and it was stated before, that GWST value correspond to the actual recharge as computed by GWC (chapter 4.5.7.3). Here it can be added, that GWST figures can be used for verification of the specific yield values. This should be done in situations where groundwater withdrawal approaches or exceeds GWST; if the base flow of the rivers is maintained on the previous level (from the period when groundwater withdrawal was small) it can be concluded that the storage of groundwater is higher than calculated and that the specific yield value should be increased. Of course, there is another possibility the groundwater level fluctuations, assumed representative for the Upazilla, are too small.

4.5.9 Trend in groundwater levels.

type of data	: input
source	: plots of water level hydrographs, GWC, BWDB.
influence on deepset area prediction	: substantial
representativeness	: varying
reliability	: varying
improvement	: not applicable

For the purpose of calculations it was necessary to categorize each Upazilla into one of the three groups: as Upazillas where a downward trend in groundwater level is detected, where there is an indication of a trend, and Upazillas where no trend is detected. Following criteria were used for this categorization:

- if any of the observation wells within the Upazilla showed downward trend, the trend was assumed to be valid for the whole Upazilla,

- if there were no data for an Upazilla, no trend situation was assumed.

The decision about trend situation was essential for calculation of the future drawdowns.

4.5.10 Total, NCA and Irrigated areas.

type of data	:	-input (total area and NCA), -output (percent of cropped and percent of irrigated area)
source	:	-MPO (total area) -Upazilla Statistics (1979-'83),vol.1,Jan. 1985 (Net Cropped Area (NCA)) -DPHE's calculations (% NCA and % irrigated area)
influence on deepset area prediction	:	substantial
representativeness	:	good
reliability	:	good
improvement	:	not applicable

The percentage of NCA was calculated from the "Upazilla Statistics" by taking into account the NCA and the total area of the Upazilla. However, the total area figure, as presented in the computer print-out, was taken from the MPO data base to ensure consistency between number of Upazillas and their respective areas.

4.5.11 Water levels.

type of data	:	input
source	:	plots of water level hydrographGWC, BWDB.
influence on deepset area prediction	:	substantial
representativeness	:	varying
reliability	:	varying
improvements	:	desirable (from other sources than BWDB's network).

For the purpose of calculations it was necessary to define only one minimum water level value and only one value for water level fluctuation for each Upazilla.
For many Upazillas the variation of these two parameters was quite large and therefore the representativeness of the data may not be good.

Normally, the maximum depth to water table was used as representative which result in overestimation of the deepset areas; for Upazilla where data from several observation wells were available and the data showing the maximum depth to water table deviated significantly from the data from other wells, this value has not been used because it was assumed that these records are either erroneous or not representative.

Improvement of the estimates of the maximum depth to water table data is essential for delineation and monitoring of the deepset areas.

4.5.12 Homested level above Field level

type of data	: input
source	: MPO Data Base
influence on deepset area prediction	: none
representativehess	: unknown
reliability	: unknown
improvement	: ?

During design of the DPHE deepset area model it was planned (as a secondary objective) to include subroutines providing information about maximum expected lift for users of STWs and MOSTIs. As it is difficult to determine reliability and representativeness of these data and as these data are not available for a large number of Upazillas, it was chosen not to include these calculations in the model.

The maximum lift calculations can be done for each Upazilla by substracting the value of this parameter from the calculated Maximum Depth to Water Table and adding "well losses" occuring during pumping. For well-functioning MOSTIs the well losses will be negligeable and for good STWs the lower elevation of the field may in many cases compensate the "well losses".

Therefore, the water level computed with reference to homested level can be used as a first approximation for evaluation of feasibility of STWs in the Upazillas considered.

4.5.13 Specific yield, SY

type of data	:	input
source	:	MPO Data Base
influence on deepset area prediction	:	substantial
representativeness	:	good
reliability	:	good
improvement	:	possible

This parameter is essential for calculation of the amount of recharge which is stored in the aquifer during monsoon and the future drawdowns caused by increased withdrawal. The direct proportionality between SY and groundwater storage (or drawdowns) and difficulties in assigning correct and representative values of SY makes proper evaluation of this parameter both important and difficult. For example an increase of SY by 100% will double the storage and almost double the drawdown; analogical situation occurs when SY is reduced.

For the hydrogeological conditions prevailing in most of the country it is unlikely, that any significant improvement in estimation of SY values can be obtained by further manipulation of the bore-log data. The Upazillawise SY-values, calculated by MPO on the basis of all the useable bore-logs, should be regarded as the best ones for the first approximation.

Later on, if discrepancy is found between the calculated groundwater storage and withdrawal (i.e. if withdrawal exceed the storage and no lowering at the water table takes place),the SY-values should be readjusted accordingly. With other words, the final SY-values should be assigned after analysis of the preliminary results, see chapter 4.6.5.

4.5.14 Drawdown factor (DDF).

The term "drawdown factor" does not exist in the hydrogeological textbooks and has been invented for the purpose of the DPHE model calculating the future drawdowns.

An explanation why this term was introduced is given in chapter 4.3.2.

Drawdown factor helps to differentiate between Upazillas where maximum depth to water increases and Upazillas where maximum depth to water table remains constant (changes caused by variation of rainfall are not taken into account). There are four values of this factor permitted in the model:

- 0.5 if no trend is detected; that means that an additional future groundwater withdrawal will be equalized by reduction in the base-flow (50%) and depletion of the groundwater storage (50%),

- 0.7 if there is an indication of a trend; in this case 30% of the extra withdrawal will be taken from the base-flow and 70% from the storage,

- 0.9 if the trend is clearly visible; in this case only 10% of extra withdrawal will come from the base flow while 90% will be taken from the storage and,

- 1.0 if practically all cropped area is irrigated and all additional groundwater withdrawal is taken from the storage.

As described in chapter 4.3.2, the future groundwater abstraction is assumed to increase in three steps. With an increase of withdrawal, the percentwise contribution of the groundwater storage will most likely increase and therefore following drawdown factor (DDF) values are chosen:

- step 1 (non-irrigated area reduced 25%), DDF values as described above.

- step 2 (non-irrigated area reduced 50%)
  DDF = 0.7 (if DDF = 0.5 or 0.7 for step 1)
  DDF = 0.9 (if DDF = 0.9 for step 1)

- step 3 (non-irrigated area reduced 75%)
  DDF = 1.0 (independent on the original DDF value)

4.5.15 Present withdrawal.

These figures are identical with figures already described in chapter 4.5.6 and are repeated in the computer print-out for comparison purpose.

4.5.16 Irrigated areas, withdrawal, groundwater levels and groundwater storage in the future.

The last 12 numbers in Table 2 contain the results of model calculations.

4.5.17 Table 3: District summaries.

All of the results presented in this table are obtained by manipulation of the numbers already printed in Table 1 and Table 2 and the figures should be self-explanatory.

However, few comments can be added to explain the reasons for chosing specific criterias applied in this Table.

4.5.17.1 Groundwater withdrawal higher than 80% of groundwater storage.

It should be expected, that with such a high withdrawal/storage ratio the groundwater level should show downward trend. Check of input data for Upazillas listed under this heading, particularly if no trend is detected, should be made.

4.5.17.2 Groundwater withdrawal higher than 50% of potential recharge.

The value of potential recharge represent the maximum inflow into aquifer under given rainfall pattern and permeability of the top layers. If the withdrawal substantially exceeds 50% of the recharge it should be expected, that mining of the aquifer is taking place. If such a mining is not shown on the water level hydrographs, the input data should be revised.

4.5.17.3 Groundwater storage higher than 50% of potential recharge.

Calculations show, that for some Upazillas the groundwater storage is close to or even higher than the potential recharge. Under normal circumstances such situation can not occur and input data should be checked.

4.6 HOW TO IMPROVE THE DEEPSET AREA PREDICTION, DATA CONSISTENCY CHECK.

All the data entered to the model were carefully checked and there should not be any obvious errors. However, the permitted variation of parameters is rather wide and no further improvement can be made by looking at the input data alone.

Therefore a check of data consistency is an important task which may narrow the permitted range of variation of the individual parameters.

Data are consistent, if comparison of results of different calculations does not lead to contradictory conclusions. If such a contradiction appears, the input data should be manipulated in order to remove this contradiction.
Of course, the data manipulation is only permitted within limits defined by the actual conditions of the modelled system.

In our model it was not possible to reduce the inconsistency of the data by re-running of the model due to time constrains (the last part of data was received in early December) and it was only possible to point out the results which are or could be erroneous.

The following variables/parameters were subjected to the data consistency check:

- net cropped area in relation to the irrigated area,

- groundwater withdrawal in relation to groundwater storage,

- groundwater withdrawal in relation to potential recharge and,

- groundwater storage in relation to potential recharge.

The results of data consistency check are summarized in table 4.5.

If the data consistency check shows that the combination of parameters used by the model leads to erroneous results, the problem arises which parameters should be adjusted.

DISTRICT	GW/GS	GW/PR	GS/PR	TOTAL U-ZIL.	U-ZILLAS WITH DATA INCONSISTENCY GW/GS>0.8	GW/PR>0.5	GS/PR>0.5
Bogra	0.74	0.41	0.56	16	10	6	9
Comilla	0.45	0.12	0.26	27	4	-	1
Dhaka	0.42	0.17	0.39	35	8	-	10
Dinajpur	0.15	0.08	0.52	23	8	-	13
Faridpur	0.07	0.26	0.27	27	2	-	2
Jamalpur	0.68	0.20	0.30	13	7	-	1
Jessore	0.31	0.21	0.67	21	2	2	14
Kushtia	0.28	0.26	0.92	12	1	4	9
Mymensingh	0.69	0.14	0.20	35	12	-	2
Pabna	0.47	0.21	0.44	18	5	2	6
Rajshahi	0.25	0.17	0.69	32	3	-	19
Rangpur	0.29	0.09	0.32	35	2	-	2
Sylhet	0.05	0.01	0.22	37	2	-	3
Tangail	0.51	0.32	0.62	11	4	2	6

Table 4.5: Number of Upazillas with probable data inconsistency (based on Appendix 3).

GW = Groundwater Withdrawal
GS = Groundwater Storage
PR = Potential Recharge

A reference to the data representativeness and data reliability (chapter4.5) should be made in this situation.

Furthermore influence of the considered parameter on the deepset area prediction should be taken into account (chapter 4.5).

The Upazillas for which there is an apparent inconsistency in the input data are listed in Appendix 3 (table 3, Headings B,C and D).

The different types of data inconsistency are described in chapter 4.6.1 - 4.6.4 and a procedure how to improve the data, in order to remove these inconsistences, is proposed in chapter 4.6.5.

4.6.1 Net Cropped Area (NCA) and irrigated area.

It may not occur that the irrigated area is larger than NCA. As the irrigated area was calculated by multiplying number of different types of irrigation wells by their respective command areas it was possible that the irrigated area could turn out to be larger than the cropped area.

This inconsistency was only discovered in one Upazilla: Gopalpur, Tangail district.
In this case the calculated irrigated area was 13% higher than NCA. The probable cause of this discrepancy is too high number of irrigation wells in operation.

4.6.2 Groundwater withdrawal and groundwater storage (Appendix 3, Table 3, Heading "B").

The calculations of groundwater withdrawal involve quite a large number of parameters: number of tubewells of different kind, size of the irrigated areas and irrigation demand as well as assumptions about unit withdrawal for some of the tubewells. Therefore a possibility for a substantial error in calculation of the groundwater withdrawal can not be excluded.

Groundwater storage depends mainly on the value of the specific yield, SY, which can vary by a factor of 10 (from less than 0.02 to more than 0.10).

As groundwater storage is directly proportional to SY, the error in calculation of the storage can be very large - much larger than possible error in groundwater withdrawal estimation.

In the computer print-out, Annex 3, the Upazillas are listed where withdrawal is greater than 80% of the storage.

As the depletion of the storage starts shortly after the end of monsoon, it is unlikely that more than 80% of the storage is available for the January-April period, when the irrigation withdrawal is taking place. Furthermore, during the January-April period there will still be some water "loss" to the base flow of the rivers.

This type of data inconsistency is present in all districts but mainly in Bogra, Jamalpur and Tangail.

For example, for Dubchachia Upazilla, Bogra district, the withdrawal is calculated to be 2.5 times higher than the storage, which indicates that the storage value (both SY and groundwater level fluctuation) is substantially underestimated. A look at the input data confirmes that both the specific yield and water level fluctuations are significantly lower than the average for the Upazilla.

4.6.3 Groundwater withdrawal and potential recharge (Appendix 3, Table 3, Heading "C").

Uncertainty with regard to calculation of the groundwater withdrawal was discussed in chapter 4.6.2

The potential recharge estimates are based mainly on the estimates of permeability (hydraulic conductivity) of the top-layers and on the rainfall distribution.

As the potential recharge represents the maximum amount of water which can enter aquifer through unsaturated zone, it is unlikely that groundwater withdrawal can significantly exceed 50% of the potential recharge whithout clear evidence of groundwater mining.

The calculations show, fig. 4.3 and table 4.5, that the average district values for groundwater withdrawal are far below the 50% limit; however, within four districts this limit is exceeded.

Four out of twelve Upazillas in Kushtia district for example (Appendix 3, page Kus.3) have withdrawal values higher than 50% of the potential recharge; only in one of these Upazillas a trend in the water table was detected (Darmuhuda). It may be concluded that the values of potential recharge at least for the three remaining Upazillas, are probably too low.

4.6.4 Groundwater storage and potential recharge (Appendix 3, Table 3, Heading "D").

The computer prints out Upazillas where the groundwater storage is larger than 50% of the potential recharge. This criteria is similar to the criteria described in chapter 4.6.3 but as groundwater storage is usually larger than groundwater withdrawal, more Upazillas will fall into this category.

The recharge taking place during monsoon has to contribute to the base flow during wet season and build up the aquifer storage which then can be utilized for sustaining of the dry season base flow, capilary flux and irrigation withdrawal.

As we are talking about the potential recharge, i.e. maximum amount of water which can enter the aquifer, it is believed, that, under normal circumstances, the storage should not exceed 50% of the potential recharge.

If the calculated storage is larger than recharge it is necessary to check the input data.

4.6.5 Procedure for improvement of data consistency.

In the previous chapters it was concluded, that input data are (or could be) inaccurate if:

- GW/GS is greater than 0.8
- GW/PR is greater than 0.5 and
- GS/PR is greater than 0.5,

where:

GW = groundwater withdrawal,
GS = groundwater storage,
PR = potential recharge.

If the first condition occurs, the most probable reason for the discrepancy is too low estimate of storage.

If the second condition occurs, then there are two possibilities: either the withdrawal is too high or the recharge is too low.

If the third condition occurs it is because the storage is too high or recharge is too low.

The procedure for removal of the data inconsistency should consist of two steps:

1. Permitted intervals for parameter variation should be established; for example:

   - the potential recharge for Upazillas within buried old river channels containing relatively coarse sediments and minor amount of clay in the top layers should be between 600 and 1200 mm,

   - the potential recharge for areas with thicker clay cover should not exceed 400 mm,

   - the SY value for Upazillas where top layers are composed predominantly of sand should be between 0.05 and 0.20,

   - The SY value for Upazillas with relatively thick clay/silt layer should be between 0.01 and 0.05.

After the intervals for parameter variation are established, it should be permitted to adjust parameter values to eliminate, if possible, the data inconsistency.

2. Upazillas appearing in the Table 3 under headings B,C and D should be screened and readjustment of the potential recharge and specific yield values should be made.

The model calculating future water table should be re-run with the new input data.

5. DPHE's HYDROGEOLOGICAL MONITORING NETWORK.

The check of data consistency and adjustment of parameters, as described in chapter 4.6.5 will increase confidence to the predictions of the deepset area simulation model. However, the best way to ensure the best service for population of the present and future deepset areas would be through establishment of a Water Level Monitoring Network.

Even if the computer calculations have been accurate down to Upazilla level there is no way to achieve reliable results down to Union level, because all the data are given on the Upazilla basis.

Large variation of hydrogeological conditions and of groundwater withdrawal within Upazilla may result in insufficient accuracy of deepset area determination. Furthermore, the BWDB's network does not always provide adequate information about the present water levels both from data quality and network's density point of view.

Therefore, DPHE's own network should be regarded as an important contribution to proper planning of the future water supply.

There are several questions to be answered before a decision about establishment of water level monitoring network is taken:

1. How many wells should the network consist of and how the wells should be distributed Upazilla-wise.

2. What kind of wells (existing or specially drilled) should be chosen.

3. How the site selection for the wells should be done and who should do the monitoring.

4. What the establishment and maintenance of the network would cost and how it should be financed.

5.1 NUMBER OF WELLS AND UPAZILLA-WISE DISTRIBUTION.

Between 300-500 observation wells situated in the present and future deepset areas would be sufficient. The Upazillas which are inadequately covered by the BWDB's network should have a preference. Locally available information (DPHE's Upazilla offices) about water level conditions should be utilized to distribute the observation wells within Upazilla in an optimal way.

5.2 KIND OF WELLS.

A specially drilled observation well, not requiring removal of the pump for water level measurements, should be preferred.
The top casing should be kept locked to prevent unauthorized access.

The wells should be marked in a way that the indentification marks could not easily be removed.

5.3 SITE SELECTION AND MONITORING.

These two aspects: site selection for the observation wells and the way the periodical monitoring is done are closely connected.

The optimal site would be a location where the dry season water table is deepest and that would normally be the case in areas with high irrigation withdrawal. However, a suitable person, who would be able and willing to take the weekly measurements, should be available within reasonable distance from the well.

It is essential to decide how the monitoring has to be carried out:

- should that be done on a voluntary basis by the local people (teacher, officials or others),

- should that be done for a fixed payment,

- should that be done by the DPHE personnel.

Each one of the above mentioned possibilities has different influence on the site selection criteria.

A possibility for construction of water level observation wells in connection with deployment of TARA pump performance monitoring wells has been recently discussed between DPHE, UNICEF, and World Bank. However, the performance monitoring network will be confined to very few Upazills and the necessary geographical coverage can not be obtained by combining these two tasks.

5.4 COST AND FINANCING OF THE MONITORING NETWORK.

Taking into account the advantages, and it may even be said the necessity of having good control of the trends in water levels, the cost of establishing and running of the Hydrogeological Monitoring Network seem to be moderate.

Construction of 500 observation wells equiped with a lock and properly marked may cost around 5 lakh (500,000).

Weekly measurements of these 500 wells (tk5/measurement) may cost arount 1.3 lakhs per year.

The processing of data would be done cost free as a routine task on the DPHE's computer.

5.5 BENEFITS FROM GROUNDWATER LEVEL MONITORING.

Under normal circumstances the transition of a given area from the non-deepset to the deepset category will take several years. Taking into account the climatic variation from year to year it is necessary to analyse at least several years of water level data to determine a trend in groundwater levels.

DPHE is responsible for planning and implementation of the domestic water supply for the rural population and has to take actions before alarming reports about epidemics, caused by scarcity of drinking water, start arriving to the Dhaka office. Such actions would be easier, if the (probably) insufficient number of TARA pumps was distributed according to the actual information received from the water level monitoring network.

It should be kept in mind, that the developed computer model may be adequate for providing estimated for the total population affected, but is not detailed enough and can not be used for establishing priorities for Upazillas or parts of an Upazilla, competing for deepset pums.

The advantages arising from establishment of a well-functioning water level minitoring network can be summarized as follows:

- an improved delineation of the present deepset areas could be made,

- an early warning about lowering of the water table would be obtained,

- priorities with regard to geographical distribution of the TARAs could be defined and periodically revised, depending on the water level observations,

- areas where the present version of the TARA can not be used, due to lifts exceeding 15m, could be predicted.

All these advantages will be achieved if the development of deepset areas comes close to the predictions from this report.

However, another development is possible; it may show that the predictions about extent of the future and/or delineation of the present deepset areas were too pessimistic, either due to the conservative assumptions made for this excercise or due to lower increase of irrigation withdrawal than anticipated. In this case the monitoring network will help to adjust the TARA pump production figures to the desired level.

Therefore, no matter how the future turns out to be, the existence of a Hydrogeological Monitoring Network will be advantegeous.