Government of the People's Republic of Bangladesh
Bangladesh Water Development Board
Flood Plan Coordination Organisation

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6)

SPECIALIST STUDY

GROUND WATER RESOURCES OF THE NORTHEAST REGION

April 1993

NOT FOR CIRCULATION

Shawinigan Lavalin (1991) Inc.
Northwest Hydraulic Consultants

in association with

Engineering and Planning Consultants Ltd.
Bangladesh Engineering and Technological Services
Institute For Development Education and Action
Nature Conservation Movement

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ACRONYMS AND ABBREVIATIONS

AST	Agriculture Sector Team
BADC	Bangladesh Agriculture Development Corporation
BGS	British Geological Survey
BWDB	Bangladesh Water Development Board
CIDA	Canadian International Development Agency
DSSTW	Deep Set Shallow Tubewell
DPHE	Directorate of Public Health Engineering
DTW	Deep Tubewell
EC	European Community
EC	Electrical Conductivity
Eh	Redox Potential
GPS	Geographical Positioning System
IDA	International Development Agency
MMI	Mott MacDonald International
MMP	Sir M. Mac Donald & Partners
MPO	Master Plan Organization
MTW	Manual Tubewell
NERP	Northeast Regional Project
pH	Hydrogen Ion Activity
SAR	Sodium Adsorption Ratio
STW	Shallow Tubewell
TDS	Total Dissolved Solids
UN DTCD	United Nations Department for Technical Cooperation and Development
USGS	United States Geological Survey
WARPO	Water Resources Planning Organization

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1. INTRODUCTION

1.1 PURPOSE

The purpose of this study is to assess the ground water resources of the Northeast Region. Figure 1 shows the study region. Specific objectives were to:

- delineate areas where ground water is available and suitable for irrigation
- identify programs required for future planning and implementation of ground water development for irrigation.

1.2 APPROACH

The study approach is based on a review of investigations already completed, particularly in the western part of the Northeast Region, and on the use of primary data (ground water levels and quality, well logs and aquifer tests) as needed to provide further clarification on various subjects and locations. The study comprised five tasks, as follows.

First Task

The first task involved the assembly and review of all earlier and recent studies in order to establish the types and quality of data available. Areal coverage and density of information generated by drilling and testing of exploratory and production wells in various parts of the region were of major concern, as it was considered necessary to establish for which parts of the region sufficient information is available to support qualified estimates of ground water potential, and in which parts there is not.

Primary data on ground water levels and quality observed at wells and piezometers in the monitoring network was also assembled and reviewed.

Completion of this task resulted in division of the Northeast Region into four subregions each characterized by the level of information available for the estimation of ground water potential.

Second Task

The second task involved the preparation of brief descriptions of the physical conditions in each subregion with regard to ground water occurrence, characterization of aquifer sequences, ground water movement and quality, and of ground water potential and availability for future development. These descriptions were based on examination of the available information details of which are to be found in the references cited.

Third Task

The third task involved the analysis of conclusions about the amount of ground water available for future development with due regard to existing and planned water resource development projects focused on irrigation.

Fourth Task

The fourth task involved the preparation of brief descriptions of existing and contemplated minor irrigation projects with emphasis on their ground water development component, i.e the type and number of wells included and the areas irrigated with ground water.

Fifth Task

The fifth task involved summarizing recognized deficiencies in the existing data base, and preparing recommendations for further data collection.

2. PRECEDING STUDIES AND DATA SOURCES

2.1 Introduction

Systematic studies of the ground water resources of the Northeast Region have mainly been carried out by preceding consultants. The most comprehensive of these is the Deep Tubewell II Project which has been in progress since 1983 and was completed in 1992 (MMI, 1992a). The main sources of primary data for these studies are the production well drilling program of BADC, and the ground water level and quality monitoring programs of the BWDB. Recently, there has also been an input on water quality from the BGS. Data available up to 1987 have mainly been incorporated in the National Water Plan -Phase II.

2.2 Definition of Subregions

Preceding consultants have studied the ground water resources of three subregions of the Northeast Region, here identified as the Northwest, West and East Subregions; these subregions correspond with the consultant's project areas. Between the West and East Subregions there is a fourth, the Central Subregion, which has not been systematically studied. Each subregion consists of a group of *thanas*. Figure 3.1 shows the subregion boundaries, and the *thanas* within each subregion. Also shown in this figure are the numbers of shallow (STW) and deep (DTW) tubewells operating in each subregion and *thana* in 1991; these numbers are taken from the well inventory prepared by the CIDA Agricultural Sector Team (AST, 1991).

2.3 Northwest Subregion

The Northwest Subregion includes the whole of Sherpur district, the northern part of Jamalpur district. Parts of Mymensingh and Netrakona districts were also included in this study.

The preceding consultant carried out a five months study (February-June 1982) based on a tubewell drilling and aquifer testing program executed by BADC (MMP, 1982). The study evaluated three aquifer tests specified by the consultant, and ground water level and quality data available from BWDB and other sources. A mathematical model was developed and calibrated, and used to estimate ground water recharge.

The BWDB ground water level monitoring network originally consisted of 11 dug wells installed between 1971 and 1977. These were replaced by 7 piezometers installed during 1985-88. Weekly observations are available in BWDB Water Supply Papers (BWDB 1981, 1984c, 1985, 1986a, 1987b, 1988, 1989, 1990, 1991a).

Systematic sampling of ground water quality was carried out by BWDB at two locations between 1979 and 1983, and one-time samples were taken at another six locations (BWDB 1983, 1984a, 1984b).

Depth-storage relationships, and ground water potential for extraction by various types of well (STW, DSTW, DTW-1, DTW-2) are available in the National Water Plan - Phase II (MPO

1987b, 1987c, 1990) for seven *thanas* in Sherpur and Jamalpur districts: Islampur, Dewanganj, Nakhla, Nalitabari, Sherpur, Sribardi, and Jhenaighati.

2.4 West Subregion

The West Subregion comprises the western sector of the Deep Tubewell II Project. It includes the districts of:

- Netrakona, except for Kaliajuri *thana*
- Mymensingh, except southwest of the Old Brahmaputra River
- Kishoreganj, except for Itna and Astagram *thanas*
- Gazipur, Kapasia *thana* only
- Narsingdi
- Narayanganj
- Munshiganj, a small part only.

The Deep Tubewell II Project has provided for this subregion the most comprehensive data available for any part of the Northeast Region (MMI 1992a, 1992b, 1992c, 1992e). The primary source of data for this project has been an extensive deep tubewell drilling, construction, and testing program carried out by BADC during 1983-92. In 1991 there were 1365 DTW's in production in this subregion (MMI 1992b).

In the northern part of this subregion, in the districts of Netrakona, Mymensingh and Kishoreganj, the BWDB ground water level monitoring network originally consisted of 52 dug wells; 12 of these were included in the network as early as 1966, and the remainder mainly during 1974-78. From 1975, and mainly during 1984-89, 46 piezometers were installed of which 27 replaced dug wells. In the southern part of the subregion, in the districts of Narsingdi and Narayanganj, and in Kapasia *thana*, the BWDB network originally consisted of 29 dug wells; 18 of these were included in the network during 1975-77, and 11 during 1978-80. Between 1977 and 1989 10 piezometers were included in the network, four of these replacing dug wells. Weekly observations of ground water level are available in BWDB Water Supply Papers (BWDB 1981, 1984c 1985, 1986a, 1987a, 1988, 1989, 1990, 1991a). One automatic ground water level recorder was installed by BWDB at Mymensingh, and it has operated since 1981 (BWDB 1991b).

Systematic sampling of ground water quality was carried out by BWDB at 7 wells (Nos. 41, 44, 45, 46, 47, 48 and 53) between 1979 and 1983, and one-time samples were taken at another 11 wells (BWDB 1983, 1984a, 1984b). Recently, the BGS has taken samples from 40 wells in this subregion; major and minor ion, and trace element concentrations, were determined. BGS also determined stable oxygen and hydrogen isotope concentrations for 30 samples (Davies 1992, Davies and Exley 1992)

Depth-storage relationships, and ground water potential for extraction by various types of well (STW, DSTW, DTW-1, DTW-2) are available in the National Water Plan - Phase II (MPO 1987b, 1987c, 1990) for all *thanas* in this subregion except for Bandar *thana* of Narayanganj district.

2.5 Central Subregion

The Central Subregion, which has not been systematically studied, includes:

- Sunamganj district
- Kaliajuri *thana* of Netrakona district
- Itna and Astagram *thana* of Kishoreganj district
- Ajmiriganj *thana* of Habiganj district

This subregion is very low-lying, subject to deep inundation during the monsoon season, and has rather limited access.

The BWDB ground water level monitoring network in this subregion consists of one dug well, and 12 piezometers of which 9 were installed in 1975. The monitoring points are located in the following *thanas*: Jamalganj (3), Derai (1), Kaliajuri (2), Itna (2), Astagram (2), and Ajmiriganj (1). Weekly observations of ground water level are available in BWDB Water Supply Papers (BWDB 1981, 1984c, 1985, 1986a, 1987a, 1988, 1989, 1990, 1991a).

No systematic sampling of ground water quality has been carried out in this subregion. The BGS sampled only one well (No.58 in Chhatak *thana*).

Depth-storage relationships, and ground water potential for extraction by various types of well (STW, DSTW, DTW-1, DTW-2) are available in the National Water Plan-Phase II (MPO 1987b, 1987c, 1990) for all *thanas* in the subregion.

2.6 East Subregion

The East Subregion comprises the eastern sector of the Deep Tubewell II Project. It includes the districts of:

- Sylhet
- Moulvi Bazar
- Habiganj, except for Ajmiriganj *thana*

The Deep Tubewell II Project, and earlier work by BWDB and BADC, have provided a fair amount of data on the ground water resources available in this subregion. The primary sources of data have been limited exploratory deep tubewell drilling and aquifer testing programs carried out by the Project and the BWDB, and the preceding exploratory and exploitary drilling and pumping of more than 200 deep tubewells in the area by BADC (MMI 1986, 1990a, 1990b, 1992f: BWDB 1986b).

The BWDB ground water level monitoring started in 1965-66 with observations at 53 dug wells distributed throughout the subregion; these dug wells were all replaced by piezometers between 1984 and 1988, although four of the dug wells in Sylhet district, and six in Moulvi Bazar district, are still observed. Another 34 piezometers were installed earlier between 1974 and 1976. Weekly observations of ground water level are available in BWDB Water Supply Papers (BWDB 1981, 1984c, 1985, 1986a, 1987a, 1988, 1989, 1990, 1991a). One automatic ground water level recorder was installed in Sylhet district by MMI, and has been operated by BADC since 1986.

Systematic sampling of ground water quality was carried out by BWDB at four wells (Nos. 78, 79, 80 and 81) between 1979 and 1983, and one-time samples were taken at another five wells (BWDB 1983, 1984a, 1984b). The BGS has recently taken samples at 20 wells, and determined the concentrations of both major and minor ions, and of trace elements (Davies 1992, Davies and exley 1992).

Depth-storage relationships, and groundwater potential for extraction by various types of wells (STW, DSTW, DTW-1, DTW-2) are available in the National Water Plan-Phase II (MPO 1987b, 1987c, 1990) for all *thanas* in this subregion, except for Madhabpur *thana* in Habiganj district.

3. GROUND WATER POTENTIAL AND AVAILABILITY FOR FUTURE DEVELOPMENT

3.1 Geomorphology and Physiography

Three geomorphologic zones are recognized in the region: hills, terraces and floodplains (Figure 4.1) (MPO, 1987a).

The region is flanked to the north by, from west to east, the Garo, Khasi and Jaintia Hills of the Shillong Plateau, and to the southeast by the fold belt of the Tripura Hills (known within Bangladesh as the Sylhet Hills). At the foot of these hills piedmont plains exist.

The northwestern and western parts of the region comprise the Old Brahmaputra floodplain. Terraces of the Madhupur Tract border this floodplain in the southwest. In the extreme south the Old Brahmaputra floodplain gives way to the Middle Meghna floodplain.

The dominant physiographic unit of the central part of the region is the Sylhet Basin. Further east is the meander floodplain of the Surma and Kushiyara Rivers which could be considered a part of the same floodplain as the Sylhet Basin.

3.2 Aquifer Sequence Characteristics

Two aquifer sequences are recognized when describing ground water occurrence in the Northeast Region (MPO, 1987 b): upper aquifer and lower aquifer. Stratigraphically, the aquifer sequences were deposited during Miocene-Pleistocene and Holocene times, and are identified as the Dupi Tila and Dihing formations, and as Recent Alluvium.

The upper aquifer sequence has been generalized based on an evaluation of more than 17000 lithological logs and over 7000 pumping tests on wells reaching down to about 300 m (MPO 1987 b). According to this generalization the upper aquifer sequence (B1 of Figure 4.2) is described as a three-layer system consisting of:

- a top silty clay/silt layer with thickness ranging from 0m to 120 m.
- a second, composite aquifer layer of fine to very fine sand with thickness ranging from 3 m to 60 m, but averaging about 20 m.
- a third, main aquifer layer of fine, medium and coarse sand ranging in thickness from 30 m to 60 m, but with layers of intercalated clay and silt

This aquifer sequence extends to a depth of 150m (MPO 1987b). Variations of this generalized sequence are shown in Figure 4.2, and discussed further below.

Based on an evaluation of 36 lithological and 20 geoelectrical logs of gas wells and deep water wells, Jones (1985) proposed the existence of six aquifer sequences separated by clay aquicludes; of these, the top two are recognized as the lower and upper aquifer sequences in the Northeast

Region (MPO 1987b). Jones considered the lower aquifer sequence to be recharged through its outcrops in the Sylhet Hills and, mainly, further south in Tripura, India; if this is correct the lower aquifer sequence has a relatively small recharge area limited to a maximum of about 4000 km^2. The required depth of drilling to intersect the lower aquifer sequence is estimated to be between 750 m and 1400 m; if this is correct the lower aquifer sequence lies well beyond the range of economic exploitation which is typically about 200 m. For these reasons, low recharge and great depth, this lower aquifer sequence need not be considered further.

Northwest Subregion

According to the preceding consultant four aquifer units exist in this subregion: Old Brahmaputra, Brahmaputra Floodplain, Paleo-Brahmaputra, and Piedmont (MMP 1982).

The Old Brahmaputra Unit consists of a 40m to 50m thickness of fine to medium grey sands filling an old channel, and overlain by transgressed sediments of diverse composition. The permeability was found to decrease in the direction of flow from 60m/d to 25m/d, and the specific yield was estimated to be 7.5%.

The Brahmaputra Floodplain Unit consists of a 30m to 50m thickness of sands, coarsening with depth, and overlain by 3m to 10m of surface clays and silts. The permeability was estimated to be between 45m/d and 95m/d, and the specific yield at 8.0%.

The Paleo-Brahmaputra Unit, in the central eastern part of the subregion, consists of:

- an aquifer of Holocene sediments 10m to 15m thick consisting of medium to coarse sands, with some gravel, and overlain by surface clays
- an intermediate aquiclude consisting of clay
- an aquifer of Pleistocene sediments below a depth of 25m to 45m
- a clay aquiclude below a depth of 90m

The permeability of the Holocene aquifer was estimated to be 10m/d to 20m/d, while that of the Pleistocene aquifer was estimated between 20 m/d and 60m/d. The specific yield of the Holocene aquifer was estimated at 5.0%.

The Piedmont Unit, in the northern part of the subregion, consists of:

- surface clays and silts to a depth of 15m to 25m
- an upper composite aquifer consisting of alternating sand and silt lenses to a depth of 40m to 50m
- a lower sandy aquifer down to about 75m depth
- a clay layer extending down to about 100 m depth.

The permeability of the upper composite aquifer was estimated at less than 20m/d down to 40m depth, and the specific yield at 6.0%. The permeability of the lower sandy aquifer was estimated to be 35m/d.

West Subregion

According to the preceding consultant (MMI 1992b) three aquifer units exist in this subregion: Brahmaputra (B), Piedmont (P), and Madhupur (M). The areal extent of these units is shown in Figure 4.1.

The Brahmaputra Unit was differentiated into three types: B1, B2 and B3. The B1 corresponds to the three-layer surface aquitard/composite aquifer/main aquifer system referred to above (Figure 4.2). The B2 and B3, while similar to B1, are distinguished from it by the presence of an intermediate aquitard between the composite and main aquifers, and the B3 is distinguished from the B2 by the presence of a particularly thick surface aquitard. The B2 is further differentiated into sub-types B2a, b and c, based on the relative thicknesses of the surface and intermediate aquitards.

In B1 the thickness of the surface aquitard is usually less than 10m, but it can be 10m to 20m thick. The depth to the top of the main aquifer is 30m to 40m. Most permeability values for the main aquifer are between 30m/d and 40m/d, and specific yields are between 5% and 7%.

In B2a and B2c the thickness, depths and aquifer characteristics are similar to those mentioned for B1 but, except in the south, in Narsingdi district, higher permeabilities are encountered ranging from 50m/d to 60m/d.

In B2b the thickness of the intermediate aquitard may be between 20m and 40m, and the depth to the top of the main aquifer between 40m and 60m. Permeabilities are low, typically between 20m/d and 30m/d and sometimes less than 20m/d, and specific yields are between 4% and 6%.

In B3 the thickness of the characteristically thick surface aquitard reaches as much as 60m in Nandail *thana*, and the prevailing permeability of the main aquifer is between 20m/d and 30m/d.

The Piedmont Unit in this subregion has the same geometry and characteristics as for this unit in the Northwest subregion - see above and Figure 4.2.

The Madhupur Unit underlies the Madhupur Tract terraces in the south western part of this subregion where types M2 and M3 are found. The surface aquitard consists of Madhupur clay and silt, and the main aquifer of Dupi Tila sands. The depth to the top of the main aquifer in M3 is between 30m and 50m, while the thickness of the surface aquitard is between 10m and 30m. Permeabilities are relatively high being between 50m/d and 60 m/d, and the specific yield is between 4% and 5%.

The *Thana* Data Sheets prepared for most *thanas* in this subregion by the Deep Tubewell II Project consultant (MMI 1992c) are an excellent tool for use in planning, designing and implementing new wells. For example, the Sheet prepared from a statistical evaluation of 221 DTWs in Purbadhala *thana* shows that screenable aquifer will be encountered at a depth between 52 m and 55 m with a probability of 90%, and that the aquifer will probably consist 29% of coarse sand and 43% of medium sand.

Central Subregion

The only information available on the lithology of the upper aquifer sequence in this subregion comes from 22 exploratory/exploitary boreholes drilled by BADC in Chhatak *thana* (MMP 1986), and from a deep borehole drilled and tested by BWDB in Sunamganj (BWDB 1986 b).

The BADC boreholes were drilled to depths of between 90 m and 100 m. A screenable aquifer was located in most of the boreholes below 46m depth. Thirty metres of screen were placed usually starting at depths between 52m and 58.5m. Pumping tests were carried out with a constant discharge of 84.9 l/s and with an average drawdown of 11.1m.

The BWDB borehole was drilled to a depth of 249m. Materials encountered were as follows:

- clay, from the surface down to 16.8 m depth
- fine sand, 3 m thick, from 16.8 m to 19.8 m depth
- clay, from 19.8 m down to 127.4 m depth
- fine to medium sand aquifer, 15.8 m thick, from 127.4 m down to 143.2 m depth
- three fine sand aquifers separated by clay aquicludes from 143.2 m down to 249 m.

East Subregion

The eastern part of the region is mostly underlain by Quaternary Alluvium deposited at the same time as the unconsolidated sediments found in the western part of the region. However, the sediments in the eastern part were deposited by the Meghna and its tributaries with drainage basins in the hills of the Shillong Plateau and in Tripura, while those in the western part were deposited by the larger Brahmaputra river system. As a consequence, the sediments in the eastern part are inclined to be more variable, and not as well sorted, as the much larger Brahmaputra deposits, and there are more frequent occurrences and greater thicknesses of non-aquiferous sediments in the lithologic logs of boreholes in the East Subregion. (Figure 4.3).

This lithologic condition is reflected in the generally lower permeabilities of the East Subregion aquifers which vary mainly between 10 m/d and 25 m/d, and in the lower probability of encountering a screenable aquifer. In the East Subregion this probability is 55% at a depth of 52m to 55m (MMI 1992f), whereas in the West Subregion, in Purbadhala *thana*, it is 90%.

It has been suggested that aquifers in this subregion lack continuity (MMP 1986). It is also evident that the generalized upper aquifer sequence, the three layer system, does not apply here. Evaluation of drawdowns in piezometers monitoring the aquifers indicates that confined aquifer conditions may prevail in the subregion.

3.3 Ground Water Level Fluctuations and Movement

Ground Water Level Observation Networks

The BWDB maintains a database of weekly observations of the ground water level at 202 locations in the Northeast Region (Figure 4.4). Observations are currently made in 53 dug wells and 60 piezometers, and in another 89 piezometers which replaced, during 1984-88, dug wells used earlier. Some water level observations go back to the years 1965-66.

In addition, 18 automatic ground water level recorders were installed by MMI during the Deep Tubewell II Project, 6 in 1986 and 12 during 1989-91; these are maintained by BADC. With the exception of one installed in Sylhet district, all are installed in the West Subregion.

Ground Water Level Fluctuations

Vertical fluctuations of the water table in the unconfined aquifer are considered to be the dominant component of ground water movement in the Northeast Region, as in the rest of Bangladesh.

During May to October the aquifers are recharged by the infiltration and deep percolation of monsoon rainfall and flood water. The rise in water table level begins with the onset of the monsoon rains in late May and continues through the following months until a peak is reached in September/October. During the subsequent dry season the water table level declines as a result of evapotranspiration supported by capillary flux from the water table through the surface clays and silts, outflow of ground water into beels, khals and rivers, and withdrawals from wells for irrigation and domestic use. This cycle in water table level is repeated annually (Figures 4.5 and 4.6).

Monitoring of the ground water level cyclic fluctuation provides a clear indicator of ground water replenishment. If the water level attained at the end of the wet season is higher than it was at the end of the previous wet season then recharge during the wet season has exceeded all withdrawals, but if it is lower then withdrawals have exceeded recharge.

Imprecision often exists in the use of the terms: "water level", "water table", and "piezometric surface". Therefore, definitions of these terms are given here to clarify their meanings as they are used throughout this report.

"The water table is defined as the surface on which fluid pressure in the pores of a porous medium is exactly atmospheric" (Freeze and Cherry, 1979). The location of this surface is disclosed by the water level encountered in a well penetrating the surficial deposits. A porous medium in which the water table forms the upper boundary is an unconfined, or water table, aquifer. The water level in a monitoring well in an unconfined aquifer is always coincident with the water table. Unconfined aquifers occur near the ground surface.

"Potentiometric (piezometric) surface" is defined as the surface of the water level elevations in wells penetrating a confined aquifer. A confined aquifer is an aquifer which is confined between two aquitards or two aquicludes. Confined aquifers are located at depth and the water level in a well drilled into a confined aquifer is found to rise above the top of the aquifer.

Figures 4.5 and 4.6 illustrate water level fluctuations below the ground surface observed at BWDB network monitoring points located at two extremities of the Northeast Region. Figure 4.5 relates to a monitoring point in Dewanganj *thana* of Jamalpur district in the Northwest Subregion. From 1971 until 1985 observations there were made in a dug well 8.0 m deep; since 1985 the observations have been made in a replacement piezometer 31.7 m deep. Prior to 1985 the amplitude of the annual fluctuation was approximately 7 m, and the level recovered almost to ground level in all years. Since 1985, however, the amplitude was only 5 m, and the level recovered only to about 1 m below ground level. It is apparent that the piezometer entered a lower aquifer with a different response to external stresses from that of the shallow aquifer penetrated by the dug well. The smaller amplitude of ground water level fluctuations in the piezometer is indicative of the higher specific yield of the deeper part of the aquifer.

Figure 4.6 relates to a piezometer located in Kanairghat *thana* of Sylhet district at the northeastern tip of the East Subregion; the piezometer is 58.3 m deep. The water level observations reveal a regular annual cycle, but with an amplitude of barely 2m and with the water level recovering only to within 2 m to 2.5m of the surface. In this case it is apparent that the piezometer penetrates a confined or semi-confined aquifer, and that the water level observations reflect the potentiometric surface for this aquifer which responds to stresses (where from ?) causing fluctuations. The ground water flow systems of the region are not yet defined and, consequently, possible recharge/discharge areas are not known.

Seven other ground water level hydrographs were prepared for observation points selected at random from groups of observation points located in various parts of the Northeast Region and with the intention of covering the whole region. These are presented in Appendix A together with explanatory notes.

Ground Water Movement

Maps showing ground water level contours, comprise an evaluation of the ground water level observations made at monitoring network wells and piezometers. Such maps are available from the Deep Tubewell II Project for the West and East Subregions, but none are available for the Northwest and Central Subregions.

For the West Subregion a map entitled "Piezometric Surface: January 1989" is available (MMI 1992b), based on BWDB network observations and recorders installed by the Deep Tubewell II Project. This map could eventually be used to interpret groundwater movement in the northern half of the West Subregion; somewhat predictably the movement is indicated as being south eastward towards the Sylhet Basin and the Meghna River. It is not clear, however, whether the data all relate to the water table in the unconfined surface aquifer, to the potentiometric surface of a confined aquifer, or to a mixture of both.

For the East Subregion two maps are available (MMP 1986), one for the highest water levels observed (3 August 1981), the other for the lowest (1982). Again, it is not clear whether the data are homogeneous or not. These maps do, however, shed some light on the following problem.

In the East Subregion, north trending anticlines of the Sylhet Hills plunge below the more recent sediments of the Surma-Kushiyara Floodplain and the Sylhet Basin. The question arises as to whether the submerged portions of these anticlines could affect ground water movement in the more recent surface sediments. If this were so ground water contour maps would indicate the existence of ground water divides over the submerged anticlines with relatively steep ground water level gradients towards the intervening synclines. Such features are not seen in the two piezometric maps available for this subregion; instead they show the ground water level dropping uniformly from east to west by about 4.6 m and 4.9 m at the lowest and highest ground water levels, respectively, over a distance of some 60 km. This suggests, quite strongly, that the submerged anticlines do not affect ground water movement in the more recent surface sediments.

In evaluating ground water level data it is important to distinguish between data representing the water table in unconfined aquifers, and those representing the potentiometric surface of confined aquifers. It is not clear in some reports whether this distinction was made while preparing the ground water level contour maps they present. These maps should therefore be used with caution.

3.4 Ground Water Quality

Quality of Available Data

Ground water quality data for 1979-83 were published by BWDB (BWDB 1983, 1984a, 1984b), as described in Section 3 above. These data were organized by NERP into tables (Appendix B) and their accuracy checked by calculating ionic balances, and comparing measured and calculated values of total dissolved solids. Out of a total of 81 analyses only 37 (from 23 sampling sites) had cation-anion balance errors of less than 10%; this acceptance level compares to a usually accepted one of 5%. Considering this high error rate it was concluded that the quality of these data leaves a lot to be desired, and that full use of them could not be made. Thus it was recognized that there is a definite need for the reliable collection and analysis of water quality data both for long-term ground water quality monitoring and for specific studies. Fortunately, the BGS water quality survey (Davies and Exley 1992) serves both these needs in a large part of the Northeast Region.

BWDB Water Quality Data

Based on the 37 acceptable water analyses, ground water quality in the Northeast Region appears to be very good. Sodium bicarbonate and calcium bicarbonate ground waters prevail.

Sodium absorption ratios (SAR) for the 37 acceptable analyses were low, but with a few exceptions. The results summarize as follows:

- 18 samples classified as S1C1, i.e. low sodium (alkali) hazard with low salinity hazard
- 16 samples classified as S1C2, i.e. low sodium hazard with medium salinity hazard

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- 3 samples classified as S2C2, i.e medium sodium hazard with medium salinity hazard.

Of the last three samples, two were from the East Subregion, and one from the Central Subregion. With regard to these 37 samples it has to be said that they do not represent coverage of the region and could be statistically significant.

Boron concentration exceeded the recommended limit for use in irrigation at one location in the North West Subregion.

Total dissolved solids (TDS) were low, but exceeded the recommended limit of 500 mg/l for drinking water in a few cases.

Nitrate (NO_3) concentrations at some locations reached up to 40 mg/l which is suggestive of localized ground water contamination. The recommended concentration limit for NO_3 in drinking water given by WHO is 50 mg/l; concentrations above this limit render water unfit for consumption by human infants. Of course, the sanitary condition of water is not indicated by chemical testing alone.

BGS Water Quality Data

A comprehensive report is available on the results of a pilot survey of ground water quality carried out by the BGS in 1992 mainly in the West and East Subregions. The report (Davies and Exley 1992) presents an atlas of some 30 maps summarizing the results of ground water analyses made in relation to aquifers and soils in these subregions. This atlas is of immediate practical use because it indicates danger zones with ground water which is potentially harmful to humans, animals, plants, and equipment. The maps show isolines of the concentrations of various chemical constituents and parameters, and one shows schematically the distribution of ground water by chemical types.

In the BGS pilot survey ground water samples were taken from 150 shallow and deep tubewells in central and northeastern Bangladesh. Of these, 62 were taken in the Northeast Region, 40 in the West Subregion, 20 in the East Subregion, and two in the Central Subregion. The wells sampled were selected on the basis that a lithologic record existed for the well, or could be correlated reliably from those of neighbouring wells.

At all sampling wells the determinations of pH, Eh, EC and HCO_3 were carried out at the well head. The concentrations of major and minor ions, and of trace elements, were carried out at BGS headquarters in Wallingford. The modes of occurrence of specific element complexes (Al, Mn, Fe) were determined for 12 samples using modern physico-chemical methods at Stirling University; of these, three samples were from the West Subregion, three were from areas adjacent and close to the West Subregion, and one was from the north of the East Subregion. The 30 samples for which stable isotope concentrations of O and H were determined were all from the West Subregion. Some conclusions of the BGS survey are referred to in the discussions, given below, of ground water quality in the subregions.

It is noteworthy that values of SAR, one of the main criteria for assessing the suitability of water for irrigation use, are not given in the BGS main report (BGS 1992), nor are values given for the major ions used in computing SAR. The BGS detailed analytical results are given in a separate volume, obtainable from BGS only on request, and were not at hand for the preparation of this report; it should be obtained in support of any further hydrogeological work in the Northeast Region.

Northwest Subregion

Data on ground water quality in this Subregion are limited to old data published by BWDB and by the preceding consultant (MMP 1982).

The ground water of this subregion, particularly in the south central part, is of the Calcium/Magnesium Bicarbonate Type typical of ground water recharge areas. Westwards the water changes, first to Mixed Cation Bicarbonate Type, and then to Sodium Bicarbonate Type. Northwards the change proceeds only to Mixed Cation Bicarbonate Type. The change from Calcium/Magnesium to Sodium is here attributed to ion exchange because there is no associated increase in salinity, specifically chlorides.

On the west bank of the Old Brahmaputra River, at Jamalpur, the ground water is of Calcium/ Magnesium Chloride Type; the chloride concentration is between 230 mg/l and 245 mg/l (below the recommended limit for drinking water), and the electrical conductance (EC) is 1210 micro S/cm.

In the southeastern part of the subregion high phosphorous contents were found in the water from numerous wells, the origin of which has not been investigated. Eh measurements did not provide meaningful results, although the high concentrations of ferrous iron and the low, or zero, concentrations of sulphates are indicative of the reducing character of the ground water. The smell of hydrogen sulphide was pronounced at one well.

The high concentrations of iron and manganese are higher than recommended for drinking water but do not represent a health hazard for humans. The usually recommended concentration limits for these metals were set low, not because of harm to humans, but for the purpose of avoiding problems in household use associated with the precipitation of their oxides which causes blockages in pipes and staining. Here the high concentrations reported are indicative of early clogging of well screens.

The dissolved solids and SAR values are generally low, SAR varying between 0.12 and 3.47.

West Subregion

The West Subregion was adequately covered with sampling points in the recent systematic survey of the BGS; the only exceptions to this relate to the northeast and southeast extremities of the subregion.

In the north of the subregion, ground water of the East Piedmont aquifer changes southwards from Calcium to Sodium Bicarbonate Type; silica is high, phosphorus greater than 1 mg/l, fluoride up to 1.2 mg/l, ferrous iron up to 20 mg/l, and some manganese and aluminum is present. The ground water appears to be fairly old as indicated by 018 stable isotope analysis.

The northern part of the Old Brahmaputra Floodplain aquifer, located between the present course of the Old Brahmaputra and the Sylhet Basin, has ground water which changes eastward from

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Calcium to Sodium Bicarbonate Type. Mineralization, including halides and iron, also increases eastward, as does pH which increases from less than 7 to 7.5. Conductivity is around 400 micro S/cm, and the contents of silica, phosphorus (0.3 to 1.0 mg.l), and zinc (greater than 0.15 mg/l) are high.

In the east of this part, close to the Central Subregion, in Mohanganj *thana* of Netrokona district, ground water of the Sodium Chloride Type was identified; this water has a high content of other halidies (fluorides, bromides and iodides) and phosphorus, a sodium content of 182 mg/l, and a conductivity of 1000 microS/cm; this is very old water, or possibly a mixture of formation water and brackish estuarine water. The SAR value of this water is almost 25 indicating a very high sodium (alkali) hazard if it is used for irrigation. It is considered that the surrounding area should be investigated in more detail.

In the northwest of the subregion, at Phulpur, well MY-324 yielded water with a boron concentration of 1.2 mg/l. The recommended limits on boron concentration in water for irrigation use are 0.67 to 1.00 mg/l for sensitive crops, and less than 1.33 to 2.00 mg/l for semi-tolerant crops. Consequently this observed boron concentration needs to be verified.

In the central part of the subregion the ground water is predominantly of the Calcium Bicarbonate Type, with pH values less than 7, Eh potentials of 300 mV to 400 mV, and conductivities less than 300 microS/cm. The aquifers here consists of typically brown sediments, and the ground water has a low content of dissolved iron; silica is high at 20 mg/l to 25 mg/l, and sulphate is more than 1 mg/l. Generally, the ground water in this part is considered of good quality.

In the east of this central part, between Netrakona and Kishoreganj, health problems occur, and are attributed to a deficiency of iodine in the groundwater used for drinking. Some fish mortalities and crop withering have been noted in the southeast of this part, and may be caused by high concentrations of zinc which range from 0.15 mg/l to a maximum of 3.23 mg/l in Kapasia *thana*; these compare to a recommended limiting zinc concentration in drinking water, based on taste, of 5 mg/l. The highest concentrations of sodium (176 mg/l) and boron (0.47 mg/l) were found in Tarail *thana* of Kishoreganj district.

In the extreme south of this subregion ground water in the Meghna Floodplain aquifer is of the Calcium Bicarbonate Type, with low Eh potentials of 100 mV to 200 mV and pH ranging from less than 6 to 6.5. The quality of this ground water is considered good.

Central Subregion

There is no spatial information available on ground water quality in this Subregion.

Among BWDB samples, one taken from a borehole in Sunamganj *thana* at a depth of 76.2 m, indicates the ground water is of Sodium Bicarbonate Type; the (sodium + potassium) concentration, expressed in mg/l of sodium, was 194.5 mg/l; the calculated TDS was 721 mg/l; and the SAR value was 11.7 indicating that the water is S2C2, or medium sodium/medium salinity hazard if used for irrigation.

The BGS sampled two wells in Jagannathpur *thana*. From concentration isolines in the BGS atlas it appears that the ground water here is also of Sodium Bicarbonate Type with a relatively high sodium concentration of greater than 100 mg/l.

There is an acute shortage of safe drinking water in some areas so that, even though no major irrigation development is envisaged, the ground water of this subregion ought to be investigated.

East Subregion

The ground water of the Surma-Kushiyara Floodplain is pre-dominantly of the Sodium Bicarbonate Type; conductivities are greater than 400 microS/cm and Eh potentialls are low ranging from 100 mV to 200 mV; the latter is indicative of a reducing characteristic of the ground water, and of high ferrous iron contents.

In the northern part of the subregion several samples were found to have high concentrations of aluminum and phosphates; phosphates, expressed as phosphorus, ranged from 3 mg/l to 8 mg/l. High phosphorus (8 mg/l) and high halides, together with large quantities of dissolved carbon dioxide and methane, were noted by the BGS at one well in Gowinghat *thana*. Methane gas was also detected in ground water samples from Zakiganj. The addition of ground water high in dissolved gases to fish ponds had disastrous effects on the fish population, and problems were also encountered when using this water for irrigation. Hydrogen sulphide was also encountered in some wells.

In the northern part of the Sylhet Hills the ground water is of the Calcium Bicarbonate Type. Eh is high and pH is low, ranging from 6.0 to 6.5; the lowest pH in the area was 4.04, measured in a well at Beani Bazar; these waters are therefore quite corrosive.

In the southern part of the subregion high concentrations of zinc, up to 1 mg/l, were found.

Along the western side of the subregion, from northwest to southwest, coverage by reliably analyzed samples is insufficient to evaluate, from the point of view of ground water quality, the feasibility of ground water development. BWDB data from Nabiganj, Habiganj, and Chunarughat *thanas* could suggest that the ground water is of the Sodium Bicarbonate Type. All the analyses evidence missing anions in the ionic balance, maybe phosphates. The area needs to be sampled in a baseline survey.

3.5 Current Estimates of Ground Water Use and Recharge

The current use of ground water is reflected in the Census of Irrigation in Bangladesh (AST 1991), carried out in March 1991. The census covered ground water extraction by STWs, DSSTWs, DTWs and MTWs (manually operated tubewells). Only wells actually operating, according to this census, are considered here in estimating ground water use in the subregions.

In estimating the total ground water volume currently extracted for irrigation, the pumping rates applied for the various well types were as follows:

MTW	:	½ l/s
STW & DSSTW	:	14 l/s
DTWa	:	42 l/s
DTWb	:	70 l/s

The two types of DTW were differentiated in the census as those yielding less than 56 l/s (2 cusecs), and those yielding more than 56 l/s. For the present estimate it was assumed that the

2L

former (DTWa) were yielding 75% of 56 l/s, and the latter (DTWb) were yielding 125% of 56 l/s. Annual extractions were computed assuming 550 hours of pumping (MPO, 1991).

Tables 4.1 to 4.4 list, for each subregion, the number of wells of each type in each *thana*, together with the corresponding irrigated areas. Tables 4.5 to 4.8 present the computed corresponding total yields and annual extractions, the latter appearing in the column headed "USE".

During the past decade several estimates of ground water recharge have been made for Bangladesh, including the Northeast Region, using mathematical models. The most comprehensive of these model studies was carried out by WARPO (formerly MPO) for the National Water Plan, Phases I and II, and it led to estimates of ground water recharge in each *thana*.

For the WARPO model a "usable recharge to technologies" was defined as the annual volume of ground water available to a particular extraction technology (type of well and pump) considering assumed limitations on pumping depth related to flood phase in each *thana*. The resulting estimates of this "usable recharge" were presented on sheets entitled "Ground Water Development Potential for Upazila" (MPO 1991).

For the present estimation of development potential in the Northeast Region, NERP has taken "medium" values of "usable recharge" from the afore-mentioned sheets for flood phase F0 and deep tubewells Type 2, except in cases where flood phase F0 represented less than 10% of the total *thana* area when "medium" values for flood phase F1 were taken. The resulting estimates of "usable recharge" are listed in Tables 4.5 to 4.8 in the column headed "USABLE".

"Usable recharge", as defined by WARPO, does not reflect recharge lost to rivers as base flow, evapotranspiration, and current ground water extraction. These so-called "area limitations" are taken into account by applying a percentage to "usable recharge" in order to obtain an estimate of "available recharge".

For the present estimation of development potential in the Northeast Region, NERP has taken the percentage to be applied to "usable recharge" as 63% based on Table 4.20 in "Northeast Region Ground Water Resources Potential" (MPO 1991). The resulting estimates of "available recharge" are listed in Tables 4.5 to 4.8 in the column headed "AVAILABLE".

The last column in Tables 4.5 to 4.8, headed "USED", gives the annual extraction of ground water, or "USE", as a percentage of the available recharge, or "AVAILABLE".

Although the largest amount of ground water currently extracted in the Northeast Region is used for irrigation, it is necessary to estimate how much is used for domestic water supply because its proportion of the extraction varies considerably across the subregions. This is especially important in the Central and East Subregions where the use of ground water for irrigation is a relatively low proportion of the extraction. The proportion of ground water used for domestic water supply in these subregions could eventually comprise a much higher proportion of total current ground water use than in the two western subregions.

According to WARPO (MPO 1991) the weighted average domestic water use in rural areas is 25 l/day per person. NERP has applied this value to population statistics given by Mohiuddin (1992) for each subregion with the following results.

Subregion	Population	Domestic Water Use (Mm^3/year)
Northwest	1,768,392	16.1
West	8,627,072	78.7
Central	2,245,402	20.5
East	5,020,286	45.8
Total	**17,661,152**	**161.1**

Assumptions regarding the mode of supply of these volumes are discussed for each subregion below.

Northwest Subregion

The AST census (Table 4.1 and Figure 3.1) showed that the numbers of wells operating in this subregion in March 1991 were as follows:

DTW	:	691
STW	:	7597
MTW	:	28344

The majority of these wells were constructed in the past decade.

From the yields given in Table 4.5 it is estimated that the annual extractions by well type are:

DTW	:	69.5	Mm^3
STW	:	210.7	Mm^3
MTW	:	280.6	Mm^3
Total	**:**	**560.8**	**Mm^3**

The total area within this subregion which is irrigated using ground water is 51,992 ha.

From Table 4.5 also it is deduced, by dividing USE by AVAILABLE, that over-extraction of ground water is currently occurring as follows:

Dewanganj *thana*	:	28%
Sribardi *thana*	:	36%
Sherpur *thana*	:	7%

Ground water occurrence in the subregion justifies the assumption that the estimated current annual domestic use of 16.1 Mm^3 is wholely supplied from ground water. When this volume is added to the 560.8 Mm^3 of ground water used for irrigation, it is apparent that total ground water use in the subregion is 576.9 Mm^3, of which domestic use comprises 2.8%.

West Subregion

The AST census (Table 4.2 and Figure 3.1) showed that the numbers of wells operating in this subregion in March 1991 were as follows:

DTW	:	2,908
STW	:	20,156
DSSTW	:	141
MTW	:	8,410

The majority of these wells were constructed in the past decade. From the yields given in Table 4.6 it is estimated that the total annual extractions by well type are:

DTW	:	274.6	Mm^3
STW	:	562.8	Mm^3 (includes DSSTW)
MTW	:	83.4	Mm^3
Total	**:**	**920.8**	**Mm^3**

The total area within this subregion which is irrigated using ground water is 149,200 ha.

From Table 4.6 also it is deduced that over-extraction of ground water is currently occurring as follows:

Kishoreganj district:

Tarail *thana*	:	7%
Katiadi *thana*	:	25%
Kuliachar *thana*	:	44%

Narsingdi district:

Raipur *thana*	:	4%

In two other *thanas* of Narsingdi district, extraction has reached 99% and 97% of available recharge, and in five other *thanas* of Kishoreganj, three of Narsingdi, one of Narayanganj, and two of Mymensingh, extraction exceeds 50% of available recharge.

Again ground water occurrence in the subregion justifies the assumption that the estimated current annual domestic use of 78.7 Mm^3 is wholely supplied from ground water, and when this volume is added to the 920.8 Mm^3 of ground water used for irrigation, it is apparent that total ground water use in the subregion is 999.5 Mm^3, of which domestic use comprises 7.9%.

Central Subregion

The AST census (Table 4.3 and Figure 3.1) showed that the numbers of wells operating in this subregion in March 1991 were as follows:

DTW	:	10
STW	:	275
MTW	:	74

These low numbers contrast sharply with those for the western subregions. The majority of these wells were constructed very recently.

From the yields given in Table 4.7 it is estimated that the total annual extractions by well type are:

DTW	:	1.0	Mm^3
STW	:	7.7	Mm^3
MTW	:	0.8	Mm^3
Total	**:**	**9.5**	$\mathbf{Mm^3}$

The total area within this subregion which is irrigated using ground water is 2645 ha.

From Table 4.7 also, it is apparent that there is no over-extraction in this subregion. However, it is to be noted that for this subregion the values of usable and available recharge may be misleading since knowledge of aquifer occurrence and conditions is limited. Also, in 9 *thanas* out of 15 in this subregion the combined areas of flood phases F0 and F1 comprise only between 0.0% and 7.9% of the *thana* area while the combined areas of flood phases F2 and F3 comprise between 46.1% and 86.8%. In general, therefore, there is not much scope for ground water development in this subregion except eventually in the less flood susceptible *thanas* and those with good access, such as Dharmapasha in the northwest and Itna and Astagram in the south.

Estimated annual domestic water use in this subregion is 20.5 Mm^3. There is inadequate information available on ground water conditions in this subregion, and what is known of them indicates difficulties in locating and exploiting shallow ground water. This does not mean that it is not possible to tap shallow ground water for domestic use at some locations. Because of the lack of information on sources of domestic water supplies in this subregion, it is assumed that most of it comes from surface water. It is proposed in Section 5.2 below that a survey of the present status of domestic water supply in the subregion be carried out.

East Subregion

The AST census (Table 4.4 and Figure 3.1) showed that the numbers of wells operating in this subregion in March 1991 were as follows:

DTW	:	193
STW	:	361
MTW	:	122

The majority of these wells were constructed in the past decade.

From the yields given in Table 4.8 it is estimated that the total annual extractions by well type are:

DTW	:	18.8	Mm^3
STW	:	9.9	Mm^3
MTW	:	1.2	Mm^3
Total	:	**29.9**	$\mathbf{Mm^3}$

The total area within this subregion which is irrigated using ground water is 8938 ha.

The validity of WARPO's recharge model is questionable for this subregion for the following reasons. First, the surface aquitard of silty clay/silt could be considerably thicker than in the western subregions. Also, the sequence of sediments below the surface aquitard in this subregion appears more complex than the three-layer generalized sequence (and its variants) of the West Subregion. In exploratory boreholes, some up to 300 m deep, three to five aquifers separated by aquicludes or aquitards were usually found in this subregion. Consequently, leaky (semi-confined) or confined aquifer conditions may be present in this subregion alongside unconfined surface aquifers. Therefore, the assumption that ground water in these deeper confined aquifers is replenished annually by rainfall and flood water, justifiable in the three-layer model of the West Subregion, may not be generally valid in this subregion. It follows from this argument that the values of usable and available recharge given in Table 4.8 will be valid only in those areas of the subregion where ground water conditions are close to those assumed in the mathematical model of the recharge process i.e the three-layer aquifer model. It seems, on the basis of the present review, that only in *thanas* of the southwest of this subregion do ground water conditions approximate those simulated in the model. More field investigation of this aspect is required.

Estimated annual domestic water use in this subregion is 45.8 Mm^3. This is larger than the volume of ground water currently used for irrigation (29.9 Mm^3). At present it is impossible to judge to what extent water for domestic use is provided from ground water and from surface water. The information on ground water conditions is insufficient for a meaningful assumption to be made in this case. It is proposed in Section 7.3 below that further exploratory drilling and aquifer testing be carried out in this subregion.

3.6 Ground Water Availability for Future Development

It needs to be emphasized that, while the available recharge estimates are useful as a basic tool for planning ground water development, its actual long-term impact in a particular area can be only be evaluated by monitoring local ground water levels to see if over-extraction is occurring. There maybe areas in which over-extraction could occur by pumping, for example, only 60% of the estimated available recharge and, conversely, there may be other areas where pumping could far exceed estimated available recharge without over-extraction occurring. Therefore, suggestions made below on the location and extent of future ground water development for irrigation in the Northeast Region are subject to thorough verification against ground water level trends in the particular areas concerned.

It is forecast that population will increase by 23.32% between 1990 and 2000, and by 59.82% between 1990 and 2015 (World Bank 1991). Populations in the Northeast Region will then be as follows:

Subregion	Population in 2000	Population in 2015
Northwest	2,180,781	2,826,244
West	10,638,905	13,787,786
Central	2,769,030	3,588,601
East	6,190,017	8,023,421
Total	**21,779,733**	**28,226,052**

It is also assumed that domestic consumption of water will increase by 2% annually between 1990 and 2000, and by 3% annually between 2001 and 2015. These increases translate into consumptions of 30 l/d per person in 2000, and 43.5 l/d per person in 2015. Domestic use ofwater in the Northeast Region will then be as follows:

Subregion	Domestic Water Use (Mm3/year)		
	Present	2000	2015
Northwest	16.1	23.9	44.9
West	78.7	116.5	218.9
Central	20.5	30.3	57.0
East	45.8	67.8	127.4
Total	**161.1**	**238.5**	**448.2**

Northwest Subregion

Ground water use for irrigation has, apparently, already reached a high level in this subregion with over-extraction indicated in three *thanas* (See Section 4.5, and Tables 4.5 and 4.9). The actual state of affairs can, however, only be evaluated reliably from ground water level monitoring data, and such evaluations should form the basis for any decision on further ground water extraction in this subregion, particularly in the three *thanas* where over-extraction is indicated. If this evaluation confirms over-extraction then there would seem to be little scope for further ground water development.

The available recharge in this subregion is estimated to be 613.9 Mm^3/year, while present total ground water use is 576.9 Mm^3/year (560.8 Mm^3/year for irrigation and 16.1 Mm^3/year for domestic water supply); hence the presently undeveloped portion of available recharge is 37.0 Mm^3/year. Out of this, 7.8 Mm^3/year may be needed for domestic water supply by 2000, leaving 29.2 Mm^3/year available for irrigation. By 2015, however, another 21.0 Mm^3/year may be needed for domestic water supply, leaving only 8.2 Mm^3/year available for irrigation (Table 4.10).

Present ground water use for irrigation in this subregion is 560.8 Mm^3/year, and the area irrigated is 51,990 ha (Table 4.9); hence the irrigation requirement is for 10786 m^3/ha. Dividing the ground water available for irrigation in 2015 (8.2 Mm^3/year) by this requirement suggests there is scope for irrigation of another 760 ha in 2015.

West Subregion

Ground water use for irrigation has, apparently, also reached a high level in this subregion with over-extraction indicated in four *thanas*, close to full utilization of available recharge indicated in two other *thanas*, and utilization exceeding 50% in eleven more *thanas*. (See Section 4.5, and Tables 4.6 and 4.9). Again, the actual state of affairs can be only be evaluated reliably from ground water level monitoring data, and such evaluations should form the basis for any decision on further ground water extraction in this subregion, particularly in the 4 *thanas* where over-extraction is indicated as already occurring.

The available recharge in this subregion is estimated to be 1749.0 Mm^3/year, while present total ground water use is 999.5 Mm^3/year (920.8 Mm^3/year for irrigation and 78.7 Mm^3/year for domestic water supply); hence, the presently undeveloped portion of available recharge is 749.5 Mm^3/year. Out of this, 37.8 Mm^3/year may be needed for domestic water supply by 2000, leaving 711.7 Mm^3/year available for irrigation. By 2015, however, another 1024 Mm^3/year may be needed for domestic water supply, leaving 609.3 Mm^3/year available for irrigation (Table 4.10).

Present use of ground water for irrigation in this subregion is 920.8 Mm^3/year, and the area irrigated is 149,200 ha (Table 4.9); hence the irrigation requirement is for 6170 m^3/ha. Dividing the ground water available for irrigation in 2015 (609.3 Mm^3/year) by this requirement suggests there is scope for irrigation of another 98,750 ha in 2015. This additional area, if taken up, should be in those *thanas* where over-extraction is not presently occurring or threatening to occur.

Central Subregion

Ground water use for irrigation in this subregion is very limited due to the prolonged and deep flooding, and to poor access.

The available recharge in this subregion is estimated to be 346.2 Mm^3/year, while present total ground water use is only 30.0 Mm^3/year (9.5 Mm^3/year for irrigation and 20.5 Mm^3/year for domestic water supply); hence, the presently undeveloped portion of available recharge is 316.2 Mm^3/year. Out of this, 9.8 m^3/year may be needed for domestic water supply by 2000, and by 2015 another 26.7 Mm^3/year. (Table 4.10).

In this subregion there is virtually no scope for groundwater development for irrigation.

East Subregion

There is a potential for ground water development for irrigation in this subregion. However, without further exploration of the locations, geometry and properties of the aquifers, and also without more studies to quantify the recharge conditions, it is difficult to be committed to any of the existing recharge estimates except the most conservative.

The available recharge was estimated by WARPO as 679.6 Mm^3/year (Table 4.9). This amount, for reasons given in Section 4.5 above, is considered to be on the high side having been derived for ground water conditions other than those prevailing in this subregion. The more conservative estimate of 211.5 Mm^3/year made by BWDB (BWDB, 1986 b), based on an analysis of ground water level hydrographs, is appraised as more appropriate at this stage of knowledge of ground water conditions in this subregion.

While present total ground water use is 75.7 Mm^3/year (29.9 Mm^3/year for irrigation and 45.8 Mm^3/year for domestic water supply); hence, the presently undeveloped portion of available recharge is 135.8 Mm^3/year. Out of this, 22.0 Mm^3/year may be needed for domestic water supply by 2000, leaving 113.8 Mm^3/year available for irrigation. By 2015, however, another 59.6 Mm^3/year maybe needed for domestic water supply, leaving 54.2 Mm^3/year available for irrigation (Table 4.10).

Present ground water use for irrigation in this subregion is 29.9 Mm^3/year, and the area irrigated is 8938 ha (Table 4.9); hence the irrigation requirement is for 3345 m^3/ha. Dividing the ground water available for irrigation in 2015 (54.2 Mm^3/year) by this requirement suggests there is scope for irrigation of another 16,200 ha in 2015.

4. RECOMMENDED GROUND WATER DEVELOPMENT INITIATIVES

4.1 Survey of Domestic Water Supply in the Central Subregion

According to the report: Rural Water Supply Status up to June 1991 (DPHE, 1991), there were 8981 tubewells operational in Sunamganj district in 1991, and serving approximately 1.6 million people or almost the entire population of the district. Experience from site visits in this district does not, however, confirm this apparently highly satisfactory situation. On the contrary, it is reported that surface water is commonly used for domestic water supply not only in Sunamganj district but generally in the Central Subregion, and that this is due to the difficulty encountered in gaining access to the shallow ground water resources which lie beneath thick surficial layers of very fine-grained paludal sediments (clays and silts, often mixed). A health hazard therefore persists throughout the subregion wherever surface water is being used for domestic purposes.

It is recommended that a survey is made of domestic water supply in the Central Subregion in order to define the nature and scale of the well water supply project required to ensure safe domestic water supplies from ground water throughout the subregion. The survey should enumerate households presently using surface water, and those presently using ground water (STW or DTW), for domestic use, and the frequency/severity of intestinal illness, if any, among household members.

4.2 Exploration of Lower Aquifer System

When the more economically accessible ground water resources of the upper aquifer system have been exhausted there will be need to exploit those of the lower aquifer system. Before this situation is reached the ground water resources of the lower aquifer system should be investigated in order to define the nature and scale of the development needed to exploit these resources. Since the yield and quality of ground water from the confined aquifers of the lower aquifer system can be expected to be lower than for those from the unconfined aquifers of the upper aquifer system, and the costs of drilling, well construction, testing and production will be higher compared to the standard for deep tubewells in the Northeast Region.

Comprehensive investigation of the lower aquifer system should include establishing the lithology, geometry and continuity of the lower aquifer sequence, its hydraulic properties and recharge (source and quantity), and the age and quality of the ground water. It is recommended, in view of the scale of such an investigation, that it be carried out by a GOB institution charged with responsibility for basic research into natural resources, and with assistance as necessary from consultants and/or universities specializing in such investigations.

5. FORTHCOMING PROJECTS

5.1 Introduction

Three large projects to support minor irrigation schemes in Bangladesh are about to start, and will have some impact on further irrigation, and ground water development for irrigation, in the Northeast Region; together these may serve 191,000 ha in the region.

5.2 World Bank Shallow Tubewell and Low Lift Pump Project

The World Bank is financing a nation-wide project to distribute low-lift pumps, and to construct and equip shallow tubewells. The project includes for 75,000 shallow tubewells to serve 340,000 ha with ground water for irrigation. It is envisaged that some 66,000 ha in the Northeast Region will benefit from this project.

5.3 ADB Northeast Minor Irrigation Project

The Asian Development Bank is financing the Northeast Minor Irrigation Project (NMIP) under which 20,000 shallow tubewells are to be provided to serve some 80,000 ha in the Northeast Region.

5.4 IDA/EC National Minor Irrigation Development Project

The International Development Agency and the European Community are financing the National Minor Irrigation Development Project (NMIPD) under which deep tubewells are to be provided to irrigate some 45,000 ha in the Northeast Region.

6. RECOMMENDATIONS ON FUTURE DATA COLLECTION AND STUDY

6.1 Ground Water Level Monitoring

The long-term impact of existing large ground water withdrawals needs to be established. The oldest available ground water level records from the monitoring network could facilitate identification of a "baseline ground water level" to which all subsequent ground water levels should be referred. Over-extraction would be indicated by the subsequent water levels falling below the baseline and showing a downward trend over a period of years. Such a study would also serve to identify the various local, intermediate and regional ground water flow systems.

6.2 Assessment of Impact of Ground Water Development

Recent planning and implementation of ground water development while paying attention to estimates of recharge, the number of wells to be constructed, and the selection of suitable technology, is all based on the assumption that the aquifers are fully recharged every year and that, hence, the influence of previous withdrawals is not carried over from one year to the next. This assumption needs to be tested before further large scale ground water development for irrigation is implemented, particularly with reference to the West Subregion.

There has been no thorough regional assessment made with the objective of evaluating the impact on the ground water resource of the annual withdrawal of large quantities of ground water. Approximately 1480 Mm^3/year of ground water are pumped annually from all of the tubewells inventoried in the western part of the region.

The impact study should be designed to test the basic hypothesis for estimates of potential recharge.

To test this assumption the baseline ground water level study recommended in Section 7.1 should be carried out. For the future the significance of ground water level monitoring must be emphasized, and impact assessment studies should be carried out before proceeding with large scale ground water development for irrigation. The continuation of ground water resources development by the installation and exploitation of more tubewells (STW, DSSTW and DTW) in the western part of the region should be closely monitored.

6.3 Exploratory Drilling and Aquifer Testing in the East Subregion

Assessments of ground water resources in the East Subregion differ, and there are areas, such as that south of Moulvi Bazar which are evidently not suitable for development by deep tubewells.

A program of exploratory drilling and aquifer testing should be carried out to fill information gaps on ground water occurrence in these areas; such a program would be carried out as part of a production drilling and well construction project. Ground water dating should be attempted and would involve the application of environmental isotope techniques to ground water samples taken from each aquifer encountered by boreholes penetrating the multi-aquifer sequences known to occur in this subregion.

Data from this project should be used to develop and calibrate a new mathematical model appropriate for the multi-aquifer sequence encountered. This model should then be used to simulate recharge of this sequence.

6.4 Baseline Survey of Ground Water Quality and Subsequent Monitoring

A baseline survey of ground water quality throughout the Northeast Region should be carried out as an extension of the pilot survey made by the BGS in 1992. The methodology for this baseline survey should closely follow that adopted for the BGS pilot survey, but nitrates should be added to the list of chemical constituents to be analyzed and the number of trace elements for which determinations were made in the BGS survey could be narrowed down to those shown to be significant in the BGS survey. In respect of regional coverage the BGS network of sampling points has to be supplemented in the East Subregion. A sampling network should also be established in the Northwest Subregion.

Initially, maximum use should be made of the results obtained in the BGS survey (Davies and Exley, 1992, 1992a). Results of water analyses carried out for the survey should be obtained from the BGS, if possible, in digitized form, and used to create a computer database of ground water quality for the Northeast Region.

Secondly, a sampling network should be designed to include those sites investigated by the BGS and to extend coverage across the region, particularly into the Northwest and Central subregions which were not included at all in the BGS survey, and into the northern part of the East Subregion where poor quality was noted by the BGS. All sites in the sampling network should be located by GPS.

Before the survey starts all possible pollutants, including fertilizers, pesticides, and chemical works effluents, need to be identified, classified by chemical type and danger hazard, and appropriate contaminant indicators and methods for their detection selected.

Technical preparation for the survey will include the purchase of equipment for well head determinations of pH, Eh, EC, free CO_2, and bicarbonate ion. Such equipment would preferably be in kit form as manufactured, for example, by HACH. A GPS will also be required for determining the geographical coordinates and altitude of sampling points.

One, adequately equipped and staffed, local laboratory should be selected and personnel trained to perform regular periodical analysis of major and minor ions (Na, K, Ca, Mg, Fe, SO4, Ci, PO4 and NO_3), and of boron, total phosphorus, and silica.

For the baseline survey contractual services of a laboratory with advanced analytical equipment should be secured for the one-time analysis of selected trace elements in ground water from new sampling points (i.e points not previously investigated by the BGS).

A regular ground water quality monitoring program should follow after the baseline survey is completed. This program is to facilitate early detection of any deterioration in the quality of ground water in any area, and so enable timely corrective measures to be taken. The monitoring of any contamination of the ground water which occurs will be an important feature of this program since it is extremely difficult to decontaminate aquifers once they are polluted; early detection of contaminants enables early identification of the source and, hence, control of contamination at the source.

The volume of work involved in the monitoring program should be assessed from the number of sampling points in the network established for the baseline survey, and from the frequency of sampling which should be twice a year, once before the onset of the monsoon and once after the monsoon.

In the monitoring program SAR values should be calculated and the water classified; SAR values reflect the excessive concentration of dissolved solids which accompanies a deterioration in ground water quality caused by irrigation.

The most common contaminant in ground water is nitrate derived from agricultural activities, livestock wastes, and sewage disposal on or beneath the land surface. Phosphates in irrigation water are beneficial to plant life and may replace fertilizers; they become pollutants, however, if they migrate into ponds and reservoirs where they cause accelerated growths of algae and aquatic vegetation.

The determination of dissolved organic carbon may prove useful as an indicator of contamination. Concentrations of dissolved methane, already detected in ground water in the north of the East Subregion, should also be monitored.

Pesticides and herbicides should be identified in areas where they are used since they can pollute aquifers; their solubility in many cases in a hundred times, or so, greater than their permissible concentrations in drinking water, and they have significant mobility in sands and gravels as a result of their high solubility.

Wells in areas with industrial developments such as pulp and paper mills, textile mills, tanneries, and others, and in the vicinity of waste disposal sites, should be closely monitored. In all instances of detection of a deterioration in ground water quality, and/or ground water pollution, corrective measures by those responsible should be requested immediately.

Programs for the protection and improvement of the quality of domestic water supplies are urgently needed not only in the Northeast Region but throughout Bangladesh. Important measures which need to be taken include (Anwar, 1993):

- restriction of pollutant emissions at source
- imposition of restrictions on the discharge of waste waters containing toxic or otherwise dangerous materials
- intensification of waste water treatment
- introduction and enforcement of pertinent regulations

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Table 4.1

NUMBERS OF OPERATING TUBEWELLS AND IRRIGATED AREAS

NORTHWEST SUBREGION

DISTRICT	AST No	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Jamalpur	298	Bakshiganj	615	2041	0	0	5	77	4	47	3655	595	2760
	297	Dewanganj	647	3021	0	0	10	209	0	0	7087	1543	4773
	296	Islampur	1885	7632	0	0	48	930	2	42	4700	713	9317
Sherpur	299	Sribardi	1050	4113	0	0	38	628	79	1045	5041	705	6491
	300	Jhenaigati	305	1856	0	0	60	1243	18	439	174	24	3562
	302	Sherpur	1652	7534	0	0	127	2526	1	16	7061	1033	11109
	301	Nalitabari	581	3551	0	0	101	2073	110	2033	190	28	7685
	303	Nakla	862	4798	0	0	86	1393	2	32	436	72	6295
SUMMARY:													
Jamalpur			3147	12694	0	0	63	1216	6	89	15442	2851	16850
Sherpur			4450	21852	0	0	412	7863	210	3565	12902	1862	35142
Total			7597	34546	0	0	475	9079	216	3654	28344	4713	51992

Note: DTWa 56L/s or Less
DTWb More than 56 L/S

Source: AST/CIDA, 1991

Table 4.2

NUMBER OF OPERATING TUBEWELLS AND IRRIGATED AREAS

WEST SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Mymensingh	304	Haluaghat	686	3355	39	235	172	3605	42	955	111	53	8203
	305	Phulpur	2356	8450	0	0	152	1800	93	1305	419	107	11662
	306	Mymensingh	894	3538	0	0	168	3118	62	1300	367	63	8019
	312	Gauripur	416	1864	0	0	145	1696	5	69	67	13	3642
	313	Ishwarganj	299	1156	0	0	109	1466	1	16	193	64	2702
	314	Nandail	309	1248	2	6	139	2360	42	851	78	15	4480
Netrokona	336	Dhobaura	0	0	0	0	0	0	0	0	0	0	0
	337	Durgapur	934	3709	0	6	18	390	0	0	26	6	4170
	338	Kalmakanda	813	3730	20	264	9	166	4	24	33	5	4189
	335	Purbadhala	911	4236	61	22	138	1882	0	0	32	7	6147
	334	Netrokona	522	2637	5	48	110	2283	0	0	46	25	4993
	333	Barhatta	249	1309	9	17	47	774	13	269	13	5	2374
	331	Atpara	93	813	3	0	5	128	49	1030	6	1	1972
	332	Mohanganj	40	268	0	0	4	130	41	934	0	0	1332
	330	Kendua	572	2412	0	0	85	1369	16	323	26	5	4109
	329	Madan	168	1080	0	0	4	121	2	55	0	0	1256

Table 4.2 (continued)

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Narayanganj	269	Rupganj	135	1138	0	0	33	988	12	409	12	6	2541
	268	Araihazar	628	3599	0	0	60	1822	0	0	40	12	5433
	267	Baidyer Bazar	135	600	0	0	35	1365	0	0	0	0	1965
	265	Bandar	35	267	0	0	0	0	0	0	0	0	267
	266	Siddirganj	48	364	0	0	1	10	0	0	0	0	374
Munshiganj	264	Gozaria	32	177	0	0	0	0	0	0	0	0	177
SUMMARY:													
Mymensing			4960	19611	41	241	885	1445	245	4496	1235	315	38708
Netrokona			4302	20194	98	416	420	7243	125	2635	182	54	30542
Kishoreganj			4122	23357	0	0	512	9595	167	3316	1943	320	36588
Gazipur			771	3088	2	4	29	492	0	0	2199	374	3958
Narsingdi			4988	21639	0	0	343	6013	41	528	2799	463	28643
Narayangonj			981	5968	0	0	129	4185	12	409	52	18	10580
Munshiganj			32	177	0	0	0	0	0	0	0	0	177
Total			**20156**	**94034**	**141**	**661**	**2318**	**41573**	**590**	**11384**	**8410**	**1544**	**149196**

Note: DTWa 56L/S or Less
DTWb More than 56 L/S

Source: AST/CIDA, 1991

Table 4.2 (continued)

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Kishoreganj	315	Hossainpur	109	311	0	0	84	1566	0	0	3	1	1878
	325	Kishoreganj	26	160	0	0	104	2082	0	0	8	2	2244
	326	Tarail	355	2427	0	0	4	45	61	1496	1	0	3968
	324	Karimganj	332	2297	0	0	96	2126	0	0	9	3	4425
	322	Nikli	349	2526	0	0	0	0	5	123	2	1	2650
	316	Pakundia	405	1822	0	0	70	953	33	483	509	140	3398
	317	Katiadi	820	4390	0	0	31	759	52	920	1193	135	6204
	320	Bajitpur	412	2533	0	0	70	1170	16	294	16	6	4003
	318	Kuliarchar	708	3640	0	0	47	791	0	0	189	27	4458
	319	Bhairab	606	3251	0	0	6	103	0	0	13	5	3359
Gazipur	276	Kapasia	771	3088	2	4	29	492	0	0	2199	374	3958
Narsingdi	275	Manohardi	864	4367	0	0	102	1569	5	69	1393	209	6214
	274	Belabo	796	2592	0	0	16	159	16	168	365	62	2981
	272	Shibpur	836	3819	0	0	87	1491	10	172	816	147	5629
	273	Raipur	1691	6855	0	0	19	174	10	119	178	32	7180
	271	Palash	167	843	0	0	31	676	0	0	28	7	1526
	270	Narsingdi	634	3163	0	0	88	1943	0	0	19	7	5113

Table 4.3

NUMBERS OF OPERATING TUBEWELLS AND IRRIGATED AREAS

CENTRAL SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Sunamganj	343	Tahirpur	3	21	0	0	0	0	0	0	0	0	21
	344	Bishwamvarpur	17	150	0	0	1	20	0	0	4	1	171
	345	Sunamganj	0	0	0	0	0	0	0	0	0	0	0
	346	Dowara Bazar	0	0	0	0	1	20	0	0	67	34	54
	347	Chhatak	0	0	0	0	7	225	0	0	0	0	225
	348	Jagannathpur	0	0	0	0	0	0	1	40	0	0	40
	339	Dharmapasha											
		Madhyanagar	70	555	0	0	0	0	0	0	0	0	555
	342	Jamalganj	0	0	0	0	0	0	0	0	0	0	0
	341	Derai	0	0	0	0	0	0	0	0	0	0	0
	340	Sullah	0	0	0	0	0	0	0	0	0	0	0
Netrokona	328	Khaliajuri	0	0	0	0	0	0	0	0	0	0	0
Kishoreganj	327	Itna	60	494	0	0	0	0	0	0	0	0	494
	321	Astagram	125	1055	0	0	0	0	0	0	3	1	1056
Habiganj	368	Ajmiriganj	0	0	0	0	0	0	0	0	0	0	0
SUMMARY:													
Sunamganj			90	726	0	0	9	295	1	40	71	35	1096
Netrokona			0	0	0	0	0	0	0	0	0	0	0
Kishoreganj			185	1549	0	0	0	0	0	0	3	1	1550
Habiganj			0	0	0	0	0	0	0	0	0	0	0
Total			**275**	**2275**	**0**	**0**	**9**	**295**	**1**	**40**	**74**	**36**	**2646**

Note: DTWa 56L/S or Less
DTWb More than 56 L/S

Source: AST/CIDA, 1991

Table 4.4

NUMBERS OF OPERATING TUBEWELLS AND IRRIGATED AREAS

EAST SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Habiganj	367	Baniachang	18	304	0	0	18	630	20	778	0	0	1712
	366	Nabigonj	15	128	0	0	0	0	8	247	1	1	376
	371	Bahubal	6	38	0	0	4	101	1	51	5	1	191
	370	Habiganj	95	648	0	0	18	547	3	101	25	7	1303
	369	Lakhai	1	6	0	0	15	455	6	235	0	0	696
	373	Madhabpur	185	1773	0	0	54	1937	0	0	3	1	3711
	372	Chunarughat	14	68	0	0	1	4	0	0	22	10	82
Sylhet	352	Companiganj	1	4	0	0	0	0	0	0	0	0	4
	353	Gowainghat	8	57	0	0	1	20	0	0	0	0	77
	354	Jaintipur	0	0	0	0	0	0	0	0	0	0	0
	355	Kanaighat	1	5	0	0	2	41	0	0	0	0	46
	350	Bishwanath	2	9	0	0	2	34	0	0	4	2	45
	351	Sylhet Sadar	8	53	0	0	12	231	0	0	4	1	285
	358	Golabganj	0	0	0	0	2	30	0	0	0	0	30
	357	Beanibazar	1	6	0	0	0	0	5	70	0	0	76
	356	Zakiganj	0	0	0	0	0	0	3	27	0	0	27
	349	Balaganj	0	0	0	0	10	82	2	26	0	0	108
	359	Fenchuganj	0	0	0	0	0	0	0	0	0	0	0

Table 4.4

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL AREA ha
			No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	No.	Area ha	
Moulvi Bazar	360	Berlekha	0	0	1	2	0	0	0	0	0	0	2
	361	Kulaura	5	87	0	0	1	16	1	12	56	17	132
	362	Rajnagar	0	0	0	0	0	0	0	0	0	0	0
	365	Moulvi Bazar	0	0	0	0	0	0	0	0	1	1	1
	364	Srimangal	0	0	0	0	0	0	0	0	0	0	0
	363	Kumalganj	0	0	0	0	3	24	1	8	1	1	33
SUMMARY:													
Habiganj			334	2965	0	0	110	3674	38	1412	56	20	8071
Sylhet			21	134	0	0	29	438	10	123	8	3	698
Moulvi Bazar			5	87	1	2	4	40	2	20	58	19	168
Total			**360**	**3186**	**1**	**2**	**143**	**4152**	**50**	**1555**	**122**	**42**	**8937**

Note: DTWa 56L/S or Less
DTWb More than 56 L/S

Source: AST/CIDA, 1991

Table 4.5

CURRENT GROUNDWATER USE, USABLE AND AVAILABLE RECHARGE

NORTHWEST SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL-ABLE	USED
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%
Jamalpur	298	Baksiganj	615	8.6	0	0.0	5	0.2	4	0.3	3655	18.3	27.4	54.2	54.3	87.2	62.2
	297	Dewanganj	647	9.1	0	0.0	10	0.4	0	0.0	7087	35.4	44.9	88.9	105.8	69.4	128.2
	296	Islampur	1885	26.4	0	0.0	48	2.0	2	0.1	4700	23.5	52.0	103.1	35.1	105.0	98.1
Sherpur	299	Sribardi	1050	14.7	0	0.0	38	1.6	79	5.5	5041	25.2	47.0	93.1	30.7	68.6	135.7
	300	Jhenaigati	305	4.3	0	0.0	60	2.5	18	1.3	174	0.9	9.0	17.7	12.3	43.7	40.4
	302	Sherpur	1652	23.1	0	0.0	127	5.3	1	0.1	7061	35.3	63.8	126.4	14.8	118.1	107.0
	301	Nalitabari	581	8.1	0	0.0	101	4.2	110	7.7	190	1.0	21.0	41.6	40.2	68.7	60.6
	303	Nakhla	862	12.1	0	0.0	86	3.6	2	0.1	436	2.2	18.0	35.6	35.4	53.1	67.1
SUMMARY:																	
Jamalpur			3147	44.1	0	0.0	63	2.6	6	0.4	15442	77.2	124.3	246.2	415.3	261.6	94.1
Sherpur			4450	62.3	0	0.0	412	17.3	210	14.7	12902	46.5	158.8	314.5	559.1	352.2	89.3
Total			**7597**	**106.4**	**0**	**0.0**	**475**	**19.9**	**216**	**15.1**	**28344**	**141.7**	**283.1**	**560.6**	**974.4**	**613.9**	**91.3**

Source: Recharge estimates, MPO 1990, 1991
Well numbers, AST/CIDA, 1991

Table 4.6

CURRENT GROUNDWATER USE, USABLE AND AVAILABLE RECHARGE

WEST SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL-ABLE	USED
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%
Mymensingh	304	Haluaghat	686	9.6	39	0.5	172	7.2	42	2.9	111	0.6	20.8	41.3	100.2	63.2	65.4
	305	Phulpur	2356	33.0	0	0.0	152	6.4	93	6.5	419	2.1	48.0	95.0	324.7	204.5	46.4
	306	Mymensingh	894	12.5	0	0.0	168	7.1	62	4.3	367	1.8	25.7	51.0	159.9	100.7	50.6
	312	Gauripur	416	5.8	0	0.0	145	6.1	5	0.4	67	0.3	12.6	24.9	99.0	62.4	40.0
	313	Ishwarganj	299	4.2	0	0.0	109	4.6	1	0.1	193	1.0	9.9	19.4	127.6	80.4	24.1
	314	Nandail	309	4.3	2	0.0	139	5.8	42	2.9	78	0.4	13.4	26.8	109.4	68.9	38.8
Netrokona	336	Dhobaura	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	65.3	41.1	0.0
	337	Durgapur	934	13.1	20	0.3	18	0.8	0	0.0	26	0.1	14.3	28.2	115.7	72.9	38.7
	338	Kalmakanda	813	11.4	61	0.9	9	0.4	4	0.3	33	0.2	13.2	25.9	107.7	67.9	38.1
	335	Purbadhala	911	12.8	5	0.1	138	5.8	0	0.0	32	0.2	18.9	37.2	130.1	82.0	45.4
	334	Netrokona	522	7.3	9	0.1	110	4.6	0	0.0	46	0.2	12.2	24.3	129.1	81.3	29.9
	333	Barhatta	249	3.5	3	0.0	47	2.0	13	0.9	13	0.1	6.5	12.8	52.5	33.1	38.8
	331	Atpara	93	1.3	0	0.0	5	0.2	49	3.4	6	0.0	4.9	9.8	46.7	29.4	33.5
	332	Mohanganj	40	0.6	0	0.0	4	0.2	41	2.9	0	0.0	3.7	7.1	38.9	24.5	29.1
	330	Kendua	572	8.0	0	0.0	85	3.6	16	1.1	26	0.1	12.8	25.4	92.0	58.0	43.8
	329	Madan	168	2.4	0	0.0	4	0.2	2	0.1	0	0.0	2.7	5.3	25.4	16.0	32.9

Table 4.6 (Continued)

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL-ABLE	USED
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%
Kishoreganj	315	Hossainpur	109	1.5	0	0.0	84	3.5	0	0.0	3	0.0	5.0	10.0	22.5	14.1	71.0
	325	Kishoreganj	26	0.4	0	0.0	104	4.4	0	0.0	8	0.0	4.8	9.4	27.4	17.2	54.8
	326	Tarail	355	5.0	0	0.0	4	0.2	61	4.3	1	0.0	9.5	18.6	27.6	17.4	107.3
	324	Karimganj	332	4.6	0	0.0	96	4.0	0	0.0	9	0.0	8.6	17.3	50.6	31.9	54.2
	322	Nikli	349	4.9	0	0.0	0	0.0	5	0.4	2	0.0	5.3	10.4	33.7	21.2	48.9
	316	Pakundia	405	5.7	0	0.0	70	2.9	33	2.3	509	2.5	13.4	26.7	50.5	31.8	83.9
	317	Katiadi	820	11.5	0	0.0	31	1.3	52	3.6	1193	6.0	22.4	44.3	56.5	35.6	124.6
	320	Bajitpur	412	5.8	0	0.0	70	2.9	16	1.1	16	0.1	9.9	19.6	41.7	26.3	74.6
	318	Kuliarchar	708	9.9	0	0.0	47	2.0	0	0.0	189	0.9	12.8	25.4	28.1	17.7	143.7
	319	Bhairab	606	8.5	0	0.0	6	0.3	0	0.0	13	0.1	8.9	17.4	64.1	40.4	43.2
Gazipur	276	Kapasia	771	10.8	2	0.0	29	1.2	0	0.0	2199	11.0	23.0	45.6	85.4	53.8	84.7
Narsingdi	275	Manohardi	864	12.1	0	0.0	102	4.3	5	0.4	1393	7.0	23.8	46.9	80.9	50.9	92.1
	274	Belabo	796	11.1	0	0.0	16	0.7	16	1.1	365	1.8	14.7	29.2	47.1	29.7	98.5
	272	Shibpur	836	11.7	0	0.0	87	3.7	10	0.7	816	4.1	20.2	39.9	65.5	41.3	96.6
	273	Raipur	1691	23.7	0	0.0	19	0.8	10	0.7	178	0.9	26.1	51.6	78.8	49.6	104.0
	271	Palash	167	2.3	0	0.0	31	1.3	0	0.0	28	0.1	3.7	7.5	22.5	14.2	52.8
	270	Narsingdi	634	8.9	0	0.0	88	3.7	0	0.0	19	0.1	12.7	25.1	54.8	34.5	72.6

Table 4.6 (Continued)

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL-ABLE	USED
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%
	267	Baidyer Bazar	135	1.9	0	0.0	35	1.5	0	0.0	0	0.0	3.4	6.7	39.5	24.9	26.7
	265	Bandar	35	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0.5	1.0	44.5	28.0	3.5
	266	Siddirganj	48	0.7	0	0.0	1	0.0	0	0.0	0	0.0	0.7	1.4	6.9	4.4	32.3
Munshiganj	264	Gozaria	32	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0.4	0.9	29.5	18.6	4.8
SUMMARY:																	
Mymensingh			4960	69.4	41	0.5	885	37.2	245	17.1	1235	6.2	130.4	258.4	920.8	580.1	44.5
Netrakona			4302	60.4	98	1.4	420	17.8	125	8.7	182	0.9	89.2	176.0	803.4	506.2	34.8
Kishoreganj			4122	57.8	0	0.0	512	21.5	167	11.7	1943	9.6	100.6	199.2	402.5	253.5	78.6
Gazipur			771	10.8	2	0.0	29	1.2	0	0.0	2199	11.0	23.0	45.6	85.4	53.8	84.8
Narsingdi			4988	69.8	0	0.0	343	14.5	41	2.9	2799	14.0	101.2	200.2	349.5	220.2	90.9
Narayangonj			981	13.8	0	0.0	129	5.4	12	0.8	52	0.3	20.3	40.1	185.0	116.6	34.4
Munshiganj			32	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0.4	0.9	29.5	18.6	4.8
Total			**20156**	**282.4**	**141**	**1.9**	**2318**	**97.6**	**590**	**41.2**	**8410**	**42.0**	**465.1**	**920.4**	**2776.2**	**1749.0**	**52.6**

Source: Well numbers, AST CIDA, 1991
Recharge estimates, MPO, 1990, 1991

Table 4.7

CURRENT GROUNDWATER USE, USABLE AND AVAILABLE RECHARGE

CENTRAL SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL -ABLE	USED	F0+F1	F2+F3
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%	%	%
Sunamganj	343	Tahirpur	3	0.0	0	0.0	0	0.0	4	0.0	0	0.0	0.0	0.0	44.9	28.3	0.3	35.7	33.5
	344	Bishwamvarpur	17	0.2	0	0.0	1	0.0	0	0.0	4	0.0	0.2	0.6	50.9	32.1	1.9	46.5	30.9
	345	Sunamganj	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	84.7	53.3	0.0	7.9	57.6
	346	Dowara Bazar	0	0.0	0	0.0	1	0.0	0	0.0	67	0.3	0.3	0.7	33.0	20.8	3.6	45.2	39.6
	347	Chhatak	0	0.0	0	0.0	7	0.3	0	0.0	0	0.0	0.3	0.6	56.7	35.7	1.6	18.5	61.1
	348	Gagannathpur	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0	0.1	0.1	41.3	26.0	0.5	17.8	69.7
	339	Dharmapasha													6.4	4.0	0.0	2.3	81.1
		Madhyanagar	70	1.0	0	0.0	0	0.0	0	0.0	0	0.0	1.0	1.9	18.4	11.6	16.8	12.3	53.3
	342	Jamalganj	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	32.7	20.6	0.0	1.7	45.7
	341	Derai	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	23.8	15.0	0.0	7.5	62.6
	340	Sullah	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	19.3	12.1	0.0	0.9	74.6
Netrokona	328	Khaliajuri	0	0.8	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	30.5	19.2	0.0	0.1	78.2
Kishoreganj	327	Itna	60	1.8	0	0.0	0	0.0	0	0.0	0	0.0	0.8	1.7	50.4	31.8	5.2	1.0	46.1
	321	Astagram	125	23.1	0	0.0	0	0.0	0	0.0	3	0.0	1.8	3.5	34.7	21.9	16.0	00	56.5
Habiganj	368	Ajmiriganj	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	22.0	13.9	0.0	1.8	86.8
SUMMARY:																			
Sunamganj			90	1.2	0	0.0	9	0.3	1	0.1	71	0.3	1.9	4.1	411.9	259.5	1.6		
Kishoreganj			0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	30.5	19.2	0.0		
Habiganj			185	2.6	0	0.0	0	0.0	0	0.0	3	0.0	2.6	5.2	85.2	53.6	9.6		
Netrokona			0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	22.0	13.9	0.0		
Total			**275**	**3.8**	**0**	**0.0**	**9**	**0.3**	**1**	**0.1**	**74**	**0.4**	**4.5**	**9.2**	**549.6**	**346.2**	**2.7**		

Source: Recharge estimates, MPO 1990, 1991
Well numbers, AST/CIDA, 1991

Table 4.8

CURRENT GROUNDWATER USE, USABLE AND AVAILABLE RECHARGE

EAST SUBREGION

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL-ABLE	USED
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELDm 3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%
Habiganj	367	Baniachang	18	0.3	0	0.0	18	0.8	20	1.4	0	0.0	2.5	4.8	54.3	34.2	13.9
	366	Nabiganj	15	0.2	0	0.0	0	0.0	8	0.6	1	0.0	0.8	1.5	105.8	66.6	2.3
	371	Bahubal	6	0.1	0	0.0	4	0.2	1	0.1	5	0.0	0.4	0.7	35.1	22.1	3.1
	370	Habiganj	95	1.3	0	0.0	18	0.8	3	0.2	25	0.1	2.4	4.8	69.6	43.9	10.9
	369	Lakhai	1	0.0	0	0.0	15	0.6	6	0.4	0	0.0	1.0	2.1	31.9	20.1	10.5
	373	Madhabpur	185	2.6	0	0.0	54	2.3	0	0.0	3	0.0	4.9	9.6	62.2	39.2	24.6
	372	Chunarughat	14	0.2	0	0.0	1	0.0	0	0.0	22	0.1	0.3	0.7	76.4	48.2	1.4
Sylhet	352	Companiganj	1	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	30.7	19.4	0.1
	353	Gowainghat	8	0.1	0	0.0	1	0.0	0	0.0	0	0.0	0.1	0.3	12.3	7.7	3.9
	354	Jaintipur	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	14.8	9.3	0.0
	355	Kanairghat	1	0.0	0	0.0	2	0.1	0	0.0	0	0.0	0.1	0.2	40.2	25.3	0.8
	350	Bishwanath	2	0.0	0	0.0	2	0.1	0	0.0	4	0.0	0.1	0.3	35.4	22.3	1.2
	351	Sylhet Sadar	8	0.1	0	0.0	12	0.5	0	0.0	4	0.0	0.6	1.3	31.6	19.9	6.3
	358	Golabganj	0	0.0	0	0.0	2	0.1	0	0.0	0	0.0	0.1	0.2	32.2	20.3	0.8
	357	Beanibazar	1	0.0	0	0.0	0	0.0	5	0.4	0	0.0	0.4	0.7	36.5	23.0	3.1
	356	Zakiganj	0	0.0	0	0.0	0	0.0	3	0.2	0	0.0	0.2	0.4	67.9	42.8	1.0
	349	Balaganj	0	0.0	0	0.0	10	0.4	2	0.1	0	0.0	0.5	1.1	24.3	15.3	7.3
	359	Fenchuganj	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	21.4	13.5	0.0

Table 4.8 (continued)

DISTRICT	AST No.	THANA	STW		DSSTW		DTWa		DTWb		MTW		TOTAL YIELD	USE	USABLE	AVAIL-ABLE	USED
			No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELD m3/s	No.	YIELDm 3/s	No.	YIELD m3/s	m^3/s	Mm3	Mm3	Mm3	%
Moulvi Bazar	360	Berlekha	0	0.0	1	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	51.2	32.3	0.0
	361	Kulaura	5	0.1	0	0.0	1	0.0	1	0.1	56	0.3	0.5	0.9	74.4	46.9	2.0
	362	Rajnagar	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	24.3	15.3	0.0
	365	Moulvi Bazar	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0	0.0	0.0	35.5	22.4	0.0
	364	Srimangal	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0	0.0	43.8	27.6	0.0
	363	Kumalganj	0	0.0	0	0.0	3	0.1	1	0.1	1	0.0	0.2	0.4	67.0	42.2	0.9
SUMMARY:																	
Habiganj			334	4.7	0	0.0	110	4.6	38	2.7	56	0.3	12.3	24.2	435.3	274.2	8.8
Sylhet			21	0.2	0	0.0	29	1.2	10	0.8	8	0.0	2.2	4.5	347.2	218.7	2.0
Moulvi Bazar			5	0.1	1	0.0	4	0.2	2	0.1	58	0.3	0.7	1.3	296.3	186.6	0.7
Total			**360**	**5.0**	**1**	**0.0**	**143**	**6.0**	**50**	**3.6**	**122**	**0.6**	**15.2**	**30.0**	**1078.8**	**679.6**	**4.4**

Source: Recharge estimates, MPO 1990, 1991
Well numbers, AST/CIDA, 1991

Table 4.9

Present Ground Water Utilization in the Region

Numbers of Wells

	Northwest	West	Central	East	Total
MTW	28344	8410	74	122	36950
STW	7597	20156	275	360	28388
DSSTW	0	141	0	1	142
DTW	691	2908	10	193	3802
Totals	**36632**	**31615**	**359**	**676**	**69282**

Source: AST/CIDA, 1991

Ground Water Use for Irrigation (Mm^3)

	Northwest	West	Central	East	Total
MTW	280.6	83.4	0.8	1.2	366.0
STW	210.7	558.8	7.7	9.9	787.1
DSSTW	0.0	4.0	0.0	0.0	4.0
DTW	69.5	274.6	1.0	18.8	363.9
Totals	**560.8**	**920.8**	**9.5**	**29.9**	**1521.0**

Irrigated Area (ha)

	Northwest	West	Central	East	Total
MTW	4712	1547	36	42	6337
STW	34546	94034	2274	3186	134040
DSSTW	0	662	0	2	664
DTW	12732	52957	335	5708	71732
Totals	**51990**	**149200**	**26452645**	**8938**	**212773**

Source: AST/CIDA, 1991

Useable and Available Recharge (Mm^3/year)

	Northwest	West	Central	East	Total
Useable Recharge	836.0	2731.7	549.6	985.0	5102.3
Adjusted Recharge[1/]	974.4	2776.2	549.6	1078.8	5379.0
Available Recharge	**613.9**	**1749.0**	**346.2**	**679.6**	**3388.8**

Source: MPO 1990, 1991

[1/] Recharge adjusted for missing data by using district averages

Table 4.10

Ground Water Availability for Future Development
(Mm³/year)

	Northwest	West	Central	East	Total
Available Recharge (1)					
Available Recharge	613.9	1749.0	346.2	211.5	2920.6
Present Situation					
Irrigation Use	560.8	920.8	9.5	29.9	1521.0
Domestic Use	16.1	78.7	20.5	45.8	161.1
Total Use	576.9	999.5	30.0	75.7	1682.1
Undeveloped Recharge	37.0	749.5	316.2	135.8	1238.5
Situation in 2000					
Additional Domestic Use	7.8	37.8	9.8	22.0	774
Available for Irrigation	29.2	711.7	306.4	581.9	1629.3
Situation in 2015					
Additional Domestic Use	21.0	102.4	26.7	59.6	209.7
Available for Irrigation	8.2	609.3	279.7	54.2	937.4

(1) Source: BWDB, 1986 b

Figure 1

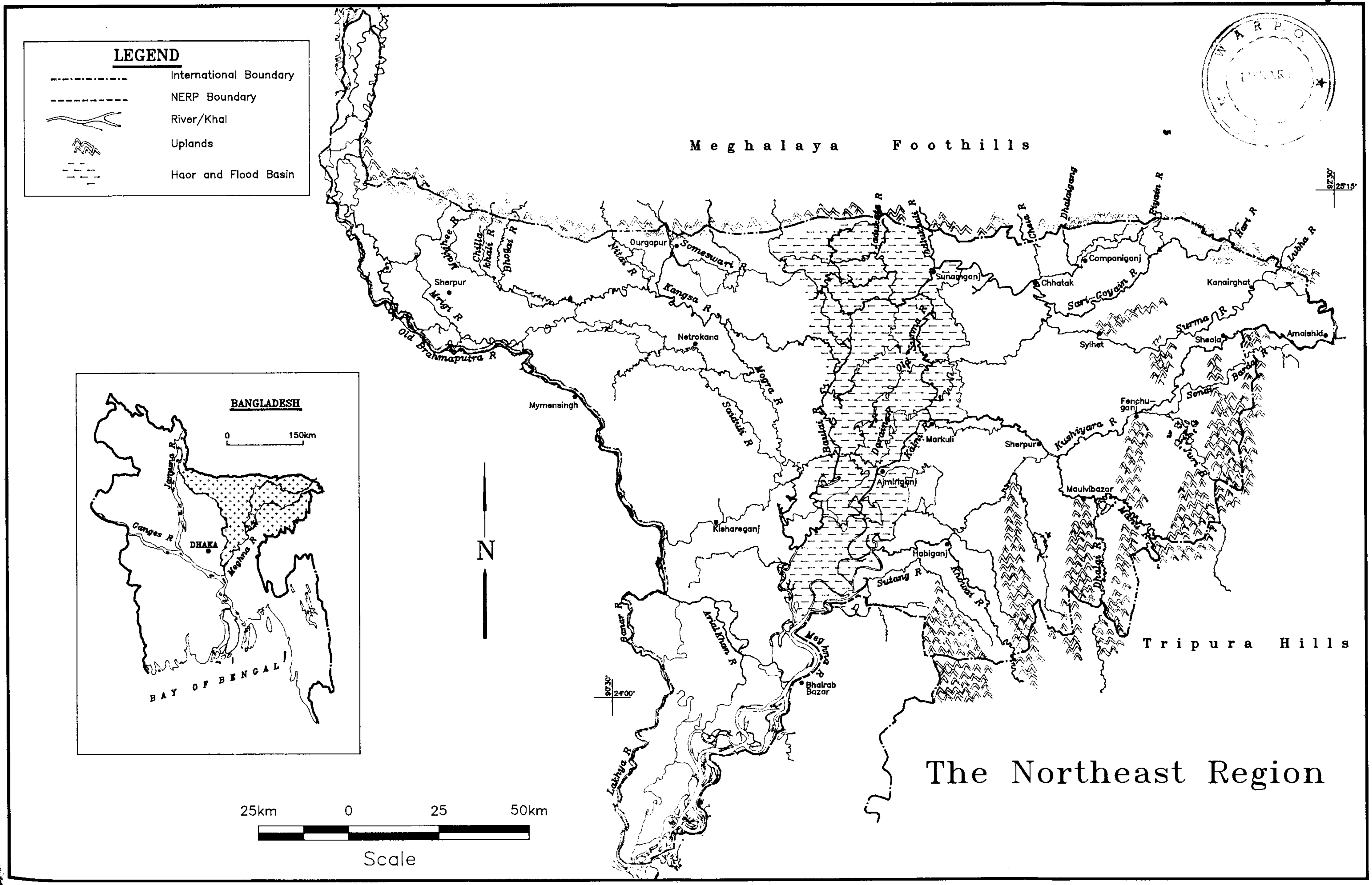
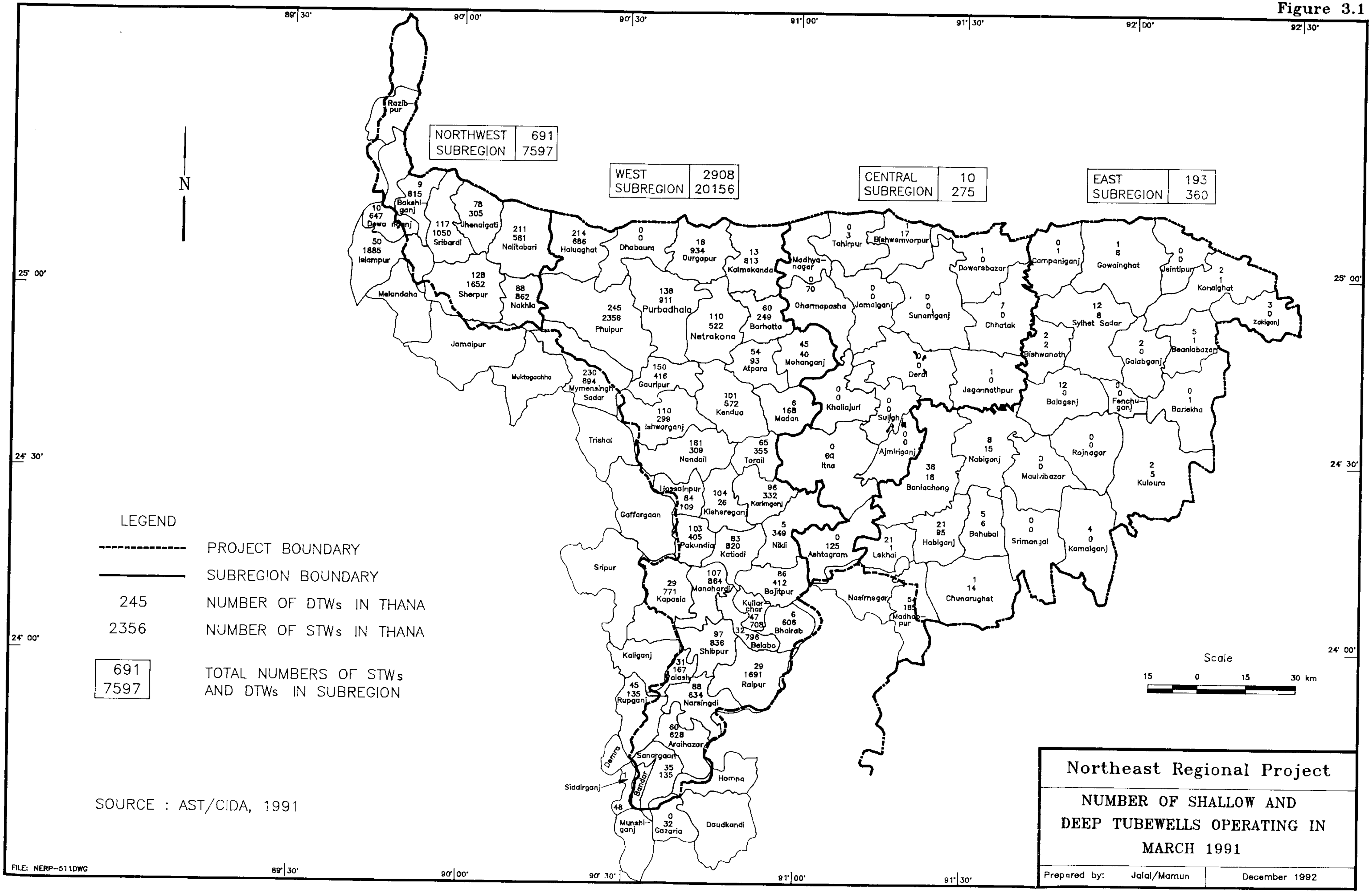

LEGEND
International Boundary
NERP Boundary
River/Khal
Uplands
Haor and Flood Basin
BANGLADESH
0
150km
Jamuna R
Ganges R
DHAKA
Meghna R
BAY OF BENGAL
Meghalaya Foothills
Tripura Hills
N
25km
0
25
50km
Scale
Old Brahmaputra R
Mymensingh
Sherpur
Mrigi R
Malijhee R
Chilla-khali R
Bhogai R
Nitai R
Durgapur
Someswari R
Kangsa R
Netrokana
Mogra R
Sarduli R
Kishareganj
Baulai R
Dharmapasha
Kalni R
Markuli
Ajmiriganj
Old Surma R
Jadukata R
Dhalukhali R
Sunamganj
Chela R
Dhalaiganj
Chhatak
Companiganj
Sari-Goyain R
Piyain R
Kanairghat
Hari R
Lubha R
Surma R
Sylhet
Sheola
Amalshid
Barak R
Sonai
Juri R
Fenchu-ganj
Kushiyara R
Sherpur
Maulvibazar
Manu R
Dhalai R
Habiganj
Khowai R
Sutang R
Meghna R
Bhairab Bazar
Arial Khan R
Banar R
Lakhya R
90°30'
24°00'
92°30'
25°15'
The Northeast Region

Figure 3.1

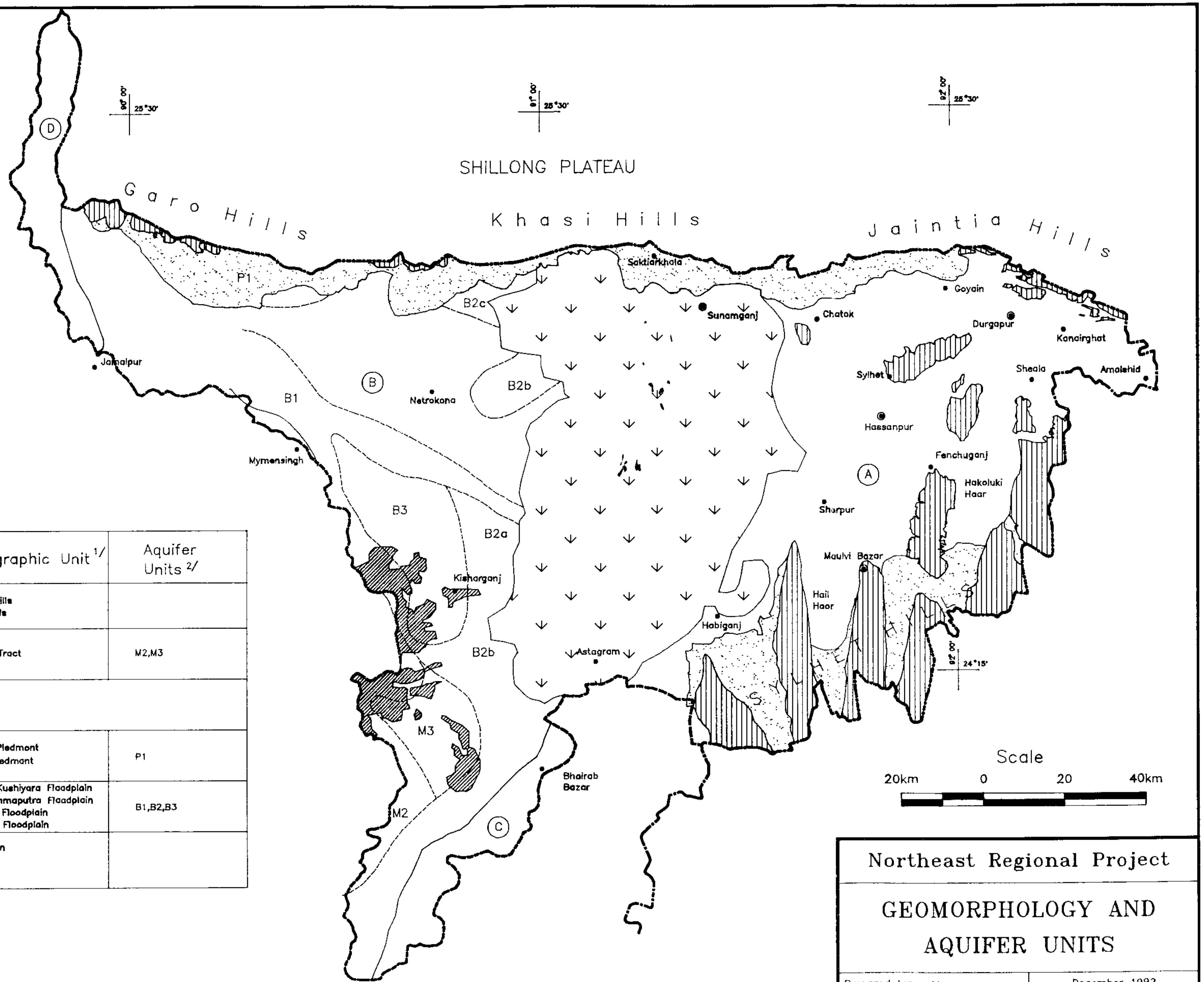


Northeast Regional Project

NUMBER OF SHALLOW AND DEEP TUBEWELLS OPERATING IN MARCH 1991

Prepared by: Jalal/Mamun | December 1992

Figure 4.1



LEGEND

	Geomorphologic Zone [1]	Physiographic Unit [1]	Aquifer Units [2]
	Hills	Northern Hills Eastern Hills	
	Terraces	Madhupur Tract	M2,M3
	FLOODPLAINS:		
	Piedmont Floodplain	Northern Piedmont Eastern Piedmont	P1
	Meander Floodplains	A Surma/Kushiyara Floodplain B Old Brahmaputra Floodplain C Meghna Floodplain D Jamuna Floodplain	B1,B2,B3
	Basin	Sylhet Basin (trough)	

SOURCE: 1/ MPO,1987a
2/ MMI,1992b

FILE: NERP-504.DWG

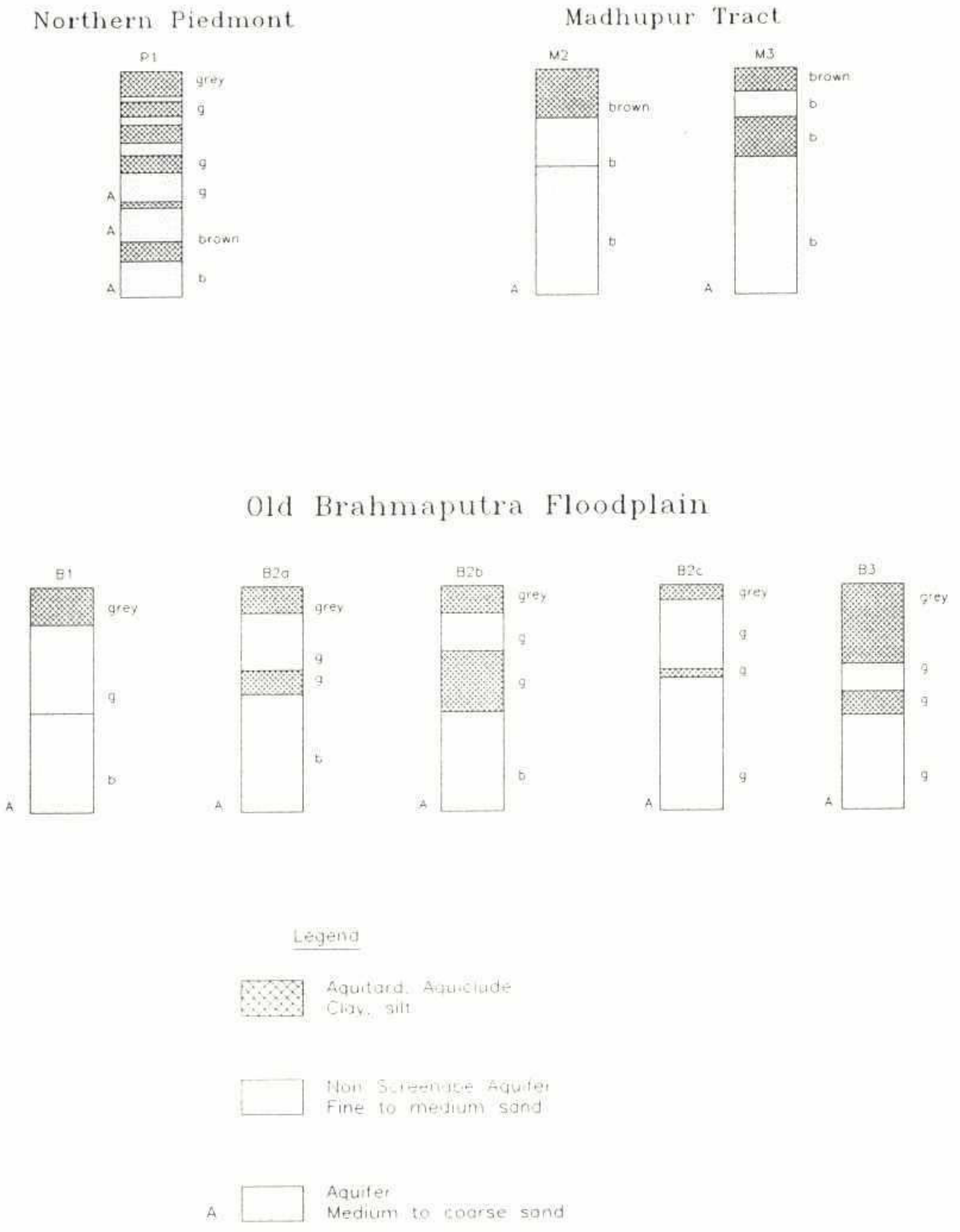
Northeast Regional Project

GEOMORPHOLOGY AND AQUIFER UNITS

Prepared by: Mamun | December 1992

WEST & SOUTHWEST SUBREGION OF NORTHEAST REGION

GENERALIZED UPPER AQUIFER SEQUENCE
AFTER MMI, 1992b

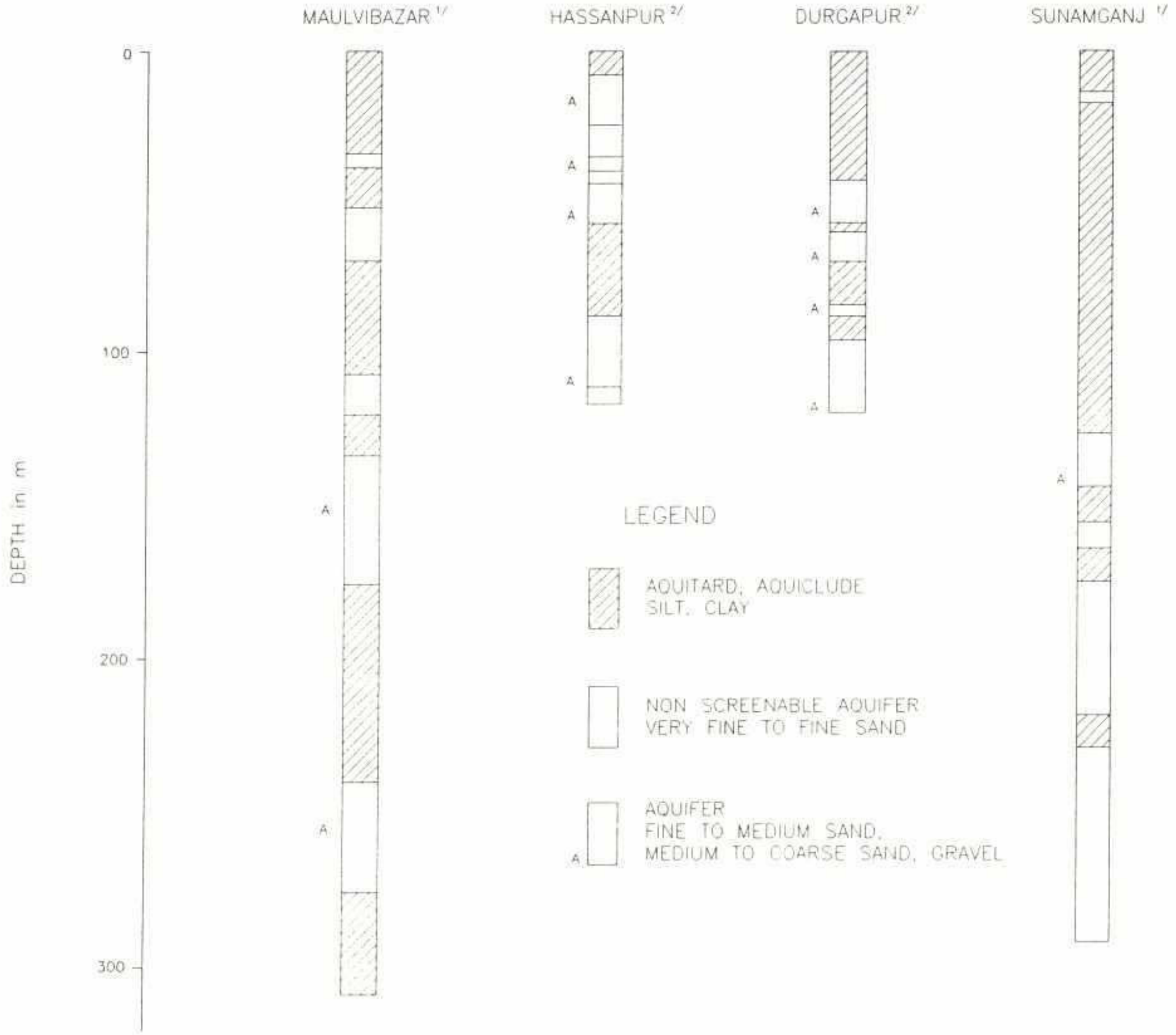


SOURCE: MMI, 1992b

FILE:NERP-513

EAST SUBREGION PART OF NORTHEAST REGION

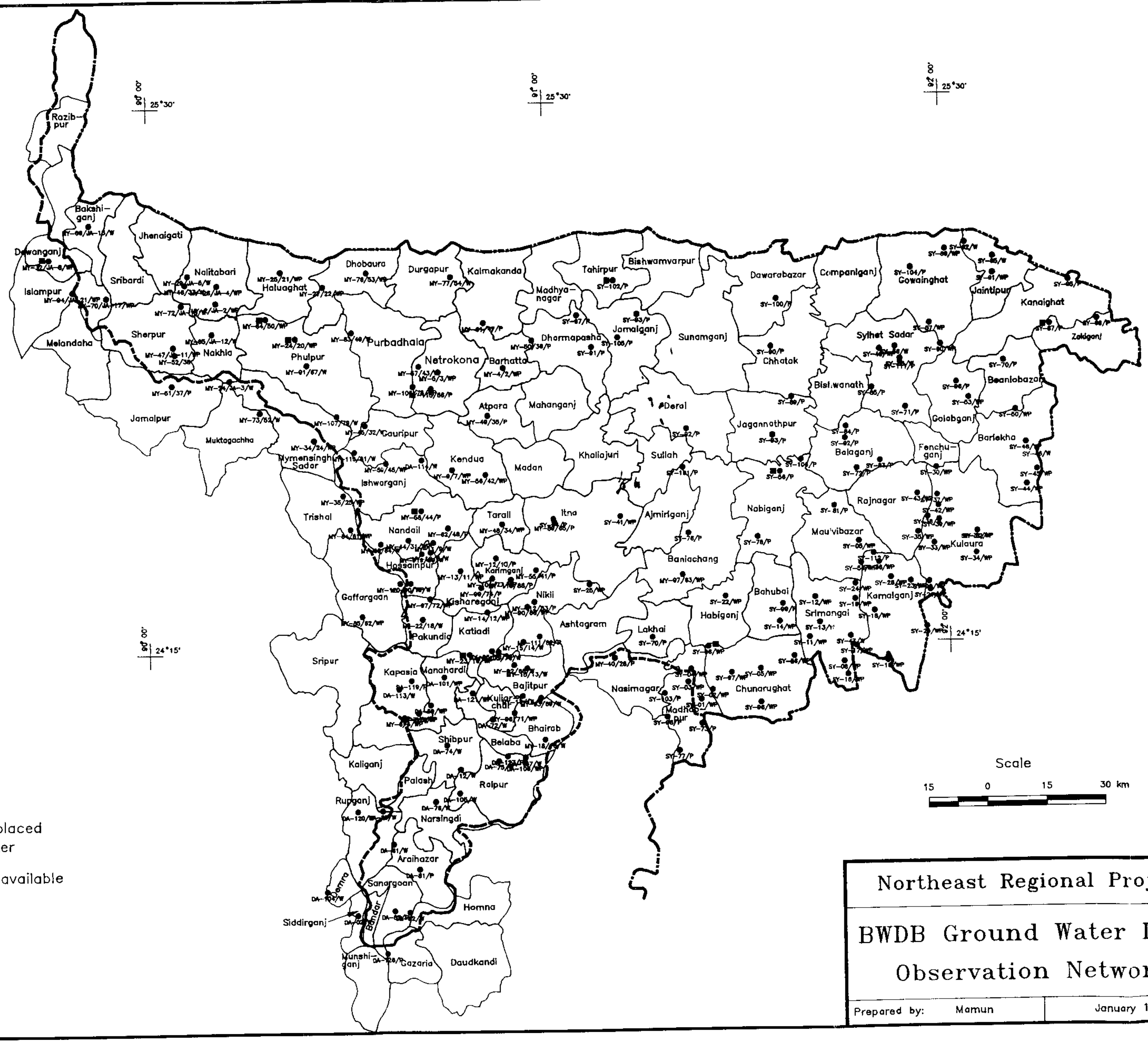
SIMPLIFIED SAMPLE LITHOLOGIC LOGS OF UPPER AQUIFER SEQUENCE



SOURCE: 1/ BWDB, 1987b
2/ MMI, 1990a

FILE NERP-512

Figure 4.4



LEGEND

W	Dug well
P	Piezometer
WP	Dug well replaced by Piezometer
■●	Hydrograph available

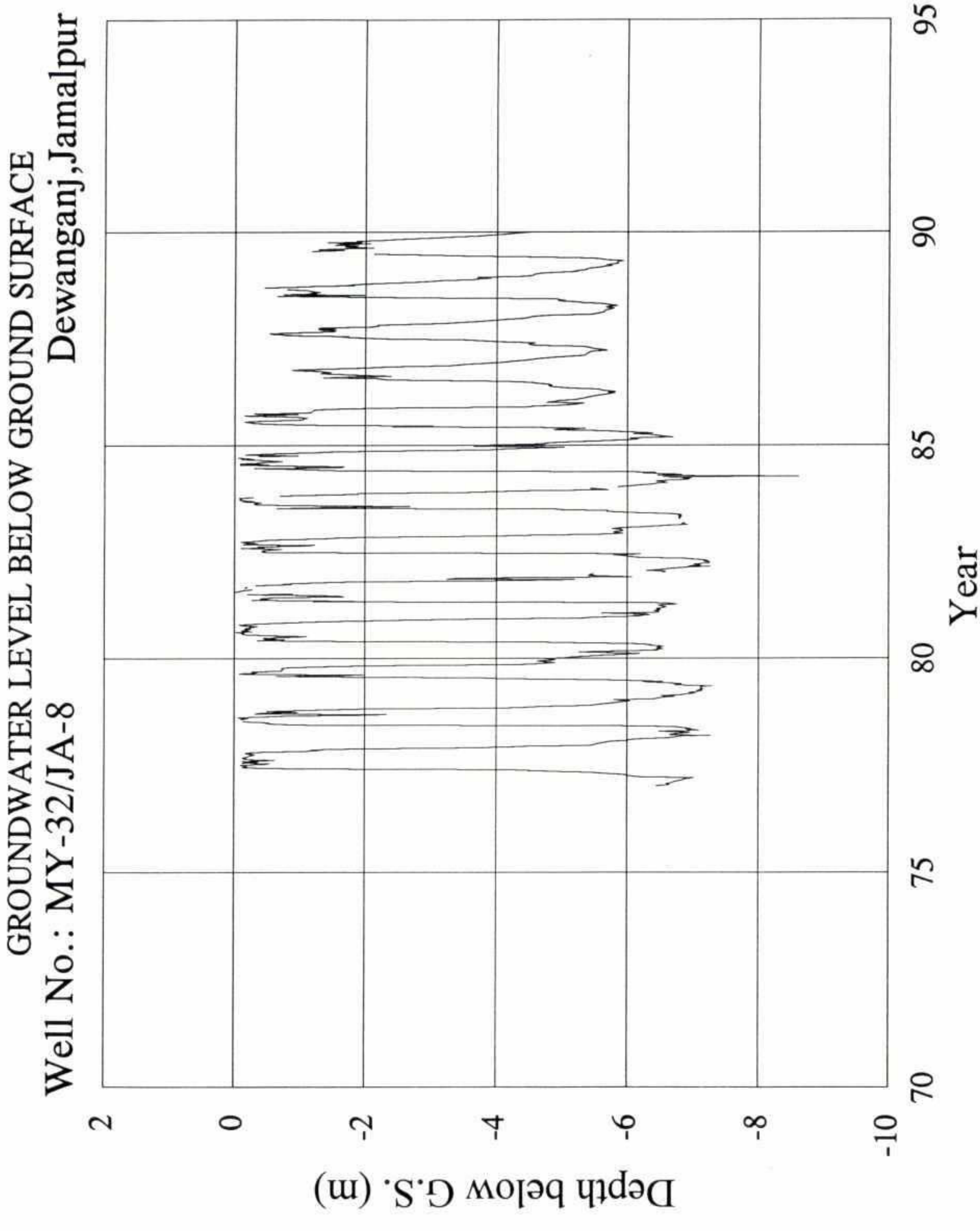
Northeast Regional Project

BWDB Ground Water Level Observation Network

Prepared by:	Mamun	January 1993

FILE: NERP-502.DWG

Figure 4.5


GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: MY-32/JA-8
Dewanganj,Jamalpur
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
70
75
80
85
90
95
Year

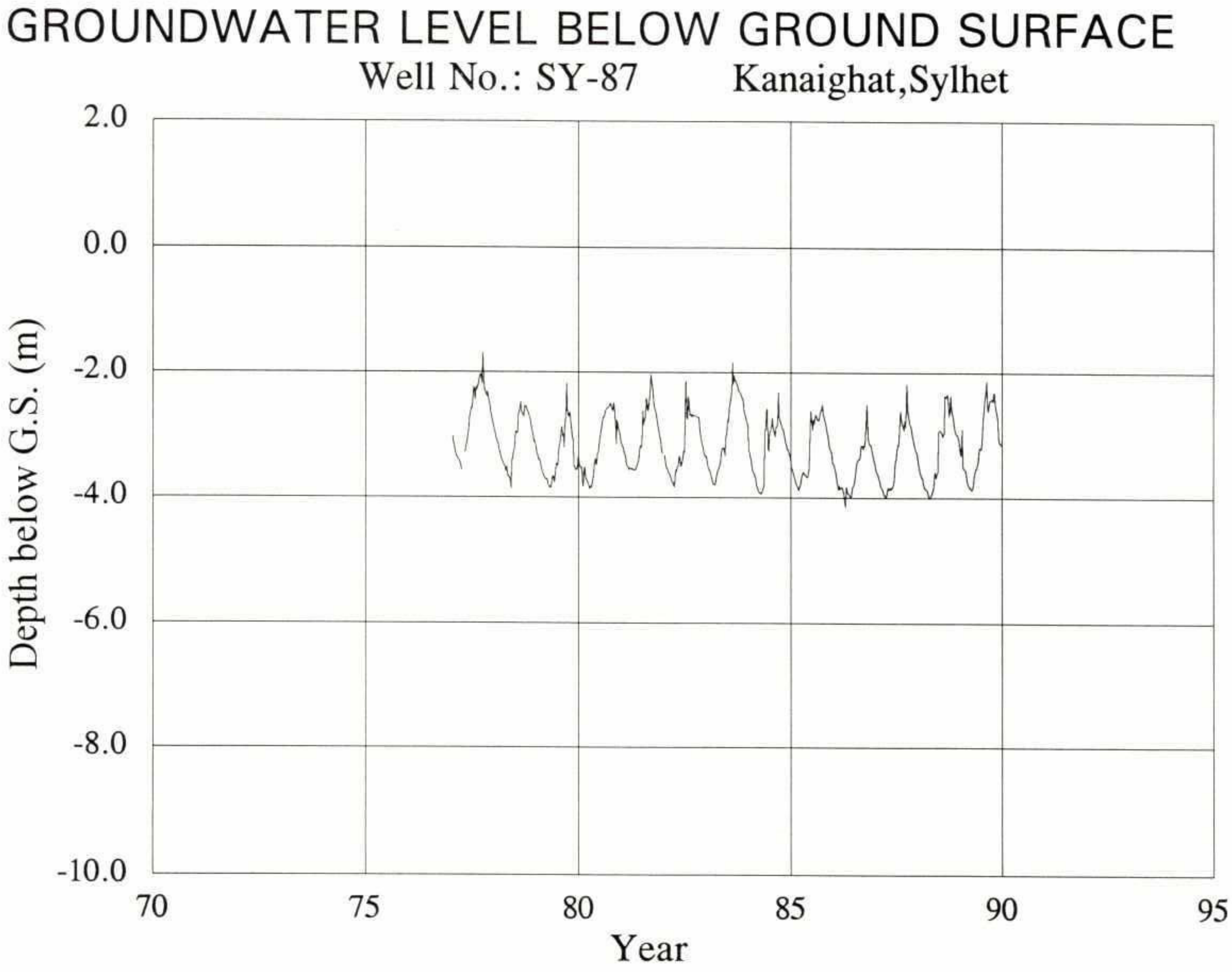

GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: SY-87
Kanaighat,Sylhet
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
Depth below G.S. (m)
70
75
80
85
90
95
Year

Figure 4.6

APPENDIX A

GROUND WATER LEVEL HYDROGRAPHS

Appendix A

GROUND WATER LEVEL HYDROGRAPHS

Explanatory Notes

1. Introduction

An interpretation is given in Section 4.3 of the ground water level hydrographs from two sites in the Northeast Region, one at its western extremity, the other at its eastern extremity (Figures 4.5 and 4.6). In this appendix interpretations are given of the hydrographs from seven other intermediate sites the locations of which are shown in Figure 4.4.

2. Site No. MY-64/50, Haluaghat, Mymensingh

The hydrograph in Figure A1 indicates a complete recovery of the water table in the 5.6 m deep dug well MY-64/50 in response to monsoon season recharge to a level of about -1 m for a period of 10 years (1977-1986). Until 1981 the water table was lowered regularly each year during the dry period to level -4 m. Since 1982 a gradual drawdown of the water table was observed which reached -5.5 m in 1986 as a result of ground water pumping in the adjacent area. The groundwater withdrawal did not affect the capability of the system to fully recover.

In 1987 a piezometer 29.0 m deep was installed at the MY-64/50 dug well site. Apparently the piezometer penetrated a different part of the same aquifer as the dug well, or a semi-confined aquifer, with possibly a lower specific yield and vertical permeability. The water table (potentiometric surface?) in the piezometer reached -1.5 m (more or less constantly) every year during the recovery part of the annual cycle and declined to -6.8 m to -7.5 m during the peak lowering in the water withdrawal cycle.

It is concluded that at the site of well/piezometer MY-64/50 a complete annual recovery of the ground water table (potentiometric surface) takes place, and the ground water is not affected by ground water withdrawal in the area.

3. Site No. MY-24/20, Phulpur, Mymensingh

The MY-24/20 dug well/piezometer is located approximately 8 km to the southeast of the previous site. The dug well, 6.5 m deep, served as a ground water level monitoring point until 1985 when it was replaced by a 32.9 m deep piezometer. The ground water level hydrograph of MY-24/20 is presented in Figure A2. This hydrograph does not display the regularity of the hydrograph in Figure A1.

The water table in the well declined from close to 0 m in the 1978 recharge peak to -1.5 m, at the end of the recharge period culmination in 1981. The latest depression was repeated in 1982, followed by a full recovery of the water table to the ground surface in 1984. The observed maximal lowering of the water table to -6.5 m took place in 1979, and again in 1983. In other years of the period 1977-1985 the low water table was always below - 5.0 m as a result of water use for irrigation which, however, apparently varied from year to year.

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The larger amplitudes of ground water table fluctuations, and the more sensitive response of the aquifer to stress caused by pumping, indicate that the specific yield of this part of aquifer is lower than that of the aquifer surrounding MY-64/50 and represented in Figure A1.

Observations of ground water level in piezometer MY-24/20 after 1985 seem erratic. The large amplitude of water table fluctuations, equal to 8.0 m, supports the statement above about the specific yield. It is also concluded that at the site of the well/piezometer MY-24/20 the annual complete recovery of the ground water table (potentiometric surface) does not take place every year, and that the water table is affected by ground water withdrawal in the area.

4. Site No. MY-58/44, Nandail, Mymensingh

Piezometer MY-58/44, located in Nandial thana of Mymensingh district, approximately in the centre of the West Subregion, is 41.5 m deep. Monitoring of the ground water table started here in 1977. The hydrograph of ground water level fluctuations below ground surface is presented in Figure A3.

Depression of the water table (piezometric surface) throughout the whole observation period (1977-1990) increased from -4 m to -8 m. This drawdown of the water table is caused obviously by increased volume of pumping. The peak water table recovery levels at the end of the recharge season fluctuated only between approximately -2 m and -3 m. It is apparent that a partial annual recovery of the water table is observed. From the graph (Figure A3) it can also be seen that lower drawdown (depression) of water in one year is followed by a lower recovery in the next recharge period.

5. Site No. MY-23/19, Katiadi, Kishoreganj

The dug well/piezometer MY-23/19 is located nearly 40 km to the south of the previous site. (Figure 4.4). The dug well, 6.5 m deep, served as the ground water level monitoring point until 1985 when it was replaced by a 21.4 m deep piezometer. The ground water level hydrograph of MY-23/19 is presented in Figure A4.

In the period from 1977 to 1985 the ground water table in the well (reflecting the water table in its vicinity) was lowered more or less to a constant level of -6 m at the end of the dry season (with exception of 1983). The same pattern was repeated after the well was replaced by a piezometer but with a smaller depression to -5.5 m. The piezometer most likely penetrates a deeper part of the same aquifer. A higher specific yield and also a higher vertical permeability are demonstrated here by a lower amplitude of water level fluctuations.

The recharge to ground water is evidently smaller than the ground water withdrawal because the water table is continuously dropping at the end of the monsoon season during the whole 1977 to 1981 period (from -1 m to -3.5 m), and also during some other periods.

6. Site No. SY-102, Tahirpur, Sunamganj

Tahirpur thana is located on the northwestern boundary of the Central Subregion (Figure 4.4). The potentiometric surface (most likely) was monitored since 1978 in piezometer SY-102, which is 59.5 m deep.

There is virtually no ground water development in Tahirpur thana (three STWs only); hence the ground water level hydrograph in Figure A5 exemplifies the natural fluctuation of the potentiometric surface in a confined (or possibly semi-confined) aquifer. The amplitude of the fluctuations varies between 2.5 m and 3 m. The highest observed level of the potentiometric surface reaches close to the ground surface and the deepest level is approximately -3.5 m.

7. Site No. SY-80, Nabiganj, Habiganj

This piezometer is located in the central western part of the East Subregion (Figure 4.4). The piezometer is 34.5 m deep and was included in the ground water level monitoring network of BWDB in 1976.

There is some limited ground water development in Nabiganj thana (eight DTWs, fifteen STWs). However, it seems that ground water pumping does not have any apparent effect on the ground water level monitored in SY-80 piezometer (Figure A6), and the level follows the natural annual recharge/discharge cycle. The amplitudes of fluctuation change slightly from year to year; usually the amplitude is 2 m and the extremes are 1.8 m and 2.5 m.

8. Site No. SY-06, Madhabpur, Habiganj

The well/piezometer SY-06 is located about 48 km to the southsouthwest from the previous site. (Figure 4.4). The well was 5.9 m deep and served as the ground water level monitoring point until 1985 when it was replaced by a 39.4 m deep piezometer. The ground water level hydrograph of SY-06 is displayed in Figure A7.

It is not clear from the depicted ground water level sequence (1977-1985) if the water table in the well is influenced by ground water withdrawals. The effect of withdrawal could eventually be observed from a lowered water table in both the recharge and drawdown peaks during the period 1982-1984. The amplitudes of annual water table fluctuations vary between 2 m and 2.5 m.

The introduction of piezometric monitoring in 1985 resulted in an ambiguous record (Figure A7). It is not clear whether the observation data are erroneous or the piezometer has penetrated a confined aquifer in the depth of 39 m with distinct fluctuations of the potentiometric surface.

9. Conclusions

Nine presented ground water level hydrographs (two hydrographs in the report and seven in this Appendix A) exhibit similarities. The characters of hydrographs lend themselves to an attempt to classify the hydrographs into distinct types:

Type 1: Hydrographs of this type show a complete recovery of the water table as a result of vertical recharge to the level of the previous year; the water table is not influenced by the volume of ground water withdrawals (Figure 4.5) even when the extraction of ground water is being gradually increased (Figure A1).

Type 2: Hydrographs of this type exhibit only a partial recovery of the water table as a result of vertical recharge, but the size of the residual drawdown (depression) of the water table is not affected by the amount of groundwater withdrawals, as assessed by maximum drawdown. If

98.

smaller withdrawal takes place a greater residual drawdown is still observed compared to the year with larger pumping (Figure A2). In this type of hydrographs only the amount of vertical recharge from the ground surface controls the magnitude of the water table recovery (Figure A4).

Type 3: Hydrographs of this type demonstrate only a partial recovery of the water table as a result of vertical recharge, and the magnitude of the residual drawdown (depression) of the water table below full recovery is affected by the amount of ground water withdrawals. As a result of smaller ground water withdrawal a subsequent recovery of the water table was observed to reach a higher level compared to the year with larger pumping (Figure A3), when also the drawdown was larger.

Type 4: Hydrographs of this type illustrate fluctuations of the potentiometric surface of confined or semi-confined (leaky) aquifers (Figures A5 and A6 and Figure 4.6 in the report) not affected by groundwater withdrawals. These fluctuations were triggered by external stresses such as the vertical recharge from ground surface (assuming a leaky-aquifer) and also possibly by recharge from unknown areas with other than vertical flow component. Depths of the piezometers are 59.5 m, 34.5 m and 58.3 m respectively, and the water level fluctuations were observed at a depth between 0 m and -4 m; consequently fluctuations of the potentiometric surface were registered.

10. Recommendations

The nine hydrographs exhibit clearly the change from prevailing unconfined (water table) aquifer conditions in the western part of the region to prevailing confined or semi-confined (leaky) aquifer conditions in the east. The hydrographs illustrate different flow systems in the region.

In the western part of the region a difference between groundwater fluctuations in shallow aquifers and deeper aquifers can be observed from water level measurements in dug wells, which were subsequently replaced by piezometers.

By plotting and analyzing all ground water hydrographs of the region a definition of flow systems could be accomplished. Such an analysis of hydrographs would improve understanding of the overall conditions of ground water movement (recharge and discharge) and of the consequences of groundwater utilization. Earlier observation records, some going back to the year 1961, should also be used where available. Due to time constrains they were not employed in this report and Appendix A.

The amplitude of the groundwater table fluctuations reflects the value of specific yield in the case of an unconfined aquifer. The fluctuations of the potentiometric surface indicate the value of storativity (or storage coefficient). The ground water hydrograph analyses could lead to the preparation of a map of values of specific yield and storativities (or at least of their ratios) which could improve the modelling of groundwater recharge.

Figure A1

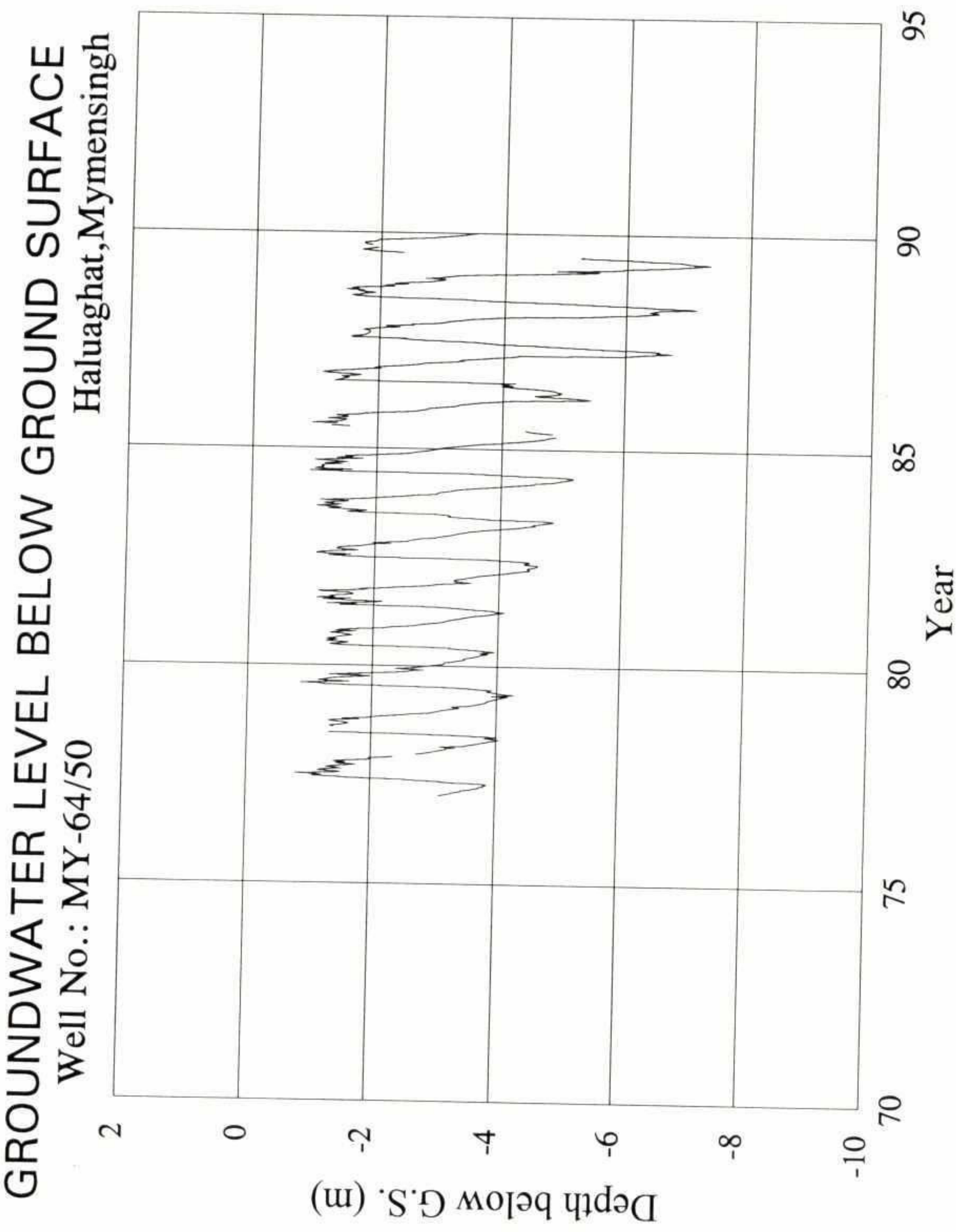
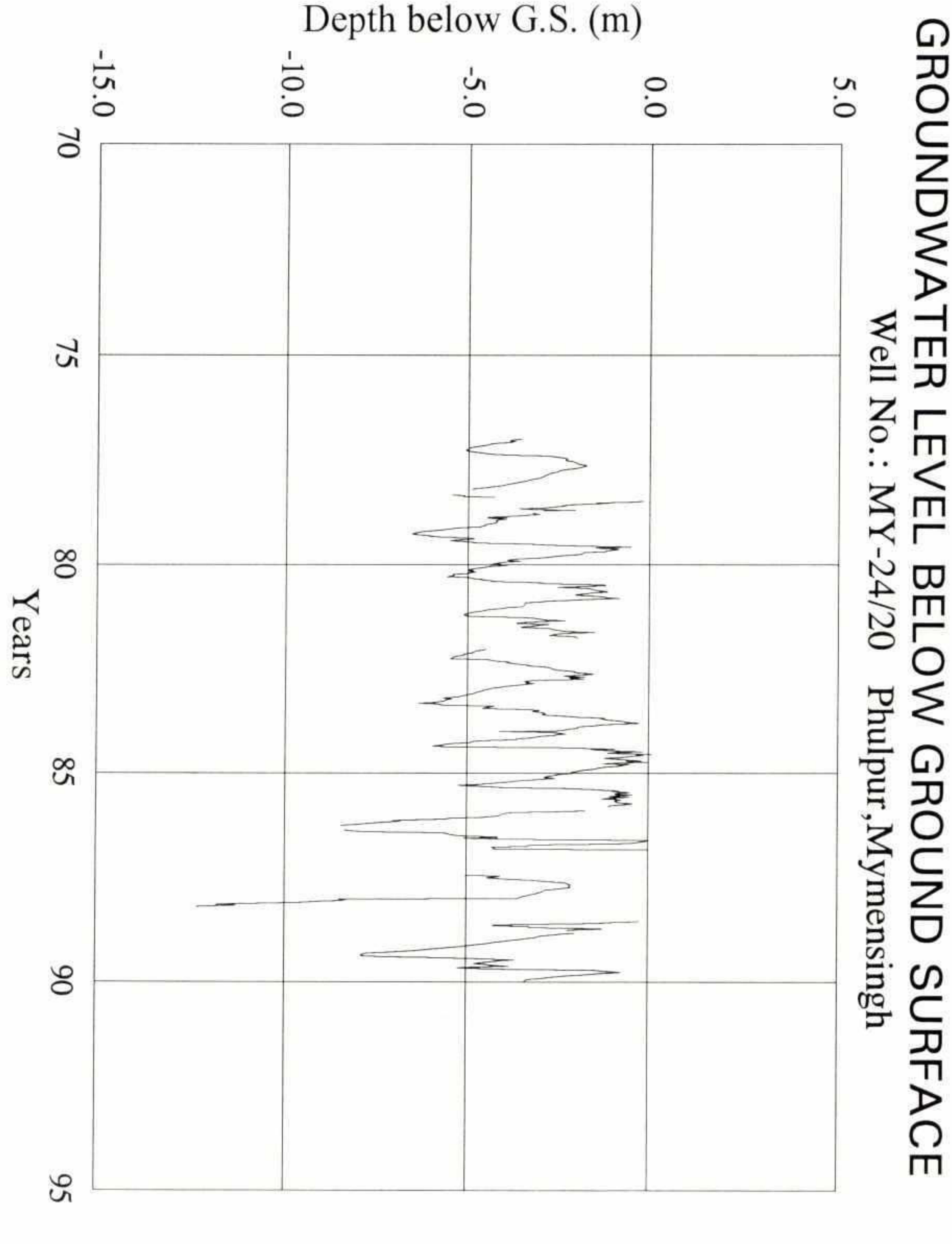
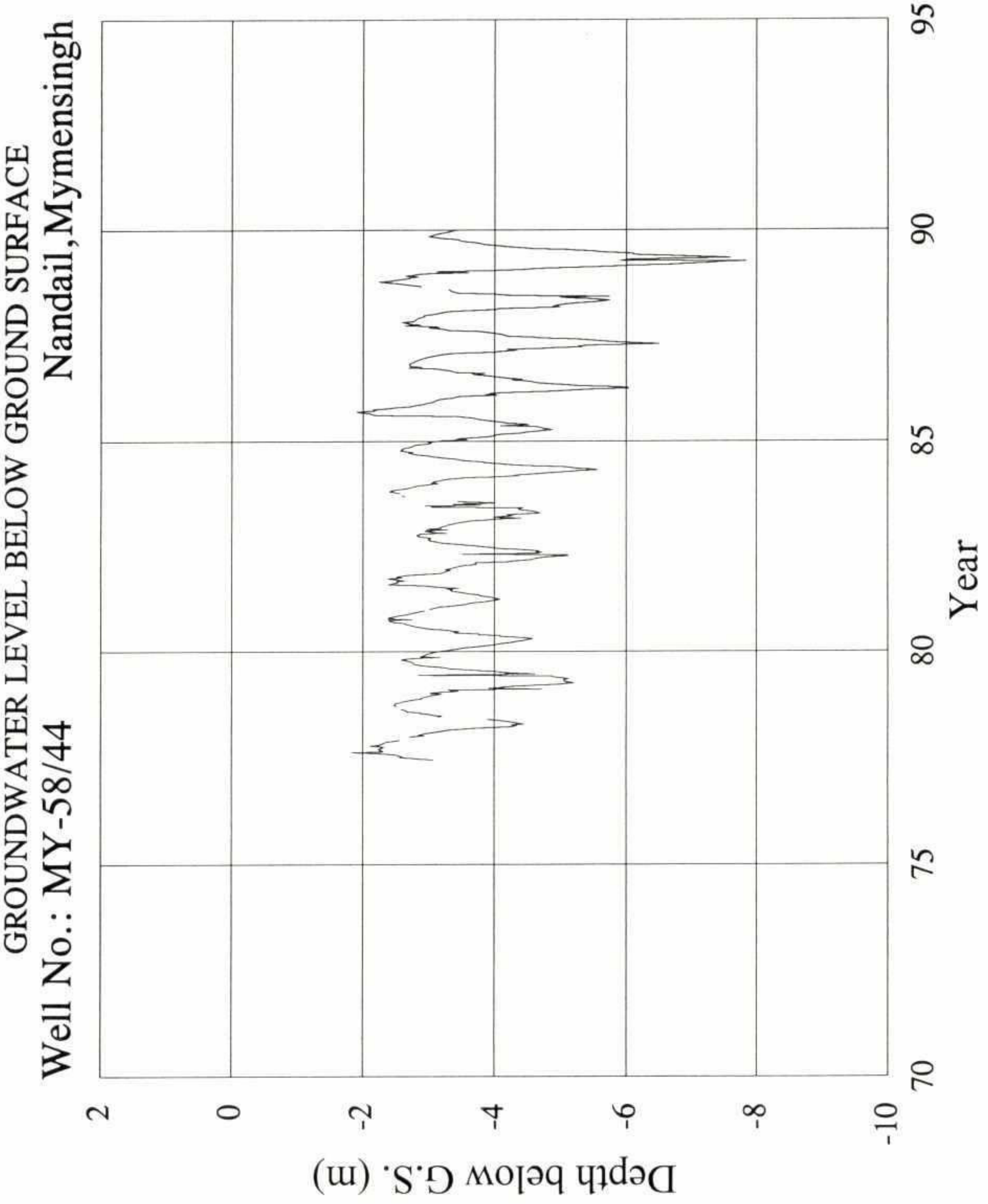

GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: MY-64/50
Haluaghat,Mymensingh
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
70
75
80
85
90
95
Year

Figure: A2



GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: MY-24/20 Phulpur,Mymensingh
Depth below G.S. (m)
5.0
0.0
-5.0
-10.0
-15.0
70
75
80
85
90
95
Years

Figure: A3


GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: MY-58/44
Nandail,Mymensingh
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
Year
70
75
80
85
90
95

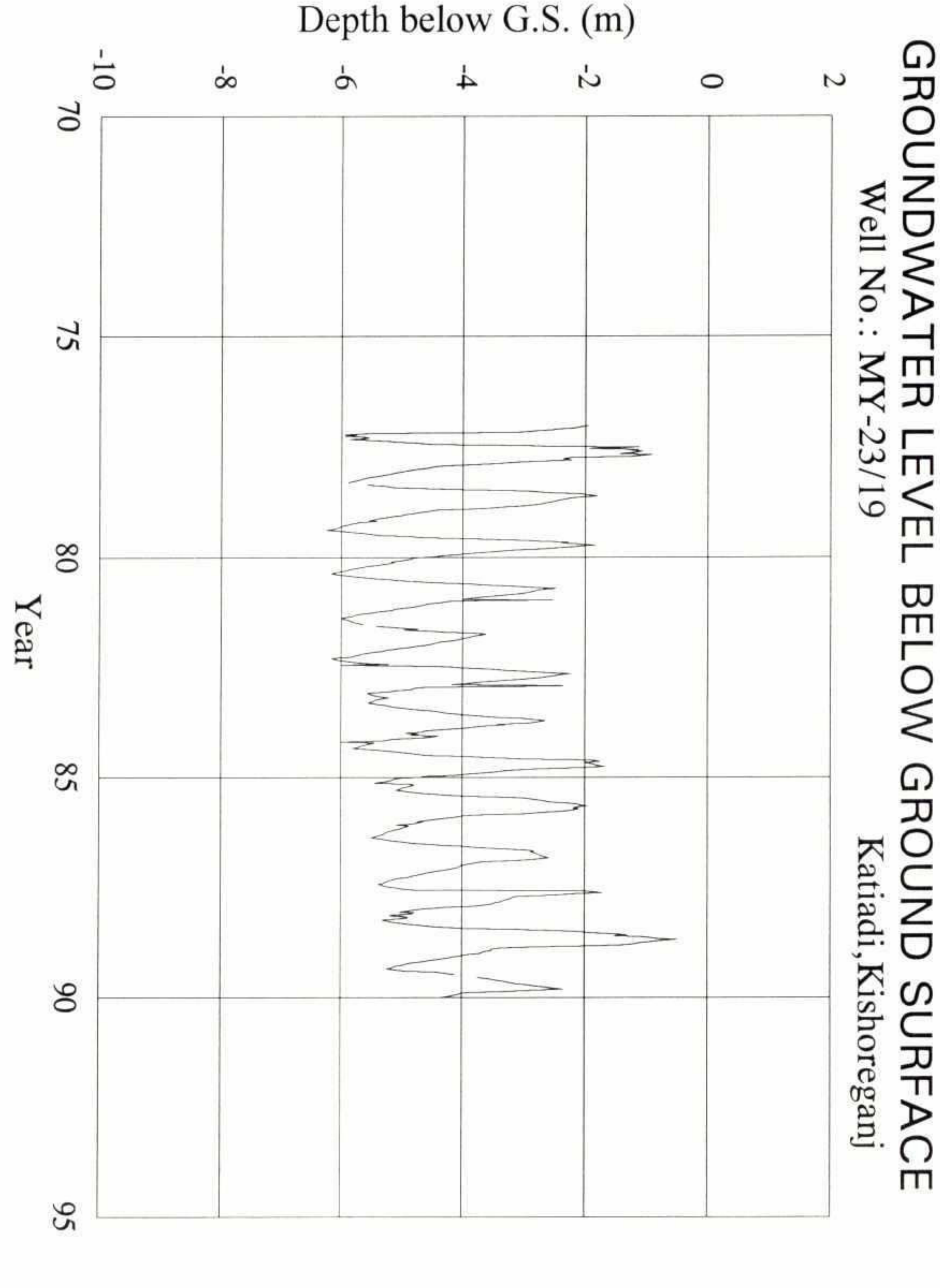

GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: MY-23/19
Katiadi,Kishoreganj
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
70
75
80
85
90
95
Year

Figure: A5

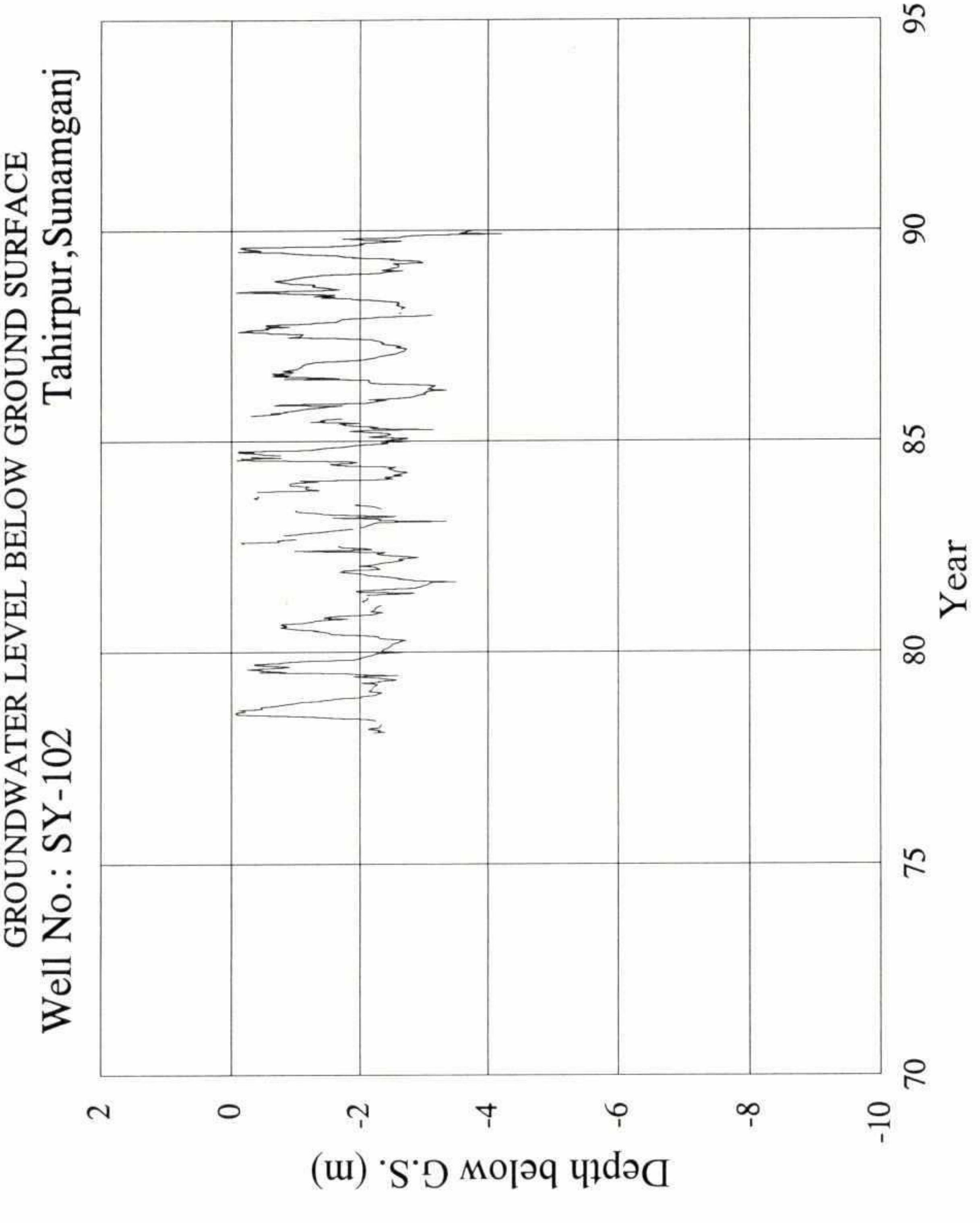

GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: SY-102
Tahirpur,Sunamganj
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
70
75
80
85
90
95
Year

Figure: A6

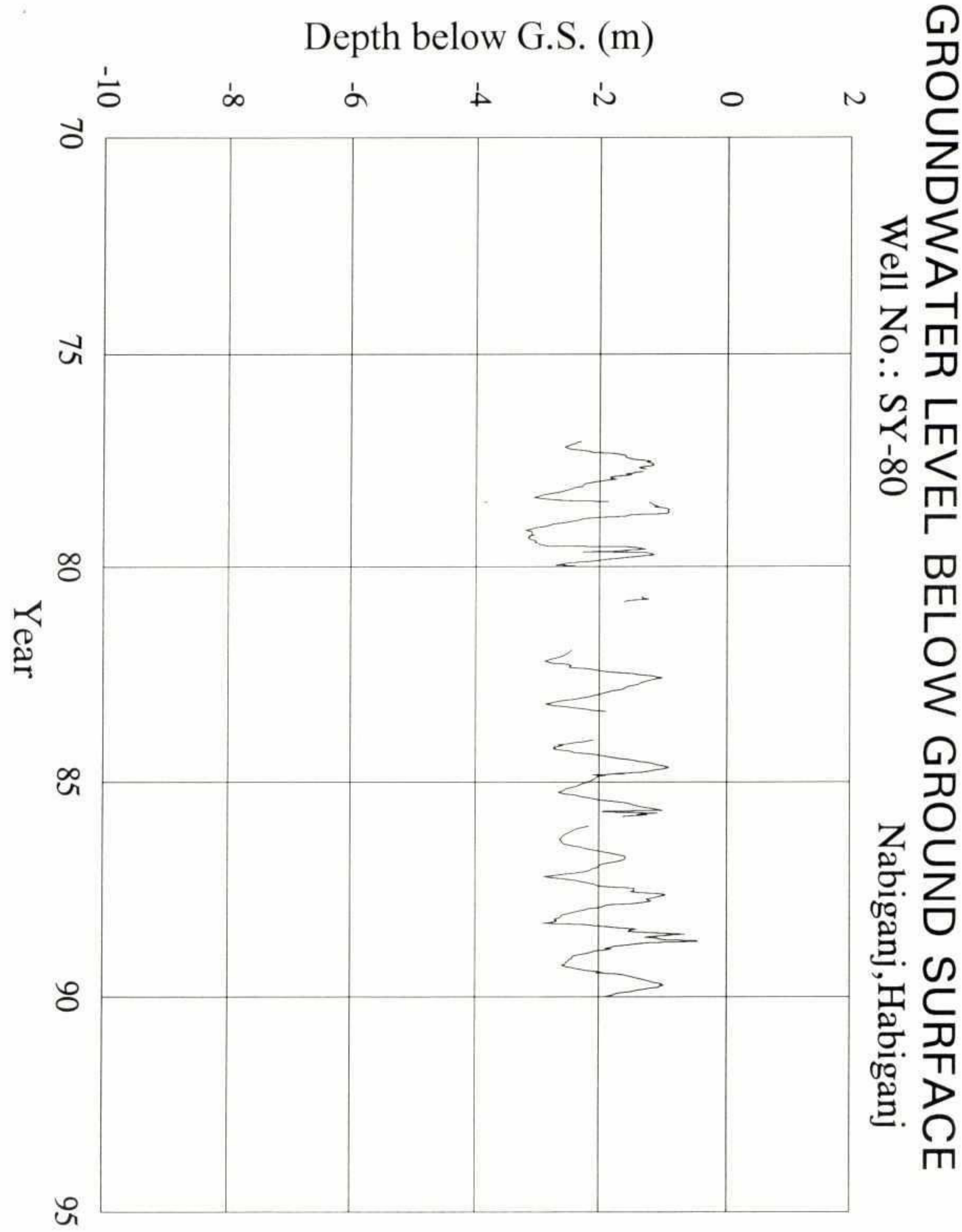
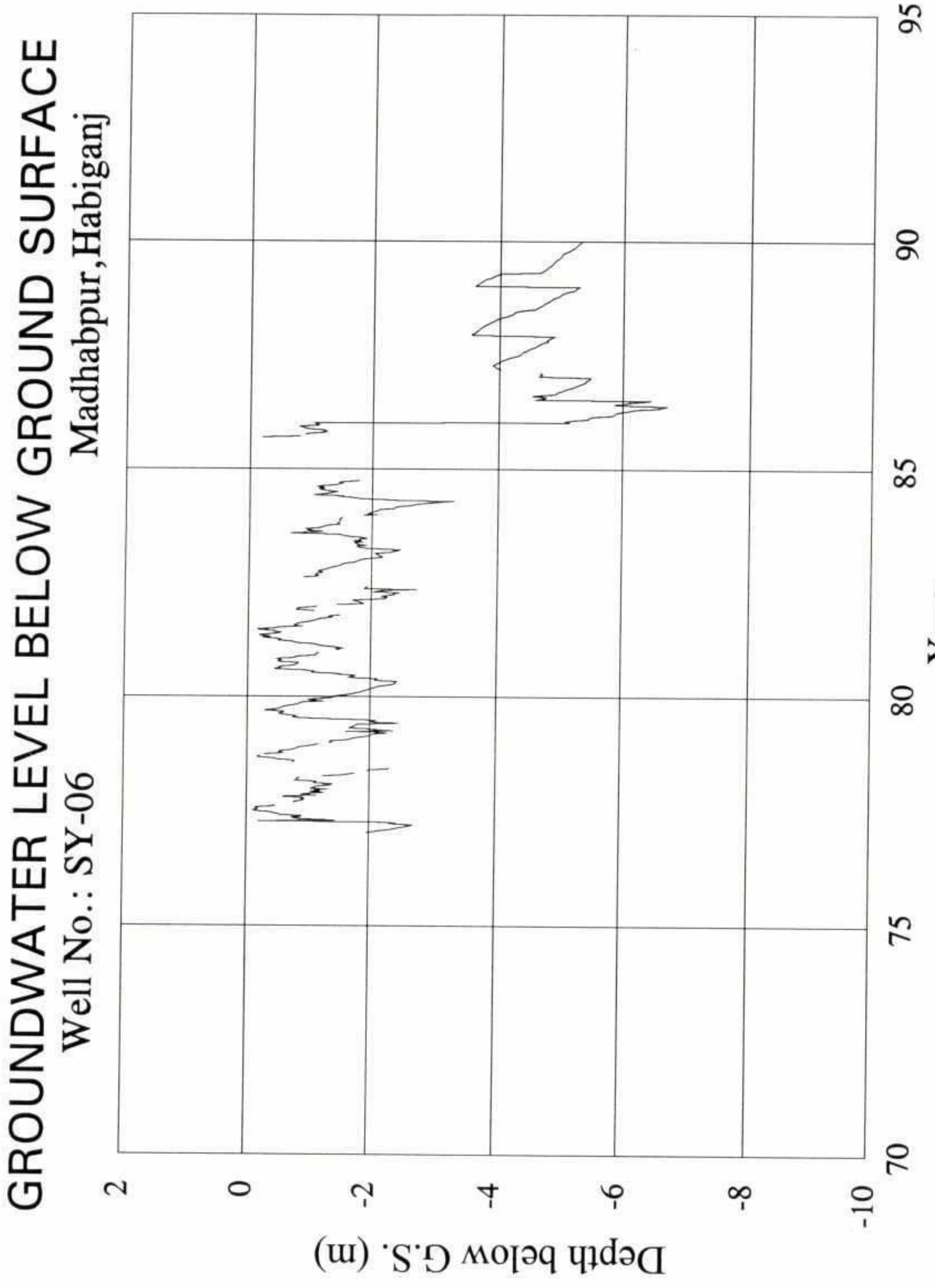

GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: SY-80
Nabiganj,Habiganj
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
70
75
80
85
90
95
Year

Figure: A7


GROUNDWATER LEVEL BELOW GROUND SURFACE
Well No.: SY-06
Madhabpur, Habiganj
Depth below G.S. (m)
2
0
-2
-4
-6
-8
-10
70
75
80
85
90
95
Year

APPENDIX B

GROUND WATER QUALITY DATA

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. : 78
Thana : Sylhet Sadar
Depth of well : 32.3 m

Date:	23.10.79		20.05.80		26.10.80		07.05.81		26.02.82		21.03.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	1.5	0.075	14.0	0.699	31.0	1.547	2.0	0.100	1.0	0.050	7.0	0.349
Mg	3.1	0.255	8.5	0.699	27.1	2.229	2.4	0.197	2.4	0.197	3.7	0.301
Na+K	61.4	2.671	69.1	3.006	47.3	2.058	59.0	2.567	58.9	2.62	54.2	2.356
Fe	6.7	0.240	1.6	0.057	12.6	0.451	5.6	0.201	4.8	0.172	6.0	0.216
Mn	Nil		Nil		N.T.		N.T.		Nil		N.T.	
SUM :		3.241		4.461		6.285		3.064		2.981		3.223
HCO3	147.0	2.409	190.0	3.114	250.0	4.098	138.0	2.262	130.0	2.131	152.0	2.491
CO3	Nil		Nil		Nil		Nil		4.0	0.133	Nil	
Cl	6.5	0.183	12.0	0.339	30.0	0.846	8.5	0.240	6.0	0.169	*.0	0.226
SO4	Nil		Nil		N.T.		N.T.		Nil		N.T.	
NO3	5.0	0.081	0.5	0.008	10.0	0.161	5.0	0.081	20.0	0.323	7.0	0.113
SUM :		2.673		3.461		5.105		2.582		2.756		2.830
% Error :		9.6		12.6		10.4		8.5		3.9		6.5
B	Nil		Nil		N.T.		N.T.		Nil		NT.	
SiO2	15.8		34.0		25.8		11.0		14.0		11.3	
CO2 (free)	7.0		190.0		2.5		2.5		Nil		2.0	
TDS	231.2		214.0		289.6		161.0		175.0		176.4	
El.Conduc.											275.0	
pH	7.0		9.0		8.5		8.5		8.0		9.0	
SAR	6.6		3.6		1.5		6.7		7.3		4.1	
TDS calc.	247.0		329.7		433.8		231.5		241.1		249.1	18.6

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. : 79
Thana : Moulvibazar
Depth of well : 32.3 m

Date:	23.10.79		20.05.80		26.10.80		07.05.81		26.02.82		21.03.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	5.5	0.274	2.0	0.100	7.5	0.374	7.5	0.374	6.5	0.324	10.0	0.499
Mg	4.6	0.378	4.9	0.403	9.2	0.757	2.4	0.197	3.4	0.280	4.9	0.401
Na+K	44.5	1.936	11.5	0.500	21.6	0.940	34.5	1.501	27.3	1.188	26.1	1.137
Fe	1.5	0.054	7.0	0.251	9.3	0.333	1.9	0.068	4.1	0.147	3.6	0.127
Mn	0.2	0.007	0.1	0.004	N.T.		N.T.		Nil		N.T.	
SUM :		2.650		1.257		2.404		2.140		1.938		2.165
HCO3	94.0	1.541	26.0	0.426	76.0	1.246	75.0	1.229	72.0	1.180	86.0	1.410
CO3	Nil		Nil		Nil		Nil		Nil	0.000	Nil	
Cl	7.0	0.197	6.0	0.169	5.0	0.141	6.5	0.183	5.0	0.141	6.0	0.169
SO4	Nil		Nil		N.T.		N.T.		Nil		N.T.	
NO3	Nil	0.000	Nil	0.000	N.T.	0.000	N.T.	0.000	Nil	0.000	N.T.	0.000
SUM :		1.738		0.595		1.387		1.413		1.321		1.579
% Error :		20.8		35.7		26.8		20.5		18.9		15.6
B	Nil		Nil		N.T.		N.T.		Nil		N.T.	
SiO2	25.5		12.3		20.5		20.0		16.3		15.8	
CO2 (free)	4.0		53.0		3.0		7.0		1.5		1.0	
TDS	124.8		138.8		96.8		110.0		98.0		95.2	
El.Conduc.											150.0	
pH	6.5		6.5		6.5		7.0		6.5		7.0	
SAR	3.4		1.0		1.8		2.8		2.2		1.7	
TDS calc.	182.8		69.8		149.1		147.8		134.6		152.3	

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. : 80
Thana : Habiganj
Depth of well : 38.4 m

Date:	22.10.79		20.05.80		25.10.80		07.05.81		26.02.82		22.03.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	14.5	0.724	1.5	0.075	15.0	0.749	20.5	1.023	16.5	0.823	21.0	1.048
Mg	7.0	0.576	2.1	0.173	7.9	0.650	9.1	0.749	5.5	0.452	7.6	0.625
Na+K	69.1	3.006	64.8	2.819	52.1	2.266	44.5	1.936	63.4	2.758	61.5	2.675
Fe	5.0	0.179	8.0	0.286	4.9	0.175	5.8	0.208	0.5	0.018	10.7	0.383
Mn	Nil		Nil		N.T.		N.T.		Nil		N.T.	
SUM :		4.484		3.353		3.840		3.915		4.052		4.731
HCO3	174.0	2.852	144.0	2.360	152.0	2.491	130.0	2.131	150.0	2.459	182.0	2.983
CO3	Nil		Nil		Nil		11.0	0.367	12.0	0.400	14.0	0.467
Cl	11.0	0.310	6.0	0.169	6.5	0.183	7.0	0.197	6.0	0.169	9.0	0.254
SO4	Nil		Nil		N.T.		N.T.		Nil		N.T.	
NO3	Nil	0.000	5.0	0.081	N.T.	0.000	N.T.	0.000	Nil	0.000	N.T.	0.000
SUM :		3.162		2.610		2.675		2.695		3.028		3.703
% Error :		17.3		12.5		17.9		18.5		14.5		12.2
B	Nil		Nil		N.T.		N.T.		Nil		N.T.	
SiO2	34.5		16.2		30.0		30.7		30.5		24.8	
CO2 (free)	4.8		129.0		4.0		Nil		Nil		14.0	
TDS	203.6		162.0		177.6		192.0		208.0		220.0	
El.Conduc.											370.0	
pH	7.0		7.5		7.5		7.5		7.5		7.5	
SAR	2.8		4.5		2.2		2.9		3.6		2.9	
TDS calc.	315.1		247.6		268.4		258.6		284.4		330.6	

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. : 81
Thana : Chunarughat
Depth of well : 32.3 m

Date:	22.10.79		25.10.80		07.05.81		26.02.82		22.03.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	9.0	0.449	7.5	0.374	12.0	0.599	9.0	0.449	16.0	0.798
Mg	5.8	0.477	3.1	0.255	5.5	0.452	5.2	0.428	2.8	0.230
Na+K	24.7	1.074	27.3	1.188	35.7	1.553	23.1	1.005	12.8	0.557
Fe	18.4	0.659	13.6	0.487	9.5	0.340	16.0	0.573	31.4	1.124
Mn	Nil		Nil		N.T.		N.T.		N.T.	
SUM :		2.660		2.304		2.944		2.455		2.710
HCO3	81.0	1.328	63.0	1.033	96.0	1.573	82.0	1.344	76.0	1.246
CO3	Nil		Nil		Nil		11.0	0.367	Nil	
Cl	9.0	0.254	3.5	0.099	6.5	0.183	7.5	0.212	10.0	0.282
SO4	Nil		Nil		N.T.		N.T.		Nil	
NO3	Nil	0.000	5.0	0.081	N.T.	0.000	5.0	0.081	0.3	0.005
SUM :		1.581		1.212		1.757		2.003		1.533
% Error:		25.4		31.1		25.3		10.1		27.8
B	Nil		Nil		N.T.		N.T.		N.T.	
SiO2	22.5		20.5		25.5		18.5		18.5	
CO2 (free)	7.0		7.0		3.0		1.0		0.5	
TDS	114.4		92.8		142.0		119.0		111.2	
El.Conduc.									165.0	
pH	6.5		6.5		7.0		7.5		7.0	
SAR	1.6		2.1		2.1		1.5		0.8	
TDS calc.	170.4		143.5		190.7		177.3		167.8	

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	Hole No.D-22		Hole No.99		Hole No.100		BADC-3		D-35	
Thana:	Madhabpur		Sunamganj		Nabiganj				Jaintiapur	
Depth in m	91.4		76.2		82.3		76.8		83.8	
	15.04.80		03.05.80		31.12.79		23.03.81		13.03.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	16.0	0.798	13.0	0.649	8.0	0.399	4.5	0.225	5.0	0.250
Mg	7.0	0.576	4.9	0.403	6.7	0.551	6.7	0.551	4.3	0.354
Na+K	48.7	2.118	194.5	8.461	91.4	3.976	55.5	2.414	36.0	1.566
Fe	0.3	0.011	4.4	0.158	20.0	0.716	8.4	0.301	11.2	0.401
Mn	Nil		Nil		0.2	0.007	0.2	0.007	Nil	
SUM :		3.503		9.670		5.650		3.498		2.570
HCO3	98.0	1.606	399.0	6.540	194.0	3.180	124.0	2.032	120.0	1.967
CO3	Nil		39.0	1.300	Nil		Nil		Nil	
Cl	9.5	0.268	31.5	0.889	24.0	0.677	6.0	0.169	7.0	0.197
SO4	Nil		Nil		5.0	0.104	N.T.		Nil	
NO3	Nil		12.0	0.194	N.T.		Nil		Nil	
SUM :		1.874		8.922		3.961		2.202		2.164
% Error :		30.3		4.0		17.6		22.7		8.6
B	Nil		Nil		Nil		N.T.		Nil	
SiO2	36.8		23.5		25.0		29.7		9.8	
CO2 (free)	Nil		Nil		Nil		19.5		7.0	
TDS	157.6		511.2		240.4		171.0		55.6	
El.Conduc.										
pH	8.0		10.0		10.0		7.0		7.5	
SAR	2.6		11.7		5.8		3.9		2.9	
TDS calc.	216.3		721.8		349.3		205.3		183.5	

Source: **BWDB**

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	JAG-1		BEA-1		BIS-1		GOL-1		GOW-1		KAN-1	
Upazila:	Jagannathpur		Beanibazar		Biswanath		Golapganj		Gowainghat		Kanaighat	
Depth in m:	96.0		82.0		116.1		142.0		86.9		121.9	
Date:	01.02.88		20.02.88		12.01.88		18.05.86		12.04.86		05.12.88	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	16.0	0.798	5.0	0.250	16.0	0.798	1.5	0.075	5.0	0.250	8.0	0.399
Mg	7.3	0.600	1.8	0.148	12.2	1.004	2.4	0.197	2.0	0.165	3.4	0.280
Na+K	22.2	0.966	20.2	0.879	21.8	0.948	133.0	5.786	157.0	6.830	31.2	1.357
Fe	14.8	0.530	10.5	0.377	8.4	0.301	0.8	0.027	0.0	0.000	28.1	1.004
Mn	Nil		Nil		Nil		Nil		Nil		Nil	
SUM :		2.895		1.654		3.051		6.085		7.244		3.041
HCO3	154.8	2.537	68.3	1.119	146.3	2.398	336.5	5.515	414.5	6.794	186.5	3.057
CO3	Nil		Nil		Nil		Nil		Nil		Nil	
Cl	37.0	1.044	7.0	0.197	2.4	0.068	4.0	0.113	10.0	0.282	31.0	0.875
SO4	6.1	0.127	0.0		4.0	0.083	2.1	0.044	6.0	0.125	0.0	
NO3	Nil		12.0	0.194	N.T.		Nil		Nil		0.0	
PO4	4.0	0.126	15.0	0.474	1.0	0.032	Nil		Nil		0.0	
SUM:		3.834		1.984		2.580		5.672		7.201		3.931
% Error:		-14.0		-9.1		8.4		3.5		0.3		-12.8
B	Nil		Nil		Nil		Nil		Nil		Nil	
CO2 (free)	28.0		25.0		39.0		12.0		0.0		69.0	
TDS	173.0		74.0		220.0		350.0		421.0			
El.Conduc.	280.0		125.0		360.0		550.0		670.0		260.0	
pH	6.6		6.5		6.9		6.9		6.8			
SAR	0.5		2.2		1.0		15.7		15.0		2.7	
IONS SUM:	262.2	6.729	139.9	3.638	212.1	5.631	480.3	11.757	594.5	14.445	288.2	6.972

Source: MMI 1990a

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	LAK-1		SYL-1		ZAK-1		KUL-1		MOU-1	
Upazila:	Lakhai		Sylhet Sadar		Zakoganj		Kulaura		Moulvibazar	
Depth in m:	100.0		114.9		78.9		103.0		68.0	
	12.03.86		16.05.85		25.04.88		12.04.88		21.04.87	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	19.0	0.948	10.0	0.499	8.8	0.439	7.6	0.379	22.0	1.098
Mg	5.0	0.411	5.0	0.411	5.4	0.444	4.6	0.378	16.0	1.316
Na+K	37.0	1.610	42.0	1.827	105.0	4.568	19.5	0.848	103.0	4.481
Fe	0.0	0.000	1.5	0.054	12.6	0.450	4.6	0.166	6.6	0.236
Mn	Nil		Nil		Nil	0.000	Nil	0.000	Nil	
SUM :		2.969		2.791		5.901		1.772		7.131
HCO3	164.6	2.698	152.4	2.498	315.8	5.176	75.6	1.239	317.0	5.196
CO3	Nil		Nil		Nil		Nil		Nil	
Cl	8.0	0.226	2.0	0.056	32.0	0.903	7.1	0.200	105.0	2.962
SO4	2.0	0.042	8.0		0.0	0.000	4.0	0.083	0.0	0.000
NO3	Nil	0.000	2.0	0.032	0.0	0.000	0.0	0.000	0.0	0.000
PO4	0.0	0.000	0.0	0.000	5.0	0.158				
SUM :		2.965		2.587		6.237		1.523		8.158
% Error :		0.1		3.8		-2.8		7.6		-6.7
B	0.0		0.0		0.0		0.0		0.0	
CO2 (free)									85.0	
TDS	172.0		173.0		359.0		85.0		400.0	
El.Conduc.	260.0		275.0		580.0		138.0		650.0	
pH	6.7		6.7		7.0		6.5		6.9	
SAR	2.0		2.7		6.9		1.4		4.1	
IONS SUM:	235.6	5.934	222.9	5.378	484.6	12.138	123.0	3.295	569.6	15.289

Source: MMI 1990a

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	IS-8		D-2		N-54		S-5		SD-8	
Thana:	Islampur		Dewanganj		Nakhla		Sherpur		Sribardi	
Depth in m:										
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca		1.50		1.85		1.25		1.78		1.40
Mg		1.02		1.43		1.10		1.22		1.45
Na+K		2.43		2.48		3.32		2.27		3.37
Fe		t		t	0.20	0.01		t		t
Mn										
SUM :		4.95		5.76		5.68		5.27		6.22
HCO3		3.61		3.92		4.13		3.54		3.75
CO3		nil		nil		nil		nil		nil
Cl		0.39		0.90		0.38		0.49		0.20
SO4		0.06		0.17		0.10		0.04		0.06
NO3		t		t		t		t		0.01
PO4		0.09		0.16		0.06		0.09		0.06
SUM :		4.15		5.15		4.67		4.16		4.08
% Error :		8.8		5.6		9.7		11.8		20.8
B	t		t		t		t		t	
CO2 (free)	1.1		1.3		3.2		2.0		1.4	
SiO2	29.0		28.5		35.0		37.3		34.2	
TDS !	190		262		182		232		182	
El.Conduc.	293		388		268		331		276	
pH	8.25		7.90		8.00		8.15		8.15	
SAR	2.16		1.94		3.06		1.85		2.82	
TDS/EC	0.65		0.68		0.68		0.70		0.66	
!! seems TDS are not laboratory but estimated values !!										

Source: MMP 1982

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	My2		My110		My521		My324		NB47	
Thana:	Mymesingh		Iswarganj		Gouripur		Phulpur		Nalitabari	
Depth in m:										
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca		1.64		1.12		1.00		1.16		1.10
Mg		1.16		0.73		0.84		1.04		0.88
Na+K		0.07		0.18		0.44		0.13		1.77
Fe		nil	1.20	0.04		nil		nil	0.74	0.03
Mn										
SUM :		2.87		2.07		2.28		2.33		3.78
HCO3		0.20		1.28		1.44		1.28		2.16
CO3		0.12		0.04		nil		t		nil
Cl		0.20		0.19		0.20		0.20		0.37
SO4		0.01		0.01		0.01		t		0.21
NO3		0.02		nil		nil		0.04		t
PO4		0.63		0.57		0.63		0.74		0.09
SUM :		1.18		2.09		2.28		2.26		2.83
% Error :		41.7		-0.4		0.0		1.5		14.3
B	0.04		0.40		0.30		1.20		t	
CO2 (free)	8.3		1.8		5.7		2.4		0.7	
SiO2	33.0		30.0		29.0		20.0		36.0	
TDS !!	236		194		201		170		156	
El.Conduc.	354		278		282		251		228	
pH	7.85		7.52		7.27		7.48		7.95	
SAR	0.06		0.18		0.46		0.12		1.78	
TDS/EC	0.67		0.70		0.71		0.68		0.68	

!! seems TDS are not laboratory but estimated values !!

Source: MMP 1982

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	My572		My174		NEP-12		NEN-61		J83		M-9	
Thana:	Haluaghat		Muklagacha		Purbadhala		Netrakona		Jamalpur		Melandah	
Depth in m:												
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	20.04	1.00	22.44	1.12	22.04	1.10	31.06	1.55	24.05	1.20	23.05	1.15
Mg	12.16	1.00	12.16	1.00	11.55	0.95	11.91	0.98	7.54	0.62	10.09	0.83
Na+K	5.06	0.22	6.21	0.27	62.53	2.72	64.83	2.82	52.64	2.29	63.45	2.76
Fe	0.02	0.00		nil	0.66	0.02		t	0.70	0.03		nil
Mn												
SUM :		2.22		2.39		4.79		5.35		4.14		4.74
HCO3	75.66	1.24	28.68	0.47	219.04	3.59	256.86	4.21	158.02	2.59	215.99	3.54
CO3	1.20	0.04	4.80	0.16		nil		nil		nil		nil
Cl	7.09	0.20	8.86	0.25	10.99	0.31	10.63	0.30	13.12	0.37	7.09	0.20
SO4		t	0.96	0.02	2.88	0.06	1.92	0.04	2.88	0.06	1.92	0.04
NO3		t		0.01		t		t		t		t
PO4	21.84	0.69	10.13	0.32	2.85	0.09	2.85	0.09	1.90	0.06	2.85	0.09
SUM :		2.17		1.23		4.05		4.64		3.08		3.87
% Error :		1.2		32.0		8.4		7.1		14.6		10.1
B	0.20		0.12		t		t		t		t	
CO2 (free)	1.2		nil		0.5		0.1		0.5		2.0	
SiO2	28.5		32.0		26.5		25.3		35.0		30.1	
TDS	236		287		216		256		159		146	
El.Conduc.	137		430		326		390		234		217	
pH	7.58		8.45		8.10		8.30		7.90		7.7	
SAR	1.26		0.26		2.69		2.51		2.40		2.77	
TDS/EC	1.72		0.67		0.66		0.66		0.68		0.67	

Source: MMP 1982

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. : 40
Thana : Jamalpur
Depth of well : 20.1 m

Date:	19.10.79		16.05.80		10.10.80		18.05.81		27.03.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	28.5	1.422	90.0	4.491	79.0	3.942	98.0	4.890	95.0	4.741
Mg	11.9	0.979	52.8	4.343	52.5	4.319	39.4	3.241	42.1	3.463
Na+K	42.0	1.827	20.7	0.900	33.0	1.436	8.8	0.383	24.4	1.063
Fe	44.0	1.576	25.3	0.906	52.4	1.876	60.4	2.163	1.5	0.054
Mn	Nil		Nil		N.T.		0.1	0.004	N.T.	
SUM :		5.804		10.641		11.573		10.681		9.321
HCO3	157.0	2.573	146.0	2.393	121.0	1.983	140.0	2.295	112.0	1.836
CO3	Nil		Nil		Nil		Nil		Nil	
Cl	21.5	0.607	231.0	6.517	239.5	6.756	234.0	6.601	244.0	6.883
SO4	Nil		Nil		5.0	0.104	5.0		N.T.	
NO3	3.0	0.048	Nil	0.000	0.5	0.008	40.0	0.645	1.5	0.024
SUM:		3.228		8.909		8.852		9.541		8.743
% Error:		28.5		8.9		13.3		5.6		3.2
B	Nil		Nil		N.T.		N.T.		N.T.	
SiO2	31.8		25.8		29.8		18.8		18.3	
CO2(free)	24.0		381.0		15.0		13.0		4.0	
TDS	178.0		559.6		562.0		572.0		718.0	
El.Conduc.									1210.0	
pH	7.5		7.0		7.0		7.0		7.0	
SAR	1.7		0.4		0.7		0.2		0.5	
TDS calc.	339.7		591.6		612.7		644.5		538.8	

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. 42
Upazila: Sherpur
Depth of well: 46.3 m

Constit.	19.10.79		17.05.80		11.10.80		19.05.81		28.11.81		15.03.83	
	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	25.5	1.272	28.0	1.397	48.5	2.420	29.0	1.447	23.5	1.173	29.0	1.447
Mg	20.7	1.703	22.0	1.810	18.6	1.530	22.0	1.810	25.3	2.081	22.6	1.859
Na+K	44.2	1.923	32.9	1.431	46.6	2.027	20.4	0.887	28.3	1.231	33.3	1.449
Fe	0.3	0.011	7.5	0.269	19.5	0.698	29.6	1.060	12.5	0.448	10.6	0.380
Mn	Nil		Nil		N.T.		0.1	0.004	N.T.	0.000	N.T.	
SUM :		4.909		4.907		6.676		5.208		4.933		5.134
HCO3	177.0	2.901	178.0	2.917	250.0	4.098	158.0	2.590	180.0	2.950	198.0	3.245
CO3	Nil		Nil		Nil		14.0	0.467	N.T.	0.000	Nil	
Cl	33.5	0.945	26.0	0.733	29.0	0.818	30.0	0.846	28.0	0.790	31.0	0.875
SO4	Nil		5.0	0.104	Nil	0.000	Nil		N.T.		N.T.	
NO3	Nil	0.000	Nil	0.000	Nil	0.000	Nil	0.000	N.T.	0.000	Nil	0.000
SUM :		3.846		3.755		4.916		3.903		3.740		4.120
% Error :		12.1		13.3		15.2		14.3		13.7		11.0
B	Nil		Nil		N.T.		N.T.		0.1		N.T.	
SiO2	32.0		30.0		32.3		23.5		22.7		25.0	
CO2(free)	8.5		89.0		3.5		Nil		11.5		3.0	
TDS	214.0		234.8		293.6		246.0		229.0		238.4	
El.Conduc.											420.0	
pH	7.5		7.5		7.0		7.5		7.0		7.0	
SAR	1.6		1.1		3.4		2.3		1.0		1.1	
TDS calc.	333.2		329.4		444.5		326.6		320.4		349.5	

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station No. : 41
Thana : Haluaghat
Depth of well : 113.4 m

Date:	15.10.79		09.05.80		12.10.80		10.05.81		26.11.81		09.04.83	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	17.0	0.848	17.0	0.848	15.5	0.773	21.0	1.048	18.0	0.898	4.0	0.200
Mg	8.5	0.699	17.4	1.431	11.0	0.905	6.7	0.551	7.9	0.650	3.7	0.301
Na+K	55.1	2.397	41.9	1.823	55.4	2.410	48.0	2.088	52.6	2.288	33.4	1.452
Fe	0.6	0.021	2.5	0.090	5.6	0.201	2.4	0.086	1.4	0.050	12.0	0.430
Mn	Nil		Nil		N.T.		Nil		N.T.		N.T.	
SUM :		3.966		4.192		4.289		3.773		3.886		2.383
HCO3	169.0	2.770	176.0	2.885	104.0	1.705	172.0	2.819	176.0	2.885	78.0	1.278
CO3	Nil		Nil		35.0	1.167	Nil		N.T.		Nil	
Cl	5.0	0.141	8.0	0.226	7.0	0.197	5.0	0.141	5.5	0.155	8.0	0.226
SO4	Nil		Nil		Nil		Nil		N.T.		N.T.	
NO3	1.0	0.016	Nil		Nil		Nil		0.1	0.001	5.0	0.081
SUM:		2.927		3.110		3.069		2.960		3.041		1.585
% Error:		15.1		14.8		16.6		12.1		12.2		20.1
B	Nil		Nil		N.T.		N.T.		N.T.		N.T.	
SiO2	31.3		30.0		30.8		23.3		24.0		20.0	
CO2(free)	5.5		5.0		Nil		3.0		4.0		7.0	
SAR	2.7		1.7		2.6		2.3		2.6		2.9	
TDS	178.4		191.2		163.6		191.0		196.0		104.4	
El.Conduc.											160.0	
pH	8.0		8.0		7.5		7.5		7.5		7.0	
SAR		2.7		1.7		2.6		2.3		2.6		2.9
TDS calc.	287.5		292.8		264.3		278.4		285.5		164.1	

Source: BWDB

RESULTS OF CHEMICAL ANALYSIS OF GROUNDWATER

Station:	No-46				No-48					
Thana:	Kisharganj				Bhairab Bazar					
Depth in m:	116.97				20.00					
Date:	05.05.81		26.11.81		11.05.80		19.10.80		21.11.81	
Constit.	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm
Ca	22.5	1.123	23.5	1.173	67.0	3.343	68.0	3.393	43.0	2.146
Mg	12.8	1.053	10.4	0.856	18.6	1.530	19.2	1.579	32.9	2.706
Na+K	53.8	2.340	60.9	2.649	38.9	1.692	42.2	1.836	30.1	1.309
Fe	1.8	0.064	1.3	0.047	4.0	0.143	0.4	0.014	4.4	0.158
Mn	Nil		Nil		Nil		Nil		Nil	
SUM :		4.580		4.724		6.709		6.823		6.319
HCO3	200.0	3.278	216.0	3.540	321.0	5.261	318.0	5.212	305.0	4.999
CO3	5.0	0.167	nil		Nil		Nil		0.0	0.001
Cl	9.0	0.254	11.0	0.310	16.0	0.451	23.5	0.663	16.5	0.465
SO4	Nil		Nil		Nil		nil		Nil	
NO3	Nil		7.0	0.113	N.T.		Nil		Nil	
SUM:		3.698		3.963		5.713		5.875		5.465
% Error:		10.7		8.8		8.0		7.5		7.2
B	Nil		Nil		Nil		N.T.		Nil	
SiO2	25.8		25.0		25.0		29.7		21.5	
CO2 (free)	Nil		9.5		5.0		6.0		10.0	
TDS	229.0		245.0		335.2		321.2		299.0	
El.Conduc.										
pH	7.5		8.0		7.5		7.5		7.5	
SAR	2.2		2.6		5.8		3.9		2.9	
TDS calc.	330.7		355.1		490.5		501.0		453.4	

Source: BWDB

APPENDIX C

FURTHER STUDIES OF GROUND WATER RESOURCES

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FURTHER STUDIES OF GROUND WATER RESOURCES

1. Introduction

Evaluation of the adequacy of the existing ground water database has led to the identification of various needs for further data studies, surveys, a modelling project, and monitoring programs. This appendix outlines the justification and requirements for these.

2. Studies

2.1 Establishment of Baseline Ground Water Levels for the Northeast Region

The most positive evidence of over-extraction of ground water in any locality is obtained when the current ground water level can be compared to that which prevailed before extraction began. This antecedent baseline ground water level may be established from the oldest ground water level records available for the locality. Decline of a ground water table, or of a potentiometric surface, is indicative of over-extraction. If over-extraction is indicated it needs to be confirmed through cross-correlation with precipitation and other stresses which could also cause the ground water table to decline. Conversely, rise of a ground water table, or of a potentiometric surface, is indicative of recharge exceeding withdrawal and, again, this indication needs to be confirmed through cross-correlation with precipitation and other stresses which could also cause the ground water table to rise.

To establish baseline ground water levels throughout the Northeast Region would involve:

- acquisition of all BWDB Water Supply Papers, particularly those pertaining to the period prior to 1977 when ground water extraction started to become significant; these papers are believed to contain all relevant ground water level data, but to the extent they do not original records should be sought; BADC autorecorder and other data should also be acquired.

- preparation of digitized files of all these groundwater level data for the 202 monitored locations in the BWDB network which lie in the Northeast Region; there should be separate files for ground water level below ground surface and referred to PWD datum.

- collection, review and selection of groundwater monitoring data obtained by BWDB from autorecorders, and of ground water monitoring data collected by BADC in the region, as part of the above activity

- supplementing the 1:500,000 project area map with CAD-plotted locations of BADC ground water monitoring sites.

- examination, analysis and evaluation of the data leading to classification of the hydrographs; data from dug wells and piezometers need to be dealt with separately, and the latter divided by the piezometer screen depth.

- preparation of separate maps of the oldest recorded water table in the unconfined surface aquifer, and of the oldest potentiometric surface in the semi-confined or confined lower aquifers (if possible); these maps should be prepared in two versions, one showing the oldest water table in terms of its depth below ground, the other showing it in terms of its elevation referred to PWD datum.

- attempt identification of the various ground water flow systems (regional, intermediate and local) in the Northeast Region, and their recharge and discharge areas.

2.2 Assessment of Ground Water Development Impacts in the Northeast Region

There has been no thorough regional assessment made with the objective of evaluating the impact on the ground water resources of the annual extraction of large quantities of ground water, specifically in the Northwest and West Subregions.

The impact study should be designed to test the basic hypothesis for estimates of potential recharge. The hypothesis assumes that the aquifer is fully recharged every year, and that the influence of previous withdrawals is not carried over in time. The ground water table hydrographs prepared in the baseline ground water level study should give spatial and temporal answers to this question.

Continuation of the present large ground water withdrawals for irrigation in some areas, and also the envisaged expansion of ground water development for irrigation, require assessment of the present status of the ground water resources.

The impact of long-term large ground water withdrawals could be determined with reference to the established baseline ground water table, and baseline potentiometric surface.

The assessment would lead mainly to a delineation of three types of area in terms of ground water availability:

- Areas where over-extraction is taking place and, consequently, there is no scope for further expansion of ground water withdrawals; the consequences of continued pumping at the present rate should be evaluated.

- Areas where the present level of withdrawal is acceptable but there is no scope for further expansion of ground water development.

- Areas where recharge is sufficient to support continuation and expansion of present ground water withdrawals

In the first type of area a year-by-year decline in ground water table level at the end of the monsoon season will indicate over-extraction. In the second type of area ground water level hydrographs could indicate annually increasing withdrawals, but the drawndown water table recovers to the previous year's level. In the third type of area groundwater fluctuations not affected by pumping would be observed.

An impact assessment should be carried out not only for any specific development area, but also for its surroundings, before proceeding with large scale ground water development for irrigation. Areas where no over-extraction is taking place, and the ground water resources are suitable for irrigation development should first be delineated.

The continuation of ground water resources development by installation and exploitation of more tubewells (STW, DSSTW and DTW) in parts of the West and Northwest subregions should be closely monitored. Any proposals on the location and extent of future ground water development for irrigation must be subject to thorough verification of ground water level trends within the area in question.

2.3 Evaluation of Hydrogeologic Data for the Central and Eastern Subregions

Assessments of ground water resources in the Central and Eastern Subregions differ. There is insufficient information available at present for meaningful conclusions to be drawn about ground water conditions there. For this reasons exploratory drilling and aquifer testing in these subregions is proposed for execution in the near future, possibly within the framework of the Northeast Minor Irrigation Project.

In the meantime it is proposed all lithologic logs and aquifer test results available with BWDB, BADC and MMI should be assembled and evaluated. The purpose of this evaluation will be to:

- aid interpretation of ground water monitoring as proposed under the Baseline Ground Water Level Study.
- enable preliminary assessment of the ground water potential prior to completion of the exploratory drilling and aquifer testing
- aid conceptualization of an appropriate mathematical model of ground water recharge and discharge in the East Subregion.

3. Surveys

3.1 Survey of Domestic Water Supply in the Central Subregion

According to the report: Rural Water Supply Status up to June 1991 (DPHE, 1991), there were 8981 tubewells operational in Sunamganj district in 1991, and serving approximately 1.6 million people or almost the entire population of the district. Experience from site visits in this district does not, however, confirm this apparently highly satisfactory situation. On the contrary, it is reported that surface water is commonly used for domestic water supply not only in Sunamganj district but generally in the Central Subregion, and that this is due to the difficulty encountered in gaining access to the shallow ground water resources which lie beneath thick surficial layers of very fine-grained paludal sediments (clays and silts, often mixed). A health hazard therefore exists throughout the subregion wherever surface water is being used for domestic purposes.

It is recommended that a survey is made of domestic water supply in the Central Subregion in

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order to define the nature and scale of the well water supply project required to ensure safe domestic water supplies from ground water throughout the subregion. The survey should enumerate households presently using surface water, and those presently using ground water (STW or DTW), for domestic use, and the frequency/severity of intestinal illness, if any, among household members.

3.2 Baseline Survey of Ground Water Quality in the Northeast Region

Population growth in the region will result in increasing demand for safe water supplies for household use, and also an increased demand for water for irrigation. More people will generate an increased amount of waste water, and more irrigated agriculture will generate additional return flows containing pesticide and fertilizer pollutants. The introduction of local industries without proper waste treatment may present new potential hazards for water quality.

Requirements for safe water for domestic use, and for water of adequate quality for irrigation, will dramatically increase and so will the amount of ground water pollutants. To be able to assess if, and in what respect, ground water quality is deteriorating, and so enable timely preventive or corrective measures, it is necessary to know what the initial reference water quality was. Otherwise, changes in water quality over time may be detected when it may be too late to take preventive or corrective measures. Therefore a survey of water quality is needed to establish a baseline to which all possible future changes in quality can be compared. Consequently, a baseline survey of ground water quality should be carried out throughout the Northeast Region.

The approach and methodology to be followed in carrying out this survey should follow that of the BGS pilot project survey carried out in 1992. The baseline survey work will then consist of:

- acquisition of the results of analyses carried out by the BGS, preferably in digitized form; these data will serve as a starting point for a digital database on ground water quality in the Northeast Region, and to point out in greater detail the needs for study under this program.

- acquisition of the results of BWDB analyses carried out to date, and the incorporation of valid results into the regional database; extensive checking of these data is seen to be necessary before such incorporation; this activity will also encompass review and checking of ground water quality data obtained from other sources.

- assessment of the areal coverage and design of the ground water quality sampling network; the BGS network of sampling points must be supplemented in the East Subregion, and a sampling network should be established in the Northwest Subregion; in the West Subregion a few additional sampling points are needed in the northeastern and southern parts; all sampling point locations should be determined in terms of geographical coordinates using GPS equipment.

- identification, before commencement of the survey, of all possible pollutants, including those from fertilizers and pesticides, and selection of contamination indicators and suitable methods of detection; the selection of constituents to be analysed should include nitrates, but trace elements may be narrowed down from those investigated by the BGS based on its findings.

- acquisition of field test equipment for well head determinations of pH, Eh, EC, free CO2 and HCO3; such portable equipment will preferably be in kit form as available from HACH and other manufacturers; also required will be GPS equipment for locating the wells (geographical co-ordinates and altitude).

- arrangement of contractual services to be provided by a well-equipped and staffed laboratory; these services are needed for determinations of major and minor ions: Na, K, K,Ca, Mg, Fe, SO4, Cl, PO4, NO3, and boron, total phosphorus and silica.

- one-time sampling at all wells in the survey network not already sampled by the BGS; it is envisaged that a crew of two will be required to take the samples, carry out well-head tests, and despatch the samples to the contracting laboratory; arrangements for the prompt despatch of the (preferably refrigerated) samples will require careful attention given the remoteness of many of the wells and the large number of samples involved.

- analysis of samples by the contracting laboratory which shall include the preparation of a suitable report presenting the data and evaluating it with particular reference to the ionic balance, and the relationship of weights of constituents analysed to independently determined total dissolved solids.

- review and incorporation of all acceptable well-head and laboratory results into the regional database.

4. Project

4.1 Ground Water Recharge Model for the East Subregion

Several quantitative estimates of recharge to ground water were made in the past decade for Bangladesh - including the Northeast Region. These assessments were made using various analytical tools inclusive of mathematical models. The Water Resources Planning Organization (WARPO) has carried out the latest and most comprehensive of the modelling studies under the National Water Plan Project, Phases I and II.

The validity of WARPO's recharge model is questionable for the East Subregion where the upper silty clay/silt layer of surface deposits could be considerably thicker than assumed in this model, and where the sequence of sediments below this surface layer appears more complex than that of the three-layer system forming the basis of the model. Because the multi-aquifer sequence of leaky (semi-confined) and confined aquifers found in this subregion does not conform to the three-layer system assumed in the model, the assumption made in the model that ground water in these aquifers is replenished annually by rainfall and flood water may not be valid. A new mathematical model is therefore required for use in this subregion, and it is suggested that the MODFLOW model developed by the United States Geological Survey (USGS) be used.

For calibration and validation of this new model, data which have been evaluated and classified under the Baseline Ground Water Level Study should be used.

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5. Programs

5.1 Ground Water Level Monitoring Program for the Northeast Region

A ground water level monitoring is needed to enable early detection of any over-extraction of ground water. It should involve continuation and integration of the monitoring activities of the BWDB, BADC, and others; these organizations may need assistance in establishing the personal computer facilities needed for preparation of digitized files, and accelerated data processing and publication. The program should be initiated as soon as possible.

The work will involve regular updating of the digitized files, classification of the hydrographs as they emerge from the processing, and examination of their relationship to the baseline water levels established for each locality so as to identify over-extraction.

The oldest data from the monitoring networks will enable establishment of a "baseline ground water level", or reference level to which other more recent and future ground water level changes would be referred.

The impact of existing long-term large ground water withdrawals could then be determined with reference to the established baseline ground water table, and baseline potentiometric surface, by means of classifying and evaluating ground water level hydrographs. At least three main types of hydrograph will be observable:

- ones showing a perennial decline of the ground water levels at the end of the monsoon season, which is indicative of over-extraction of ground water.
- ones showing a perennial decline of ground water levels at the end of the dry season, but recovery to the previous year's level, which is indicative of acceptable ground water extraction.
- ones showing fluctuations of ground water level which are not affected by pumping, and follow the natural recharge/discharge cycle.

5.2 Ground Water Quality Monitoring Program for the Northeast Region

A ground water quality monitoring program is needed to enable early detection of any ground water quality deterioration or contamination, and timely corrective measures. The program should be initiated soon after the baseline survey of ground water quality has been completed, and in consideration of its findings.

The program will involve twice yearly sampling of ground water extracted from a network of production wells. The samplings should be made at, or close to, the times of maximum and minimum ground water level as observed in the piezometric network, or say October/November and March/April. The number of wells in the sampling network should be sufficient to provide adequate areal coverage of the entire Northeast Region. In addition, the network should include some wells near to known or suspected sources of ground water contamination; these will need to be identified in setting up the program.

The program will involve routine analytical determinations both at the well head and in the laboratory as follows:

- pH, Eh, EC, HCO3, and possibly dissolved oxygen, need to be measured at the well head using appropriate kit technologies.

- Na, K, Ca, Mg, Fe, SO4, Cl, PO4, NO3, and total boron, phosphorus and silica, need to be measured in the laboratory.

From the laboratory determinations the SAR (adjusted) should be computed, and its trend over time followed as this is the primary indicator of the suitability of water for irrigation.

These routine determinations should be sufficient to enable detection of ground water deterioration due to common causes such as the use of fertilizers and the disposal of livestock waste and sewage. However, special determinations may be called for in contaminant cases, and the following should be considered on a continuous review basis:

- Dissolved methane and hydrogen sulphide; the Northeast Region overlies a major gas field and these gases are known to be leaking out of the ground, and into water wells, in several localities; these gases are toxic to fish, in particular, and should be monitored at least at some points in the network.

- Dissolved organic carbon; this is a useful indicator of pesticides and herbicides the use of which is thought to be increasing in the Northeast Region; they have a high solubility and, hence, a great mobility in ground water; they are particularly difficult to eradicate once in the ground water body, and are toxic to both fish and humans.

In setting up this program it will be particularly important to identify present and proposed chemical works. At present fertilizer factories at Fenchuganj and Chhatak, and a pulp and paper mill at Chhatak are of immediate concern. The desirability of introducing further industry into the Northeast Region indicates a potential for further ground water contamination.