CHAPTER 6

STUDY IN MODEL RURAL AREAS

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6.1 Selection of Model Rural Areas

6.1.1 Purpose and Activities

In order to collect information on hydrogeology, arsenic contamination and socio-economics, three Model Rural Areas were selected for the study. The information and data obtained were used for preparing a master plan to cope with arsenic problems in the study area.

In the Model Rural Areas, the following 8 items of activities were conducted. In this chapter, socio-economy, water use, arsenic patients and dissemination activities for arsenic measures are mentioned. Other activities are presented in the relevant chapters.

(1) Socio-economic Study
(2) Water Sampling and Analysis
(3) Drilling of Improved Deep Wells
(4) Performance Test of Arsenic Removal Equipment
(5) Core Boring
(6) Diagnosis of Arsenic Patients
(7) Setting Up A Community Organization to Lead Community Activities
(8) Raising Awareness towards Arsenic Problems

6.1.2 Model Rural Area Selection

The following criteria were applied to select Model Rural Areas in the study area:

- Villages are not located in Pourashava (Municipal) areas.
- A number of patients have been found.
- No effective mitigation activities have taken place.
- A truck carrying drilling machines is accessible.
- A local community group or a village leader is willing to make efforts to tackle arsenic problems.
- The village locations represent the geological characteristics of the study area.

Based on the existing information and the results of the field survey, the following three villages were selected as the Model Rural Areas.

(1) Bara Dudpatila (Chuadanga District)
(2) Rajinagar Bankabarsi (Jessore District)
(3) Krishna Chandrapur (Jhenaidah District)

Features of the selected villages are summarized in Table 6.1.1, and the socioeconomic conditions based on the interviews with villager leaders are presented in Table 6.1.2. The location of the Model Rural Areas is presented in Figure 6.1.1.

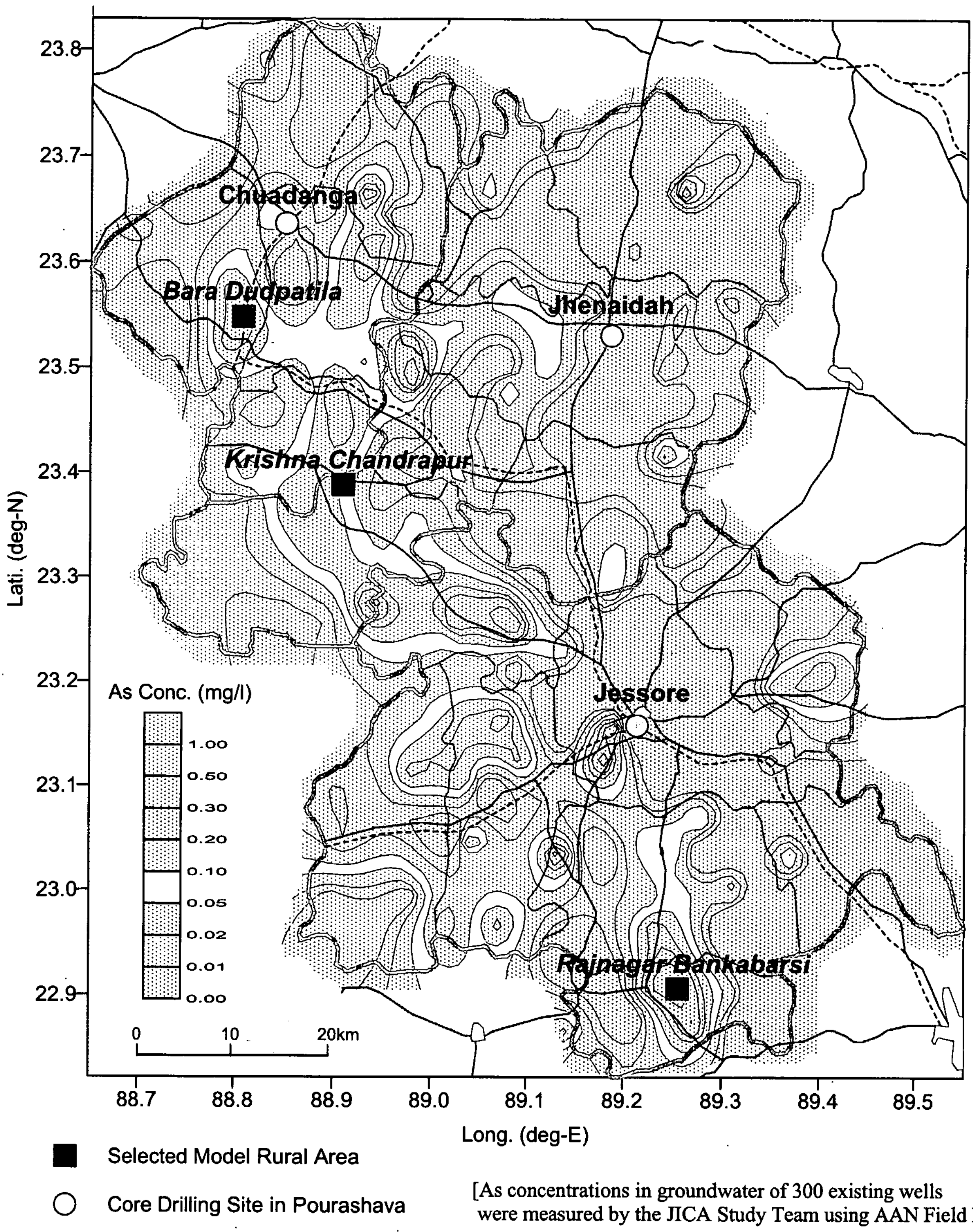
Table 6.1.1 Features of Model Rural Areas

District	Chuadanga	Jessore	Jhenaidah
Thana	Damurhuda	Keshabpur	Maheshpur
Union	Howli	Panjia	Fatehpur
Mauza	Dudpatila	Rajnagar Bankabarsi	Chandpur
# of Villages in the Mauza (Other Villages)	2 (Chhota Dudpatila)	1	3 (Chandpur, Rakhal Bhoga)
Village	Bara Dudpatila	Rajnagar Bankabarsi	Krishna Chandrapur
Population	2,300	1,800	1,000
Pop. Density	High	High in the South, Medium in the North, Low in the Center	High in the North, Low in the South
# of Households	515	380	220
# of Paras	350	7	8
Land Use	Paddy field (periphery), farm land (in the village)	Paddy field and farm land in the North, ponds in the South	Paddy field (periphery), farm land (in the village)
# of Patients	73	23	45
# of Wells	175	74	115
Arsenic Level	n.d.-1.05 mg/l	0.01-1.16 mg/l	n.d.-1.21 mg/l
Distribution of Arsenic Affected Wells	Concentrated in the center of the village (300 m x 300 m)	All over the village	Concentrated in the Center (300 m x 200 m) and the South (200 m x 100 m)
# of Ponds	Medium 5, Small 5	Large 50+	Large 3, Medium 3
Electricity	Available	Available	Not available
Access Road Condition	Unpaved for 2km from a paved road	Unpaved for 1km from a paved road	Unpaved for 2km from a paved road
Assisting NGO	ATMABISWAS	KMMS (Kapatakha Memorial Mohila Shangsta)	AID (Action In Development)
Note	One of the patients is Union Parishad Member and willing to share costs of mitigation measures.	One of the patients is school teacher.	DPHE installed one DTW, but arsenic concentration of the TW water was 0.2 mg/l as of August 11, 2000.

Notes: Population and the number of households are estimated based on the results of the household interviews conducted as a part of this study. The number of arsenicosis patients is based on the diagnosis by Dr. Faruquee, and the number of wells and their arsenic levels are based on the results of the water quality survey as a part of this study.

Table 6.1.2 Socioeconomic Conditions of Model Rural Areas

		Chuadanga	**Jessore**	**Jhenaidah**
		Bara Dudpatila	Rajnagar Bankabarsi	Krishna Chandrapur
Religion		Islam	Islam	Islam (major) Hinduism
Roof materials	Straw	50%+	30%+	80%+
	Tile	None	50%+	None
	Tin	30%+	30%-	30%-
	Concrete	30%-	None	30%-
Daily diet (Other than rice, green leafy vegetables, and other vegetables)		Fish, Fruits	Fish, eggs, fruits	Beans
Community organization	Religious facility (years of experience)	Dudpatila Jame Mosque Committee (15)	Rajnagar Bankabarsi Paschmpara (45)	Sher Ali Secretary (6)
	School activity	School managing Committee (2)	None	Ahadul Rahman Secretary (5)
NGO activity	Knowledge dissemination	BRAC, WAVE	None	None
	Assistance to the poor/handicapped	BRAC, WAVE	ASA, BRAC	None
Major communication tool in the village		Community meeting	Loudspeaker	Person to person speech
Diffusion of mass media	Radio	80%+	50%+	50%+
	TV	30%-	30%-	30%-
	Newspapers	30%-	None	None
Water consumption (Liter/day)		50	50	60
Water source	Drinking	Shallow wells	Shallow wells	Shallow wells
	Cooking	Shallow wells	Shallow wells	Shallow wells
	Other	Shallow wells	Ponds	Shallow wells
# of wells for domestic use	Communal	50	6	46
	Private	250	100	174
Communal well (domestic use) management by caretakers		Repair of facility (not paid)	Repair of facility (some are paid, some are not paid)	Repair of facility (paid)
# of wells for agricultural use	Communal	0	0	100
	Private	30	120	0
	Operation hours	18	12	12
Communal well (agricultural use) management by caretakers		n.a.	n.a.	Monitoring water withdrawal, fee collection, repair of facility (paid)
Arsenic patients	# of Patients	100	n.a.	300
	Treated ratio	30%-	n.a.	50%+
Community attitude	Unfair treatment of patients	None	n.a.	Eating and drinking
Access to medical facility	Travel time	Less than 1 hour	Less than 1 hour	Less than 1 hour
	Travel costs	5Tk by rickshaw	20Tk by rickshaw	n.a.
Action taken by community		None	None	None
Action taken by households		More than 80% of the households use arsenic safe wells	None	None



[As concentrations in groundwater of 300 existing wells were measured by the JICA Study Team using AAN Field Kit.]

Figure 6.1.1	Location of Model Rural Areas and Core Drilling Sites in Pourashavas with As Concentration
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6.2 Overview of Socioeconomic Conditions

6.2.1 General Characteristics of the Model Rural Areas

Characteristics of the Model Rural Areas regarding population, literacy, dietary habit, and household income, and their implications for arsenic problems are summarized in Table 6.2.1.

Table 6.2.1 General Characteristics of the Model Rural Areas and Their Implications for Arsenic Problems

	Characteristics	Implication for Arsenic Problems
Household Size	- Households with 3 to 5 members account for 60 to 70% of the total households. There still exist large households with more than 8 members.	- A standard unit for household based arsenic removal devices should have a capacity to supply water to a household with 5 members.
Religion	- Islam is the major religion, followed by Hinduism. - Muslims and other religious groups such as Hindus exist in one village	- The purdah system discouraging women to appear in the society, may prevent women from going to a doctor for diagnosis and treatment of arsenicosis. - Special attention should be paid to coordinating religious groups to cope with arsenic problems.
Literacy Rate	- About 15 - 35% of the households have no literate person.	- Oral communication and visual presentation should be the major means to disseminate information about arsenic problems.
Diet	- Daily diet is mainly composed of rice and vegetables. - Vegetables are usually cooked for a long time. - Meat consumption is rare	- It is desirable to help villagers to start fishery or poultry farming in those areas. - Education programs on general knowledge about food and nutrition, effective cooking methods, etc are necessary.
Property Ownership	- The rate of house lot ownership is high (86-96%). - No common land exists in the Model Rural Areas.	- It is less controversial to select a school playground as a site for a deep tube well used by villagers if the school is located in the arsenic contaminated area.
Income and expenditure	- The average annual cash income is estimated at 25,000 Tk in Bara Dudpatila, 31,000Tk in Krishna Chandrapur, and 33,000 Tk in Rajnagar Bankabarsi.	- Wealthy households may be able to pay the initial costs of arsenic removal devices from their savings; other households may need to sell some of their property or take out loans.

6.2.2 Water Fetching and Consumption

Characteristics of villages regarding water fetching and consumption, and their implications for arsenic problems are summarized in Table 6.2.2.

Table 6.2.2 Water Fetching and Consumption Practices and its Implications for Arsenic Problems

	Characteristics	Implication for Arsenic Problems
Water Source	- The main source for drinking and cooking water is shallow wells. - For bathing and washing, shallow wells, ponds, and rivers are used. - One shallow tube well serves about 2 to 5 households. - It is very difficult to encourage villagers to drink pond water. - Rainwater is not utilized enough. The major reason is that using tube wells is easier and drinking rainwater is considered as unsophisticated.	- Villagers solely depending on shallow tube wells for their drinking and cooking water are considered to be more vulnerable to arsenicosis. - Water fetching becomes a bigger workload, when a newly installed deep tube well is the only source for arsenic safe water. - If ponds are the only source for arsenic safe water, the introduction of a pond sand filter should accompany. - Proper training on how to collect and use rainwater, and creating a good image of rainwater harvesting are necessary
Water Fetching	- The average total time spent on water fetching is 11 minutes in Bara Dudpatila, 62 minutes in Rajnagar Bankabarsi, and 17 minutes in Krishna Chandrapur. - In Rajnagar Bankabarsi 70% of the households depend on DPHE deep tube wells far from their houses. - Wives are mainly in charge of water fetching. - Water containers are carried in women's arms or by tools such as rickshaw vans and bicycles when men are in charge.	- It is desirable to introduce tools to carry water pots to reduce the workload of water fetching .
Water Consumption	- The estimated average water consumption for drinking and cooking (consumed as food and drink) for a household with 5 members is about 45 liters per day during the rainy season. The water consumption may increase by 15% during the dry season.	- It is appropriate for household-based arsenic removal devices to have a capacity to provide 45 to 50 liters of water per day.
Willingness to pay for arsenic safe water	- The average willingness to pay for obtaining arsenic safe water per month is about 30 Tk in Bara Dudpatila, 50 Tk in Rajnagar Bankabarsi, and 75 Tk in Krishna Chandrapur. Their average ratios to monthly cash income are about 1.4%, 1.3%, and 3.5% respectively.	- The average household with an annual cash income of 30,000Tk could pay about 50 Tk per month for obtaining arsenic safe water.

6.3 Water Quality

6.3.1 Groundwater Quality

1) Survey Method

The groundwater quality of all the existing tube wells was investigated in October 2000. There are 172 tube wells in Bara Dudpatila, 115 wells in Krishna Chandrapur, and 74 in Rajnagar Bankabarsi.

Groundwater samples from the existing wells were collected for the arsenic analysis with the AAS in Jhenaidah Laboratory. At the time of the groundwater sampling, groundwater quality including arsenic was tested in the field. The tested parameters are:

(1) Arsenic (AAN Field Kit)
(2) Dissolved iron, Fe^{2+} (Fe^{2+} pack test kit)
(3) pH (potable pH meter)
(4) Oxidation-reduction potential, ORP (potable ORP meter)
(5) Electric conductivity, EC (potable EC meter)

In addition, 5 groundwater samples for general water quality analysis were collected from each model village.

2) Arsenic

Figure 6.3.1 summarizes the results of the arsenic analysis with the AAS in the model rural areas. The results show that the degree of arsenic contamination in the existing wells varies by village. About 2/3 of the wells in Bara Dudpatila are contaminated by arsenic. In Krishna Chandrapur, about 3/4 of the wells are contaminated. Most of the tube wells in Rajnagar Bankabarsi village are contaminated by arsenic.

In Bara Dudpatila village, 35.5% of the wells satisfy the Bangladeshi drinking standard of 0.05 mg/l. On the other hand, 1.16% of the wells have an As concentration greater than 1.0 mg/l. 12.79% of the wells have an As concentration of 0.5 to 1.0 mg/l. The wells containing 0.1 to 0.5 mg/l of As are the majority in the village, occupying 36.63% of the total.

In Krishna Chandrapur, 25.27% of the total wells have an As concentration within the Bangladesh standard value. On the other hand, there is one (1) well containing more than 1.0 mg/l of As. 26.96% of the wells have an As concentration between 0.5 and 1.0 mg/l. 38.26% of the wells contain 0.1 to 0.5 mg/l of As showing the majority in the village.

In Rajnagar Bankabarsi village, there is only one well showing an As concentration less than 0.05 mg/l. The well is a deep tube well drilled by DPHE. The rest of the wells are shallow wells contaminated with arsenic. There is no well showing more than 1.0 mg/l of As, however, 53.42% of the wells show an As concentration between 0.5 and 1.0 mg/l. Wells with 0.1 to 0.5

mg/l of As occupy 42.47% of the total.

a. Bara Dudpatila village

Figure 6.3.2 shows the arsenic concentration map of the village in October 2000. The highly contaminated zone with As concentrations of more than 0.5 mg/l is distributed in the central to the northern part of the village. On the other hand, less contaminated areas with less than 0.05 mg/l of As are found in the western part, southern part, and eastern part of the village. In the western part of the village, the groundwater is almost free of arsenic, showing less than 0.01 mg/l of As.

b. Krishna Chandrapur village

Figure 6.3.3 shows the arsenic concentration map of the village in October 2000. The highly contaminated zone with As concentrations of more than 0.5 mg/l is distributed in the northern part and the eastern part of the village. The less contaminated area with less than 0.05 mg/l of As are found in the western part. The As concentration in the southern part ranges from 0.1 to 0.2 mg/l.

c. Rajnagar Bankabarsi village

Figure 6.3.4 shows the arsenic concentration map of the village in October 2000. There is no arsenic safe shallow tube well in the village. The highly contaminated groundwater with more than 0.5 mg/l of As is distributed in wide areas from the central to southern parts and western part of the village. In the eastern part, the As concentrations range from 0.1 to 0.2 mg/l.

3) EC, Fe^{2+} and pH

Village	EC	Fe^{2+}	pH
Bara Dudpatila	50 to 140 mS/m	central area: 1 to 10 mg/l	Mostly 7.2-7.3
Krishna Chandrapur	Mostly less than 100 mS/m.	Entirely 1 to 10 mg except some area	Mostly 7.1-7.2
Rajnagar Bankabarsi	Mostly more than 200 mS/m	Mostly 5-10 mg/l	Mostly 7.1-7.2

4) General Parameters

Figure 6.3.5 shows the trilinear diagram of the shallow groundwater. The diagram shows that the chemical composition of Bara Dudpatila water and Krishna Chandrapur water is similar. However, in Rajnagar Bankabarsi groundwater is different from others, characterized by high percentages of Cl and Na.

6.3.2 Pond Water Quality

The samples were collected from 2 ponds in Bara Dudpatila, 5 ponds in Krishna Chandrapur, and 20 ponds in Rajnagar Bankabarsi village.

Pond water quality including arsenic was tested in the field. The tested parameters in the field and their methods are the same as the exiting wells:

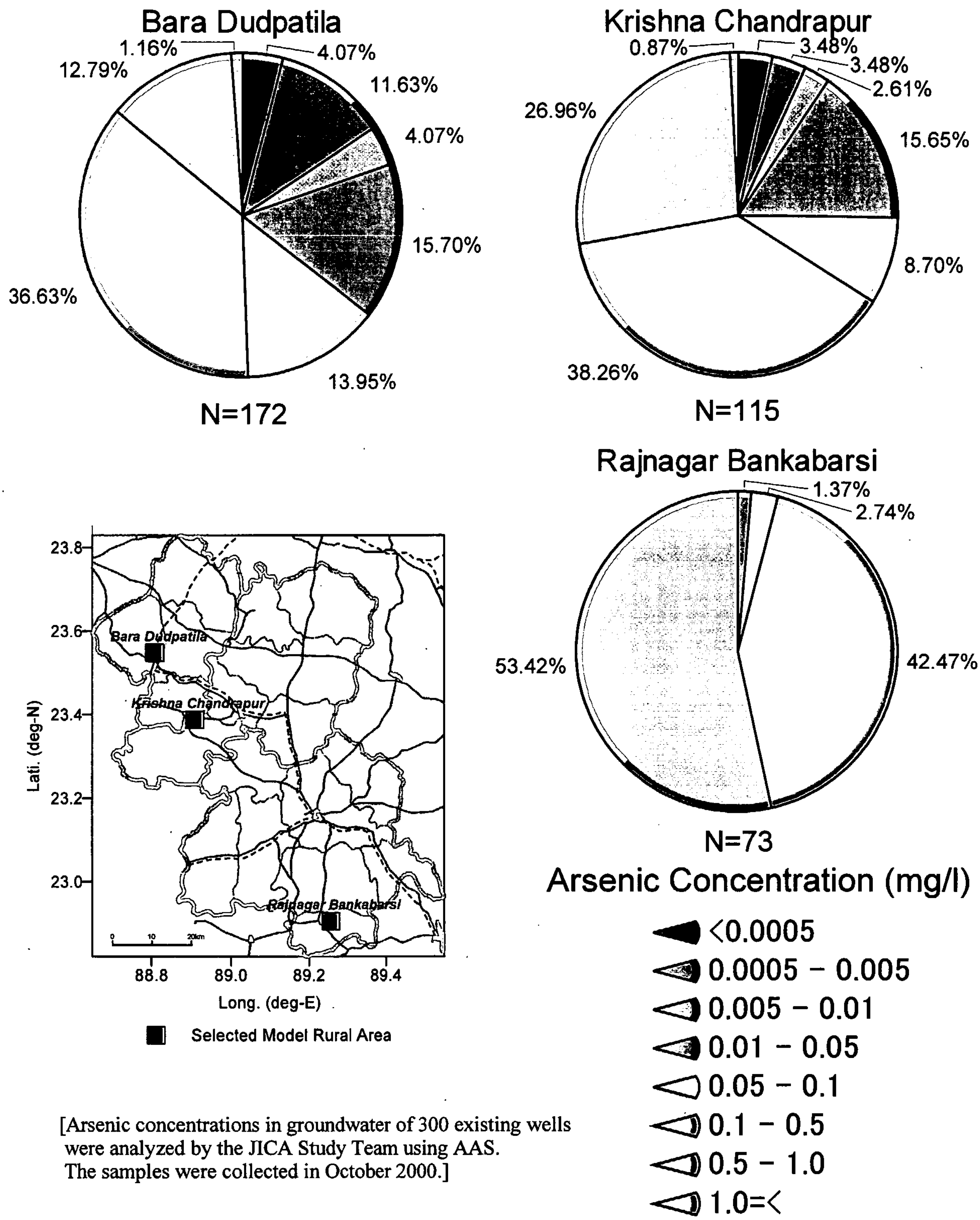
1) Arsenic, EC, Fe^{2+} and Others

Village	Arsenic	EC	Fe^{2+}	Others
Bara Dudpatila	Less than 0.01 mg/l	10.7-20.8 mS/m	Not detected by pack test	7.8-8.0
Krishna Chadrapur	3 ponds: more than 0.01 mg/l	13.2-42.8 mS/m	not detected by Nack test	7.6-8.6
Rajinagar Bankabarsi	9 ponds: more than 0.01 mg/l	29.2-99.4 mS/m	One pond: 0.2 mg/l	7.1-8.6

2) General Parameters

Figure 6.3.6 shows the trilinear diagram of pond water in the model rural areas. The samples from Bara Dudpatila and Krishna Chandrapur are plotted in the left marginal area of the diamond-shape graph, indicating that the water is rich in Ca + Mg in cations and rich in HCO_3 in anions. The pond water samples of Rajnagar Bankabarsi village are plotted in the central area of the diamond-shape graph. Compared with the other villages, the pond water of Rajnagar Bankabarsi is characterized by higher ratios of Na in cations and Cl in anions.

As concentrations and other major ions of the pond water are much less than those of the shallow groundwater. However, bacteria very often contaminate the pond water. Therefore, it is necessary to monitor and evaluate the quality and quantity of pond water for safe drinking water use.



[Arsenic concentrations in groundwater of 300 existing wells were analyzed by the JICA Study Team using AAS. The samples were collected in October 2000.]

Figure 6.3.1	Arsenic Concentrations of Exsiting Wells in Model Rural Areas Analyzed by AAS

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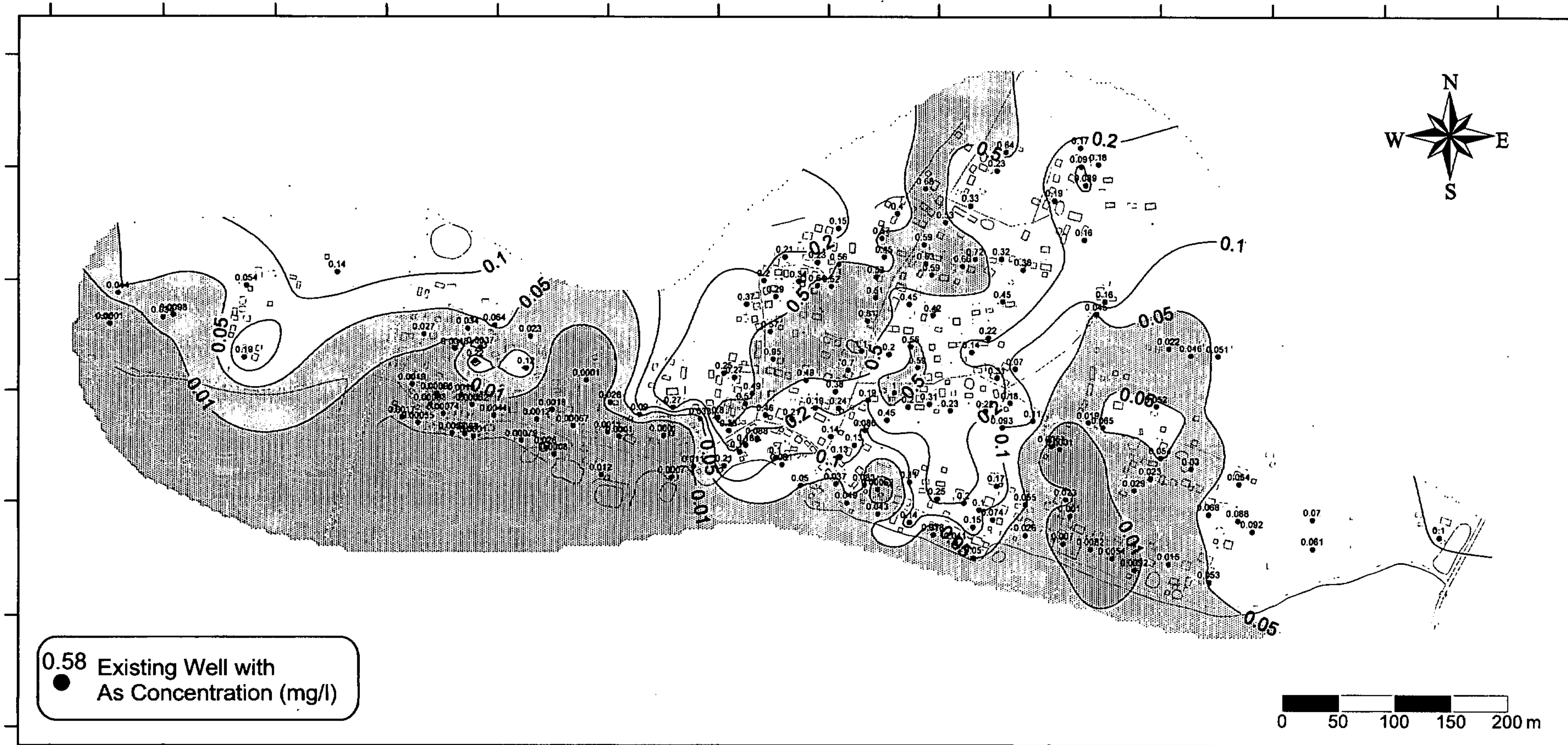
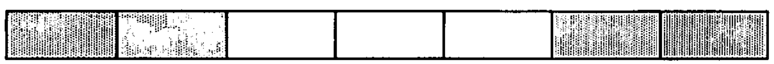


As Concentration (mg/l) by AAS



[The groundwater samples were collected from 172 existing wells in October 2000.
The arsenic concentrations were analyzed by AAS in Jhenaidah Laboratory.]

Figure 6.3.2	Arsenic Concentration Map of Bara Dudpatila Village (October 2000)
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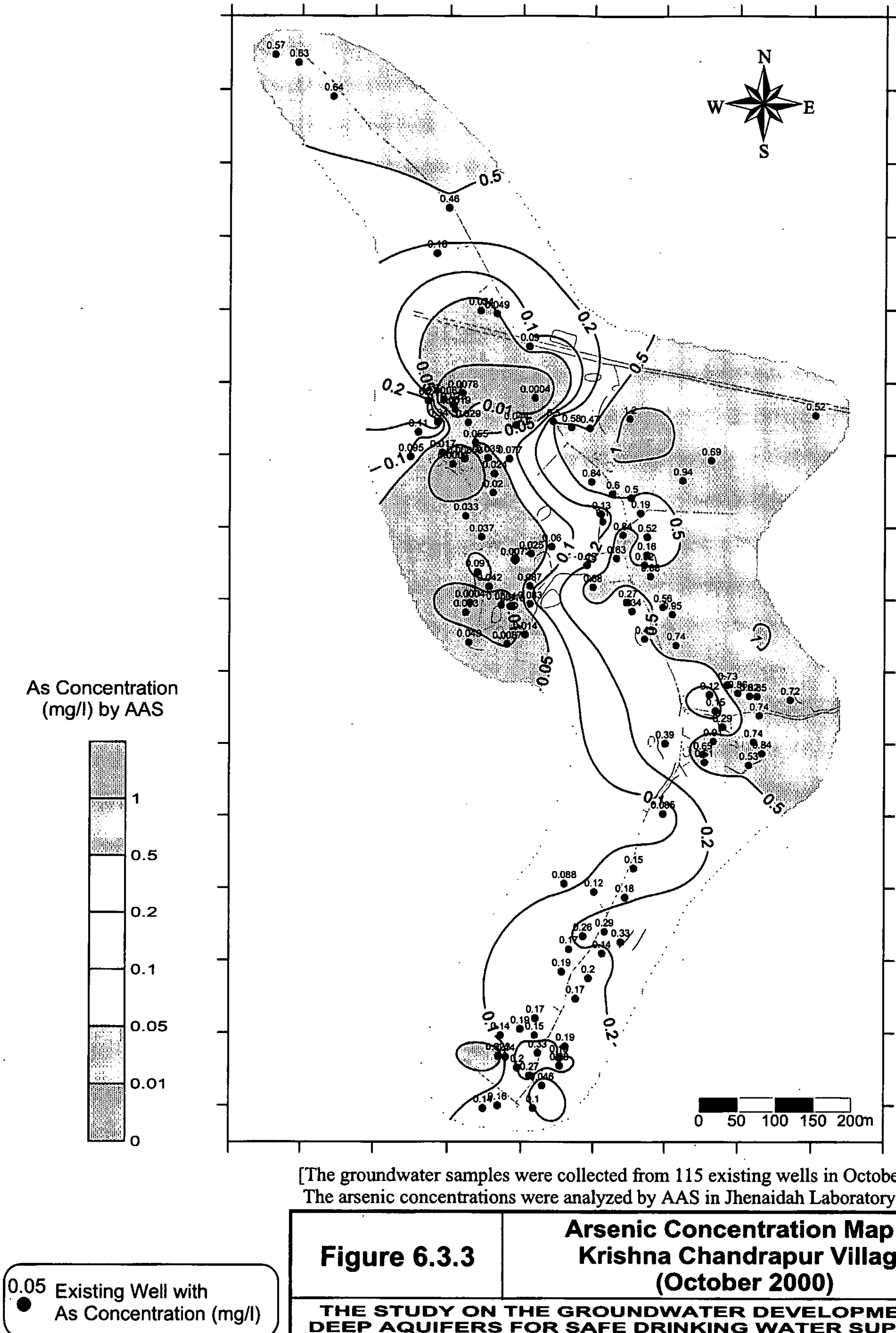

[The groundwater samples were collected from 115 existing wells in October 2000.
The arsenic concentrations were analyzed by AAS in Jhenaidah Laboratory.]

Figure 6.3.3	**Arsenic Concentration Map of Krishna Chandrapur Village (October 2000)**
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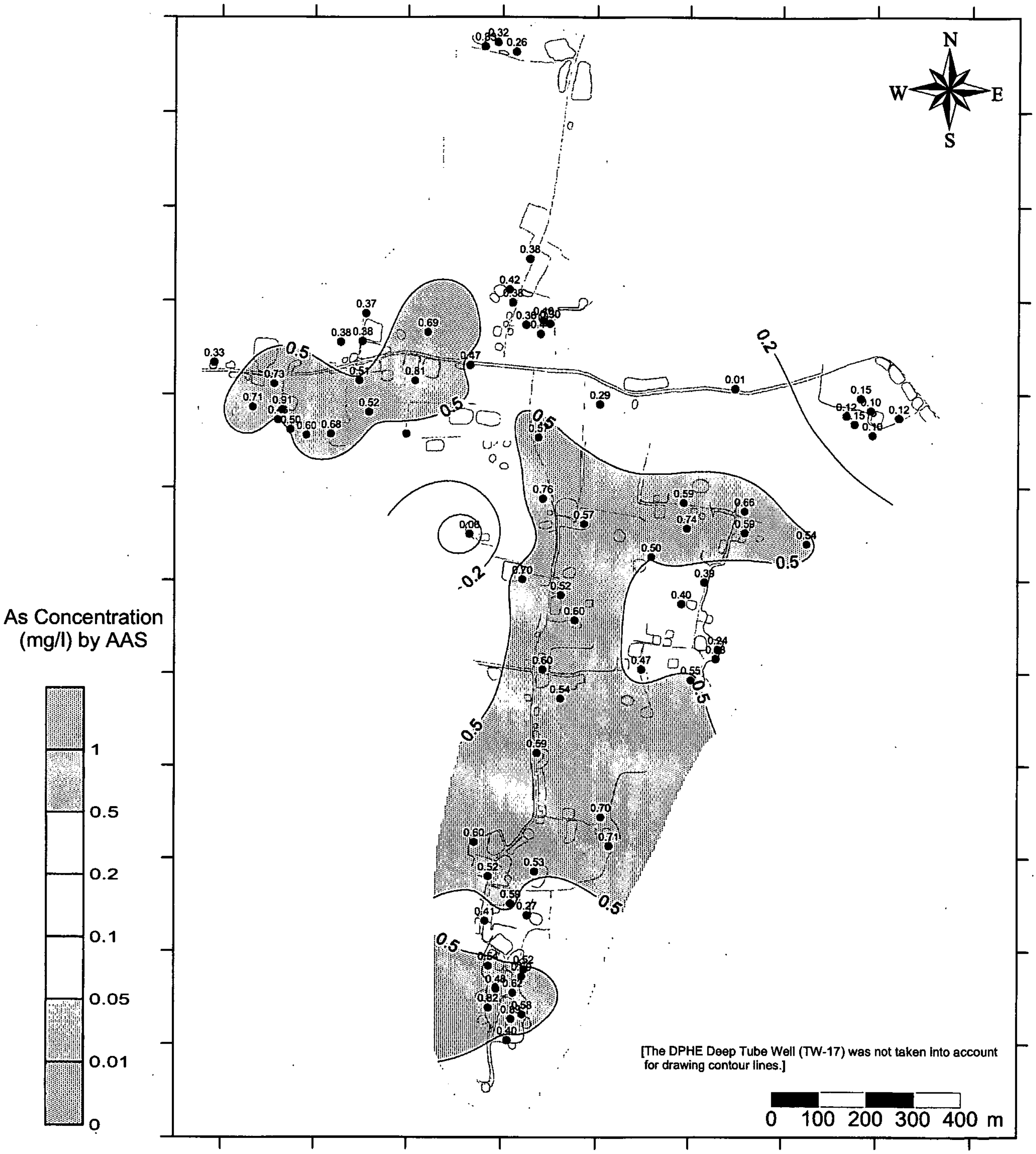

[The groundwater samples were collected from 74 existing wells in October 2000. The arsenic concentrations were analyzed by AAS in Jhenaidah Laboratory.]

0.58 Existing Well with As Concentration (mg/l)

Figure 6.3.4	**Arsenic Concentration Map of Rajnagar Bankabarsi Village (October 2000)**

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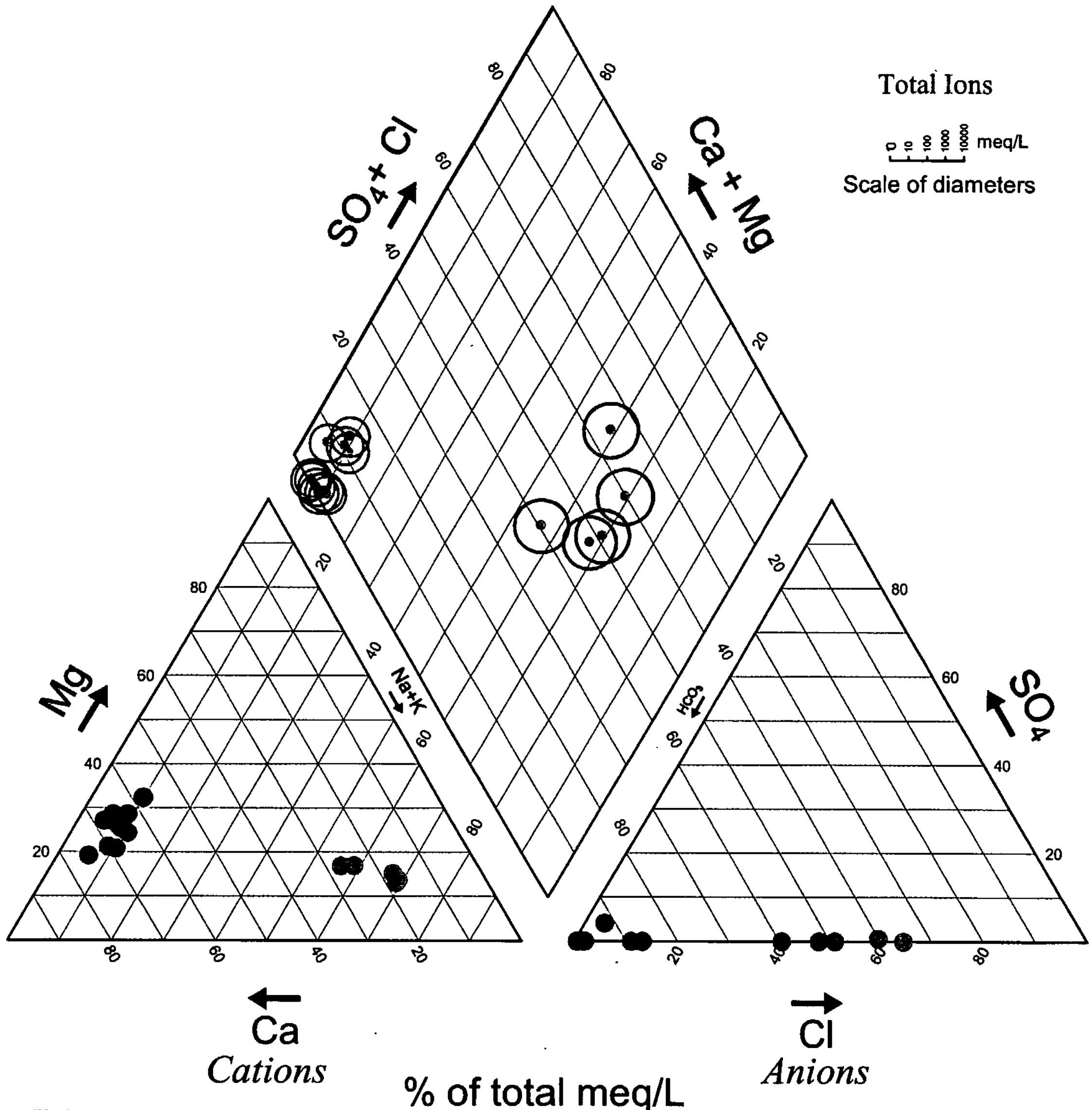

Shallow Tubewell Groundwater Samples

- Bara Dudpatila
- Krishna Chandrapur
- Rajnagar Bankabarsi

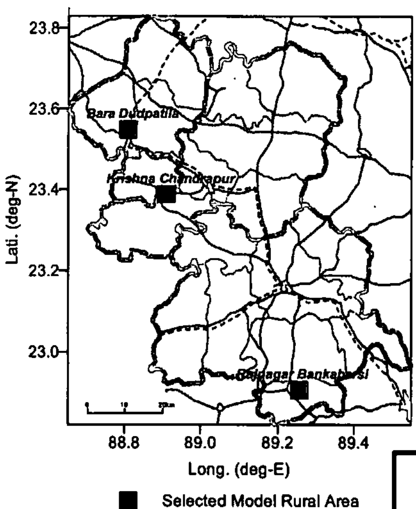

Figure 6.3.61	Trilinear Diagram of Shallow Groundwater in the Model Rural Areas

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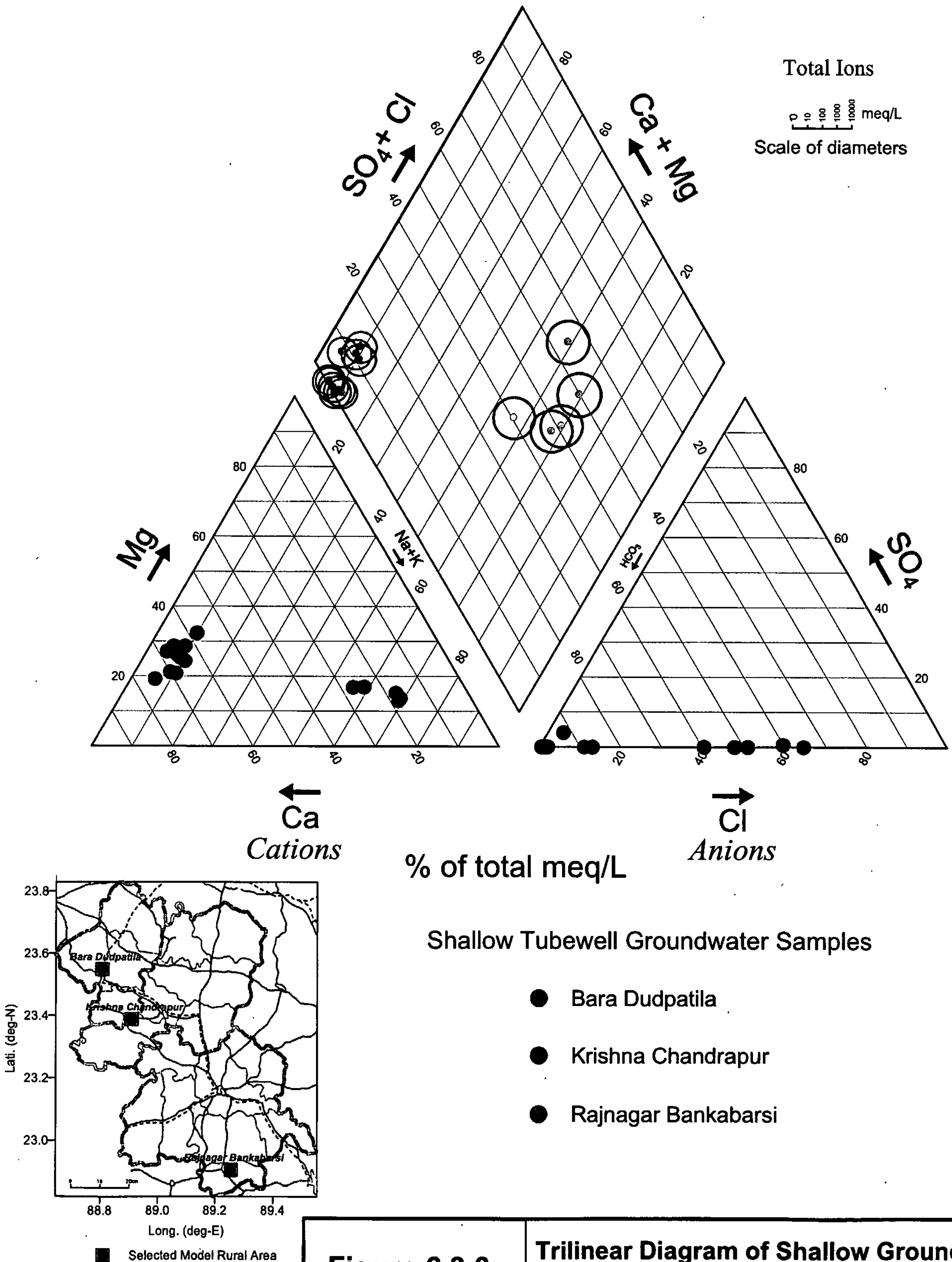

Figure 6.3.6 Trilinear Diagram of Shallow Groundwater in the Model Rural Areas

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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6.4 Identification of Arsenicosis Patients

6.4.1 Diagnosis of Arsenicosis Patients

1) Diagnosis in Model Rural Areas

A formal diagnosis of arsenicosis patients was conducted with the assistance of a doctor of from the Asia Arsenic Network in November 2000 and March 2001.

2) Arsenicosis Patients by Sex and Age

During the first diagnosis in November 2000, 73 arsenicosis patients were identified in Bara Dudpatila (Chuadanga), 23 in Rajnagar Bankabarsi (Jessore), and 45 in Krishna Chandrapur (Jhenaidah). In March 2001, 11 additional 11 patients were identified in Bara Dudpatila and 2 in Rajnagar Bankabarsi. More than 60% of the patients identified are male (see Table 6.4.1).

Arsenicosis patients identified are in a wide range of age groups; the youngest is 13 years old, and the eldest is around 80 years old. Figure 6.4.1 shows the number of arsenicosis patients by age group by in each Model Rural Area. The ratio of younger patients is high in Bara Dudpatila and Krishna Chandrapur while patients are evenly distributed to among the age groups in Rajnagar Bankabarsi.

Table 6.4.1 Number of Arsenicosis Patients by Sex

Model Rural Area	No. of Patients		
	Total	Male	Female
Bara Dudpatila (Chuadanga)	84	53 (63.1%)	31 (36.9%)
Rajnagar Bankabarsi (Jessore)	25	21 (84.0%)	4 (16.0%)
Krishna Chandrapur (Jhenaidah)	45	30 (66.7%)	15 (33.3%)
Total	154	104 (67.5%)	50 (32.5%)

6.4.2 Tube wells Used by Arsenicosis Patients

There seems to be a relationship between the arsenic concentration of tube well water and the drinking water source of the patients; the higher the ratio of tube wells whose users have been found arsenicosis patients. Figure 6.4.2 shows the ratio of tube wells used by arsenicosis patients to the total number of tube wells in the same range of arsenic concentration among the 360 tube wells in the Model Rural Area.

6.4.3 Characteristics of Arsenicosis Patients

There is a difference in the ratio of arsenicosis patients to the total village population at risk among the three Model Rural Areas. Table 6.4.2 shows the estimated population at risk and the actual number of the arsenicosis patients in each Model Rural Area. The population at risk was estimated by multiplying the total population by the ratio of tube wells whose arsenic concentration is equal to or over 0.05 mg/l, which is the Bangladeshi standard. For some of the tube wells whose arsenic concentration was measured twice (October and December 2000), if either result is equal to or over 0.05 mg/l, the tube well is categorized as arsenic contaminated.

Table 6.4.2 Population at Risk of Arsenicosis

	Bara Dudpatila	Rajnagar Bankabarsi	Krishna Chandrapur
# of TW	172	73	115
# of TW (0.05 mg/l≦As)	116 (67.4%)	71 (98.6%)	93 (80.9%)
Average As concentration	0.20 mg/l	0.48 mg/l	0.30 mg/l
Median As concentration	0.10 mg/l	0.51 mg/l	0.17 mg/l
Estimated population	2,300	1,800	1,000
Population at risk	1,550	1,775	809
# of Arsenicosis patients	84	25	45
Ratio of patients to population at risk	0.054	0.014	0.056

Although the average arsenic concentration of the tube wells in Rajnagar Bankabarsi is the highest among the three Model Rural Areas, the ratio of arsenicosis patients to total population at risk is the lowest. There may be several factors explaining the difference in the prevalence of arsenicosis among the three villages.

6.4.4 Treatment and Management of Patients

1) Distribution of Vitamin Tablets

Upon the diagnosis of the arsenicosis patients in November 2000, patients were told to drink arsenic safe water and take nutritious food. In addition, vitamin A, E, and C tablets were provided to the patients who showed moderate and severe melanosis and keratosis (85 out of the 141 patients). Vitamins was were also provided also in March 2001.

2) Dissemination of Information on Arsenic Safe Water

Based on the results of the field test, tube wells in which the arsenic concentration is over 0.5 mg/l were have been painted with red so that villagers can tellidentify the wells highly arsenic contaminated with arsenic wells. More precise information on the arsenic concentration of tube wells based on the analysis by with the AAS was provided to villagers, and tube wells has have been painted based on the level of arsenic contamination.

In addition, arsenic removal plants and deep tube wells have been installed in the Model Rural Areas to supply arsenic safe water. In Bara Dudpatila, the improved deep tube wells drilled by the JICA Study Team, arsenic removal plants such as passive sedimentation plant and an activated alumina plant (see Chapter 7 for details) have been installed and used by the villagers.

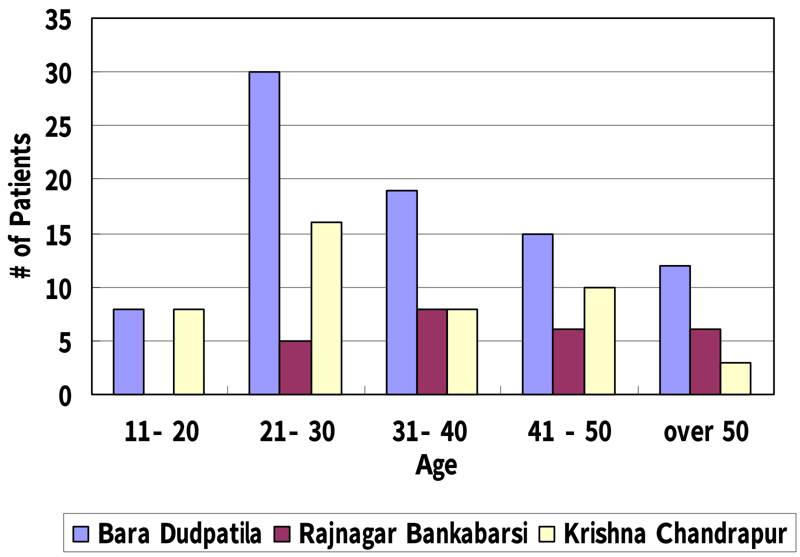
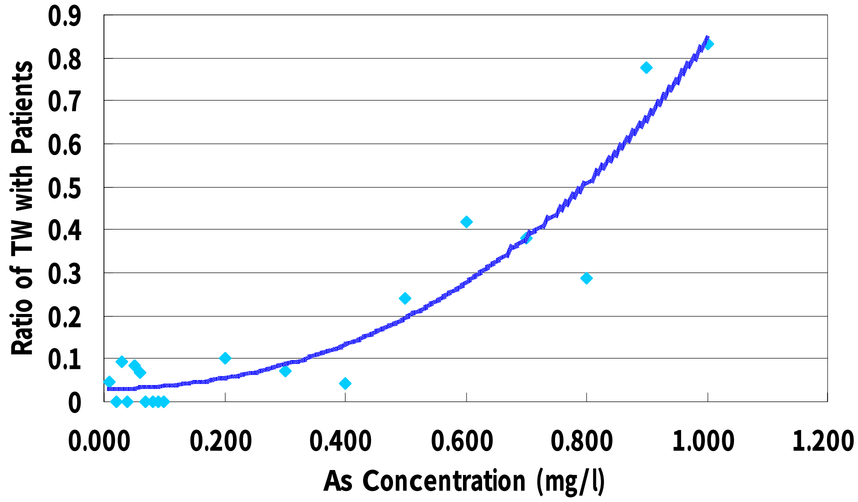


Figure 6.4.1 Number of Arsenicosis Patients by Age



Notes: Tubewells are categorized into 20 ranges by arsenic concentration of the water (0.01 mg/l interval up to 0.1 mg/l and 0.1 mg/l interval up to 1.0 mg/l).

Figure 6.4.2 The ratio of tube wells used by arsenicosis patients to the total number of tube wells in the same range of arsenic concentration among the 360 tube wells in the Model Rural Area

6.5 Awareness Raising Activities in the Model Rural Areas

6.5.1 Community Organization

1) Formation of Community Organization

The Study Team requested, through the DPHE District Executive Engineer, Union Parishad Members and social elite in each Model Rural Area to mobilize villagers to form a community organization comprised of approximate 20 members (half are male and the other half are female). Before the community organization was formed, the doctor of AAN gave a lecture on arsenic problems in Bangladesh and other villages' efforts. The Study Team designated one local NGO to assist villagers to form and run the community organization

Three local NGOs that are assisting the Model Rural Areas are ATMABISWAS, KMMS and AID.

2) Activities Led by Community Organization

The community organizations have led several activities in the Model Rural Areas. The main topics of the meetings are as follows:

- Arsenic contamination of tube wells in the village
- The socioeconomic condition of the village
- Arsenic removal plants and their installation
- Awareness raising

The community organizations are active in Bara Dudpatila and Rajnagar Bankabarsi; they were holding meetings to discuss sites for drilling deep tube wells and installing arsenic removal plants, informing villagers of arsenic problems.

6.5.2 Raising Awareness of Arsenic Problems

1) Awareness of Arsenic Problems in the Study Area

Correct understanding of a problem is the basis of solving the problem and the source of enthusiasm for action. DPHE and UNICEF carried out a communication campaign through mass media in 2000. According to the 300-village survey, more than half of village leaders know symptoms of arsenic poisoning. Only 11 villages have taken actions to tackle arsenic problems. Although arsenic patients have been found in the Model Rural Areas, no community action has been taken.

2) Training on Awareness Raising Activity in the Model Rural Area

The JICA Study Team trained representatives of the Model Rural Areas and the assisting NGOs on awareness raising activity so that they can educate villagers about arsenic problems and mobilize them to take actions against arsenic problems. The training on raising awareness of arsenic was held and the training program was conducted on November 5, 2000 at Banshte Shikha, Jessore with a total of 15 participants (Two villagers from each Model Rural Area and three from each assisting NGO). The main topics were as follows:

A. Overview of arsenic contamination of groundwater
B. Introduction on arsenic
C. Source of arsenic in water and the environment
D. Effects of arsenic
E. Prevention of arsenicosis
F. Community mobilization and community participation

3) Communication Material

Because the average literacy rate is less than 30% in the study area[1], visual and oral communication are considered to most fit the local condition in order to disseminate information on arsenic problems. The material presents information on symptoms, cause, and prevention methods of arsenicosis as a picture-story show.

4) Awareness Raising Activities in the Model Rural Area

The awareness raising activities by the trainees from the Model Rural Areas were conducted by door-to-door visits and small gatherings .The follow-up interviews with villagers in the Model Rural Areas to see the effectiveness of the awareness raising activities were conducted. However, the results indicate that the villagers' memories are diminishing as time goes by since intensive awareness raising activities were not undertaken after that. Continuous awareness raising activities are necessary to refresh memories and keep the villagers concerned about the prevention of arsenicosis.

5) Dissemination of Information on Arsenic-Safe Water in Model Rural Areas

As part of the awareness raising activities, the Study Team informed the villagers of the arsenic level of tube well water and their locations. Based on the AAS analysis, tube wells have been colored red if its arsenic concentration was equal to or over 0.1 mg/l, yellow if it was less than 0.1 but more than 0.05 mg/l, or green if it was equal to or below 0.05 mg/l.

In addition, the JICA Study Team demonstrated how to collect rainwater by using locally available goods such as sari and colshi at a village meeting. With the help of increased awareness, the ratio of villagers harvesting rainwater increased in every Model Rural Area

[1] Adult literacy rate is 20.1% in Chuadanga, 25.6% in Jessore, and 19.3% in Jhenaidah.

6.5.3 Awareness toward Arsenic Problems and Change in Water Sources

Since the introduction of JICA improved deep tube wells (DTW) and arsenic removal plants to the Model Rural Areas, the villagers' sources of drinking water have changed.

1) Change in Water Sources in Rajnagar Bankabarsi between Oct. '00 and Mar. '01

In Rajnagar Bankabarsi, right after the JICA improved deep wells were installed, the villagers started fetching water from the wells. As of March 2001, 57% of the villagers were using the JICA improved deep wells.

2) Relationship between Awareness towards Arsenicosis and Water Fetching Practices in Rajnagar Bankabarsi

After the intervention of the JICA Study Team, most of the former shallow tube well users in Rajnagar Bankabarsi switched to either the JICA improved deep tube wells or the DPHE deep tube well, which requires them to spend more time on water fetching. The increased awareness toward arsenicosis, especially of the cause and prevention method, might have consequently triggered their change in water fetching practices.

3) Factors Influencing Water Fetching Practice

Three main factors influencing water fetching practice have been identified based on the results of the interviews and discussions with the villagers in the Model Rural Areas; they are the physical conditions concerning water fetching such as distance and road conditions to and from the water source, awareness toward arsenic problems, and other people's practice. As shown in the case of Rajnagar Bankabarsi, high awareness toward arsenic problems encouraged the villagers to spend more than 40 minutes per trip on average on fetching water from the DPHE DTW.

In Bara Dudpatila and Krishna Chandrapur, there was no choice other than STW before the JICA Study Team's intervention, and awareness toward arsenic problems was lower than that in Rajnagar Bankabarsi. Fetching water from the JICA DTW was not the practice of the majority. In addition, the arsenic concentration in water from the JICA DTW sometimes exceeded 0.05 mg/l; therefore the wells have been painted yellow. Those factors discourage the villagers from spending more time on fetching water from the JICA DTW. However, their awareness toward arsenic problems has increased compared to one year before, and rainwater harvesting demonstrated by the JICA Study Team has led to an increase in the households practicing rainwater harvesting in the Model Rural Areas.

6.5.4 Awareness Raising Programs for the Future

Based on the experience gained from the Study and other organizations activities, awareness-raising programs to be implemented as part of the priority project would be divided into three stages.

- 1st Stage: general introduction of arsenic problems and setting up a community organization that leads community activities related to arsenic problems
- 2nd Stage: training of the community organization members to mobilize villagers
- 3rd Stage: dissemination of information, activities by villagers, and continuous follow-ups

The community organization should be comprised of representatives from various social groups, such as men, women, adults, youngsters, laborers, and workers, and have 10 to 20 members. Tasks such as overall coordination (chairperson), record keeping (secretary), awareness raising, patient support (removal of stigma, fund raising for those who need financial support, other mental care), water testing and monitoring, safe water procurement (introduction of new water sources and/or utilization of existing water sources), and arsenicosis prevention (preliminary diagnosis of arsenicosis, advice on nutrition) shall be shared among the community organization members. A third party such as an outside expert should monitor the community organization's activities to ensure the quality and intensity of the activities.

CHAPTER 7

ARSENIC CONTAMINATION MEASURES

Summary Report

CHAPTER 7 ARSENIC CONTAMINATION MEASURES

7.1 Improvement of Urban Water Supply System

7.1.1 Problems in Water Supply Facilities

The following are the problems found in the Pourashava Water Supply System (PWSS).

1) Water Quantity Management

It seems that the amount of water at each production well and the amount of water delivered are calculated by multiplying operation time to the rating capacity of the pump. Accurate measurement records that can be used for management and technical evaluation were not properly preserved in the office.

2) Water Quality Management

Water quality is not regularly examined. The main water quality problems are iron content and coliform bacteria (apart from arsenic). The relation between the content of iron and the color is well known. If the color is measured and recorded, the iron content can be presumed. If the residual chlorine is measured and recorded, the safety of water can be guaranteed.

3) Water Supply Service Time

Seven PWSS in the study area supply water for 2 to 10 hours. This may create a dangerous situation such as seepage of the polluted water into the pipe when not in operation.

4) Water Treatment

The iron removal treatment facility composed of the aeration chamber, sedimentation basin and the rapid sand filter is installed in Jessore PWSS. However, this facility is not operated now because of the high operation cost and requirement of 24-hour operation.

Because the water source is a deep well, bacillus pollution is not considered. However, it is necessary to prevent secondary pollution. The continuous injection of chlorine is indispensable.

5) Overhead Tank

No overhead tanks were installed in Sailkupa, Kaligonj, Kotchandpur and Moheshupur. Groundwater is supplied directly by the production well pump, although Jessore, Jhenaidah and Chuadanga PWSS have overhead tanks. Without an overhead tank, it is not possible to meet the variational water consumption of the customer.

6) Master Meter and Water Meter

Though the flow meter is set up in a few well pumps, the flow meter is not set up in most of the well pumps. Moreover, the flow meter is not even set up in the overhead tank outlet pipe.

7.1.2 Arsenic Measures for Pourashava Water Supply System

According to the arsenic analysis of the production wells in the PWSS, slight arsenic contamination was detected at Chuadanga, Jhenaidah and Meohesupur (see Chapter 4). In these three PWSS, the arsenic removal plant should be installed. In Satkhira and Manikganj, in a similar situation of the vicinity, an aeration system and a rapid filter are operated to remove iron and arsenic. Arsenic can be reduced below the standard value as well as iron. The operation and maintenance is comparatively easy and managed well in these Pourashavas. If the arsenic concentration is about 0.1 mg/l or less, this facility can be recommended as the standard facility. Although seven Pourashavas are situated in a seriously arsenic affected area, most of their production wells have not yet been polluted by the arsenic. A large amount of groundwater can be supplied to the area where people are affected by arsenic contamination of the shallow hand tube wells (HTW). PWSS should supply water to the community in the Pourshava where house connection pipes are not installed and polluted HTWs are being utilized.

There are a lot of transportation methods, for instance, carrying by manpower, rickshaws, water tank trucks, transport of water by pipe, etc. It is necessary to organize the transportation methods according to the situation in the region.

7.1.3 Rehabilitation Plan

The PWSS should be rehabilitated based on the following basic concepts.

a) Maximum utilization of the existing water supply systems.
b) Appropriate technology
c) Cost effectiveness
d) Universal metering and tariff collection
e) Safe and potable water

1) Water Supply for Arsenic Affected Areas in Porashava

There is a sufficient amount of groundwater for supply because the PWSS deep wells are not contaminated with arsenic except in Chuadanga, Moheshpur and Jehnaidah Porashavas. In the area within the Pourashavas where house connections are not installed and shallow groundwater is contaminated with arsenic, the PWSS water shall be expanded.

2) Measure Against Leakage

There is a lot of water leakage at present. The leakage rate must be decreased to less than 30%, which is targeted in the National Policy. This could be achieved by the installation of a master meter in the system, a water meter at individual house connections and the replacement of superannuated distribution pipes.

3) Continuous Water Supply for 24 hours

It is indispensable to keep a constant pressure in the pipe by constructing overhead tanks. Otherwise, sewage is infiltrated in the pipe and the sanitary safety cannot be maintained. Presently, water is supplied for 2 to 10 hours in seven PWSS. Jessore PWSS is the longest water supply among the 7 Pourashavas. Kaligonji PWSS is operated only for 2 hours. It is possible to supply water 24 hours by increasing the operation time of the production wells even in the future except in Jessore and Chuadanga Pourashavas.

Table 7.1.1 Present Daily Service Time (Hour/day)

	Jessore	Jhenaidah	Sailkupa	Kaligonji	Kotchandpur	Moheshupur	Chuadanga
Service Time (hour)	10	5	4.5	1.9	5.5	4	6

4) Chlorine Disinfection

Disinfection by chlorine is indispensable for the piped water supply. The chlorine agent is injected to keep the residual chlorine at a certain level in the water in the distribution pipe. The purpose of chlorination is to give the effect of a disinfectant if a contaminant intrudes into the water. The initial purpose of water supply is to protect people from waterborne communicable diseases caused by polluted water. After achieving this purpose, it is necessary to raise the technological level to treatment and removal of harmful substances contained in a very small amount.

5) Revenue Management

Seven PWSS in the study area are not metered and the water tariff is a low fixed amount according to the diameter of the individual house connection pipe. The customer only pays the charge for the fixed amount water service. Moreover, there is no charge for the use of a public stand post. A lot of water is wasted and leaked. The present financial statement of the seven PWSS is presented in Table 7.1.2. Though it may not solve a lot of problemsby only revising the water tariff system, at least a commodity charge system should be introduced. The water tariff system should be able to cover the maintenance expense.

Table 7.1.2 Average Monthly Financial Statement for O&M in TAKA

	Jessore	Jehnaidah	Sailkupa	Kaligonji	Kocchandpur	Moheshupur	Chuadanga
Income	449,700	148,000	16,700	17,000	20,100	18,000	136,000
Expenditure	564,700	140,000	21,300	40,800	17,600	36,000	157,000
Balance	-115,000	8,000	-4,600	-23,800	2,500	-18,000	-20,900

Source: JICA Study Team

7.1.4 Organization and Management

DPHE is an organization in charge of the planning phase and the construction phase. The water supply system is handed over to the Pourashava municipality when it is completed. The person in charge of the PWSS cannot have the future view in the management plan or the future planning of the system. He is only in the place where given facilities are operated, although the responsibility of laying service connections and distribution mains less than 100 mm in diameter and revenue generation lies with the Pourashava (LGED 1994).

The PWSS must provide good quality water abundantly, stably, and economically. The PWSS has to receive a water charge appropriate to the services provided for the customers. From this point of view, neither the authority nor the management ability to promote this is given to the PWSS. In order to apply such a managing ability to the PWSS, the National Policy announced in 1998 that the authority and the responsibility at the government and local levels should be clarified by the thought of devolution. The arrangement of the law and the regulating system is a pressing need.

The maintenance business of water supply service needs a section which takes charge of tariff collection and accounting, a section which operates and manages facilities, a section which does the maintenance check management as for facilities, and the water quality and the hygiene management section, etc. A special, high skilled worker is needed respectively. It is necessary to train these workers systematically. Training by using real facilities at the planning phase, construction phase, and upon completion is effective.

7.2 Arsenic Removal Equipment

7.2.1 Objective

The objective of the arsenic removal experiment in this project is to provide information necessary to draw up a master plan for arsenic mitigation, in case deep aquifer development can not be a solution for all the area. Arsenic issues such as arsenic removal efficiency, operation and maintenance and cost etc were studied.

7.2.2 Basic Approach for Arsenic removal experiment

Arsenic removal technology can be categorized into four groups, namely co-precipitation, adsorption, membrane separation and solar distillation as shown in Table 7.2.1.

Table 7.2.1 Four categories of arsenic removal technologies

Principle	Individual Technology	Advantage	Disadvantage
Co-precipitation	・ Alum ・ Iron ・ Lime Softening ・ Passive sedimentation	・ Cost of equipment and consumable is relatively inexpensive	・ Difficult to remove As(III). ・ Required oxidation agent. ・ Required chemical to add. ・ Complication in operation. ・ Sludge generation.
Adsorption	・ Activated alumina ・ Oxidized iron ・ Charcoal	・ Cost of equipment and consumable is relatively inexpensive. ・ Less waste generated compared to precipitation ・ Simple operation.	・ Difficult to remove As(III). ・ Required oxidation agent. ・ Need to replace adsorbent →Waste generation. ・ Required periodical monitoring. ・ Influenced by other dissolved ion.
	・ Ion exchanged resin	・ Some resin capable to remove As(III). ・ Regeneration process is possible for some resin ・ Simple operation.	・ Expensive consumable (resin) ・ Need to replace adsorbent →Waste generation. ・ Required periodical monitoring. ・ Influenced by other dissolved ion.
Membrane separation	・ Reverse osmosis ・ Electrodialysis	・ Capable to treat large volume.	・ Difficult to remove As(III). ・ Required power for pressurized pump. ・ Expensive consumable
Solar distillation	・ Basin –type	・ Capable to. Remove As(III). ・ Simple operation and maintenance. ・ No chemical and consumable. ・ No influence of other dissolved ions.	・ Capacity is small.
	・ Vacuum type, multi effect type		・ Efficiency is not yet demonstrated.

7.2.3 Design of Arsenic Removal Equipment

1) Basic plan for experiment

The experimental filed test plan was made for the following five technologies.

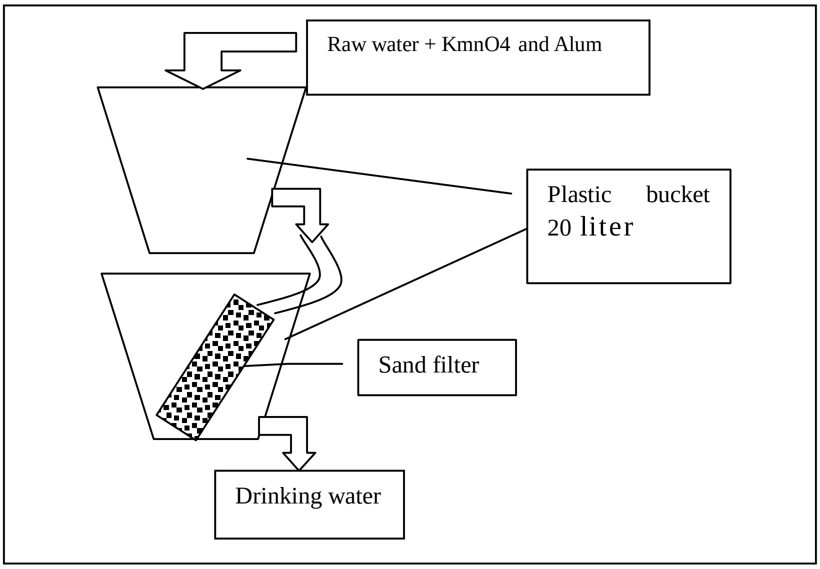
Table 7.2.2 Summary of Arsenic Removal Experiment Plan

	Category	Scale	Timing
Double bucket	Co-precipitation	Household	Immediate-emergency option
Aeration and passive sedimentation	Co-precipitation	Community	Immediate-emergency option
Adsorption by Activated Alumina	Adsorption	Community	Long-term option
Solar distillation (Basin)	Distillation	Household	Long-term option
Solar distillation (Vacuum)	Distillation	Household (or community)	Long-term option

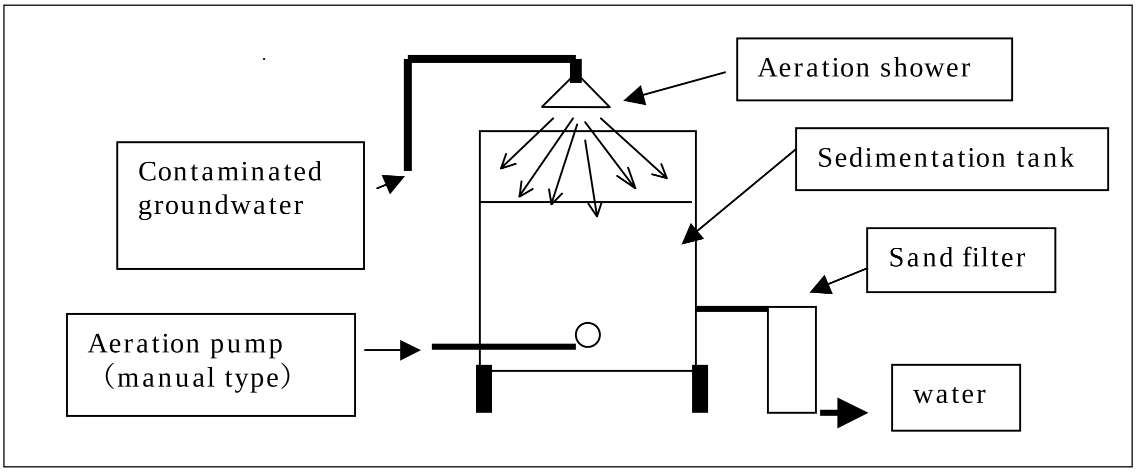
Multiple units were installed for the technologies that are influenced by a variation of water chemistry. A household base unit was also tested at multiple locations to check operation and maintenance conditions

2) Double bucket system

The system was developed under the DPHE/DANIDA project. The system applies arsenic removal by co-precipitation with alum followed by sand filtration. The first bucket colored red is used to mix arsenic contaminated water with added oxidizing chemical (KMnO4) and alum. After precipitation, treated water is fed to the second bucket colored green for filtration by fine sand to provide drinking water. The system will produce approx. 20 liters of drinking water per process. The system is designed for a household base.



3) Passive sedimentation system

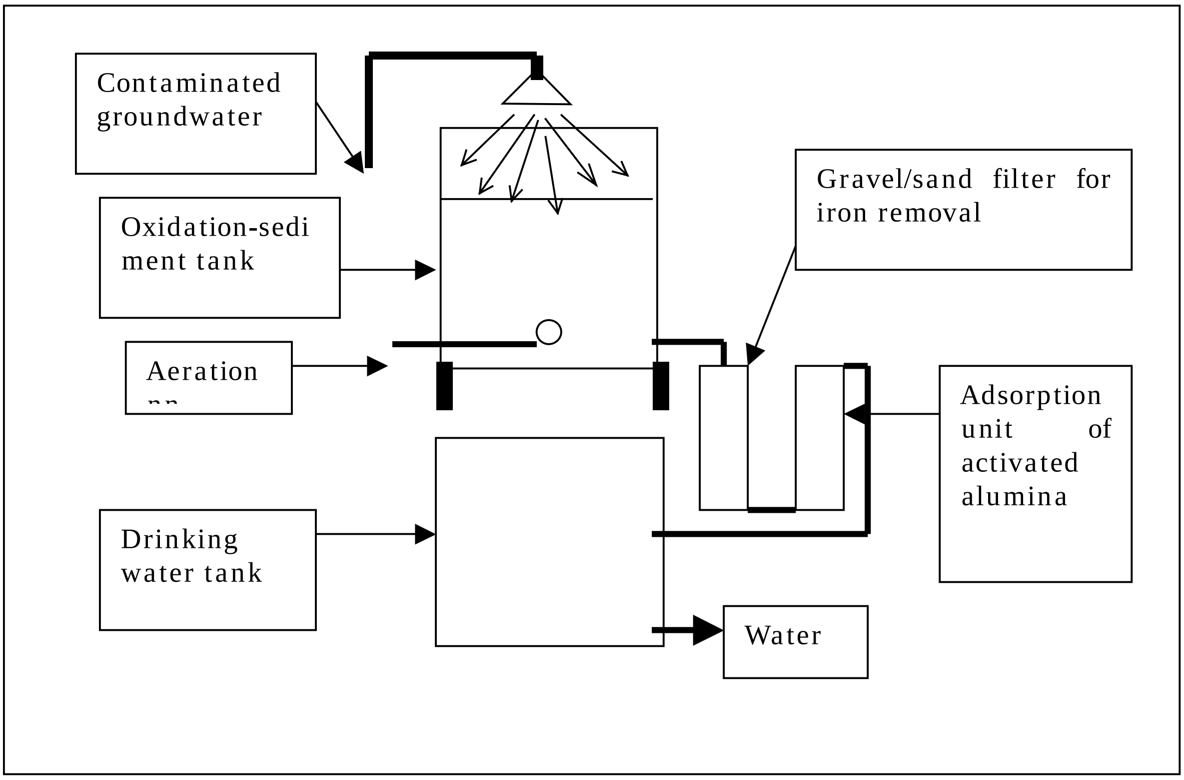


Dissolved iron when in contact with air, it is oxidized and precipitated as iron oxide. Iron oxide is known to co-precipitate with arsenic and also to adsorb arsenic at the surface. Furthermore, arsenic itself is also oxidized from a more toxic trivalent species As (III) to less toxic pentavalent As (V), though the reaction is slow. The system is a combination of an active aeration and oxidation unit and filtration unit to remove suspended particles of oxidized iron. The system can treat approx. 200l of water per process and is expected to provide a water supply for few families.

4) Activated alumina system

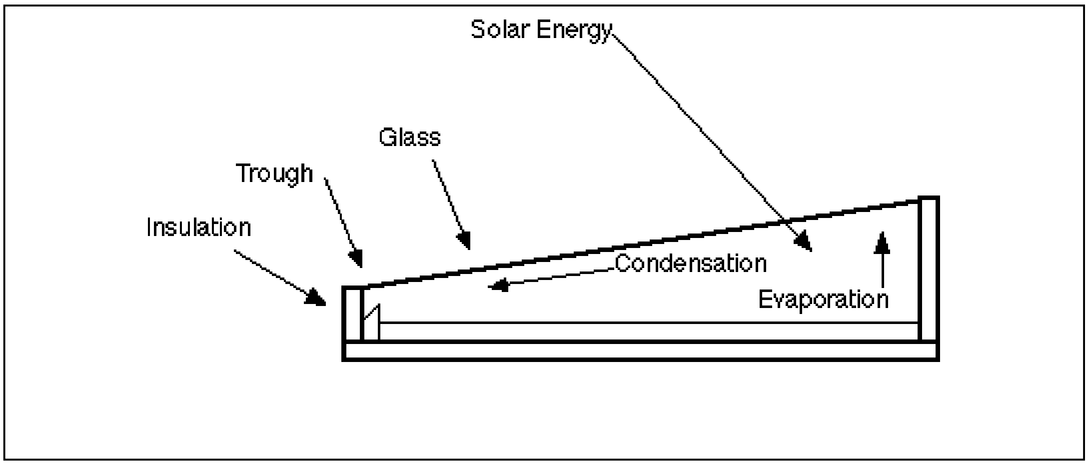
Activated alumina is known to adsorb arsenic and other substances. Adsorption capacity of activated alumina for arsenic is highly effective for pentavalent As (V) while is less effective for trivalent As (III). Therefore the system is combination of pre-treatment by aeration/oxidation and iron removal filter and adsorption unit of activated alumina. The system is designed for treatment of approx. 1,000l/day for drinking water. Community based use is expected.

The system is considered as long-term option.



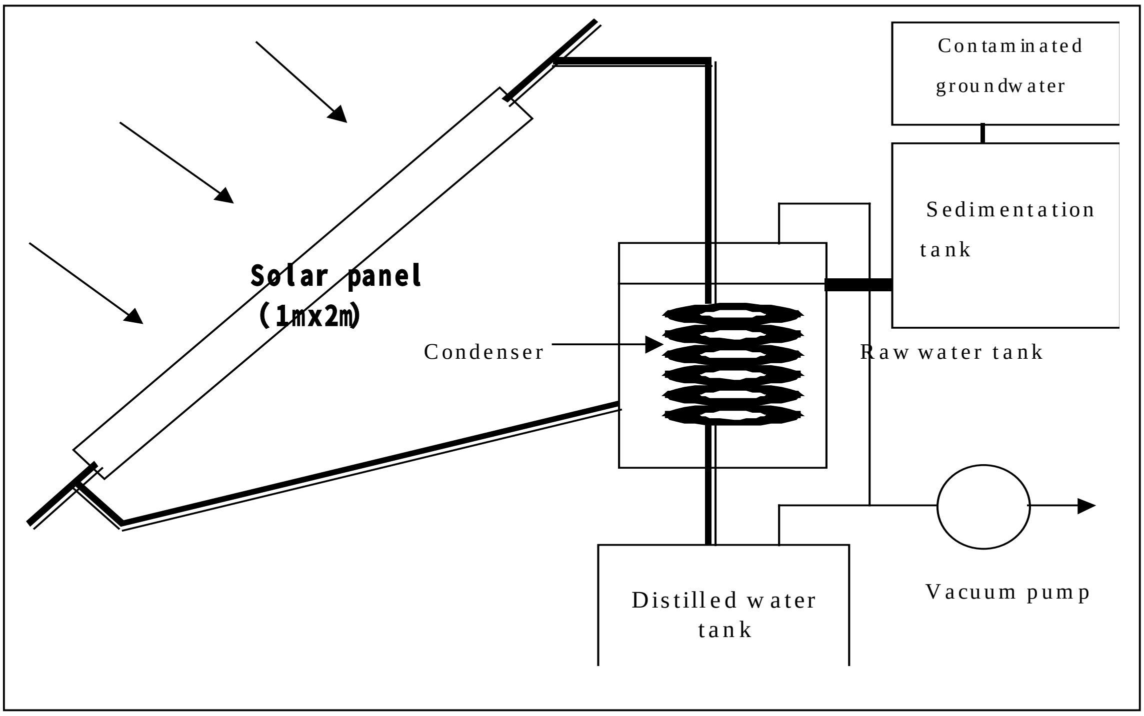
5) Basin type solar still

A basin-type solar still utilizes solar energy to heat water to produce distilled water. Solar distillation technology has perfect arsenic removal efficiency regardless of the original arsenic content with no use of chemicals or consumables. Further, it will not generate waste sludge. The only drawback is its small capacity. Therefore, the test is focused on its capacity under Bangladesh climatic conditions. The system is considered as a long-term option.



6) Vacuum type solar still

A Vacuum-type solar still can produce distilled water at a much higher efficiency than a basin-type, as the boiling point of water is lower in a vacuum. The system is considered as a long-term option.



7.2.4 Field test

1) Methodology

The arsenic removal equipment was installed in the model rural area. After installation, its performance was measured during the duration of the study. For this purpose, raw tube well water before treatment and the treated water from the equipment were measured and sampled.

The field measurement parameters were as follows.

EC, ORP, pH, Temp. As (by AAN field kit) and Fe2+ (by pack test)

Two types of sampling programs were done. Comprehensive sampling was conducted for 27 analytical parameters. Arsenic sampling was conducted for only Arsenic testing by AAS.

The table below summarizes the water quality character of the three villages. The data are the statistics of all raw water measurements taken during the arsenic removal experiment.

Table. 7.2.3 Water quality of three villages

Village		Arsenic mg/l	EC mS/m	pH	ORP mV	Fe^{2+} mg/l
Bara Dudpatila	Average	0.26	68	7.3	190	3.1
	min.	0.045	39	7.1	81	0.5
	Max	0.47	100	7.5	340	10
	Standard deviation	0.14	21	0.11	77	2.4
Krishna Chandrapur	Average	0.22	83	7.2	130	4.1
	min.	0.041	40	7	-20	0.2
	Max	0.43	130	7.5	270	10
	Standard deviation	0.13	21	0.15	71	2.7
Rajnagar Bankabarsi	Average	0.49	260	7.2	110	3.3
	min.	0.29	230	7.1	89	1
	Max	1.4	280	7.3	140	5
	Standard deviation	0.28	12	0.072	16	1.7

2) Double bucket system

The double bucket system is one of the most extensively used systems in the field, mainly under the DPHE/DANIDA project in Noakhali District. Good removal of arsenic was reported. Therefore, the operational aspect of the system was focused on the experiment. How to secure adequate operation, especially the handling of chemicals, by each household may be a key issue for the system. In consideration of the above, two forms of the chemical, i.e. conventional powder form and tablet form, were prepared for testing.

In summary, the findings from the field test of the double bucket system are as follows.

(1) Removal of arsenic is not consistent and varies by water quality.

(2) Water quality varies not only between villages but also within villages.

(3) One indicator of water quality preventing good removal is high EC.

(4) Increased dosing of chemicals improved the removal rate from high EC water at Rajnagar Bankabarsi, but not from water at Krishna Chanrapur.

(5) Chemical in tablet form does not dissolve easily.

(6) Possibility of leakage from sand filter exists.

(7) Arsenic staya as dissolved species or as particles smaller than 0.45μm.

(8) Bucket is vulnerable to cracking.

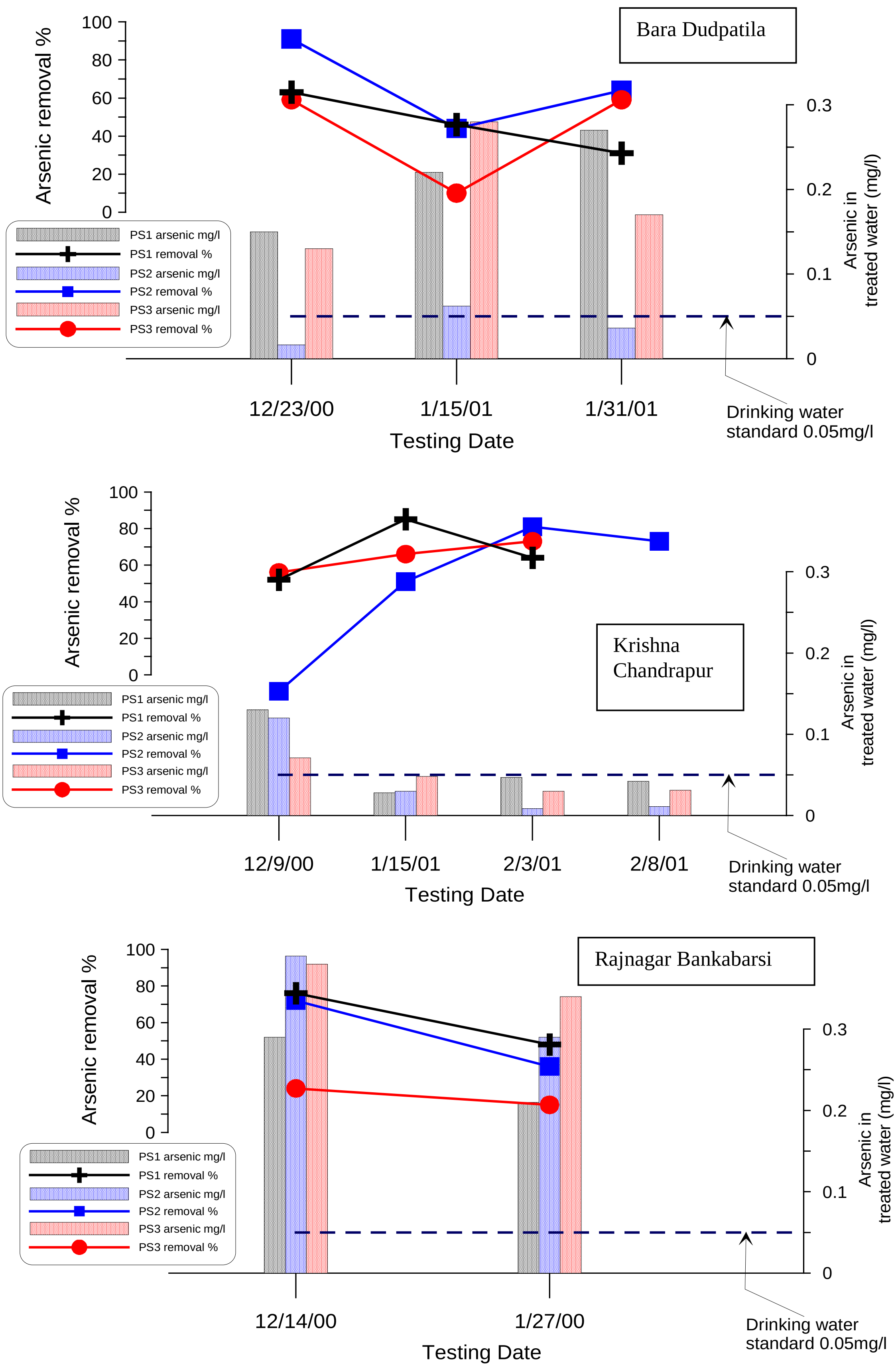


Figure 7.2.1 Result of passive sedimentation units

3) Passive sedimentation system

The passive sedimentation system can be the most economical arsenic removal technology. Some reported on the effectiveness of the method, but there is no solid technical information regarding its effectiveness, limitations or pre-requisites for application. Therefore, the purpose of the experiment is to define the effectiveness and limitations at given conditions. For this purpose, three units per village were installed to observe various raw water quality conditions.

Table 7.2.4 Test data of passive sedimentation by chemical oxidation

Village	Unit	Water	Date	As (field) mg/l	As (AAS) mg/l	pH	ORP (mV)	EC (mS/m)	Fe2+ mg/l	As removal
Bara Dudpatila	KMnO4 1mg/l added									
	PS1	Raw	2/10/01	0.9	0.47	7.2	270	99.4	2	
		Treated	2/10/01	0.2	0.28	7.48	320	97	0	40%
		Filtered	2/10/01	NA	0.27	NA	NA	NA	NA	43%
	PS3	Raw	2/10/01	0.7	0.43	7.19	121	72.9	10	
		Treated	2/10/01	0.02	0.078	7.49	322	74.9	0	82%
		Filtered	2/10/01	NA	0.075	NA	NA	NA	NA	83%
Rajnagar Bankabarsi	KMnO4 1mg/l added									
	PS1	Raw	2/4/01	0.6	0.41	7.2	121	255	5	
		Treated	2/4/01	0	0.26	7.53	331	261	0	37%
	PS2	Raw	2/4/01	0.4	0.49	7.15	101	276	2	
		Treated	2/4/01	0.01	0.013	7.64	328	270	0	97%
	PS3	Raw	2/4/01	0.5	0.43	7.24	102	272	5	
		Treated	2/4/01	0.01	0.26	7.6	332	265	0	40%
	KMnO4 1.5mg/l added									
	PS1	Raw	2/4/01	0.5	0.35	7.12	125	262	2	
		Treated	2/4/01	0.02	0.21	7.52	328	256	0	40%
	PS2	Raw	2/4/01	0.2	0.41	7.19	94	272	2	
		Treated	2/4/01	0.06	0.25	7.62	332	275	0	39%
	PS3	Raw	2/4/01	0.6	0.44	7.31	99	271	1	
		Treated	2/4/01	0.05	0.24	7.51	336	267	0	45%

The arsenic removal efficiency varied considerably by village, by units within the same village and by the date of sampling for the same unit. One of the major reasons for such variation may be the different operating conditions of the units by the caretakers as well as the project staff.

Based on the results, all passive sedimentation units in Rajanagar Bankabarsi and PS1 and PS2 units in Bara Dudpatila were suspended and caretakers were recommended not to use treated water for drinking purposes after March, 2001.

4 units of passive sedimentation were monitored for its removal efficiency.

Table 7.2.5 Monitoring of Passive Sedimentation units

		Arsenic content in treated water (mg/l) and removal %				
		Jan.2001	Feb. 2001	March 2001	April 2001	June 2001
Krishna Chandrapur	PS 1	*0.064(66%)*	0.042(68%)	*0.052(81%)*	*0.061(70%)*	0.043(83%)
	PS 2	0.030(51%)	0.0087(81%)	0.0057(98%)	0.01(93%)	0.04(70%)
	PS 3	0.048(66%)	0.030(73%)	0.025(84%)	0.030(47%)	*0.18(-)*
Bara Dudpatila	PS 2	0.036(64%)	-	0.029(74%)	*0.067(-)*	*0.13(61%)*

A summary of the findings is as follows.

(1) Removal of arsenic by passive sedimentation vary considerably by operating condition.

(2) If properly operated for suitable water quality, 75% removal can be expected. Therefore, 0.2 mg/l is the limiting concentration for inlet water.

(3) High Fe^{2+}/As ratio and low Cl ion concentrations are indication of suitable water quality.

(4) Chemical oxidation by potassium permanganate is effective in improving the removal rate only for water with high Fe^{2+} concentrations.

4) Activated alumina system

Activated alumina adsorption is used widely for water treatment. Various technical reports were also available regarding arsenic removal by activated alumina. Therefore, the focus of the experiment was not just its removal efficiency, but the effect of water quality on the breakthrough volume and operational aspect as a community based system.

Initially, each 20kg of promoted activated alumina was packed in the filter housing. As the bulk density of the activated alumina used is 0.91g/cm^3, 20kg is equivalent to approx. 22 liters. The breakthrough volume of normal activated alumina for As (V), reported in literature, is over 10,000. The manufacturer of promoted activated alumina (ALCAN) claims that the product is five times more capable than normal activated alumina. Assuming the breakthrough volume to be 10,000 for 22 liters of adsorbent, the unit can treat up to 220,000 liters of water. This is equivalent to 220 days use at 1,000 liters per day. In the same way, if the breakthrough volume is 20,000, the unit can be used for 440 days without replacement in theory.

Table 7.2.6 shows the results of tests in three villages.

Table 7.2.6 Test data of activated alumina

Village	Unit	Water	Date	As (field) mg/l	As (AAS) mg/l	pH	ORP (mV)	EC (mS/m)	Fe2+ mg/l	As removal
Bara Dudpatila	AA	Raw	1/31/01	0.01	0.045	7.28	241	67	2	
		Treated	1/31/01	0	0.0015	7.05	235	58	0	97%
Krishna Chandrapur	AA	Raw	2/3/01	0.3	0.38	6.98	NA	127	5	
		Treated	2/3/01	0	0.083	7.39	283	117	0	78%
		Raw	2/8/01	NA	0.43	6.99	112	65(?)	10	
		Treated	2/8/01	0	0.051	7.27	152	127	0	88%
		Treated	2/17/01	0	0.035	6.72	326	126	0	92%
Rajnagar Bankabarsi	AA	Raw	1/27/01	0.9	0.42	7.19	132	262	2	
		Treated	1/27/01	0	0.088	7.45	293	128	0	79%
		Raw	2/5/01	0.7	0.36	7.32	125	226	5	
		Treated	2/5/01	0.02	0.11	7.64	330	233	0	69%
		Raw	2/6/01	0.6	0.42	7.32	100	255	1	
		Treated	2/6/01	0.01	0.18	7.57	329	255	0	57%

A summary of the findings is as follows.

(1) Activated alumina removes arsenic as expected from normal water (not saline and high EC).

(2) Saline water and water with high EC values reduce the performance.

(3) Breakthrough volume varies depending on raw water quality. Extensive monitoring is required.

(4) Operation was interrupted because of an electricity problem.

5) Basin type solar distillation system

As for solar distillation, the arsenic removal efficiency is not an issue. Theoretically, it will remove all dissolved species, except some of the volatile components. Table 7.2.7 shows the results of testing of the unit in Bara Dudpatila. Arsenic was reduced to 0.001 mg/l, which is near the detection limit of the analytical system. It is also noted that the EC value was reduced from 71.3 to 4.38 mS/m. This demonstrates the removal of all dissolved species. The common problem found in other arsenic removal technologies, the influence of other dissolved ions, is not a problem for the solar distillation technology.

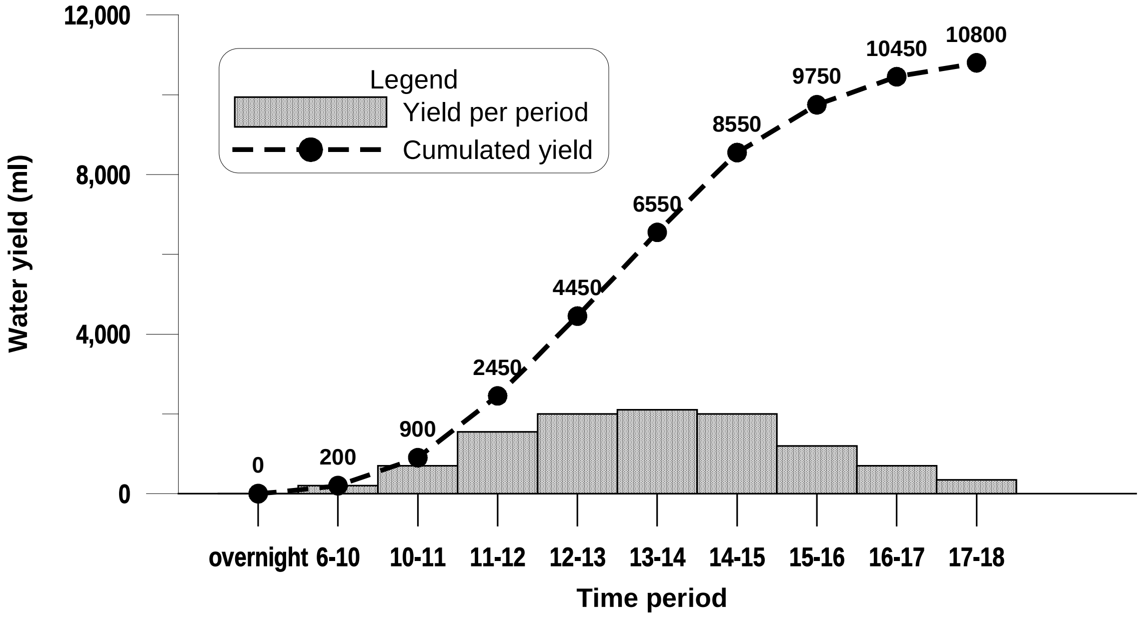
Table 7.2.7 Test data of basin-type solar distillation

Unit	Water	Date	As (field) mg/l	As (AAS) mg/l	pH	ORP (mV)	EC (mS/m)	Fe2+ mg/l	As removal
SSB	Raw	2/15/01	0.6	0.099	7.32	286	71.3	2	99%
	Treated	2/15/01	0	0.0011	7	409	4.38	0	

Instead, the major challenge of the unit is its yield.

In the figure, the bar chart shows the water yield per sampled time period and the symbol and line graph shows the cumulated water yield. At Bara Dudpatila, approx.12 to 13 liters of water were produced in a day. Since the unit has a basin size of 6 m^2 (1 m x 2 m basin x 3), its efficiency can be calculated as 2 .0 to 2.2 liters/m^2. This is in the same range as reported for the efficiency of the basin-type unit. It shall be noted that 0.7 to 1 liter of water was also produced during the nighttime. The water vapor produced and condensed in the glass cover the previous day is the reason for such production. At Krishna Chandrapur, approx. 11 liters of water were produced. As nighttime production was missing in the Krishna Chnadrapur test, the overall yield at the two villages is almost the same.

It is expected, with the increase in temperature and stronger sunshine toward summer, that the yield will further increase in the coming months.



Basin type solar distillation unit experimental data of Feb. 17, 2001

Figure 7.2.2 Yield of basin-type solar distillation at Krishna Chandrapur

A summary of the findings is as follows.

(1) Solar distillation completely removes arsenic as well as other potential pollutants dissolved in water.

(2) Basin-type solar distillation can produce approx. 2.0-2.2 liters/m2/day in the Bangladesh climate.

(3) The unit shall be improved to include glass protection and a bottom cleaning feature.

6) Vacuum-type solar distillation system

A vacuum-type solar distillation unit was installed at Krishna Chandrapur in late February. The unit applies a solar cell-powered vacuum to the water kept in the conventional solar panel to

enhance its distillation. The solar panel itself receives an area of sunlight of approx. 1.8 m^2. This is approximately 30% of the area compared with the basin-type unit, which has a 6 m^2 area.
The tests for its water distillation capacity were conducted from March 3 to 6, 2001. As a result, the following quantities of water were obtained at each test.

March 3 8.30 liters (4.6 liters/m^2/day)

March 4 8.07 liters (4.5 liters/m^2/day)

March 5 9.45 liters (5.25 liter/sm^2/day)

Bottlenecking to produce more water is not at the boiling process but at the condensation process. The unit designed as a single effect was not effective in the climatic condition in Bangladesh. Nevertheless the experiment provides solid data for a single effect unit. The potential yield by the multiple effect system can be estimated theoretically as approx. 4 times the yield for the multiple effect system simulation. If we apply this case, a vacuum-type, multiple effect system can produce approx. 20 liters/m^2/day.

Table 7.2.8 Test data of Vacuum type Solar Distillation unit

Water	Date	As (field) mg/l	As (AAS) mg/l	pH	ORP (mV)	EC (mS/m)	Fe2+ mg/l	As removal
Raw	3/26/01	0.5	0.13	7.08	129	79.9	5.0	100%
Treated	3/26/01	0.0	<0.0005	7.82	184	0.90	0.0	
Raw	5/21/01	0.3	0.12	7.08	109	81.3	4.0	100%
Treated	5/21/01	0.0	<0.0005	7.56	397	1.25	0.0	

Table 7.2.8 shows the results for water quality and arsenic removal,. Arsenic removal was almost perfect at 100%.
A summary of findings is as follows.

(1) Solar distillation completely removes arsenic as well as other potential pollutants dissolved in water.

(2) Vacuum-type solar distillation can produce approx. 4.5 to 5.0 liters/m^2/day in the Bangladesh climate.

(3) If improved to a multiple effect system, theoretically, the unit can produce 4 times the amount of water or 18 to 20 liters/m^2/day.

7.2.5 Evaluation and Conclusion

Evaluation of the arsenic removal device were compiled using the criteria as shown in Table 7.2.9. Criteria was categorized for 1) arsenic removal, 2) operation and maintenance and 3) cost. As far as arsenic removal efficiency is concerned, distillation technologies shows almost complete removal data. Activated alumina and aeration/passive sedimentation shows acceptable removal under the appropriate condition.

Operation and maintenance aspect is more complicated. It is difficult to conclude any one of the technologies has clear advantage over others. Solar distillation has advantage in all aspect except is small quantities of produced water. Double bucket has more problem in operation and monitoring aspect than others.

Regarding the cost, some explanation of the table figure is necessary. Unit cost of the system as well as expected life time of the unit are approximate at this stage. Obviously solar distillation has highest cost / l as its small capacity. For operational cost, manpower cost was not quantified at this table as we assume all operation to be done by the users. Consumable cost for activated alumina based on 20,000TK /year and 1000l/ day capacity. For monitoring, monthly monitoring at 500TK/analysis cost which is standard DPHE charge.

Ideally, the device shall be of very easy to use and maintain, treat sufficient quantity of water, less risk of miss operation or secondary hazardous accident, consistent arsenic removal efficiency down to 0.05mg/l, less monitoring requirement, less problem in waste disposal, economically feasible in both initial and running cost, and socially acceptable.

Unfortunately, the study could identify no single arsenic removal device or technology which fulfills all of the requirement necessary to be used in rural condition of Bangladesh. Every technology has advantage in one aspect but has disadvantage in another aspect. Therefore, at this stage, choice of the device depends on the condition given to specific site and situation.

As a result, three technologies or device are recommended for the different condition assumed as follows.

1. Aeration/passive sedimentation
2. Solar distillation combined with rain water harvesting
3. Adsorption based arsenic removal device

Table 7.2.9 Evaluation of Five Technologies

Aspect	No.	Criteria/Question	Double bucket system	Aeration / Passive sedimentation	Activated alumina	Basin solar distillation	Vacuum solar distillation
Arsenic removal efficiency	1.1	Different removal efficiency for As(III) and As(V)?	Yes	Yes	Yes	No	No
	1.2	Oxidation process required for removal of As(III)?	Yes	Yes	No	No	No
	1.3	Removal efficiency changed by continued use?	No	No	Yes	No	No
	1.4	Removal efficiency influenced by the other dissolved ions?	Yes	Yes	Yes	No	No
	1.6	Field test data. Removal rate.	Not satisfactory	70-90% for adequate quality of raw water	85-95% before breakthrough	99-100%	100%
Operation and maintenance	2.1	Household or community based? What is capacity per unit?	Household 20l/day	Community 400l/day	Community 1000l/day	Household 12l/day	Household 9l/day
	2.2	What is dairy operational procedure? Number of step? Labor time required?	3 step 10-20 min.	2 step 40min.	2 step 10-20min.	1 step 20min.	4 step 30 min
			Refer to flow sheet.				
	2.4	What is maintenance procedure? weekly, monthly? Number of step?	Cleaning bucket and sand filter daily	cleaning tank and sand filter weekly	back flushing every few days	flush bottom water daily	maintenance of vacuum pump once a year
	2.5	Consumable required? What? How often? Is that potentially hazardous?	Yes, $KMnO_4$ and alum, Hazardous	No	Activated alumina 1-2 time/year	No	No
	2.6	Chemicals required? What? How often? Is that potentially hazardous?	Yes, Daily, $KMnO_4$ and alum, Hazardous	No	No	No	No
	2.7	Waste generated? How much /day, month	Yes. Few gram/day	Yes, few gram/day	Yes, 20-80kg/year	No	No
	2.8	Monitoring requirement	Modest	Modest	High	No	No
	2.8-1	1.3, 1.4, 1.5 is yes, monitoring required.How often ?	Minimum monthly	minimum monthly	minimum monthly		
	2.8-2	Monitoring parameters? Arsenic? Other ions?	Arsenic	Arsenic and Iron	Arsenic	not required	not required
	2.9	Operational risk?	Handling of chemical, miss operation,	No removal of arsenic if miss operated	No removal of arsenic if breakthrough occur	Less production of arsenic free water	Less production of arsenic free water

			no arsenic removal, excess chemical				
Cost	3.1	Equipment cost					
	3.1-1	cost/unit	500TK	15,000TK	100,000TK	100,000TK	500,000TK
		Expected life time of the equipment	3 years	10 years	10 years	10 years	20 years
	3.1-2	unit cost/l of treated water over expected life time (TK/l)	0.034	0.014	0.027	2.854	1.712
	3.2	Operating cost (TK/l)					
	3.2-1	Manpower	NA	NA	NA	NA	NA
	3.2-2	Consumable	0	0	0.055	0	0
	3.2-3	Chemical (TK/l)	0.002	0	0	0	0
	3.2-4	Power or any other utility	0	0	0.003	0	0
	3.2-5	Monitoring (500TK/analysis)	0.822	0.055	0.016	0	0
	3.2-6	Waste treatment disposal site construction, collection, transportation	Required	Required	Required	not required	not required
	3.3	Use of locally available material					
	3.3-1	Equipment	Yes	Yes	Yes	Yes	No
	3.3-2	Consumable	Yes	NA	No	not required	NA
	3.3-3	Chemical	Yes	NA	NA	NA	NA

7.3 Improved Deep Well

A manpowered jetting method widely used in the rural area of Bangladesh was improved by using several drilling and sealing techniques. The techniques were applied to examine whether the contaminated water from surface and shallow layers intrude into the deep aquifer or not. After site geology and local drilling skills were examined, the specifications for the improved deep well (properly sealed) were developed. A total of 9 improved deep wells were drilled in the three model rural areas (3 wells per model rural area).

7.3.1 Necessity of the Improved Deep Well

In Bangladesh, the donkey method (up to the depth of 100 to 200 m) is used for well drilling.
This method is to manually operate a donkey pump, circulate mud water (made from cow dung and bentnite), and rotate a rod. It is used for drilling a deeper well such as DPHE well, which is constructed as an arsenic protection measures.
A well becomes completed by the installation of a screen pipe. Sand or gravel is filled between the screen pipe and the borehole as a filter. The sand filter is expected to be naturally created. It is thought, however, that the arsenic contaminated water in the shallow aquifer may have intruded into the deep aquifer along the well casing because the annulus between the well casing

and the borehole is not sealed (see Figure 7.3.1).

To utilize a safe deep aquifer and prevent arsenic contamination due to the well structure, it is necessary to establish an improved well construction technique, which enables firm sealing for the donkey method.

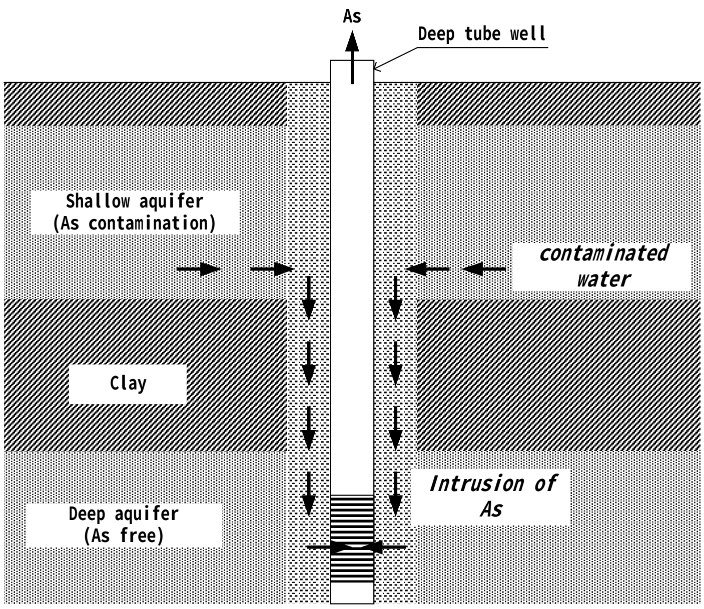


Figure 7.3.1 Arsenic contamination of a deep well due to no sealing

7.3.2 Type of Improved Deep Well

The following three types of deep wells dug by the donkey methods were examined in this study (see Figure 7.3.2):

1) Type A: Sealing with cement by enlarging the drill diameter.

2) Type B: Using a special sealing material (Nice seal)

3) Type C: Using mechanical seal

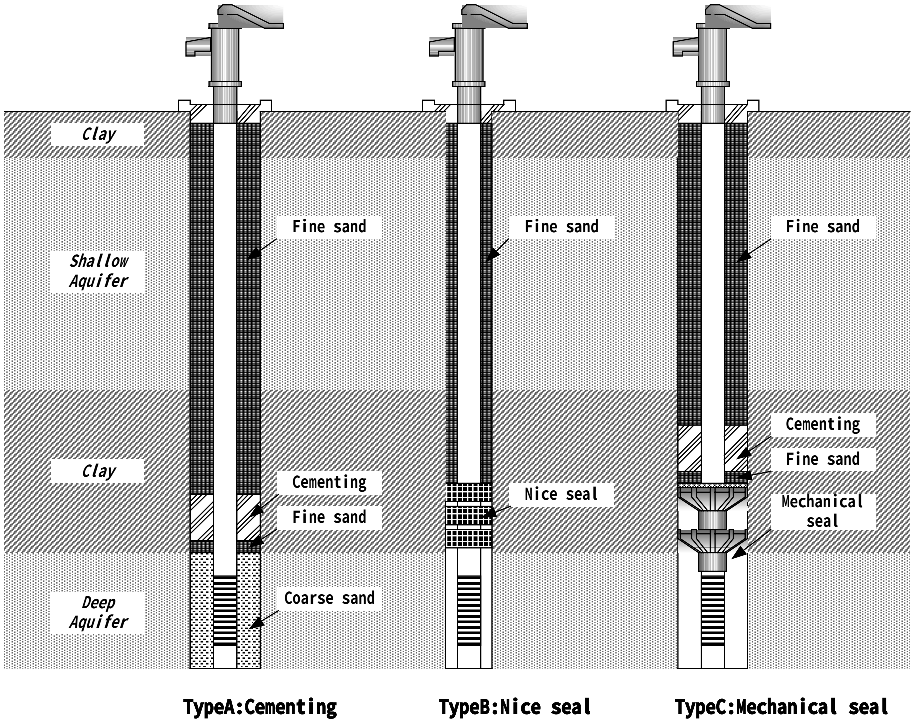


Figure 7.3.2 Structure of Improved Deep Well

7.3.3 Construction methods of Improved Deep Well

1) Particular Tools

a) Cutter with diamond tip (φ 90 and 150 mm)	1 for each diameter
b) Tremie tube for cementing (φ 38 mm vinyl pipe)	120 m
c) Resistivity logging equipment (IDOPACK-10)	1
d) Resistivity logging cable (l=200 m)	1 roll

2) Sealing Method in Type A

Spaces between the wall of the borehole and the screen section of the well casing is filled with coarse sand up to the boundary of the clay layer. Fine sand is filled in the upper part of the coarse sand filter with the depth of 0.5 m, and cement is filled with the depth of 5 m from the upper part of the fine sand filter. Then, fine sand is filled up to the surface. Portland cement with a water/cement ratio of about 50% is used for cementing. Injection of the cement milk is for the depth of 0.5 m on the first day.

3) Sealing Method Type B

The casing pipe is wrapped with the Nice seal at the level of the upper part of the screen section where the lower boundary of the clay formation exists (see Figure 7.3.3).

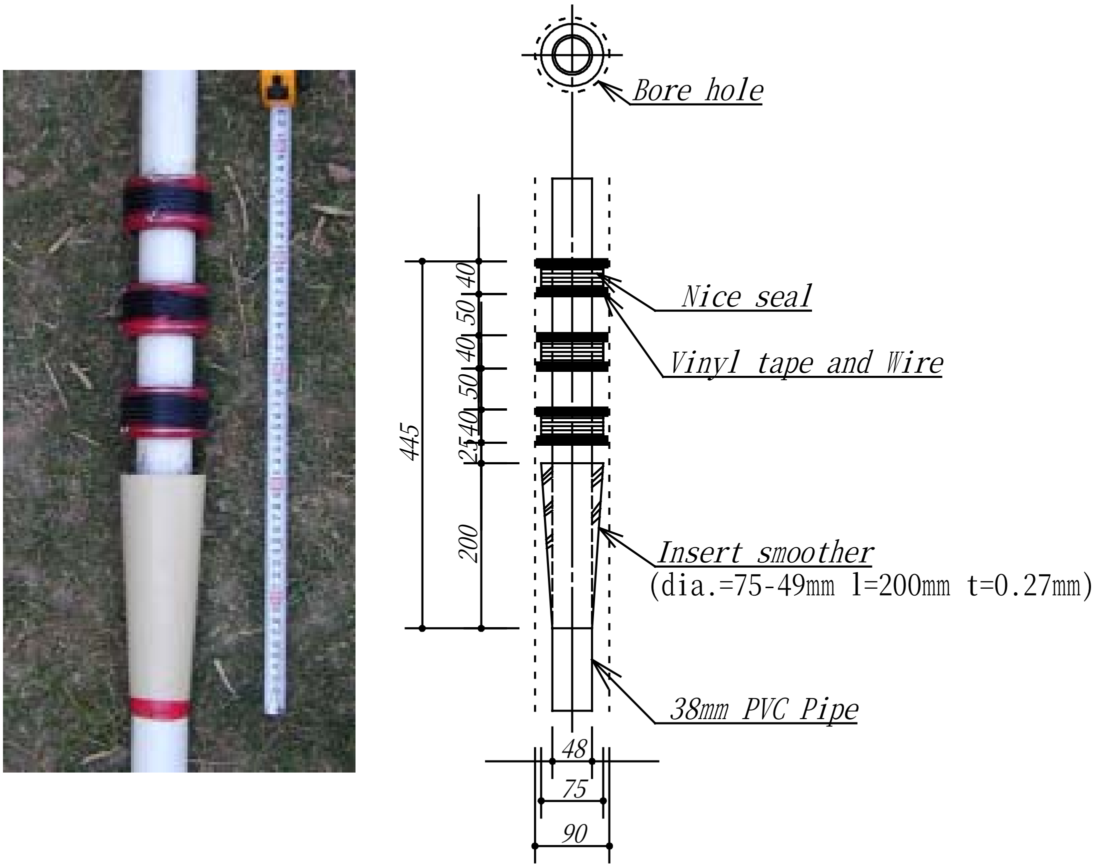


Figure 7.3.3 Wrapping of the casing with the Nice seal

4) Sealing Method in Type C

The mechanical seal is attached at 0.5 m intervals in the upper part of the screen where the clay formation exists. The *fatrra* is placed on the basket, and then some clay is put into the basket. The borehole is filled with fine sand for the depth of 0.5 m and then cement for the depth of 5 m.

The mechanical seal is commonly called a ‘metal-petal-basket’ and used for observation wells for land subsidence. The filling material is prevented from dropping down from the upper part as the seal spreads like petals (see Figure 7.3.4).

The method of cementing is the same as Type A.

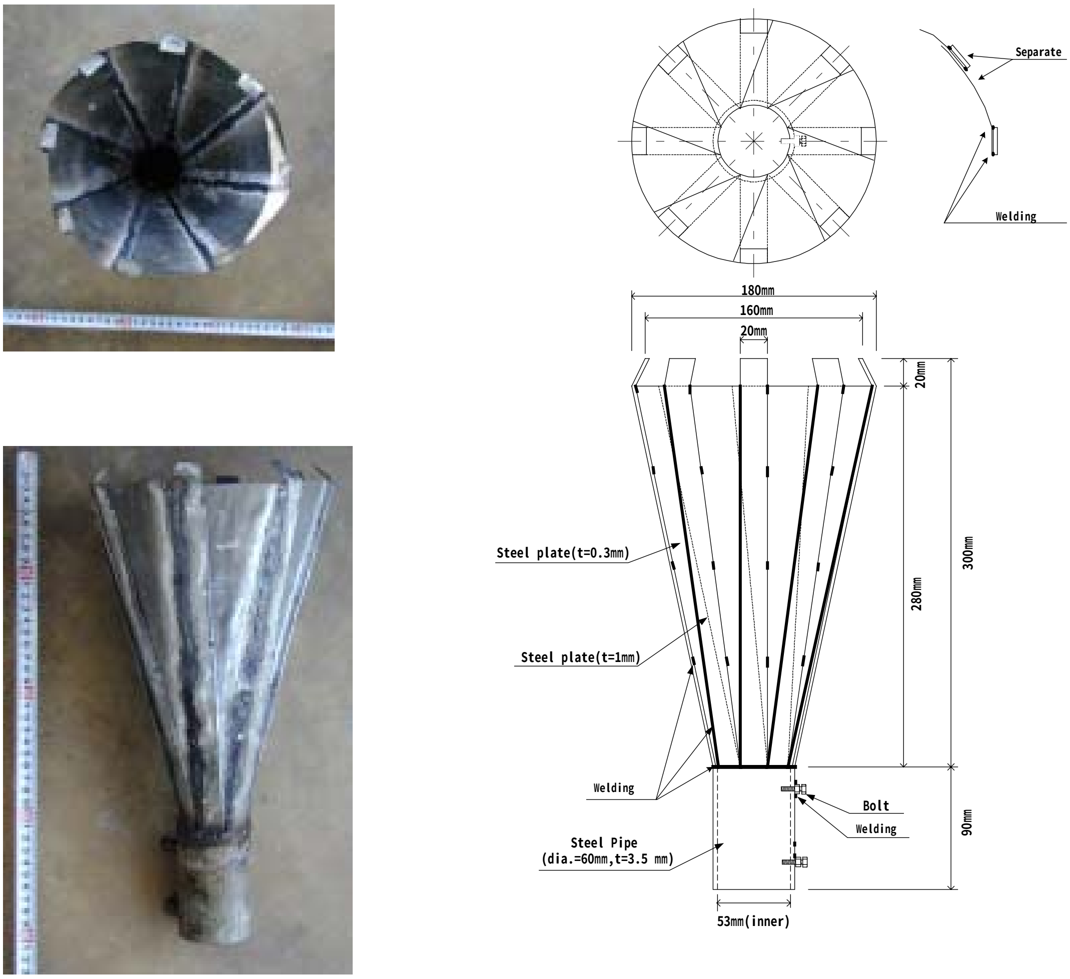
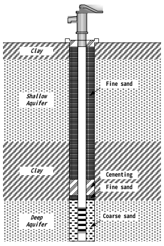
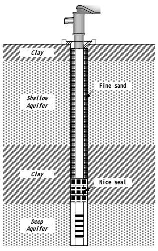
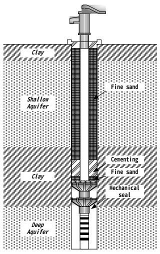


Figure 7.3.4 Metal-petal-basket

7.3.4 Results of improved deep well construction

The three types of the improved deep wells were drilled in each of the model rural areas, namely Rajnagar Bankabarsi, Krishna Chandrapur, and Bara Dudpatila. The results of the construction and evaluation are presented in Table 7.3.1.

Table 7.3.1 Characteristic and evaluation of Improved deep well

Well type	Characteristic			Evaluation
TypeA 	Local availability of sealing materials	Available	○	○ Sealing is reliable if the seal is carefully installed.
	Reliability of the seal	Cement sticks to the earth tightly. It is possible to seal at optional level.	○	
	Easiness of construction	A casing pipe can be inserted smoothly because nothing is attached to the PVC pipe. However, the pipe could be blocked on its way unless the pipe is incerted slowly, being shaked.	△	
	Cost	68,595TK		
	Construction period	10-20days		
TypeB 	Local availability of sealing materials	Not available (need to be imported from Japan)	×	× Durability of the sealing materials is unknown, and construction of Type B well is difficult. Sealing materials have to be imported.
	Reliability of the seal	Since there is a space below the Nice seal, intrusion of arsenic contaminated water could not be prevented if the wall of the borehole around the Nice seal is broke down. The life of the Nice seal is unknown.	△	
	Easiness of construction	The Nice seal is likely to prevent smooth insertion of the PVC pipe into the borehole, which results in failure of inserting the pipe to the planned depth (one failure was experienced in the study).	△	
	Cost	48,340TK		
	Construction period	7-14days		
TypeC 	Local availability of sealing materials	Available, but making Metal-pet al-basket is difficult.	△	× If Type C well is constructed properly, the sealing is reliable. However, the construction of the well is difficult.
	Reliability of the seal	Cement sticks to the earth tightly.	○	
	Easiness of construction	The metal-petal basket, which is attached to the PVC pipe, is likely to prevent smooth insertion of the pipe. This may results in failure of inserting the pipe to the planned depth (one failure was experienced in the study). The sealing could not be sucessuful when cement milk drops down through the spaces that would be created between the metal-petal basket and the wall of the borehole.	×	
	Cost	70,645TK		
	Construction period	10-20days		

7.4 Alternative Water Sources

7.4.1 Problems of Alternative Water Sources

Problems concerning alternative water sources in the Study Area and their utilization are as follows:

1) Rainwater

The annual rainfall in the Study Area is 1,500 to 1,800 mm, however, as rainfall is concentrated in the rainy season, it is difficult to utilize rainwater in the dry season.

As part of the measures against arsenic contamination, action is now being taken to make the use of Rainwater Harvesters (RWH) more widespread in the villages; but in order to do so, public education encouraging the utilization of rainwater is necessary.

2) Ponds

Innumerable ponds of various sizes exist in both urban and rural areas. As they are located within the villages, excrement and urine from livestock as well as domestic wastewater are washed into these ponds when it rains and they are believed to be contaminated with fecal coliform (bacteria). Moreover, some ponds are used for fish cultivation and contain large quantities of feed and chemicals that reportedly include substances that are highly toxic to humans.

Therefore, prior to utilizing pond water, whether or not water quality levels safe for drinking water can be secured and the supply capacity should be verified. Examinations should be conducted.

3) Rivers and Lakes

In the Study Area, small and medium-sized rivers and crescent-shaped lakes exist on the Ganges Plain, however, in the dry season, many of them dry up. They are not believed to be as contaminated as the ponds but as the Study Area is in an agricultural region where rice paddies concentrate, contamination by agricultural chemicals needs to be considered.

In order to be used as a drinking water source, water quality, water treatment measures, as well as measures against the decline in water level during the dry season need to be examined.

4) Groundwater from Water Table Aquifer

As part of steps being taken against arsenic contamination, additional dug wells taking water from very shallow water table aquifers are being constructed. According to tests conducted by DCH and BRAC, arsenic was not detected in samples from dug wells, however, the aquifers of dug wells are often connected to shallow aquifers which are contaminated with arsenic. It is necessary to monitor the arsenic levels. The water level during the dry season must be examined at the same time as well as water quality testing.

7.4.2 Review on Alternative Water Supply Facilities

In Bangladesh, there have been various measures to cope with the water supply problem. The three main types of water supply facilities are as follows.

(1) Rainwater Harvester (RWH)
(2) Pond Sand Filter (PSF)
(3) Dug Well

1) Rainwater Harvester (RWH)

a. Facility

Rainwater is stored in some kind of water tank. Rather than building a water storage facility, the practice of placing jars outside with clothes to collect rainwater has become widespread, as in the case of AAN in dealing with the problem in Samta village. A summary of the facility constructed under the “Action Research into the Community Based Arsenic Mitigation” project is as follows.

- Water Source: Rainwater
- Water Storage Capacity: 3,200 liters (DPHE Model)
  515 liters (BRAC Model)
- Construction: Concrete foundation
  Precast concrete ring
  Concrete lid
  Downspout or catchment pipe
- Construction cost: 8,000 to 10,000 Taka (DPHE Model)
  1,800 Taka (BRAC Model)

b. Use of Facilities

The main problems suggested by the report were as follows:

(1) A great number of residents do not like rainwater and do no understand the effectiveness of using rainwater.
(2) When there is a safe well, rainwater is not used.
(3) Residents do not want to invest in RWHs as they can only be used in the rainy season.
(4) As rain concentrates in the rainy season, the cost would be tremendous to build a facility to supply water for consumption in the dry season.

2) Pond Sand Filter (PSF)

a. Facility

This facility is effective in filtering out impurities in the water and, therefore, can eliminate cloudiness and odor. It is also effective against fecal coliform (bacteria) and according to a BRAC report, by using a PSF, the number of fecal coliform in a water source can be reduced by a double digit amount. However, in the case of water sources that contain a large number of fecal coliform, the apparatus cannot bring the amount of the bacteria under the standard value. Therefore, if fecal coliform cannot be eliminated to a safe limit, water needs to be treated by boiling or some other method of sterilization.

A summary of the facility set up by ANN is as follows.

- Water Source: Pond
- Water Supply Capability: 1,000 liters / hour
- Construction: Intake pipe or hand pump
  Receiving layer
  Gravel filtering layer
  Sedimentation layer
  Sand filtering layer
  Water tank/Sterilization tank
  Faucet

b. Problems

The main problems suggested by the report were as follows.

In the dry season, large amounts of algae grow in lakes and ponds and in the wet season, rainwater that falls in the surrounding area flows into the ponds making them muddy.

After conducting a study on water filtered through a PSF, fecal coliform and other common bacteria were frequently found at amounts exceeding the permissible range.

It is difficult to locate a pond that is suitable for use of PSF. A great many ponds are used for fish cultivation and these ponds contain feed and chemicals that are harmful to human beings. In addition, residents are more inclined to use ponds for fish cultivation, as it is a source of cash income, rather than just to secure a drinking water source.

The ponds dry up in the dry season.

Traditionally, pond water is utilized only for cooking, not for drinking. As a result, although a PSF is set up, the water is only used for cooking.

(1) Most residents consider pond water to have an odor and do not like the taste in comparison with well water.

(2) Residents who have seen worms and scorpions filter through a PSF are hesitant about using one.

(3) In the dry season, pond water concentrates giving off a strange odor and the residents tend not to use it.

3) Dug Well

a. Facility

Facilities set up under the "Action Research into Community Based Arsenic Mitigation" project consist of existing dug wells that have been improved as well as newly constructed dug wells that have had lids and hand pumps put on them.

b. Problems

(1) In general, dug well water is contaminated with fecal coliform and other common bacteria.
(2) In the dry season, the water level declines and the dug wells run dry.
(3) According to DCH and BRAC reports, although dug wells are not contaminated with arsenic, aquifers supplying it water are connected to shallow aquifers, which are contaminated with arsenic and, therefore, the potential for arsenic contamination cannot be denied.

7.4.3 Proposal for Alternative Water Source Development

The quality and seasonal utilization conditions of alternative water sources in the Study Area are organized in the table below. However, there are only a few prospective water sources in the Study Area that can be used with certainty in the dry season. A plan for the development of alternative water sources should be devised after fully grasping the water sources' supply capacities. If a water source is judged not able to supply water year-round, a complementary utilization plan such as using pond water and rainwater in the rainy season and safe groundwater (arsenic has been removed) in the dry season should be examined.

Moreover, the quality of the raw water from the alternative sources must be studied to confirm that they are suitable for development and use. At the same time, after the facilities are open for community use, water quality needs to be monitored to ensure that the water supply is safe. Water treatment methods need to be examined as all the water sources, apart from rainwater, are thought to be contaminated with fecal coliform and other matter.

Furthermore, educational activities to encourage residents to use the facilities and to inform them about hygiene (boiling and sterilizing of water, etc) need to be held prior to construction of the facility.

Alternative Water Sources in Study Area

Water Source	(Water Quality) Arsenic	(Water Quality) Fecal Coliform / Common Bacteria	Seasonal Utilization Conditions
Rainwater	Safe	Safe	Not usable in dry season
Ponds	Safe	Contaminated	Water level drops or runs dry in dry season
Rivers/Lakes	Safe	Contaminated	Water level drops or runs dry in dry season
Groundwater from Ultra Shallow Aquifers (Dug Wells)	Safe/Contaminated	Contaminated	Water level drops or runs dry in dry season

CHAPTER 8

MECHANISM OF ARSENIC CONTAMINATION AND DEEP AQUIFER EVALUATION

CHAPTER 8 MECHANISM OF ARSENIC CONTAMINATION AND DEEP AQUIFER EVALUATION

8.1 Hydrogeologic Structure and Contamination Mechanism

8.1.1 Occurrence of Arsenic Source

In the sediments in Bangladesh, it is common that the arsenic content ranges from 1 to 30 mg/kg (= ppm) (McArthur et al., 2001; RGAG and MURG, 2000; Yamazaki et al., 2000; Nickson et al., 1998, 2000; AAN/RGAG/NIPSOM, 1999; DPHE, 1999). For example, the core sample analysis at Samta village in Jessore District shows that the arsenic content in the muddy layer and sandy layers except the peaty layer within 15 m in depth ranges from 0.7 to 23 mg/kg (Yamazaki, et al., 2000; RGAG and MURG, 2000). The results of the total arsenic content analysis in 21 samples done by DPHE (2000) showed the average value was 4 mg/kg and the values ranged from 0.4 to 10 mg/kg. Similarly, the samples in the Red River Delta in Vietnam show that the arsenic content in the sediments at depths from 12 to 40 m ranges from 6 to 33 mg/kg in brown to black clay, 2 to 12 mg/kg in gray clay, and 0.6 to 5 mg/kg in brown to gray sand (Berg et al., 2001).

If it is assumed that the sediment having an arsenic content of more than 30 mg/kg is the source of arsenic, the source sediments were found at CH-2 and CH-BD sites in Chuadanga District and JS-2 and JS-RB sites in Jessore District. On the other hand, the results of core boring show there is no arsenic source at JH-1 and JH-KC sites in Jhenaidah District.

At CH-2 site in Chuadanga Pourashava, the arsenic source was found in silty clay samples (207.50 to 207.72 m, 117.26 ppm), fine to medium sand samples (228.00 to 228.70 m, 51.20 ppm), and very fine sand and silt samples (244.74 to 245.17 m, 35.39 ppm). At the site, the arsenic source occurs in the deep portion at depths from 200 to 250 m. In other words, the arsenic source was found from the lower part of D formation and E formation.

At CH-BD site in Bara Dudpatila village in Chuadanga district, the arsenic source was found in clayey silt samples (111.65 to 111.85 m, 42.71 ppm), clayey silt samples (228.50 to 229.00 m, 93.57 ppm), and very fine to fine sand samples (290.00 to 290.40 m, 47.09 ppm). At the site, the arsenic source occurs in the middle and deep portions at depths of around 110 m and from 230 to 290 m. In other words, the arsenic source was found in C formation and E formation.

At JS-2 site in Jessore Pourashava, the arsenic source was found in peat samples (8.40 to 8.60 m, 56.55 ppm; 9.15 to 9.30 m, 45.00 ppm), clay samples (13.00 to 13.50 m, 46.86 ppm; 14.00 to 14.45 m, 46.87 ppm), peaty silt samples (14.45 to 14.78 m, 63.15 ppm), silty clay samples (15.35 to 15.80 m, 35.11 ppm), silty clay samples (18.00 to 18.50 m, 41.52 ppm), and peaty silt samples (19.08 to 19.18 m, 50.70 ppm). At the site, the arsenic source occurs in the shallow portion at depths from 8 to 20 m. In other words, the arsenic source was found in the upper part of A formation.

At JS-RB site in Rajnagar Bankabarsi village in Jessore District, the arsenic source was found in peat samples (8.00 to 8.21 m, 57.12 ppm), silt samples (254.54 to 254.91 m, 67.61 m), and clayey silt samples (256.23 to 256.66 m, 60.22 ppm). At the site, the arsenic source occurs in the shallow and deep portions at depths of around 8 and 255 m. In other words, the arsenic source was found in the upper part of A formation and E formation.

Although the six (6) core boring sites (i.e. 3 sites in Pourashava areas and 3 sites in the model rural areas) were selected from the areas of shallow groundwater contaminated by arsenic, the results show that the shallow arsenic source was found at only two (2) sites (JS-2 and JS-RB). On the other hand, the arsenic source was found in the middle portion (100 to 200 m in depth) and deep portion (200 to 300 m in depth) at three (3) sites (CH-2, CH-BD and JS-RB).

The previous studies in Bangladesh show that the arsenic source mainly occurs in the shallow portion within a depth of 100 m (AAN/RGAG/NIPSOM, 1999; RGAG/MURG, 2000; DPHE, 1999, 2000a, 2000b; Yamazaki et al., 2000). However, in the study, the arsenic source was found not only in the shallow portion but also in the middle and deep portions (100 to 300 m in depth).

8.1.2 Arsenic Source and Hydrogeologic Structure

As mentioned before, the arsenic source found in the study area by the core boring survey mainly consists of fine sediments such as clay, silt, peat, and very fine to fine sand. From a hydrogeological point of view, these sediments are categorized as “aquitard” or “aquiclude”. Generally, the sediments composing the aquitard or aquiclude have small permeability. Although groundwater still passes through the less permeable sediments, the sediments separate the upper aquifer from the lower aquifer due to the contrast of hydraulic conductivity.

In the study area, the most important hydrogeologic structure is the clayey layers in C formation, which separate the deep aquifer from the shallow aquifer in the southern part of the study area. The clayey layers can contribute as an aquitard. The area of extent, thickness and hydraulic conductivity of the aquitard are very important factors to control the three-dimensional groundwater flow in the study area. According to the result of core sample analysis done at Rajnagar Bankabarsi village in Keshabpur, the total arsenic content in the aquitard ranges from 5 to 10 ppm, indicating that there is no arsenic source in the aquitard.

The active arsenic source that has caused the present arsenic contamination in groundwater is located in the shallow portions in the study area. The clayey layers, particularly peat, were confirmed to have a high total arsenic content, ranging from 30 to 60 ppm at JS-2 and JS-RB sites. The data of Samta village also showed that the organic muddy layer in the shallow zone has a high arsenic content ranging from 47 to 262 mg/kg. The shallow muddy layer also behaves as an aquitard, which separates unconfined aquifers from confined aquifers in Samta village (RGAG and MURG, 2000) . It is observed in Samta village that although the groundwater in the unconfined aquifer dries up during the latter part of dry seasons, the groundwater level is about 0.5 m higher than that in the confined aquifers in rainy seasons.

From a hydrogeological viewpoint, the shallow alluvial clay has significant characteristics in particularly in its physical properties. Because the clay is soft and not pre-consolidated, the hydraulic conductivity is relatively greater than that of pre-consolidated clay. It is also known in such soft clay that the coefficient of volume compressibility and specific storage are larger particularly in peat. From the characteristics, it is predicted that a relatively greater amount of water in the clay or peat may be drained when some load is given. In other words, the amount of squeeze per unit volume in the soft clay and peat at shallow depths may be greater than those in the deep layers. The area of extent, continuity, and thickness of the clay/peat are also important factors that control three-dimensional groundwater flow.

8.1.3 Contamination Mechanism

In the study, the actual conditions of groundwater contamination by arsenic including its aerial extent and magnitude in large scale (= 3 districts) and small scale (= model village) are understood. The presence of an arsenic source not only in the shallow portion but also in the deeper portion is also confirmed. The vertical distribution of arsenic concentrations in groundwater and total arsenic contents in soil are also examined.

Although the precise mechanism particularly of the dissolution of arsenic into groundwater was not examined in the study because it was out of the scope of work, the study can imply the movement of contaminated groundwater after dissolution. Based on the results of various hydrogeological and groundwater investigations done in the study, the following contamination mechanism can be implied.

1) Distribution of Arsenic Source

As mentioned in the previous section, the possible arsenic source in geologic layers was found not only in the shallow portion but also in the deeper portions. However, it is evaluated that the shallow arsenic source is active at present, because the arsenic concentration is high in the shallow portion, and it generally decreases with depth. In addition, the horizontal distribution of arsenic concentrations in groundwater suggests that the distribution of the arsenic sources in the shallow portion is not uniform in the study area. They mainly occur in the western part of the study area. Further, the distribution of arsenic concentrations in groundwater significantly varies even within a village, indicating that the occurrence of arsenic sources is not uniform in a small area. The irregular distribution of arsenic concentrations in small areas were found in Samta village in Jessore (Yokota et al., 1977; AAN/RGAG/NIPSOM, 2000; RGAG and MURG, 2000), Bara Dudpatila village in Chuadanga District and Krishna Chandrapur village in Jhenaidah District by the study. On the other hand, the screening survey done in the 16 Mouzas in

Keshabpur Upazila and the distribution of arsenic concentrations in Rajnagar Bankabarsi village show that the arsenic contamination in groundwater occurs almost uniformly in the area, implying that the arsenic source is also almost uniformly distributed.

It is presumed that the distribution of arsenic sources in the shallow portion is geologically and geomorphologically controlled. The depositional environment, sedimentary history and delta evolution should be further studied in the Ganges Delta.

2) Dissolution of Arsenic

Although a detailed study on arsenic dissolution was not done in the study, it was found that most of the arsenic contaminated groundwater in the study area is characterized by a low Eh and high iron concentration. This indicates the dissociation of ferric oxyhydroxide and release of iron and arsenic ion into the groundwater. On the other hand, pyrite minerals were not found in the core samples obtained in the study by naked eye observation.

Therefore, the pyrite oxidation hypothesis is highly unlikely as the mechanism for the arsenic contamination, at least as the immediate event took place. The very low concentrations of sulfate ions in most of the study area also support this idea. The reduction of iron oxyhydroxide is the most likely mechanism taking place at the present moment. However this does not exclude the contribution of other mechanisms such as phosphorus substitution of arsenic from the lattice of iron oxyhydroxide. Also this does not exclude the possibility of the oxidation of pyrite prior to the absorption of arsenic into iron oxyhydroxide.

3) Transport of Arsenic

After the dissolution of arsenic into groundwater, the arsenic contaminated groundwater basically moves along with the groundwater flow. Under natural conditions without any groundwater pumpage by human beings, the velocity of groundwater flow is estimated to be very small because the hydraulic gradient in the Ganges delta and in the study area is comparatively small. However, if the groundwater is extracted by wells, the natural groundwater system will be disturbed.

It has been said that the groundwater use particularly for irrigation purposes has drastically increased since the 1980's; however, an estimation of groundwater pumpage has not been done in Bangladesh. This study estimated the monthly groundwater pumpage for irrigation use and for domestic use from 1983 to 2000 based on the available data/information including existing statistical data, meteorological data, land use information by satellite imagery analysis, the GIS database system and the field investigation results done in the study. As a result, the total groundwater pumpage in the study area in January 1983 was estimated as 3.359 million cubic meters per day (= MCM/day), while the groundwater pumpage in January 2000 was estimated as 15.133 MCM/day, increasing 4.5 times. It is also estimated that the annual average value of groundwater pumpage is 8.27 MCM/day and the pumpage for agricultural use occupies 98.9% of the total. On the other hand, the amount for domestic pumpage occupies only 1.1% of the total.

The impact of such an increase in groundwater pumpage on the groundwater environment in the study area is judged not small. The data on groundwater levels in western Bangladesh monitored by BWDB show the declining trend of groundwater levels (Shibasaki and RGAG, 1997). Particularly, the groundwater levels in the dry seasons declined clearly year by year. The groundwater levels in Samta village also show that the changes of groundwater levels in the first aquifer are thought to be caused not only by the seasonal change of groundwater recharge but also by the vertical movement of groundwater forced by the excessive pumpage from the upper sandy layer (RGAG and MURG, 2000).

Although it is estimated that some portions of pumped groundwater again infiltrate into the ground and return back to the groundwater body, the accelerated circulation of groundwater in the shallow portion could cause changes in the physical and chemical conditions of the underground environment. Therefore, it is implied by the study results that the increase in groundwater pumpage for irrigation use has had some impact on the groundwater conditions in the study area, and the occurrence of groundwater contamination by arsenic might have also been caused by the impact.

8.2 Simulation of Groundwater Contamination

8.2.1 Purpose of Groundwater Simulation

In the study, one of the important purposes of groundwater simulation is to simulate the movement of arsenic contaminated groundwater. Although the precise mechanism of arsenic dissolution into groundwater has not been fully revealed yet, the movement of contaminated groundwater can be simulated by assuming several solute-transport conditions. Another important purpose is to predict the future movement of arsenic contaminated groundwater under several groundwater use conditions. Particularly if the deep aquifer is extensively developed in the future, it is possible that the present groundwater flow system will be highly disturbed and the presently safe deep groundwater resources will be spoiled after some time. The groundwater simulation study can provide the prediction results of the future distribution of groundwater levels (piezometric heads) as well as the distribution of arsenic concentrations.

8.2.2 Methodology

In the study, three (3) kinds of groundwater simulation models were constructed based on the hydrogeological conditions of the study area. To simulate groundwater flow and movement of contaminated groundwater by arsenic, two (2) kinds of simulation programs, viz. MODFLOW and MT3D, were employed. The constructed simulation models and the computer programs used in the study are shown in Table 8.2.1.

Table 8.2.1 Groundwater Simulation Models and Programs Used in the Study

Model Name	Program Used	Purpose
Vertical 2-D Local Model	Visual MODFLOW with MT3D	Simulate local groundwater flow and arsenic contamination pattern in village scale
3-D Regional Model	MODFLOW, MT3D	Simulate three dimensional regional groundwater flow and arsenic contamination
Vertical 2-D Regional Model	MODFLOW, MT3D	Simulate vertical 2-D regional groundwater flow and arsenic contamination

8.2.3 Vertical 2-D Local Model

1) Purpose

In the study, detailed arsenic contamination maps of three (3) villages in Chuadanga, Jhenaidah and Jessore districts were prepared based on the testing of arsenic concentrations by AAS in all the existing wells. From the results, it was revealed that the distribution of arsenic concentrations greatly vary in Bara Dudpatila village in Chuadanga district and Krishna Chandrapur village in Jhenaidah district. The arsenic concentrations in the shallow tube wells show less than 0.01 mg/l in some parts in the villages, while in the other parts the concentrations show more than 0.5 mg/l. It was found that the distance between the highly contaminated wells (0.5 mg/l<) and less contaminated wells (<0.01 mg/l) is only 50 m in some places, even though the shallow wells have almost the same well depths and they tapped the same aquifer.

To examine the actual distribution of contaminated groundwater as well as to understand the movements of contaminated groundwater under different hydrogeologic conditions, the Vertical 2-D Local Model was constructed.

2) Hydrogeological Modeling

The hydrogeologic settings for the Vertical 2-D Local Model were conceptually assumed based on the geologic conditions in the model rural areas and in Samta village. In the conceptual model, hydrogeologic structures are also simplified to examine the typical movement patterns of contaminated groundwater.

For the Vertical 2-D Local Model, the model domain is 500 m in width (= horizontal direction) and 300 m in depth (vertical direction). In horizontal direction, each model cell is 5 m in width. In vertical direction each model cell is 5 m in thickness. Therefore, the modeled domain has 100 x 60 = 6,000 cells.

In the model, the top and bottom elevations of each layer are set according to the assumed hydrogeological conditions. For the type of each layer, "confined/unconfined (transmissivity is variable)" is assigned to all the model layers. A uniform value of specific storage (= 0.0001 m^{-1}) was given to each cell. The values of effective porosity, total porosity, and specific yield are uniformly assigned, having 0.2, 0.25, and 0.2, respectively. It is assumed that the values of vertical hydraulic conductivity (kv) are 1/5 of the horizontal hydraulic conductivity (kh) values. Initial piezometric heads of 0 m in elevation are uniformly given to the all model cells. A recharge rate is not given to the model because the simulation was mainly carried out by steady-state simulation. Instead, a constant head boundary condition was assigned to the top layer of the model.

For the solute transport simulation by MT3D program, the initial arsenic concentration was assumed to be 10 μg/l (0.01 mg/l) uniformly. For the advection calculation, Hybrid Method of Characteristics (HMOC) was employed. Longitudinal dispersivity was uniformly assumed to be 5.0 m. The ratio of horizontal dispersivity to longitudinal dispersivity is uniformly set at 0.1. The vertical to longitudinal ratio is uniformly set at 0.01. In the simulation, the molecular diffusion coefficient is treated as 0.0. It was assumed that chemical reactions, ion exchange, and absorption did not occur in the solute-transport simulation.

3) Case-01 Simulation

The Case-01 simulation was carried out to understand the natural groundwater flow conditions in a local area. It is assumed that the groundwater flow occurs only due to the groundwater level difference caused by topographic conditions. A constant head boundary was assigned at the top layer. The higher values of constant head were given to the central area of the model, expressing that the village center has a slightly more elevated groundwater level than the surrounding paddy field. The boundary conditions and the input parameters of the Case-01 simulation are shown in Figure 8.2.1 (a).

The steady-state simulation was carried out using the MODFLOW program. The simulated piezometric heads and flow vectors are shown in Figure 8.2.1 (b). The most equipotential lines are concentrated in the shallow clay layer because its hydraulic conductivity is comparatively smaller than the other layers. From the simulation result, it is understood that the local groundwater flow is generated by the potential difference at the constant head boundary. The groundwater moves perpendicular to the potential lines from the village center to the surrounding paddy field.

Based on the computed groundwater flow by the steady-state simulation, the solute transport simulation was carried out for a 50-year simulation period. Figure 8.2.2 shows the simulated arsenic concentrations over the simulation period. The shallow contaminated groundwater firstly moves horizontally after 1 to 2 years because the arsenic sources are located just above the clay layer. After 5 years, the contaminated water has penetrated the clay layer and reached the fine sand layer below the clay at the central part of the village. However, the contaminated water moves laterally in the fine sand layer and turns upward towards the paddy field. The downward, horizontal and upward flow pattern can be seen clearly after 20 years. The shallow contaminated water ultimately reaches the paddy field. The distribution pattern is almost stabilized after 40 years. The bottom of the plumes is located at about –100 m in elevation, but the contaminated groundwater does not enter the coarse sand layer occuring below –105 m in elevation. In the deep portion, the contaminated groundwater from the deep arsenic source occurs just near the sources even after 50 years. It is evaluated that the movement of deep contaminated groundwater is very slow under natural conditions without pumping wells.

4) Case-02 Simulation

The Case-02 simulation was carried out to simulate the groundwater flow and movement of contaminated groundwater with irrigation wells. Two irrigation wells are located in the paddy field with a pumpage of 1,000 m^3/day per well. The irrigation wells extract groundwater from the main aquifer (= coarse sand layer). The boundary conditions and the input parameters of the Case-02 simulation are shown in Figure 8.2.3 (a).

The steady-state simulation was carried out using the MODFLOW program. The simulated piezometric heads and flow vectors are shown in Figure 8.2.3 (b). The depressions of piezometric head having about –5.7 m in elevation are formed by the well pumpage. The groundwater moves towards the depressions. It is noted that the flow vectors show an almost vertical flow in the fine sand layer and medium sand layer, although the lateral flow is dominant in the coarse sand layer.

Based on the groundwater flow computed by the steady-state simulation, the solute transport simulation was carried out for a 50-year simulation period. Figure 8.2.4 shows the simulated arsenic concentrations from 1 year to 50 years. In the shallow portion, the contaminated groundwater moves along with the vertical groundwater flow. After 5 years, the plumes have reached the coarse sand layer. After entering the coarse sand layer, the flow directions are vended horizontally and move towards the screen portions of the irrigation wells. After 10 years, the plumes in the shallow portion reached the well screens. However, it is noted that the arsenic concentration of the pumped water is predicted to be below 500 mg/l, because the contaminated groundwater mixes with the uncontaminated water in the coarse sand layer. The distribution patterns of the contaminated groundwater from the shallow arsenic sources become almost stable after 20 years of the simulation. The shapes of the contamination plumes are different from place to place. The movement of contaminated groundwater in the deep fine sand layer is very slow compared with the shallow ones. The shapes of deep plumes are different from place to place. The deep contaminated groundwater below the village center mainly moves downward, but the contaminated water below the village perimeter moves horizontally, and the contaminated water below the paddy field moves upward. The maximum travel distance of deep contaminated groundwater is about 70 m for the 50-year period under the model conditions.

It should be noted that the arsenic concentrations in the shallow fine sand layer and medium sand layer still have a wide range of variation after 50 years, showing very high concentrations below the arsenic source but uncontaminated water occurring just in neighboring areas. This simulation result can greatly support the actual arsenic contamination characteristics in the shallow portion in the rural villages, such as Samta, Bara Dudpatila and Krishna Chandrapur villages in the study area. It should also be mentioned that the arsenic concentration of the water pumped by the irrigation wells is not so high because the wells extract not only the contaminated groundwater but also the fresh groundwater from the shallow zone without passing the shallow arsenic sources and from the deeper zones. Therefore, the contaminated water is mixed with the uncontaminated water in the wells, and the pumped water will show not so high concentrations of arsenic. In contrast, if there are shallow tube wells having screens beneath the shallow arsenic sources, the groundwater will be fully contaminated because the arsenic contaminated water moves down from the arsenic sources straightly without mixing with the uncontaminated water. In the deep portion, the results show that the contaminated groundwater only occurs in limited areas even after 50 years. The flow directions of the contaminated water vary from place to place. The simulation results suggest that the degree and extent of the deep aquifer contamination under the simulation conditions will be more limited than the shallow contamination even though the arsenic content in the source and dissolution conditions are the same as the shallow ones.

5) Case-03 Simulation

The Case-03 simulation was carried out to understand the groundwater flow conditions in the local area when a deep well for domestic use was constructed in the village. The pumpage of the deep well is set at 200 m^3/day. The two (2) irrigation wells are located at the perimeter of the village area, which is the same as the Case-02 simulation. It is assumed that the deep well has screens from –260 to –280 m in elevation in the deep fine sand layer. The boundary conditions and the input parameters of the Case-03 simulation are shown in Figure 8.2.5 (a).

The steady-state simulation was carried out using the MODFLOW program. The simulated piezometric heads and flow vectors are shown in Figure 8.2.5 (b). The simulated piezometric heads show that a small piezometric depression is created by the deep well, however, most groundwater flows towards the screen portions of the irrigation wells. The piezometric heads at the screens of the irrigation wells are about –6.1 m, whereas the head at the screen portion of the deep well is about –6.2 m.

Based on the computed groundwater flow by the steady-state simulation, the solute transport simulation was carried out for a 50-year simulation period. Figure 8.2.6 shows the simulated arsenic concentrations from 1 year to 50 years. The solute transport simulation shows that the arsenic from the shallow source does not reach the deep domestic well even after 50 years. It also shows that the arsenic concentration of the pumped water from the deep well is not so high because of the low velocity of the deep groundwater flow and mixture of fresh water and contaminated water. In the shallow portion, the contaminated groundwater moves along with the vertical groundwater flow. After 10 years, the plumes have reached the screen portions of the irrigation wells. The shallow contaminated groundwater mostly moves towards the depressions from 20 to 50 years. Some portions of the shallow contaminated plumes slightly move downward, however, they do not reach the screen portion of the deep well even after 50 years.

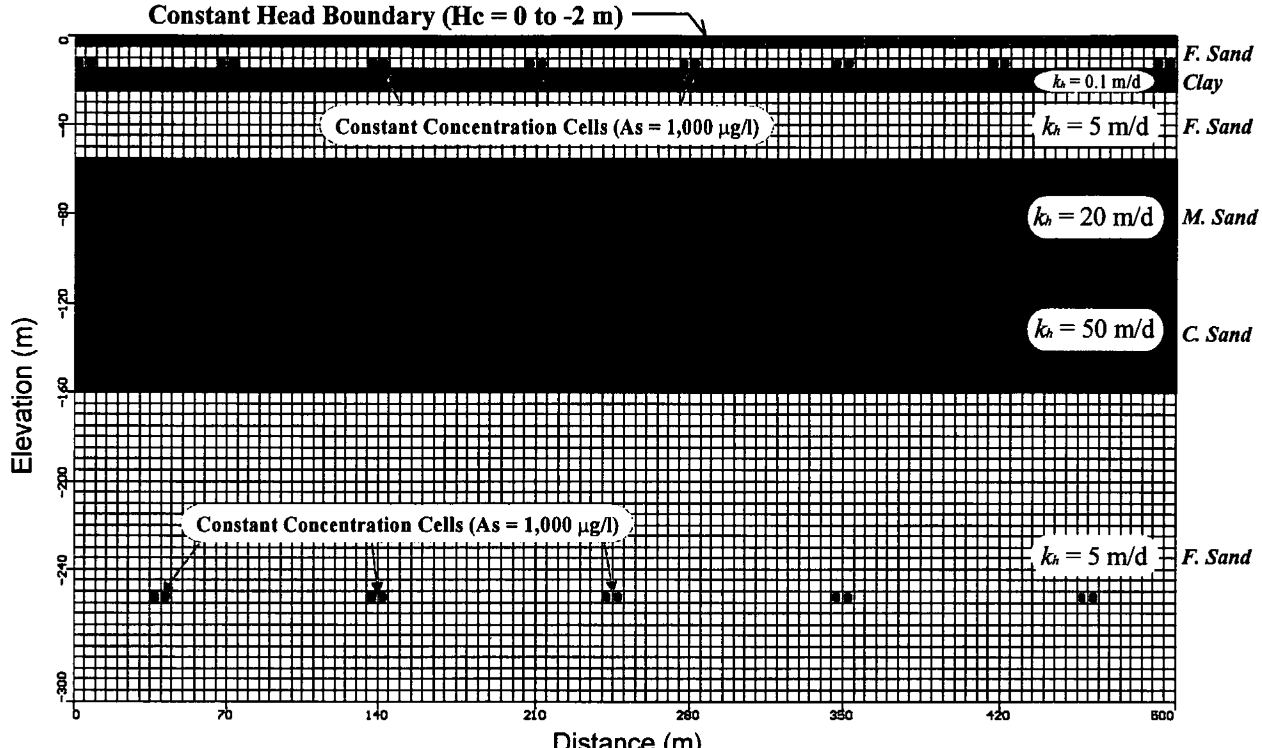
In the deep portion, the deep contaminated groundwater slowly moves toward the depression caused by the deep well. The contaminated groundwater originating from the deep arsenic sources located at 30 to 50 m away from the deep well reaches the well screen after 10 years. However, the maximum travel distance of the deep contaminated groundwater is only about 140 m for the 50-year period. The simulation result shows that the shallow contaminated groundwater does not reach the deep well when the pumping rate of the deep well is limited. It should also be mentioned that the arsenic concentration of the pumped water by the deep well is not so high because the movement of deep contaminated water is slow and the well extracts not only the contaminated groundwater but also the fresh groundwater from the shallow zone.

6) Case-04 Simulation

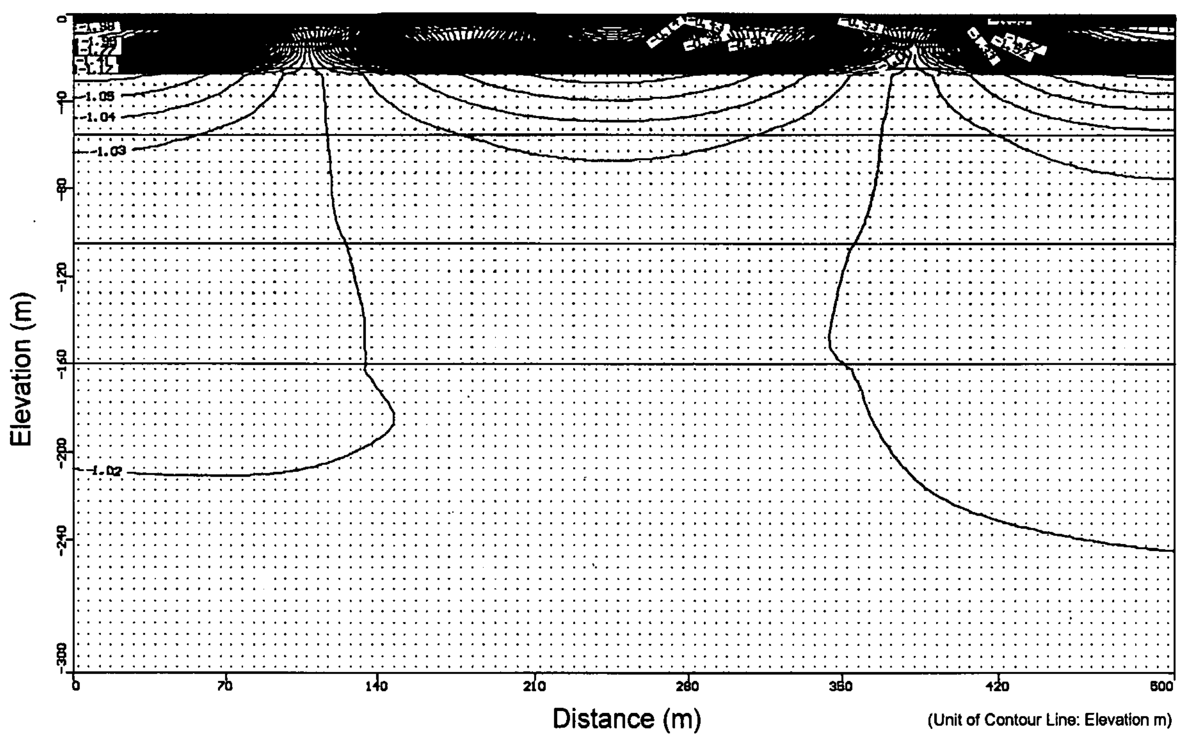
The Case-04 simulation was carried out to examine the groundwater flow conditions and movement of arsenic contaminated groundwater when a deep irrigation well was added to the Case-03 simulation. The pumpage of the deep irrigation well is set at 1,000 m^3/day. The pumping conditions of the two existing irrigation wells and the deep domestic well are the same as the Case-03 simulation. The boundary conditions and the input parameters of the Case-04 simulation are shown in Figure 8.2.7 (a).

The steady-state simulation was carried out using the MODFLOW program. The simulated piezometric heads and flow vectors are shown in Figure 8.2.7 (b). The simulated piezometric heads show that a large piezometric depression is created by the deep irrigation well. On the other hand, the depression created by the deep domestic well in the Case-03 simulation disappeared because the pumping rate is smaller than the deep irrigation well. Although some groundwater flows into the existing irrigation wells, the remaining groundwater flows towards the screen portion of the deep irrigation well. The piezometric heads at the screens of the existing irrigation wells are about –8.4 m, whereas the head at the screen portion of the deep irrigation well is about –9.2 m.

Based on the groundwater flow computed by the steady-state simulation, the solute transport simulation was carried out for a 50-year simulation period. Figure 8.2.8 shows the simulated arsenic concentrations from 1 year to 50 years. The solute transport simulation shows that the arsenic from the shallow source reaches the deep irrigation well after 20 years and most of the deep groundwater is contaminated after 30 years. The distribution pattern of arsenic contaminated groundwater is almost stabilized after 40 years. From the results, it is understood that the impact of groundwater pumpage by the deep irrigation well is quite large because the large amount of the pumpage totally disturbs the existing groundwater flow conditions. It is noted that although the pumpage of the deep irrigation well is the same as the existing irrigation wells (= 1,000 m^3/day per well), the piezometric depression created by the deep irrigation well is lower because the hydraulic conductivity of the deep fine sand layer is smaller than that of the coarse sand layer. The simulation results indicate that the unregulated development of deep groundwater could totally destroy the existing groundwater flow system and the deep groundwater could be contaminated by the intrusion of shallow contaminated groundwater. On the other hand, the deep groundwater is not contaminated when the deep groundwater pumpage is limited as shown in the Case-03 simulation. Therefore, it is very important to estimate a permissible amount of deep groundwater pumpage considering the hydrogeologic conditions and water balance conditions including existing groundwater pumpage.

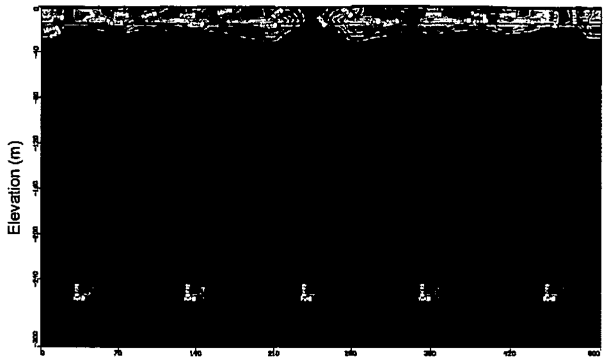


(a) Vertical 2-D Local Model Conditions

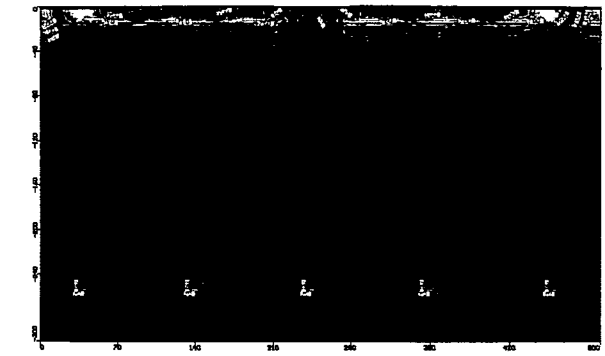


(b) Simulated Piezometric Heads by Steady-State Simulation

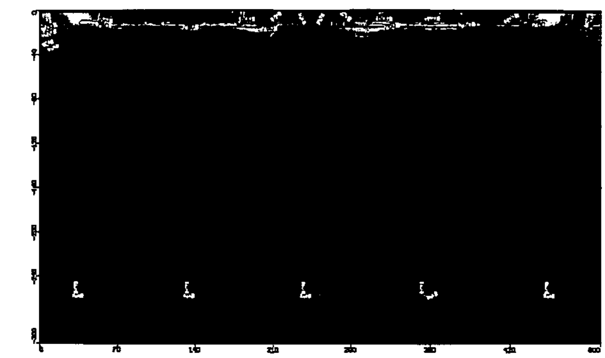
Figure 8.2.1	Model Conditions and Simulated Piezometric Heads (Case-01, No Well)
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



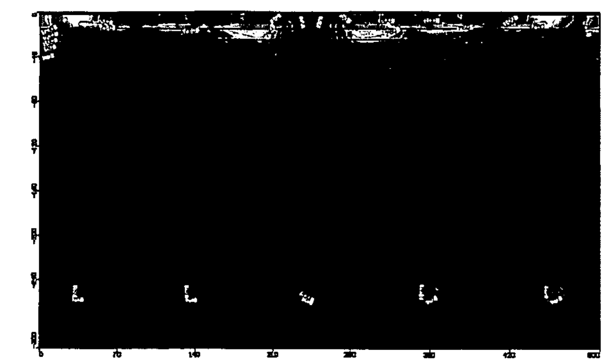
(a) Simulated Concentrations after 1 Year



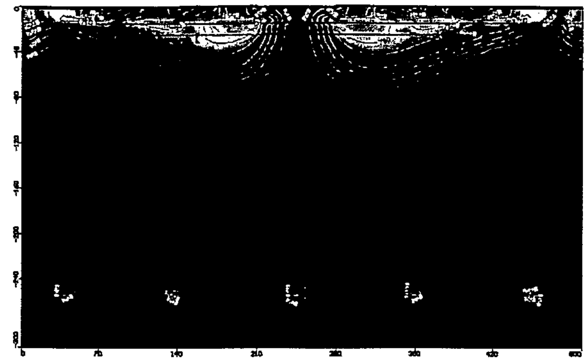
(b) Simulated Concentrations after 2 Years



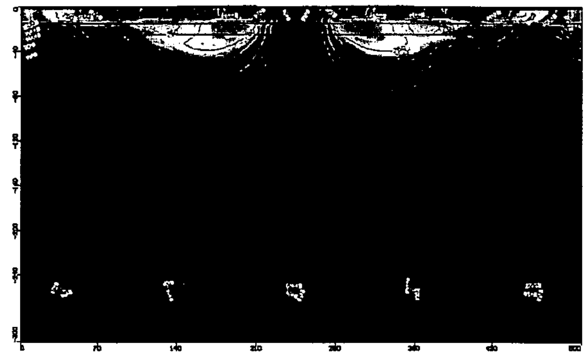
(c) Simulated Concentrations after 5 Years



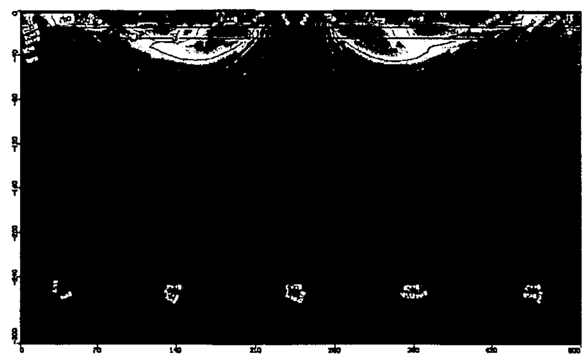
(d) Simulated Concentrations after 10 Years



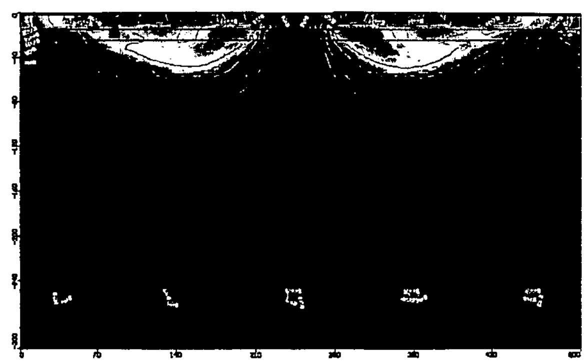
(e) Simulated Concentrations after 20 Years



(f) Simulated Concentrations after 30 Years



(g) Simulated Concentrations after 40 Years



(h) Simulated Concentrations after 50 Years

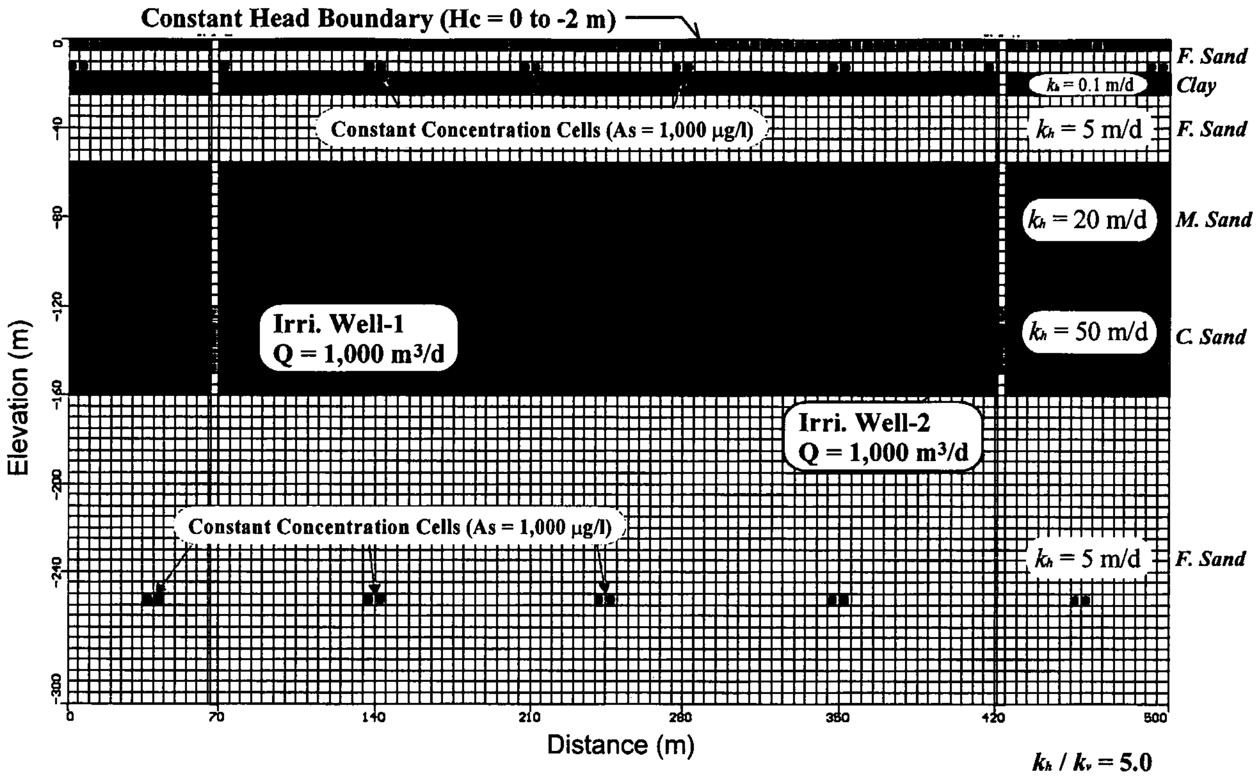
Simulated As Concentration in Groundwater

(Unit: μg/l)

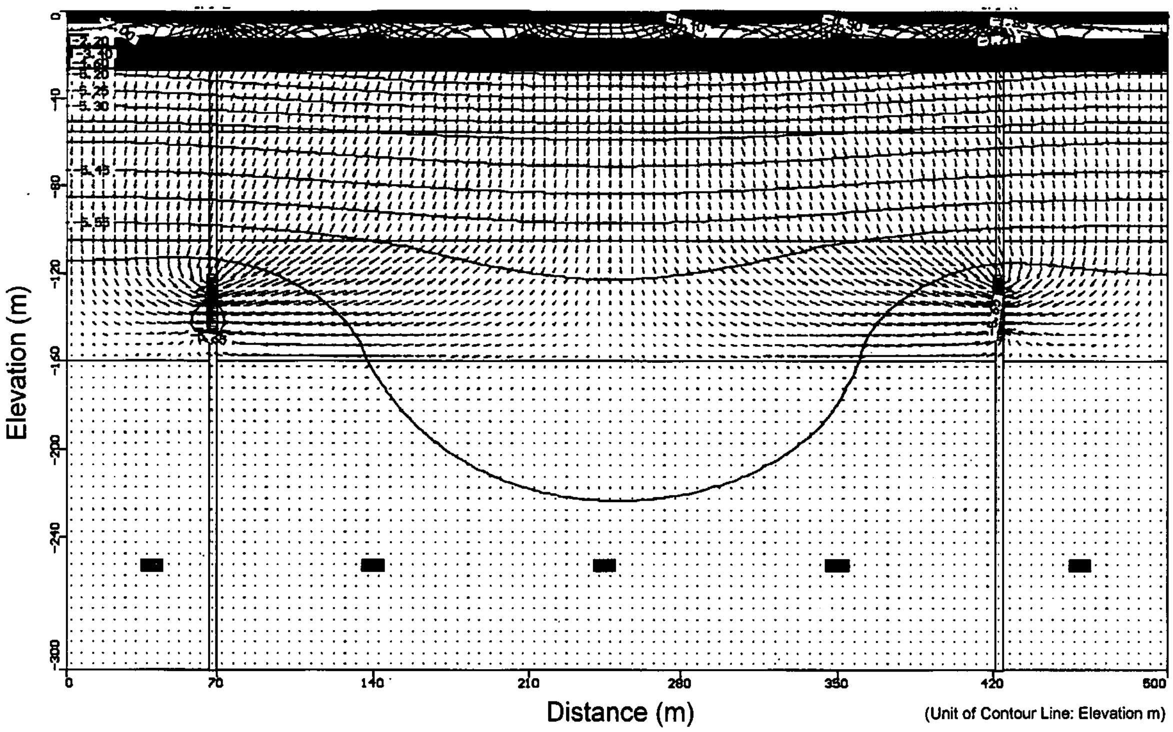
Figure 8.2.2	Simulated Arsenic Concentrations (Case-01, No Well)

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

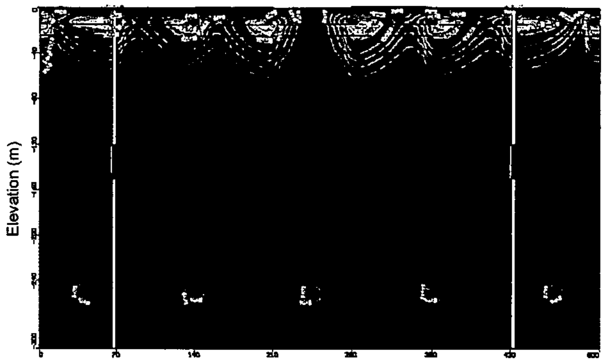


(a) Vertical 2-D Local Model Conditions

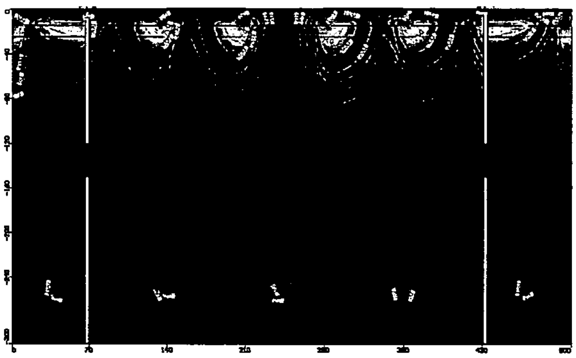


(b) Simulated Piezometric Heads by Steady-State Simulation

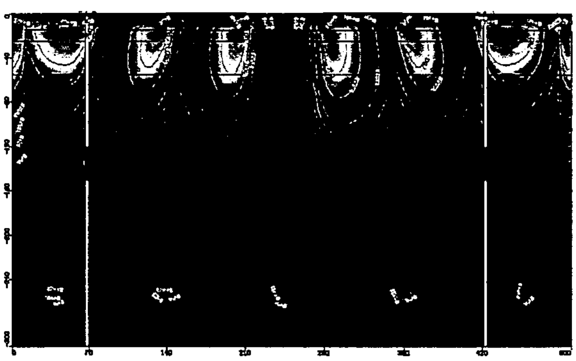
Figure 8.2.3	Model Conditions and Simulated Piezometric Heads (Case-02, Irrigation Wells)
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



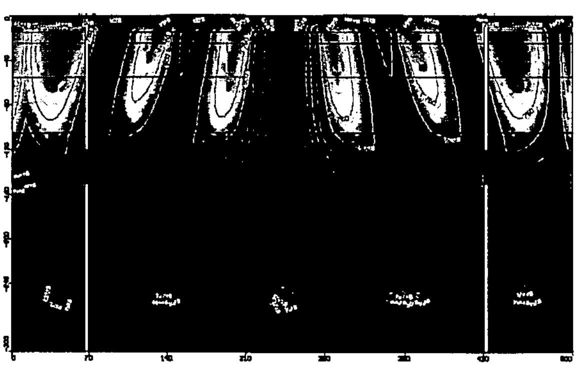
(a) Simulated Concentrations after 1 Year



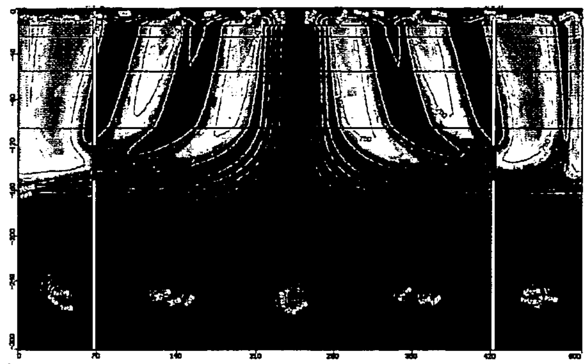
(b) Simulated Concentrations after 2 Years



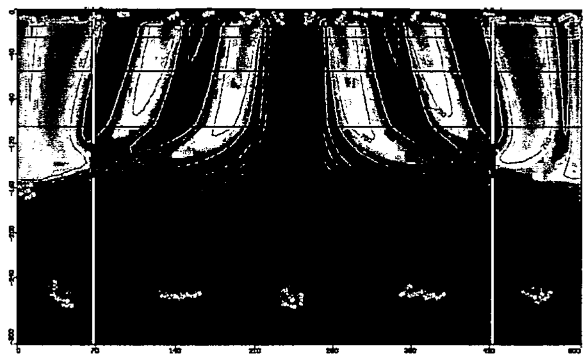
(c) Simulated Concentrations after 5 Years



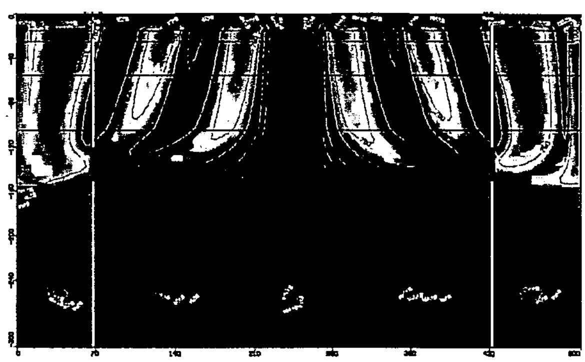
(d) Simulated Concentrations after 10 Years



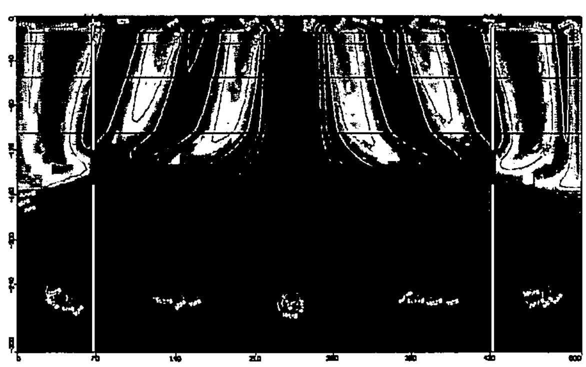
(e) Simulated Concentrations after 20 Years



(f) Simulated Concentrations after 30 Years

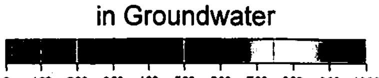


(g) Simulated Concentrations after 40 Years



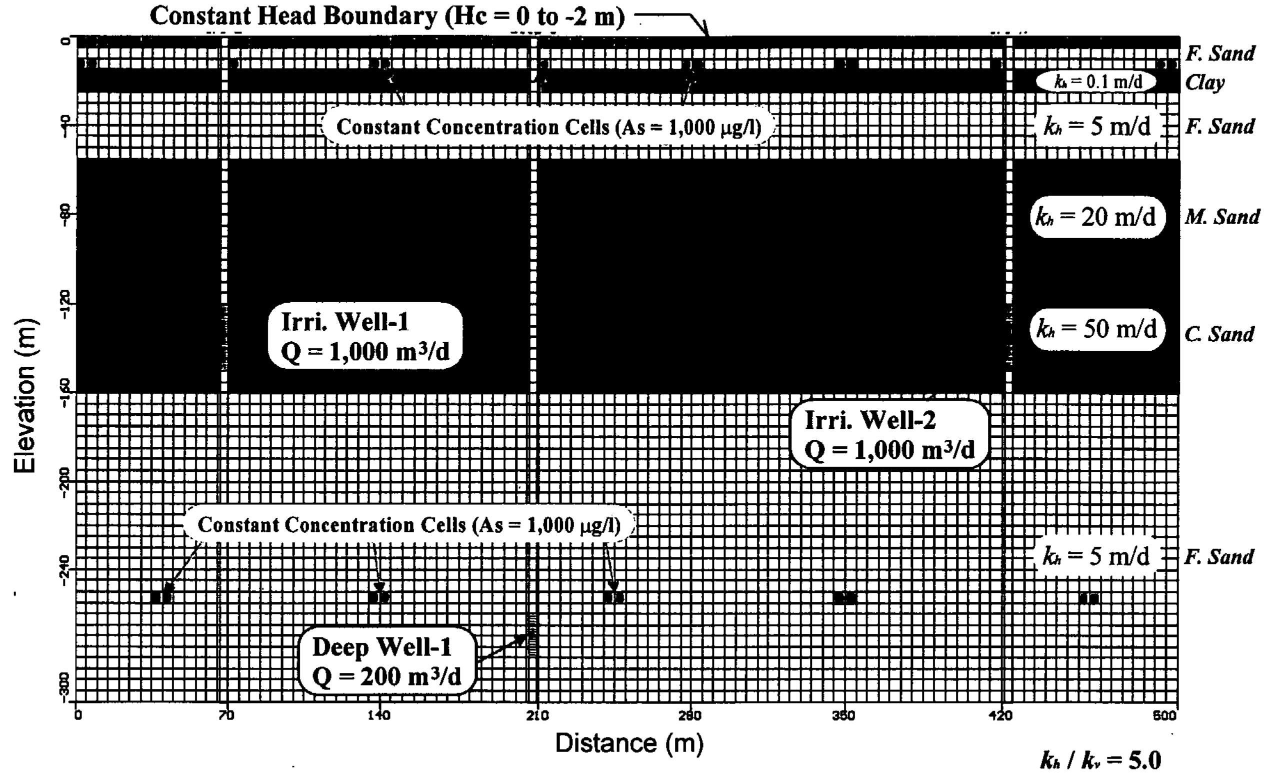
(h) Simulated Concentrations after 50 Years

Simulated As Concentration in Groundwater

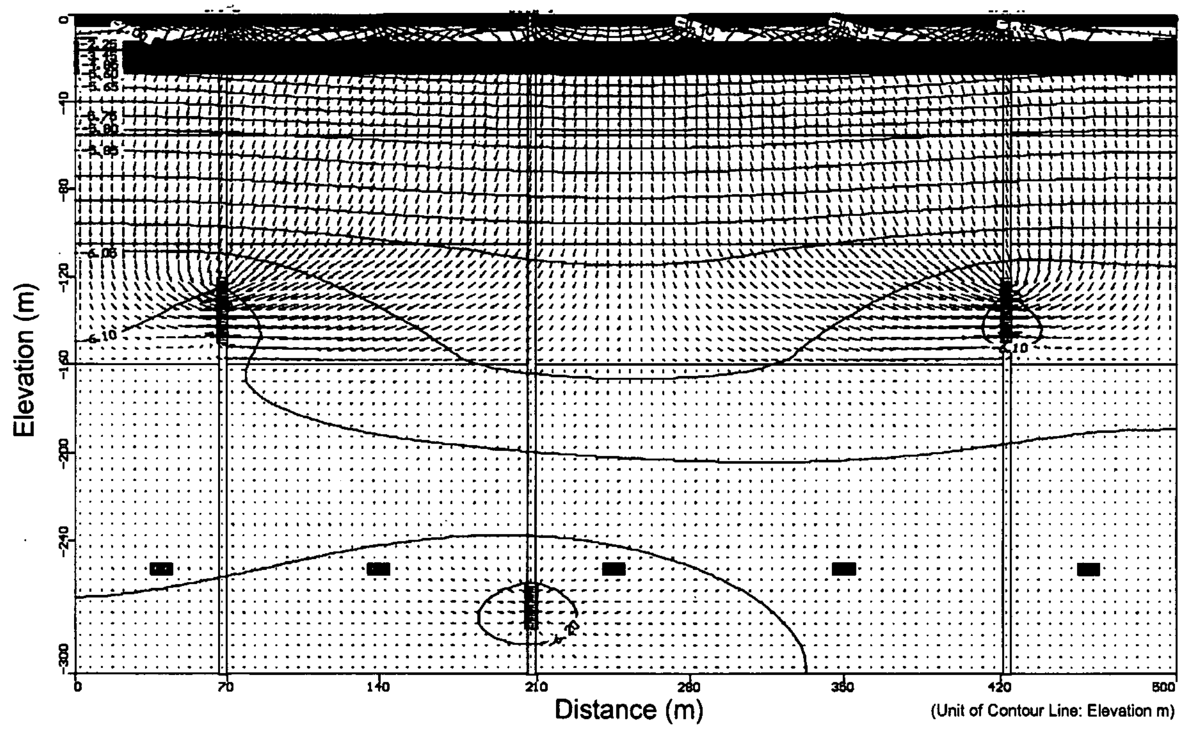


(Unit: μg/l)

Figure 8.2.4	Simulated Arsenic Concentrations (Case-02, Irrigation Wells)
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

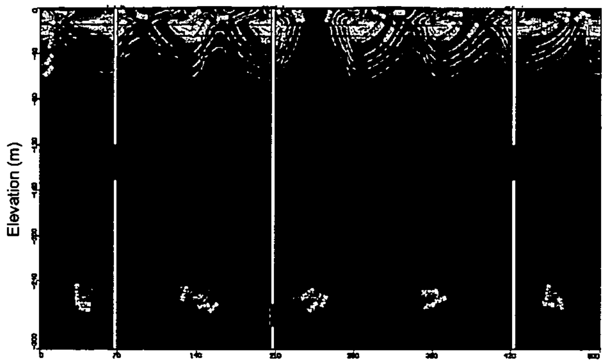


(a) Vertical 2-D Local Model Conditions

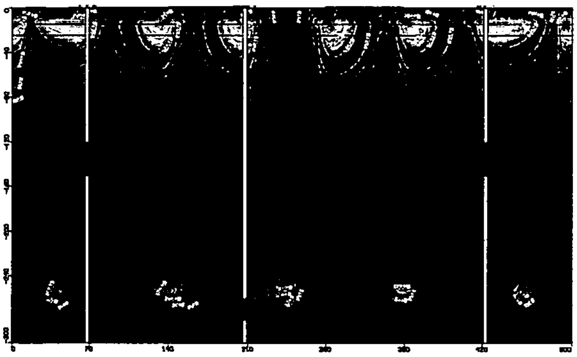


(b) Simulated Piezometric Heads by Steady-State Simulation

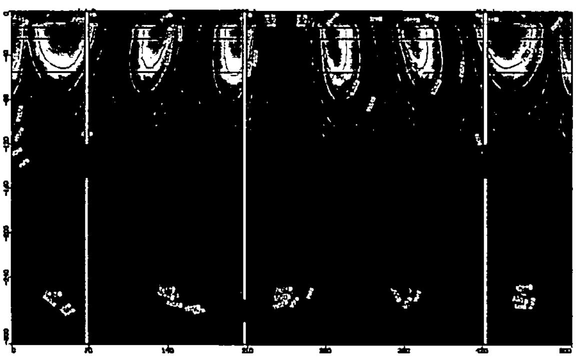
Figure 8.2.5	**Model Conditions and Simulated Piezometric Heads (Case-03, Case-02 with A Deep Domestic Well)**
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



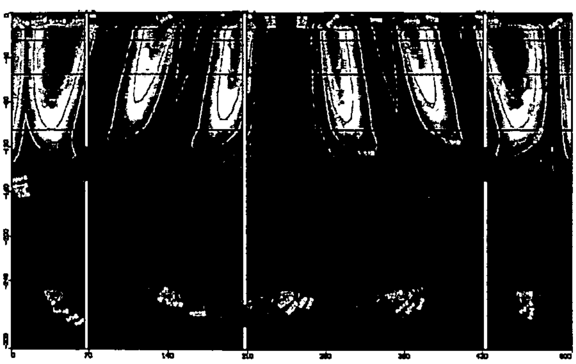
(a) Simulated Concentrations after 1 Year



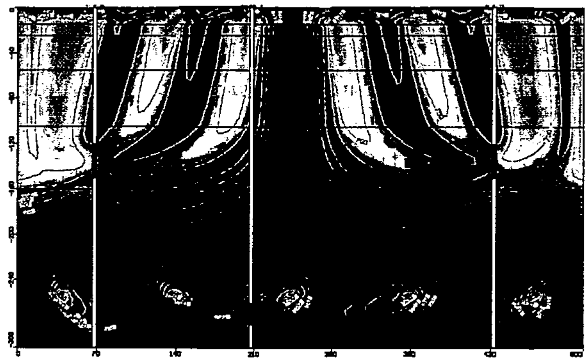
(b) Simulated Concentrations after 2 Years



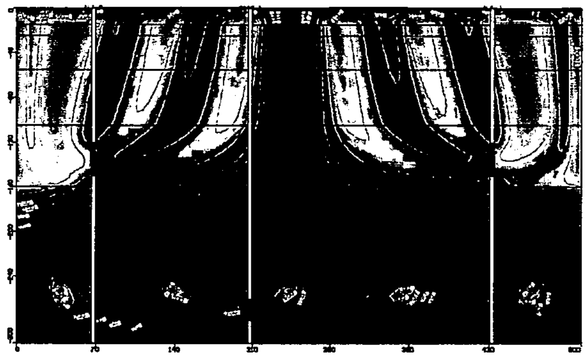
(c) Simulated Concentrations after 5 Years



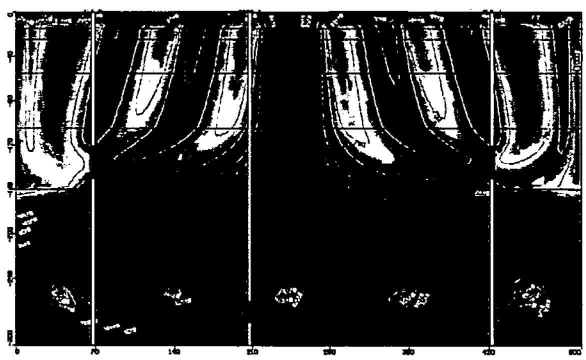
(d) Simulated Concentrations after 10 Years



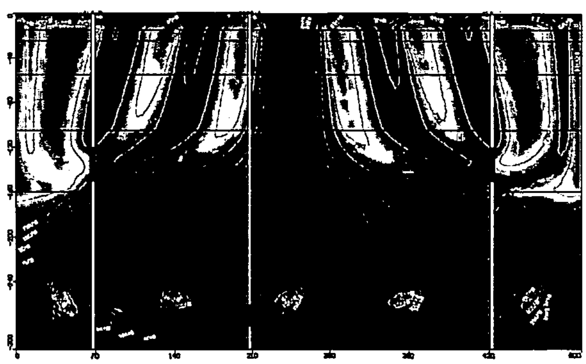
(e) Simulated Concentrations after 20 Years



(f) Simulated Concentrations after 30 Years

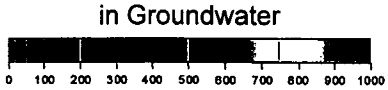


(g) Simulated Concentrations after 40 Years



(h) Simulated Concentrations after 50 Years

Simulated As Concentration in Groundwater

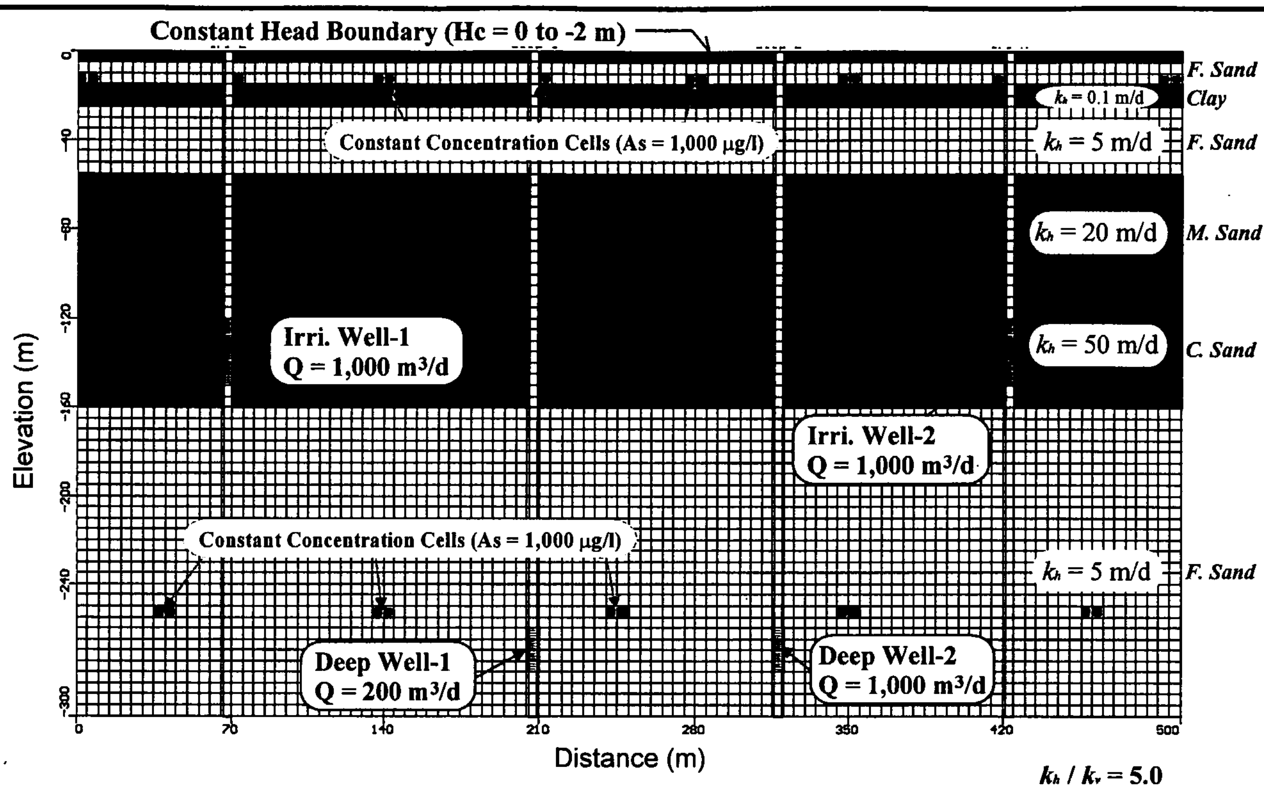


(Unit: μg/l)

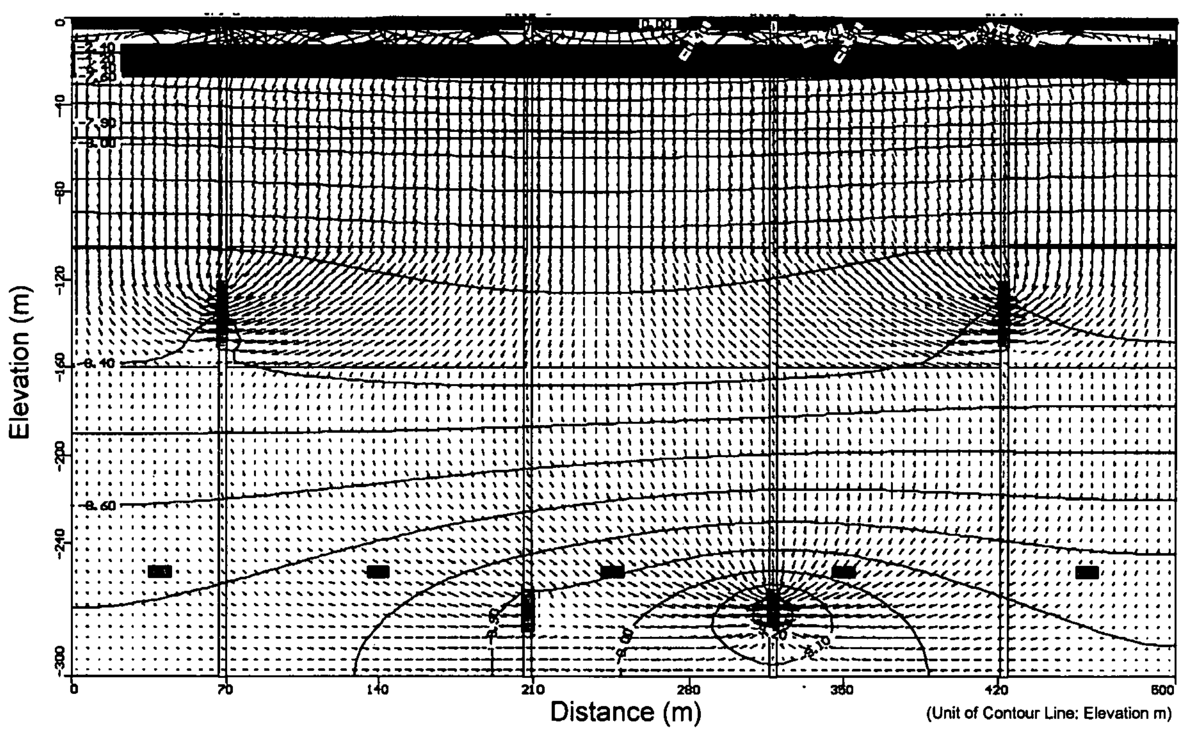
Figure 8.2.6	**Simulated Arsenic Concentrations (Case-03, Case-02 with A Deep Domestic Well)**

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



(a) Vertical 2-D Local Model Conditions



(b) Simulated Piezometric Heads by Steady-State Simulation

Figure 8.2.7	Model Conditions and Simulated Piezometric Heads (Case-04, Case-03 with A Deep Irrigation Well)
	THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH
	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

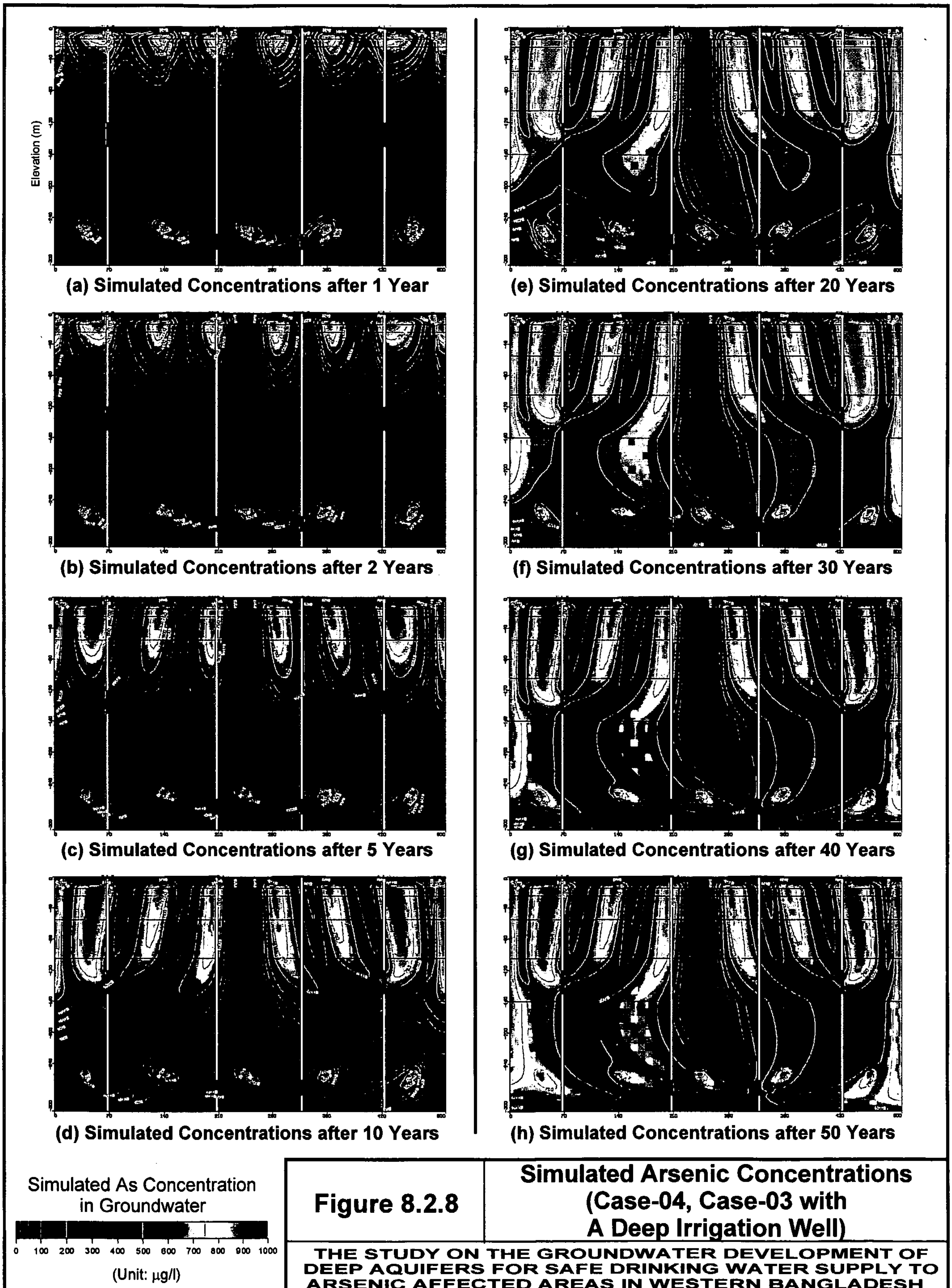


Figure 8.2.8	Simulated Arsenic Concentrations (Case-04, Case-03 with A Deep Irrigation Well)

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

8.2.4 3-D Regional Model

1) Purpose

The 3-D Regional Model aims at examining the regional groundwater flow conditions in the study area considering those hydrogeologic characteristics and existing groundwater pumpage.
After calibrating the model by comparing the simulated groundwater flow with the actual groundwater flow, the model can be used to predict future groundwater conditions such as future groundwater levels and future groundwater flow directions. The predictions under several scenarios can provide information on the optimal and sustainable use of groundwater resources.

2) Hydrogeological Modeling

As mentioned before, the subsurface geology in the study area can be divided into 5 geologic formations up to a depth of 300 m. In the 3-D Regional Model, 6 model layers are prepared to reflect the actual hydrogeological conditions as shown in Table 8.2.2.

Table 8.2.2 Hydrogeological Modeling for 3-D Regional Model

Geologic Formation	Model Layer	Aquifer Type	Model Facies
A Formation	Layer-1	Unconfined	Clay
	Layer-2	Unconfined/Confined	Clay, Sand
B Formation	Layer-3	Confined	Clay, Sand, Gravel
C Formation	Layer-4	Confined	Clay, Sand, Gravel
D Formation	Layer-5	Confined	Clay, Sand, Gravel
E Formation	Layer-6	Confined	Clay, Sand, Gravel

Figure 8.2.9 shows the model grid used for the 3-D Regional Model. The model covers the whole study area, having 97 columns x 118 rows x 6 layers (= 68,676 cells). The modeled domain is 118km in N-S direction and 97 km in W-E direction. The size of each cell is 1,000 m x 1,000 m in N-S and W-E directions. The total number of the cells in a layer is 97 columns x 118 rows = 11,446. Among the cells, the study area occupies 6,018 cells. For the vertical direction, the model bottom was set at -500 m in elevation to consider the deep regional groundwater flow. Although the actual bottom elevation of E formation was not confirmed by the drilling within a depth of 300 m, the model assumed that E formation has a bottom elevation of -500 m.
The thickness and facies of each layer was computed based on the drilling results of the study as well as the existing well records. The top and bottom elevation maps and the isopach maps of the geologic layers and facies isopach maps (clay thickness, sand thickness, and gravel thickness) were prepared. Based on the hydrogeological investigations done in the study, the isopach maps by facies of Layer-1 to Layer-6 are prepared. The hydraulic conductivity (k) of

each layer was set based on the results of the pumping test. For the MODFLOW program, the transmissivity (*T*) of each model layer is computed by [(thickness of sand layers) x k_s + (thickness of gravel layers) x k_g]. On the other hand, the actual vertical hydraulic conductivity was not measured in the study; the value was estimated based on the facies of clayey layers. The values of the storage coefficient were computed based on the thickness of each layer and the estimated specific storage by aquifer material.

3) Model Calibration

It is very important to calibrate the model by imputing historical groundwater pumpage and recharge data. In the study, the model calibration was performed on a monthly basis for a period from January 1983 to December 2001 (19 years = 228 steps). The groundwater pumpage for irrigation and domestic use was estimated using the GIS database system, land use conditions by satellite imagery interpretation, and existing statistical data. The groundwater recharge is estimated on a monthly basis based on the climate data in the study area using the SCS method developed by the U.S. Soil Conservation Service (1972). The recharge is applied to the top layer in the model.

Table 8.2.3 shows the data type of groundwater pumpage data available in the study area. It is noted that, although the definition of “shallow” and “deep” has been clearly made in the study, the “shallow” and “deep” in the groundwater pumpage data are after the original data source. Therefore, it is set that the AG-STW pumpage extracts groundwater from Layer-2 and Layer-3, whereas the DM-STW pumps groundwater only from Layer-2. In the model, it is assumed that no groundwater is pumped from Layer-1 because the upper A formation only consists of clay layers.

Table 8.2.3 Type of groundwater pumpage data

Data Name	Data Type	Aquifer Pumped	Model Layer Pumped
AG-STW	Agricultural Shallow Tube Wells	Lower A formation and B formation	Layer-2 Layre-3
AG-DTW	Agricultural Deep Tube Wells	B formation	Layer-3
DM-STW	Domestic Shallow Tube Wells	Lower A formation	Layer-2
DM-DTW	Domestic Deep Tube Wells (Pourashava Production Wells)	C formation	Layer-4

Figure 8.2.10 shows the historical groundwater pumpage by data type and by model layer. Figure 8.2.11 shows the historical groundwater pumpage by user type and model layer. The groundwater pumpage has increased since 1980’s especially for the irrigation wells in the study

area. The pumpage of the year 2000 is estimated to be 3,016.0 MCM/year, which is 4.5 times the pumpage in the year 1983 (= 670.4 MCM/year). It should be noted that the groundwater pumpage for agricultural use occupied 98.9% of the total in 2000, however, the amount of domestic pumpage occupied only 1.1%.

For estimating groundwater recharge in the study area, the climate data measured at Jessore meteorological station were used. The daily rainfall data from 1990 to 1999 and the daily pan-evaporation data from 1988 to 1995 were used for the water balance computation. Since there are some missing pan evaporation data, the monthly average values of pan-evaporation are obtained. The water balance computation was performed on daily basis from 1990 to 1999. Table 8.2.4 shows the estimated yearly water balance in the study area. The annual groundwater recharge ranges from 258.4 to 593.1 mm, which occupies 17.3 to 30.4% of the annual rainfall.

Table 8.2.4 Estimated annual water balance in the study area

Year	Rainfall (mm)	Pan-Evaporation (mm)	Inter-ception Loss (mm)	Surface Runoff (mm)	Actual Soil Evapo-ration (mm)	Actual Trans-piration (mm)	Soil Moisture (mm)	Groundwater Recharge (mm)
1990	1686	1788.96	27.5	112.65	497.87	527.40	7.57	513.02
1991	2052	1788.96	20.5	445.83	454.44	506.93	38.78	593.08
1992	1333	1790.94	17.0	129.42	388.91	479.05	0.00	357.41
1993	1802	1788.96	25.5	252.79	492.77	536.18	0.00	494.76
1994	1260	1788.96	21.0	76.06	409.12	438.80	0.00	315.01
1995	1397	1788.96	22.5	77.44	404.83	526.17	7.36	358.69
1996	1775	1790.94	20.0	275.62	424.92	525.13	4.72	531.97
1997	1553	1788.96	23.5	119.23	474.75	512.65	0.41	427.17
1998	1490	1788.96	26.0	135.16	510.38	550.57	9.86	258.44
1999	1467	1788.96	15.5	140.53	413.38	472.88	2.49	432.08

For estimating the monthly groundwater recharge for the periods from 1983 to 1989 and from 2000 to 2001, the relationship between the monthly groundwater recharge and the monthly rainfall from 1990 to 1999 was examined. It is understood that no groundwater recharge occurs when the monthly rainfall is less than 75 mm. When the monthly rainfall is more than 75 mm, a linear correlation is found between the monthly recharge and the monthly rainfall with a correlation coefficient of 0.84. Therefore, the monthly groundwater recharge in the periods said above, where daily rainfall data are not available, is computed from the monthly rainfall data using the regression equation obtained from the graph analysis.

The calibration of 3-D model is generally not easy even for modifying one parameter. This is because when the parameter value of a cell is modified, it will affect piezometric heads of not only horizontally surrounding cells but also vertically surrounding cells. It is also needed to consider the pumpage distribution of each aquifer unit near the cell as well as the possible range of variation of the parameter. As a result of the model calibration, some unreliable parameter values that could not be obtained from the study were modified within the possible range of variation. The modified parameters were vertical hydraulic conductivity and specific storage. The reasonable boundary conditions such as the constant head boundary at some parts of the model perimeter to express the continuity of aquifer systems and the general head boundary at the top layer to express the interaction of surface water and groundwater were assigned.

4) Results of Historical Simulation

After the model calibration, the historical groundwater simulation was carried out. The simulation period is from January 1983 to December 2001. The simulation was carried out as a transient simulation, and the simulation time step was set at 28 to 31 days depending on the number of days in the month.

Figure 8.2.12 shows the simulated piezometric heads in Jhenaidah Pourashava with the actual groundwater level records (BWDB Je-49). The simulated groundwater level of Layer-1 shows the groundwater levels of the unconfined aquifer; the changes in groundwater level are highly affected by the occurrence of groundwater recharge. Compared with the simulated groundwater level in Layer-1, the simulated piezometric heads in Layer-2 to Layer-6 decline every year. The comparison of the simulated heads with the actual groundwater levels measured at BWDB Je-49 well shows good agreement for a period from 1984 to 1994. Figure 8.2.13 shows the simulated groundwater levels in Jessore Pourashava with the actual groundwater level records (BWDB A-9). Since the absolute elevations of simulated piezometric heads are slightly different from the actual head due to the location difference, the range of fluctuation and decreasing trend of groundwater levels are reasonably simulated. It is, therefore, evaluated that the 3-D Regional Model can simulate the actual groundwater levels in Jhenaidah and Jessore Pourashavas.

Figure 8.2.14 shows the distribution of simulated piezometric heads in Layer-3 in year 2001. In the dry seasons from January to April, the piezometric heads declined in the study area. The areas having piezometric levels below 0 m above sea level (masl) in January are distributed in the southern to eastern part of Jessore district and western Jessore district. In April, the areas below 0 masl in piezometric head extended up to northern Jhenaidah district. However, the piezometric heads recovered in the rainy season. In July the piezometric heads in the entire study area significantly recovered. There is no area having piezometric heads below 0 masl. In October, the piezometric heads are slightly lower than that in July, but the heads are still higher than 0 masl in the southern part of Jessore district. Figure 8.2.15 shows the comparison of the simulated piezometric heads in Layer-2 with the actual groundwater levels measured at the 300 existing wells in January 2001. The general distribution pattern of simulated piezometric heads shows good agreement with the actual groundwater levels. The actual groundwater levels below 0 masl in the southeastern and southwestern parts of Jessore district are reasonably simulated. The slightly elevated groundwater levels from central Jhenaidah district to western Jessore district are also simulated by the historical simulation. Therefore, it is evaluated that the calibrated 3-D Regional Model can be used for future prediction.

5) Future Pumping Scenarios and Cases

Predictions of future groundwater flow and piezometric heads were carried out using the calibrated 3-D Regional Model. The prediction period is from January 2002 until December 2020 (= 19 years). The prediction was carried out by transient simulation having 228 stress periods. It is assumed that the amount of monthly groundwater recharge in the prediction period is the same as the average value of the estimated groundwater recharge from 1990 to 1999.

For the future prediction, three (3) future pumping scenarios were prepared as shown in Figure 8.2.16.Scenario-1 assumes that the pumpage in 2001 continues until 2020. Scenario-2 assumes that the future pumpage increases by the past increasing trend (= linear projection). Scenario-3 was prepared considering the socio-economic conditions and slow down of the increasing trend of agricultural groundwater use.

For each pumping scenario, several pumping cases were set as shown in Table 8.2.5. Case-1 assumes that that the future groundwater pumpage occurs at the same aquifers and the same locations. Case-2 assumes that the future groundwater demand for domestic use by shallow tube wells (DM-STW) will shift to Layer-5 (= D formation, Deep Aquifer) for a period from 2002 to 2011. In this case, the horizontal location of future pumpage is assumed to be the same as the present location. Case-3 assumes that the future demand of DM-STW in Urgent Areas and Semi-Urgent Areas of arsenic mitigation will shift to Layer-5 considering the Regional Rural Water Supply System proposed in the master plan of the study. In this case, the future demand of DM-STW in the Observation Area will be pumped by the existing shallow tube wells, and the demand in the Urgent and Semi-Urgent Areas in the southern part of the study area will be pumped by future deep hand tube wells or future production well(s) in each Mouza. The demand in the Urgent and Semi-Urgent Areas in the central and northern part of the study area will be pumped by future production wells that will be constructed at the central part of each Upazila. Case-4 assumes that the agricultural pumpage will shift to Layer-5 from 2002 to 2020 at a rate of 1% every year. In this case, the horizontal location of future agricultural pumpage is assumed to be the same as the present location.

Table 8.2.5 Future groundwater pumpage scenarios and cases

Scenario	Scenario Description	Case	Case Description	Name of Pumpage Data
1	Continue 2001 Pumpage until 2020	1	Pump from the same aquifers	FQ-01
		2	Shift DM-STW Pumpage to Deep Aquifer (Layer-5) from 2002 to 2011	FQ-02
2	Increase Pumpage by Past Trend (Linear Projection)	1	Pump from the same aquifers	FQ-03
		2	Shift DM-STW Pumpage to Deep Aquifer (Layer-5) from 2002 to 2011	FQ-05
		3	Shift DM-STW Pumpage to Deep Aquifer (Layer-5) in Urgent And Semi-Urgent Areas Considering Regional Rural Water Supply System	FQ-07
		4	Shift Agricultural Pumpage to Deep Aquifer (Layer-5)	FQ-09
3	Increase Pumpage by Socio-Economical Projection	1	Pump from the same aquifers	FQ-04
		2	Shift DM-STW Pumpage to Deep Aquifer (Layer-5) from 2002 to 2011	FQ-06
		3	Shift DM-STW Pumpage to Deep Aquifer (Layer-5) in Urgent and Semi-Urgent Areas Considering Regional Rural Water Supply System	FQ-08

6) Results of Future Simulation

a. Scenario-1 Simulation

The groundwater pumpage by Scenario-1 is shown in Figure 8.2.17. It is assumed that the annual total groundwater pumpage is 3,152.0 MCM/year from 2002 to 2020. The pumpage in intercalary years is set at 3,166.6 MCM/year.

(i) Case-1, Scenario-1 Simulation

Figure 8.2.18 shows the groundwater pumpage for the Case-1, Scenario-1 simulation. The groundwater pumpage by each user type maintains the 2001 pumpage until 2020. The annual pumpage by AG-STW and AG-DTW is 2,815.2 and 303.4 MCM/year, respectively. The annual pumpage by DM-STW and DM-DTW is 25.22 and 8.15 MCM/year. The amount of pumpage is slightly higher in intercalary years.

The result of the Case-1, Scenario-1 simulation shows that the future piezometric heads until 2020 will be almost the same as the present piezometric heads in 2001. The contour lines of simulated piezometric heads become smoother with depth. Figure 8.2.19 shows distributions of the simulated piezometric heads in Layer-3 in 2020. The depressions showing below 0 masl are formed in the southern part of the study area in January and April 2020. The lowest simulated piezometric head in April 2020 is –6.251 masl in Layer-3, –6.246 masl in Layer-2 and Layer-4, and –5.376 masl in Layer-5.

(ii) Case-2, Scenario-1 Simulation

Figure 8.2.20 shows the groundwater pumpage for the Case-2, Scenario-1 simulation. The amount of pumpage for AG-STW, AG-DTW, and DM-DTW is the same as Case-1, Scenario-1. For DM-STW, it is assumed that the pumpage will shift from Layer-2 to Layer-5 for the period from 2002 to 2010. This case assumes that all the existing domestic pumpage from the shallow tube wells will shift to the deep groundwater in the whole study area by 2011 to evaluate the impact of using deep groundwater for domestic purpose.

The result of the Case-2, Scenario-1 simulation shows that the piezometric heads of Layer-5 in April 2020 will be slightly lowered in the southern part of the study area as shown in Figure 8.2.21. Figure 8.2.21. The maximum head difference in Layer-5 is simulated as 17.6 cm. On the other hand, the impact of shifting DM-STW pumpage from Layer-2 to Layer-5 will be almost negligible in Layer-2 to Layer-4.

Figure 8.2.22 shows the difference of simulated piezometric heads between Case-1 and Case-2, Scenario-1 in Jessore district. At Rajnagar Bankabarsi village in Keshabpur upaliza, Jessore district, the piezometric heads in Layer-5 and Layer-6 will decline about 8.2 cm compared to the result of the Case-1 simulation. However, the simulated heads from Layer-1 to Layer-4 show no impact because of the occurrence the clayey layers in Layer-4 (=C formation). In Jessore Pourashava, the slight impacts will be found in Layer-3 to Layer-6. However, the maximum head difference will be only about 5 cm in Layer-5. The simulated heads in Layer-1 and Layer-2 will be slightly higher than the Case-1 result. It is noted that the irregular peaks of the Layer-1 and Layer-2 graphs indicate convergence error of the simulation generated by the drastic change in groundwater pumpage. In Jhenaidah Pourashava, a small impact of about a 1 cm decline in piezometric head is predicted in Layer-4 to Layer-6. The impact at Krishna Chandrapur village in Moheshpur Upazila will be very small. There will be no impact in Chuadanga Pourashava and Bara Dudpatila village in Chuadanga district even though the DM-STW pumpage in the district will shift to the deep aquifer.

It is, therefore, concluded from the simulation results that the impact of shifting DM-STW pumpage from Layer-2 to Layer-5 will be limited in the southern part of the study area where the deep aquifer is separated from the shallow aquifer by the thick clay layer. However, the difference of simulated piezometric head is only 17.6 cm at the maximum because the amount of shifting pumpage is very small compared to the remaining agricultural pumpage.

b. Scenario-2 Simulation

The groundwater pumpage by Scenario-2 is shown in Figure 8.2.23. Scenario-2 is the worst scenario prepared for the future prediction. It is assumed that the total annual pumpage will increase to 4,434.2 MCM/year in 2010 and 5,884.9 MCM/year in 2020.

(i) Case-1, Scenario-2 Simulation

Figure 8.2.24 shows the groundwater pumpage for the Case-1, Scenario-2 simulation. The groundwater pumpage for AG-STW will increase from 2,946.9 MCM/year in 2002 to 5,343.5 MCM/year in 2020. The AG-DTW pumpage will increase from 312.6 MCM/year in 2002 to 480.9 MCM/year in 2020. The DM-STW pumpage will increase from 26.63 MCM/year in 2002 to 44.31 MCM/year in 2020. The DM-DTW pumpage will increase from 9.12 MCM/year in 2002 to 16.19 MCM/year in 2020.

The result of the Case-1, Scenario-2 simulation shows that the future piezometric heads will straightly decline from 2002 to 2020. Figure 8.2.25 shows the simulated piezometric heads at Jessore Pourashava. The simulated piezometric heads will decline particularly in dry seasons. The heads of Layer-3 will be the lowest, declining from –0.91 masl in April 2002 to –5.85 masl in April 2020. The simulated heads in rainy seasons will also gradually decline year by year. The simulated head in Layer-2 will be 6.51 masl in September 2002 but it will reach 5.40 masl in September 2020. It should be noted that the simulated piezometric heads in Layer-1, which express the groundwater levels of the shallow unconfined aquifer, will also decline year by year. The groundwater level will decrease 0.83 m in the dry season and 1.07 m in the rainy season for the period from 2002 to 2020. Figure 8.2.26 shows the simulated piezometric heads of Layer-1 and Layer-2 at the model rural areas in the study area. The simulated heads straightly decline from 2002 to 2020 at all the locations. A large decline in piezometric heads in Layer-2 will be observed at Rajnagar Bankabarsi village in southern Jessore district from –5.09 masl in April 2002 to –10.98 masl in April 2020.

Figure 8.2.27 shows distributions of the simulated piezometric heads in Layer-3 in 2020. The depressions showing below 0 masl are formed in the southern to eastern part of Jessore district, western Jessore district, and the central and northern parts of Jhenaidah district in January 2020. The depressions become larger in April 2020. The deepest piezometric heads in Layer-3 will be –13.10 masl in April 2020. Although there is no pumpage from Layer-5 in this simulation, the deepest piezometric head in Layer-5 will be –11.83 masl in the southeastern part of Jessore district. In the rainy season, the simulated heads will be almost recovered in the study area, however, the heads below 0 masl will remain in the southeastern part of Jessore district.

Figure 8.2.28 shows the difference of piezometric heads between Case-1, Scenario-2 and Case-1, Scenario-1 in April 2020. The negative values indicate that the heads simulated by Case-1, Scenario-2 are lower than that by Case-1, Scenario-1. The head difference of more than 5 m is found in southern to eastern Jessore district, western Jessore district, and northern Jhenaidah district. On the other hand, the difference is less than 3 m in most parts of Chuadanga district. The maximum head difference is 7.20 m in Layer-2, 7.21 m in Layer-3, 7.21 m in Layer-4, and 6.68 m in Layer-5. In the rainy season, the head difference is smaller than that of dry season as shown in Figure 8.2.29. The maximum head difference of 2.75 m is found in Layer-2 in the western part of Jessore district. In Layer-3, the maximum head difference is 1.68 m. The areas having a head difference of more than 0.8 m are distributed in central to western Jessore district and northern Jhenaidah district.

(ii) Case-2, Scenario-2 Simulation

Figure 8.2.30 shows the groundwater pumpage for the Case-2, Scenario-2 simulation. The amount of pumpage for AG-STW, AG-DTW, and DM-DTW is the same as Case-1, Scenario-2. For DM-STW, it is assumed that the pumpage will shift from Layer-2 to Layer-5 for the period from 2002 to 2010. This case assumes that all the existing domestic pumpage from the shallow tube wells will shift to the deep groundwater in the whole study area by 2011 to evaluate the impact of using deep groundwater for domestic purposes under the worst scenario.

The result of the Case-2, Scenario-2 simulation shows that the piezometric heads of Layer-5 in April 2020 will be lowered in the southern part of the study area as shown in Figure 8.2.31. The maximum head difference in Layer-5 is simulated as 30.7 cm. On the other hand, the impact of shifting DM-STW pumpage will be only 1 to 2 cm in Layer-3 and Layer-4 in northern Jessore district to central Jhenaidah district.

Figure 8.2.32 shows the difference of simulated piezometric heads between Case-1 and Case-2, Scenario-2 in Jessore district. At Rajnagar Bankabarsi village, the piezometric heads in Layer-5 and Layer-6 will decline about 14.5 cm at the end of 2020 compared with the result of the Case-1 simulation. However, the simulated heads from Layer-1 to Layer-4 show no impact because of the occurrence of the clayey layer in Layer-4 (=C formation) even though the scenario is the worst one. It is noted that the head difference in Layer-5 and Layer-6 becomes greater even after all the DM-STW pumpage shifted to Layer-5 in 2011. This phenomenon is not observed in the Scenario-1 simulation. In Jessore Pourashava, the increase in head difference is found in Layer-3 to Layer-6. The maximum head difference will be 8.8 cm in Layer-5. The head difference in Layer-3 and Layer-4 is almost stabilized after 2010; however, the difference will continue to increase in Layer-5 and Layer-6. The simulated heads in Layer-1 and Layer-2 will be 2 to 7 cm higher than the Case-1 result. It is noted that the irregular peaks of the Layer-1 and Layer-2 graphs indicate a convergence error in the simulation generated by the drastic change in groundwater pumpage. In Jhenaidah Pourashava, a small impact of about a 2.3 cm decline in piezometric head at the end of 2020 is predicted in Layer-5. The impact on Layer-4 and Layer-6 is about 1.7 cm. The impact at Krishna Chandrapur village will be within 1 cm. In Chuadanga district, the impact cannot be predicted even though the DM-STW pumpage in the district will shift to the deep aquifer under the worst scenario.

It is concluded from the simulation results that the impact of shifting DM-STW pumpage from Layer-2 to Layer-5 will be limited even though the pumping scenario is the worst one. The clear difference of piezometric head with the maximum value of 30.7 cm is found in Layer-5, however, the impact will mainly occur in Jessore district. The impact on Layer-3 and Layer-4 is limited in the central part of the study area. The limited impact of shifting DM-STW pumpage can be explained by the relatively small amount of DM-STW pumpage and the occurrence of the clayey layer in Layer-4 (= C formation) in the southern part of the study area. On the other hand, no impact on the simulated heads is predicted in Chuadanga district because the Layer-5 is directly connected with the upper layers without clay. Therefore, it can be said that the shallow and deep aquifers in the areas behave as a single aquifer with a considerable aquifer thickness. The productivity in terms of transmissivity of the single aquifer is high because of the higher hydraulic conductivity and greater aquifer thickness.

(iii) Case-3, Scenario-2 Simulation

In Scenario-2, the Case-3 pumpage plan is prepared considering the proposed Regional Rural Water Supply System, assuming that the demand of DM-STW will be pumped from future production wells installed in Layer-5. At first, the Urgent Area, Semi-Urgent Area, and Observation Area are determined based on the GIS analysis. In Case-3, it is assumed that the demand of DM-STW in the Urgent Area and Semi-Urgent Area will be shifted to Layer-5. In the observation area, it is assumed that existing domestic shallow tube wells shall be used continuously in future. In the area where the thick clayey layers do not exist in Layer-4 (= C formation), the demand of DM-STW is summed up by each Upazila then distributed to future production wells for the Regional Rural Water Supply System. In the Urgent and Semi-Urgent areas in Jessore district except Chaugachha and Jessore Sadar upazilas, it is assumed that the demand of DM-STW shall be pumped by deep hand tube wells or smaller deep production wells for the Mouza water supply. The Case-3 pumping plan assumes that these deep wells in the southern part of the study area shall be constructed in every 1km x 1km grid.

Figure 8.2.33 shows the distribution of groundwater pumpage from Layer-5 in December 2020 by Case-3 of Scenario-2. The future deep production wells for the Regional Rural Water Supply System are located in the central areas of upazila areas as shown in the figure. In Jessore Sadar upazila, two (2) future production wells will extract groundwater at a rate of 897 m^3/day per well. In Chuadanga Sadar upazila, 5 deep production wells will pump groundwater from Layer-5 at a rate of 880 m^3/day per well. The pumpage of future production wells in Chaugachha and Moheshpur upazilas is set at 873 m^3/day per well and 765 m^3/day per well, respectively. It is noted that although the idea of the Regional Rural Water Supply System proposed in the master plan shall use the existing Pourashava production wells in available areas, Case-3 of Scenario-2 assumes that all the water for the system shall be pumped from the deep production wells to be installed at Layer-5.

Figure 8.2.34 shows the groundwater pumpage for the Case-3, Scenario-2 simulation. The amount of pumpage for AG-STW, AG-DTW, and DM-DTW is the same as Case-1 and Case-2, Scenario-2. For DM-STW, it is assumed that the pumpage will shift from Layer-2 to Layer-5 for the period from 2002 to 2010. It is understood from the graph that the pumpage from Layer-2 gradually decreases from 2002 to 2011, however, the pumpage from Layer-2 starts to increase from 2012 because the demand of DM-STW straightly increases. In 2020, it is estimated that 13.68 MCM/year out of 44.31 MCM/year will be pumped from Layer-5.

The result of the Case-3, Scenario-2 simulation is shown in Figure 8.2.35. Compared with the Case-1 simulation, the piezometric heads of Layer-5 in the southern part of Jessore district will be lowered 27.3 cm at the maximum in April 2020. On the other hand, the maximum decline in piezometric heads in Layer-5 by the pumpage of future production wells will be 1.04 m at central Chaugachha upazila in Jessore district. In Layer-2 to Layer-4, the impact of the future production wells can be seen in Chaugachha and Jessore Sadar upazilas in Jessore district, Moheshpur upazila in Jhenaidah district, and Chuadanga Sadar and Jibannagar upazilas in Chuadanga district. However, the maximum decline in piezometric heads in Layer-4 is only 7.8 cm in Chuadanga, 7.1 cm in Chaugachha, and 6.1 cm in Moheshpur. The decline of simulated heads becomes smaller in upper layers.

Figure 8.2.36 shows the simulated piezometric head difference between Case-1 and Case-3 of Scenario-2 at the Chaugachha future well site and Moheshpur future well site. At the Chaugachha site, the maximum head difference of 1.04 m is predicted in Layer-5 in December 2020. The second largest head difference will be found in Layer-6, showing 0.40 m in December 2020. At the Moheshpur site, the maximum head difference is recoded in Layer-5, showing 0.35 m in December 2020. The difference in Layer-6 is only 10 cm at that time.

Figure 8.2.37 shows the distribution of piezometric heads in Layer-5 in 2020. Compared with the result of the Case-1 simulation, it is understood that the regional groundwater flow system does not change significantly by the construction of the Regional Rural Water Supply System. The difference of the equal line of piezometric heads can be seen in only a limited area in Chaugachha upazila. It is, therefore, evaluated that the impact of the Regional Rural Water Supply System is very limited even in the worst scenario. The simulation results indicate that the system could be an important mitigation measure to supply safe drinking water in the arsenic affected rural areas.

(iv) Case-4, Scenario-2 Simulation

The Case-4 pumping plan is prepared to evaluate the impact of shifting agricultural pumpage from Layer-2 to Layer-5. The partial shifting of the agricultural pumpage at a rate of 1% every year is added to the Case-3, Scenario-2 simulation. It is assumed that the shift in the agricultural pumpage will occur in the whole study area. The pumping locations are assumed to be the same as the existing well locations.

Figure 8.2.38 shows the groundwater pumpage for the Case-4, Scenario-2 simulation. The amount of pumpage for DM-STW and DM-DTW is the same as Case-3 of Scenario-2. For AG-STW pumpage, 1,015.3 MCM/year out of 5,343.5 MCM/year will be extracted from Layer-5 in 2020. For AG-DTW, 91.35 MCM/year out of 480.9 MCM/year will be pumped from Layer-5 in the same year. It is noted that the pumpage from Layer-5 clearly appears in the monthly total pumpage graph in the Figure 8.2.38 e).

Figure 8.2.39 shows the distribution of simulated piezometric heads in Layer-5 in 2020. The simulation result shows that even the partial shifting of agricultural pumpage (19% in 2020) from Layer-2 to Layer-5 will have a great impact on the groundwater flow in Layer-5 particularly where the deep aquifer is overlain by the clayey layer of C formation. The lowest piezometric head in Layer-5 in January and April 2020 is –16.33 and –20.84 masl, respectively.

Figure 8.2.40 shows the simulated piezometric heads at Rajnagar Bankabarsi village in Jessore district. It is clearly seen that the piezometric heads in Layer-5 and Layer-6 sharply drop year by year. The simulated heads in Layer-5 and Layer-6 in April 2020 are –20.72 and –20.50 masl, respectively.

Figure 8.2.41 shows the difference of piezometric heads between Case-4 and Case-1 of Scenario-2 in April 2020. The shifting of agricultural pumpage will have an impact only on Layer-5. The maximum head difference is simulated as 11.7 m. The distribution pattern of the head difference is similar to the thickness of the clayey layer in C formation. On the other hand, the piezometric heads in Layer-2, Layer-3 and Layer-4 slightly rise about 0.6 m at the maximum compared with the simulated heads by Case-1. The simulation result indicates that the piezometric heads in the deep aquifer, which is overlain by the clayey layer in C formation, is sensitive against the deep aquifer development. The reason can be explained by the fact that the replenishment of groundwater to the deep aquifer from shallow zones is restricted by the occurrence of the clayey layer.

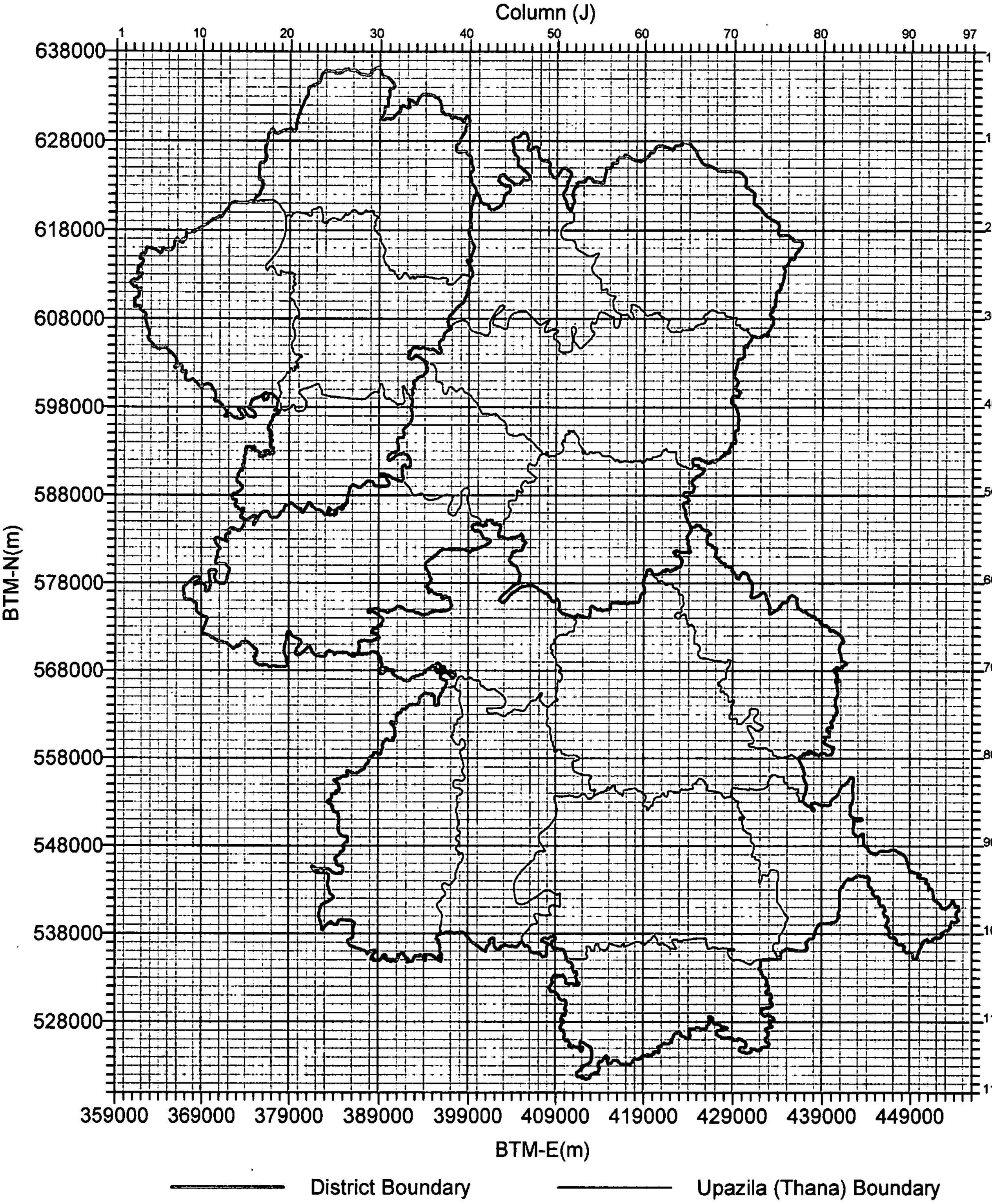


Figure 8.2.9	Model Grid for 3-D Regional Model

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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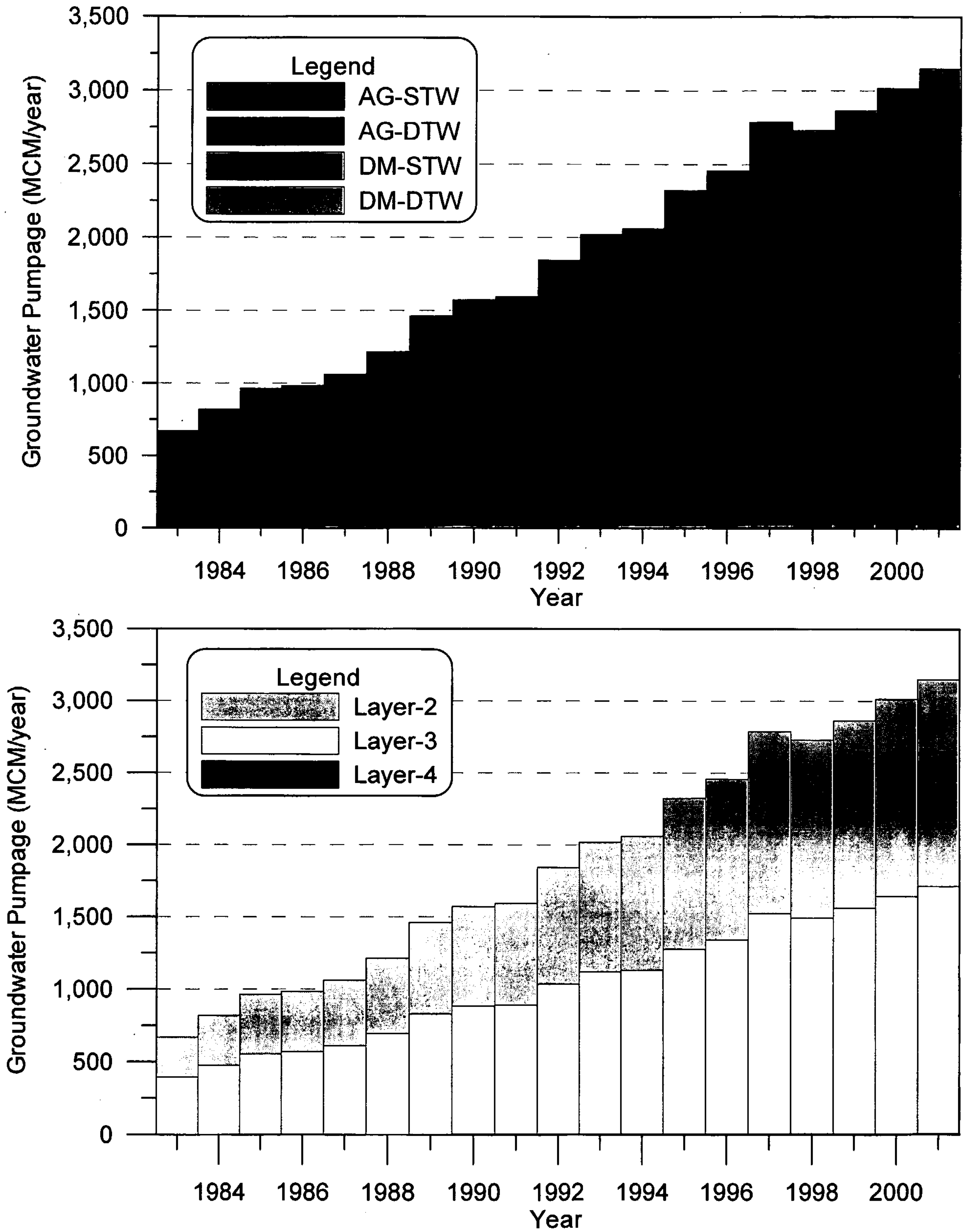

Figure 8.2.10	Historical Groundwater Pumpage Input to 3-D Regional Model
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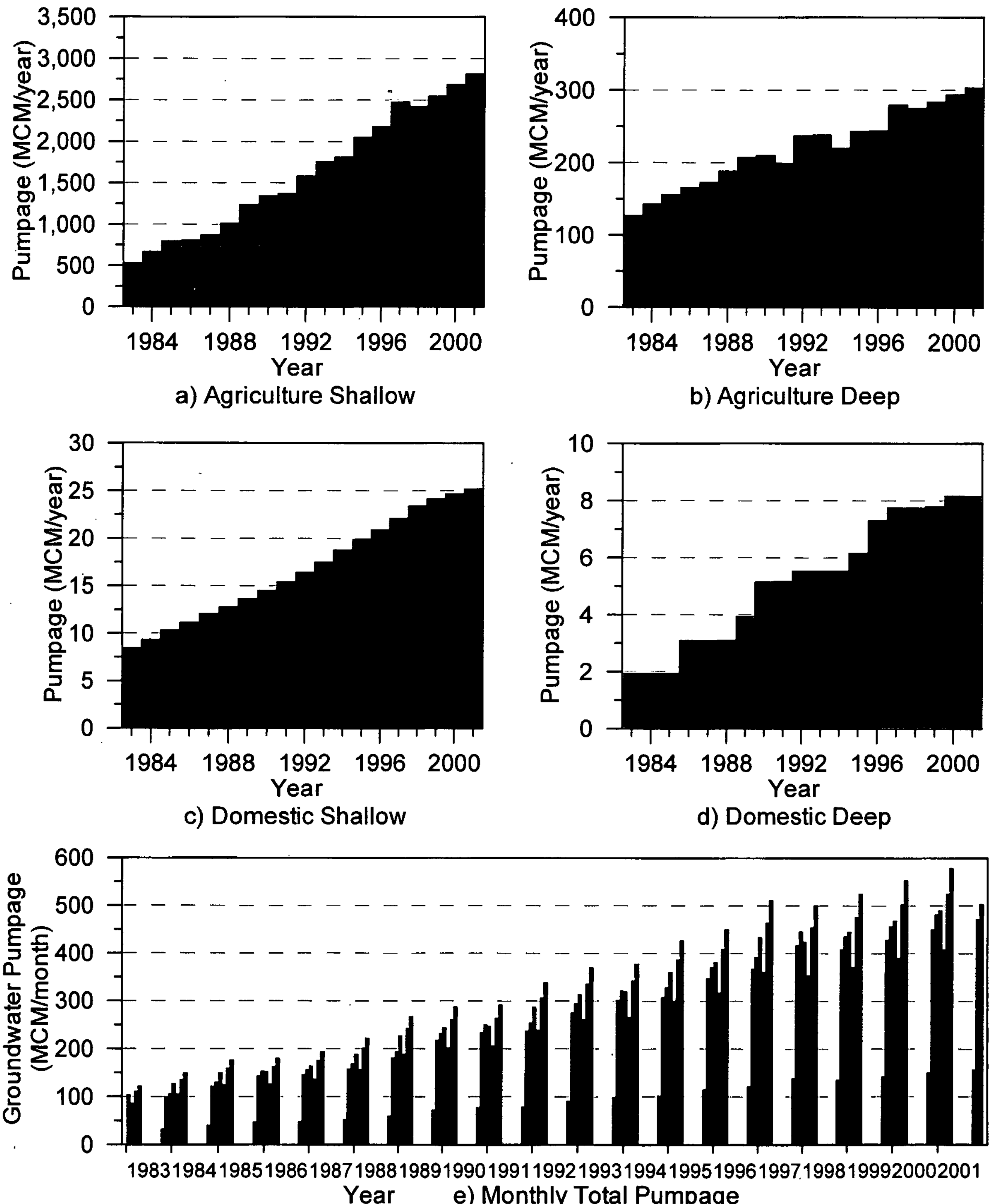

Legend
Layer-2
Layer-3
Layer-4

Figure 8.2.11	**Historical Groundwater Pumpage by User Type and Model Layer**

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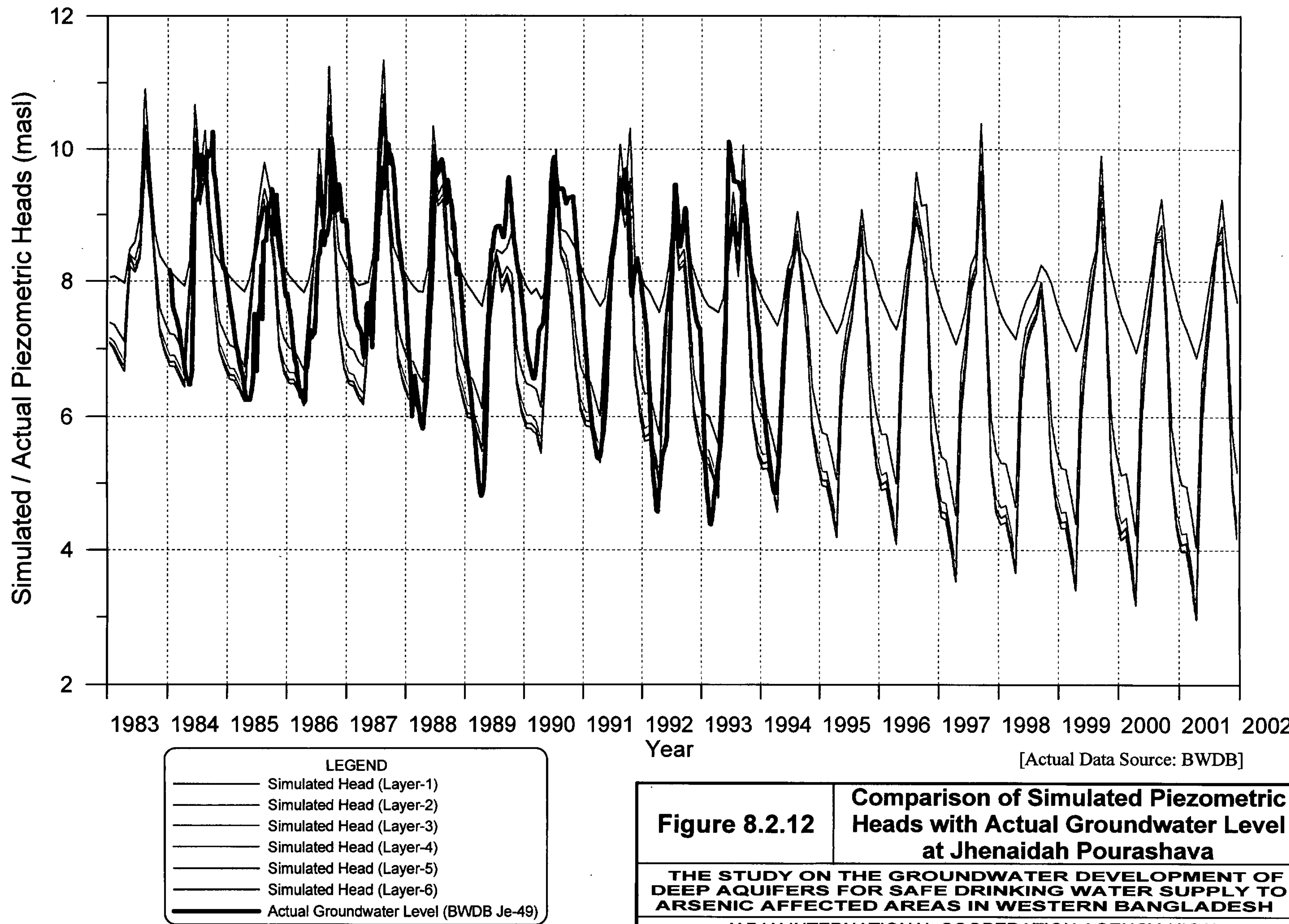

Figure 8.2.12	Comparison of Simulated Piezometric Heads with Actual Groundwater Level at Jhenaidah Pourashava

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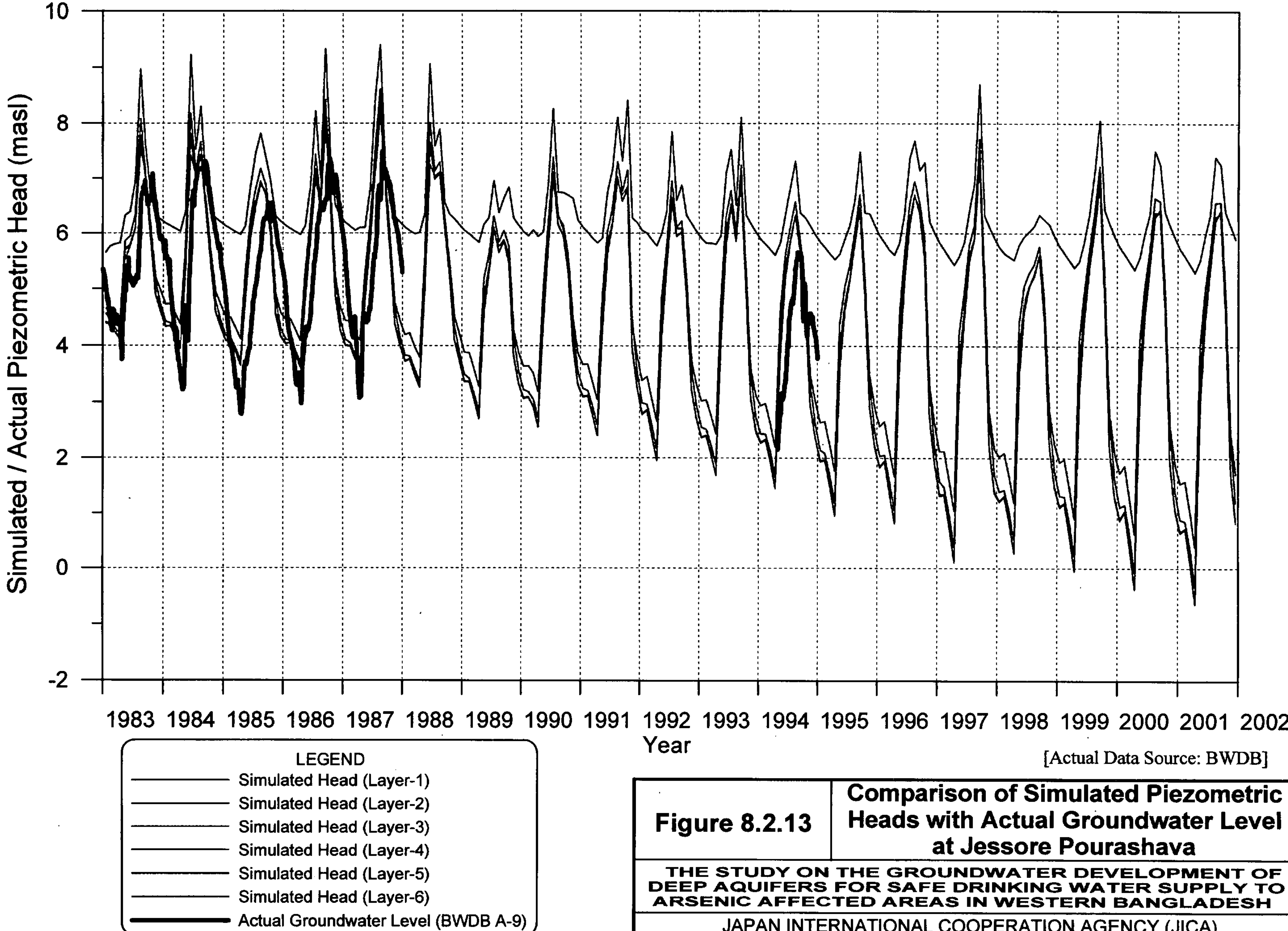

[Actual Data Source: BWDB]

Figure 8.2.13	Comparison of Simulated Piezometric Heads with Actual Groundwater Level at Jessore Pourashava

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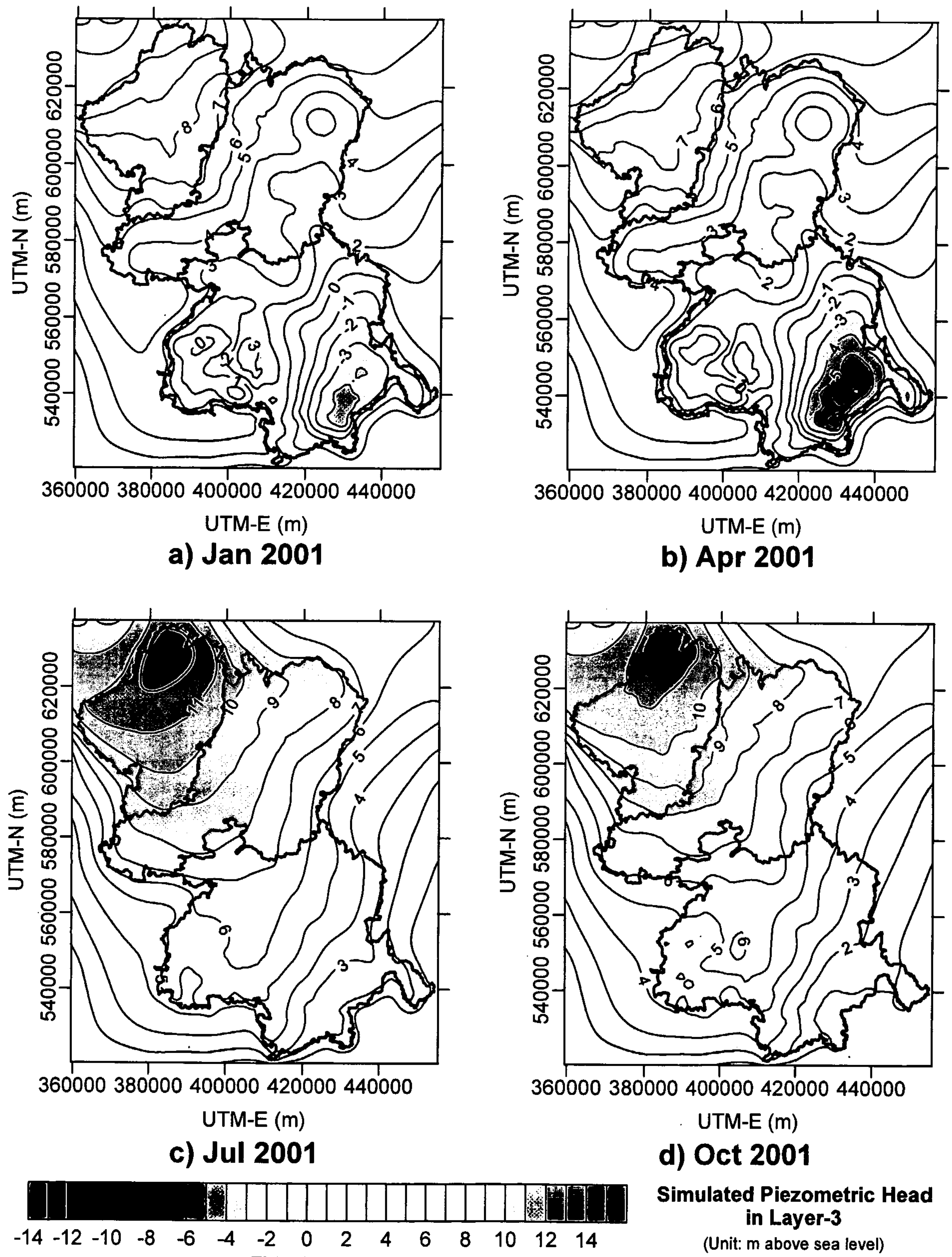

Figure 8.2.14	Distribution of Simulated Piezometric Heads in Layer-3 in 2001 by Histrical Simulation

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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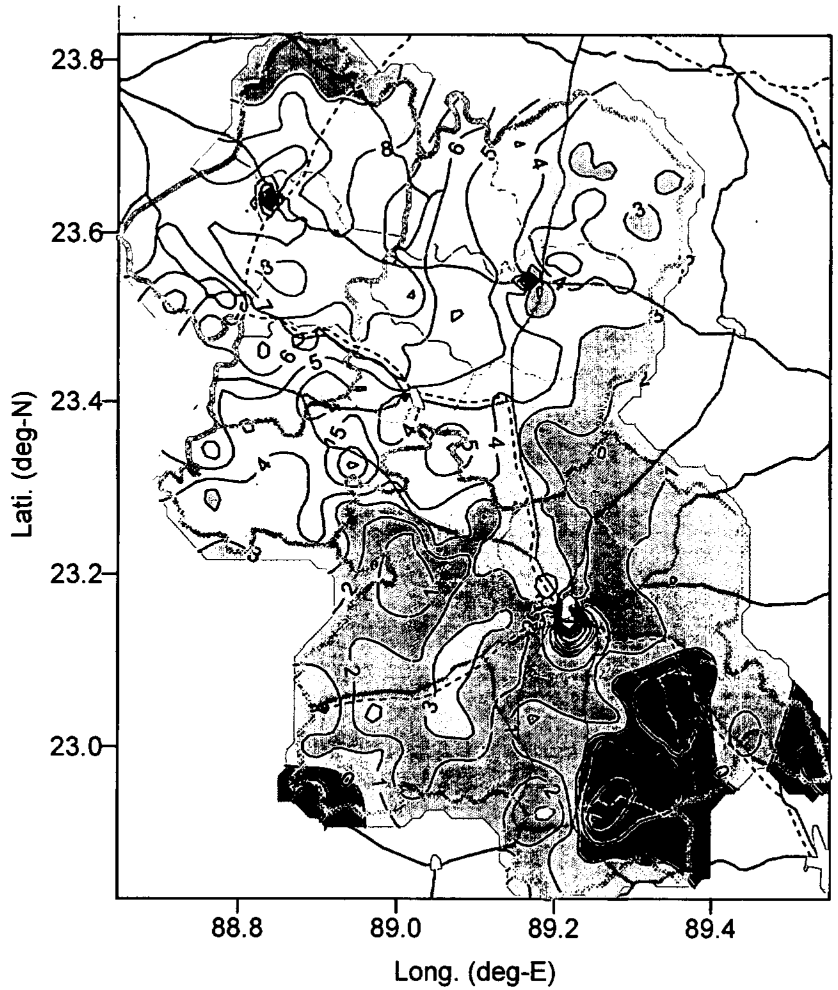
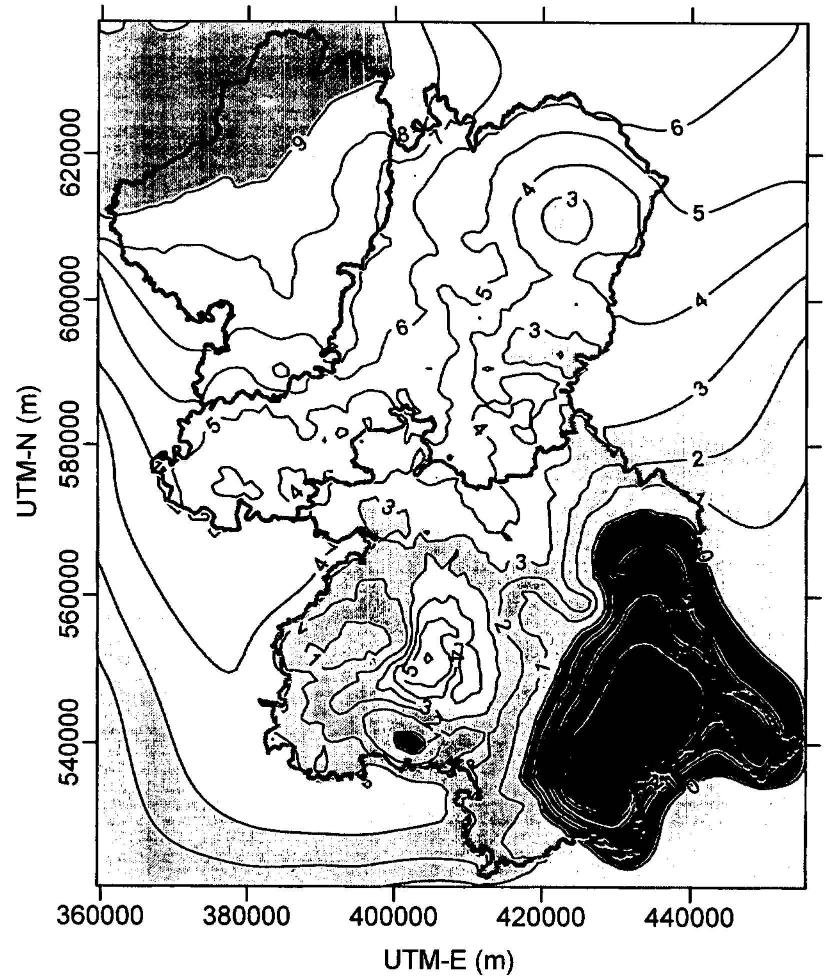


a) Actual Groundwater Levels in January 2001 Measured at 300 Existing Wells



b) Simulated Piezometric Heads in Layer-2 in January 2001 by Historical Simulation

Actual Groundwater Level and Simulated Piezometric Head

-5 -3 -2 -1 0 1 2 3 4 5 6 7 8 9

(Unit: m above sea level)

Figure 8.2.15	Comparison of Simulated Piezometric Heads with Actual Groundwater Levels in January 2001

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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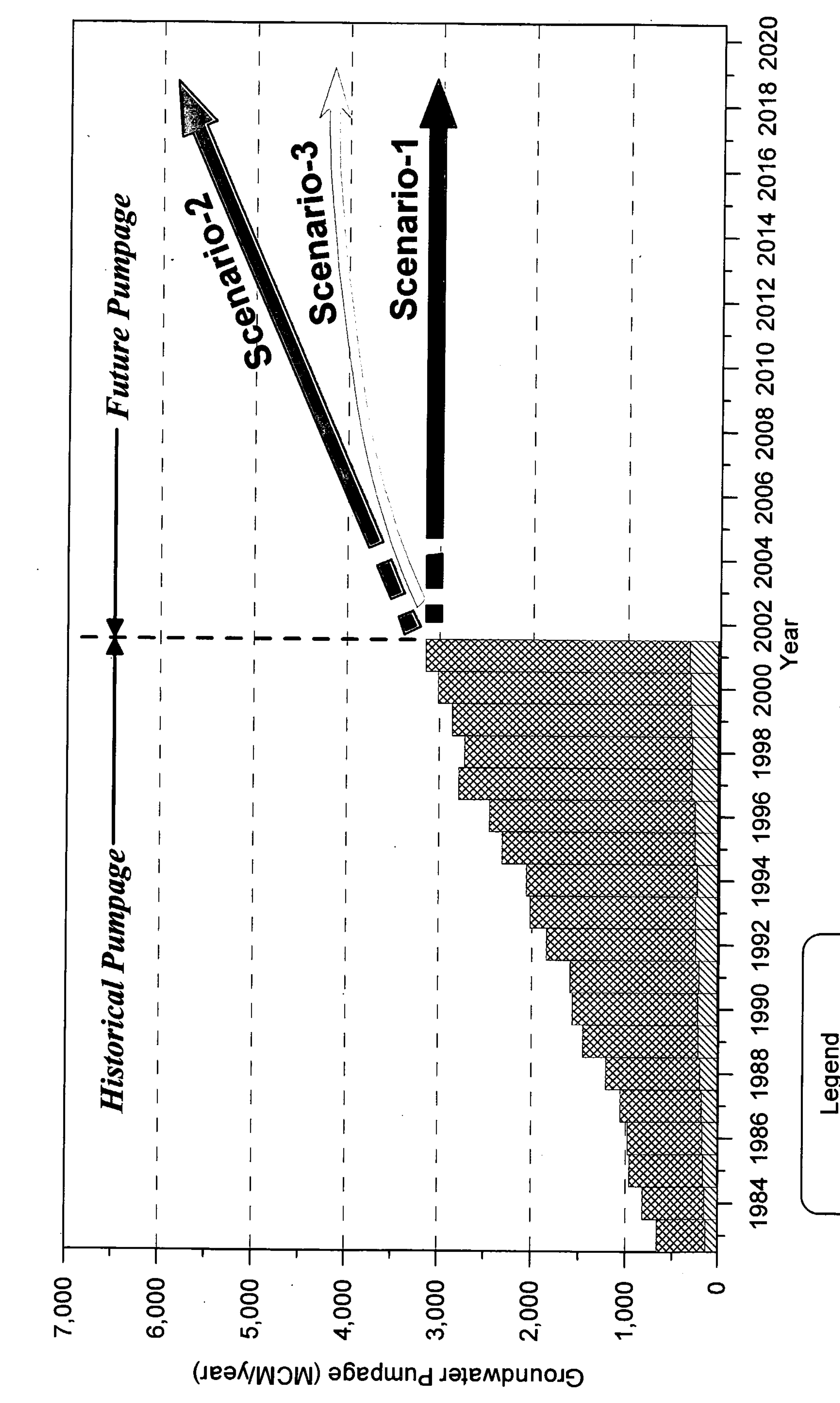

Figure 8.2.16 Concept of Future Groundwater Pumpage Scenarios

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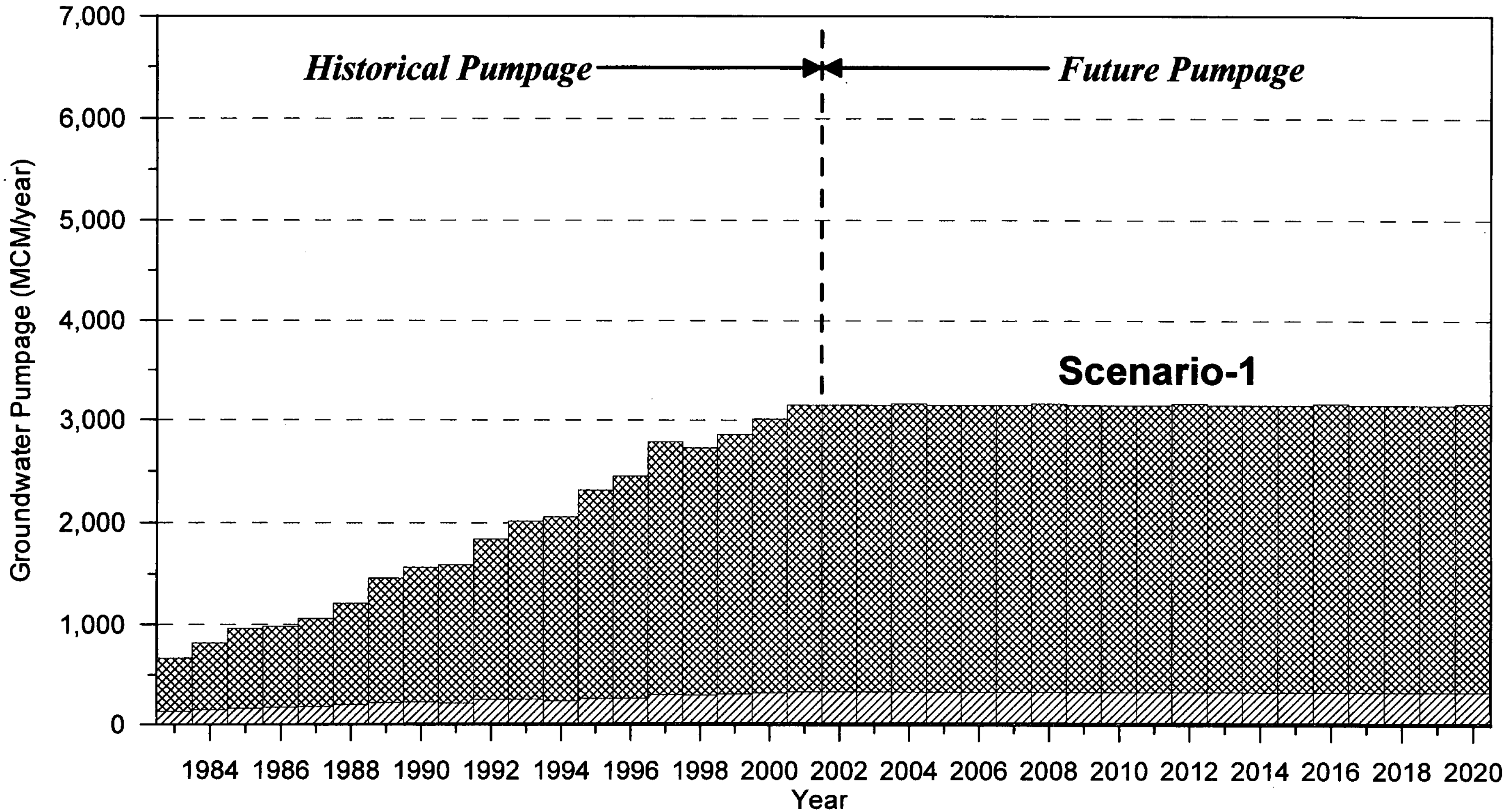

Figure 8.2.17	Future Groundwater Pumpage by Scenario-1

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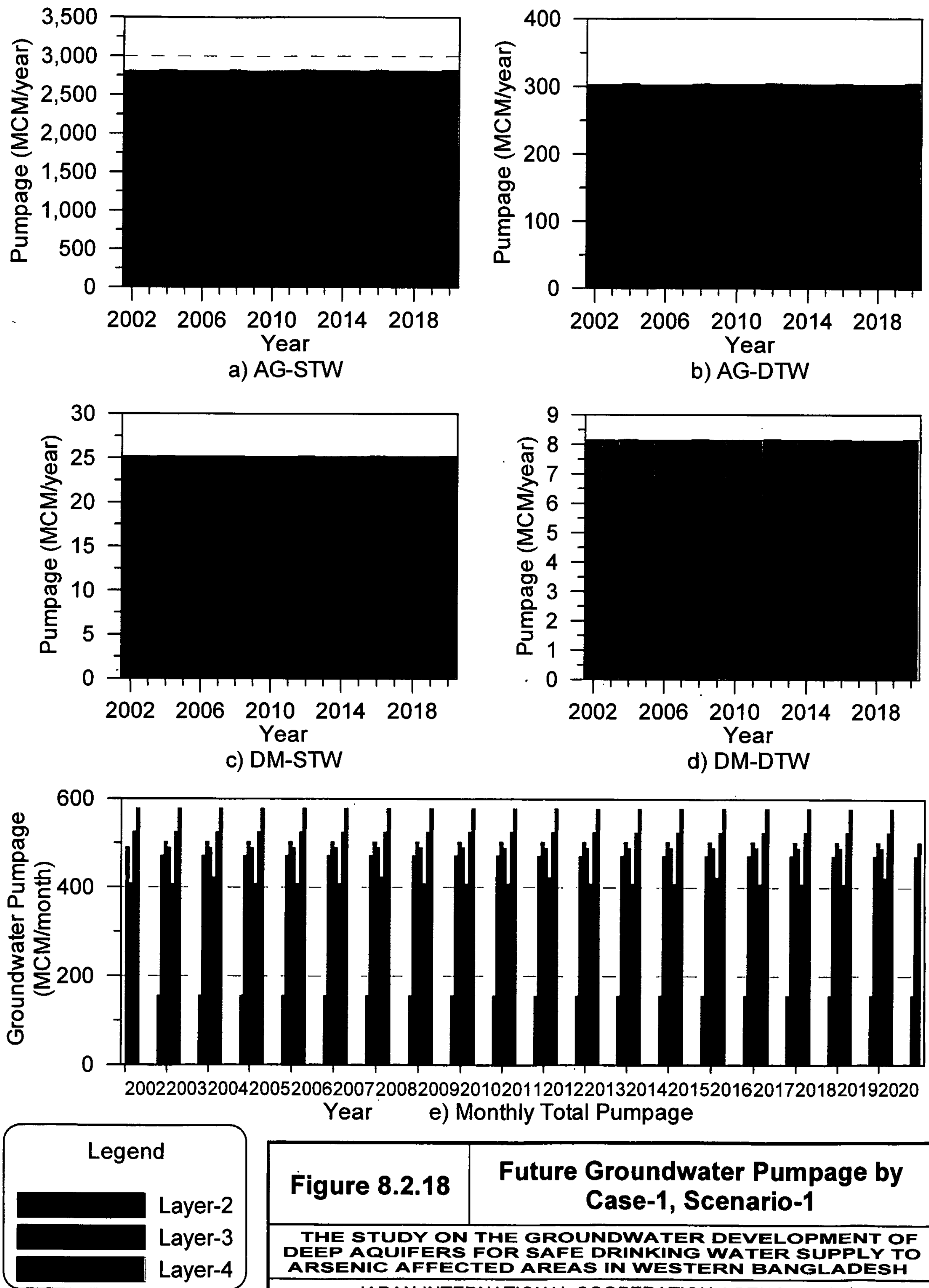

Figure 8.2.18	Future Groundwater Pumpage by Case-1, Scenario-1

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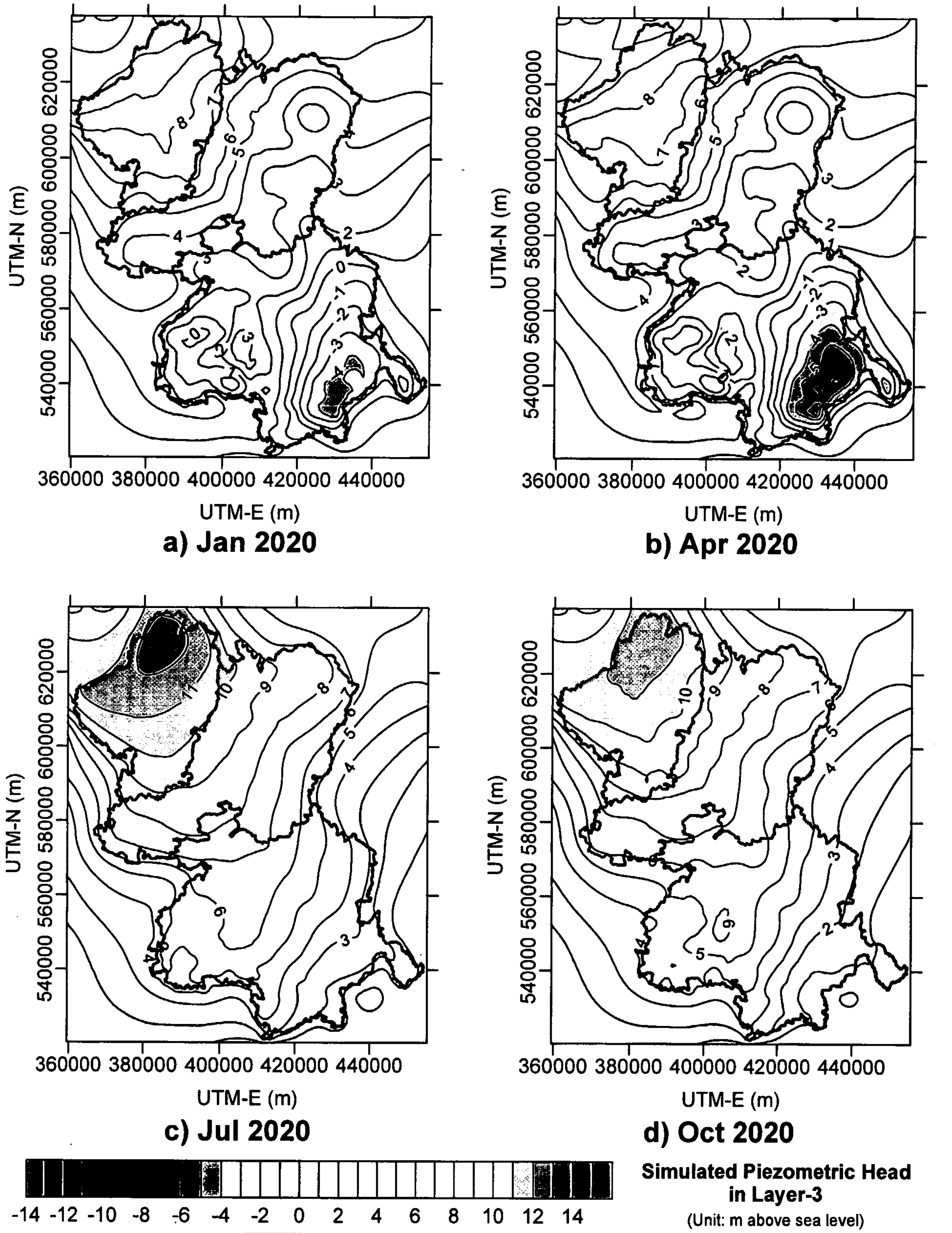

Figure 8.2.19	Distribution of Simulated Piezometric Heads in Layer-3 in 2020 by Case-1, Scenario-1
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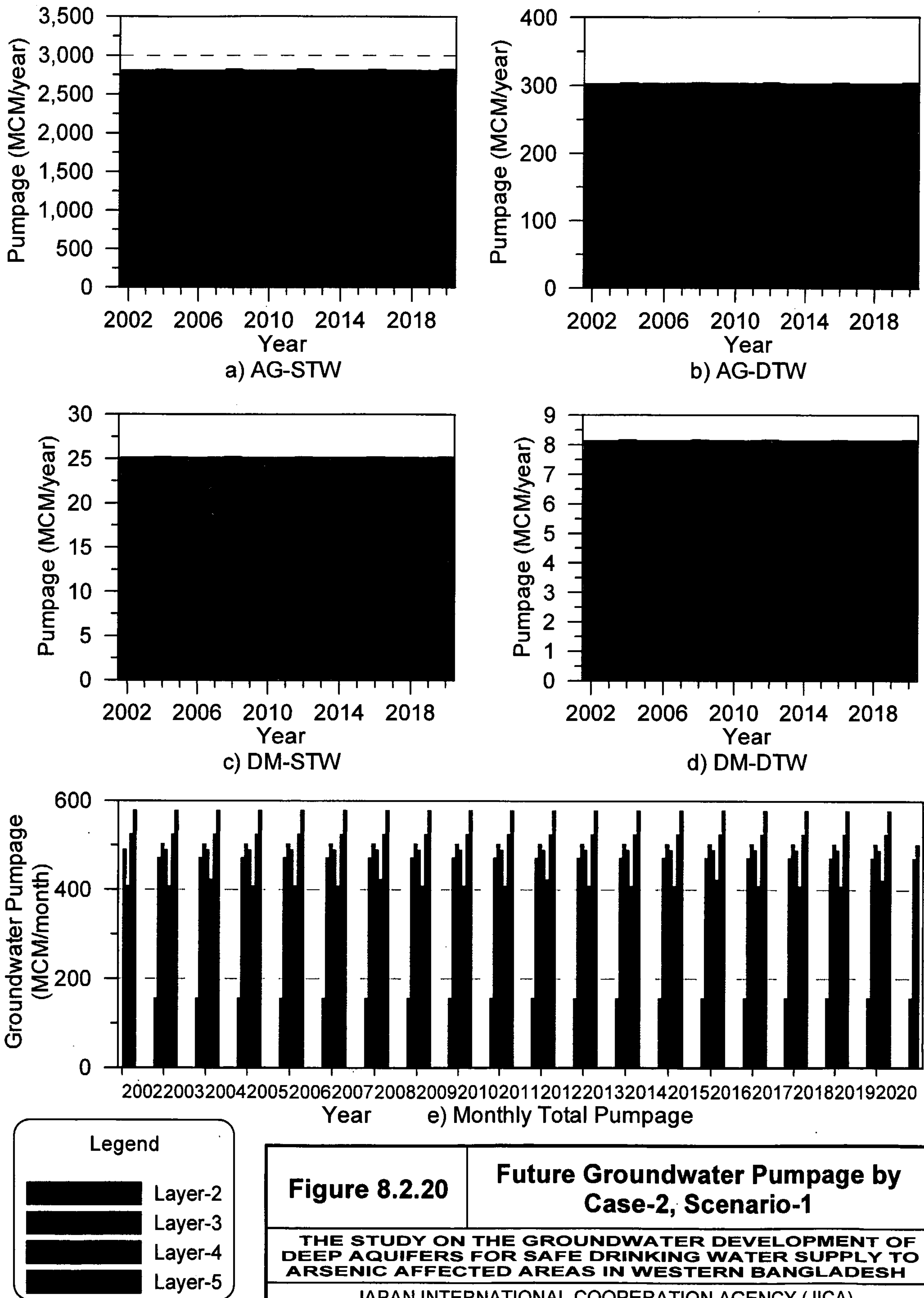

Figure 8.2.20	**Future Groundwater Pumpage by Case-2, Scenario-1**

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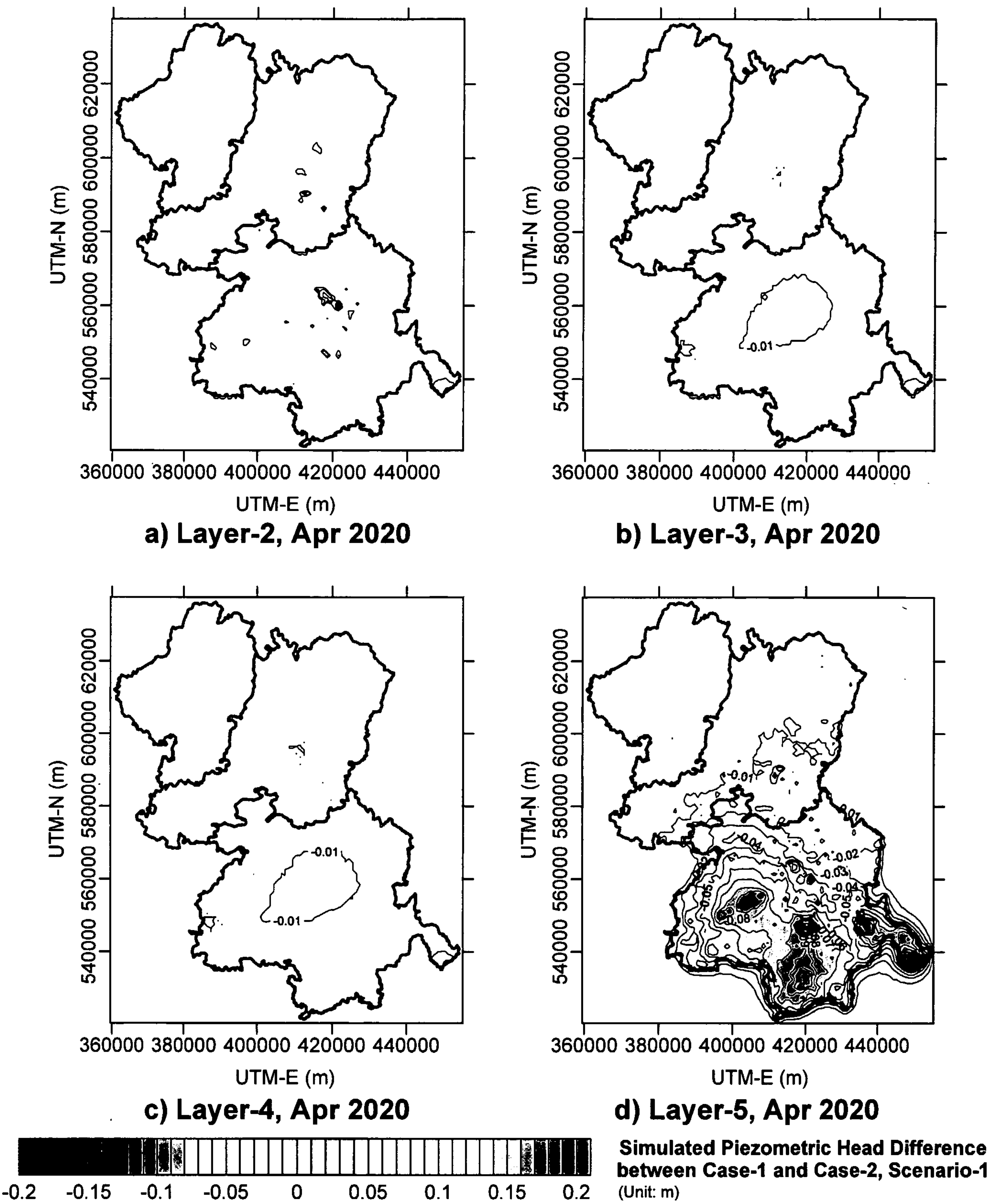

Figure 8.2.21	Difference of Simulated Piezometric Heads between Case-1 and Case-2, Scenario-1 in Apr 2020
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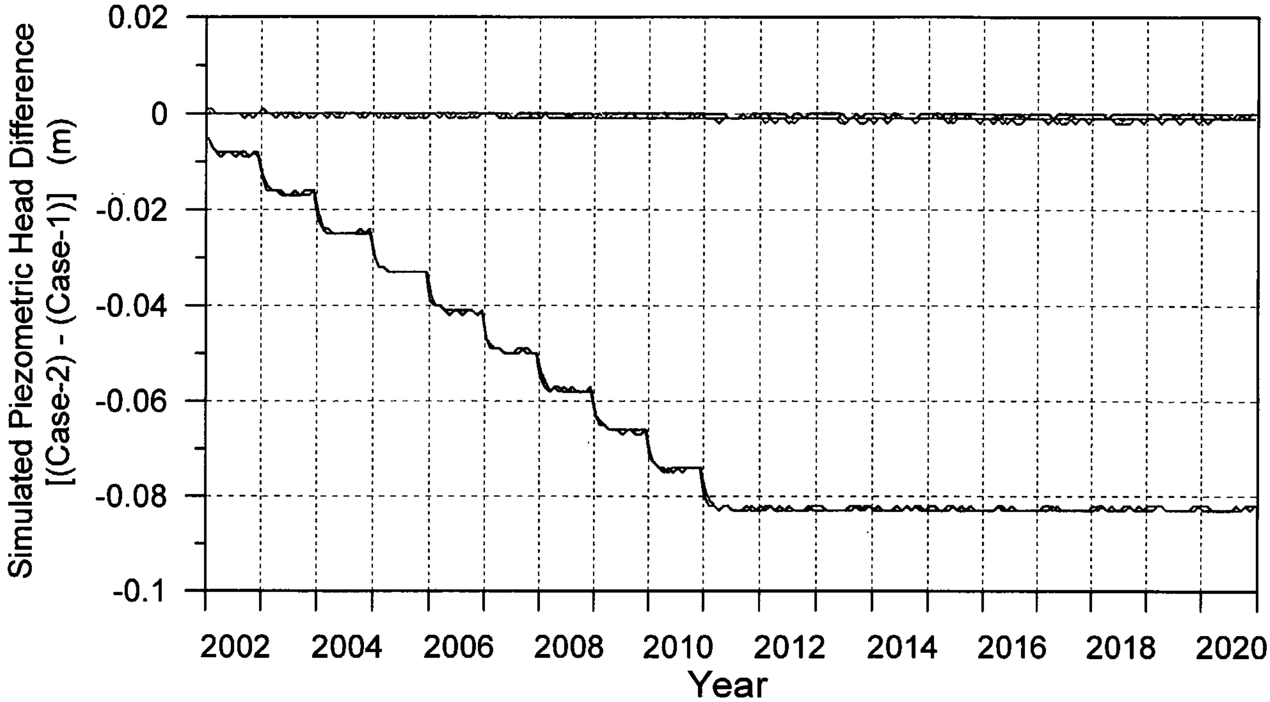
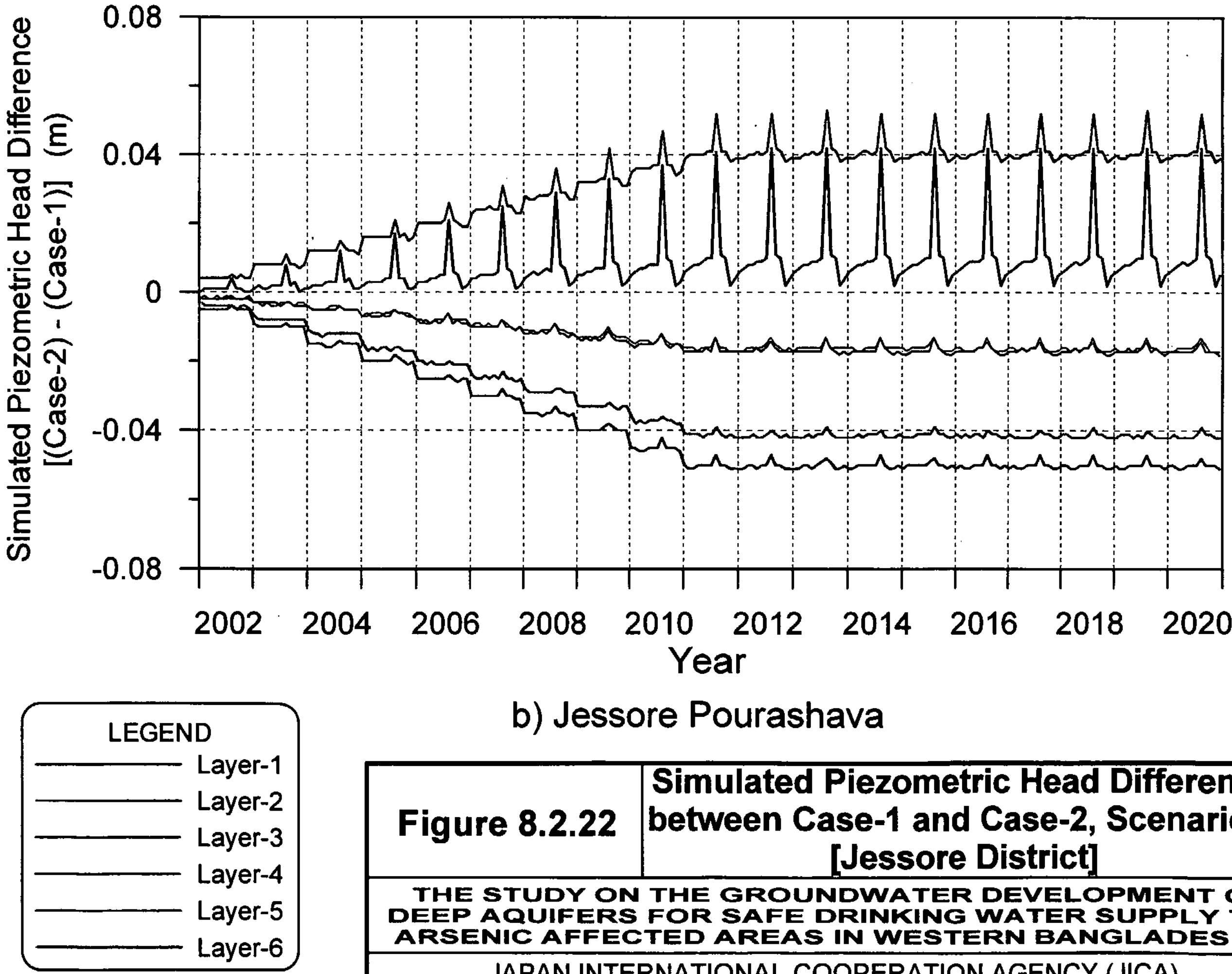


a) Rajnagar Bankabarsi, Keshabpur



b) Jessore Pourashava

Figure 8.2.22	**Simulated Piezometric Head Difference between Case-1 and Case-2, Scenario-1 [Jessore District]**
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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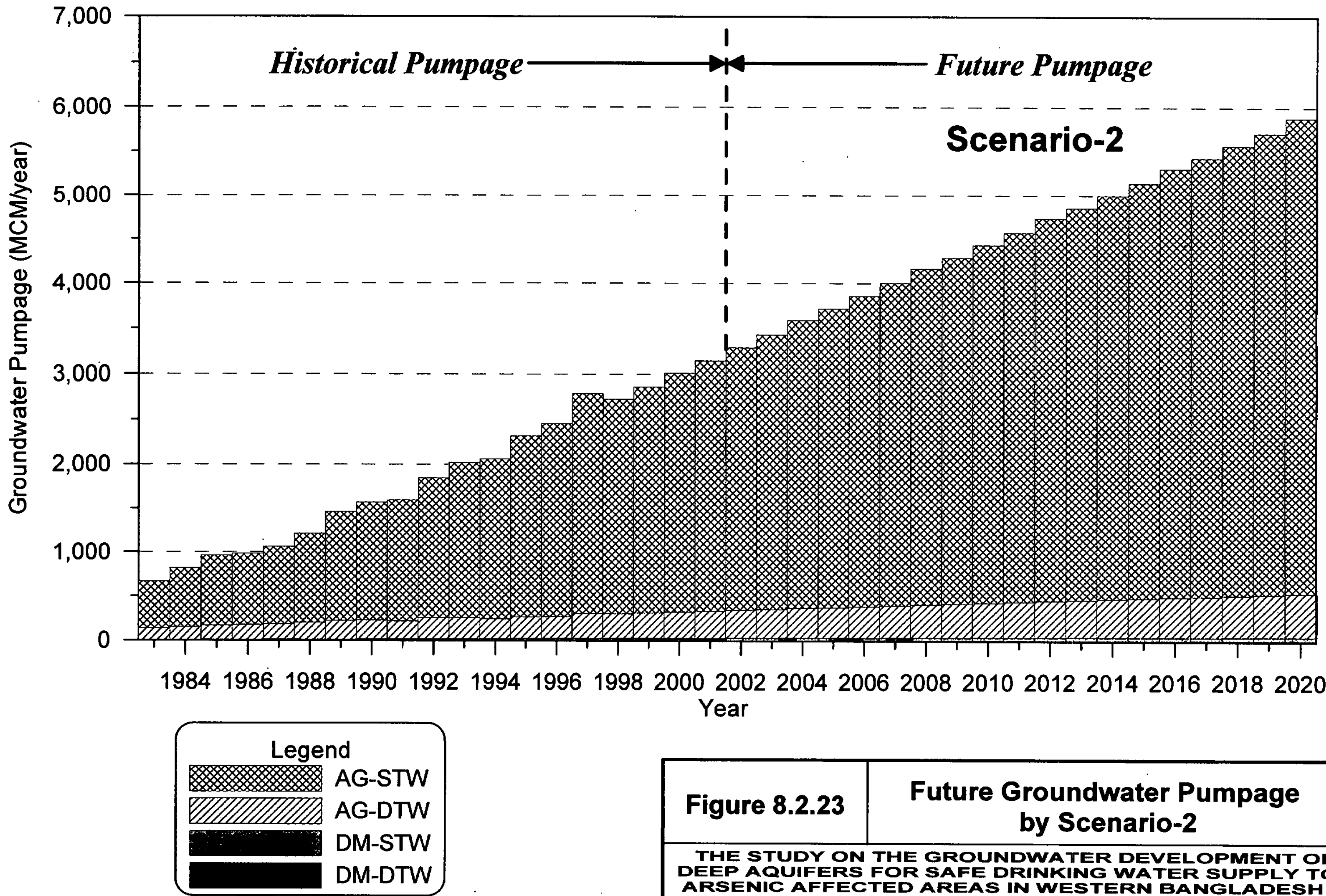

Figure 8.2.23	Future Groundwater Pumpage by Scenario-2
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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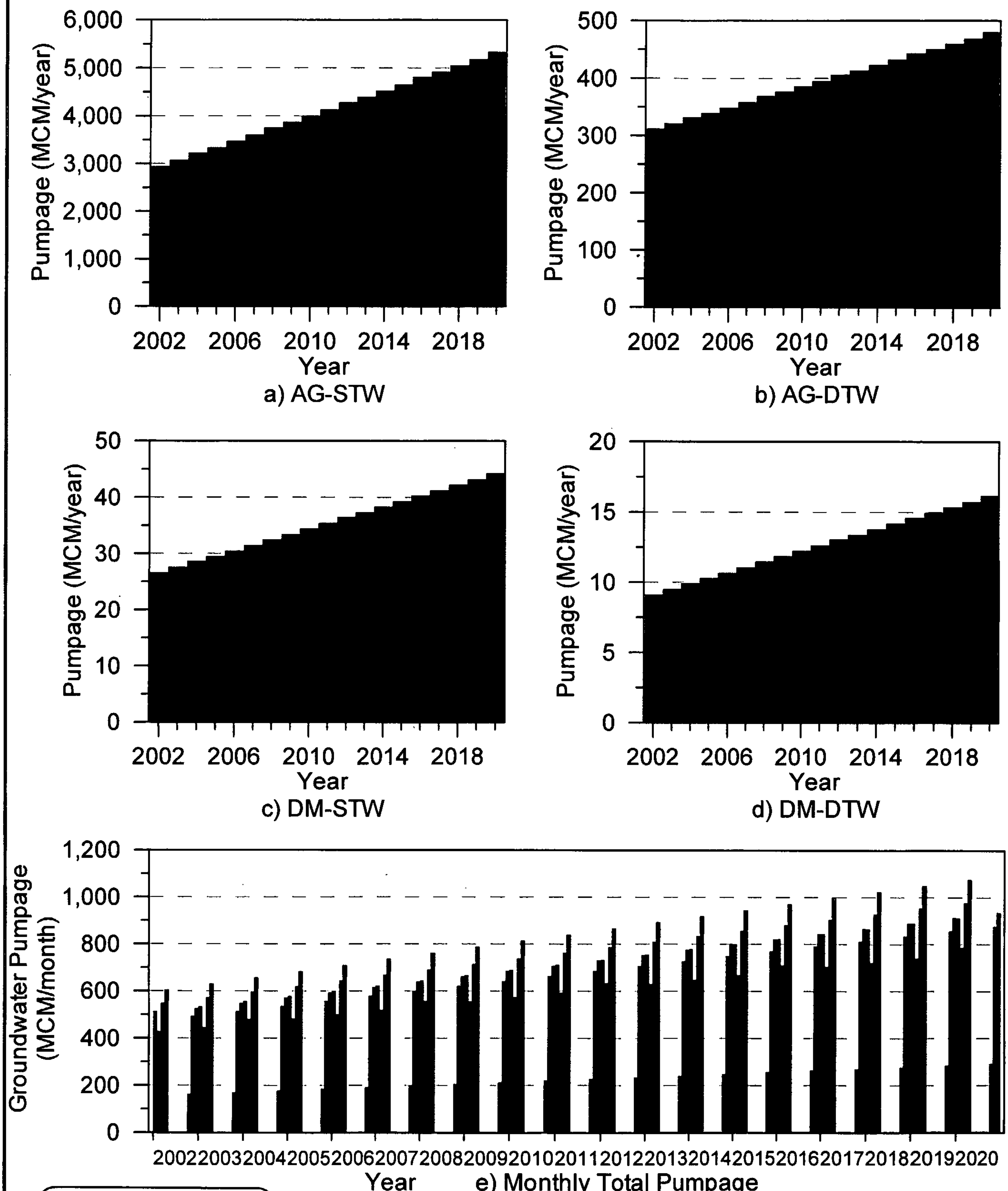

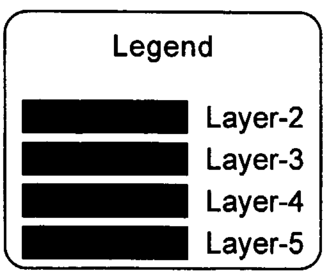

Figure 8.2.24	Future Groundwater Pumpage by Case-1, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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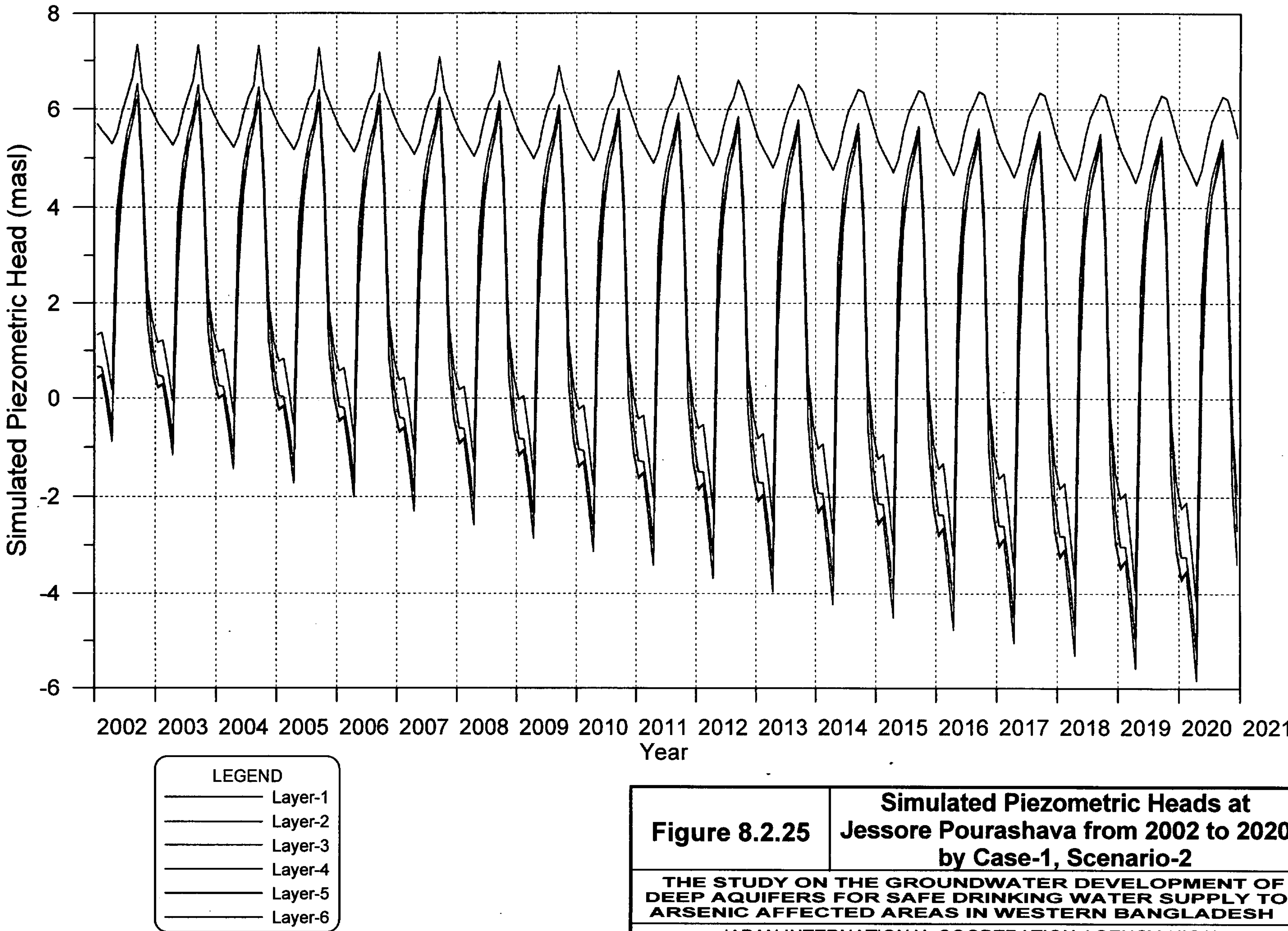

Figure 8.2.25	Simulated Piezometric Heads at Jessore Pourashava from 2002 to 2020 by Case-1, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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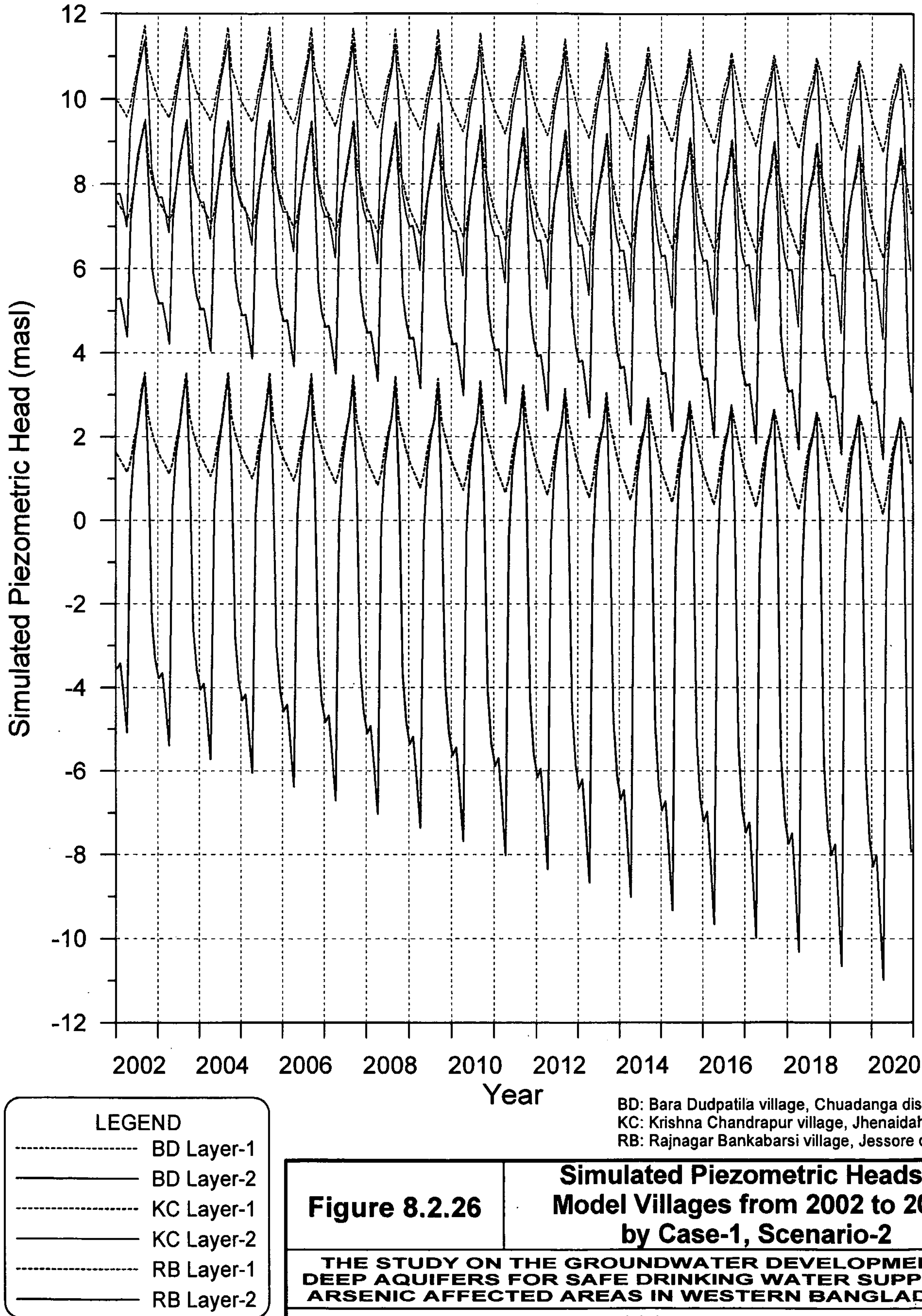

BD: Bara Dudpatila village, Chuadanga district
KC: Krishna Chandrapur village, Jhenaidah district
RB: Rajnagar Bankabarsi village, Jessore district

Figure 8.2.26	Simulated Piezometric Heads at Model Villages from 2002 to 2020 by Case-1, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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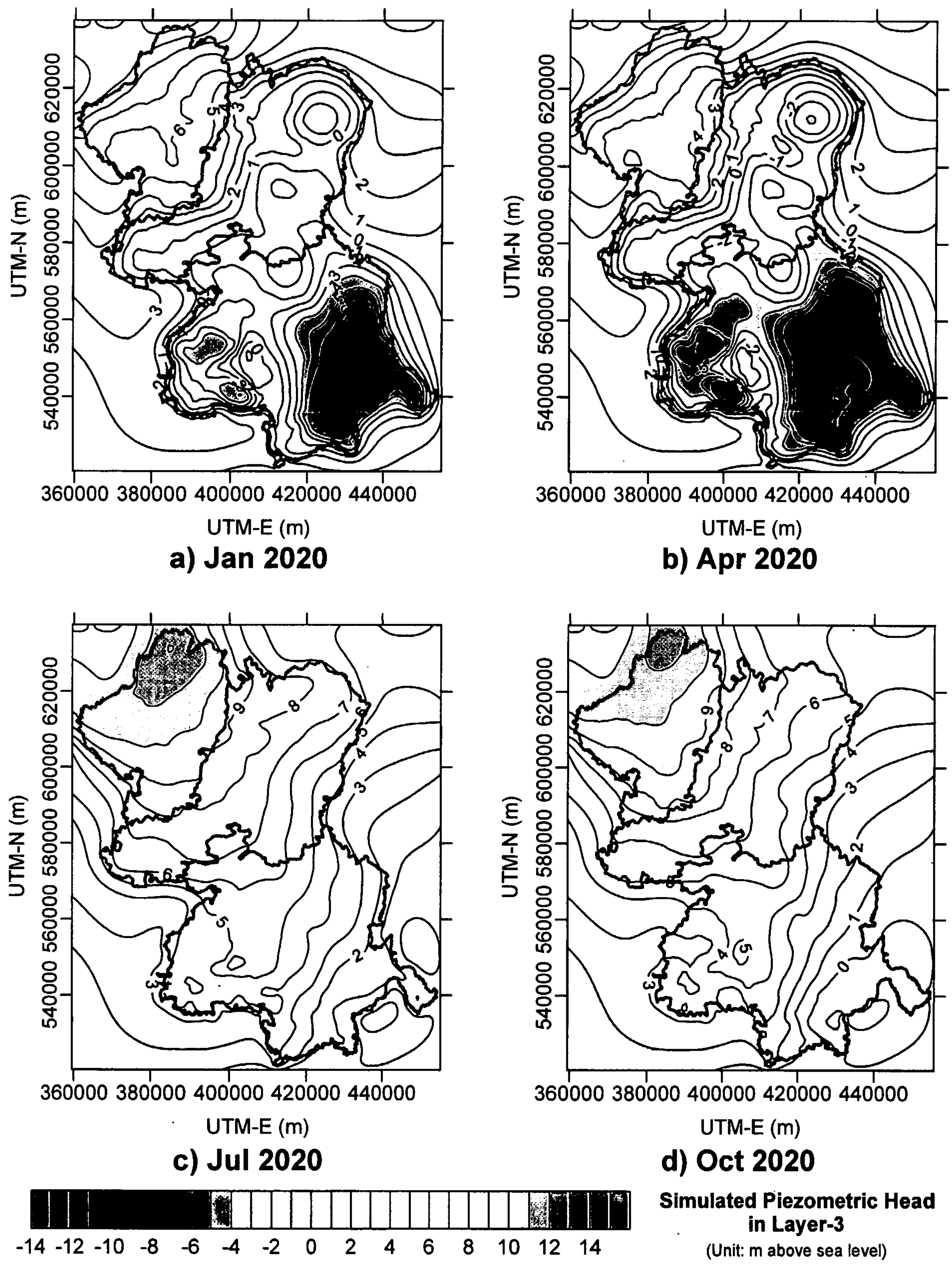

Figure 8.2.27	Distribution of Simulated Piezometric Heads in Layer-3 in 2020 by Case-1, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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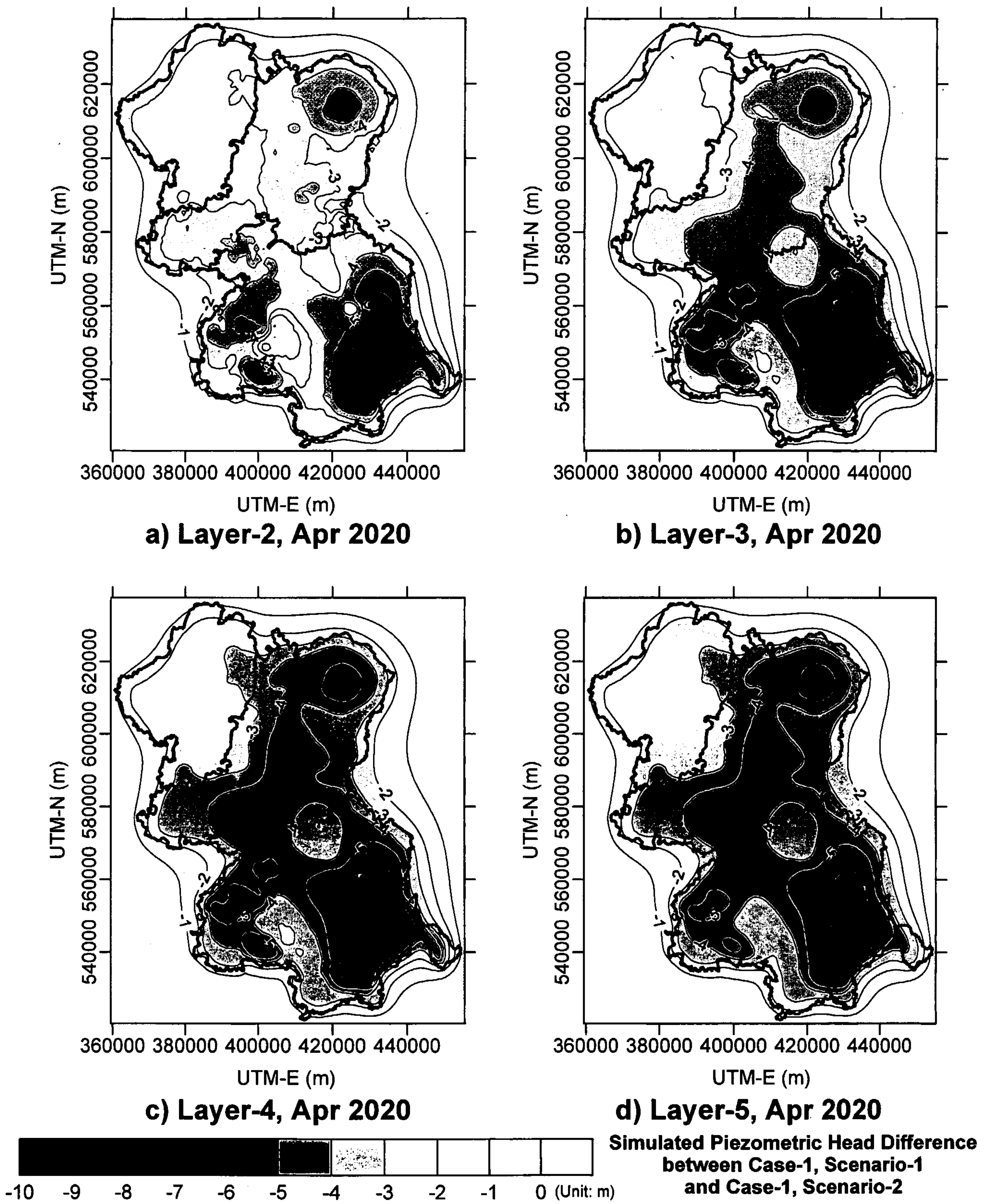

Figure 8.2.28	Difference of Simulated Piezometric Heads between Case-1, Scenario-1 and Case-1, Scenario-2 in Apr 2020

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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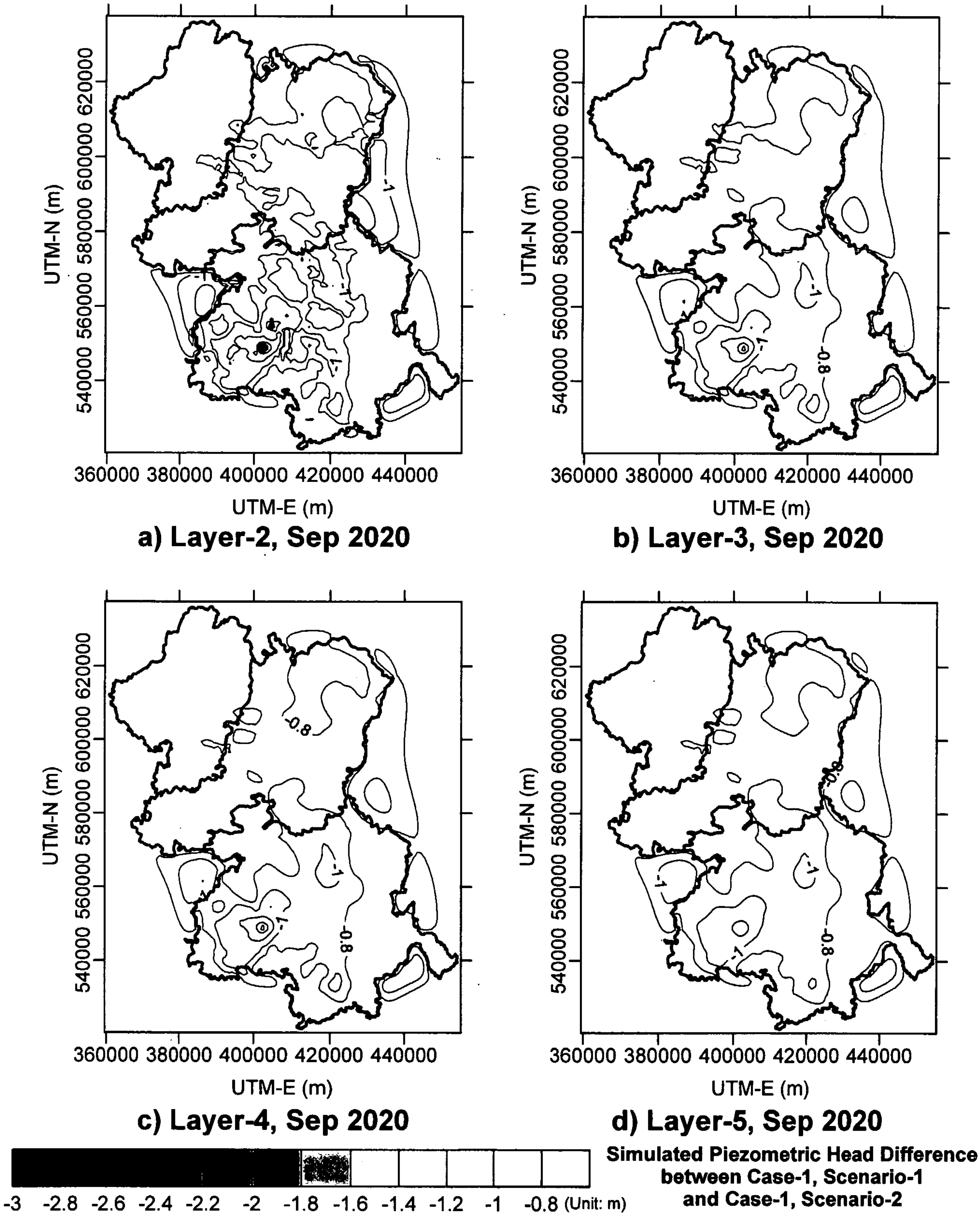

Figure 8.2.29	Difference of Simulated Piezometric Heads between Case-1, Scenario-1 and Case-1, Scenario-2 in Sep 2020
	THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH
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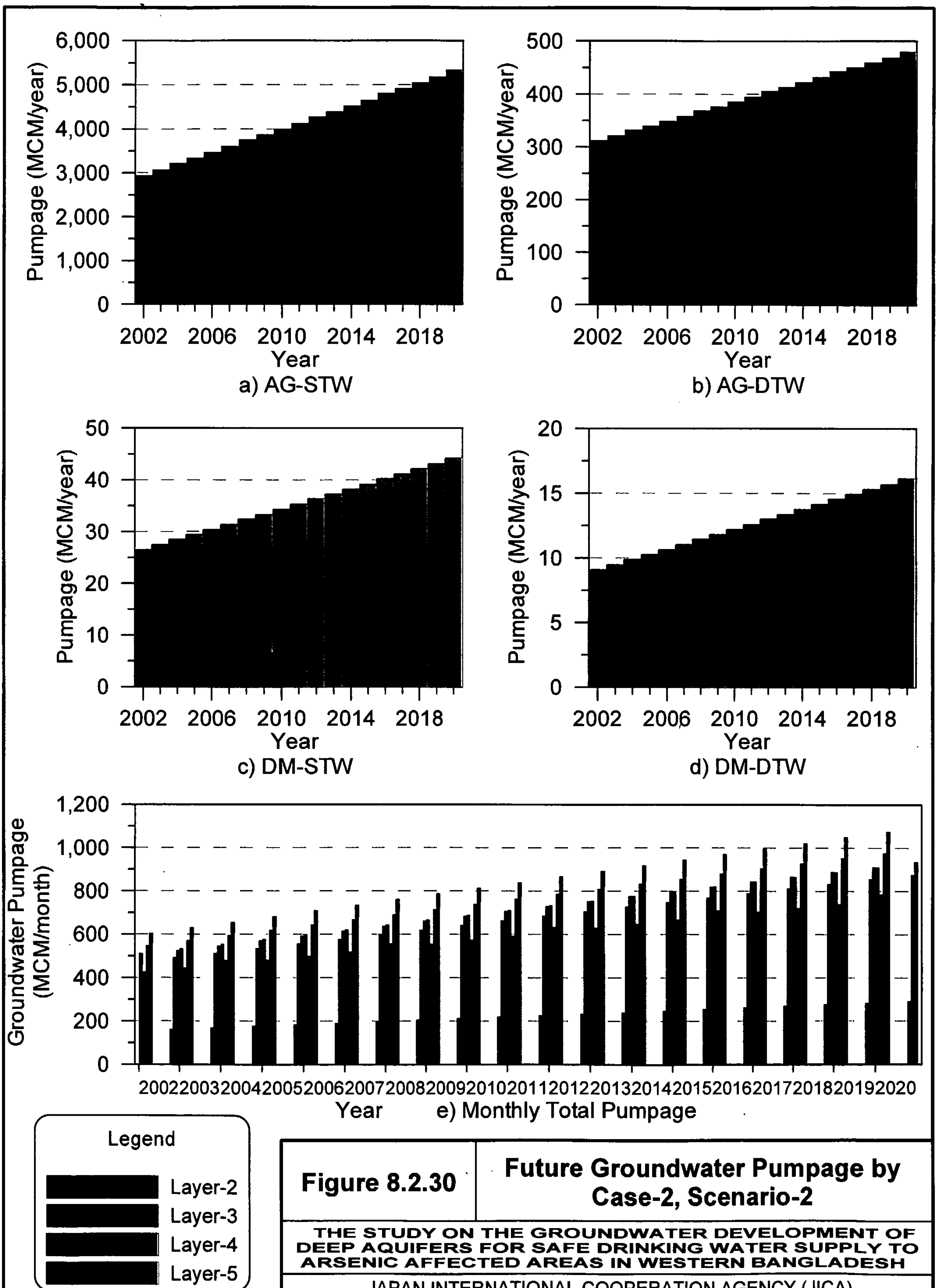

Figure 8.2.30	Future Groundwater Pumpage by Case-2, Scenario-2
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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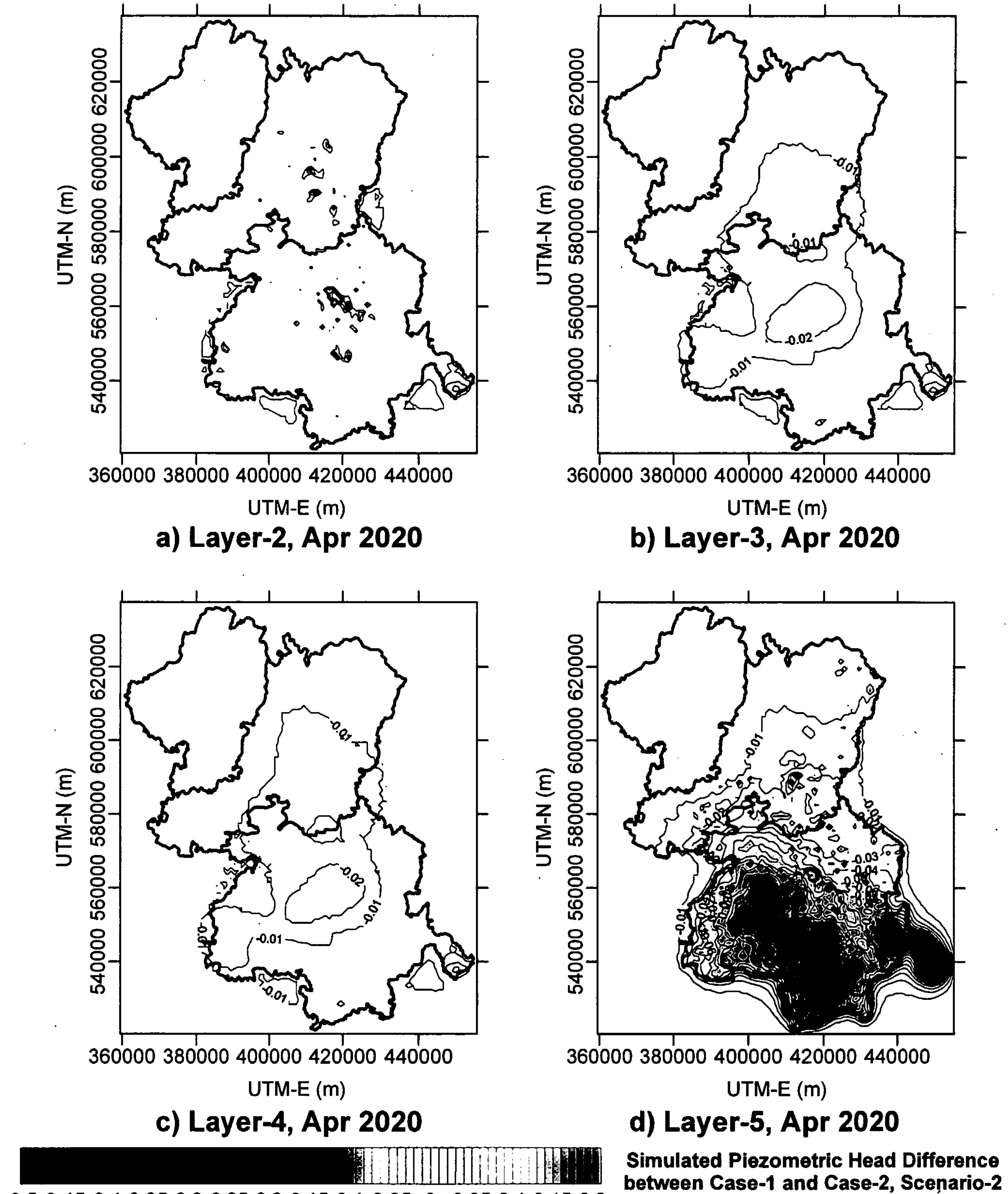

Figure 8.2.31	Difference of Simulated Piezometric Heads between Case-1 and Case-2, Scenario-2 in Apr 2020
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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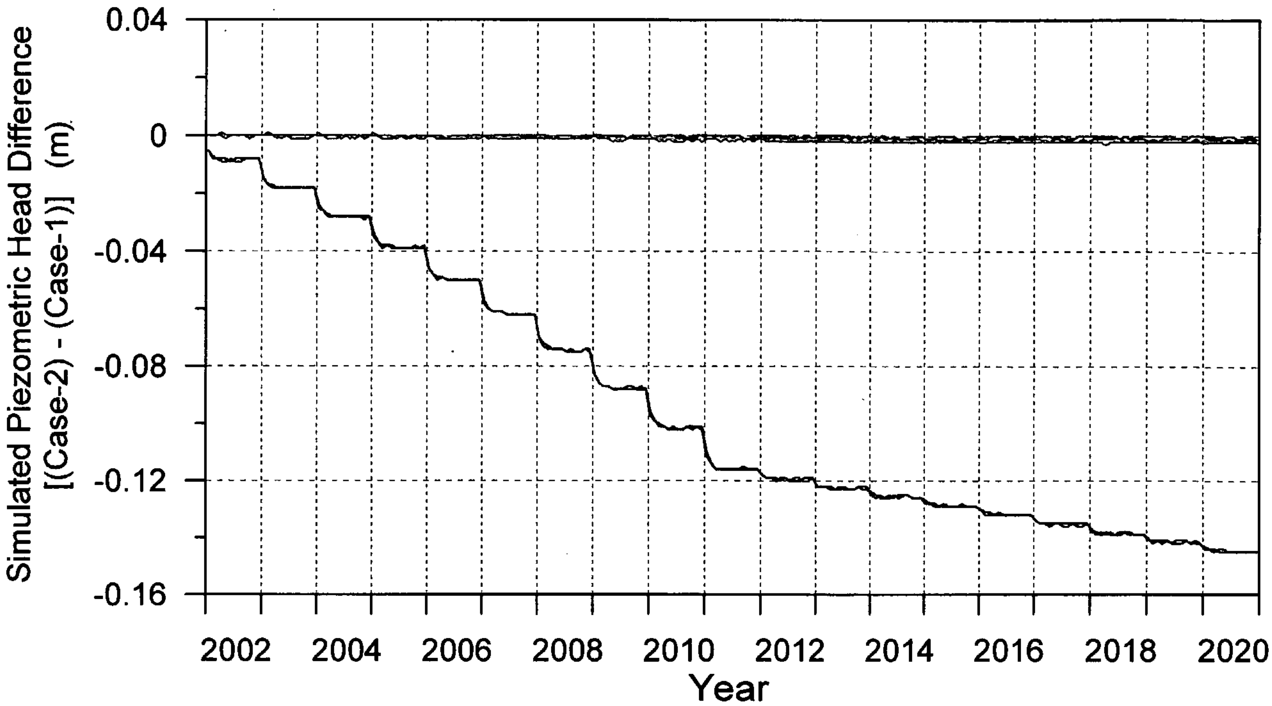
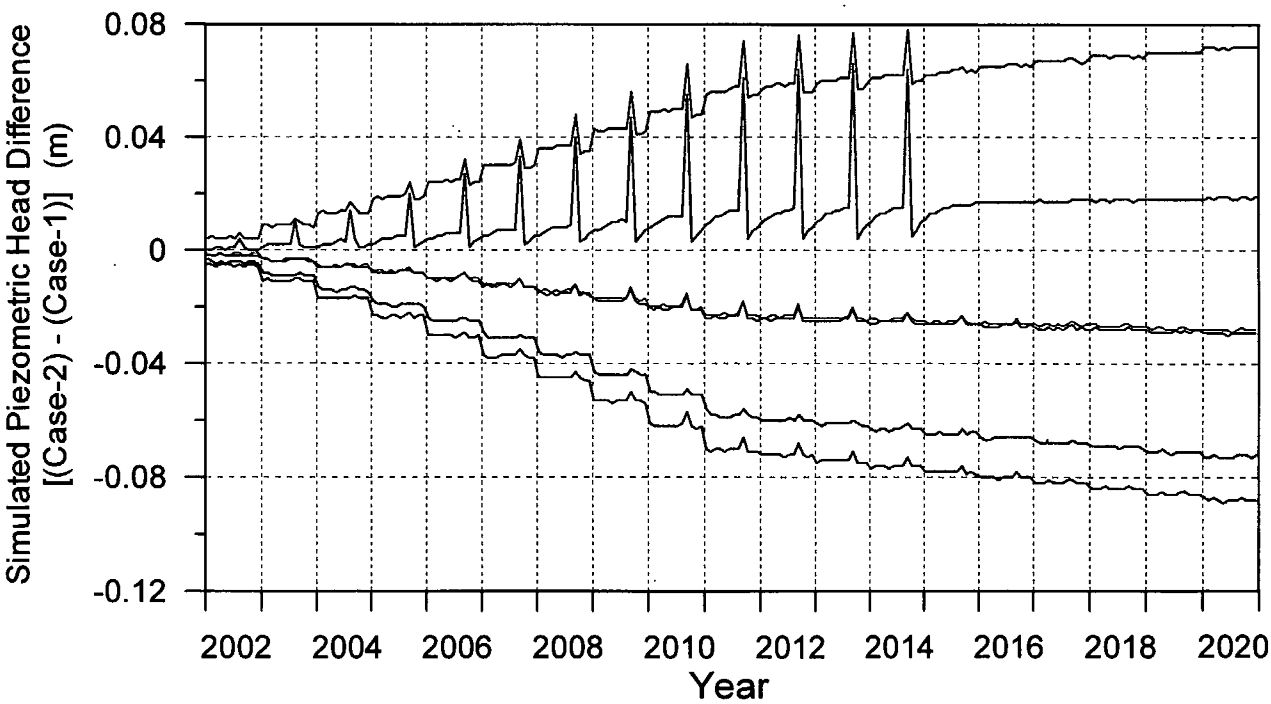


a) Rajnagar Bankabarsi, Keshabpur



b) Jessore Pourashava

LEGEND
- Layer-1
- Layer-2
- Layer-3
- Layer-4
- Layer-5
- Layer-6

Figure 8.2.32	Simulated Piezometric Head Difference between Case-1 and Case-2, Scenario-2 [Jessore District]
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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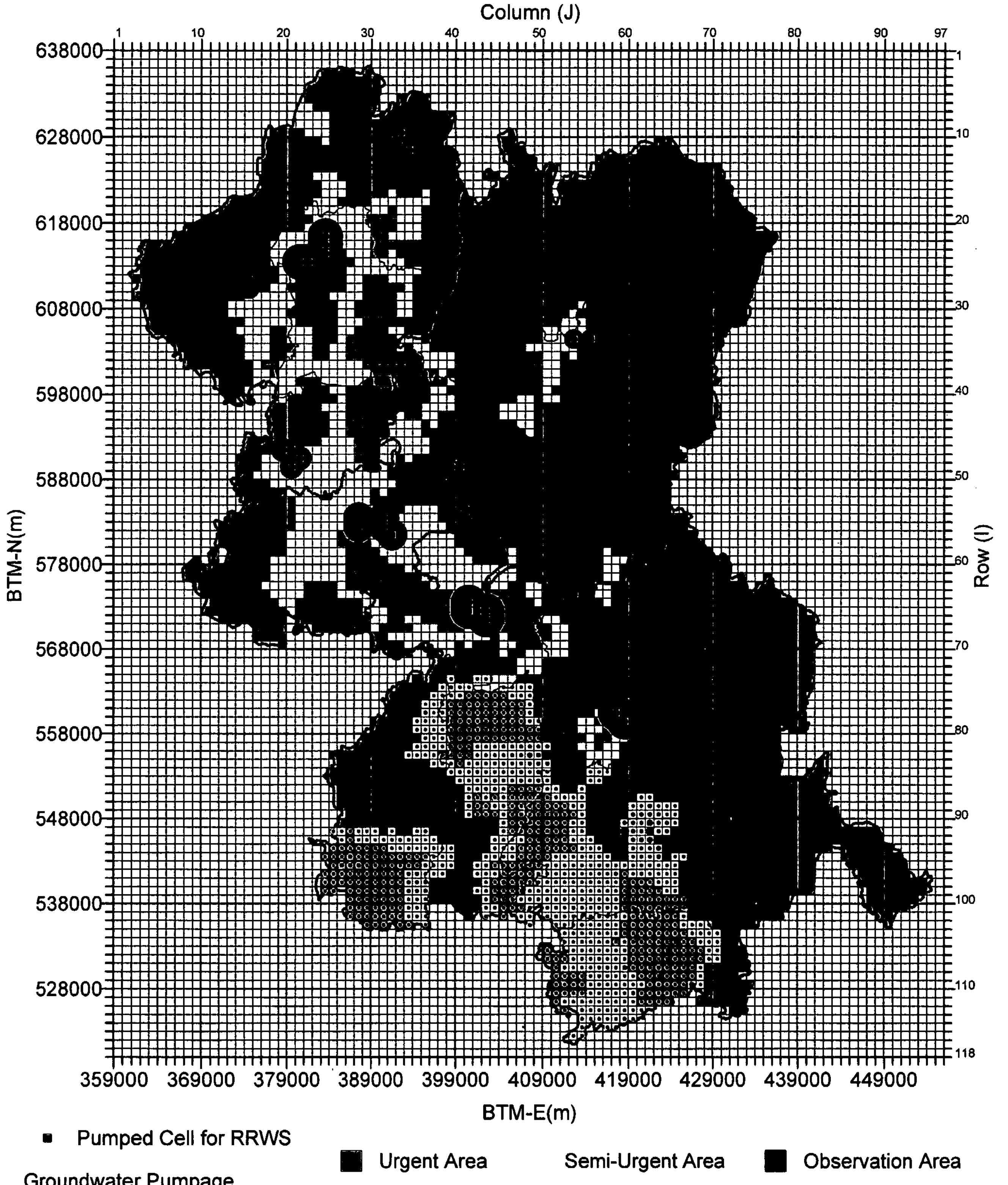

Figure 8.2.33	Distribution of Groundwater Pumpage from Layer-5 in Dec 2020 by Case-3, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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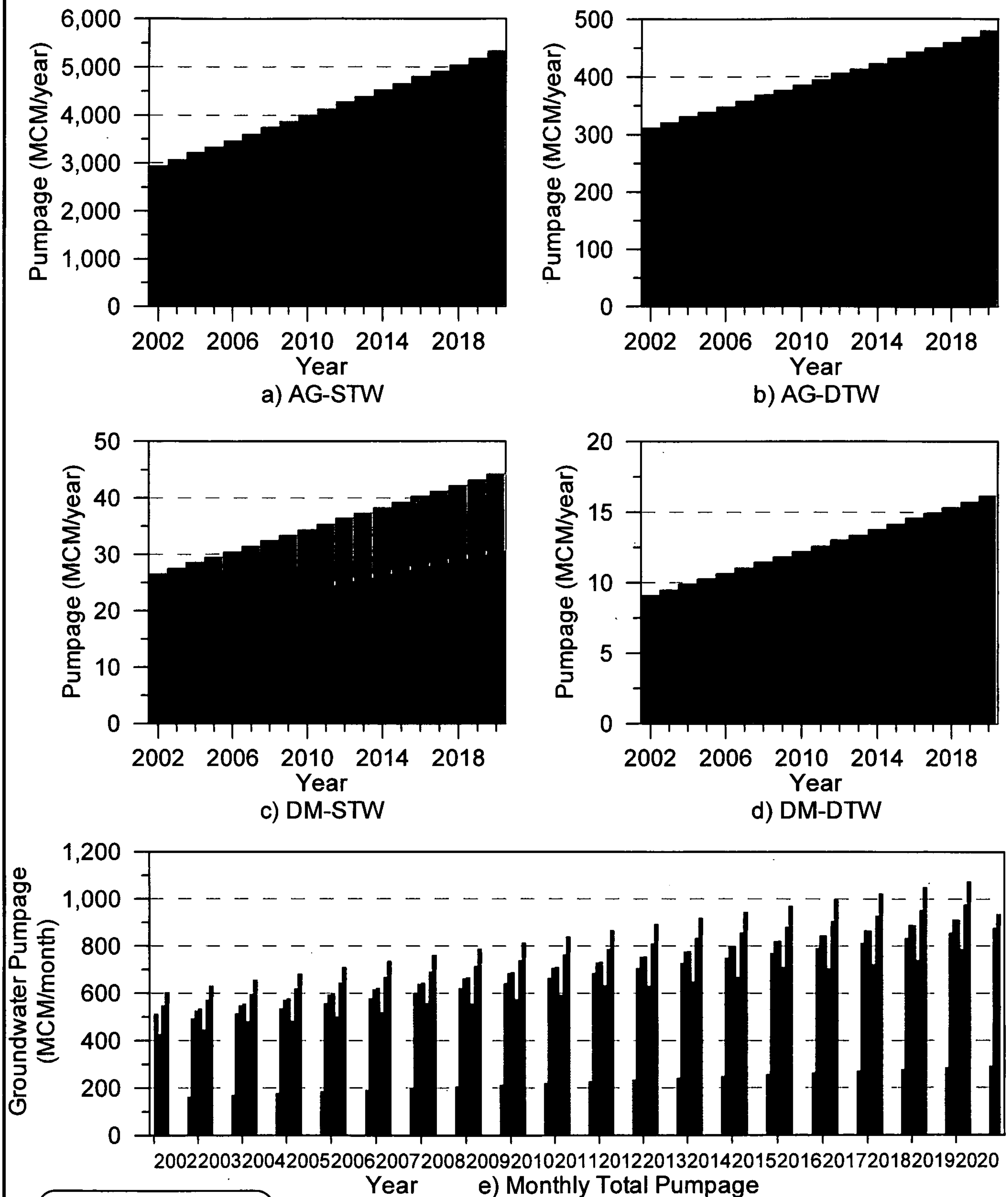

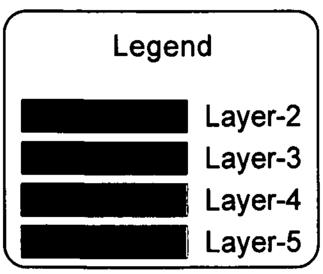

Figure 8.2.34	Future Groundwater Pumpage by Case-3, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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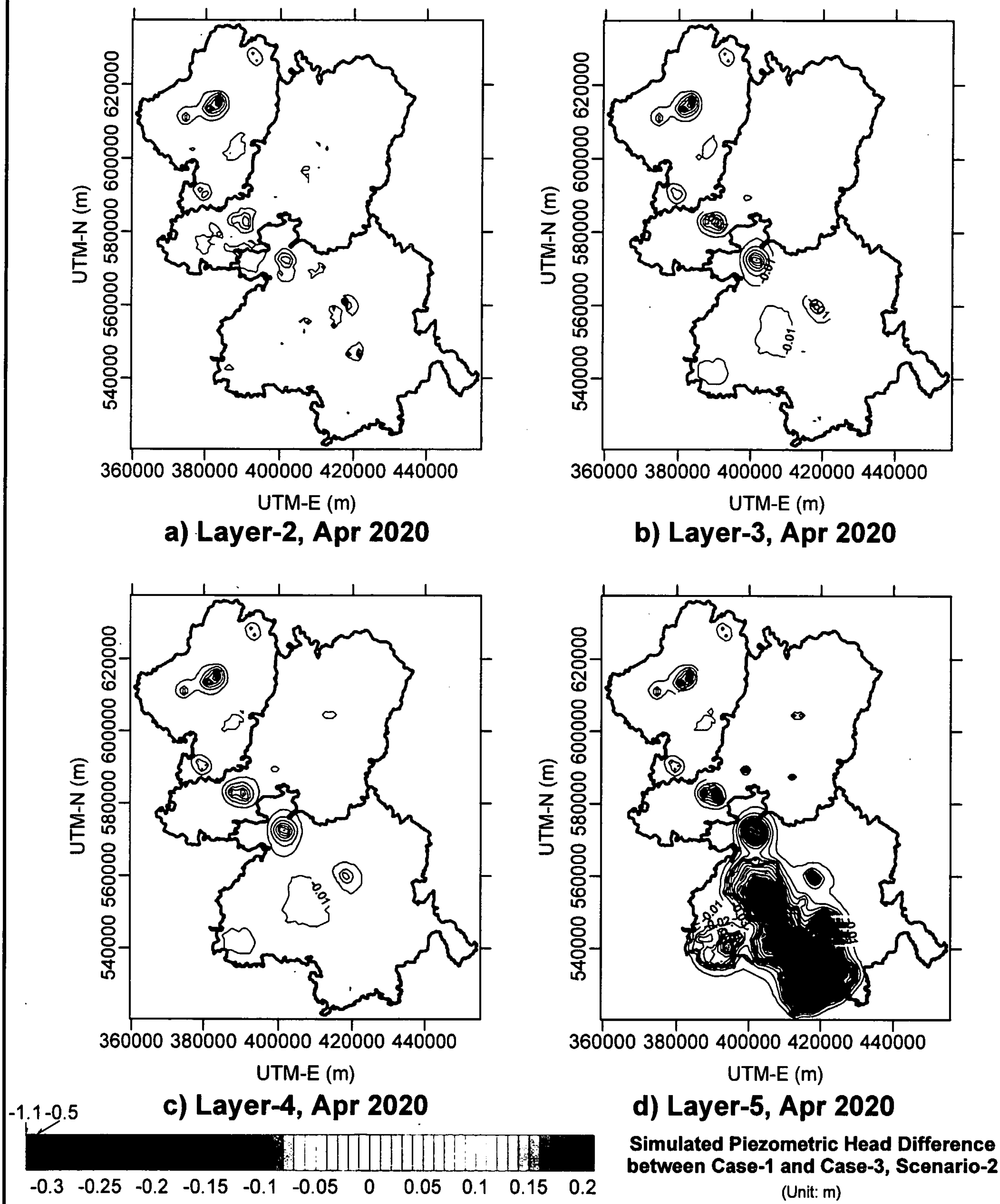

Figure 8.2.35	Difference of Simulated Piezometric Heads between Case-1 and Case-3, Scenario-2 in Apr 2020
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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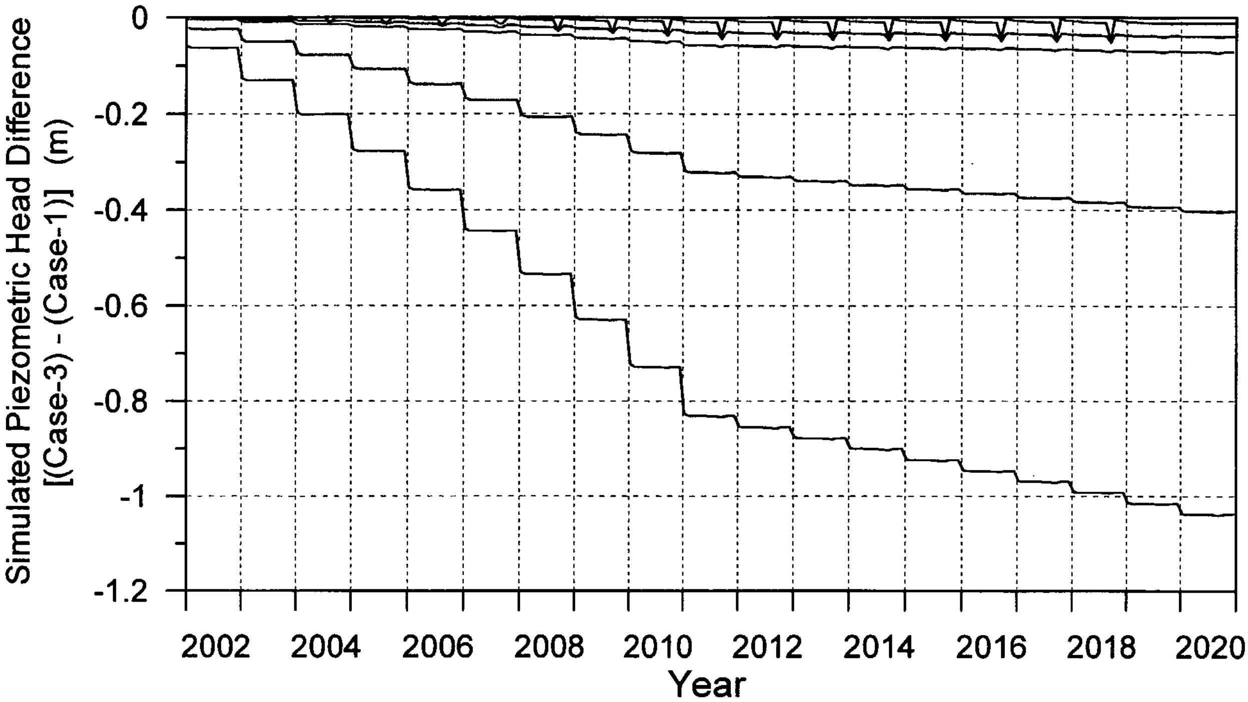
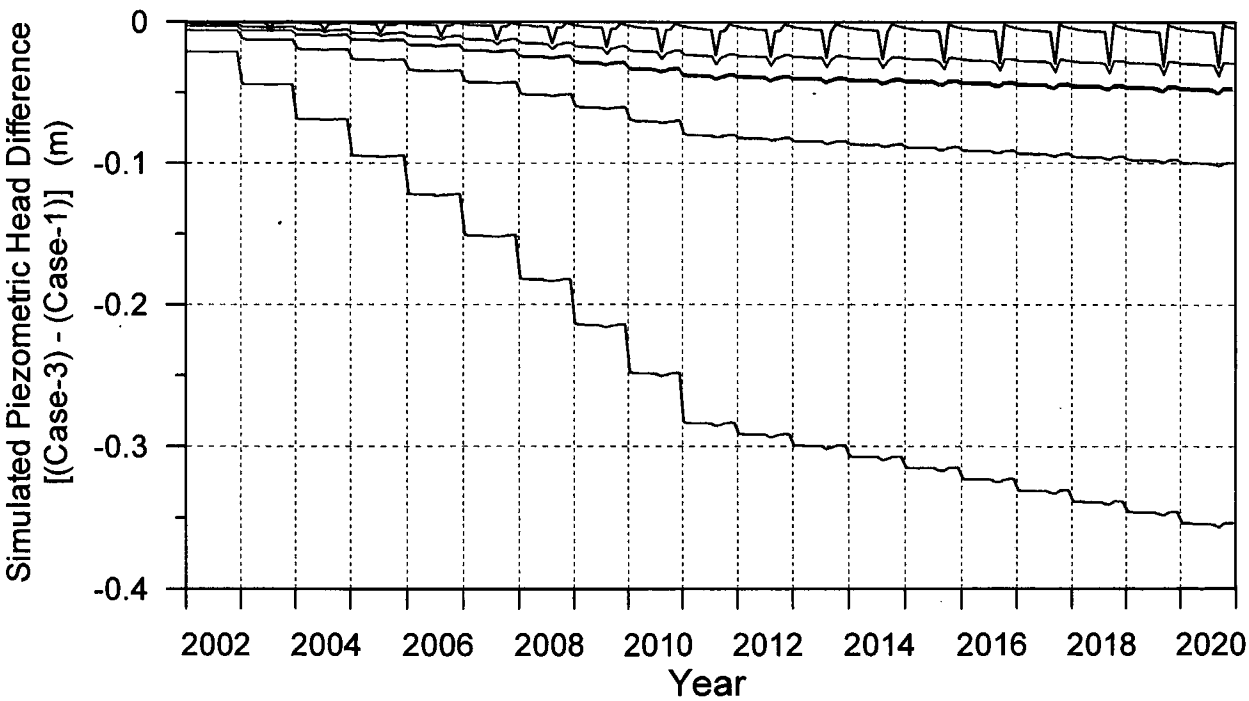


a) Chaugachha Future Well Site



b) Moheshpur Future Well Site

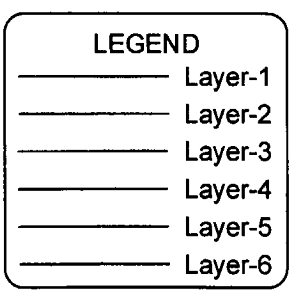


Figure 8.2.36	Simulated Piezometric Head Difference between Case-1 and Case-3, Scenario-2 [Chaugachha and Moheshpur]
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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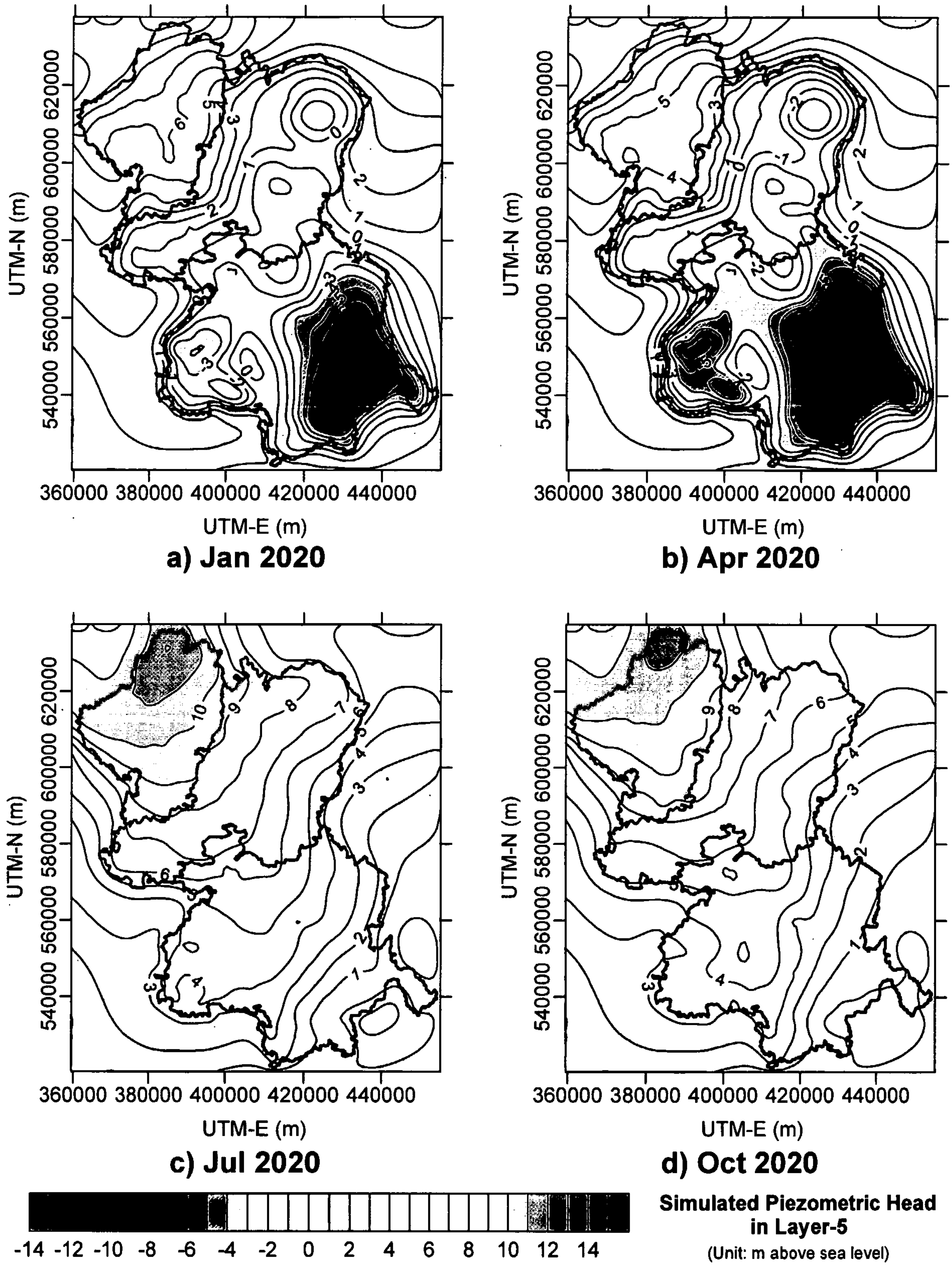

Figure 8.2.37	Distribution of Simulated Piezometric Heads in Layer-5 in 2020 by Case-3, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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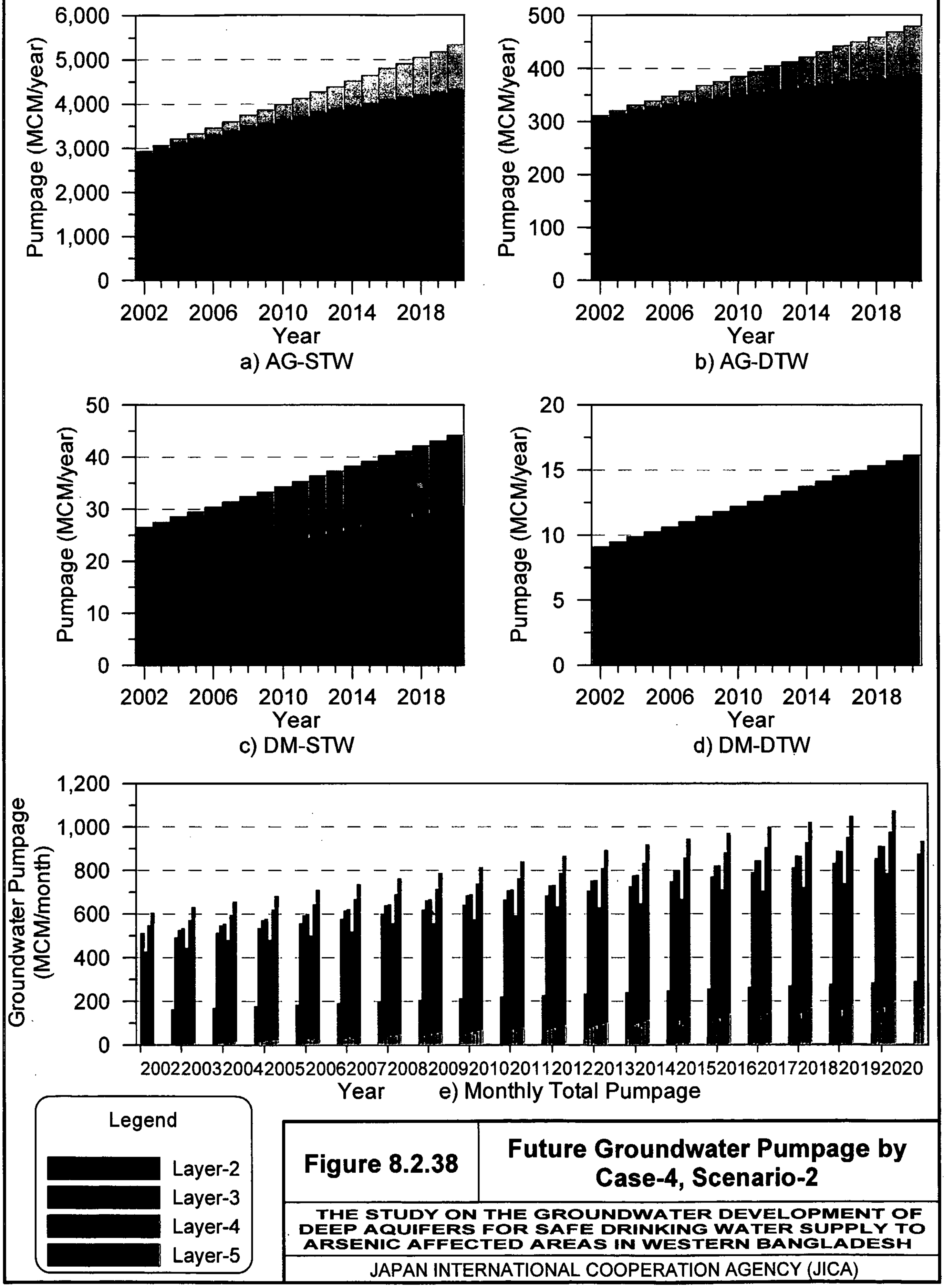


Figure 8.2.38	Future Groundwater Pumpage by Case-4, Scenario-2
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

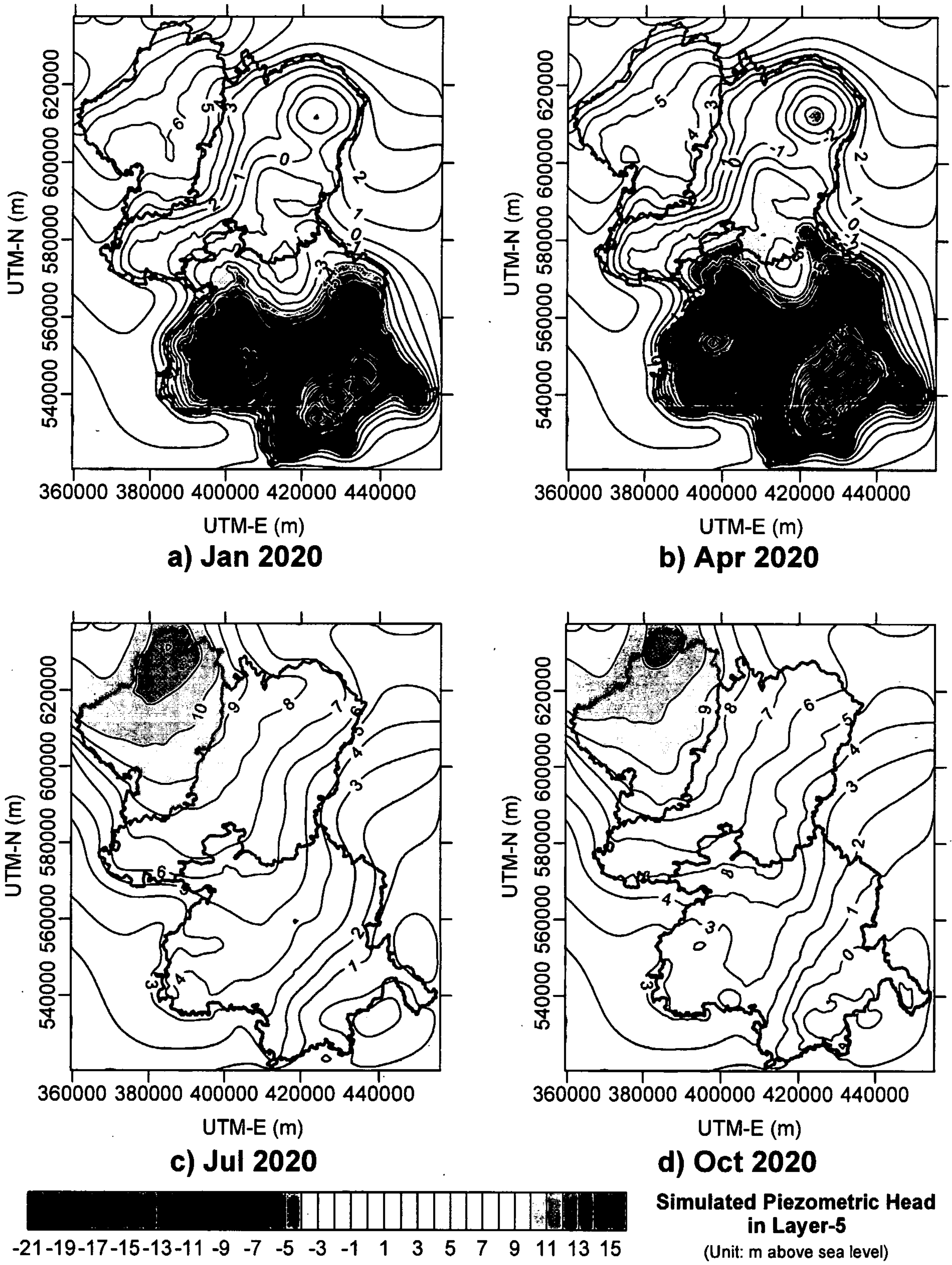


Figure 8.2.39	Distribution of Simulated Piezometric Heads in Layer-5 in 2020 by Case-4, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

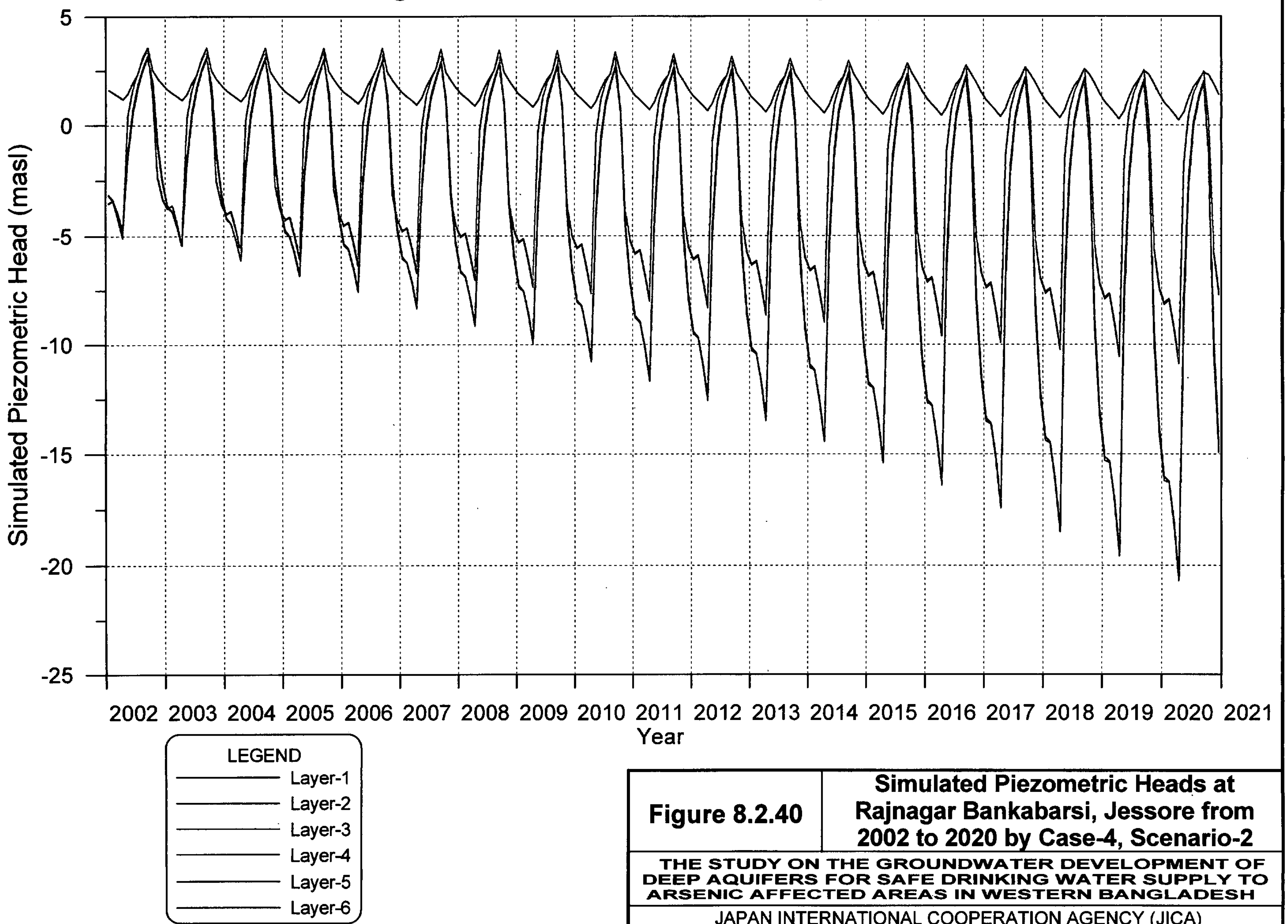
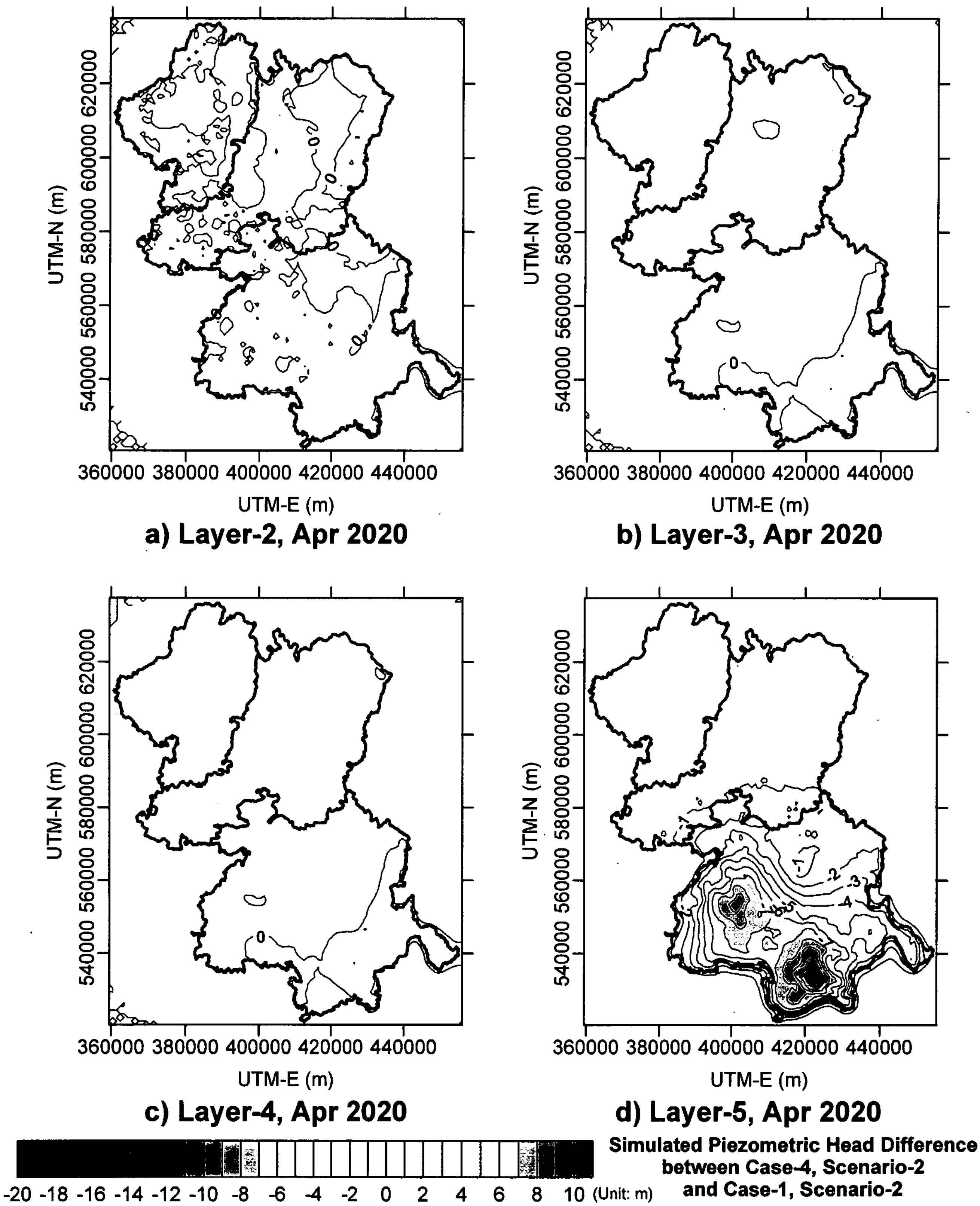


Figure 8.2.40	Simulated Piezometric Heads at Rajnagar Bankabarsi, Jessore from 2002 to 2020 by Case-4, Scenario-2

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



Simulated Piezometric Head Difference between Case-4, Scenario-2 and Case-1, Scenario-2

Figure 8.2.41	**Difference of Simulated Piezometric Heads between Case-4, Scenario-2 and Case-1, Scenario-2 in Apr 2020**
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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8.2.5 Vertical 2-D Regional Model

1) Purpose

The Vertical 2-D Regional Model was constructed to simulate vertical groundwater flow across the study area. The model can also simulate the movement of groundwater contaminated by arsenic. The vertical 2-D models are widely used for simulating hydrogeologically controlled groundwater flow and the occurrence of land subsidence, saline water intrusion, etc. Based on the computed piezometric heads, a solute transport program can simulate the movement of arsenic contaminated water under some assumed conditions. The results of the vertical 2-D regional simulation help to understand the transport mechanism of arsenic contaminated groundwater and the future impact of deep groundwater development.

2) Hydrogeological Modeling

As mentioned before, the subsurface geology in the study area can be divided into 5 geologic formations up to a depth of 300 m. Further, the facies of each geologic formation can be identified as shown in the geological profiles. In the modeling study, the geological profile along B-B' line, which is shown in Figure 8.2.42 with the location map and aquifer classification, is used to construct the model.

Figure 8.2.43 shows the model grid used for the Vertical 2-D Regional Model. The width of the modeled domain is 100,000 m (= 100 km). The model takes into account the hydrogeologic conditions up to a depth of 400 m. Each model cell has a width of 1,000 m along the X-axis. The thickness of cells above a depth of 100 m is 5 m, and those below the depth are 10 m so as to express the actual hydrogeologic conditions in A1 and A2 members in A formation and B formation. The total number of cells is 100 columns x 50 layers = 5,000.

Figure 8.2.44 shows the assignment of facies and stratigraphic boundaries in the model. The assignment was made based on the geological profile along B-B' line. The facies are categorized into 7 facies, viz. clay to silt, silt rich alternation, sand rich alternation, very fine to fine sand, fine to medium sand, medium to coarse sand, and gravel. The facies of the deeper portion below 300 m were estimated from the resistivity profile prepared by the TEM prospecting. This portion may belong to E formation, however, it is named as E' formation in the model. In the model, the occurrence of the clayey layer in C formation, which separates deep aquifer from shallow aquifer in the southern part of the study area, is clearly indicated.

3) Model Calibration

It is very important to calibrate the model by imputing historical groundwater pumpage and recharge data. In the study, the model calibration was performed on a monthly basis for a period from January 1983 to December 2001 (19 years = 228 steps). The groundwater pumpage for irrigation and domestic use were estimated using the GIS database system, land use conditions by satellite imagery interpretation, and existing statistical data. The groundwater pumpage data used in the 3-D Regional Model were arranged for the vertical model. Figure 8.2.45 shows the location of the V2D Regional Model with the pumped cells used for the pumpage data of the vertical model.

The groundwater pumpage data for the 3-D model layer were assigned to each model cell by considering the hydraulic conductivity of the cell. The hydraulic conductivity value of each facies was set based on the apparent hydraulic conductivity values obtained from the pumping test. The pumpage of the particular 3-D model layer is distributed to the cells belonging to the corresponding formation in the vertical model. The amount of assigned pumpage to a cell is proportional to its hydraulic conductivity. It is assumed that the groundwater is not extracted from clay to silt cells. Figure 8.2.46 shows the vertical distribution of groundwater pumpage estimated for the month of December 2001. It is noted that the groundwater pumpage of production wells in Jessore and Jhenaidah Pourashavas was also taken into account.

As a result of the model calibration, some of the unreliable parameter values were modified within the possible range of variation. The modified parameters were vertical hydraulic conductivity and specific storage. Table 8.2.6 summarizes the identified geohydrologic parameters input to the model.

The constant head boundary was assigned to the top of the model layer, assuming that the groundwater levels in the clay layer are almost constant. The heads at the constant head boundaries are given considering the topographic elevation and average depth to the groundwater level in unconfined aquifers. The general head boundaries are assigned to both sides of the model perimeter (J = 1 and J = 100) to express the continuity of the aquifer system. At the bottom of the model (K = 50), no flow boundaries are assigned.

Table 8.2.6 Identified Input Parameters for Vertical 2-D Regional Model

3D Model Layer	Hydrogeologic Unit	Geohydrologic Parameter	Facies 1 Clay-Silt	2 Silt rich Alt.	3 Sand rich Alt.	4 vf-f Sand	5 f-m Sand	6 m-c Sand	7 Gravel
Layer-1	A formation (A1 member)	kh (m/d) kv (m/d) Ss (m^{-1}) kh/kv	ID: 101 0.01 to 0.03 0.002 to 0.006 1.00E-02 5	-	-	ID: 104 0.5 0.1 7.50E-04 5	-	-	-
Layer-2	A formation (A2 member)	kh(m/d) kv(m/d) Ss(m^{-1}) kh/kv	ID: 201 0.009 0.0018 6.75E-03 5	-	-	ID: 204 1.5 0.15 6.00E-04 10	ID: 205 5 2.5 5.00E-04 2	-	-
Layer-3	B formation	kh (m/d) kv (m/d) Ss (m^{-1}) kh/kv	ID: 301 0.0075 0.0015 5.00E-03 5	-	-	ID: 304 2 0.2 5.00E-04 10	ID: 305 6 3 3.00E-04 2	ID: 306 25 12.5 1.00E-04 2	-
Layer-4	C formaton	kh (m/d) kv (m/d) Ss (m^{-1}) kh/kv	ID: 401 0.005 0.001 3.00E-03 5	ID: 402 1 0.05 1.00E-03 20	-	ID: 404 2.4 0.24 4.00E-04 10	ID: 405 10 5 2.00E-04 2	ID: 406 100 50 1.00E-04 2	ID: 407 150 75 5.00E-05 2
Layer-5	D formation	kh (m/d) kv (m/d) Ss (m^{-1}) kh/kv	ID: 501 0.004 0.0008 1.00E-03 5	ID: 502 0.5 0.025 8.00E-04 20	ID: 503 0.6 0.04 6.00E-04 15	ID: 504 2.05 0.205 3.00E-04 10	ID: 505 8 4 1.50E-04 2	-	ID: 507 50 25 4.00E-05 2
Layer-6	E formation (above 300 m in depth)	kh (m/d) kv (m/d) Ss (m^{-1}) kh/kv	ID: 601 0.003 0.0006 2.00E-04 5	ID: 602 0.4 0.02 6.00E-04 20	ID: 603 0.45 0.03 6.75E-03 15	-	ID: 605 5 2.5 1.20E-04 2	ID: 606 10 5 8.00E-05 2	-
	E' formation (below 300 m in depth)	kh (m/d) kv (m/d) Ss (m^{-1}) kh/kv	ID: 701 0.001 0.0002 1.00E-04 5	ID: 702 0.1 0.005 4.00E-04 20	ID: 703 0.25 0.016666667 2.00E-04 15	ID: 704 0.5 0.05 1.00E-04 10	ID: 705 2.5 1.25 7.00E-05 2	ID: 706 5 2.5 5.00E-05 2	-

ID: Identification No. of Facies, kh: horizontal hydraulic conductivity, kv: veritical hydraulic conductivity, Ss: specific storage

4) Results of Historical Simulation

After the model calibration, the historical groundwater simulation was carried out. The simulation period is from January 1983 to December 2001. The simulation was carried out as a transient simulation, and the duration of the stress period was set at 28 to 31 days depending on the number of days in the month.

Figure 8.2.47 shows the simulated piezometric heads in December 2001 by the Vertical 2-D Regional Model. The depressions of the piezometric heads are located in B formation in the Keshabpur area and in B and C formations in the Jessore Pourashava area, where piezometric heads show below –1 masl. Although the groundwater pumpage is mainly distributed in A and B formations, the lowered piezometric heads below 0 masl are extended up to D formation from the Jessore Pourashava area to the Keshabpur area. Based on the distributions of the piezometric heads, the groundwater flow directions can be drawn as shown in the figure. Because the groundwater flows from the higher potential area to the lower potential area, it is estimated that the deep groundwater mainly flows upward towards the center of the piezometric depressions. The shallow groundwater moves mainly towards the center of depressions. From the groundwater flow patters, it is evaluated that shallow groundwater in A and B formations will not reach the deeper aquifers at depths below 200 m under the present conditions.

Figure 8.2.48 shows the simulated arsenic concentrations in December 2001 by the Vertical 2-D Regional Model. Since the actual arsenic contamination along the geologic profile is limited, it is assumed that the arsenic sources are located sporadically in A formation and some cells in B, C, and D formations. The simulation results show that the contaminated groundwater mainly moves vertically in the model for the 19-year simulation period, but the water does not move in a horizontal direction. This is because the vertical groundwater flow is dominant in the model. Further, although the lateral groundwater flow can be simulated by the model, the horizontal distance is very much greater than the vertical distance so that the contaminated water does not move laterally within the simulation period. In addition, the contaminated groundwater in shallow portions is extracted by the existing wells so that the shallow contaminated groundwater cannot reach the deeper potions. It is noted that the arsenic contaminated groundwater from the source located in C formation near the Jessore Pourashava production wells relatively extended in a vertical direction. This is explained by the greater advection and dispersion due to the greater seasonal fluctuations of piezometric heads in the comparatively permeable aquifer. On the other hand, the dissolved arsenic from the source in D formation moves within a very limited area, indicating that the movement of contaminated water is very small due to the smaller hydraulic conductivity and smaller hydraulic gradient under the present groundwater use conditions.

5) Results of Future Simulation

Future groundwater flows are simulated using the calibrated Vertical 2-D Regional Model. The same pumping scenarios and cases prepared for the 3-D Regional Model were used for the simulation. From the pumping scenarios and cases, the pumping plans shown in Table 8.2.7 are used in the Vertical 2-D Regional simulation.

Table 8.2.7 Future groundwater pumpage scenarios and cases used for the future simulation by Vertical 2-D Regional Model

Scenario	Scenario Description	Case	Case Description	Name of Pumpage Data
1	Continue 2001 Pumpage until 2020	1	Pump from the same aquifers	FQ-01
		2	Shift DM-STW Pumpage to Deep Aquifer (D and E formations) from 2002 to 2011	FQ-02
2	Increase Pumpage by Past Trend (Linear Projection)	1	Pump from the same aquifers	FQ-03
		2	Shift DM-STW Pumpage to Deep Aquifer (D and E formations) from 2002 to 2011	FQ-05
		4	Shift Agricultural Pumpage to Deep Aquifer (Layer-5)	FQ-09

a. Scenario-1 Simulation

The groundwater pumpage by Scenario-1 assumes that the existing pumpage in 2001 will continue until 2020. Along the Vertical 2-D Regional Model, the annual total groundwater pumpage is 59.87 MCM/year from 2002 to 2020. The pumpage in intercalary years is set at 60.14 MCM/year.

(i) Case-1, Scenario-1 Simulation

The result of the Case-1, Scenario-1 simulation shows that the future piezometric heads will gradually decline in the deeper layers in the southern part even though the future pumpage will be maintained at the same amount of 2001. Among the 12 months of a year, the lowest piezometric heads are simulated in April and the highest heads are simulated in September every year.

Figure 8.2.49 shows the distribution of groundwater pumpage and simulated piezometric heads in January. April, September, and December in 2005. Two major piezometric depressions showing below –1 masl are found at the Jessore Pourashava area and the Keshabpur area throughout the year. The lowest piezometric head in April 2005 is –6.29 masl found in B formation in the Keshabpur area. In September 2005, the simulated heads are recovered in most parts of the modeled domain because the groundwater pumpage occurs only for domestic use from the lower A formation and the upper C formation. However, the piezometric depressions still remain in the southern part showing –1 to –3 masl. In December 2005, the heads in the depressions are again lowered and the heads in B and C formations in the central part and northern part also start to decline. In 2010, although the amount of groundwater pumpage is the same as that in 2005, the piezometric depressions become wider and lowered. The area having below –1 masl in piezometric head expanded to the bottom of E formation in the Jessore Pourashava area. Some parts of E’ formation also show piezometric heads below 0 masl. The lowest simulated head in April 2010 is –6.45 masl in B formation in the Keshabpur area. In 2015, the simulated heads are gradually lowered and the area of the depressions is further expanded. The lowest piezometric heads in April 2015 is –6.53 masl. Figure 8.2.50 shows the distributions of simulated piezometric heads in 2020. The lowest head in April 2020 is –6.57 masl. The piezometric heads in E and E' formations show below 0 masl. However, it is noted that the center of depressions is still located in B formation in the Keshabpur area and the Jessore Pourashava area. Therefore, the groundwater flow directions below B formation are generally still upward.

Figure 8.2.51 shows the difference of simulated piezometric heads between 2002 and 2020 by the Case-1, Scenario-1 simulation. It is understood from the figures that the simulated heads are lowered particularly in the deeper portions of the southern to central parts of the modeled area. The maximum head difference in April is 3.29 m. This could be explained by the fact that the facies of E and E' formations in the southern to central areas are dominated by clayey layers so that the relatively higher piezometric heads remain in the beginning of the future simulation due to their small permeability. However, the heads in the clayey layers gradually decline because the groundwater is still pumped in the upper layers and the deep groundwater moves upward. The similar gradual decline in piezometric head over time can also be observed in the clayey layer of C formation in the Keshabpur area.

(ii) Case-2, Scenario-1 Simulation

Case-2 assumes that the DM-STW pumpage will shift from the lower A formation to D and E formations from 2002 to 2011. According to the assumption, 0.266 MCM/year of DM-STW will be shifted to the deep aquifers in 2005 and 0.599 MCM/year will be shifted in 2010. From 2011, all the demand for DM-STW (= 0.666 MCM/year) will be pumped from the deep aquifers.

Figures 8.2.52 and 8.2.53 show the groundwater pumpage and simulated piezometric heads in 2005 and 2020, respectively. In April 2005, the maximum groundwater pumpage per cell from the deep aquifers is 19.7 m^3/day. Compared with the simulation result of Case-1, the piezometric heads in the deep layers slightly decline and the areas below –1 masl in D and E formation are slightly expanded. The maximum pumpage per cell in April of 2010 is 44.2 m^3/day, and the maximum pumpage in April from 2011 to 2020 is 49.2 m^3/day. In 2020, the simulated heads show below –2 masl in D and E formation in the Jessore Pourashava area.

Figure 8.2.54 shows the difference of piezometric heads between Case-1 and Case-2, Scenario-1 in 2020. In December 2020, the maximum head difference is 0.88 m in E formation in the Jessore Pourashava area. The influence of shifting DM-STW pumpage to the deep aquifers is a more than 0.3 m decline in D, E and E' formations from southern Jhenaidah district to southern Jessore district, and 0.2 to 0.3 m in C formation in the southern Jessore district.

b. Scenario-2 Simulation

The groundwater pumpage by Scenario-2 assumes that the future groundwater pumpage will increase straightly by the past increasing trend by the linear projection. Along the Vertical 2-D Regional Model, the annual total groundwater pumpage increases from 62.76 MCM/year in 2002 to 112.00 MCM/year in 2020. The annual total pumpage in 2005, 2010, and 2015 is 70.88 MCM/year, 84.42 MCM/year, and 97.95 MCM/year, respectively.

(i) Case-1, Scenario-2 Simulation

The result of the Case-1, Scenario-2 simulation shows that the future piezometric heads will greatly decline in the model domain particularly in the Jessore area. Among the 12 months of a year, the lowest piezometric heads are simulated in April and the highest heads are simulated in September every year.

Figure 8.2.55 shows the distribution of groundwater pumpage and simulated piezometric heads in January, April, September, and December in 2005. Two major piezometric depressions showing below –1 masl are found at the Jessore Pourashava area and the Keshabpur area throughout the year. The areas of the depressions are wider than those of Case-1, Scenario-1. The lowest piezometric head in April 2005 is –7.51 masl found in B formation in the Keshabpur area. In September 2005, the simulated heads are recovered in most parts of the modeled domain; however, the piezometric depressions still remain in the southern part showing –2 to –4 masl. In December 2005, the heads in the depressions are again lowered and the heads in B and C formations in the central part and northern part also start to decline. Figure 8.2.56 shows the distributions of simulated piezometric heads in 2020. Compared with the previous years, the simulated heads are more lowered and the areas of the depressions are further expanded. It is noted that the piezometric heads in Jhenaidah district are also lowered below 0 masl and the depressions below –3 to –5 masl appears in the lower A formation to C formation by 2015. In 2020, most of the modeled domain shows below 0 masl in piezometric head. The lowest piezometric head in April 2020 is –14.27 masl. The piezometric heads in E and E' formations show below –4 masl in Jhenaidah and below –6 m in Jessore district. However, it is noted that the center of depressions is still located in B and C formations in the Keshabpur area and the Jessore Pourashava area. Therefore, that the groundwater flow directions below B formation are generally upward in this simulation.

Figure 8.2.57 shows the difference of simulated piezometric heads between 2002 and 2020 by the Case-1, Scenario-2 simulation. It is understood from the figures that the simulated heads are lowered particularly in B and C formations in the Jessore Pourashava area. The head difference is the largest in April. The maximum head difference in April is 9.45 m located in the Jessore Pourashava area. In Jhenaidah district, the head difference is 6 to 7 m in the northern part and in the southern part. In September, the head difference in the shallow zone from A to C formations becomes smaller, but the head difference of more than 5 m remains in the deeper portions particularly in Jhenaidah district.

From the simulation results, it is concluded that the piezometric heads will decline 3 to 9.5 m in most of the modeled domain for a period from 2002 to 2020 when the groundwater pumpage increases by Case-1, Scenario-2. Although the Case-1 assumes that the future pumpage will be extracted from the shallow aquifers, declines of 4 to 6 m are predicted in D and E formations by 2020. However, the centers of depressions are located in B and C formations so that the shallow groundwater above the depressions will not come down to the deep aquifers. In addition, it should be noted that the piezometric heads in the deep aquifers in Jhenaidah district are lower than the shallow ones in September 2020 so that the groundwater flow directions are downward at that time. However, it is evaluated that the amount of groundwater entering from C formation to D formation is very small due to the smaller hydraulic conductivity of D formation. Moreover, it is simulated that the groundwater once entered to the deep aquifer in a short time (= the latter part of rainy season) will again move upward for a period from the dry season to former part of the rainy season. Therefore, it is judged that the possibility of deep groundwater contamination from the shallow contaminated groundwater is very small in Case-1, Scenario-2 in Jhenaidah district.

(ii) Case-2, Scenario-2 Simulation

The Case-2 assumes that the DM-STW pumpage will shift from lower A formation to D and E formations from 2002 to 2011. According to the assumption, 0.312 MCM/year of DM-STW will be shifted to the deep aquifers in 2005 and 0.818 MCM/year will be shifted in 2010. From 2011, all the demand for DM-STW will be pumped from the deep aquifers. The DM-STW pumpage from the deep aquifers in 2015 and 2020 is 1.037 MCM/year and 1.169 MCM/year, respectively.

Figures 8.2.58 shows the groundwater pumpage and simulated piezometric heads in 2005. In April 2005, the maximum groundwater pumpage per cell from the deep aquifers is 23.0 m^3/day. The lowest simulated head in April 2005 is –7.50 masl. Compared with the simulation result of Case-1, Scenario-2, the piezometric heads in the deep layers decline and the areas below –1 masl in D and E formation are slightly expanded. Figure 8.2.59 shows the results in 2020. The maximum pumpage per cell in April of 2020 is 86.3 m^3/day. The piezometric heads in most parts of the modeled domain show below 0 masl except in September 2020. In April 2020, the piezometric heads in most parts of B and C formations show below –4 masl. In the depressions in the Jessore Pourashava area and the Keshabpur area show below –12 masl. The lowest piezometric head in April 2020 is –14.23 masl.

Figure 8.2.60 shows the difference of piezometric heads between Case-1 and Case-2, Scenario-2 in 2020. In December 2020, the maximum head difference is 1.50 m in E formation in the Jessore Pourashava area. The influence of shifting DM-STW pumpage to the deep aquifers is a more than 0.5 m decline in D, E and E' formations from southern Jhenaidah district to central Jessore district, and 0.3 to 0.4 m in C formation in the southern Jessore district.

From the simulation results, it is evaluated that the impact of shifting the DM-STW pumpage to the deep aquifers is larger compared with that of Case-2, Scenario-1. However, the distribution of piezometric heads in 2020 show that the depressions are still located in B and C formations in this case. The groundwater flow directions in the deep aquifers are generally upward towards the depressions in the shallow aquifers.

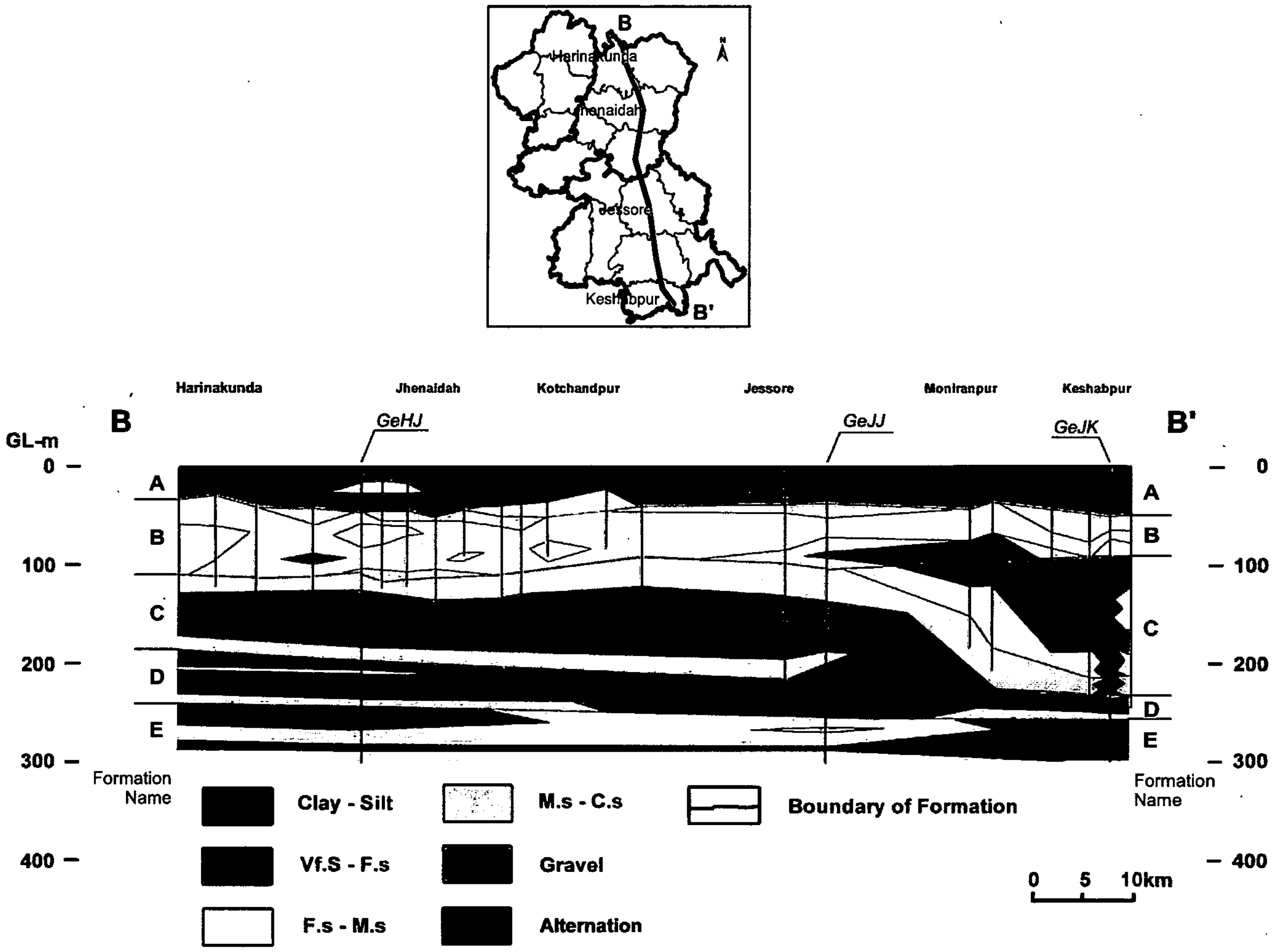
(iii) Case-4, Scenario-2 Simulation

The Case-4 assumes that the agricultural pumpage will shift to D and E formations from 2002 to 2020 at a rate of 1% every year in addition to the Case-3, Scenario-2 pumping plan. According to Case-4, the pumpage from D and E formations increases from 0.616 MCM/year in 2002 to 20.690 MCM/year in 2020. The pumpage from the deep aquifers in 2005, 2010 and 2015 is 2.783 MCM/year, 7.456 MCM/year, and 13.382 MCM/year, respectively.

Figure 8.2.61 shows the groundwater pumpage and simulated piezometric heads in 2005. In April 2005, the maximum groundwater pumpage per cell from the deep aquifers is 217.3 m^3/day. The lowest simulated head in April 2005 is –7.19 masl. The centers of the piezometric depressions are still located in B and C formations; however, the depressions have already started to expand to D and E formations. In December 2005, a new piezometric depression with heads below –3 masl is created in D and E formations in the Jessore Pourashava area. Figure 8.2.62 shows the groundwater pumpage and simulated piezometric heads in 2020. The maximum groundwater pumpage per cell from the deep aquifers in April 2020 is 1,602.8 m^3/day. The piezometric heads in the deep depressions show below –17 masl even in the rainy season. The lowest simulated head in April 2020 is –23.45 masl. The piezometric heads below –15 masl are distributed from C formation to E' formation in December 2020. The groundwater flow system has been totally disturbed by this year and it is possible for the shallow contaminated groundwater to directly intrude the deep aquifers.

Figure 8.2.63 shows the difference of piezometric heads between Case-1 and Case-4, Scenario-2 in 2020. In December 2020, the head difference of more than 14 m can be found at the northern and southern Jessore Pourashava area. Due to the shifting of 19% of the agricultural pumpage, the piezometric heads from southern Jhenaidah district to southern Jessore district are lowered more than 10 m in the dry season. Even in September 2020, the heads of the deep aquifers are 10 to 11 m lower than those in Case-1. On the other hand, the simulated heads in A to C formations are slightly recovered at 1 to 2 m. As a result, the head difference between the shallow groundwater and the deep groundwater becomes greater.

The simulation results indicate that the overexploitation of deep groundwater will cause severe depressions of piezometric head in the deep aquifers. Under the conditions, almost all the groundwater flows towards the deep depressions. This situation should be avoided in future for the sustainable use of precious groundwater resources.



Subsurface Geology and Aquifer Classification

Geologic Age	JICA Study Team (2002)		BGS/DPHE (2001)
	Subsurface Geology	Aquifer Classification	
Holocene	A formation	First Aquifer (Shallow Aquifer)	Upper shallow aquifer
	B formation		
Late Pleistocene	C formation	Second Aquifer (Middle Aquifer)	Lower shallow aquifer
Plio-Pleistocene	D formation	Third Aquifer (Deep Aquifer)	Deep aquifers
	E formation		

Figure 8.2.42 **Geological Profile (B-B') and Aquifer Classification**

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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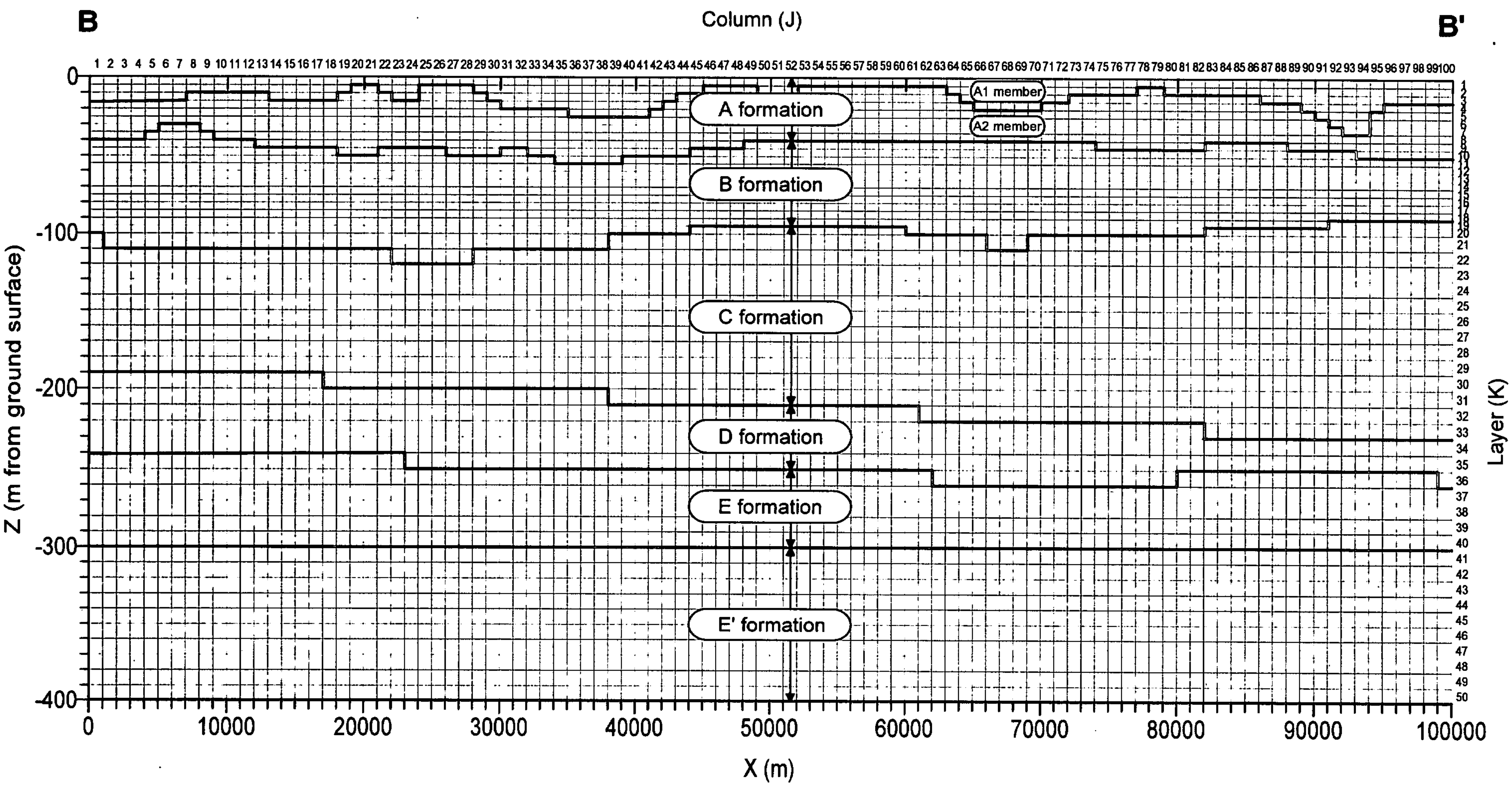

Stratigraphic Boundary

Figure 8.2.43

Model Grid for Vertical 2-D Regional Model

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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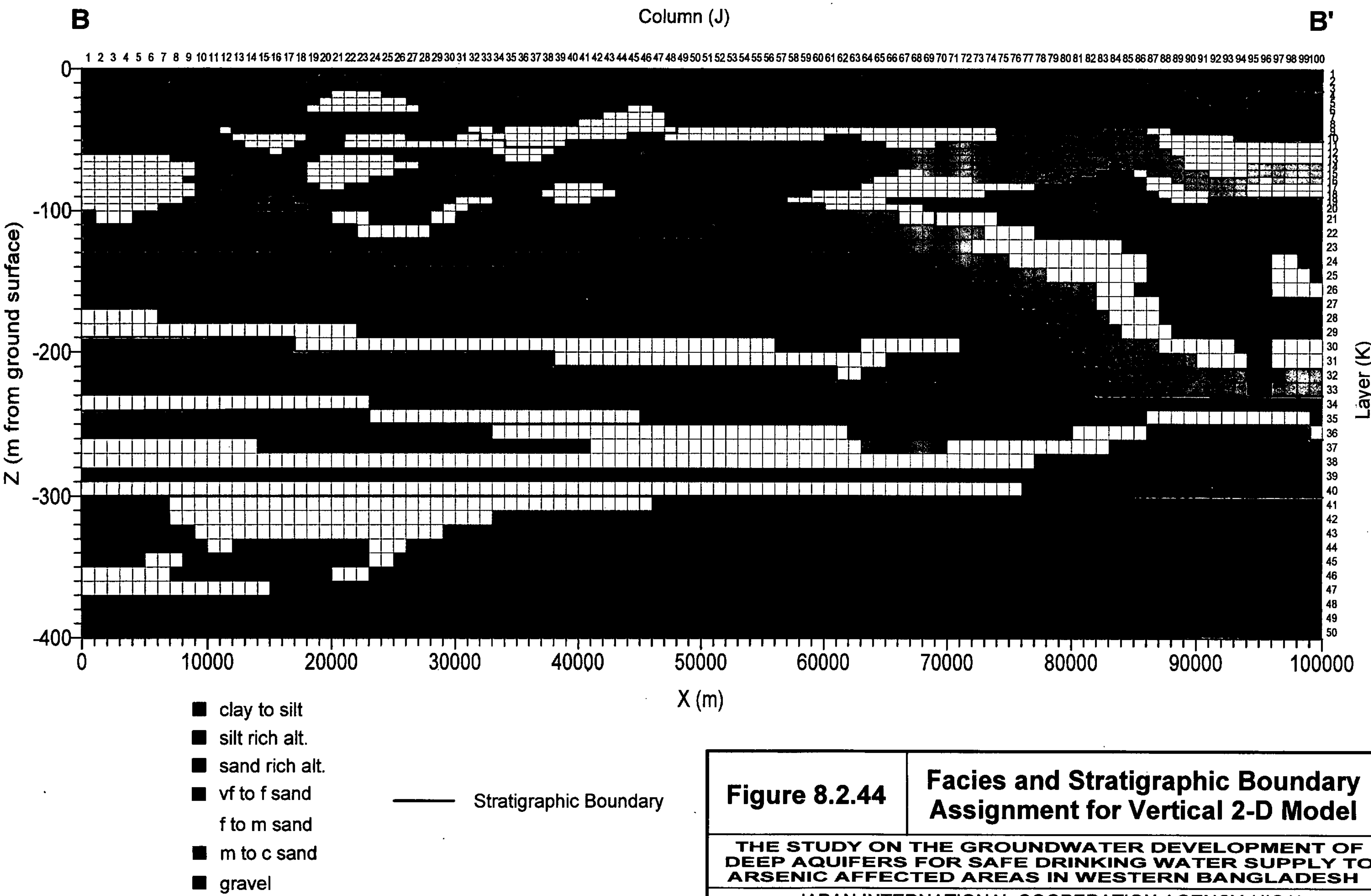

Figure 8.2.44 | **Facies and Stratigraphic Boundary Assignment for Vertical 2-D Model**

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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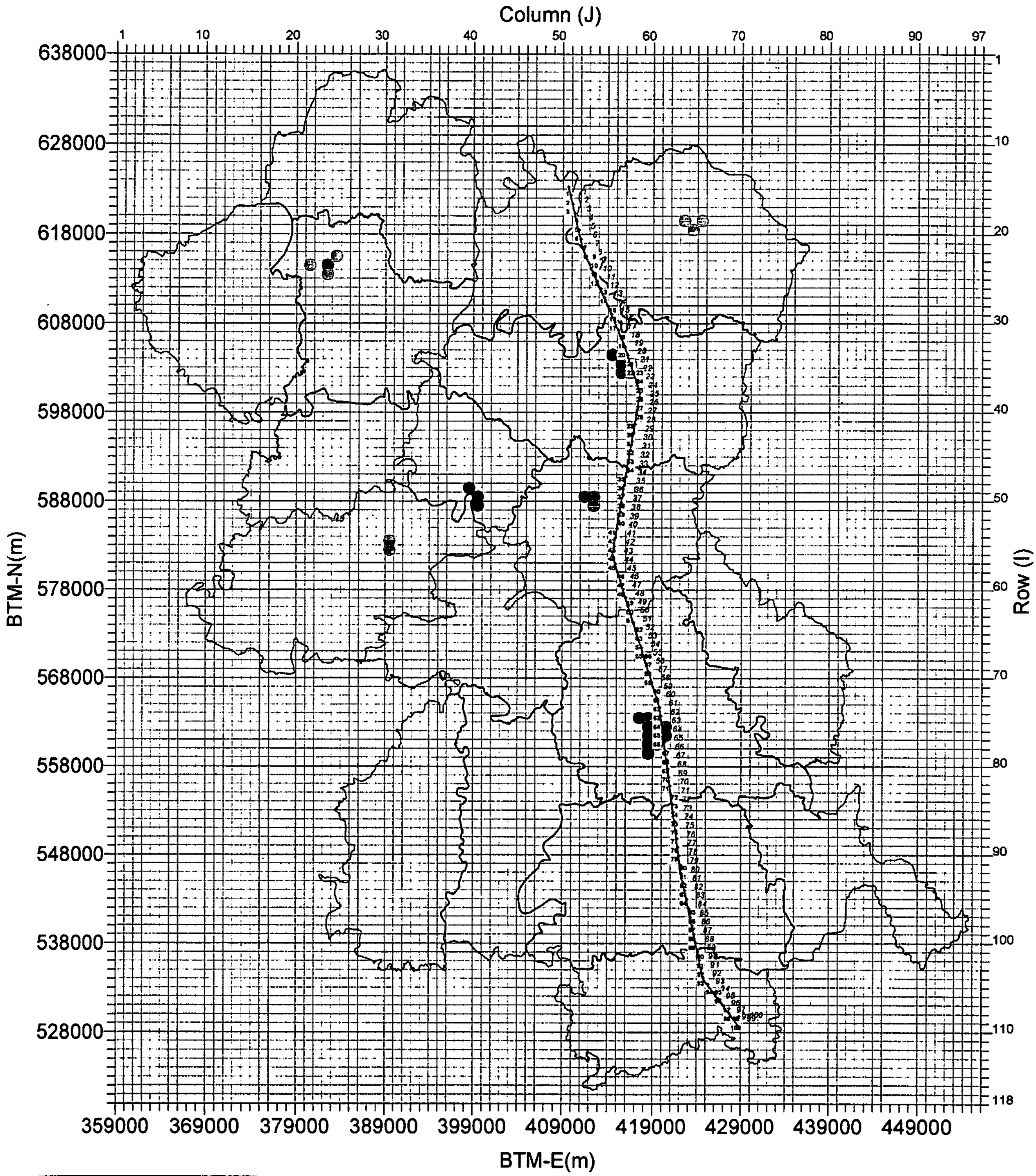

Pumpage of Pourashava Production Wells (m^3/day/cell)

- 1 to 200
- 200 to 400
- 400 to 600
- 600 to 1000
- 1000 to 3000

65 Pumped Cell of 3-D Regional Model Used for Vertical 2-D Regional Model with Corresponding Column (J) Number

28 Profile Line for V2D Regional Model with Column (J) Number

Figure 8.2.45	**Location of V2D Regional Model with Pumped Cells Used for V2D Pumpage Data**

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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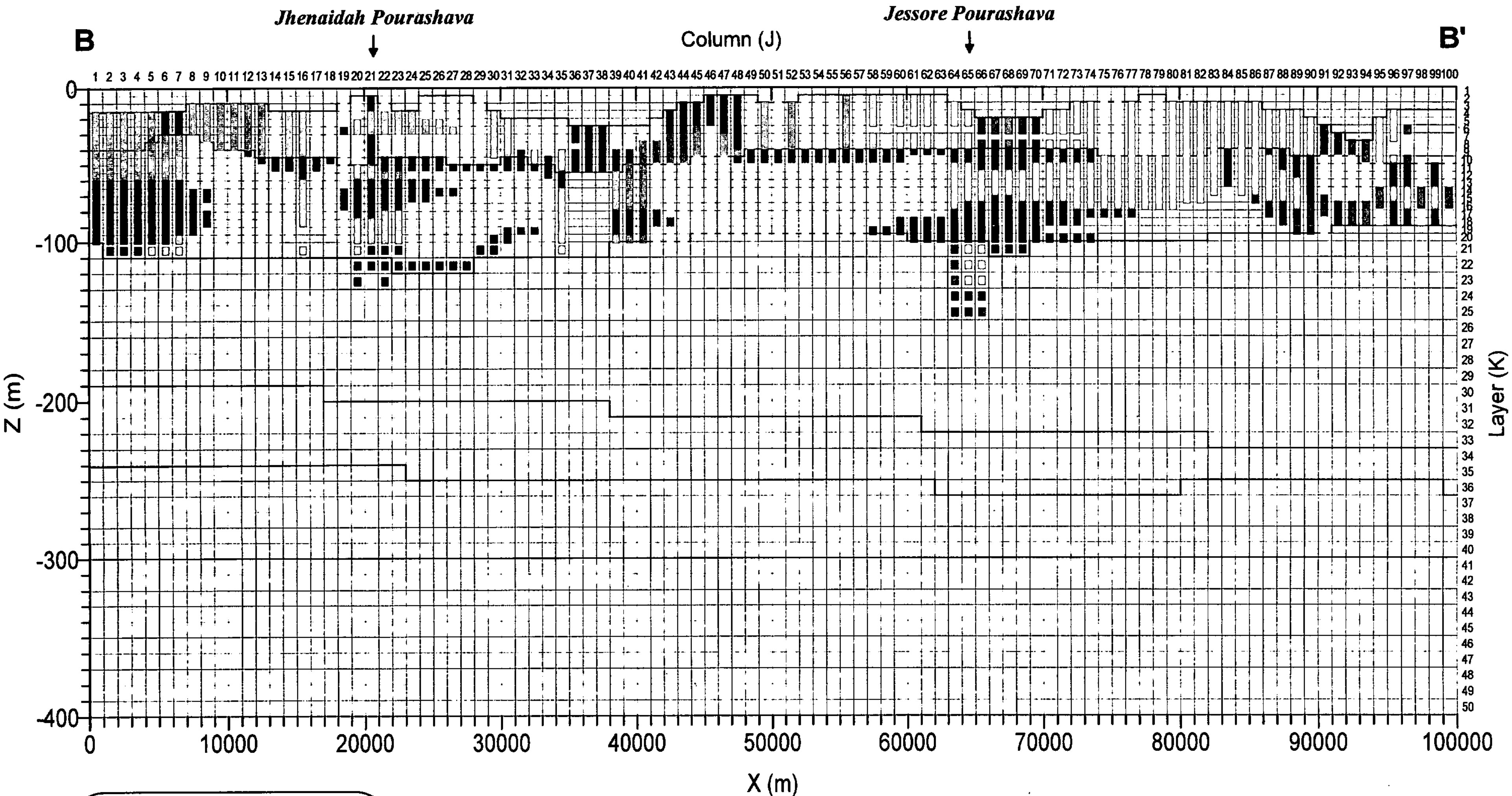

Groundwater Pumpage per Cell
(December 2001)

- 0.4 to 50 m³/day
- 50 to 100 m³/day
- 100 to 200 m³/day
- 200 to 400 m³/day
- 400 to 800 m³/day

Stratigraphic Boundary

Figure 8.2.46	Estimated Groundwater Pumpage for Vertical 2-D Model (Dec 2001)
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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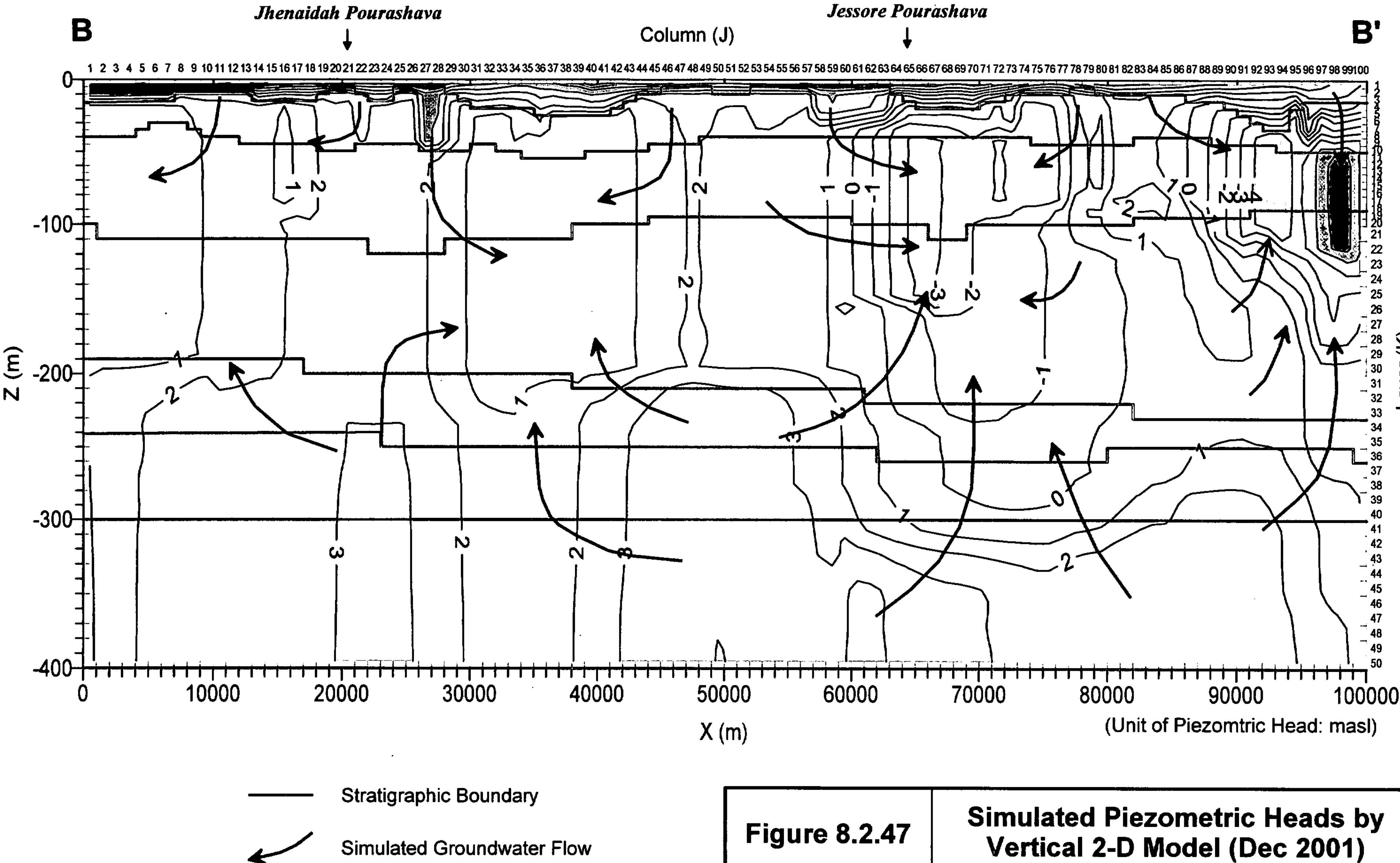

Figure 8.2.47	Simulated Piezometric Heads by Vertical 2-D Model (Dec 2001)

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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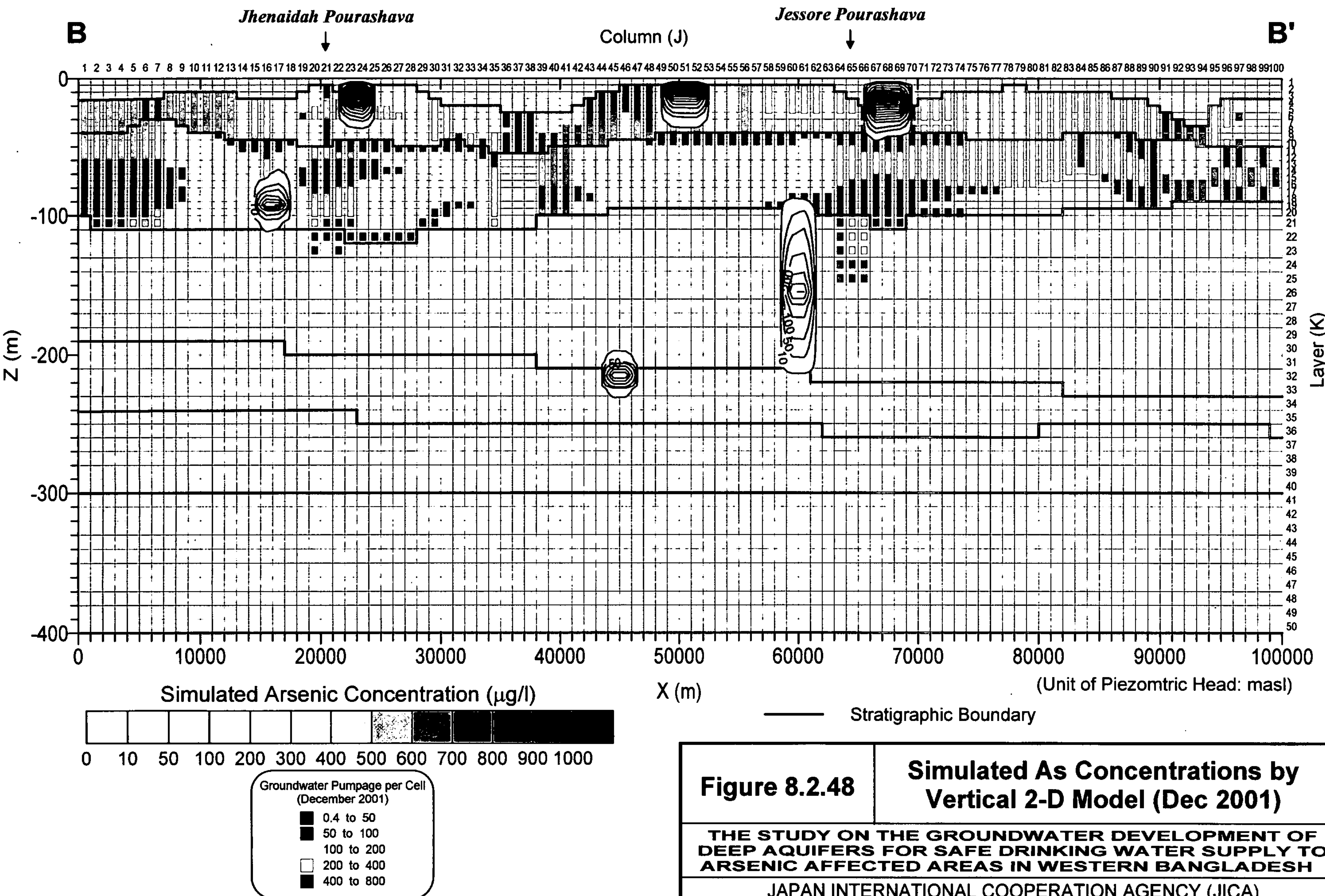
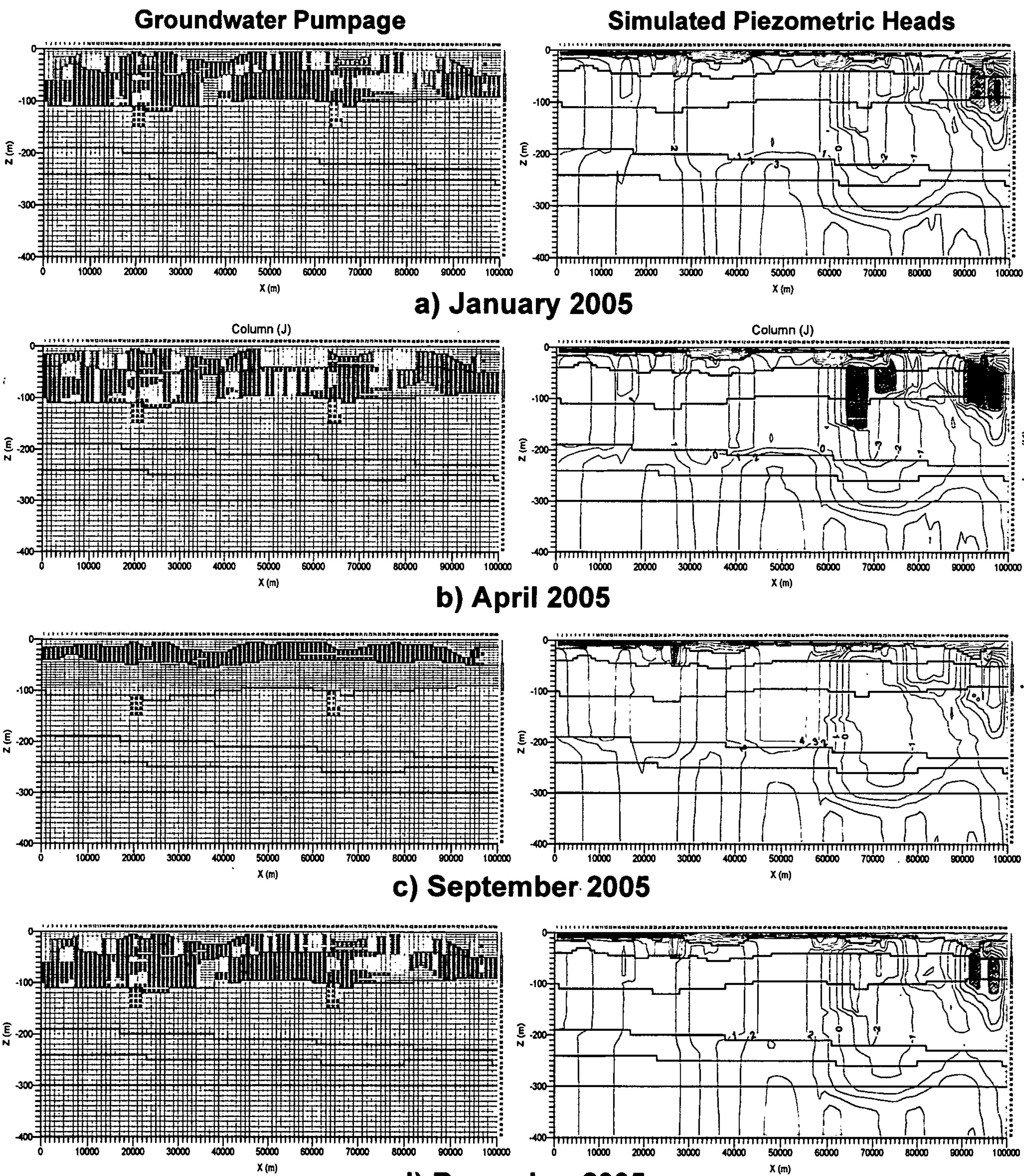


Figure 8.2.48	Simulated As Concentrations by Vertical 2-D Model (Dec 2001)
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	



Groundwater Pumpage per Cell
(Unit: m³/day)

- 0.1 to 50
- 50 to 100
- 100 to 200
- 200 to 300
- 300 to 500
- 500 to 1000
- 1000 to 2000

Simulated Piezometric Head (masl)

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10

Figure 8.2.49	Groundwater Pumpage and Simulated Piezometric Heads by Case-1, Scenario-1 in 2005

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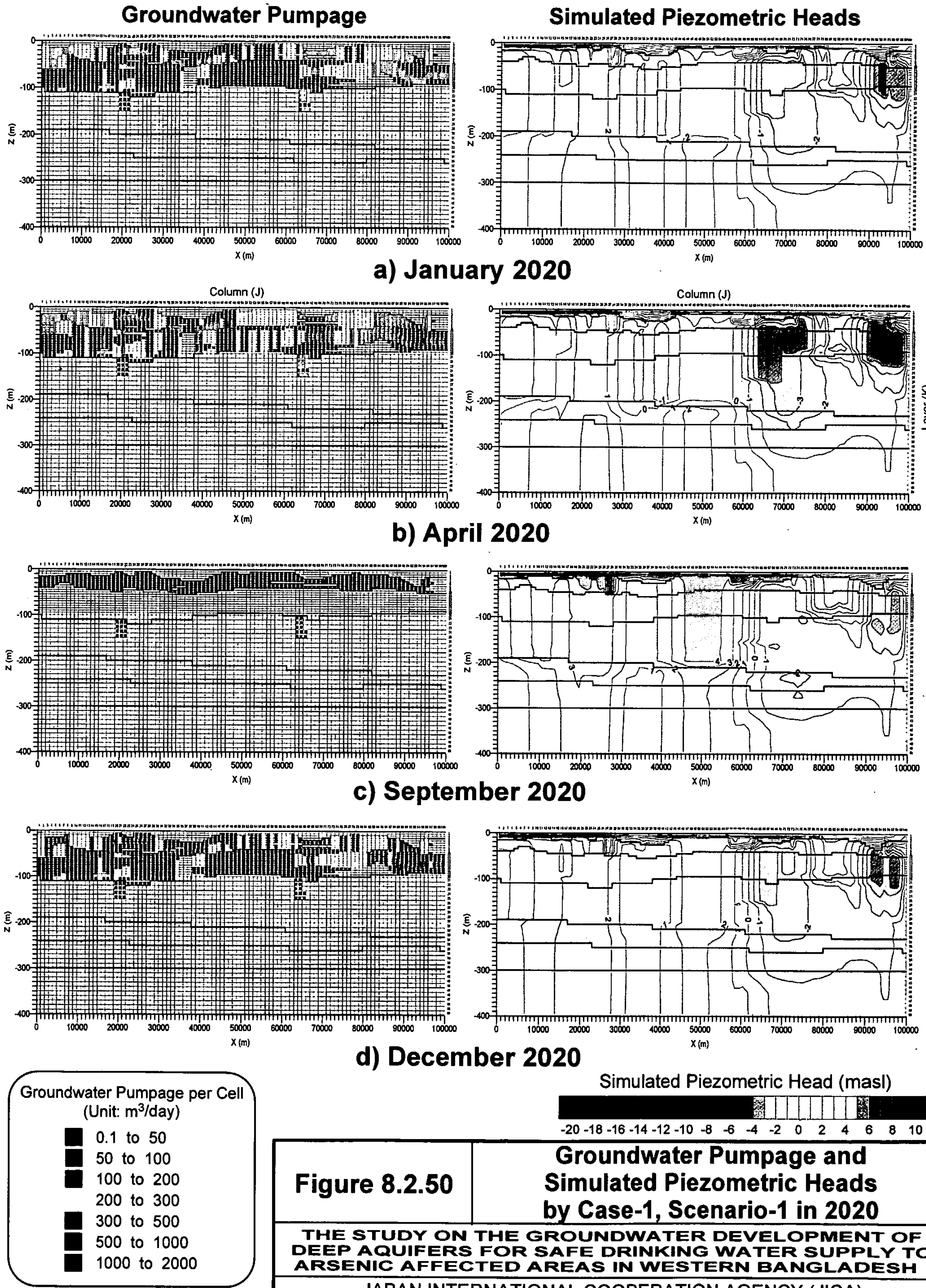

Figure 8.2.50	Groundwater Pumpage and Simulated Piezometric Heads by Case-1, Scenario-1 in 2020

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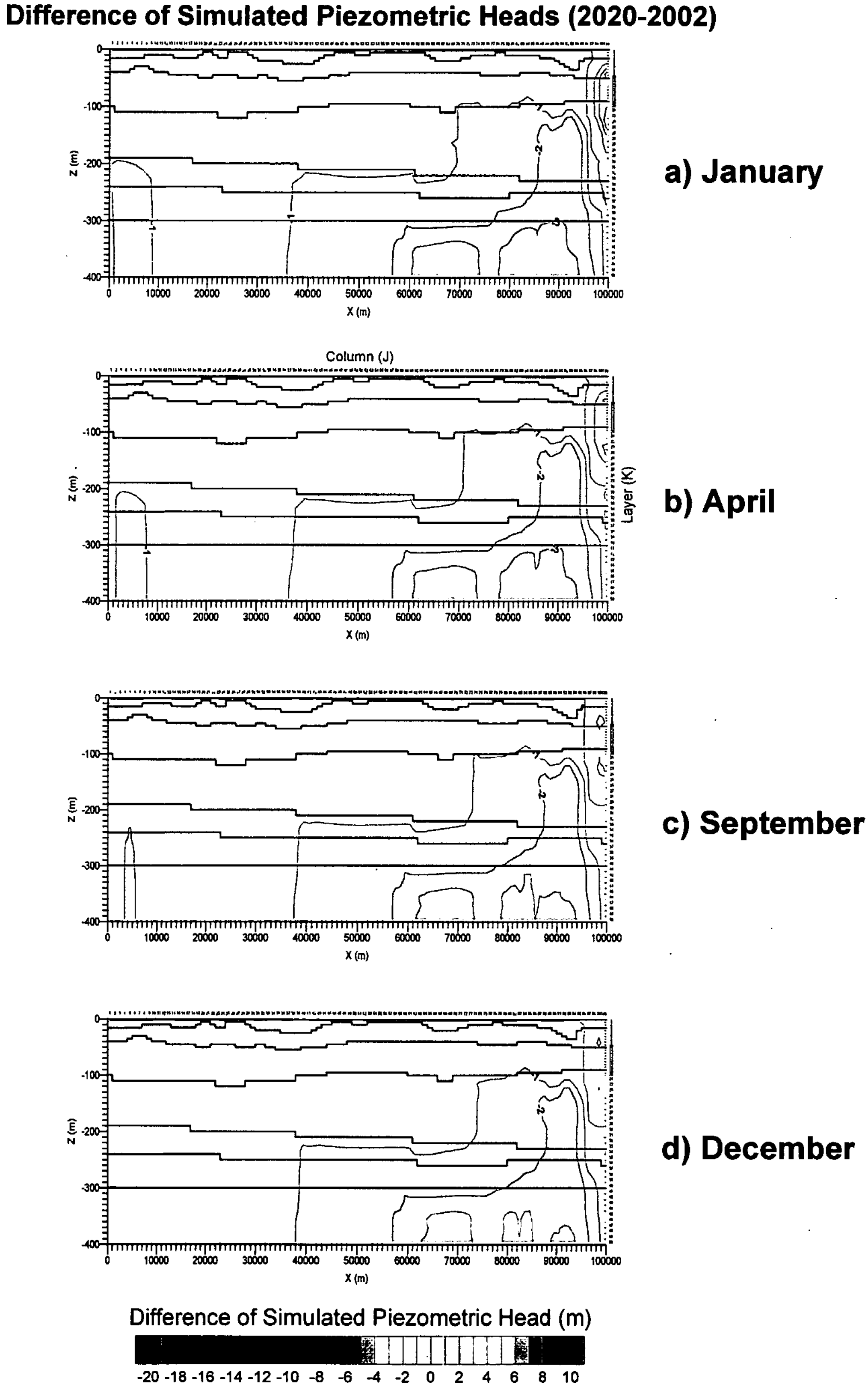

Figure 8.2.51	**Difference of Simulated Piezometric Heads between 2002 and 2020 by Case-1, Scenario-1**

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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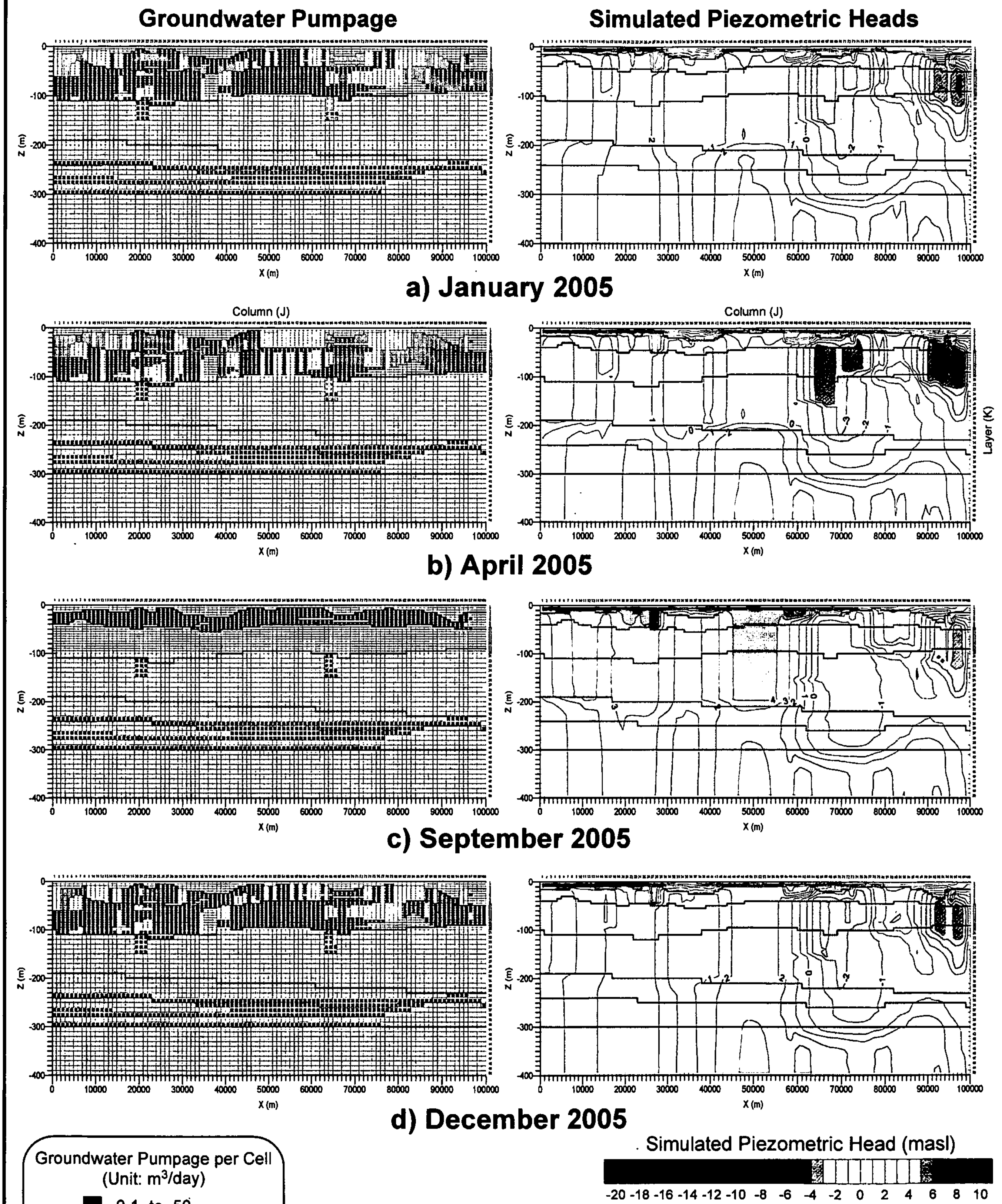

Figure 8.2.52	Groundwater Pumpage and Simulated Piezometric Heads by Case-2, Scenario-1 in 2005

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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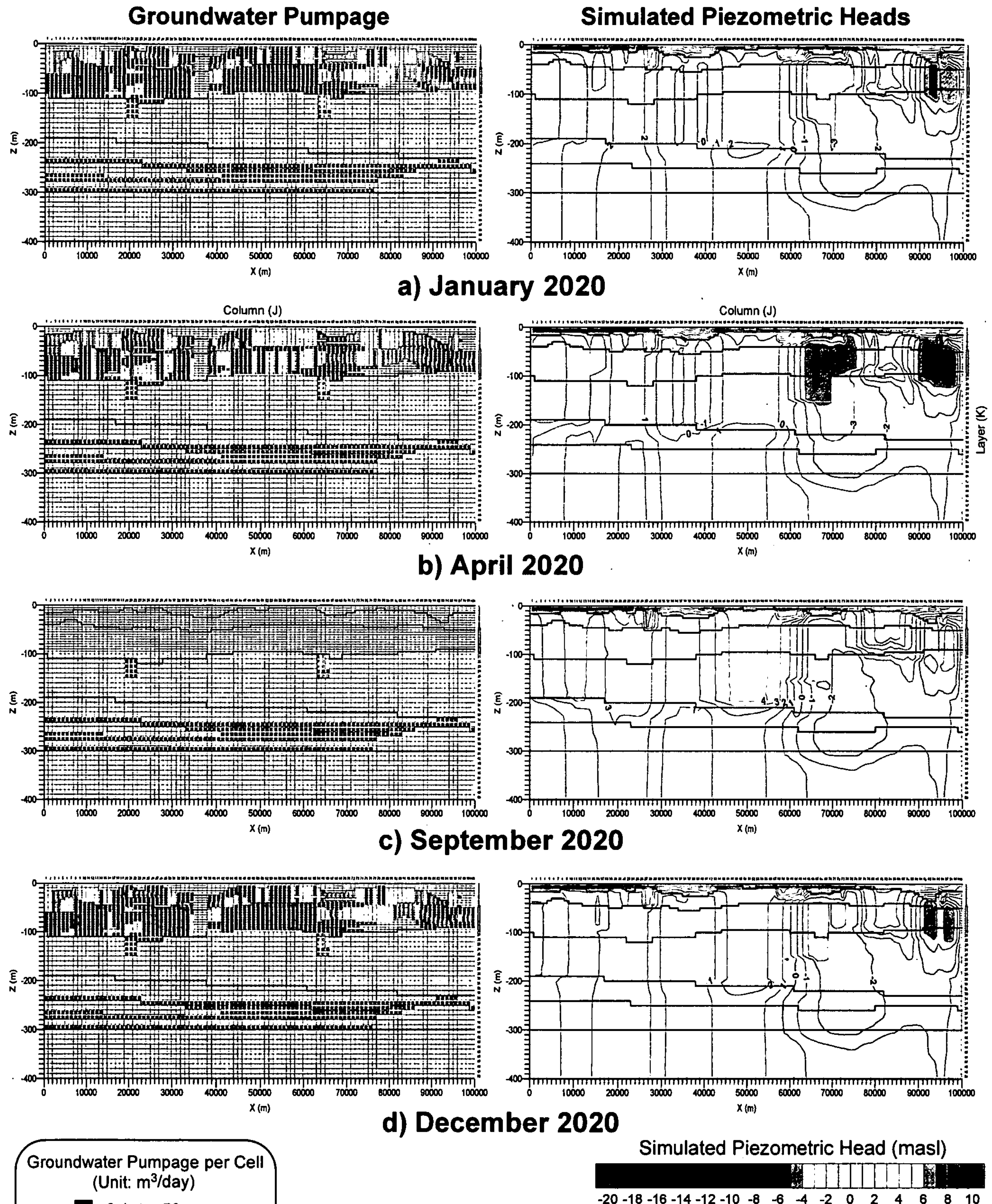

Groundwater Pumpage per Cell
(Unit: m³/day)

- 0.1 to 50
- 50 to 100
- 100 to 200
- 200 to 300
- 300 to 500
- 500 to 1000
- 1000 to 2000

Figure 8.2.53	Groundwater Pumpage and Simulated Piezometric Heads by Case-2, Scenario-1 in 2020

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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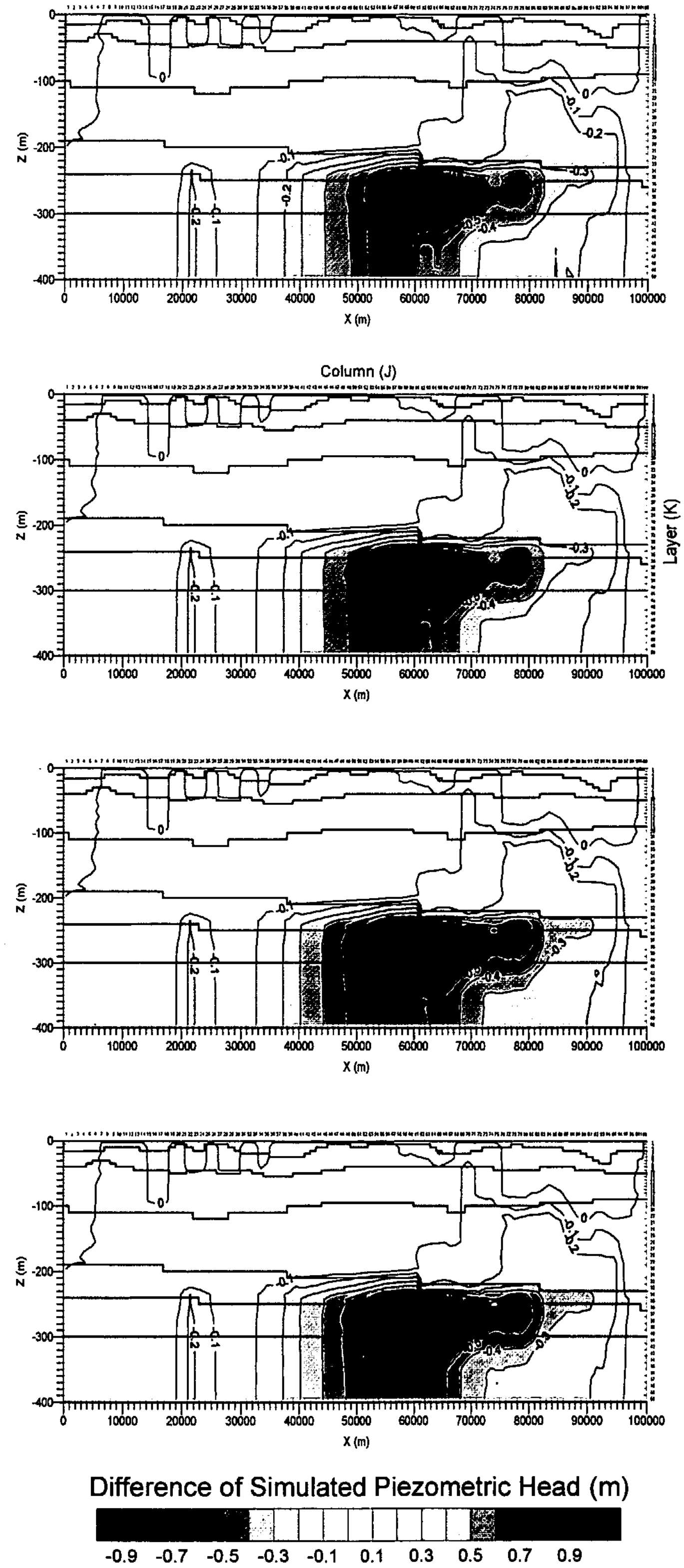
Difference of Simulated Piezometric Heads [(C2,S1) - (C1, S1)]



a) January

b) April

c) September

d) December

Figure 8.2.54	**Difference of Simulated Piezometric Heads between Case-1 and Case-2, Scenario-1 in 2020**

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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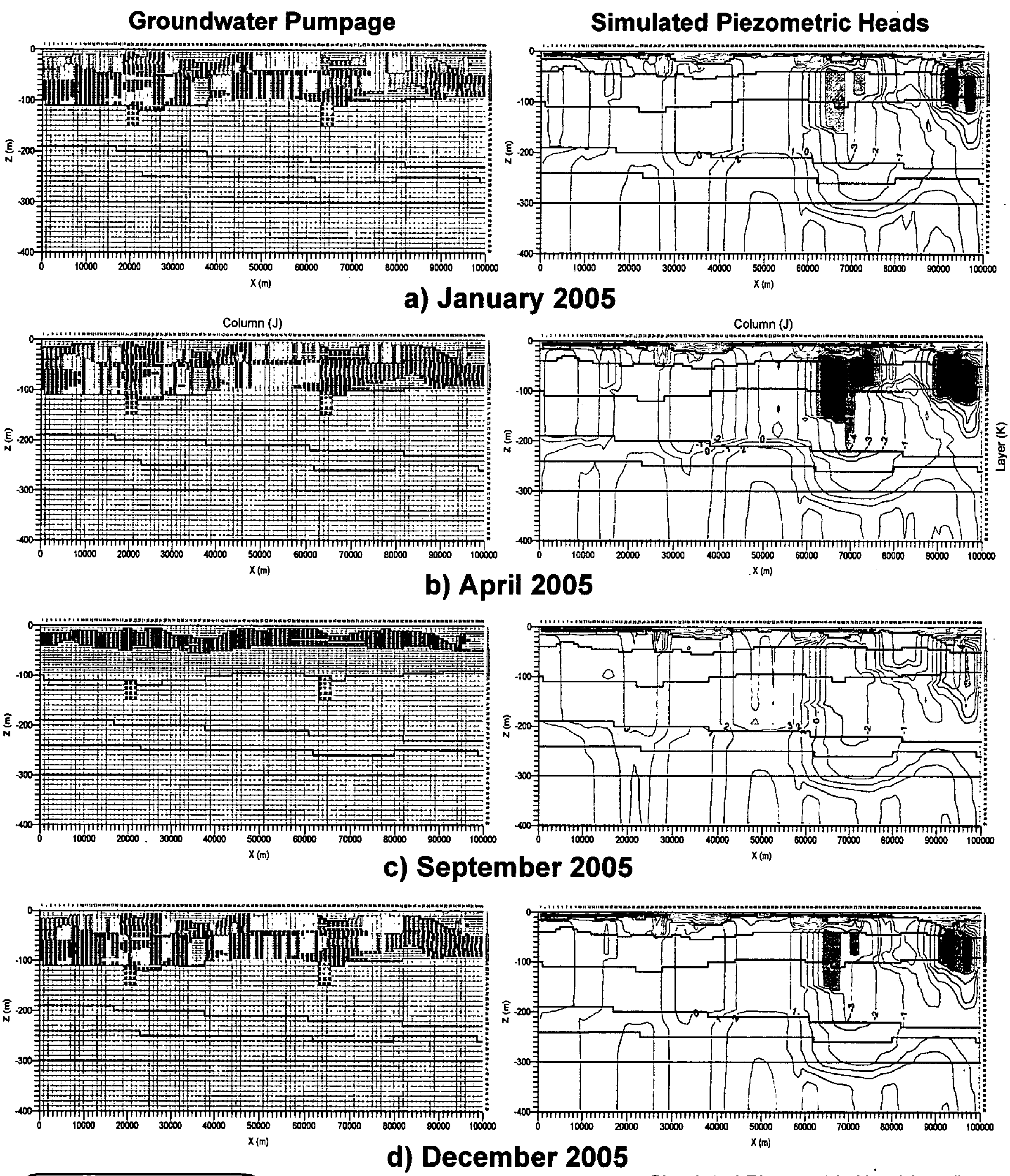

Groundwater Pumpage per Cell
(Unit: m^3/day)

- 0.1 to 50
- 50 to 100
- 100 to 200
- 200 to 300
- 300 to 500
- 500 to 1000
- 1000 to 2000

Simulated Piezometric Head (masl)

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10

Figure 8.2.55	Groundwater Pumpage and Simulated Piezometric Heads by Case-1, Scenario-2 in 2005

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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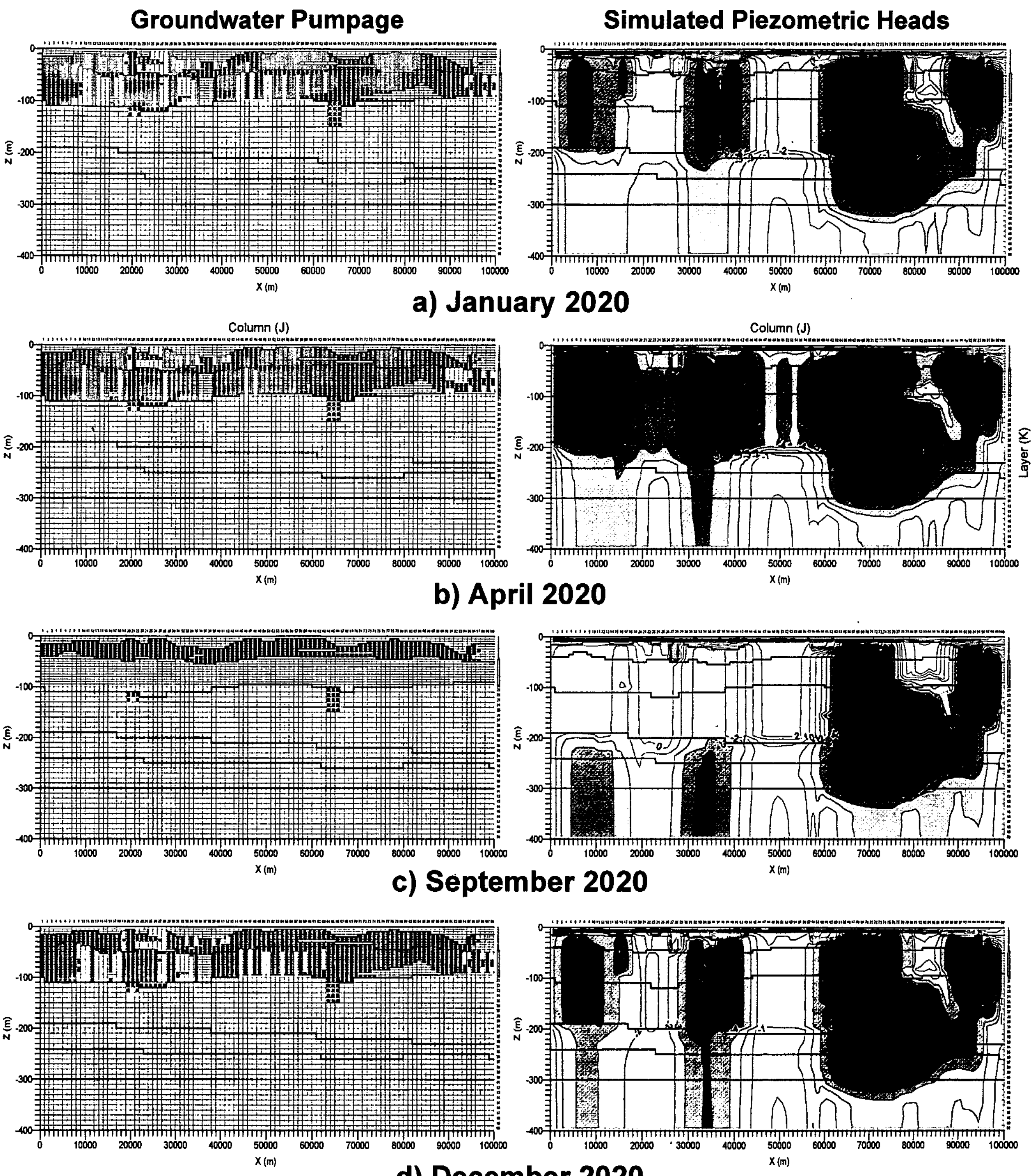

Simulated Piezometric Head (masl)

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10

Groundwater Pumpage per Cell
(Unit: m³/day)

- 0.1 to 50
- 50 to 100
- 100 to 200
- 200 to 300
- 300 to 500
- 500 to 1000
- 1000 to 2000

Figure 8.2.56	Groundwater Pumpage and Simulated Piezometric Heads by Case-1, Scenario-2 in 2020

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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Difference of Simulated Piezometric Heads (2020-2002)

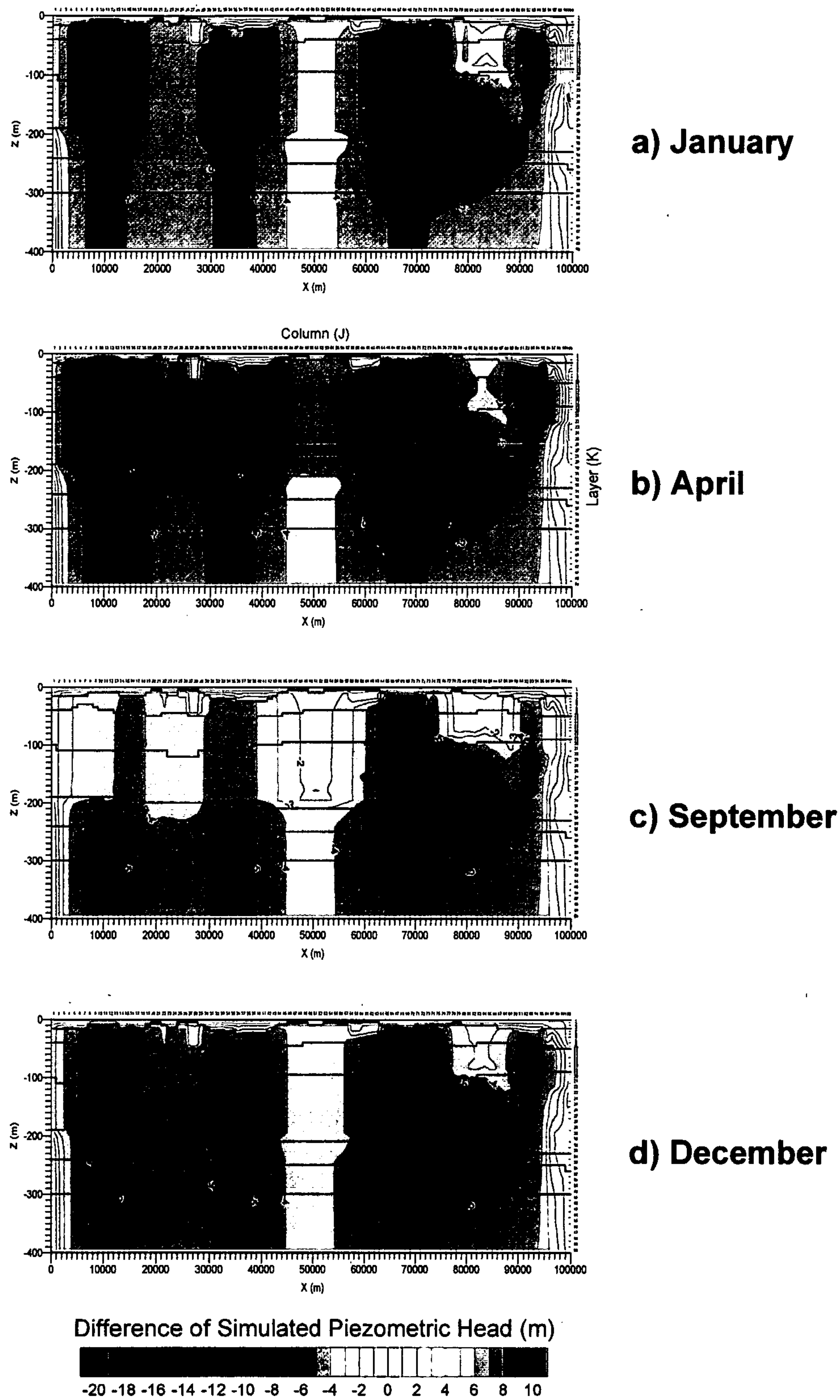

Figure 8.2.57	Difference of Simulated Piezometric Heads between 2002 and 2020 by Case-1, Scenario-2
THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH	
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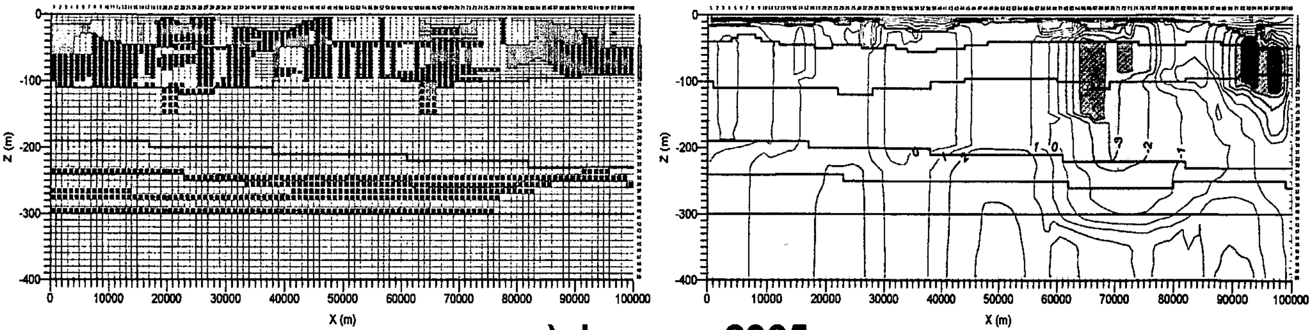
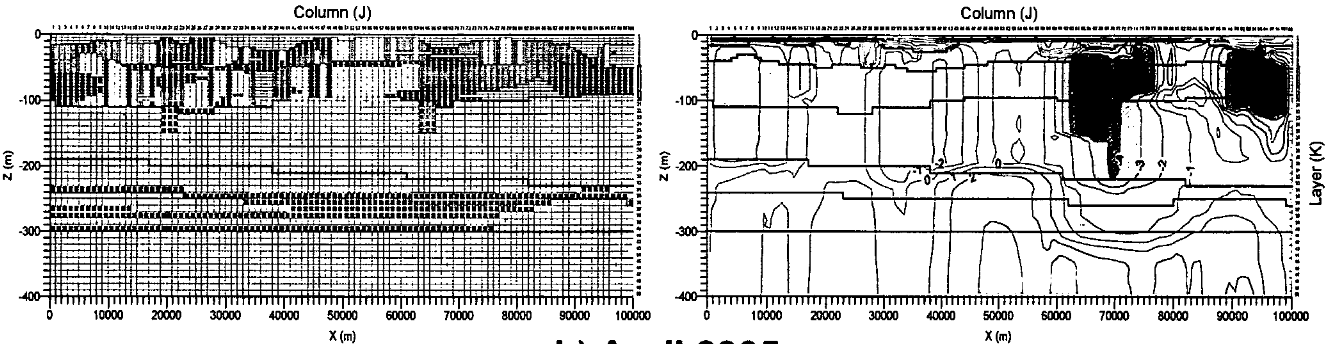
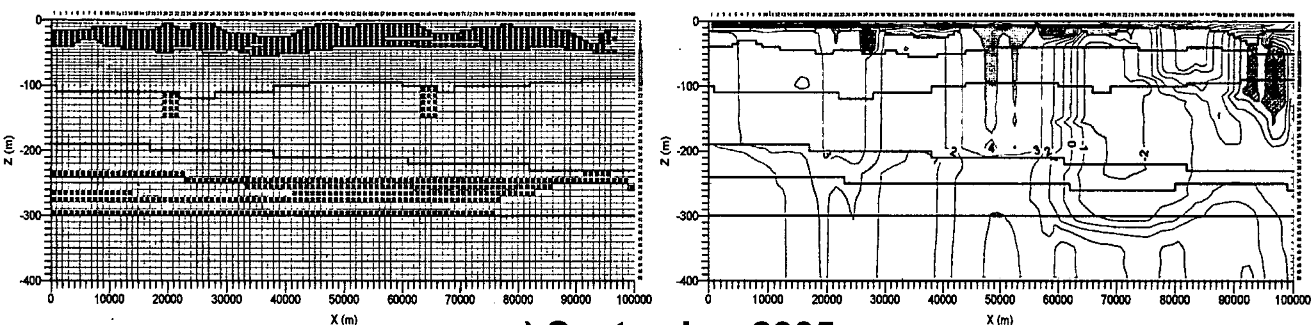
Groundwater Pumpage | Simulated Piezometric Heads



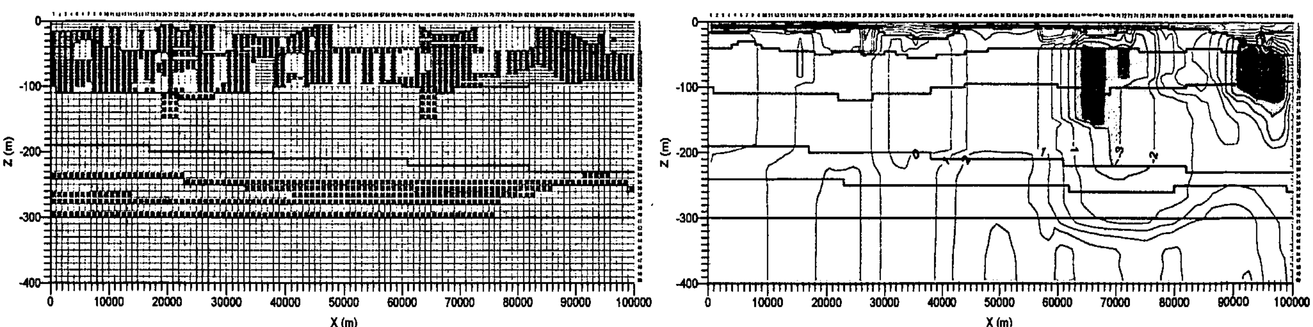
a) January 2005



b) April 2005



c) September 2005



d) December 2005

Groundwater Pumpage per Cell (Unit: m^3/day)

- 0.1 to 50
- 50 to 100
- 100 to 200
- 200 to 300
- 300 to 500
- 500 to 1000
- 1000 to 2000

Simulated Piezometric Head (masl)

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10

Figure 8.2.58	Groundwater Pumpage and Simulated Piezometric Heads by Case-2, Scenario-2 in 2005

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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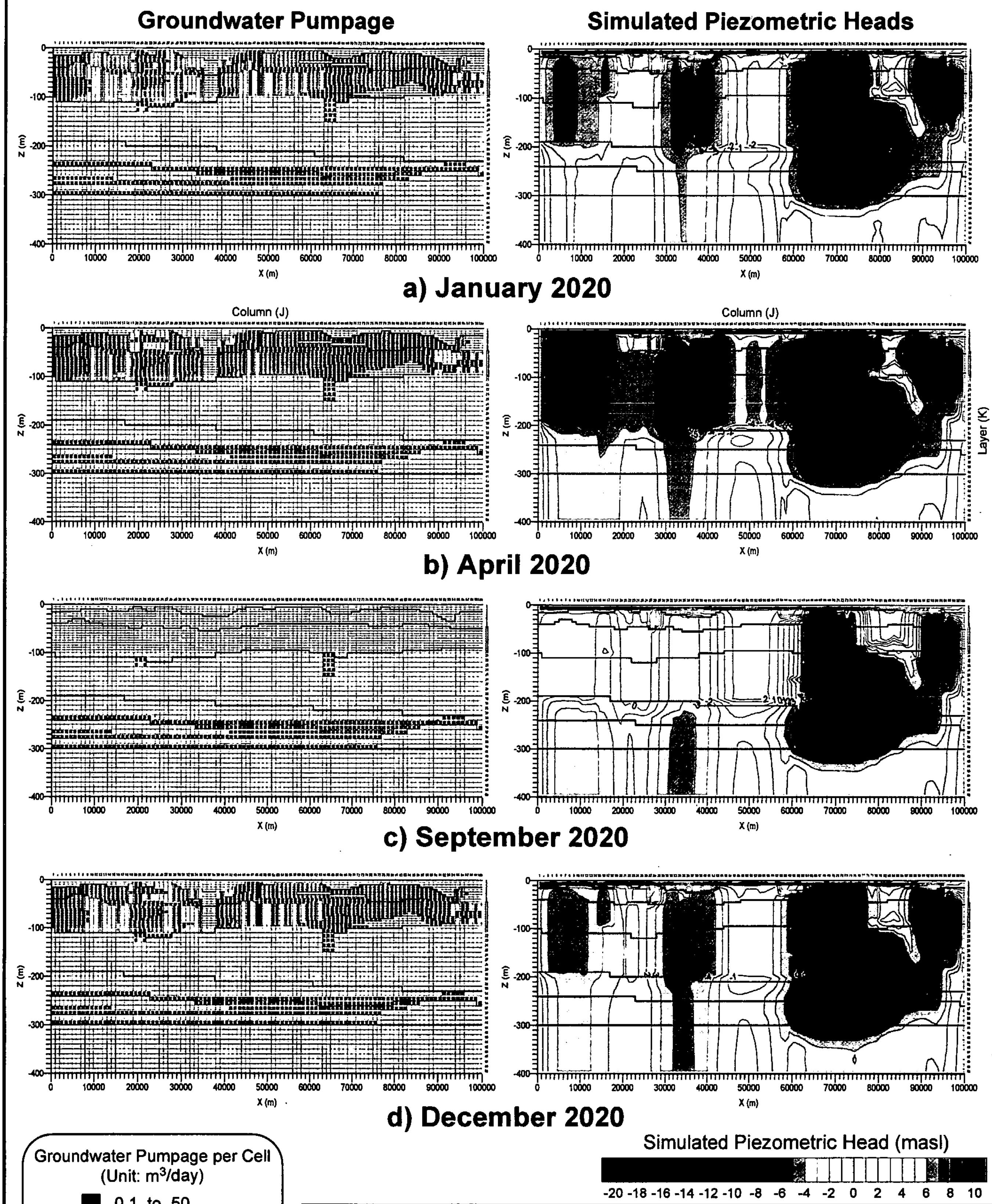

Figure 8.2.59	Groundwater Pumpage and Simulated Piezometric Heads by Case-2, Scenario-2 in 2020

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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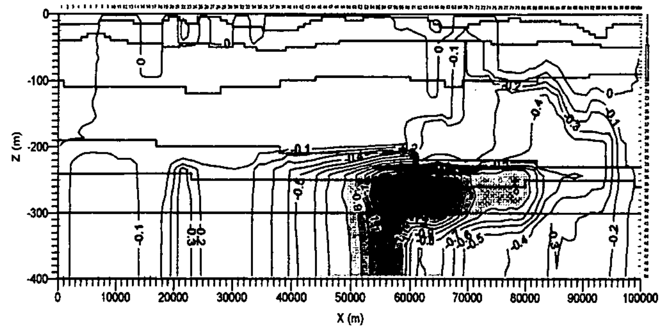
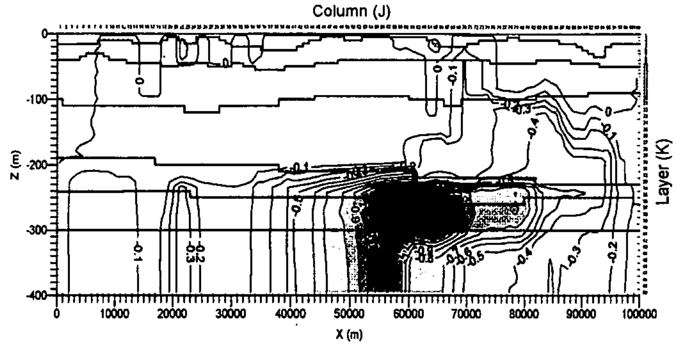
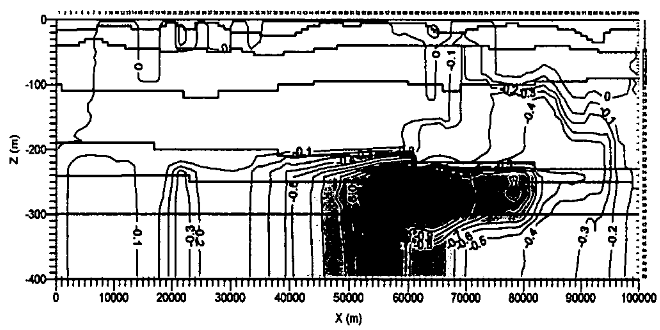
Difference of Simulated Piezometric Heads [(C2,S2) - (C1, S2)]



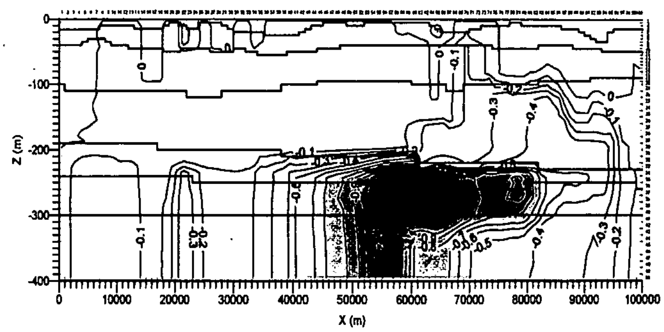
a) January



b) April



c) September



d) December

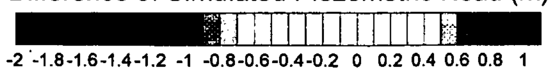


Figure 8.2.60	**Difference of Simulated Piezometric Heads between Case-1 and Case-2, Scenario-2 in 2020**
	THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH
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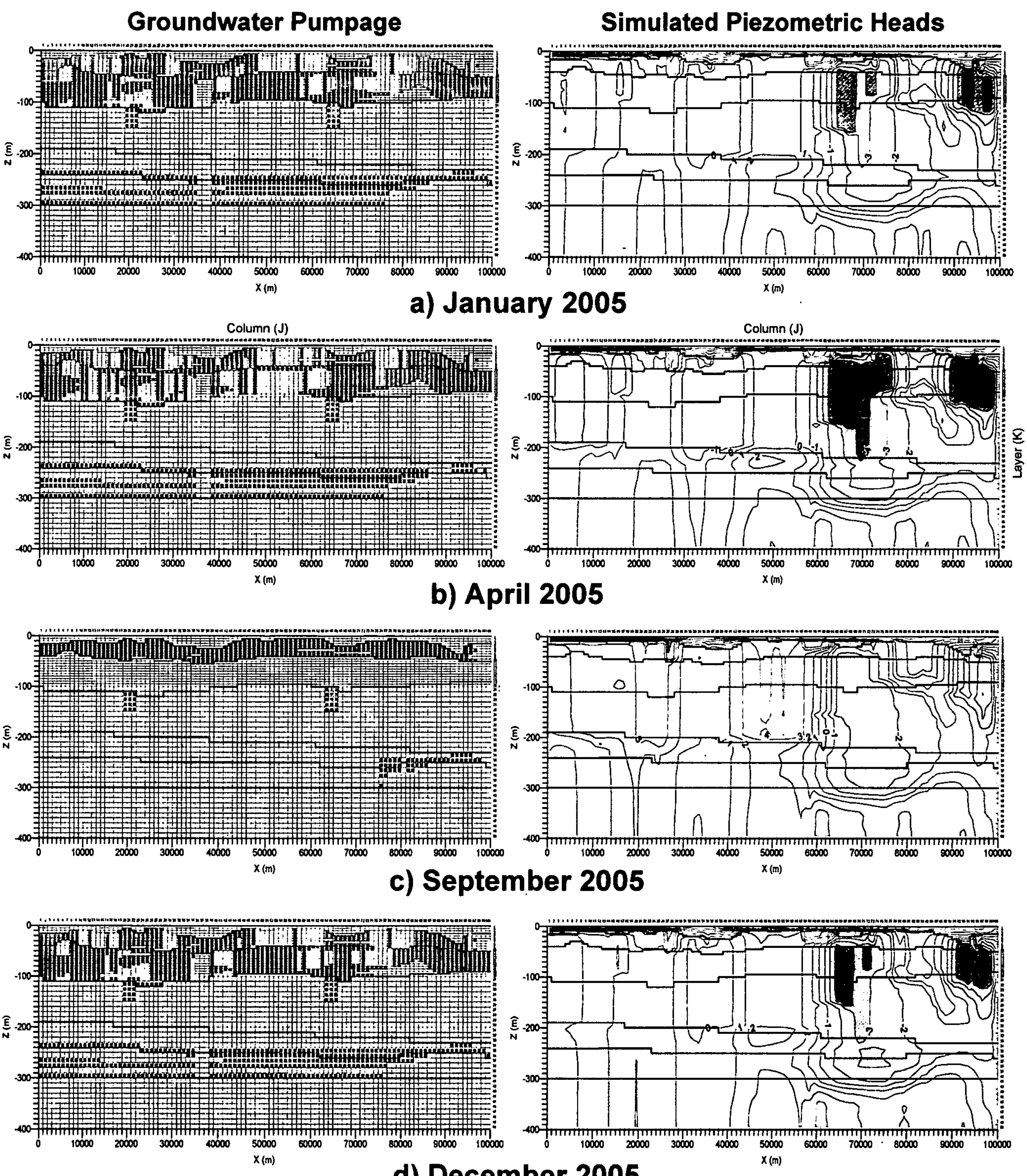

Simulated Piezometric Head (masl)

-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10

Groundwater Pumpage per Cell
(Unit: m^3/day)

- 0.1 to 50
- 50 to 100
- 100 to 200
- 200 to 300
- 300 to 500
- 500 to 1000
- 1000 to 2000

Figure 8.2.61	Groundwater Pumpage and Simulated Piezometric Heads by Case-4, Scenario-2 in 2005

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

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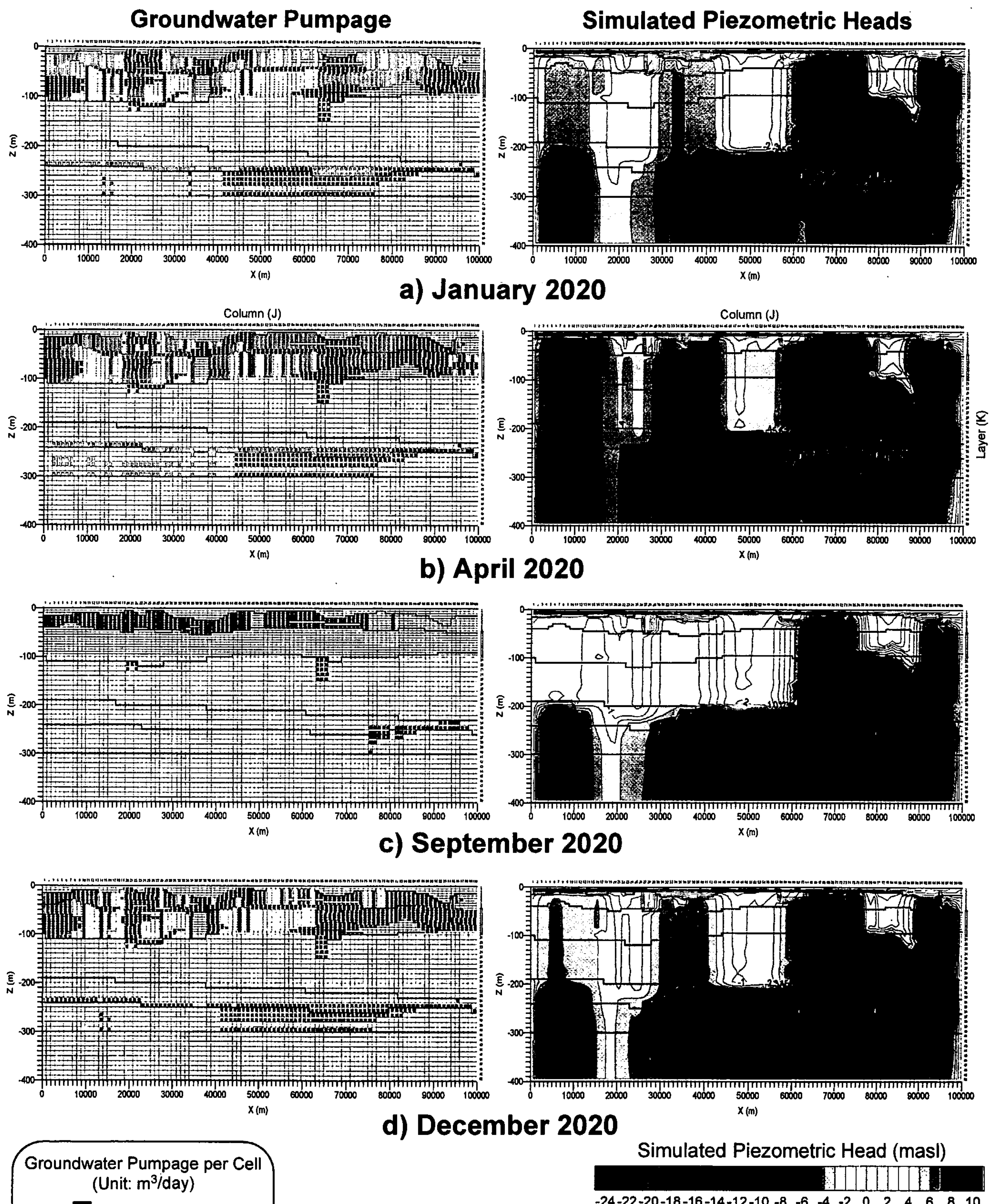
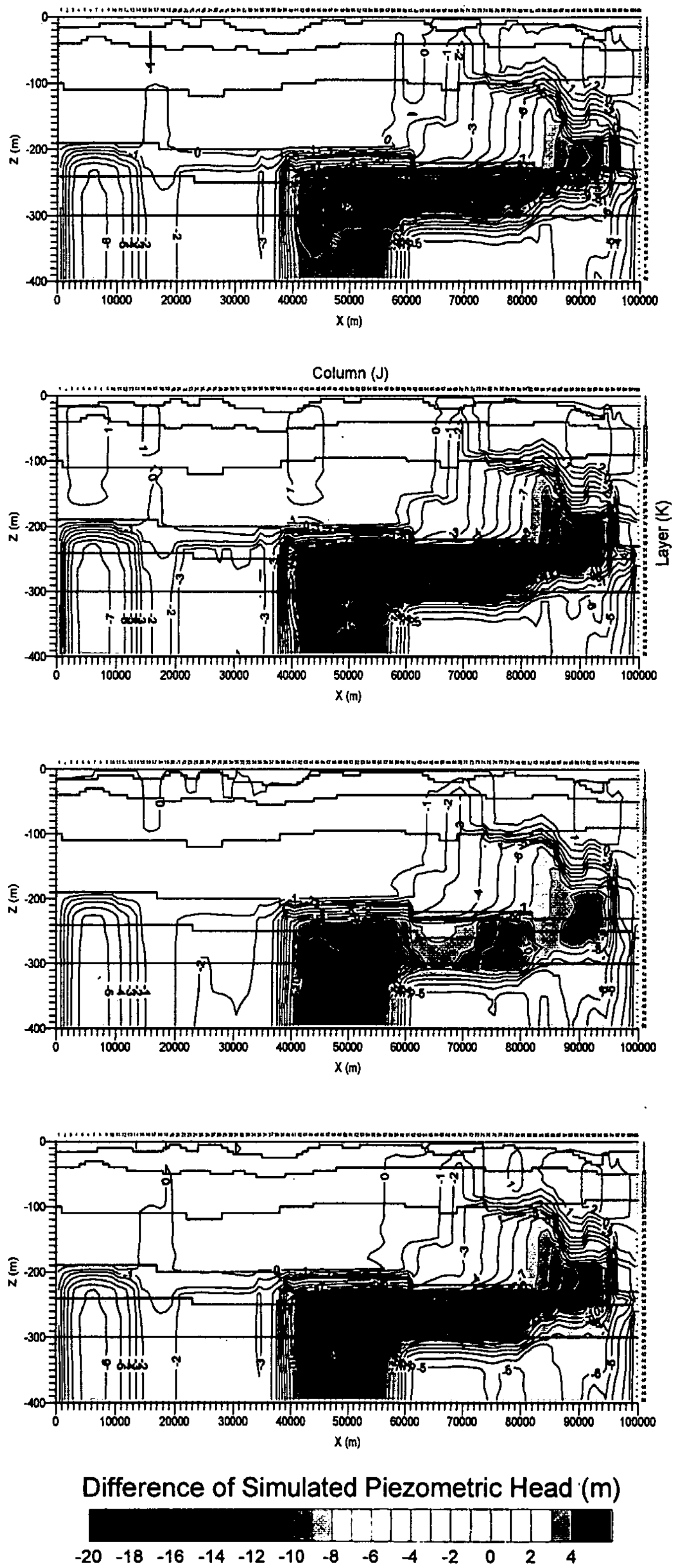


Figure 8.2.62	Groundwater Pumpage and Simulated Piezometric Heads by Case-4, Scenario-2 in 2020

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

Difference of Simulated Piezometric Heads [(C4,S2) - (C1,S2)]



a) January

b) April

c) September

d) December

Figure 8.2.63	**Difference of Simulated Piezometric Heads between Case-1 and Case-4, Scenario-2 in 2020**
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8.3 Evaluation on Possibility of Deep Groundwater Development

8.3.1 Evaluation of Present Groundwater Flow Conditions

The results of various hydrogeological and groundwater field investigations as well as the results of the groundwater simulation show that the present groundwater flow in the study area has already been greatly disturbed by groundwater use particularly for irrigation. According to the groundwater pumpage estimation, groundwater is extracted from almost all the grids (1km x 1km in size).

The groundwater is extracted mainly by irrigation shallow wells, which tap the lower part of A formation. According to the groundwater pumpage estimation for the year 2000, an average of 7.373 MCM/day is pumped from the shallow irrigation wells in the study area. On the other hand, the average groundwater pumpage from the deep irrigation wells is 0.807 MCM/day in that year. The ratios of groundwater pumpage from shallow irrigation wells and deep irrigation wells to the total irrigation pumpage are 90.13% and 9.87%, respectively. In the same year, the average groundwater pumpage from the domestic shallow wells and Pourashava production wells are 0.067 MCM/day and 0.022 MCM/day, respectively.

The growth of groundwater pumpage from the shallow irrigation wells is also significant. The average pumpage in 1983 was 1.467 MCM/day, so that the pumpage increased 5.02 times from 1983 to 2000. Meanwhile, the groundwater pumpage from the deep irrigation wells was 0.352 MCM/day in 1983. Therefore the pumpage increased 2.29 times from 1983 to 2000.

The total groundwater pumpage for domestic use in 1983 was estimated as 0.028 MCM/day (0.023 MCM/day by shallow wells and 0.005 MCM/day by production wells). In 2000, the total domestic groundwater pumpage rises to 0.090 MCM/day, showing a 3.16-fold increase. However, the domestic groundwater pumpage occupies only 1.09% of the total groundwater pumpage. In 1983, the ratio of domestic groundwater pumpage to the total groundwater pumpage was 1.54%.

From the results of the groundwater pumpage estimation said above, it is clearly understood that the impact of irrigation groundwater use on the groundwater flow in the study area has been very significant since 1983 until the present time. It is evaluated that the growth of irrigation groundwater use particularly by shallow irrigation wells has caused the declining of groundwater levels particularly in the dry season, which is monitored by the existing BWDB monitoring wells and simulated by the 3-D Regional Model.

The results of groundwater simulation by the Vertical 2-D Regional Model show that when there is an active source of arsenic in the shallow portion of A formation, the arsenic is dissolved into the shallow groundwater and the contaminated groundwater vertically moves downward. However, the simulation results show that the contaminated groundwater is extracted by the groundwater extraction mainly by the shallow irrigation wells. Moreover, the results indicate that the shallow contaminated groundwater has no chance to reach the deep aquifers because the flow directions of deep groundwater are dominated by the upward movement. Therefore, it can be said that although the shallow irrigation wells might cause the arsenic contamination in the shallow aquifers, the intensive pumpage prevents further contamination in the deep aquifers in the event that the shallow irrigation pumpage is distributed throughout the entire area.

The results of groundwater simulation by both 3-D Regional Model and Vertical 2-D Regional Model show the comparatively large decline of groundwater levels in southern Jessore District. The cause of the large drawdown is explained by the hydrogeologic structure. As already mentioned in Chapter 5, the thick clay layer occurring in C formation has an important role in controlling the regional groundwater flow in the study area. When the groundwater is extracted from the shallow aquifers (A and B formations) in the area, the groundwater levels start to decline but are not supplemented fully due to the existence of the clay layer. It is observed by the Vertical 2-D regional simulation result that equal lines of piezometric heads are concentrated in the clay layer, indicating that the clay layer prevents the supplemental groundwater flow from the upstream area and from deeper aquifers.

8.3.2 Impact of Future Deep Groundwater Development

It is simulated by the Vertical 2-D Local model that, if the piezometric heads of deep aquifers are lower than that of shallow aquifers, the shallow groundwater will definitely move downward and enter into the deep aquifers. Therefore, it is very crucial that the piezometric heads in the deep aquifers be controlled at heads higher than the heads in the shallow aquifers.

The simulation results by Vertical Models suggest that if all the existing irrigation pumpage is moved to the deep aquifers, the present groundwater flow system will be totally destroyed and the shallow contaminated groundwater will enter into the deep aquifer and the deep groundwater will be contaminated. Such an extreme case must be avoided in the future groundwater development.

Some researchers/scientists insist that the present irrigation pumpage must be stopped immediately because the pumpage is nothing but the cause of the arsenic problem. But it is not possible to stop all the irrigation pumpage at once because the water is needed for agricultural production, which is still most of the important economic activity in Bangladesh. From the scientific view of groundwater hydrology, it is not necessary to stop all the irrigation pumpage at the existing irrigation wells. This is because, as mentioned above, the irrigation pumpage might have caused the arsenic contamination, but the wells are also functioning as “barrier wells” to prevent further contamination in the deep aquifers. It is noted that there is a possibility that the upper part of the deep aquifer may be contaminated by the existing irrigation wells’ pumpage under certain conditions that permit the flow path to enter the upper part of the deep aquifer. However, if there is no deep groundwater pumpage, the contaminated groundwater will ultimately be extracted by the irrigation wells.

It is, therefore, recommended that the indiscriminate development of deep groundwater be avoided. The government and responsible agencies should establish the necessary regulations to give priority to drinking water purposes in order to exploit the deep groundwater resources. It is also necessary to establish the groundwater monitoring and management systems to monitor and control present and future groundwater use. Unless those policy, regulations, and monitoring and management systems are established, the precious natural resources of the country will be damaged soon. It should be noted that once the deep groundwater is contaminated, it is very difficult to remedy the quality.

8.3.3 Necessary Measures to Use Deep Groundwater

Several technical measures are needed for the sustainable use of deep groundwater. Because the hydrogeological conditions and groundwater conditions are different from place to place, the plan of deep groundwater development should be established after investigating those conditions in detail.

It is known by the study that the productivity of the deep aquifer is generally smaller than that of presently used main aquifers in B and C formations. In other words, a certain amount of groundwater pumpage will cause larger drawdown in the deep aquifer. If the large amount of drawdown is generated in the deep aquifer, it is possible that the shallow contaminated groundwater will move down into the deep aquifer. Therefore, the aquifer productivity and hydrogeologic conditions should be site-specifically investigated and evaluated to prevent such secondary contamination.

The monitoring of deep groundwater as well as shallow groundwater is also very important. Although the detailed mechanism of arsenic contamination has not been fully revealed yet, the deep groundwater should carefully be used while monitoring groundwater levels and groundwater quality.

If the deep groundwater is continuously used in future, the deep groundwater located in deeper in depth will move upward and be pumped up by the wells. So far the hydrogeological conditions and groundwater quality of deeper aquifers below 300 m in depth are not known. It is necessary to investigate the deeper groundwater conditions before the development of the target deep groundwater.