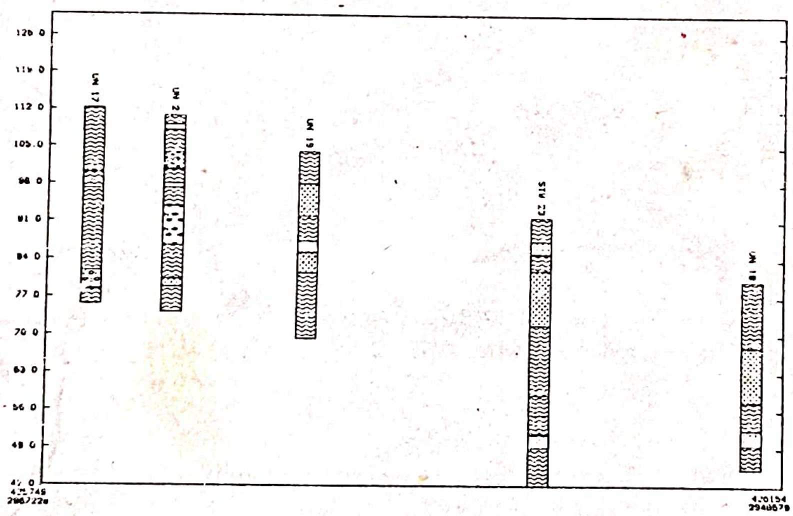
Shallow Ground Water Resources of the Siraha District
Eastern Development Region, Nepal

Technical Report No. 18

By
DIBYA RATNA KANSAKAR, Divisional Geologist



United Nations Development Program and
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NEP/86/025
Shallow Ground Water Investigations in Terai
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Executing Agency:
United Nations Department of Technical Co-operation for Development

Implementing Agency:
Ground Water Resources Development Board, HMG, Nepal

March 1992

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ABBREVIATIONS

ADB - Asian Development Bank
ADBN - Agriculture Development Bank of Nepal
DTW - Deep Tube Well
GDC - Groundwater Development Consultants (International) Ltd.
GWRDB - Ground Water Resources Development Board
GWS - Ground Water Software, UN/DTCD.
MCM - Million Cubic Meters
NRSC - National Remote Sensing Center, Nepal/GTZ/World Bank
SIRDP - Sagarmatha Integrated Rural Development Project
SIW - Shallow Irrigation Well
STW - Shallow Tube Well
UNDP - United Nations Development Program
UN/DTCD - United Nations Department of Technical Co-operation for Development

ABSTRACT

Siraha District, the most western district of the Eastern Development region, has a total surface area of about 1188 km^2 out of which the Terai portion covers about 930 km^2. The average annual precipitation in the period between 1987 and 1990 is about 1313 millimeters of which more than 85% is received during the monsoon. The population in Siraha, according to the 1981 census, was 375,358, out of which almost 96% live in rural setting. Agriculture is the dominant economic activity in the district. Approximately 27% of the farm land is irrigated for a single crop and only about 6% is irrigated year round. The present investigation has indicated that the aquifer in Siraha has the potential to provide water to irrigate a substantial proportion of the remaining 94% of un-irrigated or single crop irrigated land.

The aquifer is comprised of an indeterminate number of interconnected lenses of sand, gravel and pebbles intercalated with some silts and clays which comprise a very large ground water reservoir. Eighteen pumping tests were conducted and transmissivities were determined to range from a low of 36 to as high as 1422 m^2/day. Yields of existing wells range from less than 1 to more than 13 liters per second (l/s). The yield potential map indicates that except for the north easter sector, the Siraha District has good Shallow Irrigation Well potential.

Fluctuations observed in the water level change maps are relatively small and are due to seasonal variation only. Stress on the aquifer due to pumping is not evident.

Recharge in the Siraha District aquifer is principally from local precipitation. Estimates of potential recharge vary from about 122 MCM to 274 MCM per year. This compares favorably with the estimated ground water outflow to India of about 17 MCM per year, suggesting that 100 MCM to 257 MCM per year of ground water is available for utilization in the district.

1. INTRODUCTION

1.1 Purpose and Scope

The United Nations Department of Technical Co-operation for Development(UN/DTCD) and the Ground Water Resources Development Board (GWRDB), HMG/Nepal instituted a project in 1987, NEP/86/025, to investigate the shallow ground water resources of "Districts in the Terai" (Appendix A). This report on Siraha District is one of a series of reports from the project. The status of the project is shown in Figure 1.

The purpose of the project is to conduct an orderly and defined investigation of shallow ground water in each Terai district. A major goal of NEP/86/025 project is to develop scientific procedures for the collection, interpretation, and presentation of ground water data, throughout the Terai in Nepal.

A principal component of this goal is the development of a computerized Ground Water Information System (GWIS) to manage the groundwater information obtained in this project. Eventually the GWIS should become a major tool in many aspects of groundwater data storage, retrieval, and dissemination for all groundwater information collected by Department of Irrigation (DOI).

A second major goal is to train Nepalese hydrogeologists to implement the procedures. This should facilitate optimum development of ground water resources of the Terai, in particular, and Nepal in general.

A third major goal is to define the areal extent of each Terai district where a shallow irrigation well (SIW) may be developed. A SIW is defined in the section on shallow ground water availability.

Ground water must be utilized in the best possible manner to ensure availability of this most important natural resource now and in the future. Irrigation wells in Siraha District in the Terai will help Nepal increase agricultural production for an increasing population, for export, for valuable foreign exchange, and demonstrates the economic importance of ground water.

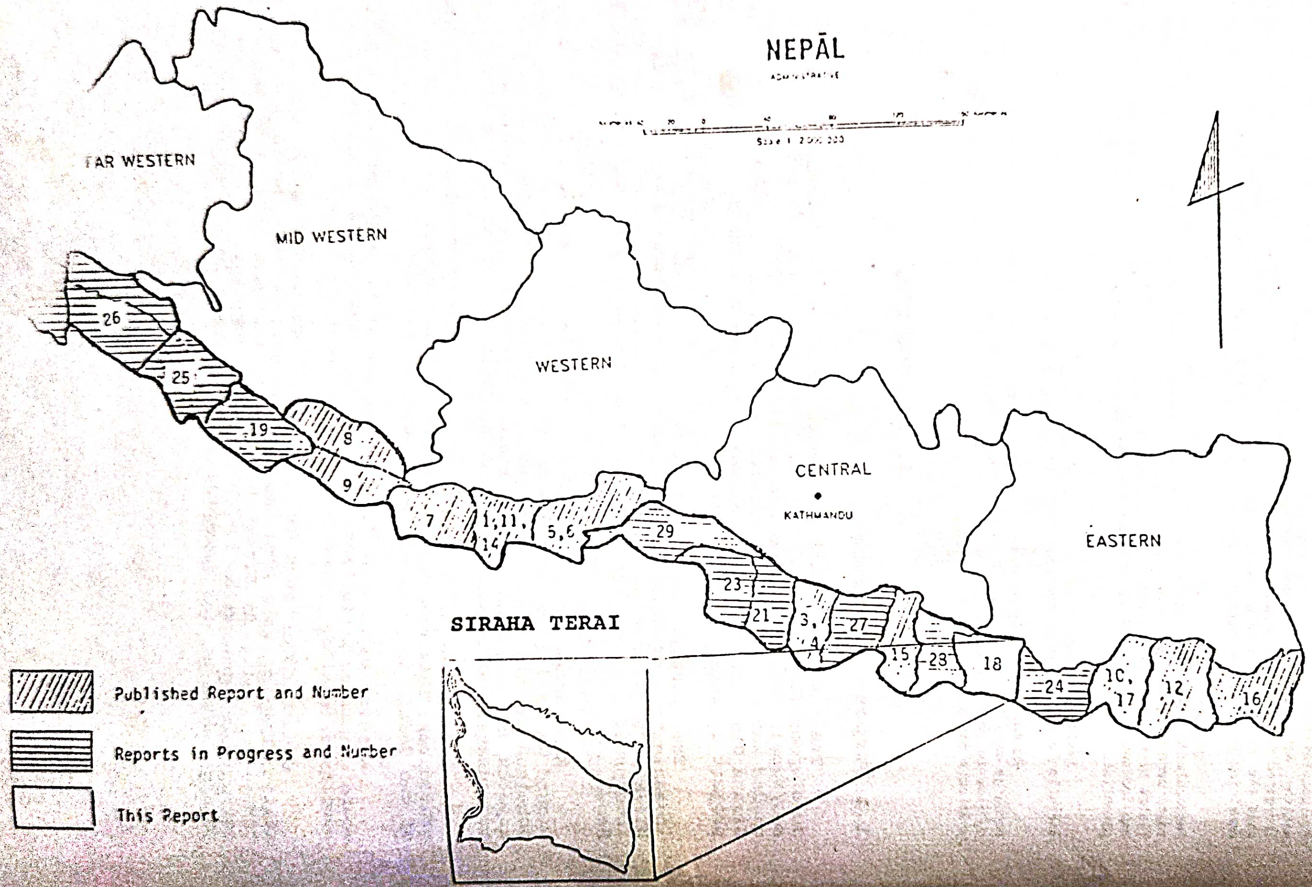


Figure 1. Index map showing status of Ground Water Reports from the Shallow Ground Water Investigation in the Terai.

This report should be considered in light of the above goals. Ground water data has been collected, placed in an information system and is being interpreted and presented. Training takes place during these activities, and finally, an area is defined where a SIW may be located.

1.2 Location and Extent of Area

Siraha District is the most western district in the Eastern Development Region of Nepal. It lies between the LANDSAT IMAGERY (NRSC, 1987) co-ordinates: X = 413000 - 453000 and Y = 2935000 - 2975000. Dhanusha District borders on the west along the Kamala River and Saptari District on the east. It has India to its south and the Udayapur District to the north. Lahan is the administrative headquarter of this district, and is served by the national East-West Highway. The total area of Siraha District is about 1188 km^2 (Statistical Pocket Book, Nepal (SPBN), 1986), out of which the Terai portion covers about 930 km^2 (Tillson, 1985). The Terai portion is shown in the inset in figure 1 and is the part discussed in this report. (Please note that the contour line of 150 m approximates the physical upper limit of the Terai Quaternary sediments.)

1.3 Previous Investigations

Siraha and surrounding districts have been investigated and studied previously by several workers and projects. Reports by these investigators are listed in the selected References.

1.4 Methods of Investigation

Field work in this district began in the spring of 1989 and for the most part was completed in 1990. The work consisted of drilling wells, making water level measurements, lithologic determinations and aquifer tests. Altitude surveys of land surfaces at wells were carried out in 1991 (DEVTEC Nepal, 1991).

Water level monitoring in Siraha District was initiated in May 1987 with an ambitious monitoring network that included 40 mostly private shallow tube wells (STW). But for various reasons, regular monthly water level measurements in those wells are not available. It is only since April 1990 that a regular water level measurement data from a monitoring network consisting mostly of the Project drilled wells became available.

The current project had a target of drilling 25 wells averaging 40 meters (m) in depth for a total of 1000 m. However, 26 wells were drilled, 2 were failures, leaving 24 wells that averaged 32.5 m in depth for a total of 830 m. The new wells were located to obtain maximum geographic coverage within the district and thus maximum information about the nature of the aquifer. Manual methods were used to drill 17 of the new wells and 7 were drilled with a rotary rig. Drill cuttings were collected and examined. Lithologic logs and other information were collected on 24 project drilled Shallow Tube Wells (STW), one drilled under the program of the Agriculture Development Bank, Nepal (ADBN) and one deep tube well (DTW) drilled by GWRDB.

Aquifer or pumping tests were conducted on 16 of the project wells and one observation well. One private well drilled under the ADBN program was also pump tested. However, these tests were marginally performed.

1.5 Well Identification System

Wells in this report are identified in several ways: 1) they are numbered sequentially and given a location name; 2) each has a computer file name or number which includes the letters SR for Siraha District and the sequence number; 3) additional identification (ID) is provided by another secondary number to differentiate wells drilled for this project (UN and a sequential number) from wells drilled by GWRDB (GW and a sequential number) and from the ADBN private wells (AD and a sequential number); 4) X and Y coordinates have been digitized from the 1:500,000 LANDSAT imagery map of Nepal and are another ID.

1.6 Topography and Drainage

Siraha District is in the Terai Physiographic Province of Nepal in the south and in the Siwalik Hills Province in the north. Altitudes in Siraha District range from more than 700 meters in the north to about 69 meters at the border with India.

The Kamala river is the biggest river in the district, which forms the western border with Dhanusha District of Central Development Region. Several other streams, such as Bhatiwalan, Mainawati, Gagan etc. are in the district. All of the streams flow from north to south.

1.7 Climate

The climate of Siraha District is subtropical with a mean monthly temperature of 15° C in January and 31° in June. Table 1 lists average annual maximum and minimum temperatures at Janakpur, (Dhanusha District), the nearest meteorological station to Siraha District.

Table 1. Average maximum and minimum monthly temperatures at Janakpur.

January		February		March		April		May		June	
max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
28.0	4.0	30.2	4.0	38.6	8.2	40.0	10.4	42.0	18.0	40.0	20.0
July		**August**		**September**		**October**		**November**		**December**	
max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
38.0	20.5	37.6	21.0	37.0	20.4	34.5	16.0	32.0	8.0	29.0	5.0

High humidity is prevalent except in winter and becomes oppressive in summer. The climatic characteristics of Siraha District, as in other parts of the Terai is that about 85% of the total annual rainfall is delivered by monsoon in four months from June to September. Annual precipitation from 1978 to 1989 recorded at the Janakpur Meteorological Station is given in Table 2 (SPBN,1990), and the average rainfall for those 9 years is 1313 millimeters. Figure 2 shows monthly rainfall for 1987-1990.

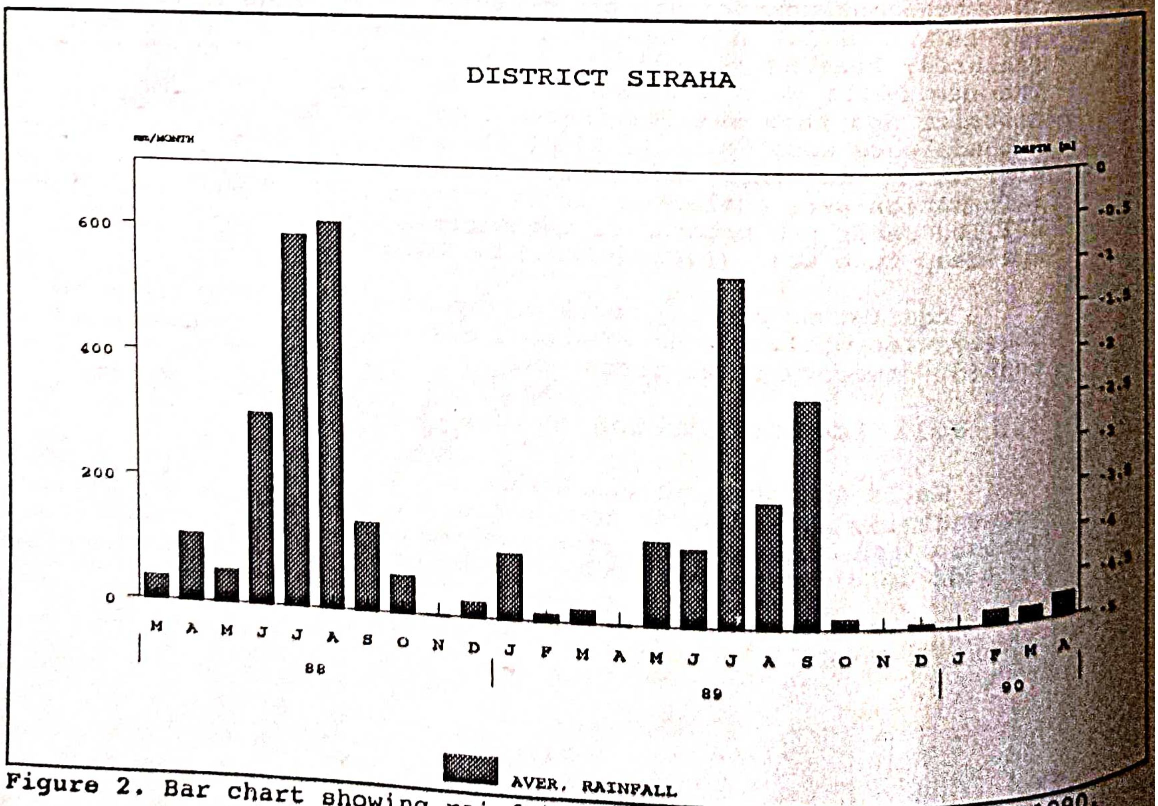


Figure 2. Bar chart showing rainfall recorded at Janakpur, 1988-1990.

Table 2. Annual rainfall at Janakpur, 1978 - 1989 (in mm).

Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Rainfall (mm)	1203	1011	1049	1201	581	1726	1829	1939	1282	2389	1975	1514

Source: Statistical Pocket Book, Nepal, 1990.

1.8 Population

There were about 375,358 people in Siraha District in 1981 giving an average population density of about 316 persons per km^2 (SPBN,1990). Table 3 lists the figures from the 1981 census. About 3.7% of the population in Siraha District were living in an urban setting in 1981.

Table 3. Population in Siraha district and in Lahan in 1981.

	Total Population	Population	
		Male	Female
Siraha	375,358	194,958	180,400
Lahan	13,775	7,303	6,472

Source: Statistical Pocket Book, Nepal, 1990.

1.9 Agriculture

The principal crops grown in Siraha District are paddy, maize, millet, wheat, barley, oilseeds, potato, tobacco, sugarcane, pulses and others. Statistics for crops are listed in Table 4 (Agricultural Statistics of Nepal (ASN),1990).

Table 4. Principal crops harvested in 1988-1989 in Siraha District.

Crop	Area (Ha)	Yield (kg/Ha)	Production (Metric Tons)
Paddy	64,330	1,839	118,300
Maize	2,760	1,565	4,320
Millet	1,540	1,000	1,540
Wheat	13,500	1500	20,250
Barley	30	667	20
Oilseed	2,230	578	1,290
Potato	630	9,206	5,800
Tobacco	1,540	779	1,200
Sugarcane	1,050	24,000	15,200

Source: Agricultural statistics of Nepal,ASN,1990.

1.10 Acknowledgements

The information compiled and presented in this report is mostly from the Ground Water Resources Development Board office in Siraha. Some wells drilled by GWRDB/Siraha are also included. The pumping tests carried out by GWRDB, Siraha have provided a wealth of valuable information necessary for aquifer evaluation.

The work of the staff engaged in hydrogeological work in Siraha, both in the field and office, is highly appreciated. The present final report is based on the initial interpretation and presentation in draft form prepared by Mr. S.R. Uprety and Mr. S.M. Amatya, and are duly acknowledged. The authors wish to express his sincere gratitude to Mr. Y.L. Vaidya, Deputy Director General, Department of Irrigation, HMG/Nepal for his support and encouragement to prepare this report. The support and guidelines provided by Dr. R.M. Tuladhar, National coordinator of the Project NEP/86/025, and the staff at the central office, Kathmandu during preparation of this report is much appreciated. Mr. J.M. McNellis, Chief Technical Adviser to the project NEP/86/025 is duly acknowledged for his constant guidance and advice during the preparation of this report.

2. GEOLOGY, LITHOLOGY AND WATER SUPPLY

Investigation of ground water in the Terai is incomplete without a comprehensive description of the geologic framework of the area. However, this project focused on just the Terai and did not consider the relationship of the area with the Siwalik Hills. Therefore, the discussion of geology is cursory.

Sediments comprising the Terai plain are thick clastic deposits of Pleistocene and Quaternary age and are accumulating to the present day. The most permeable portions of the Terai sediments are the coarse fractions. Thus sand, gravel and larger fractions will be called aquifer in the succeeding discussion.

The deposits are placed in two groups for hydrologic and lithologic purposes, the Bhabar Zone deposits and the Terai Plain deposits. The division is not easily defined in the subsurface because of the nature of the sedimentation processes.

2.1 Lithological Cross sections:

The well locations and traces of lithological cross sections for Siraha district are presented in Figure 3. The individual cross sections were produced using UN/DTCD Ground Water Software (GWS) (Karanjac, 1989). They are shown in Figures 4 to 7 and are described below. The vertical axis of the individual cross section represents elevation above sea level in meters.

No attempt has been made to connect permeable layers in the cross sections as this is a "risky" undertaking in Quaternary deposits near the Siwaliks across the Terai Plain which is cross-cut by many present rivers and buried channels of the rivers of the past. The lithology of the sediments changes rapidly over small distances. Four cross sections are presented to understand and gain an appreciation for the rapid changes within the subsurface of the terai. the descriptions of the cross sections are as follows:

Lithological cross section I - I' (Figure 4) shows the section along the W-E direction in the northern part of the Siraha District. The elevation of land surfaces varies from about 100.75 to 140.00 m. This section consists of data from five UN wells, viz. UN 4, UN 7, UN 9, UN 17 and UN 21. The wells in this section contain a considerable thickness of sand and gravel. This section shows more coarse grain sized sediment than the southern section.

Lithological cross section II - II' (Figure 5) represents the lithological section along a W-E direction in the southern part of the district. The land surface elevation varies from about 75.49 to 99.76 m. This section consists of UN 3, UN 16, UN 18, UN 20 and UN 22. Wells in this section are rich with sand layers as the aquifer.

Lithological cross section III - III' (Figure 6) presents the lithological section in a N-S direction in the eastern part of the district. The surface elevations in this section varies from 126.01 m in the north to 85.11 m in the south. It includes the following five UN wells : UN 7, UN 8, UN 13, UN 14 and UN 20. No obvious trend in grain size variation could be observed from this cross section.

Lithological cross section IV - IV' (Figure 7) is the cross section in a N-S direction in the western part of Siraha District. The land surface gradually decreases from north to south and ranges from 112.19 m in the north to 80.12 m in the south. It represents lithologic information from five UN wells, namely UN 2, UN 17, UN 18, UN 19 and UN 23. The northern two wells (UN 2 and UN 17) have some gravel component in its aquifer whereas the central and southern wells are rich in sand layers.

The grain size of Terai sediments appears to decrease slightly from north to south, although the trend is not prominent in the lithologic cross sections presented here. Lithologic logs of individual wells from the district are presented in Appendix B.

The 24 successful UN investigation wells drilled during this project, one DTW and one private STW that were pump tested provide important information on the composition and distribution of these Terai deposits. The well locations are shown on Figure 3. Available pertinent well data on these wells are shown in Table 5.

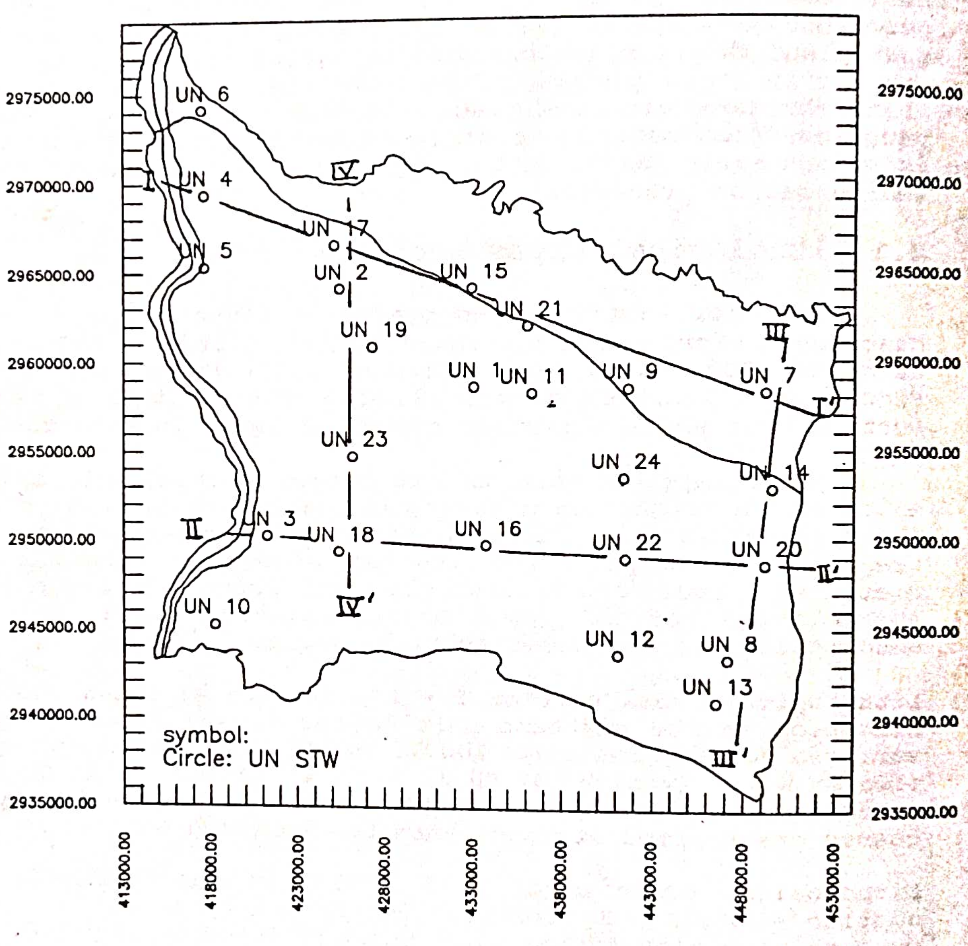


Figure 3. Location of UN wells and traces of Cross Section lines.

2.2 Bhabar Zone Deposits

2.2.1 Lithology, distribution and thickness

Bhabar Zone deposits occur, albeit discontinuously, at the surface along the base of the Siwalik Hills at the north edge of the Terai and also along major rivers transecting the Terai. The outcrop area of Bhabar Zone is estimated at 180 km^2 in Siraha District (Tillson, 1985), and is a principal recharge area for the ground water reservoir of the Siraha Terai.

TABLE 5: List of Tube Wells with Basic Data

S. No.	File Name in Computer	Well Number (1)	Location: Village Name	Landsat Co-ordinates (2) X	Landsat Co-ordinates (2) Y	Elev. from MSL (m) (3)	Depth of Well (m)	Length of Screen used (m)	Screen Position (m)	Screen Type	Permeable Thickness (m)	Permeable Percent of depth (m)	Drilling Date	Well Diameter (inch)	Water Level BGL (m)
1	SRS01.LTH	UN 1*	SIMARA	433000.	2958625.	117.47	44.50	3.0	28.7-31.7	Slotted	21.9	49.2	31.01.90	4	+2.0
2	SRS02.LTH	UN 2	MITHILESHWOR	425375.	2964125.	110.80	36.60	6.1	18.1-24.2	,,	13.7	37.4	21.01.90	4	
3	SRS03.LTH	UN 3*	BASBITTA	421250.	2950250.	75.49	44.20	6.1	11.9-18.0	,,	22.6	51.1	26.01.90	4	2.41
4	SRS04.LTH	UN 4*	KARJANHA	417625.	2969375.	100.75	29.50	9.2	8.9-18.1	,,	18.8	63.7	16.01.90	4	3.50
5	SRS05.LTH	UN 5*	BHEDIYA	417500.	2964250.	90.43	22.70	6.1	8.9-15.0	,,	20.9	92.1	08.01.90	4	1.64
6	SRS06.LTH	UN 6	BANDIPUR	417500.	2974125.	105.08	9.50	3.0	5.5-8.5	,,	8.9	93.7	03.01.90	4	
7	SRS07.LTH	UN 7*	AMAHI	449125.	2958250.	126.01	39.60	5.2	33.1-38.3		5.2	13.1	03.07.89	4	2.60
8	SRS08.LTH	UN 8*	NAHARA	447125.	2943375.	89.75	39.60	5.5	9.4-14.9		20.2	51.0	16.05.89	4	1.50
9	SRS09.LTH	UN 9*	KANCHHIBAZAR	441625.	2958500.	129.67	30.5	5.4	5.9-11.3	Slotted	9.1	29.8	09.03.89	4	1.02
10	SRS10.LTH	UN 10*	MADAR	418250.	2945250.	70.17	34.80	5.5	9.1-14.6		15.3	44.0		4	1.85
11	SRS11.LTH	UN 11*	BARHARI	436250.	2958250.	97.82	18.30	4.8	9.1-13.9		7.1	38.8		4	1.95
12	SRS12.LTH	UN 12*	SUNDARPUR (S)	441125.	2943625.	84.01	39.60	5.8	9.1-14.9		8.5	21.5	30.06.89	4	5.25
13	SRS13.LTH	UN 13*	PADAUL	446500.	2941000.	85.11	39.60	5.4	31.3-36.7		7.6	19.2	21.05.89	4	1.58
14	SRS14.LTH	UN 14*	RAGHUNATHPUR	449500.	2952875.	109.51	13.70	5.5	7.6-13.1		8.8	64.2	12.05.89	4	6.48
15	SRS15.LTH	UN 15	CHOHARWA	432875.	2964125.	140.21	24.40	6.5	11.6-18.1		11.6	47.5		4	
16	SRS16.LTH	UN 16	KABILASI	433750.	2949750.	87.20	18.30	7.1	9.1-16.2		9.2	50.3	14.05.89	4	
17	SRS17.LTH	UN 17	RAMNAGAR	424750.	2966750.	112.19	36.60	3.4	31.1-34.5		3.3	9.0	04.06.89	4	
18	SRS18.LTH	UN 18	HAKPARA	425375.	2949375.	80.12	34.80	5.5	12.3-17.8		12.3	37.1		4	
19	SRS19.LTH	UN 19	BARCHHAWA	427250.	2960875.	104.06	34.80	5.6	6.1-11.7		12.0	34.5		4	
20	SRS20.LTH	UN 20*	TILEBONA	449125.	2948625.	99.76	36.60	5.5	9.4-14.9		7.3	19.9	05.05.89	4	
21	SRS21.LTH	UN 21*	KASAHA	436000.	2962000.	^140.00	43.00	7.6	25.6-33.2	Slotted	23.4	54.4	09.02.90	4	3.91
22	SRS22.LTH	UN 22*	SUNDARPUR (S)	441500.	2949000.	93.80	37.50	6.1	8.3-14.4	,,	11.0	29.3	13.12.89	4	3.50
23	SRS23.LTH	UN 23*	LAXMIPUR	426150.	2954750.	91.70	49.70	7.3	12.5-19.8		14.9	30.0	28.03.90	4	1.78
24	SRS24.LTH	UN 24*	RAMPUR	441400.	2953500.	105.66	35.00	5.5	15.2-20.7	Slotted	9.2	26.3	18.04.90	4	1.30
25	SRS25.LTH	ADB/N*	CHOHARWA	432875.	2964125.		18.30	6.1	8.8-14.9	,,	6.1	33.3	1986	4	2.17
26	SRD26.LTH	DTW 1/R2	BHULKIA	419250.	2972750.	118.55		11.4	84.0-95.4				OCT. 1979	4	4.93

(m) Meter

(1) Well with pumping tests have an *

(2) X and Y coordinates are taken from the 1:500,000 map of Nepal, a composite of LANDSAT imagery [National Remote Sensing Center (NRSC, 1984)]. The coordinates were read with the help of project-supplied digitizer.

(3) The absolute elevation of the well above the mean sea level. The elevation interpolated from 1:125,000 scale district map has symbol ^.

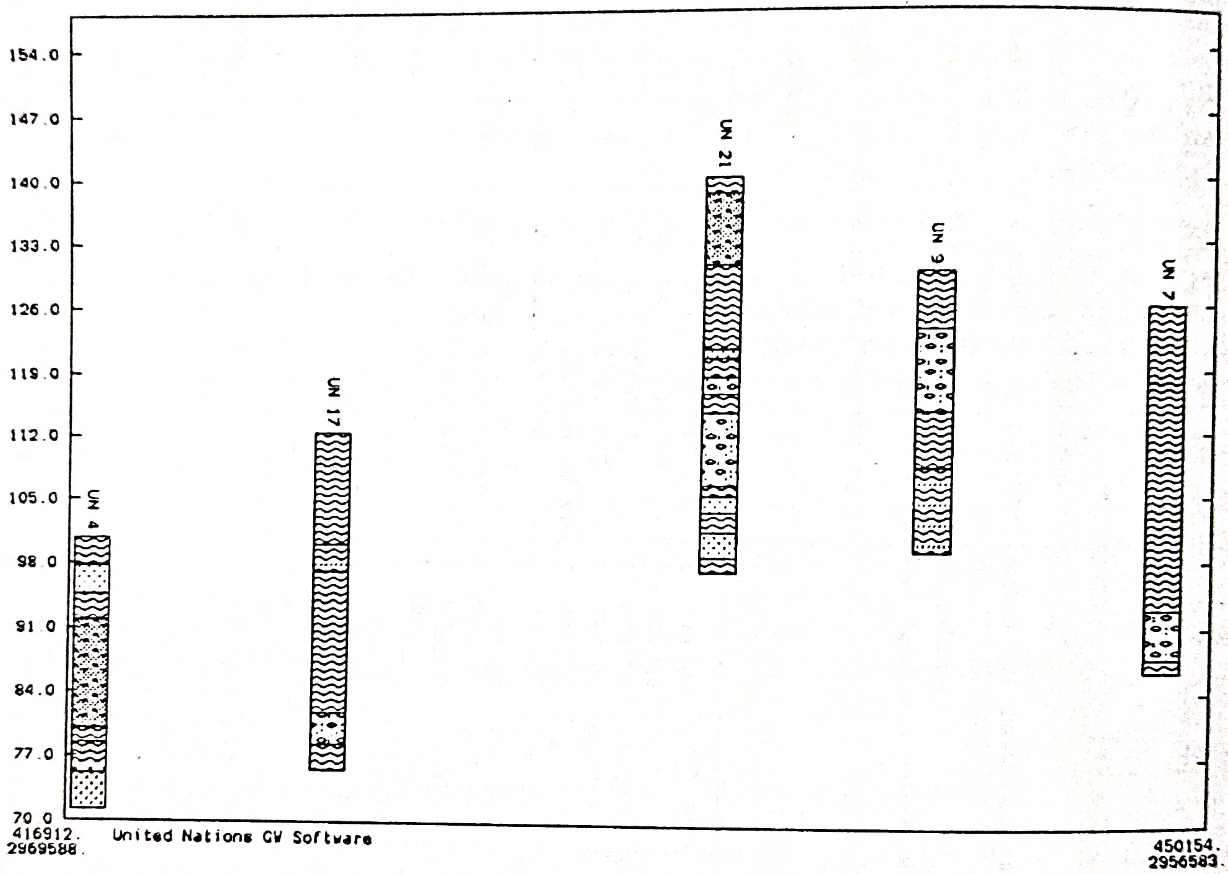


Figure 4 . East-West Cross Section I-I'

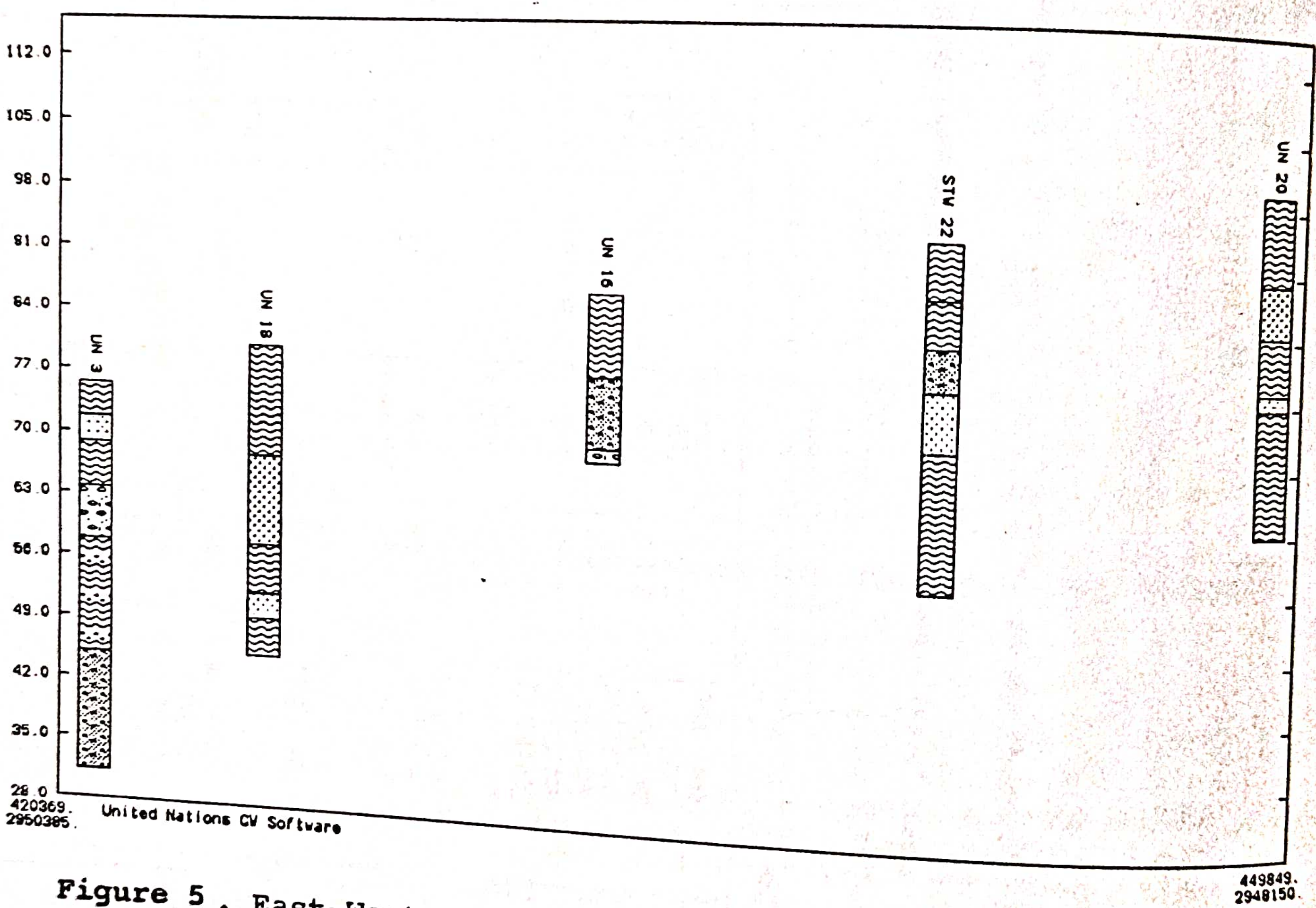


Figure 5 . East-West Cross section II-II'

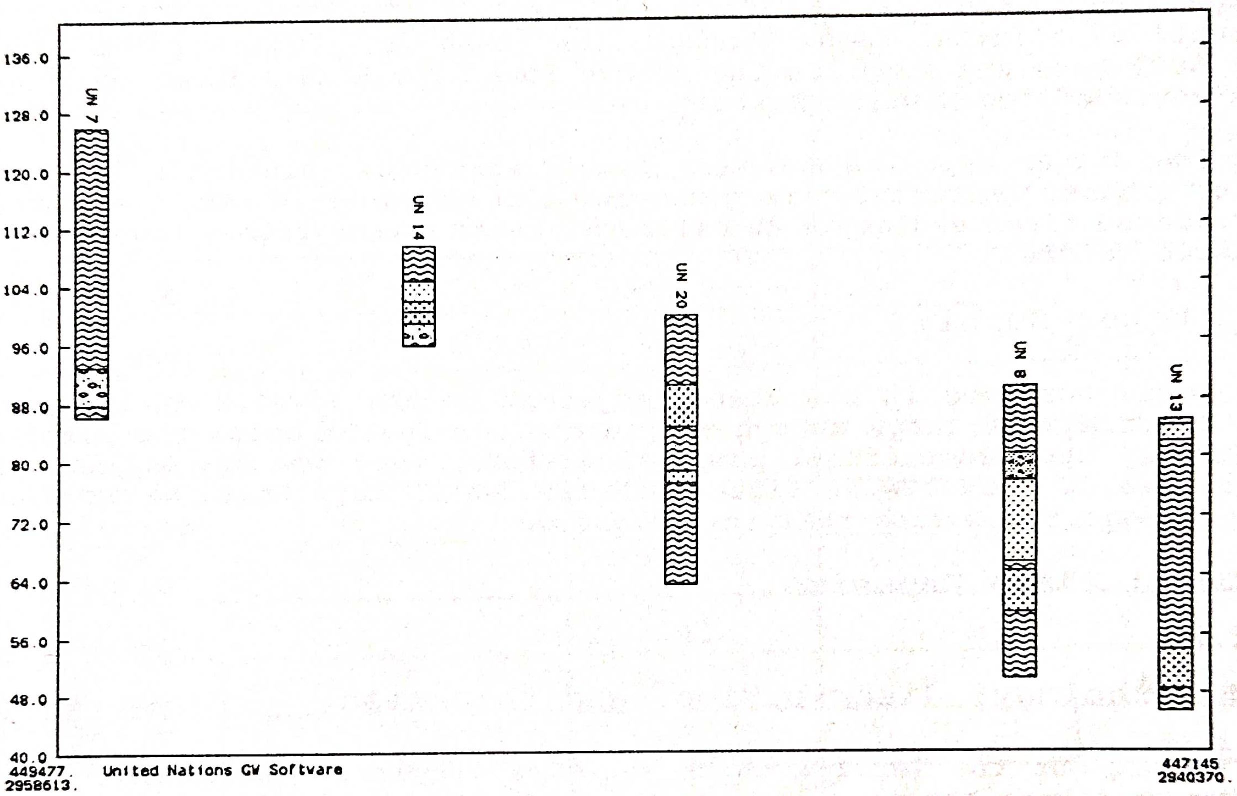


Figure 6 . North-South Cross Section III-III'

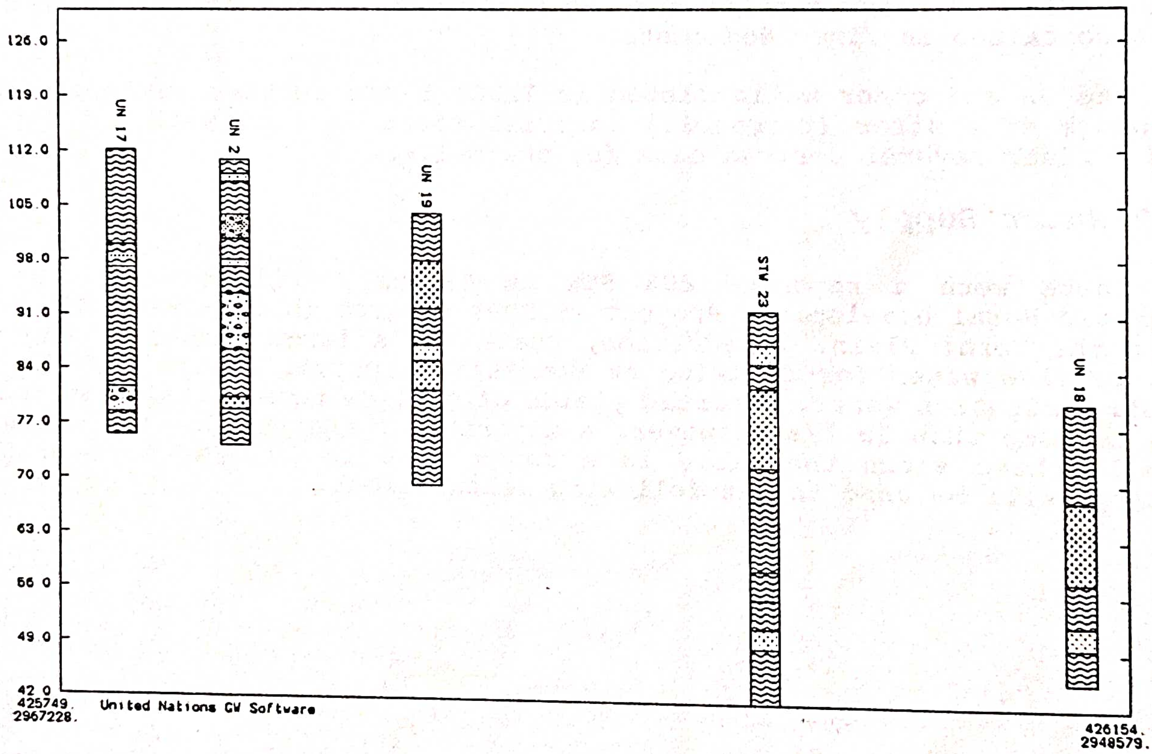


Figure 7 . North-South Cross section IV-IV'

The Bhabar is derived principally from erosion of the Siwalik Formations found in the Siwalik Hills. Streams cut through the hills, abruptly debauch onto the much flatter Terai which is the north portion of the Ganges Plain, and dump their sediments as alluvial fans. Through time these fans coalesce and are covered with other sediments and comprise the Bhabar Zone. The Bhabar Zone may also be found at depth south of the Siwalik Hills.

The Bhabar deposits are very poorly sorted and contain a large proportion of coarse grained material, ranging in size from sand to boulders. There are intercalated finer sediments as well. Thickness ranges from a few meters to more than a hundred meters.

2.2.2 Water Supply

Wells screened in the Bhabar adjacent to the Siwalik Hills experience water level fluctuations large enough to place water levels below the lifting capability of commonly used centrifugal pumps. Therefore, very few STW obtain water from the Bhabar. Yields from DTW in Siraha District which may obtain water from the Bhabar were not measured during this investigation.

2.3 Terai Plain Deposits

2.3.1 Lithology, distribution, and thickness

Throughout the Terai a thick sequence of clastic sediments, the Terai Plain deposits, has been and is being deposited. These sediments are at the surface except for the outcrop area of the Bhabar Zone. These deposits cover about 750 km^2 in Siraha and their thickness may exceed 2000 meters along the Indian border. The Terai Plain area is a major recharge source to the ground water reservoir.

The Terai Plain sediments are comprised of rock material eroding from the Siwalik Hills and the mountains to the north. Sediment particles range in size from clay to gravel and the proportions vary widely. However, they generally comprise more clay, silt, and fine sand than sand and gravel. The coarser size fractions appear to be lenticular in cross section and are described as sand lenses or sand and gravel lenses contained in finer sediments.

The UN and other wells listed in Table 5 are further analyzed regarding the percentage of aquifer (permeable) material found in each well and for all wells. Table 6 lists several derived data for the wells.

2.3.2 Water Supply

There were a reported 896 STW in Siraha drilled under the Sagramatha Integrated Rural Development Project (SIRDP) program in mid-1986 (GDC). These wells are in the Terai Plain. In addition, there are a large number of dug wells. Some wells provide water for drinking or domestic purposes. Others, STW in particular, provide irrigation water. Reported yields of shallow tube wells range from less than 1 l/s to more than 13 l/s. However, a majority of the pump tested wells (12 out of 18 wells) have shown the yield in a range of 6 to 10 l/s. An average of 8 l/s discharge will be used in the following calculations.

Table 6. Summary of well and aquifer data from UN and private wells listed in Table 5.

WELL DETAILS	STW	DTW	ALL TUBE WELLS
Number of Wells	25	1	26
Total drilled depth	811.7 m	*	811.7 m
Average well depth	32.5 m		32.5 m
Screen used	143.4 m	11.4 m	154.8 m
Average screen/well	5.73 m	11.4 m	5.95 m
Wells with screen	25	1	26
AQUIFER DETAILS			
Calculation depth	40	40 m	40 m
Cumulative depth	790.3 m	40 m	830.3 m
Aquifer thickness	246.2 m	5.9 m	252.1 m
Aquifer as percent of depth	31.15 %	16.86 %	30.36 %

* Total Depth of well not known.

3. HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS

Quantitative predictions about the behavior of the ground water reservoir in Siraha District are dependent on knowledge of the values of the hydraulic constants of the aquifer. These hydraulic properties are in turn dependent upon dimensional and geological parameters of the aquifer.

The constants needed are transmissivity (T), storage (S), and leakage (p'). The quantity of water available from an aquifer depends on the ability of the aquifer to store and to transmit water. The ability of an aquifer to store water is measured by its storage coefficient and the ability to transmit water by its transmissivity. The Terai reservoir may include many semi-confining beds and the ability of these beds to transmit water vertically - up or down - into an aquifer is measured by leakage.

3.1 Pumping Tests

Eighteen aquifer tests were analyzed by pumping test programs developed by UN/DTCD to determine the storage coefficient and the transmissivity of the Terai Plain aquifers. The test data were analyzed by the Theis, and the Jacob methods. Each test was analyzed by the preceding methods in an attempt to arrive at aquifer coefficients judged to be most nearly correct.

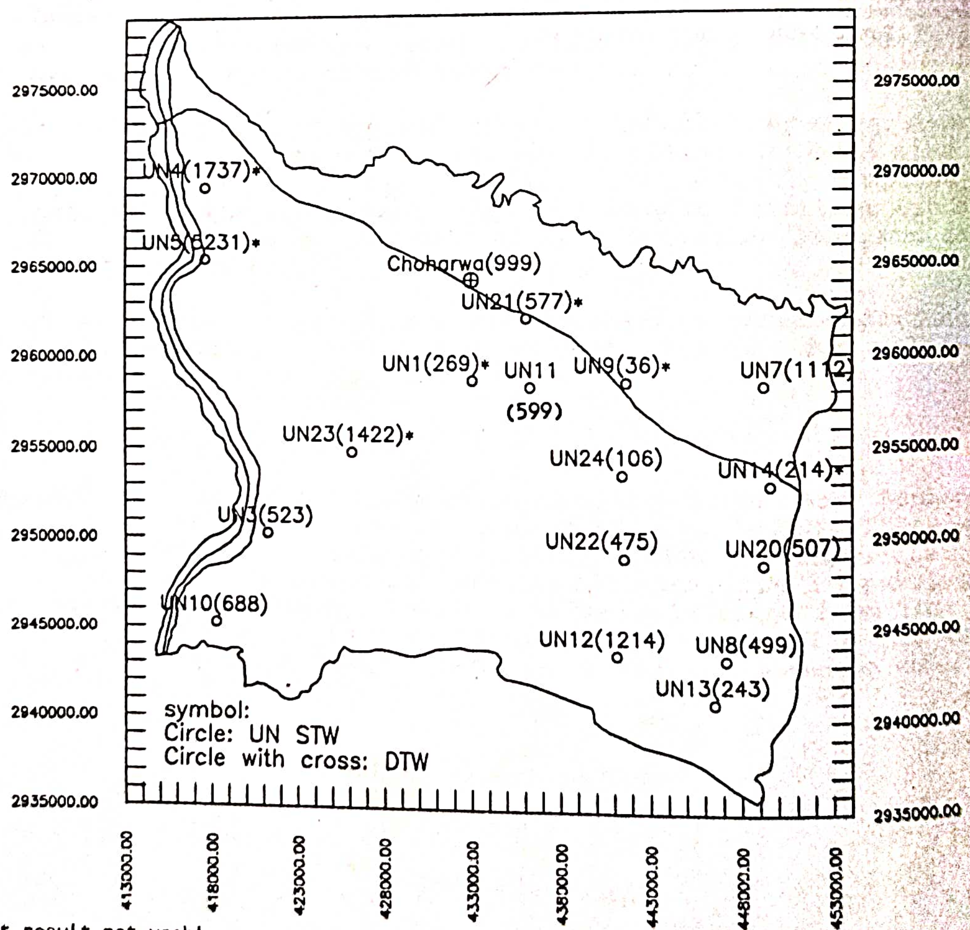


Figure 8. Map showing transmissivity values (in parenthesis) in Siraha

Seventeen project drilled STW and one private STW were pump tested. Eleven out of 18 tests are marginally acceptable. The results are listed in table 7 and the graphs are shown with observed data points and a computer-fitted curve in Appendix C. It should be noted, however that the numeric results they provide should be used with caution.

Transmissivities in the district (Fig.8) represent only a crude picture, as the data used are not satisfactory. The data problems include uncertainty about the quality of the lithologic logs, inadequate geographic distribution of tested wells, questionable pump test data and questionable results from the few pumping tests.

The limited quantity and the questionable quality of the data makes any definitive statements about transmissivity speculative. If the limited data in Table 7 are used, the transmissivity of the shallow aquifer in Siraha District averages about 669.4 m^2/day. Transmissivities above 500 m^2/day are considered sufficient for water supply and small scale irrigation. Prior to large scale development of ground water in Siraha, additional pump tests properly run, would be extremely beneficial.

Table 7. Hydrologic properties from pumping tests.

Well No.	Date of Test	Transmissivity (m^2/day)	Aquifer Thickness (m)	Hydraulic Conductivity (m/day)	Aquifer Lithology
UN 1 *	12.02.90	269	4	67	S & G
UN 3	29.01.90	523	6	87	S & G
UN 4 *	18.01.90	1937	12	161	S & G
UN 5 *	10.02.90	5231	10	523	S & G
UN 7	04.12.89	1112	5	222	S & G
UN 8	12.07.89	499	4	125	S & G
UN 9 *	08.12.89	36	9	4	S & G
UN 10	14.12.89	688	8	86	S & G
UN 11	20.12.89	599	4	140	S & G
UN 12	27.12.89	1214	7	173	S
UN 13	25.05.89	243	5	49	S
UN 14 *	16.05.89	214	6	36	S & G
UN 20	08.05.89	507	6	84	S
UN 21 *	14.02.90	577	8	72	S & G
UN 22	20.04.90	475	5	95	S & G
UN 23 *	02.04.90	1422	10	142	SC
UN 24	20.04.90	106	7	15	S & G
STW choharwa	04.04.90	999	6	166	S & G

Note: * Results not usable.

4. GROUND WATER

The discussion on ground water will cover general ground water concepts. The data acquired in this ground water investigation will be used to help quantify major components of the Siraha District ground water system.

4.1 Source

The primary source of ground water in Siraha District is local precipitation. For example, ground water in the Bhabar Zone and the Terai Plain deposits is derived from precipitation that falls on Siraha and the watersheds of the streams that traverse Siraha, including the Siwalik areas of those watersheds. Ground water consists of precipitation that percolates through the materials on the earth's surface to the water table. Figure 9 illustrates the relationship between precipitation and water levels in selected wells.

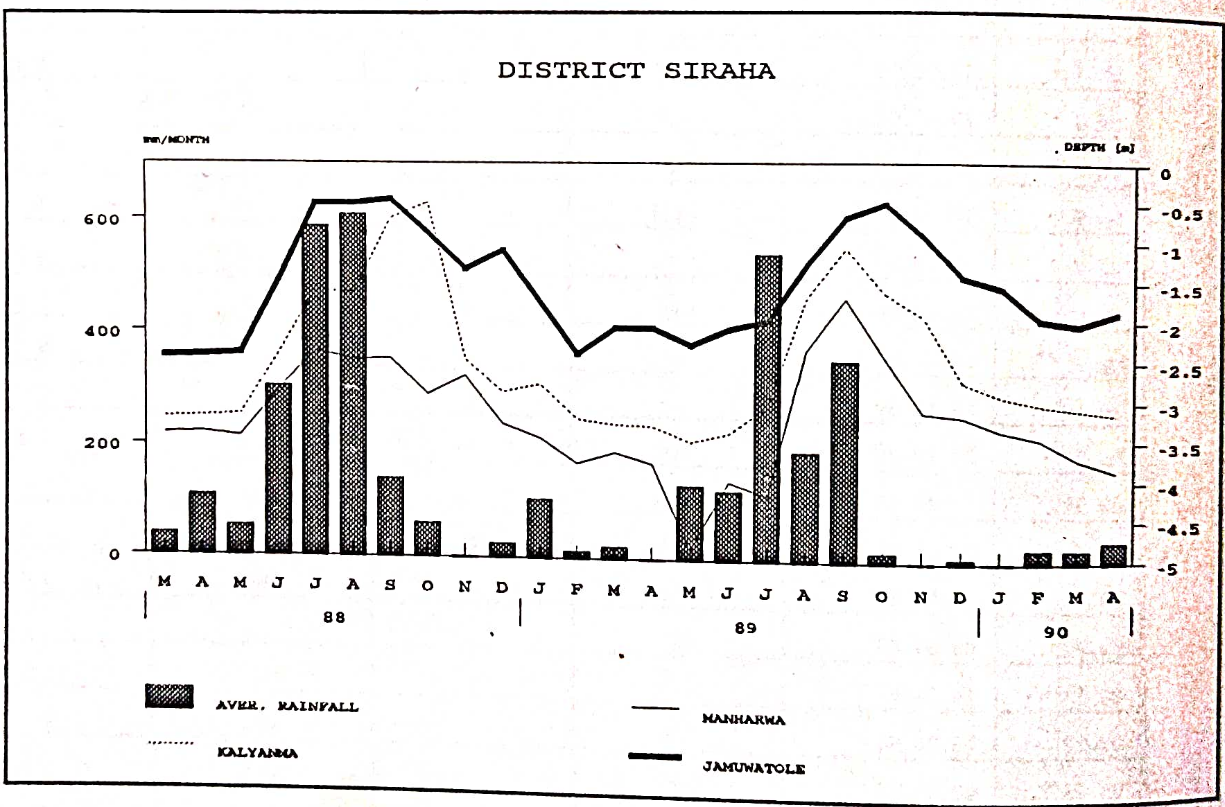


Figure 9. Relationship between rainfall and water levels in selected wells in Siraha.

4.2 Water Level Network

A water level network is a major tool in ground water hydrology and regular measurement of water level in wells in a network are required for quantitative recharge and discharge calculations. Location of private STW and dug wells and the UN STWs in the network in Siraha District are shown in Figures 10 and 11 respectively.

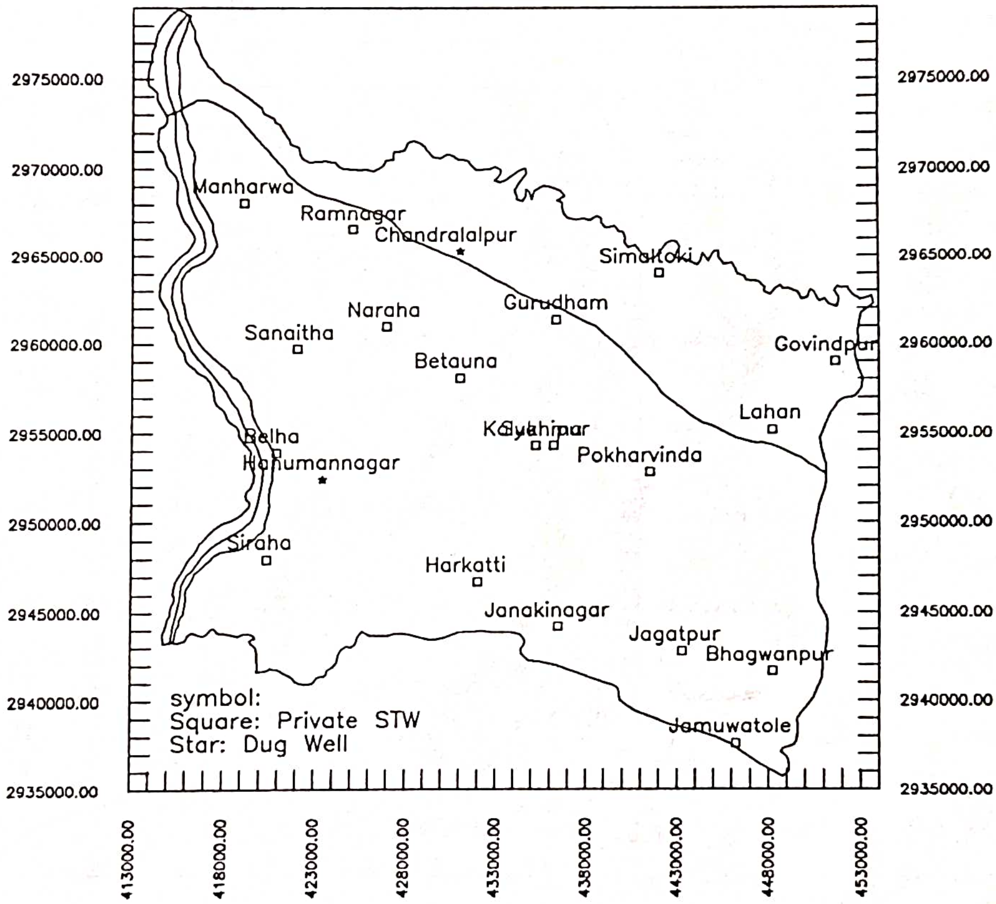


Figure 10. Location of Private STW and Dug Wells in Siraha.

4.3 Occurrence and Movement

Water in unconsolidated aquifers occurs in the interstices between rock particles. The rate at which water will move through these aquifers depends on the hydraulic gradient and on the shape, size, and the interconnection of the contained voids or interstices. The quantity of ground water available to wells depends on the areal extent and the saturated thickness of the aquifer. Interstices in sand and gravel are larger and better connected than interstices in silt and clay. Thus, water will flow freely through a coarse gravel under a low hydraulic gradient, but will move with extreme slowness through clay even under a high hydraulic gradient.

The shape and slope of the water table in May and September,1990 in Siraha District are shown on Figure 12 by contours drawn through points of equal altitude of the water table. Ground water moves down gradient at right angles to the contours. The contours indicate that ground water was moving generally from north to south. The spacing of the contours indicates a hydraulic gradient of 5 meters per kilometer at the north to 1.43 meter per kilometer on the south.

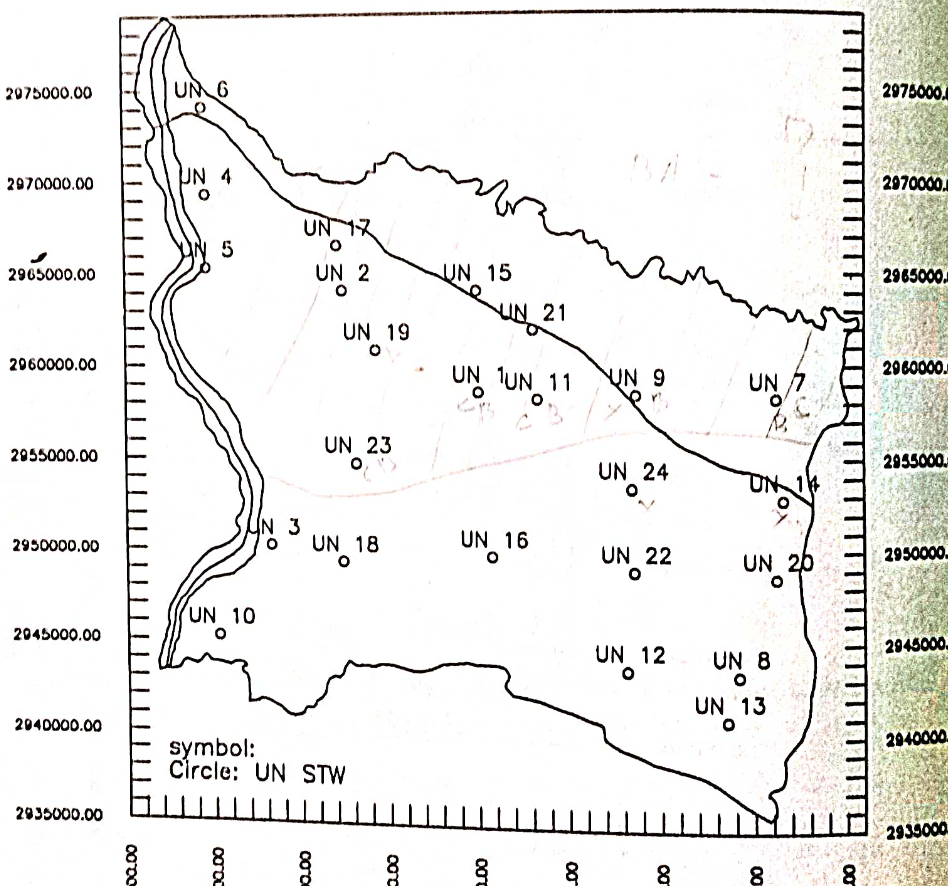


Figure 11. Location of UN STW in Siraha.

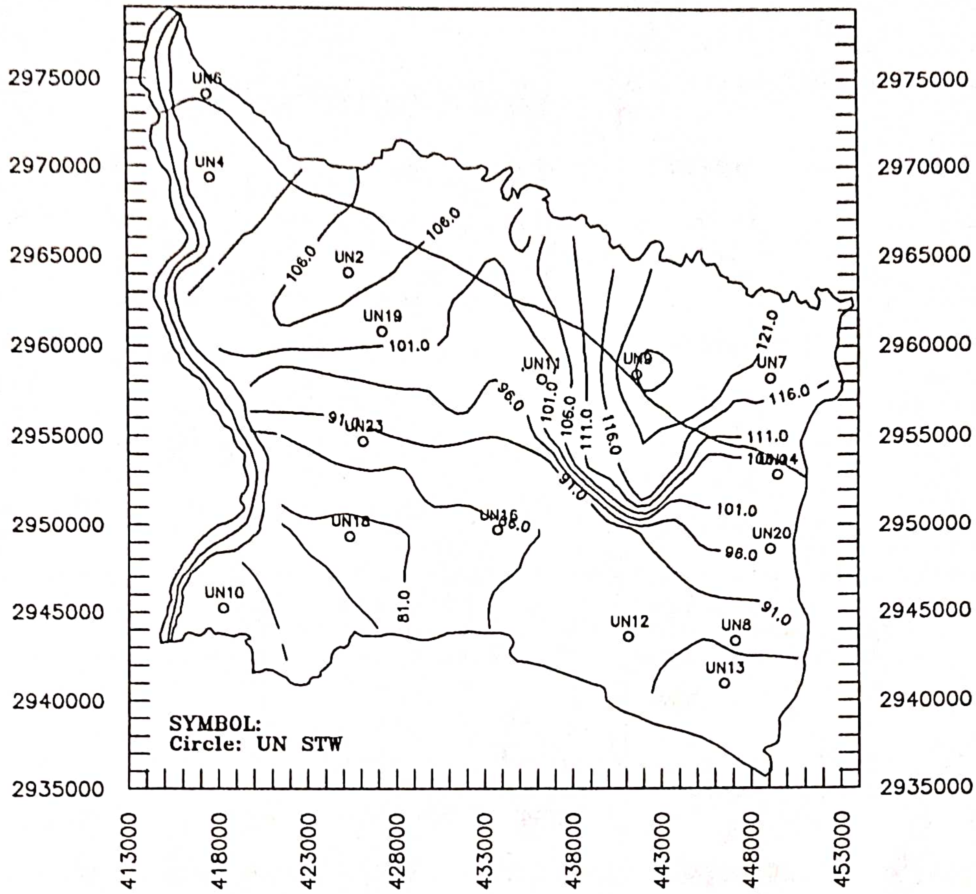


Figure 12 a. Contour Map of Water Table in Siraha, May 1990.

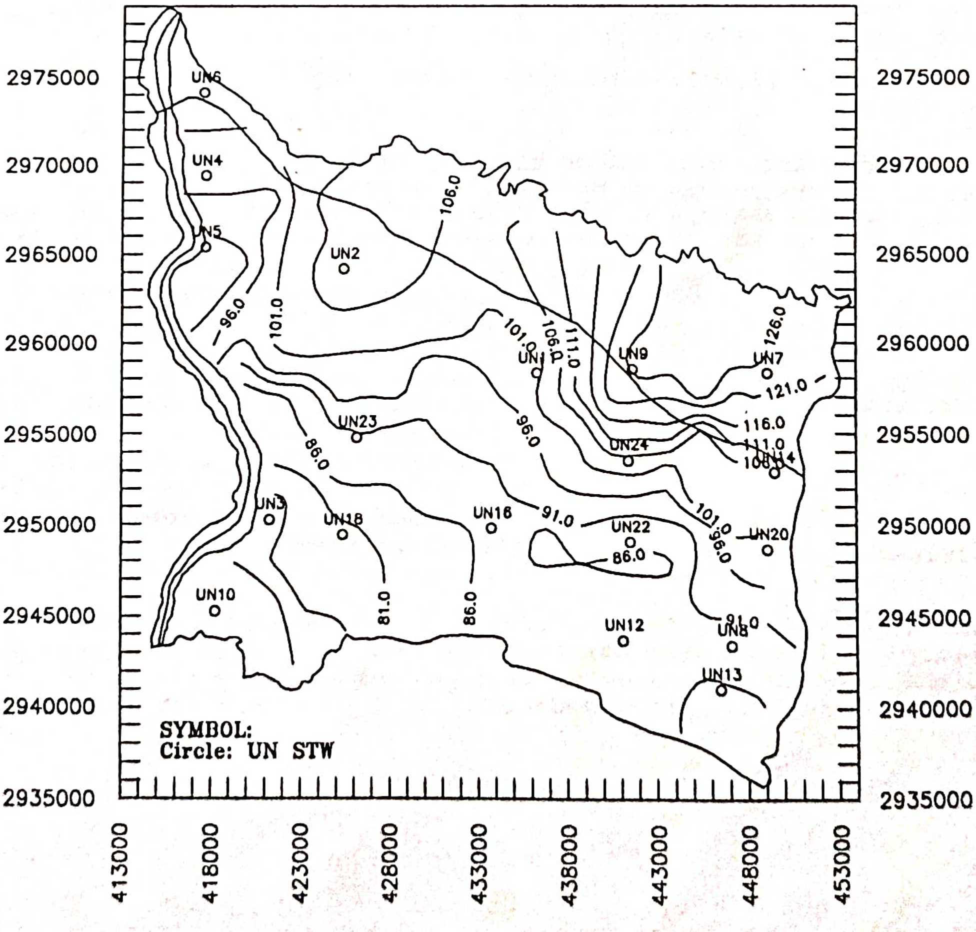


Figure 12 b. Contour Map of Water Table in Siraha, Sepatember 1990.

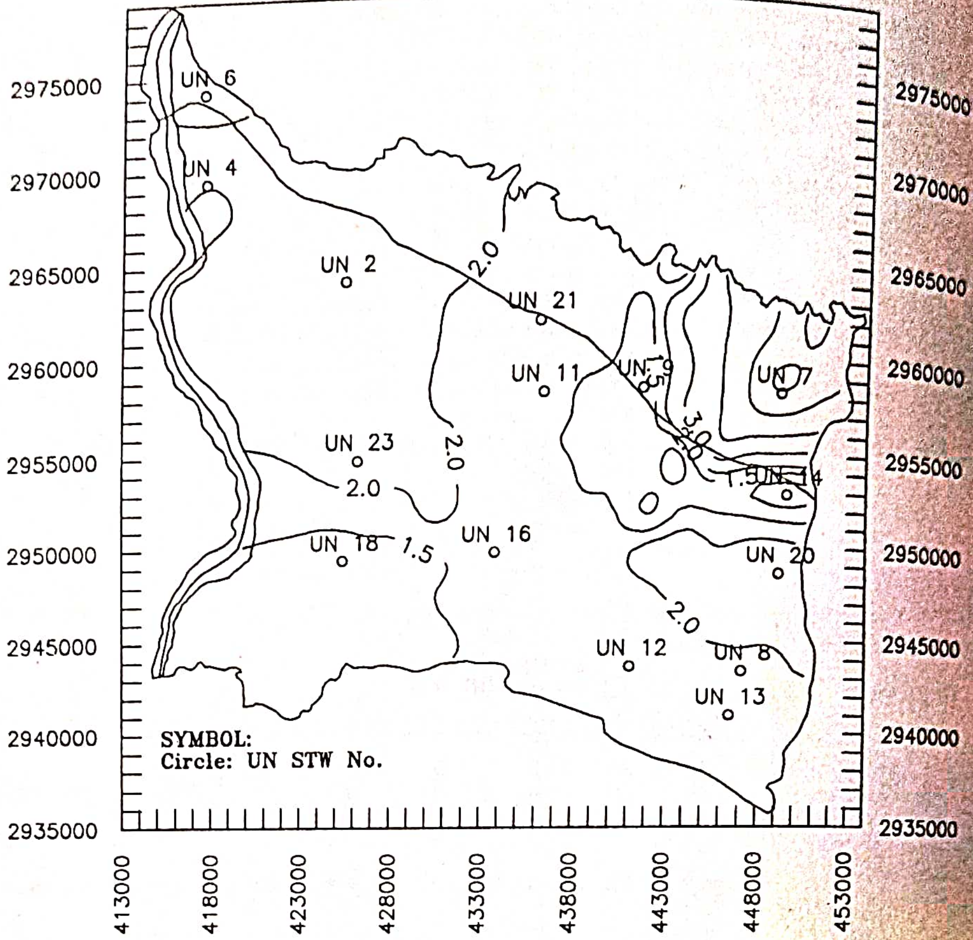


Figure 13. Rise of water level, May - September, 1990 in siraha.

The quantity of water flowing through a given cross-sectional area of an aquifer can be computed by the formula:

Q = pAv = KIA = TIL

where **Q** is the quantity of water,
p is the porosity of the aquifer material,
A is the cross-sectional area,
v is the average velocity of ground water,
K is the hydraulic conductivity, and
I is the hydraulic gradient.
T is the Coefficient of Transmissibility
L is the Width of the cross-section through which the discharge occurs

The approximate rate of movement of ground water through an aquifer is obtained by transposition of the above formula to :

v = KI/p

An estimate of the quantity of water moving as subsurface outflow to India is calculated using the following assumptions:

Average Transmissivity along India border in Siraha is 600 m^2/day
Average Hydraulic gradient is 0.00143
Aquifer width (length of border with India) is 36 km

$Q = TIL = 600 * 0.00143 * 36 = 30{,}888\ m^3/day$
or, about **11.27 MCM** per year ....(1)

The rate of flow is calculated using:

Hydraulic conductivity of 50 m/day
Hydraulic gradient of 0.00143
Assumed porosity of 15%

$v = KI/p = (50 * 0.00143)/0.15 = 0.48\ m/day$

The value of **Q** can also be calculated using the above velocity value:

Average aquifer saturated thickness is the average % of coarse grained material in the STW, or 31.15 % of 40 meters, or 12 meters,

Assumed effective porosity of 15%,
Aquifer width (distance along border with India) 36 km,
Hydraulic gradient of 1.43 meter per kilometer (0.00143), and
Velocity or rate of flow is 0.48 m/day.

From $Q = pAv$, we obtain $Q = 0.15 * 12 * 36 * 0.48 = 31{,}104\ m^3/day$
or about **11.35 MCM per year** ....(2)

The two vlaues for **Q** are in agreement with each other.

Thus the volume of water flowing to India through the upper 40-50 meters is about 11 million m^3 per year at a rate of 0.48 m per day. If the rate of flow is doubled, the volume of water flowing to India also doubles, but it is still relatively a small amount.

4.4 Storage

The total thickness of the Terai sediments in Siraha District is not known but even if only the upper 50 meters are considered, the volume of ground water in storage is quite large. The volume of drainable water is a function of thickness and specific yield of the saturated sediments. An average specific yield for sediments from a similar depositional environment and similar lithologies, e.g. the High Plains aquifer of the United States is 0.15 (Gutentag et al., 1984). The drainable water in storage may be calculated by multiplying aquifer thickness, estimated specific yield and area of the aquifer.

The water levels in the Terai Plain deposits seldom are less than 5 meters and in the Bhabar Sone deposits less than 10 meters. Therefore, the Terai Plain in general would have 45 m and the Bhabar 40 m of saturated sediment in the upper 50 m.

The volume of drainable water in storage is not calculated because all the drainable water in storage cannot be recovered and used. The recoverable volume of water is site-specific and depends on well construction and design, lithology, saturated thickness, hydraulic conductivity, specific yield and drainage time.

4.5 Changes in Storage

One method of assessing changes in the amount of ground water in an aquifer involves periodic water-level measurements, construction of water-level-change maps from the measurements, and computation of the volume of material and water involved in the change. Unless heavy pumping disturbs natural conditions, the changes in storage in an aquifer reflect seasonal changes in precipitation and evapo-transpiration. Water-level-change maps may show, by minor fluctuations and trends, essentially static conditions in a relatively undisturbed aquifer.

Figures 14 and 15 shows depth to water table for 1988 and 1989 in Siraha. Note the difference in the distribution of the wells (Figure 10) on the 1988 maps which are from measurement of dug wells and private shallow tube wells and the well distribution on the 1990 maps (Figure 11) which are from UN wells only.

Figures 16 and 17 show the water level change maps for 1988 and 1989. The maps document changes within each year which are attributed primarily to seasonal variations. However, comparison of the two maps with Figure 13 points out the difference in populations of wells used for water level measurements.

Water level measurements provide extremely important information about the ground water situation in an area. The hydrologist must be very careful, however, as water levels from different aquifers may lead to incorrect conclusions and potentially large errors in judgement.

Tables of water level measurements from wells in Siraha are given in Appendix D, and hydrographs of selected wells are shown in Appendix E.

4.6 Discharge

Ground water in the Terai portion of the Siraha District is discharged from the aquifer by wells, evapotranspiration, subsurface outflow, and inflow to streams. Measured data about these methods of ground water discharge are not plentiful and not of the best quality. Therefore, large estimates of well discharge are made to provide considerable stress on the aquifer.

4.6.1 Pumping By Wells

Pumpage records for irrigation wells are few or not available. However, an estimate of pumpage may be calculated by assuming a specific number of irrigation wells, the number of hours each well is pumped in a year, and the average yield of each well.

Assume there are 1000 shallow tube wells in Siraha and each yields 20 l/s and each is pumped for 2160 hours per year. These assumptions result in the following calculation:

$$(1000 * 20 * 2160 * 60 * 60) / 1000 = 155.5 \text{ MCM per year.}$$

The figure of 155 MCM will be used later in a comparison of recharge and discharge.

4.6.2 Evapotranspiration

Direct evaporation occurs in areas where the water table is near the land surface, such as along stream banks and in stream beds. The potential for evaporation is high during the rice growing season as the paddies are really large bodies of surface water during that time. Finally, during and after the monsoon the water levels are at or near the surface at many places in Siraha.

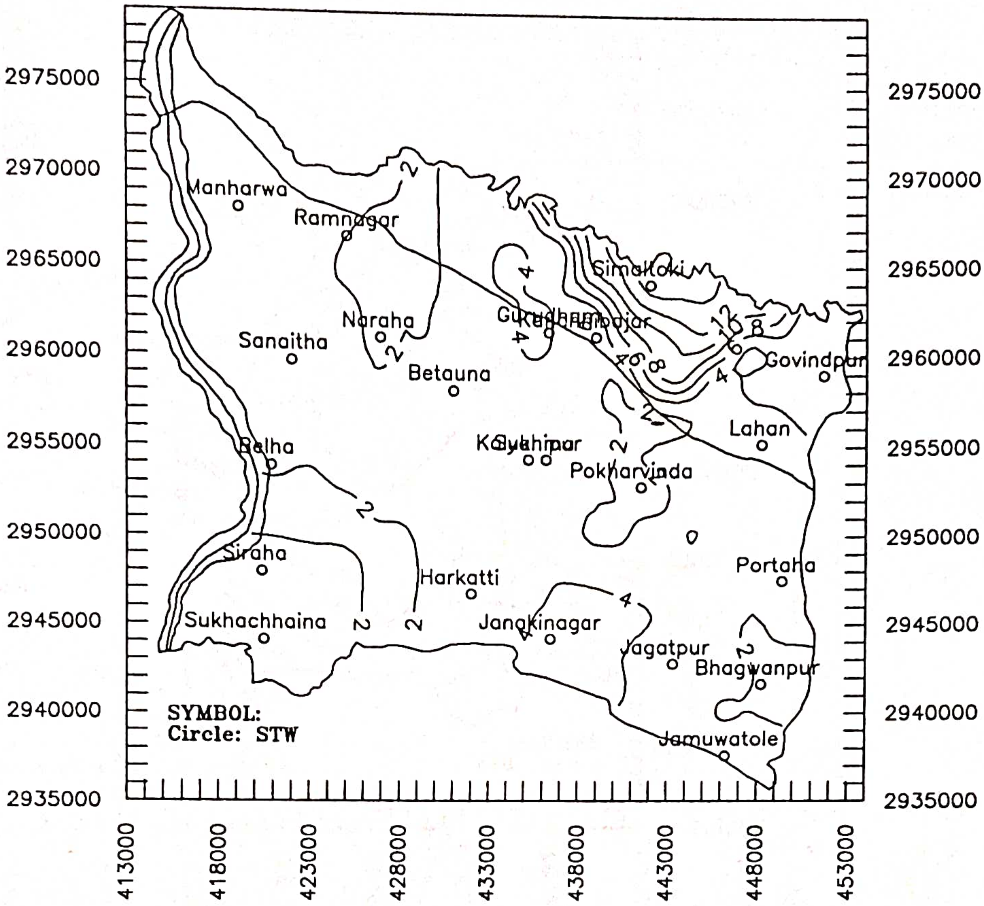


Figure 14 a. Depth to Water Table in Siraha, May 1988.

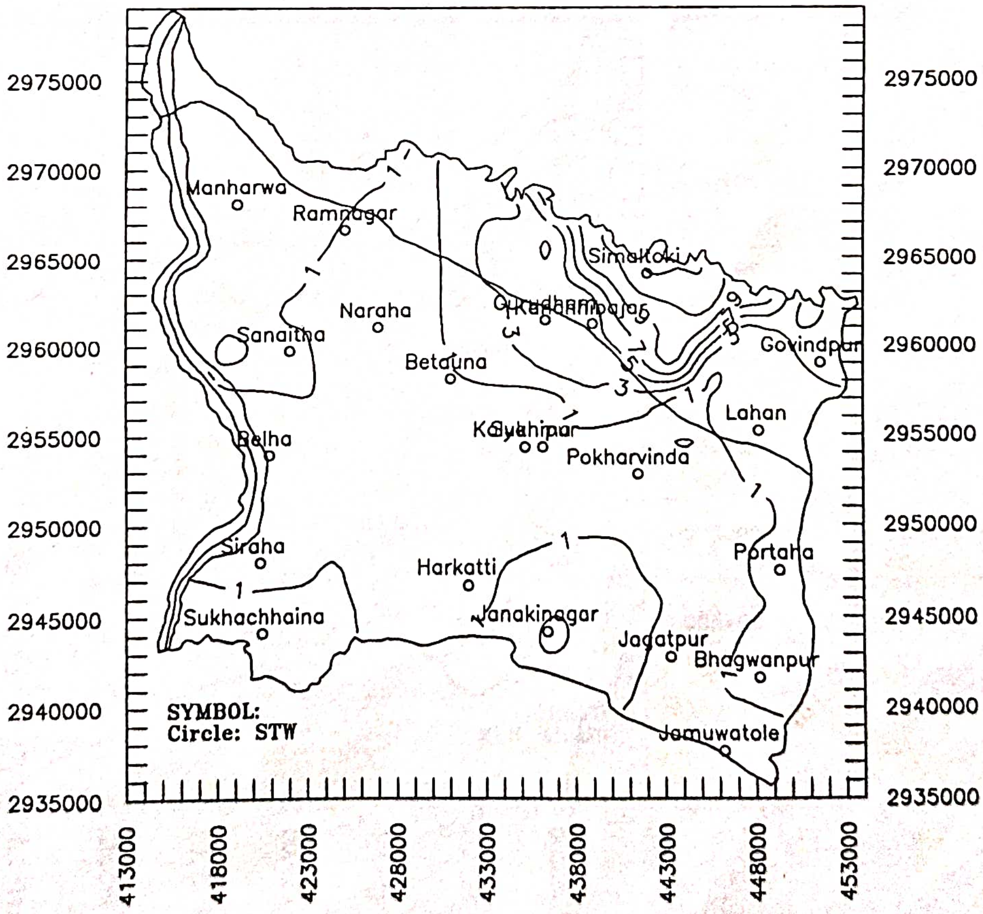


Figure 14 b. Depth to Water Table in Sirana, September 1988.

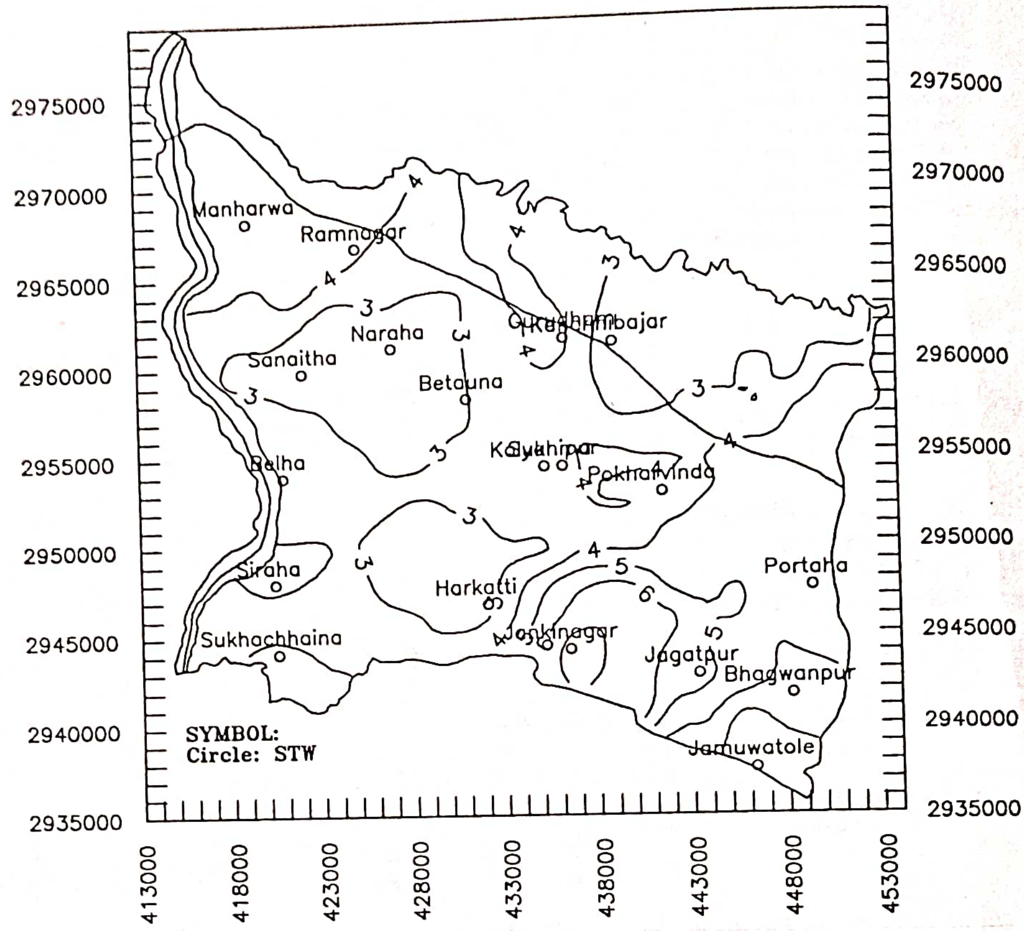


Figure 15 a. Depth to Water Table in Siraha, May 1989.

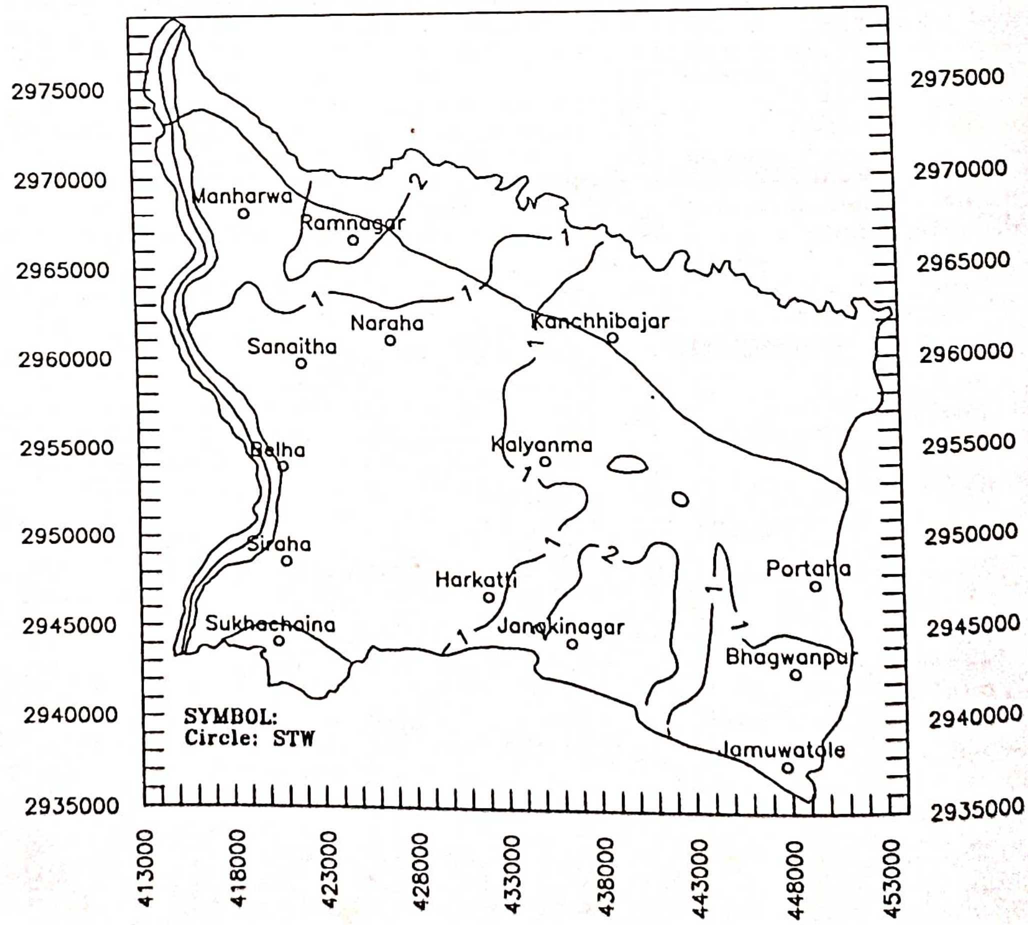


Figure 15 b. Depth to Water Table in Siraha, September 1989.

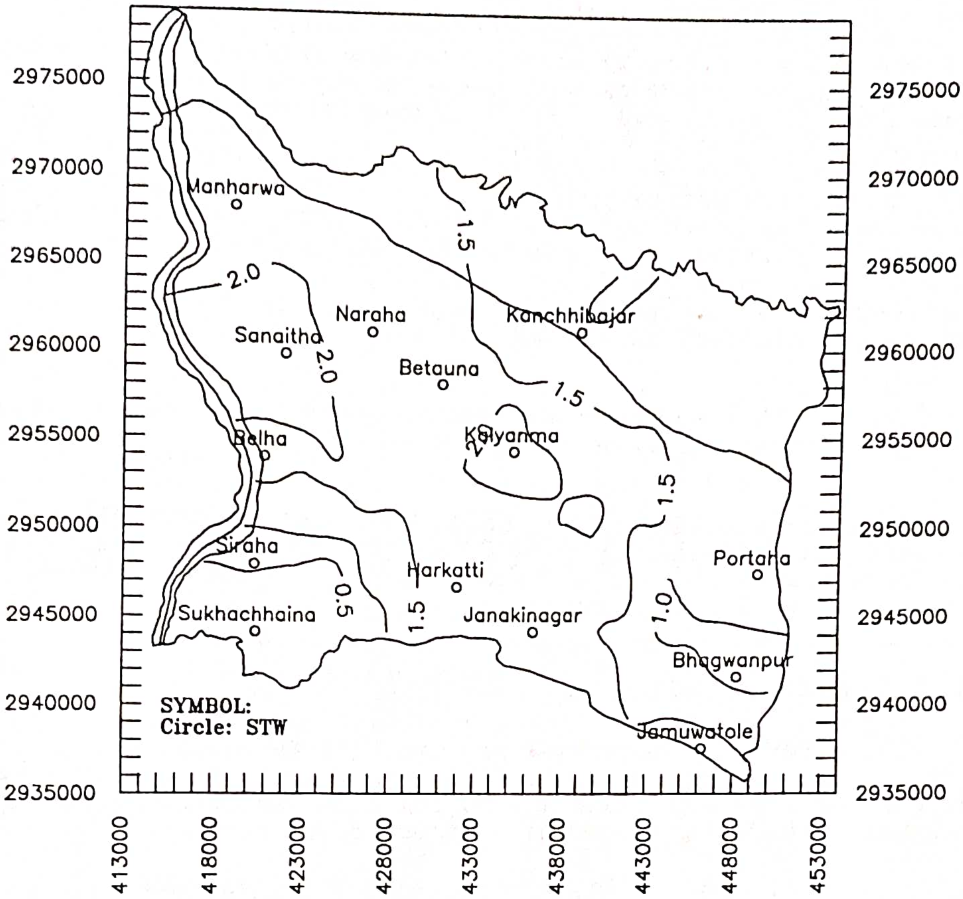


Figure 16. Rise of Water Level in Siraha, May-September 1988.

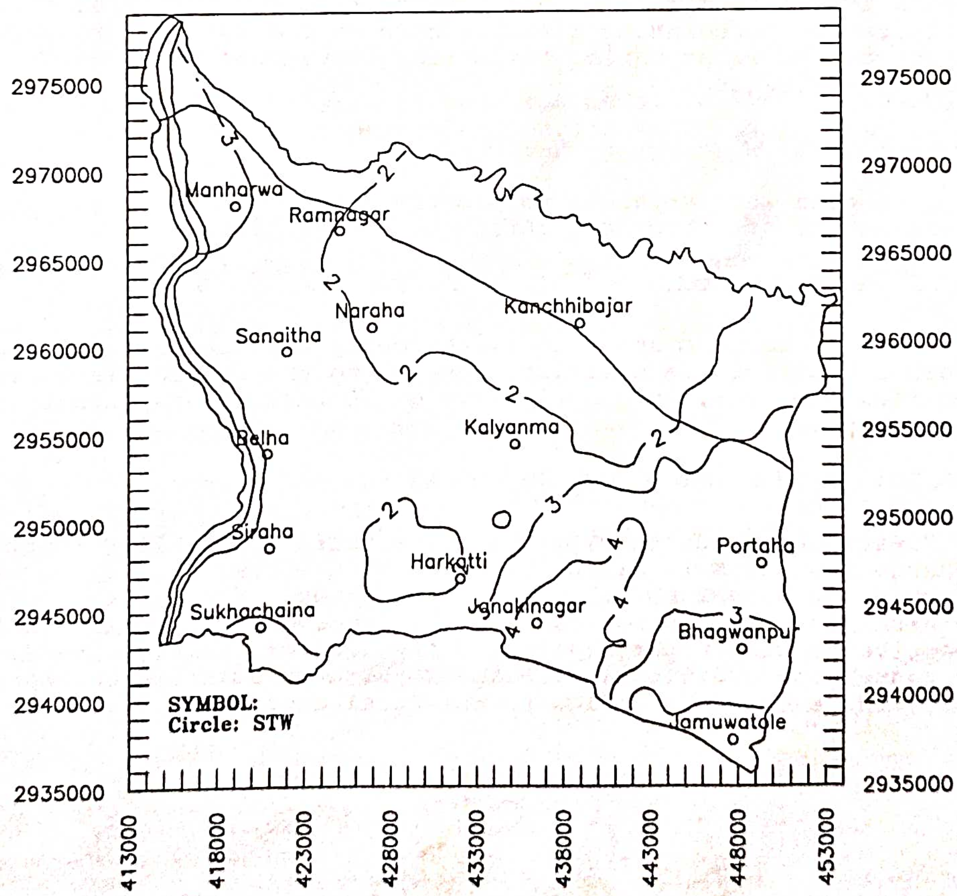


Figure 17. Rise of Water Level in Siraha, May-September 1989.

The transpiration by plants from the saturated zone is not confined to the water courses where large vegetation may be found. Rather, transpiration is occurring in the forests and from growing crops.

An estimate of potential evapotranspiration was made using the water table fluctuation between Pre- and post-monsoon periods over the district. This assumes the principal cause of fluctuation to be loss of ground water due to evapotranspiration. The average fluctuation over the district is estimated at 2 m with 1.5 m of the fluctuation attributed to evapotranspiration, the specific yield of the saturated sediments is estimated at **0.15** and the area of Terai in the district is 930 km^2. Thus,

1.5 * 0.15 * 930 km = **209 MCM** of ground water potentially evapotranspired each year in Siraha.

Lowering the water table below the depth of most evapotranpiration processes wouldeffectively permit the 279 MCM of ground water potentially evapotranspired each year to become recharge. this additional recharge would be available to irrigate crops.

4.6.3 Inflow To Streams

The water level contours of Figure 12 show that the Kamala River is a gaining river during the dry part of the year in Siraha. However, no stream flow records were available and no low flow measurements were examined or made. Hence there is no estimate of inflow to streams.

4.7 Recharge

The aquifer in Siraha is recharged by subsurface inflow from stream valleys entering the district, by subsurface inflow from the Siwalik Hills, by seepage losses from streams during high flow and perennial streams and by precipitation percolating directly through the soil and rock materials on the surface to the water table. These four increments of recharge result from local precipitation.

4.7.1 Subsurface Inflow

No data were obtained to provide a basis for a quantitative determination of subsurface inflow to the aquifer.

4.7.2 Seepage Losses From Streams

The drainage systems in Siraha carry large amounts of surface water in, across and out of the district. Seepage to the aquifer is substantial during high flow. However, no quantitative determination of seepage into the aquifer was attempted.

4.7.3 Percolation From Rainfall

Percolation of precipitated water into the aquifer is the primary recharge mechanism in Siraha District. The Bhabar Zone is particularly receptive to direct percolation to the water table due to the large size of the particles comprising the deposits. However, the Terai Plain is also receptive to direct percolation to the aquifer. Finally,the Siwalik exposures may contribute additional recharge through percolation to the aquifer and subsequent subsurface inflow to the Terai aquifer.

Three estimates of recharge from precipitation are calculated. The first method utilizes estimated from Duba (1982); method two assumes 10% of rainfall becomes recharge; and the third method assumes a specific yied or effective porosity of saturated sediments and an average water level rise of 2.5 m in the district. Each method uses an area of 930 km^2 for the Terai in Siraha District.

Method 1:

Duba (1982) estimated 32% of the rain that falls on the Bhabar and 20% that falls on the Terai plain in the Siraha District would percolate to the aquifer. However,no estimate of recharge was made by Duba for the Siwalik Hills contribution.The calculation for recharge from precipitation using estimates by Duba is given below:

Volume of recharge (m^3) = annual precipitation in meters * area of interest in Km^2 * % to aquifer

Thus for the Bhabar Zone deposits:
1.313 m * 180 Km^2 * 32% = 76.8 MCM (about **77 MCM**)

And for the Terai Plain deposits:
1.313 m * 750 km^2 * 20% = 196.95 MCM (about **197 MCM**)

and the sum is about **274 MCM** per year of recharge.

Method 2:

A more conservative estimate of recharge is calculated by taking 10% of the average annual precipitation and assuming it will recharge the ground water reservoir. The calculation is ;

For Terai,

1.313 m * 930 km^2 * 10% = **122.1 MCM** per year of recharge

Method 3:

Assume the storage coefficient or specific yield is 0.15, the annual water level fluctuation is 2 m over an area of 930 km^2 in the district, the calculation is :

For Terai,

0.15 * 2 m * 930 km = **279 MCM** per year of recharge.

4.8 SUMMARY OF GROUND WATER SYSTEM

The indeterminate number of interconnected aquifers in the Siraha Terai are subject to recharge (addition of water to the aquifers), storage (retention of water in the aquifers), and discharge (diversion of water from the aquifers). The relation is simple and direct. When recharge exceed discharge, (during monsoon period) the quantity of water in storage increases and the water table rises. Conversely, when discharge exceeds recharge, (during dry period) the quantity of water stored decreases and the water table declines. The monsoon raises the water table as the aquifer(s) are recharged by percolation of rain, seepage from streams and by subsurface inflow from the Siwaliks. The dry season lowers the water table as the water is pumped, transpired, evaporated, and moves in the subsurface toward the south.

The water level change maps reflect the recharge, change in storage and discharge taking place in the Siraha ground water system. The change maps indicate the system is maintaining equilibrium as agricultural practices replace the forests. Put another way, stress on the aquifer, for the short period of record of this project, shows no discernible effect on the water level maps.

The recharge and discharge estimates seem reasonable. Table 8 brings these figures together. This is not a water balance as no numeric estimate of water in storage is provided. Water in storage is a large volume but only a part of it would provide water to wells.

Table 8. Estimates of ground water recharge and discharge in Siraha.

Item	Recharge	Discharge
Recharge by 3 methods:		
1). **Duba's estimate.**	**274 MCM**	
2). **Conservative estimate (using 10% of rainfall).**	**122 MCM**	
3). **Calculation considering specific yield and fluctuation in Water table.**	**279 MCM**	
Discharge		
1). **Pumpage.**		**155 MCM**
2). **Evapotranspiration.**		**209 MCM**
3). **Outflow to India.**		**11 MCM**

Information about the recharge and discharge in the ground water system in Siraha district is not complete. Several of the components necessary to fully describe the system have not been measured or observed. However, estimates are made for some major components where data are lacking with the thought that the estimates may be refined as additional data are collected in the future; and other components are not known and not estimated as their influence will become measurable as the ground water system is developed. The status of data components required to describe the Siraha ground water system are listed in Table 9.

Table 9.Status of components required to describe Siraha Ground Water System.

Component	Available	M(easured) E(stimated)	Reliability	Areal distribution
Siwalik information	No			
Bhabar zone delineation	No			
Terai Plain delineation	No			
Detailed well inventory	No			
Lithology of wells	Yes	M	Adequate	Adequate
Aquifer tests	Yes	M	Poor	Poor
Storage coefficient Transmissivity Leakage	Yes Yes No	E M	Poor	Poor
Water level measurements	Yes	M	Adequate	Adequate
Weather records	Yes	M	Adequate	Adequate
Pumpage records	Yes	E		
Stream flow records	No			
Evaporation data	No			
Transpiration data	No			

5. SHALLOW GROUND WATER AVAILABILITY

Areal delineation of probable SIW is a major goal of the present project. The criterion defining a SIW are listed below:

1. a water level that does not exceed 7 meters in depth in the dry season while pumping
2. a discharge adequate to irrigate an individual farm, as required
3. no deeper than 50 meters
4. 100 mm or 4 inches in diameter
5. use a centrifugal pump
6. powered by a diesel or electric motor
7. drilled by indigenous methods

The definition includes depth, diameter, energy source, types of pump and method of drilling a well all predicted to be within the range of resources a farmer may command.

Figure 18 shows the areas of probable SIW in Siraha District. Contours of depth to water have not exceeded 5 meters during the dry season in the area shown since the project began. The depth to water criterions is the most

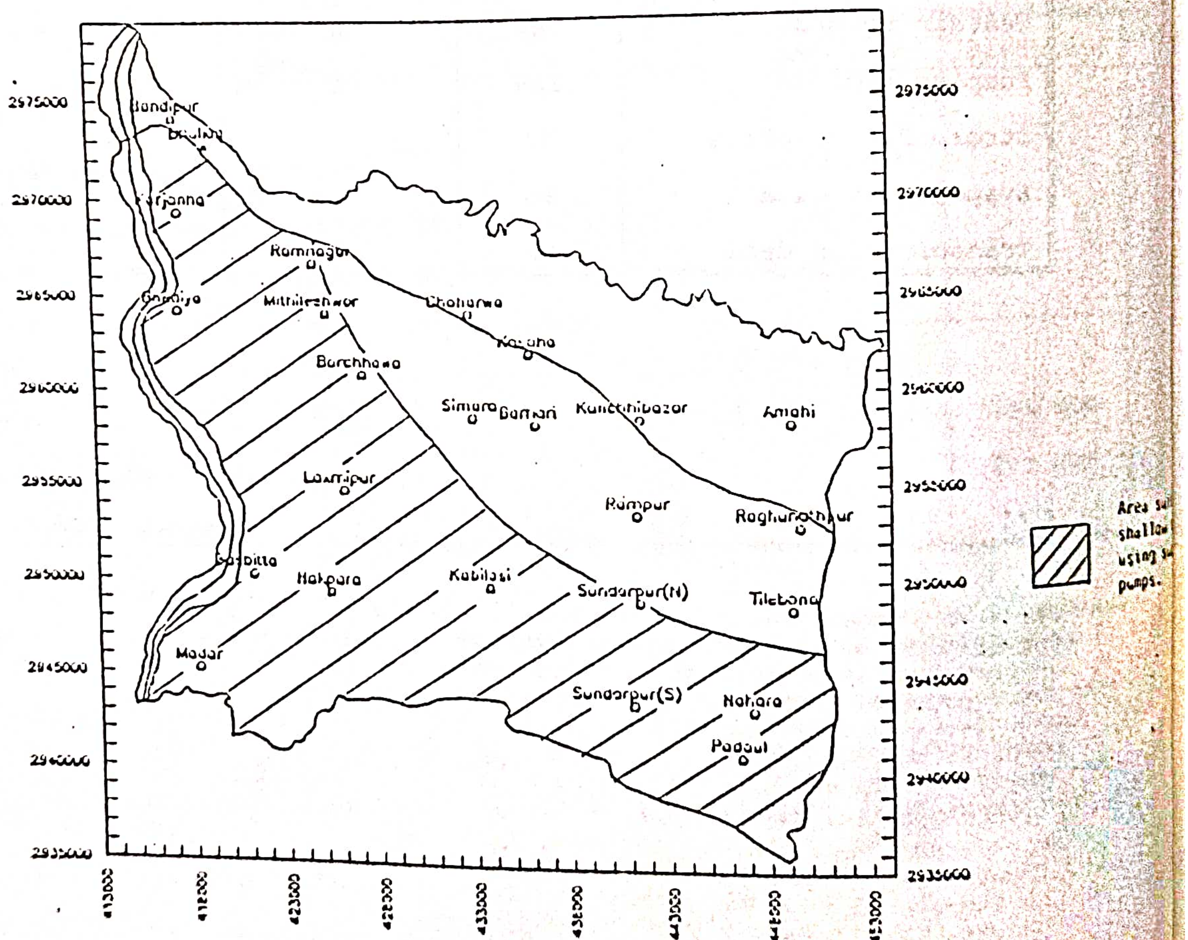


Figure 18. Map showing areas potential for Shallow Irrigation Well in Siraha.

important hydrologic constraint in the above definition of the SIW. Wells in the Terai will almost always find water but the wells may not yield water to a centrifugal pump during the dry season if the depth to water exceeds 7 meters. Three meters of drawdown must be exceeded before a well would cease to produce irrigation water in the designated areas.

Wells drilled to 40 meters should find about 12 meters of aquifer material, on average. This also means that some wells may find practically no aquifer and some wells may find practically all aquifer. In other words, holes will be drilled which will be unsuccessful wells because there is insufficient aquifer at that location.

The practice of drilling test holes to assist in choosing a productive location to place an irrigation well is common and frequently required in many ground water areas in many countries. The depositional environment of the aquifers in the Terai is such that very different lithologies may be encountered in two test holes within relatively few meters of each other. Thus, the map shows potential SIW area but does not guarantee success at each and every well location within those area.

Individual farms in Siraha averaged about 1.4 hectares in area in 1981 (SPBN 1986). A well that pumps 3 liters per second could cover one hectare with about 5 centimeters of water in 48 hours. The average farm could be irrigated with such a well. However, it is questionable if average size farms in Siraha are economic, even with the technology limited by the definition. The limiting factor, economically is the average size of a farm.

6. UTILIZATION OF GROUND WATER

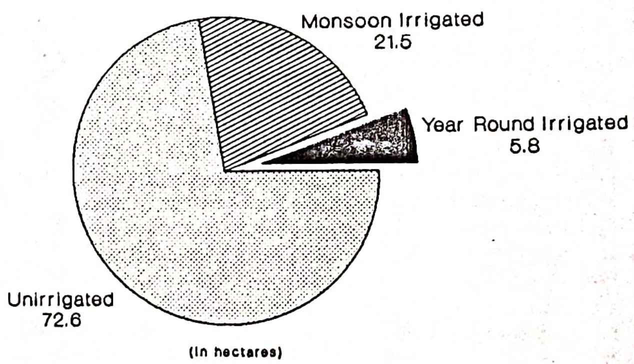
Ground water in Siraha District is utilized by families, villages, town and schools for drinking water; for watering animals; for business and industrial purposes; but the largest use and the use that seems destined to have a large increase in the future is for irrigation of crops. Table 10 indicates only 5.8% of potential irrigation land in Siraha is irrigated the year around, leaving 94.2% or about 73,171 hectares that could be irrigated the whole year. The food requirements of the expanding population of Nepal will require more and more year round irrigation in the Terai and therefore in Siraha.

Table 10. Status of irrigated land in Siraha District (in hectares)

Total area	Year round irrigated area	Monsoon irrigated area	Total irrigated area	Total irrigable area	Unirrigated area
77,726	4,555	16,738	21,292	77,726	56,433
100%	5.8%	21.5%	27.39%	100%	72.6%

Source: Agricultural Statistics of Nepal, 1990.

Figure 19. Status of Irrigated Land in Siraha



7. SUMMARY AND RECOMMENDATIONS

7.1 Summary

Field work for this project in Siraha began in the May of 1989 and for the most part was completed in 1990. the work consisted of drilling investigation wells, lithologic determinations, aquifer tests,making water level measurements, and altitude surveys of land surface at wells.

There were 17 manually drilled wells and 7 wells were drilled with a rig. The average depth of the wells is about 32.5 meters although the desired depth was 50 meters. The deepest well drilled was 49.7 m (UN 23) and the most shallow wells is 9.5 m (UN 6). Slightly more than 31% of the sediments encountered were sand and gravel and are considered aquifer. The western, southwestern and southern parts of Siraha Terai are found to be suitable for shallow tube well irrigation.

Eighteen wells were pump tested. The range of transmissivities is from 36 to 1214 m^2/day.

The water level monitoring network progressed from a network of private STW and Dug Wells in 1987 to Project STW and some private STW in 1990. As expected, the wells have the deepest water levels just prior to the monsoon and the shallowest water levels just after the monsoon. Water level contour maps indicate the ground water flows from north to south in general with a gradient of about 5.7 meters per kilometer in the northeast and about 1.43 meters per kilometer in the southern parts.

The aquifer in Siraha is recharged primarily by precipitation percolating directly through the soil and rock materials on the surface to the water table. The Bhabar Zone is particularly receptive to direct percolation to the water table because of the large size of the particles constituting the deposits. However, the Terai Plain is also receptive to direct percolation of precipitation to the aquifer. As much as 273 MCM per year may potentially be available for recharge although a more conservative estimate of about 121 MCM must be available. Even the latter estimate compares favorably with the 17 MCM of water flowing to India per year. Thus, it is obvious that the various parameters of aquifer in Siraha favorably indicate the availability of adequate ground water resource for potential use in irrigating the remaining unirrigated land in the district.

The water level change maps reflect the recharge, change in storage and discharge taking place in the Siraha ground water system. The change maps indicate the system is maintaining equilibrium as agricultural practices replace the forests. In other words, stress on aquifer, for the short period of record of this project, shows no discernible effect on the water level maps.

7.2 Recommendations

Ground water in Siraha district is utilized by families, villages, town and schools for drinking water, for watering animals, and for business and industrial purposes, but the largest use and the use that seems destined to have a large increase in the future is for irrigation. This report provides valuable data for planning and continuing development of the ground water resource but large scale development in a specific area should include additional investigative wells and properly designed and completed aquifer tests to help maximize success.

8. GLOSSARY OF TERMS

Aquifer: A rock formation, bed, or zone that contains water that is available to wells. An aquifer is sometimes referred to as a water-bearing rock, or water-bearing bed.

Evapotranspiration: The combined total water evaporated by heat energy and transpired by plants into the atmosphere.

Gaining stream: A stream or reach of a stream whose flow is being increased by inflow of ground water. Replaces the term "effluent stream."

Ground water: Water in the saturated zone or water below the water table.

Hydraulic conductivity: A measure of the rate of flow of water through an aquifer, which is dependent primarily on the nature of the interstices within the aquifer. Expressed in units of length per units of time that are consistent and suitable to the problem involved.

Hydraulic gradient: Gradient of the water table measured in the direction of the greatest slope, generally expressed in meters per kilometer.

Inflow: Movement of ground water into an area in response to a hydraulic gradient.

Interstice: An opening or void in a rock. Interstices may be filled with air, gas, oil, water, or some other material. The interstices in an aquifer are filled with water.

Outflow: Movement of ground water from an area in response to a hydraulic gradient.

Percolation: The movement of water through soil and rock to the saturated zone.

Permeability: The capacity of water-bearing rock or soil to transmit water, which is related to the size and interconnection of interstices. Replaced by the term "hydraulic conductivity."

Porosity: The porosity of a rock is its property of containing openings or interstices.Quantitatively, the porosity of a rock is the ratio (usually expressed as a percentage) of the volume of openings in the rock to the total volume of the rock.

Recharge: The process by which water is absorbed and added to the saturated zone. Also used to designate the quantity of water added to the ground-water reservoir.

Runoff: The discharge of water through surface streams. It includes both surface-water runoff and ground-water runoff. Also used to designate the quantity of water discharged as runoff.

Saturated zone: The zone of porous rocks saturated with water. Ground water is contained in this zone.

Specific yield: also called effective porosity (Johnson, 1967), is defined as the ratio of (1) the volume of water that the saturated sediment will yield by gravity drainage to (2) the total volume of saturated rock. Specific yield is expressed as a dimensionless fraction or percentage. Specific yield depends on particle size, shape, sorting, and cementation of the aquifer material and drainage time.

Specific retention: It is the difference between porosity and specific yield and is defined as the ratio of (1) the volume of water retained in the rock after gravity drainage to (2) the total volume of the saturated rock.

Storage: Water stored in openings in the saturated zone is said to be in storage. Discharge of water from an aquifer not replaced by recharge is said to be from storage.

Storage coefficient: The volume of water released from or taken into storage per unit surface area of an aquifer per unit change in the component of head normal to that surface.

Transmissibility: The transmissibility of a rock or soil is its capacity to transmit water under pressure. Replaced by the term "transmissivity."

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Expressed in units of length squared per units of time. Replaces the term "coefficient of transmissibility." To convert a value for coefficient of transissibility to an equivalent value of transmissivity, multiply by 0.134.

Water table: The upper surface of the saturated zone where the pressure is atmospheric. The water table is not a plane surface, but has irregularities much like the land surface.

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APPENDIX A

NEP/86/025 PROJECT DOCUMENT DETAILS

The project NEP/86/025 - Shallow Ground Water Investigations in the Terai - is executed by the United Nations Department of Technical Co-operation for Development. It is designed as a four year project primarily oriented to collect field data to establish a ground water data base and to assess the development potential of shallow aquifers all over the Terai. The government counterpart agency is the Ground Water Resources Development Board (GWRDB) under the Department of Irrigation (DOI), Ministry of Water Resources, HMG, Nepal. The project began in June 1987.

The immediate objectives of project NEP/86/025 are:

(1) To generate technical information on the occurrence and potential of shallow ground water resources in the Terai.

(2) To obtain the information regarding drilling and construction of shallow tube wells.

(3) To enhance the technical capacity of GWRDB with regard to exploration, assessment and development of ground water resources.

The following project outputs are anticipated:

(a) Computerized data base with about 2000 shallow water points from all over the Terai. This was expanded in December 1988 to include deep wells. Information on well location, lithology, hydrogeological parameters, water use, water levels, and etc.

(b) Maps of pre-monsoon (maximum) and post-monsoon (minimum) water levels expressed both in relative depths and in absolute elevations above mean sea level.

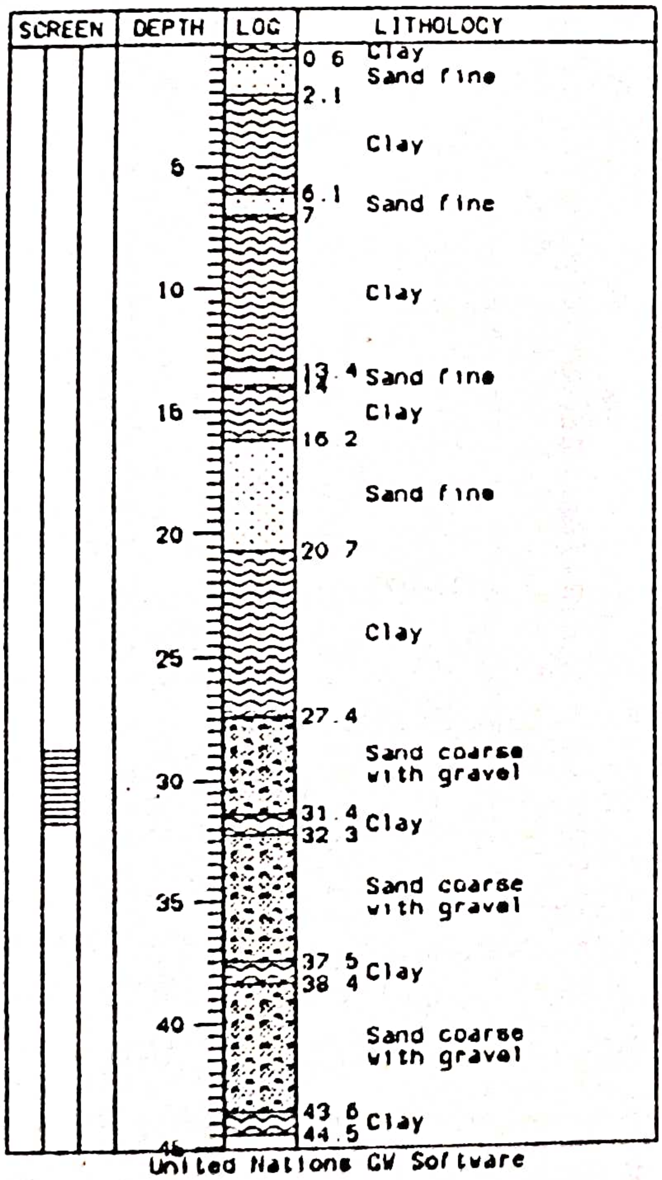
(c) Hydrographs (water level graphs) from selected observation points in a minimum period of eleven months.

(d) Reports on mathematical modelling.

(e) Report on drilling methods and results in shallow water well drilling in the Terai.

Well No UN 1	Location: SIMARA
Elevation: 117 473	X = 433000 Y = 2958625
Method of Drilling: Rig	
Drilling Dates 31 01 90 - 02 02 90	
Total Depth : 44 50	
Comments : Screen Position 28 7 - 31 7 m Screen Type: Slotted	

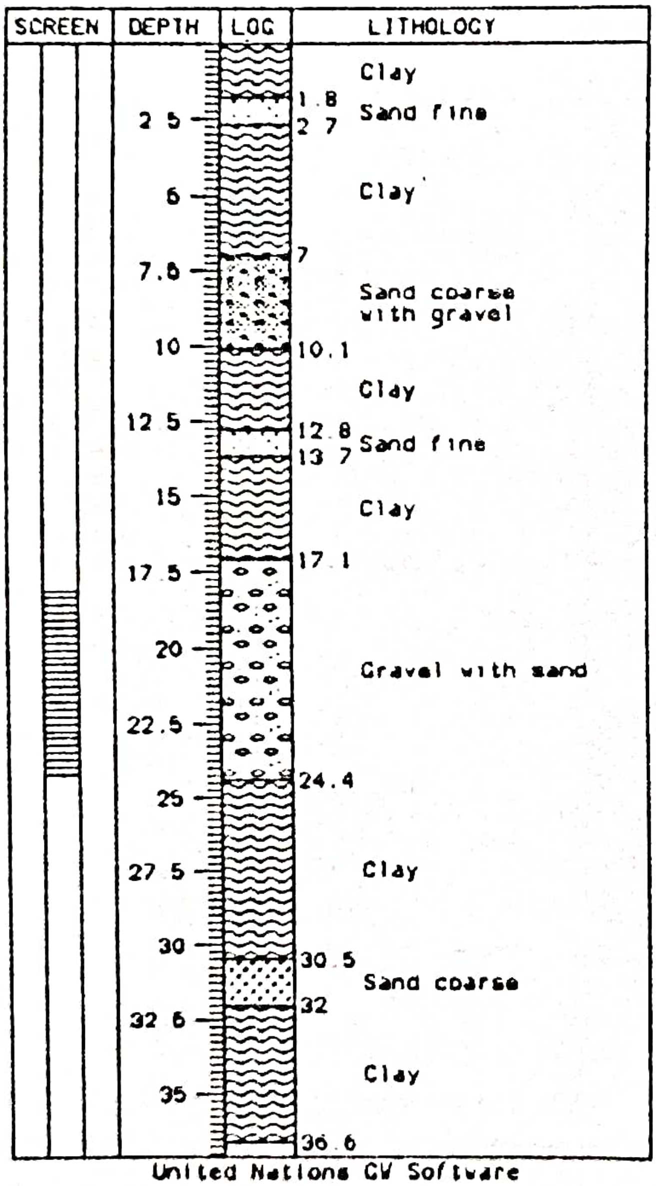
WELL LOG



B 1. Log of UN 1

Well No UN 2	Location: MITHILESHWOR
Elevation 110.798	x = 425375 Y = 2964125
Method of Drilling: Rig	
Drilling Dates : 21.01.90 - 23.01.90	
Total Depth 36.60	
Comments : M.P: 0.53 m. Screen Position: 18.1 - 24.2 m Screen Type: Slotted.	

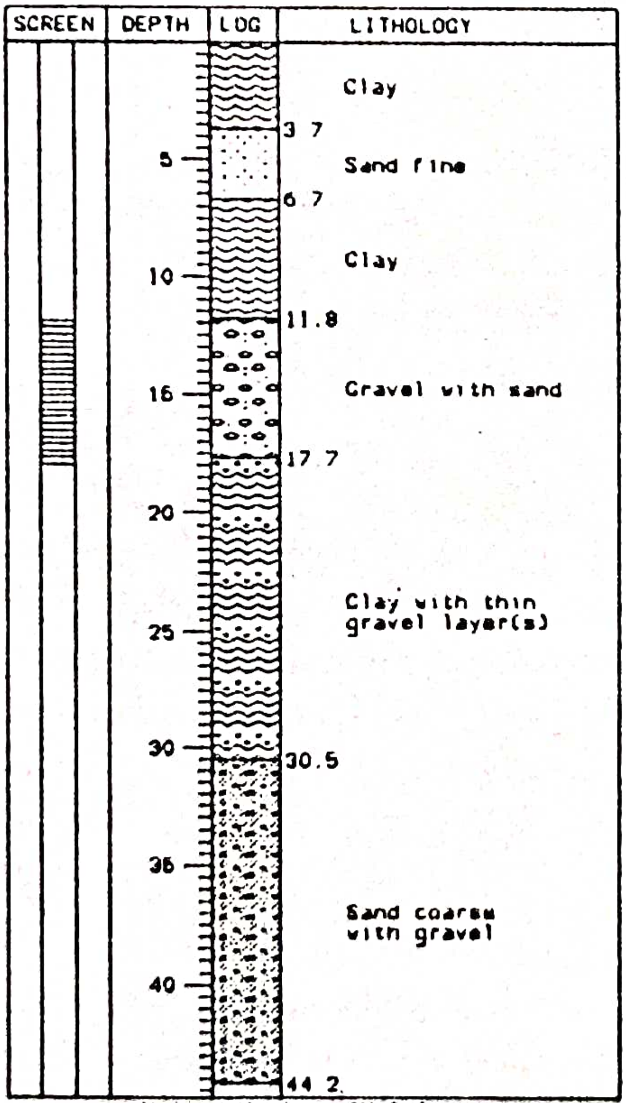
W E L L L O G



B 2. Log of UN 2

Well No UN 3	Location: BASBITTA
Elevation. 75.492	X = 421250 Y = 2950250
Method of Drilling. Rig	
Drilling Dates : 26 01 90 - 29.01.90	
Total Depth · 44 20	
Comments : M P 0 43 m Screen Position: 11.9 - 18 m Screen Type Slotted.	

WELL LOG



United Nations GV Software

PUMPING TEST

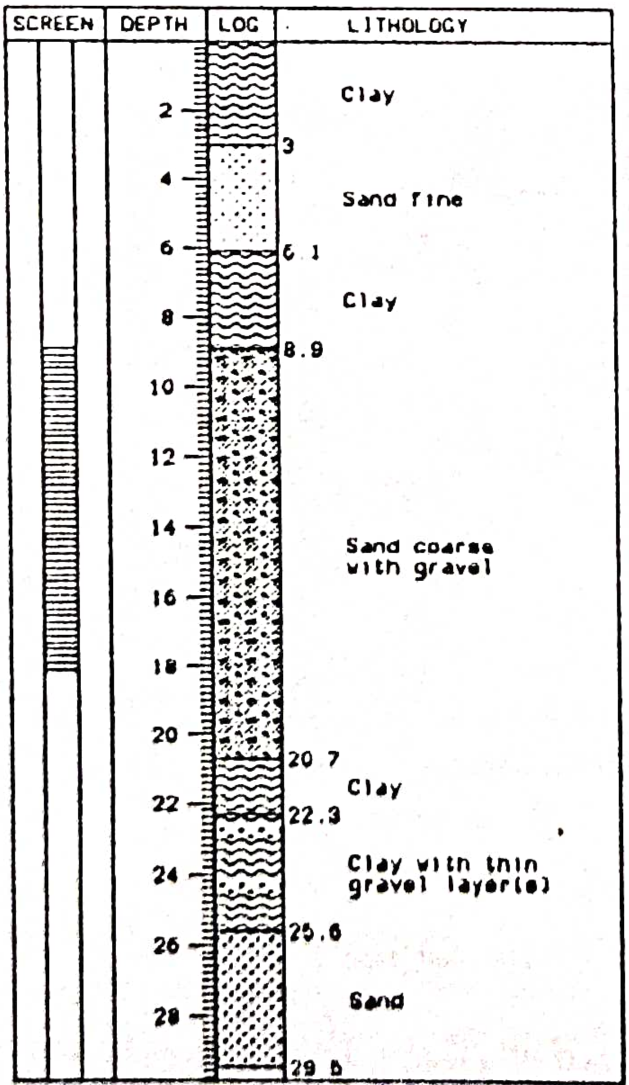
Date: 29.01 90
Capacity. 13 l/sec
Duration: 70 min
Transmiss.: 523 m2/day
Method : Theis
SWL: 2.41 m (b g.l)
DWL: 5.76 m.

Comments.
Out of 190 min. total duration only 70 min. usable.

B 3. Log of UN 3

Well No UN 4	Location: KARJANHA
Elevation. 100.75	X = 417625 Y = 2969375
Method of Drilling: Rig	
Drilling Dates 16.01.90 - 18.01.90	
Total Depth 29.50	
Comments: M.P: 0.35 m Screen Position: 8.9 - 18.1 m Screen Type: Slotted	

W E L L   L O G



United Nations GW Software

PUMPING TEST

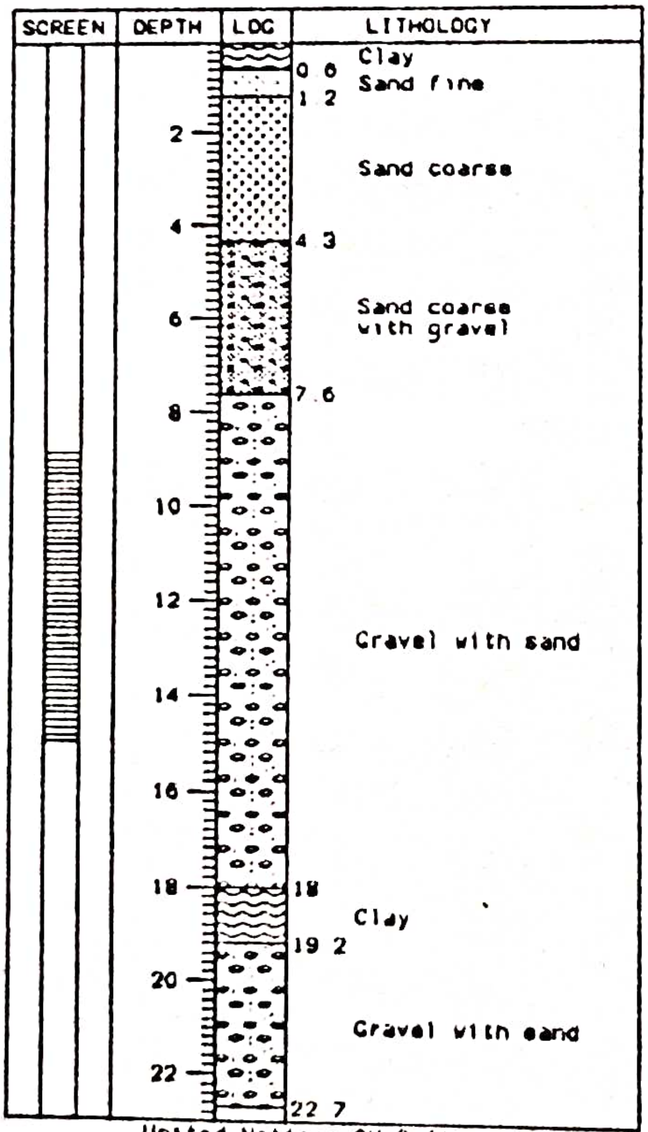
Date. 18.01.90
Capacity. 10 l/sec
Duration: 20 min.
Transmiss 1937 m2/day
Method: Theis
SWL: 3.5 m. (b.g.l)
DWL: 4.96 m

Comments
Out of 180 min. total duration only 20 min. usable.

B 4. Log of UN 4

Well No UN 5	Location BHEDIYA
Elevation. 90.434	X = 417500 Y = 2964250
Method of Drilling. Rig	
Drilling Dates . 08.01.90 - 12.01.90	
Total Depth · 22 70	
Comments : M P 0 45 m Screen Position: 8.9 - 15 m Screen Type· Slotted.	

W E L L   L O G



United Nations GW Software

PUMPING TEST

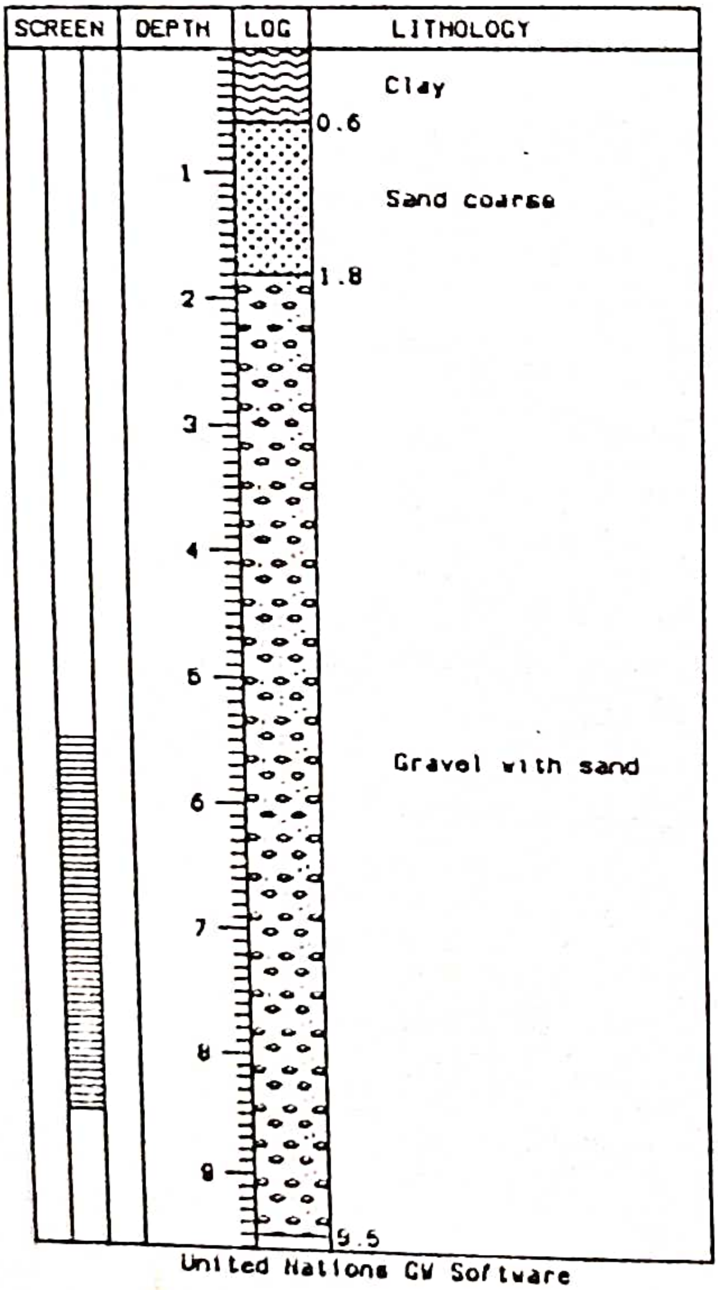
Date: 10 02 90
Capacity: 23 l/sec
Duration: 10 min.
Transmiss.: 5231 m2/day
Method : Theis
SWL: 1.64 m. (b.g l)
DWL: 3.05 m.

Comments.
Out of 240 min. total duration only 10 min. usable, but the output seems to be very high

B 5. Log of UN 5

Well No UN 6	Location: BANDIPUR
Elevation: 105.083	X = 417500 Y = 2974125
Method of Drilling: Rig	
Drilling Dates : 03 01 90 - 07 01 90	
Total Depth : 9.50	
Comments : M.P. 0.71 m. Screen Position. 5.5 - 8.5 m Screen Type: Slotted.	

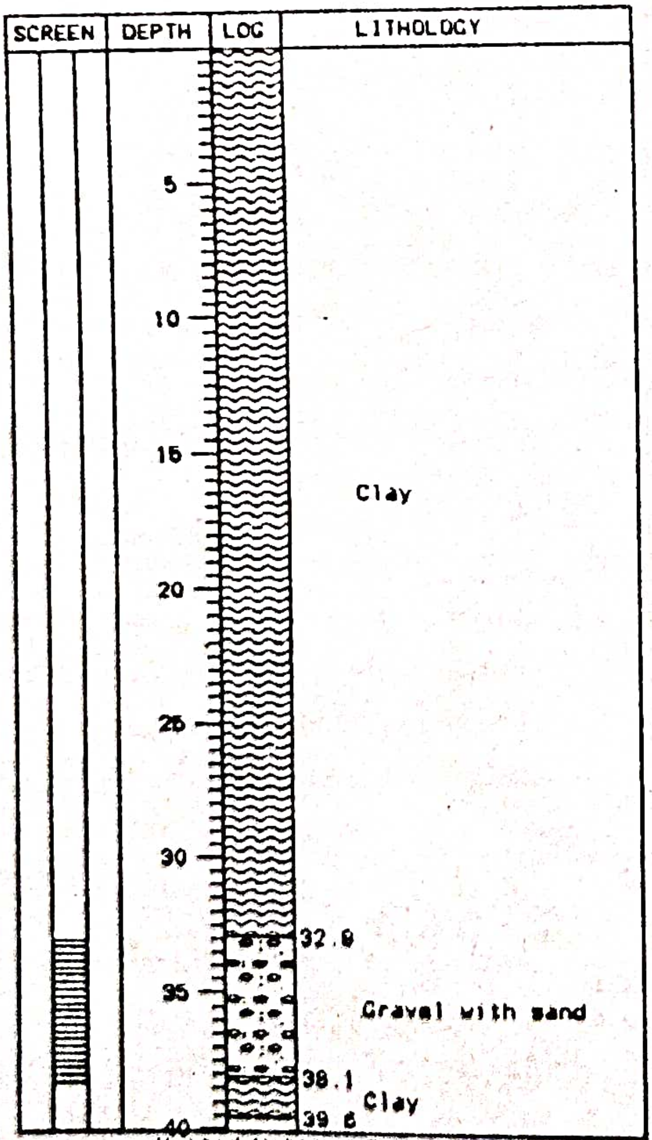
WELL LOG



B 6. Log of UN 6

Well No. UN 7	Location: AMAHI
Elevation. 126.008	X = 449125 Y = 2958250
Method of Drilling:	Manual
Drilling Dates	03.07.89 - 04.07.89
Total Depth	39.60
Comments :	M.P: 0.85 m Screen Position: 33.1 - 38.3 m.

W E L L   L O G



United Nations GV Software

PUMPING TEST

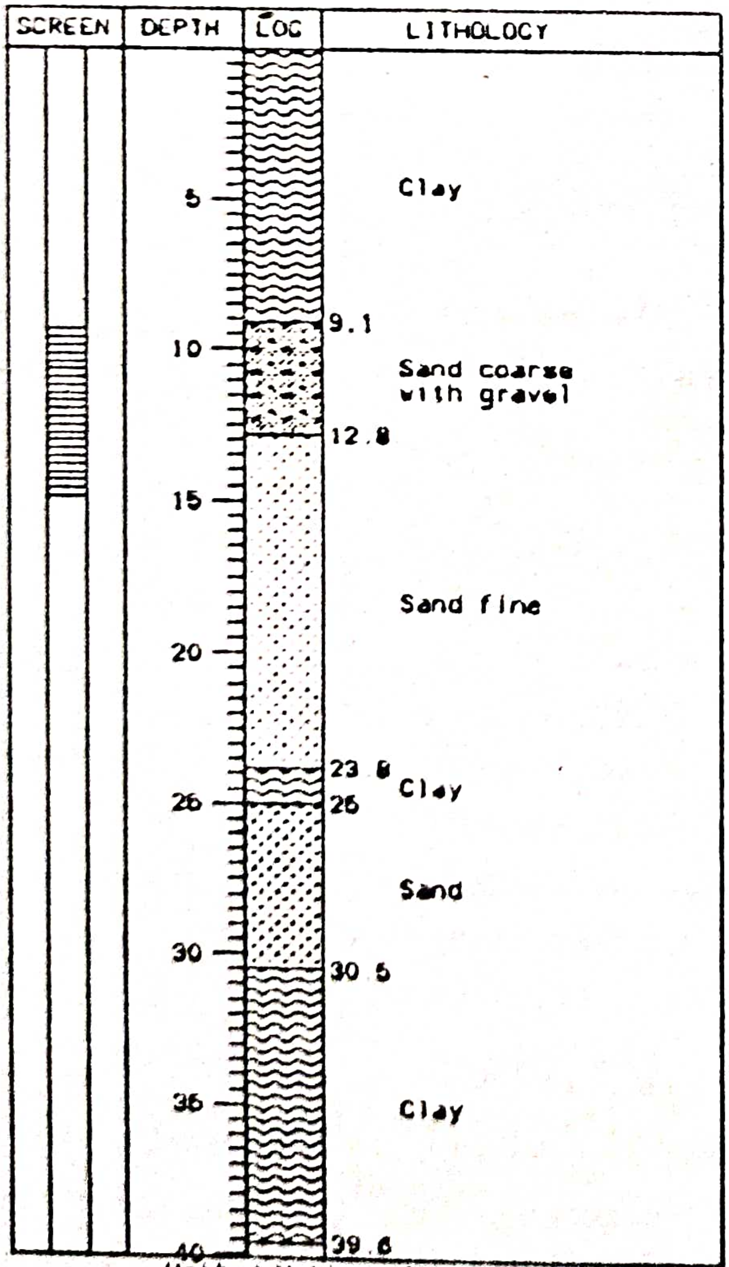
Date: 04.12.89
Capacity: 4.5 l/sec
Duration: 150 min.
Transmiss : 1112 m2/day
Method : Jacob
SWL: 2.6 m. (b.g.l)
DWL: 8.04 m.

Comments:
Out of 240 min. total duration only 150 min. usable.

B 7. Log of UN 7

Well No UN 8	Location: NAHARA
Elevation: 89.752	X = 447125 Y = 2943375
Method of Drilling: Manual	
Drilling Dates : 16.05.89 - 20.05.89	
Total Depth : 39.60	
Comments : M.P: 0.3 m. Screen Position: 9.4 - 14.9 m.	

W E L L L O G



United Nations GW Software

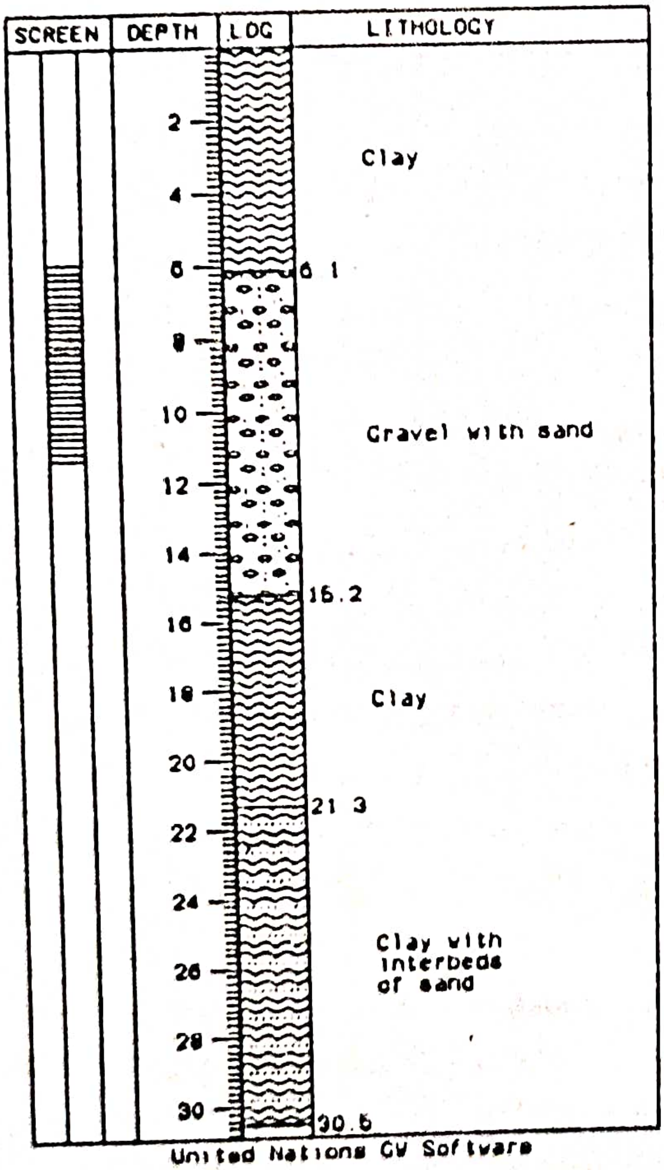
PUMPING TEST

Date: 12.07.89
Capacity: 7 l/sec
Duration: 170 min.
Transmiss.: 499 m2/day
Method : Theis
SWL: 1.5 m. (b.g.l)
DWL: 3.3 m.

B 8. Log of UN 8

Well No UN 9	Location KANCHHIBAZAR
Elevation 129 667	X = 441625 Y = 2958500
Method of Drilling	Manual
Drilling Dates	22 05 89 - 24 05 89
Total Depth	30 50
Comments .	M.P: 0.42 m. Screen Position 5 9 - 11 3 m

WELL LOG



United Nations GW Software

PUMPING TEST

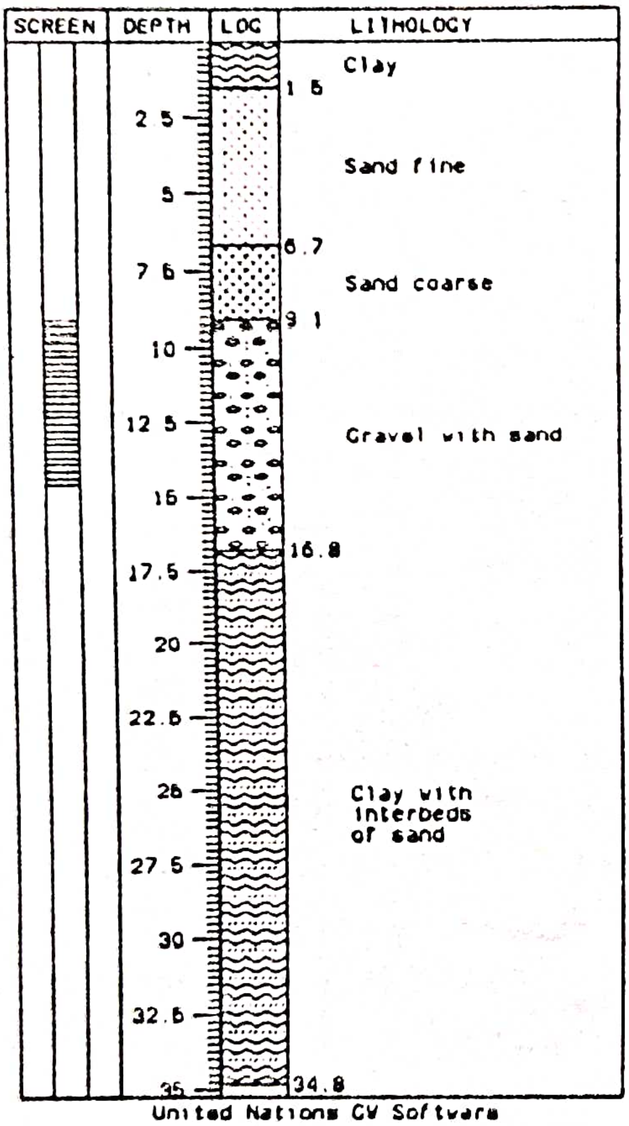
Date: 08.12.89
Capacity 0 5 l/sec
Duration: 110 min.
Transmiss.: 36 ms/day
Method Theis
SWL: 1.02 m. (b g l)
DWL. 4.61 m.

Comments
Out of 270 min, total duration only 110 min. usable

B 9. Log of UN 9

Well No UN 10	Location MADAR
Elevation 70.17	X = 418250 Y = 2945250
Method of Drilling Manual	
Drilling Dates	
Total Depth 34.80	
Comments . M.P: 0.15 m. Screen Position 9.1 - 14.6 m	

W E L L L O G

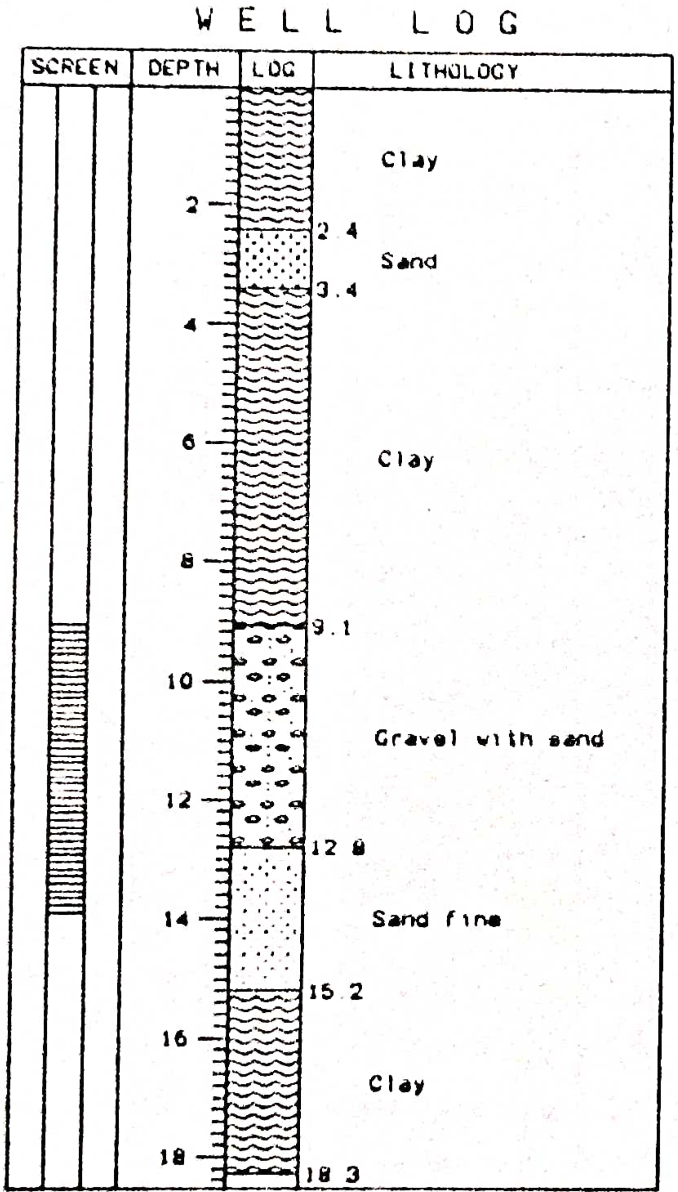


PUMPING TEST

Date. 14.12.89
Capacity: 6.3 l/sec
Duration: 110 min.
Transmiss.. 688 m2/day
Method Theis
SWL: 1.85 m. (b.g.l)
DWL. 4.73 m.

B 10. Log of UN 10

Well No. UN 11	Location BARHARI
Elevation. 97.817	X = 436250 Y = 2958250
Method of Drilling. Manual	
Drilling Dates :	
Total Depth 18.30	
Comments M.P. 0.15 m Screen Position: 9.1 - 13.9 m.	



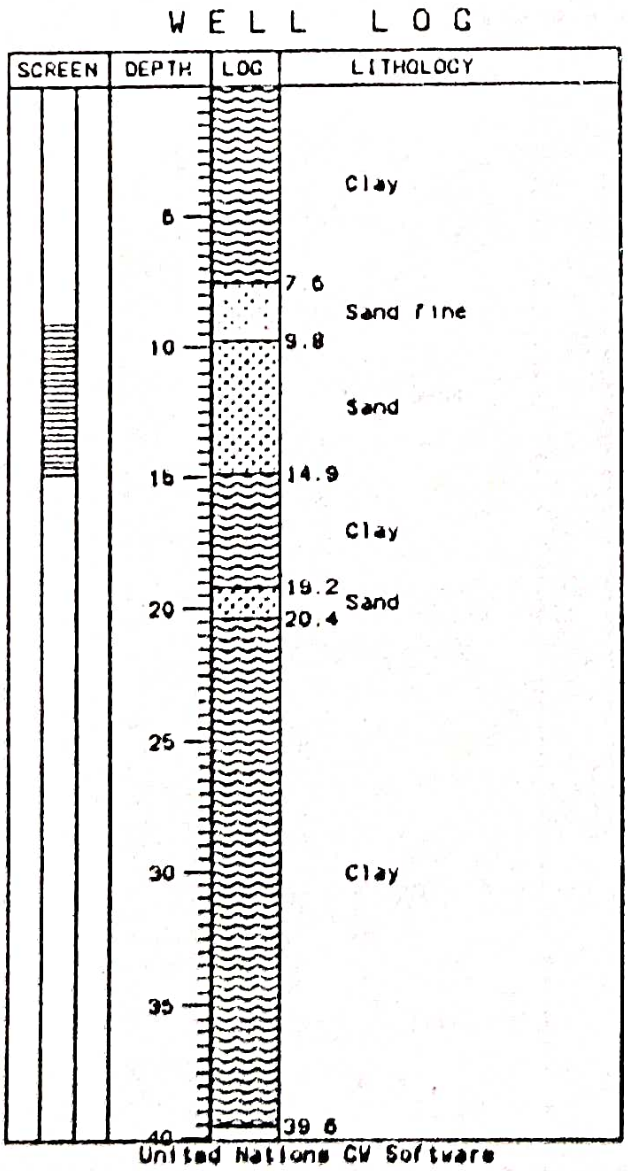
United Nations GW Software

PUMPING TEST

Date: 20.12.89
Capacity: 6.9 l/sec
Duration. 150 min.
Transmiss.: 559 m2/day
Method : Theis
Stor.Coeff. : 0.00082
SWL: 1.95 m (b.g.l)
DWL. 2.38 m.

B 11. Log of UN 11

Well No UN 12	Location SUNDARPUR(S)
Elevation. 84.005	X = 441125 Y = 2943625
Method of Drilling. Manual	
Drilling Dates 30.06.89 - 02.07.89	
Total Depth 39.60	
Comments : M.P 0.42 m Screen Position: 9.1 - 14.9 m.	



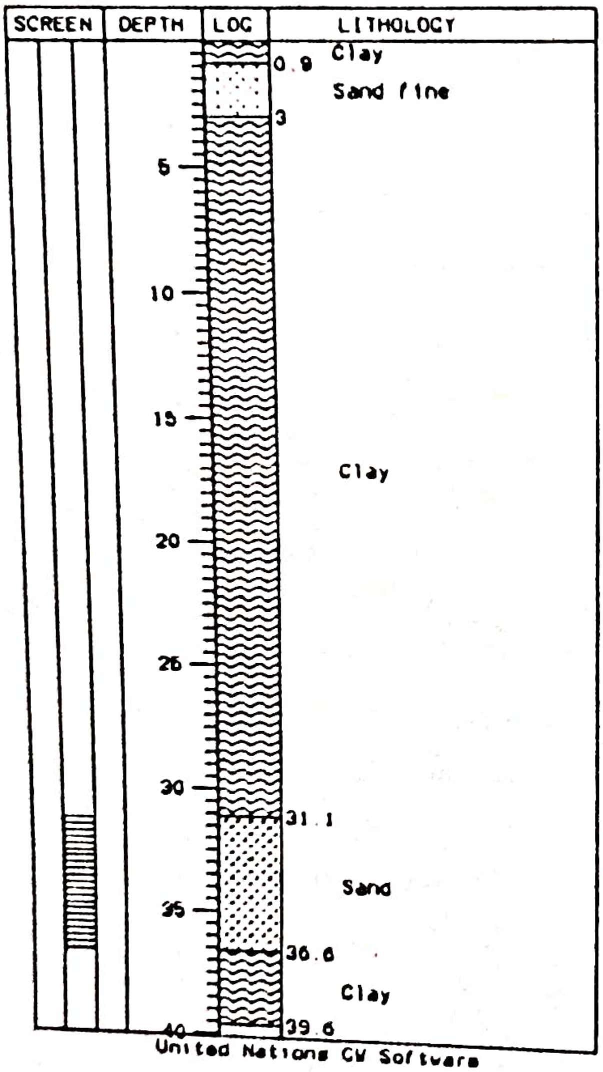
PUMPING TEST

Date: 27.12.89
Capacity: 10 l/sec
Duration: 240 min
Transmiss.: 1214 m2/day
Method : Theis
SWL: 5.25 m. (b.g.l)
DWL: 7.13 m.

B 12. Log of UN 12

Well No. UN 13	Location: PADAUL
Elevation: 85 11	X = 446500 Y = 2941000
Method of Drilling: Manual	
Drilling Dates : 21 05 89 - 24 05 89	
Total Depth 39 60	
Comments . M.P: 0.45 m. Screen Position: 31.3 - 36.7 m.	

W E L L   L O G



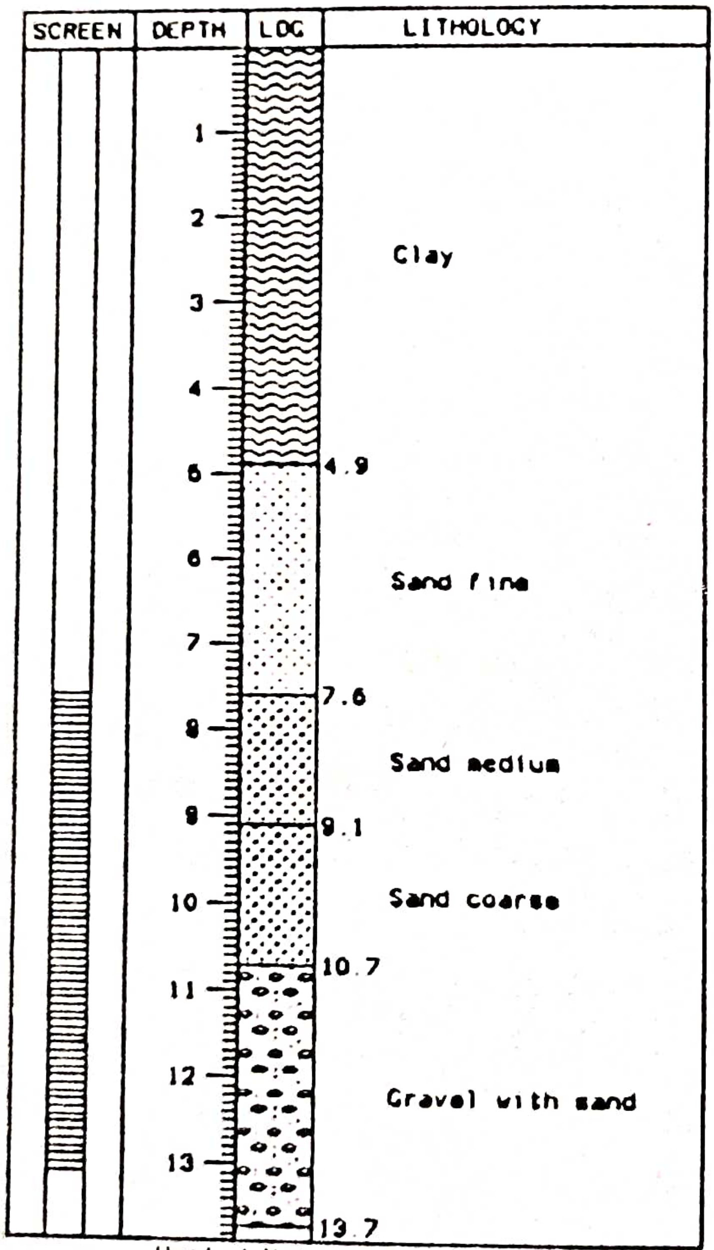
PUMPING TEST

Date. 25.05.89
Capacity. 8 l/sec
Duration: 110 min
Transmiss.. 243 m2/day
Method : Theis
SWL: 1.58 m. (b.g.l)
DWL: 5.52 m.

B 13. Log of UN 13

Well No UN 14	Location: RAGHUNATHPUR
Elevation: 109.507	x = 449500 Y = 2952875
Method of Drilling: Manual	
Drilling Dates : 12.05.89 - 15.05.89	
Total Depth 13.70	
Comments : M.P: 0.45 m. Screen Position: 7.6 - 13.1 m.	

WELL LOG



United Nations GW Software

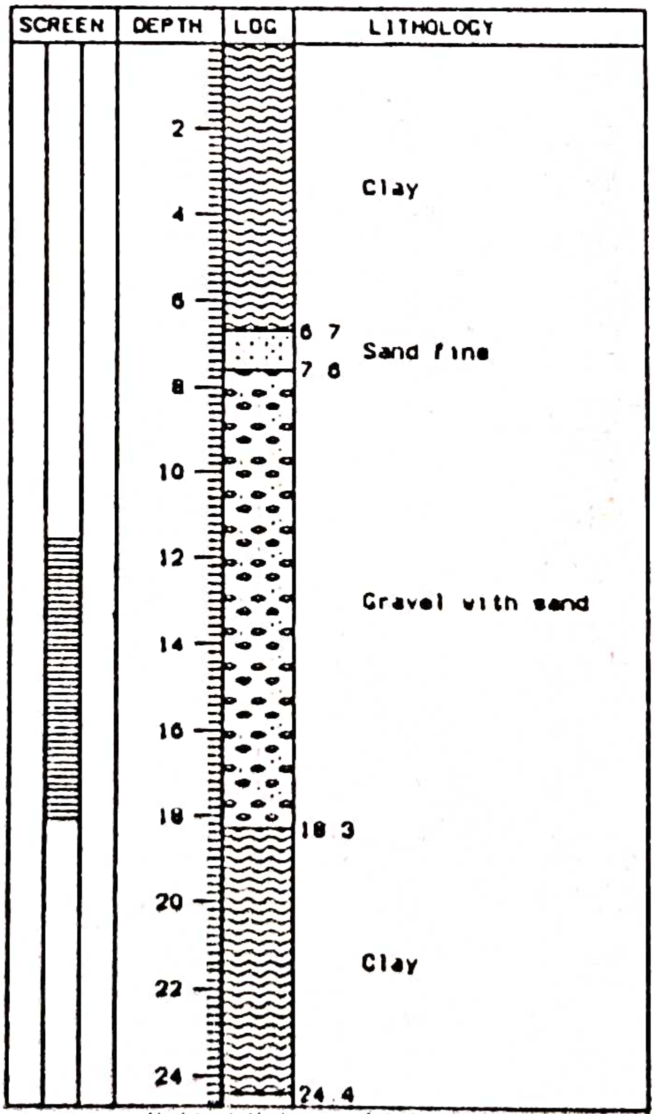
PUMPING TEST

Date: 16.05.89
Capacity: 8 l/sec
Duration: 90 min
Transmiss.: 214 m2/day
Method : Theis
SWL: 4.30 m. (b.g.l)
DWL: 6.48 m.

B 14. Log of UN 14

Well No UN 15	Location: CHOHARWA
Elevation: 140 21	x = 432875 Y = 2944125
Method of Drilling: Manual	
Drilling Dates :	
Total Depth : 24 40	
Comments : Screen Position: 11.6 - 18 1 m	

WELL LOG

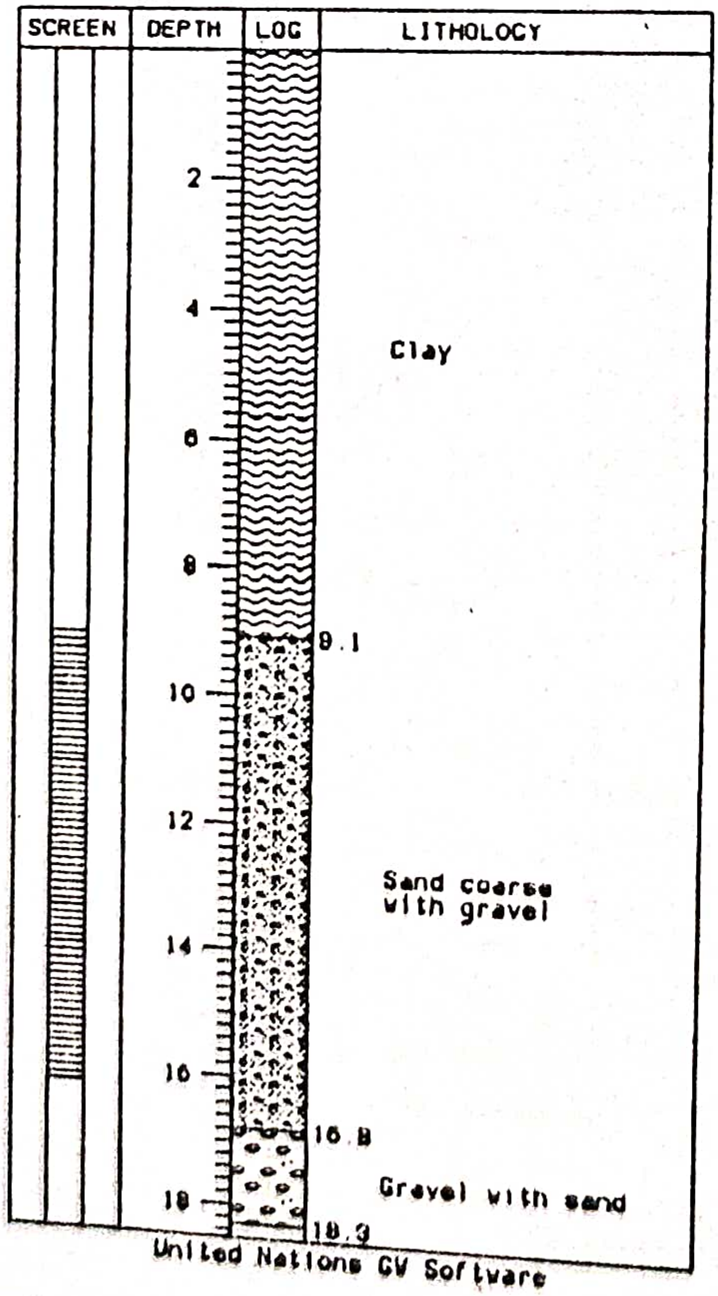


United Nations GW Software

B 15. Log of UN 15

Well No UN 16	Location: KABILASI
Elevation: 87.203	X = 433750 Y = 2949750
Method of Drilling: Manual	
Drilling Dates : 14 05 89 - 20 05 89	
Total Depth : 18 30	
Comments :	

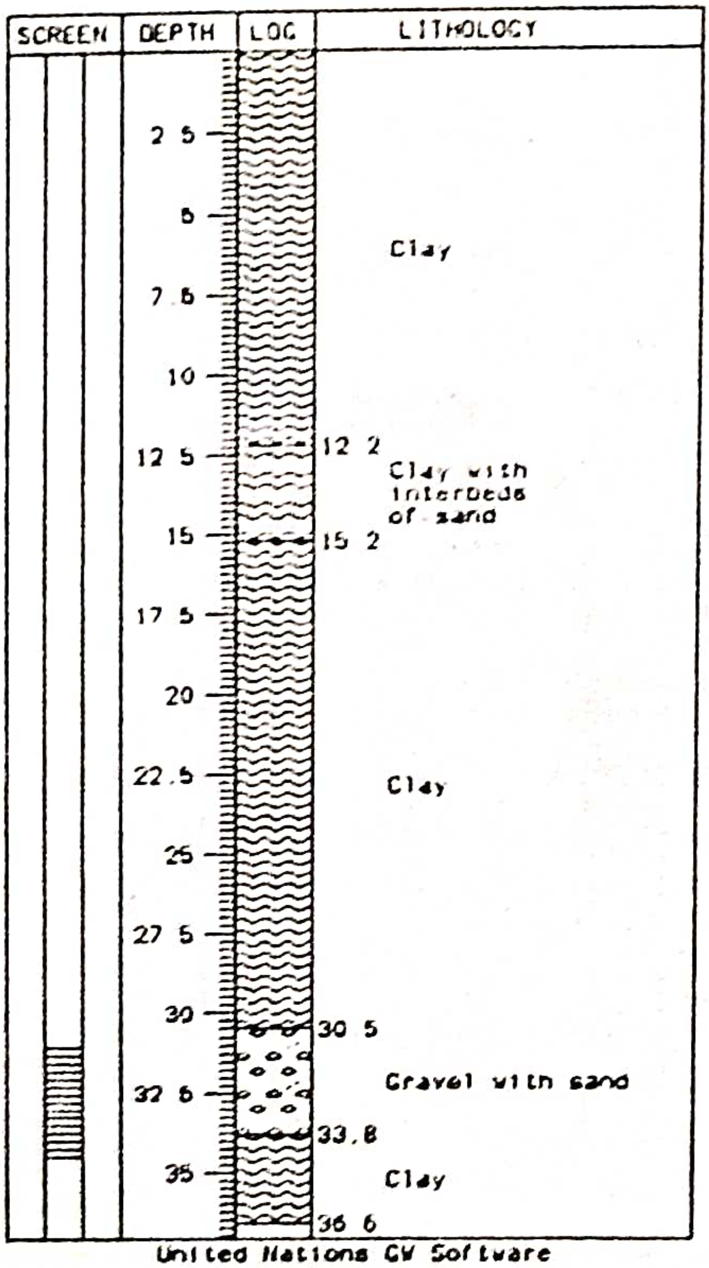
W E L L L O G



B 16. Log of UN 16

Well No UN 17	Location RAMNAGAR
Elevation 112 180	x = 424750 Y = 2966750
Method of Drilling	Manual
Drilling Dates	04 06 89 - 09 06 89
Total Depth	36 60
Comments	Screen Position 31 1 - 34 5 m

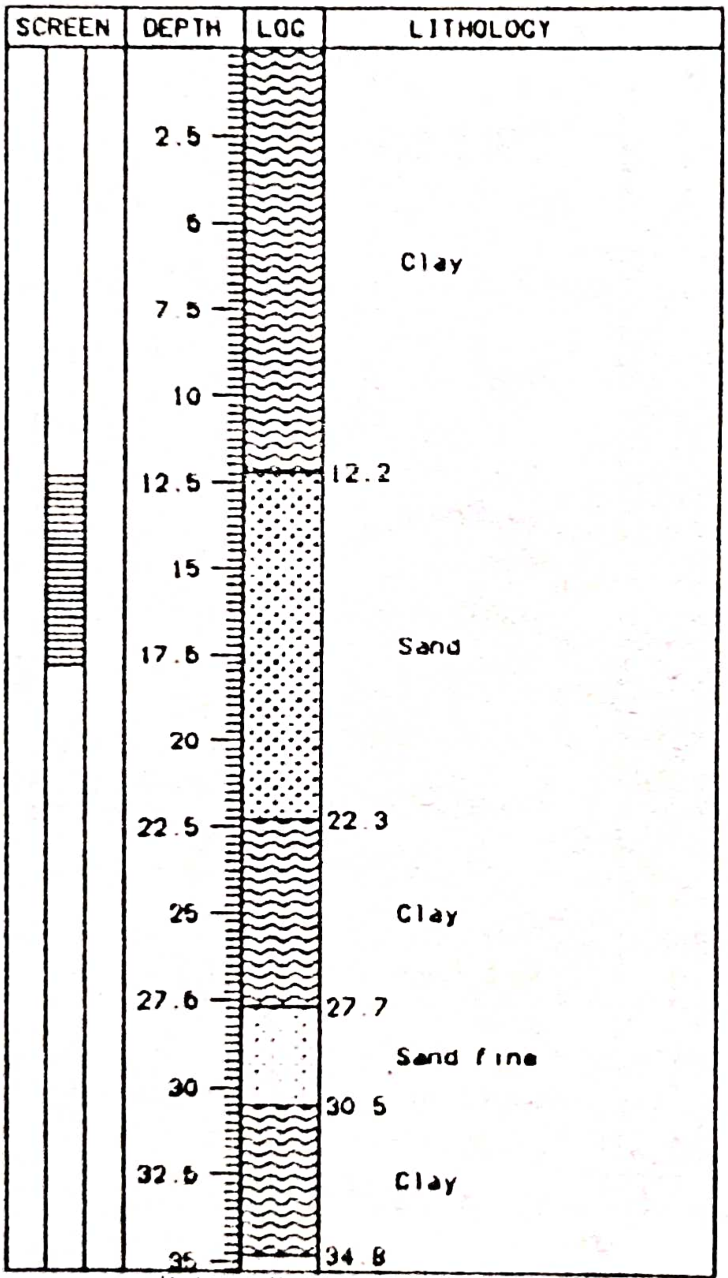
W E L L L O G



B 17. Log of UN 17

Well No UN 18	Location: HAKPARA
Elevation: 80 118	x = 425375 y = 2949375
Method of Drilling: Manual	
Drilling Dates	
Total Depth 34 80	
Comments : M P 0 15 m Screen Position 12 3 - 17 8 m	

W E L L L O G

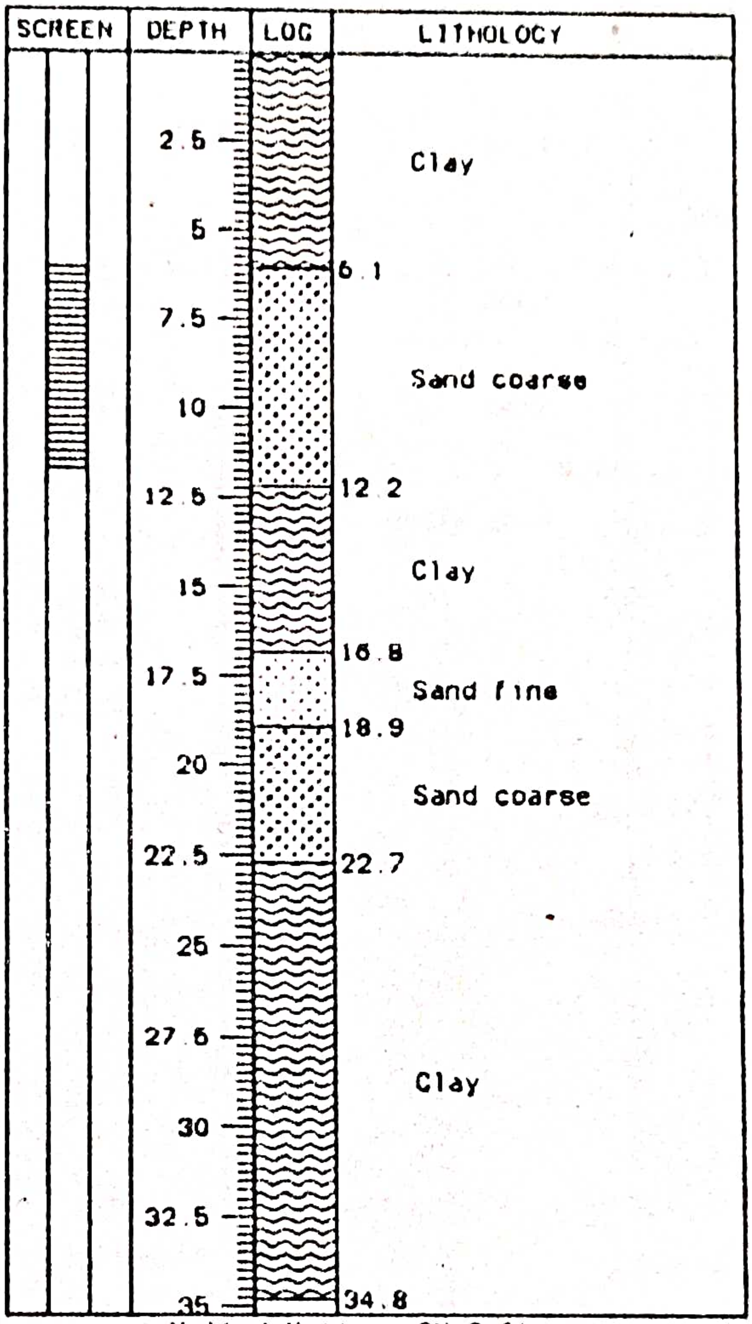


United Nations GW Software

B 18. Log of UN 18

Well No UN 19	Location: BARCHHAWA
Elevation: 104 06	X = 427250 Y = 2960875
Method of Drilling: Manual	
Drilling Dates	
Total Depth : 34 80	
Comments M P 0 15 m Screen Position: 6.1 - 11.7 m.	

W E L L   L O G

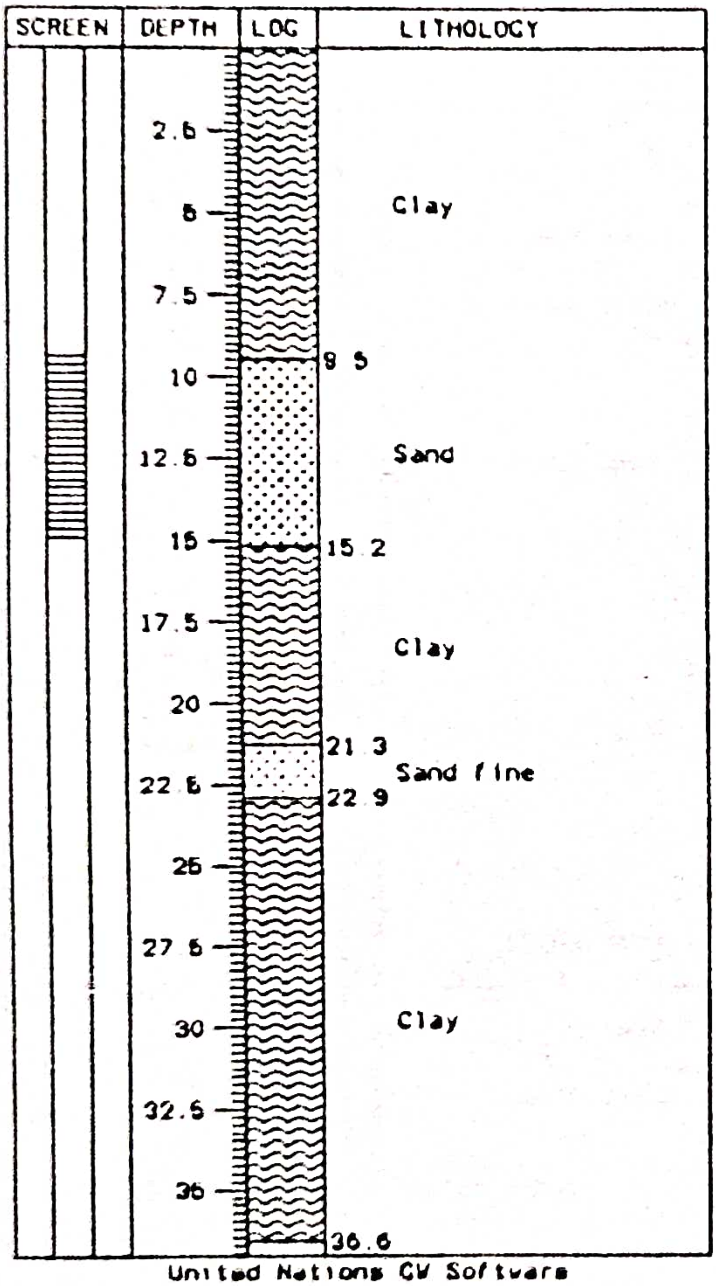


United Nations GW Software

B 19. Log of UN 19

Well No UN 20	Location: TILEBONA
Elevation: 99 763	X = 449125 Y = 2948625
Method of Drilling: Manual	
Drilling Dates 05 05 89 - 07 05 89	
Total Depth 36 60	
Comments . Screen Position: 9.4 - 14.9 m.	

WELL LOG



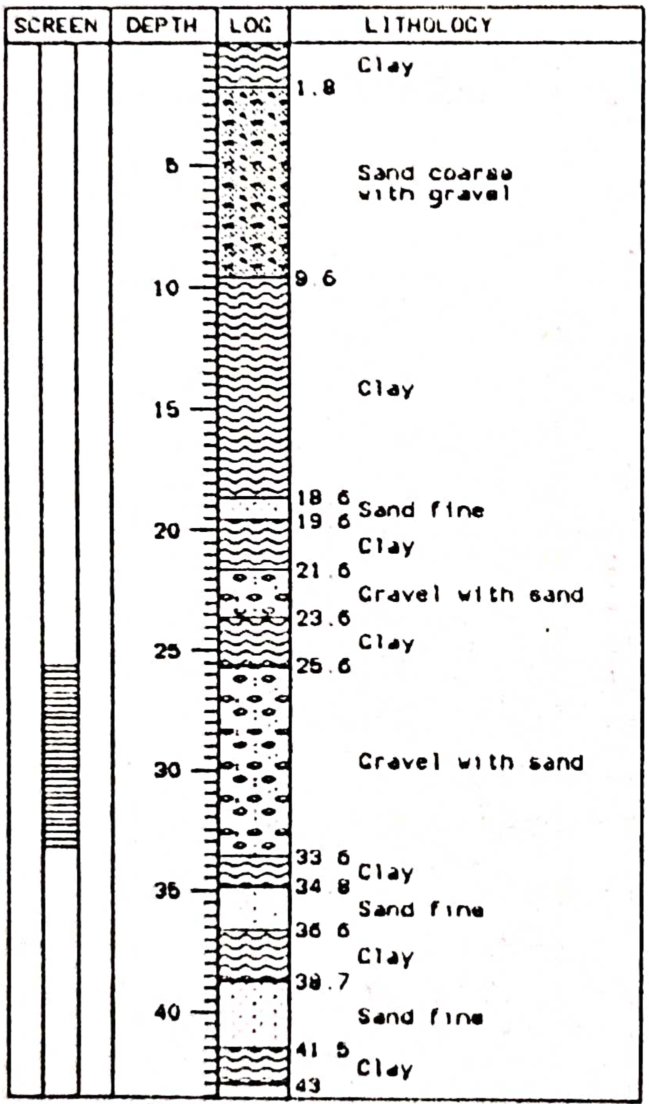
PUMPING TEST

Date: 08.05.89
Capacity: 7 l/sec
Duration 100 min
Transmiss.: 507 m2/day
Method : Theis
SWL: 3.91 m. (b.g.l)
DWL: 7.87 m.

B 20. Log of UN 20

Well No. UN 21	Location: KASAHA
Elevation. 140 (approx. X36000 Y = 2962000	
Method of Drilling: Rig	
Drilling Dates 09.02.90 - 11.02.90	
Total Depth 43.00	
Comments : M.P: 0.5 m Screen Position: 25.6 - 33.2 m Screen Type: Slotted	

W E L L L O G



United Nations GW Software

PUMPING TEST

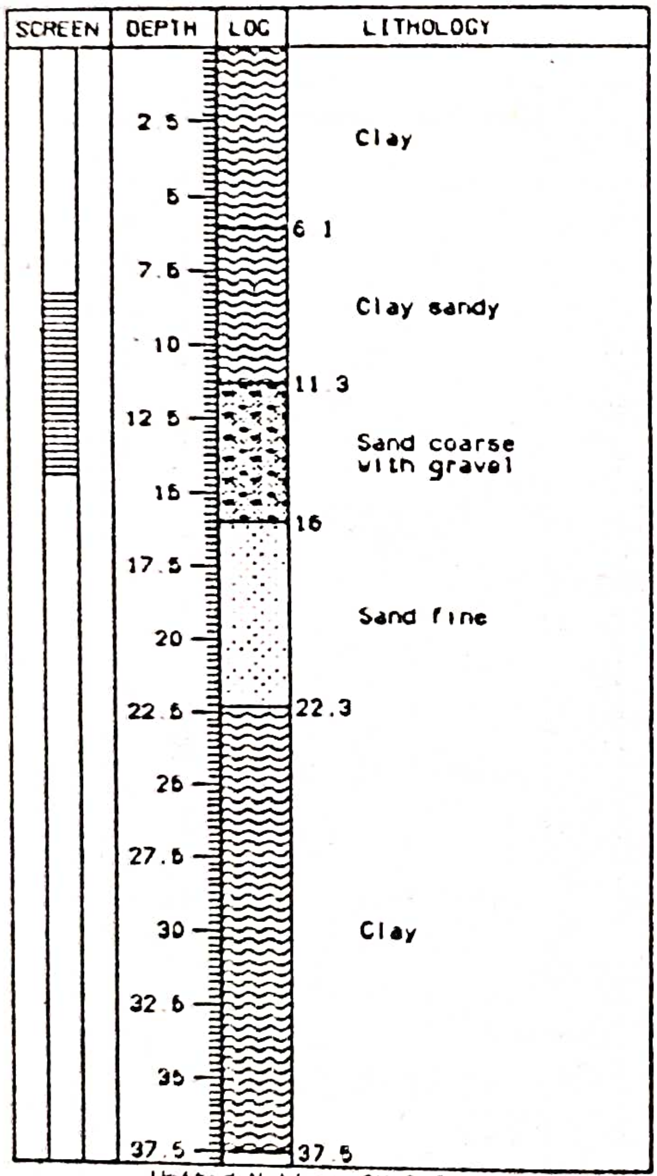
Date: 14.02.90
Capacity: 9 l/sec
Duration: 18 min.
Transmiss.: 577 m2/day
Method : Theis
SWL: 3.5 m. (b.g.l)
DWL: 7.1 m.

Comments:
Out of 240 min. total duration only 18 min. usable.

B 21. Log of UN 21

Well No STW 22	Location: SUNDARPUR(N)
Elevation: 93 797	x = 441500 Y = 2949000
Method of Drilling	Manual
Drilling Dates	18 04 90 - 20 04 90
Total Depth	37 50
Comments :	M.P 0 25 m Screen Position. 8.3 - 14.4 m Screen Type Slotted

WELL LOG



United Nations GW Software

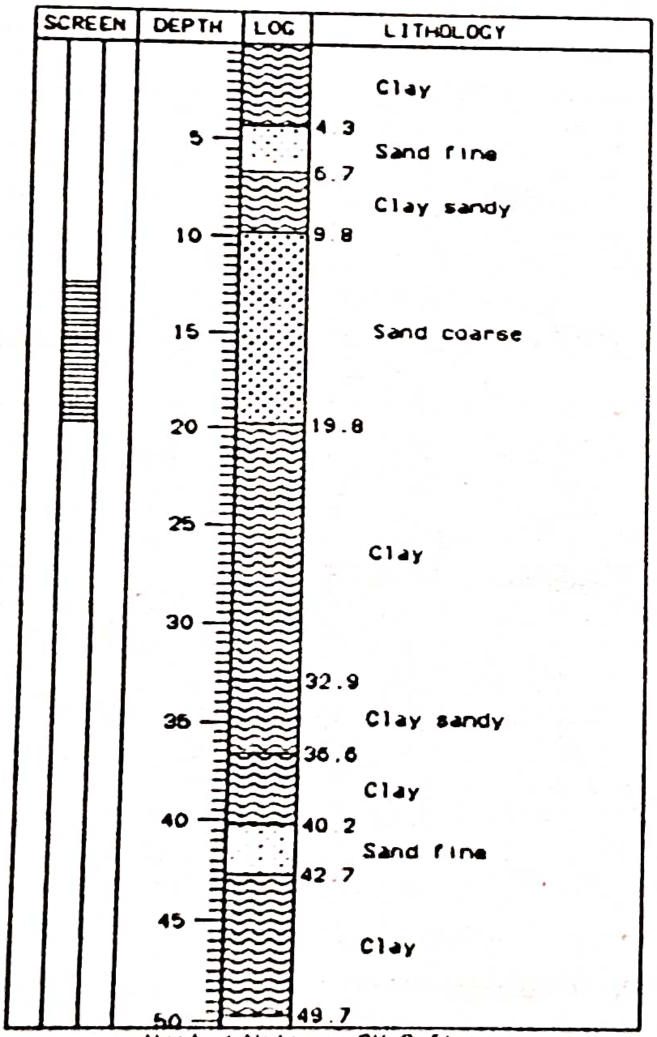
PUMPING TEST

Date: 20.04.90
Capacity: 6 l/sec
Duration 150 min
Transmiss : 475 m2/day
Method : Theis
Stor.Coeff.. 0.42E-03
SWL: 1.78 (b.g.l)
DWL: 2 08

B 22. Log of UN 22

Well No. STW 23	Location LAXMIPUR
Elevation 91.704	X = 426150 Y = 2954750
Method of Drilling: Manual	
Drilling Dates: 28.03.90 - 02.04.90	
Total Depth: 49.70	
Comments: M.P: 0.2 m Screen Position: 12.5 - 19.8 m.	

W E L L   L O G



United Nations GW Software

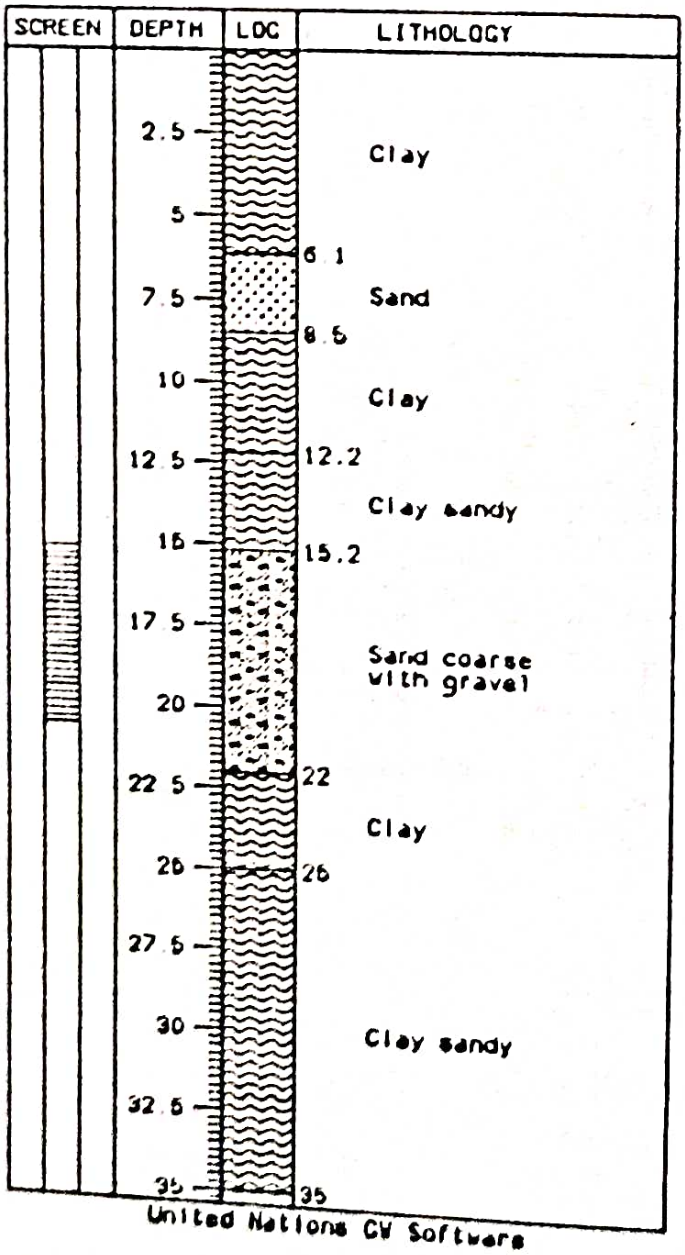
PUMPING TEST

Date: 02.04.90
Capacity: 6 l/sec
Duration: 180 min.
Transmiss.: 1066 m2/day
Method: Jacob
SWL: 1.3 m. (b.g.l)
DWL: 8.5 m.

B 23. Log of UN 23

Well No STW 24	Location: RAMPUR
Elevation: 105.655	X = 441400 Y = 2953500
Method of Drilling Manual	
Drilling Dates 18.4.90 - 20.4.90	
Total Depth : 35.00	
Comments : M.P: 0.25 m Screen Position: 15.2 - 20.7 m Screen Type. Slotted.	

WELL LOG



PUMPING TEST

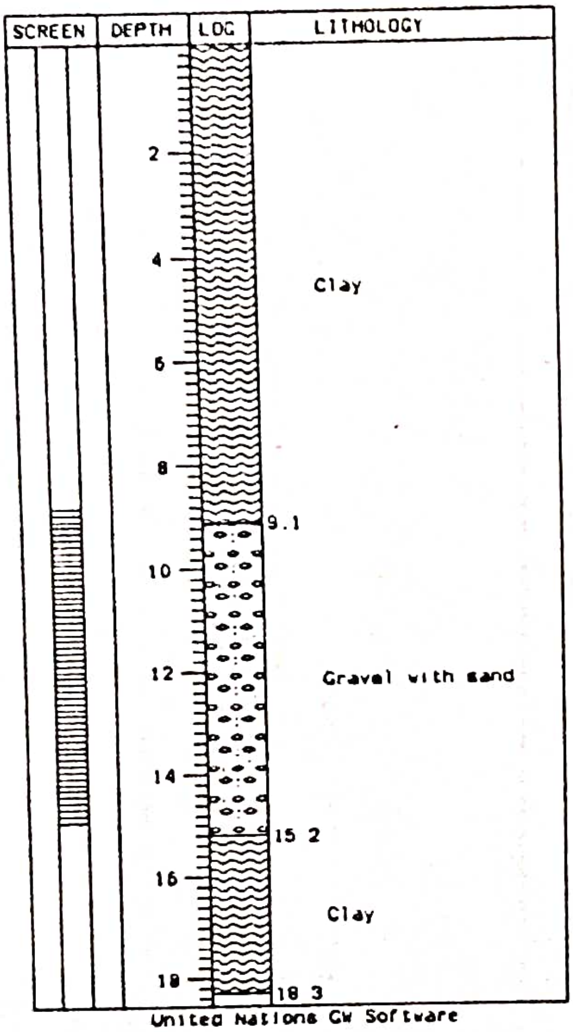
Date: 20.4.90
Capacity. 2.5 l/sec
Duration: 180 min
Transmiss : 106 m2/day
Method : Theis
SWL: 2.17 (b.g.l)
DWL: 7.73

B 24. Log of UN 24

Appendix B. Contd...

Well No. STW	Location. CHOHARWA
Elevation 140	X = 432875 Y = 2944125
Method of Drilling. Rig	
Drilling Dates : 1986	
Total Depth : 18 30	
Comments. M.P. 0.57 m Screen Position 8.8 - 14.9 m Screen Type Slotted Private 4" Well.	

WELL LOG



PUMPING TEST

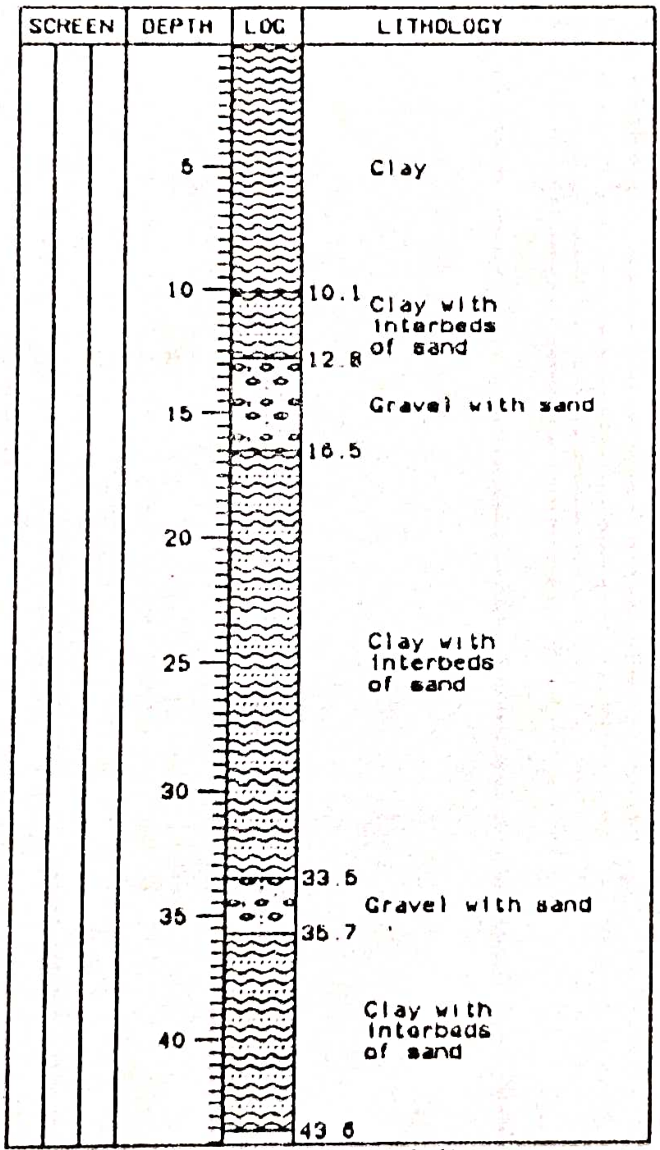
Date 04 04 90
Capacity: 7.5 l/sec
Duration. 90 min.
Transmiss.. 999 m2/day
Method . Theis
SWL. 4.93 (b.g.l)
DWL 5 14

Comments:
Out of 120 min. total duration
only 90 min. usable

B 25. Log of ADB/N STW at Choharwa

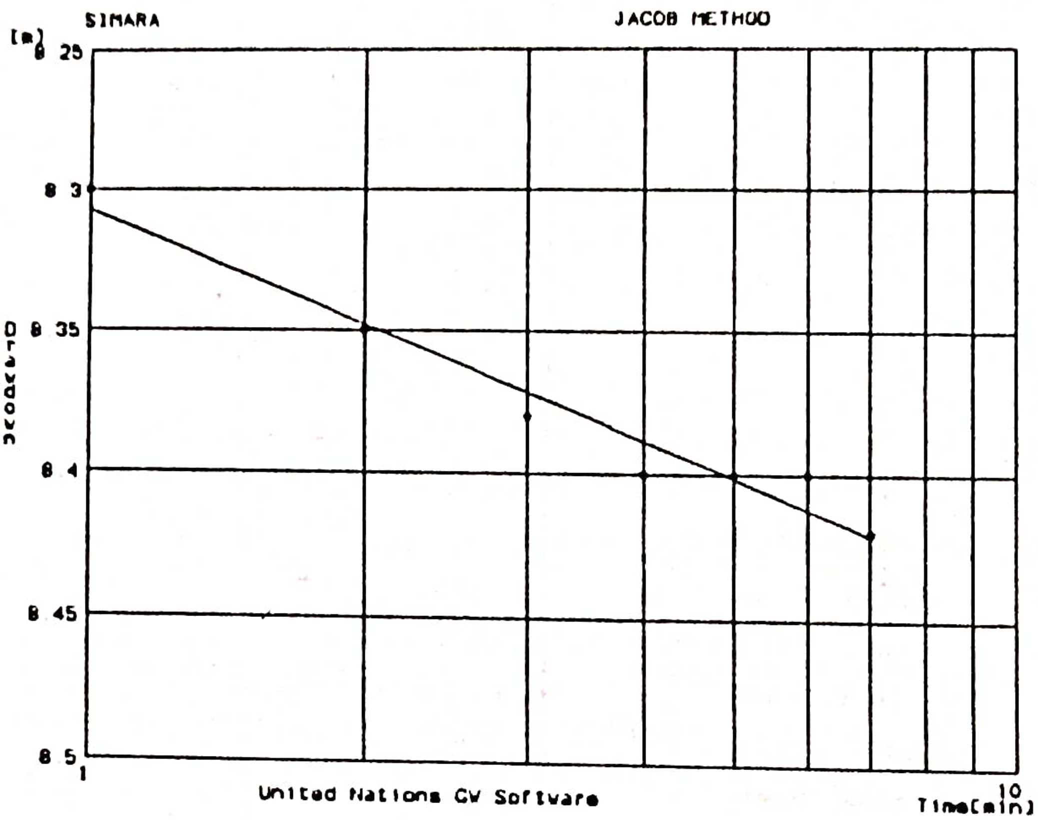
Well No DTW 1/R2	Location: BHULKIA
Elevation: 108	x = 419250 y = 2972750
Method of Drilling: Rig	
Drilling Dates OCT 79 - APR 80	
Total Depth : 43 60	
Comments : Screen Position: 84.0 - 95.4 m	

W E L L L O G

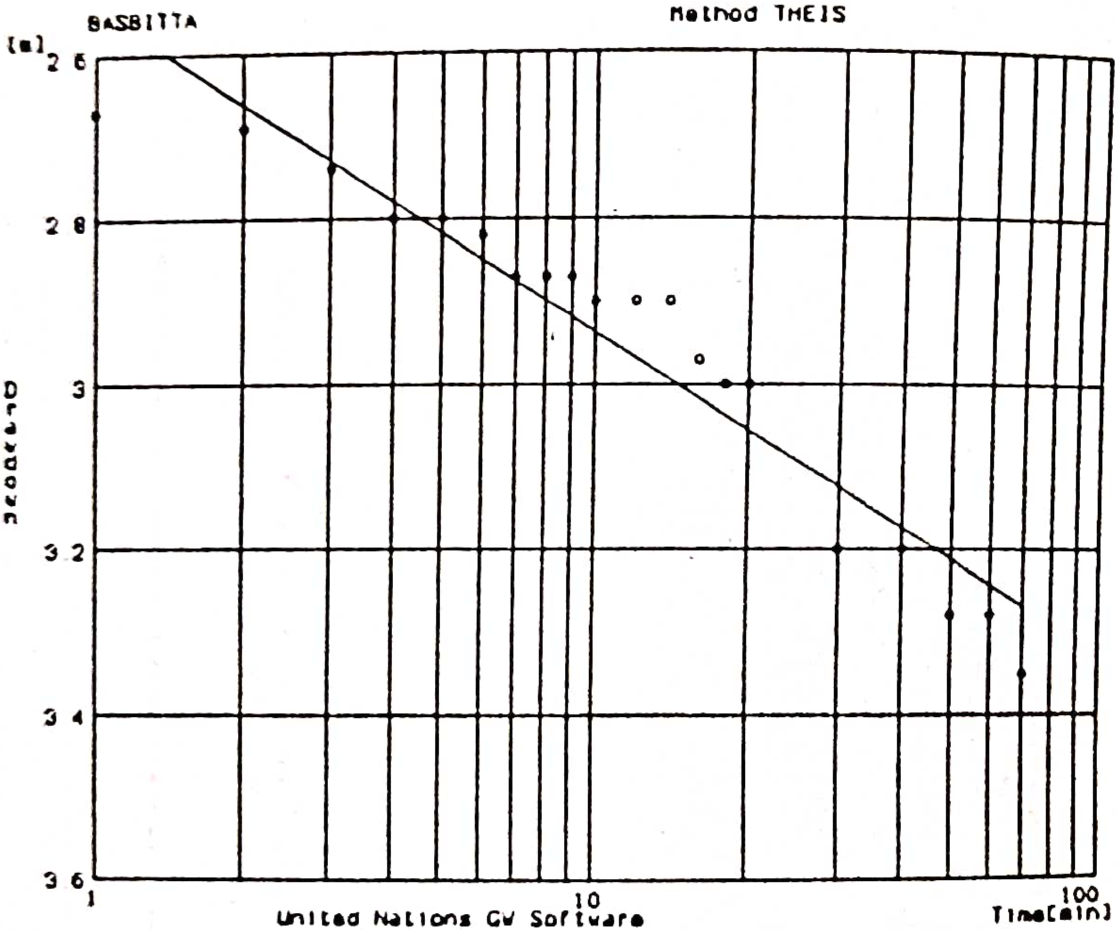


United Nations GW Software

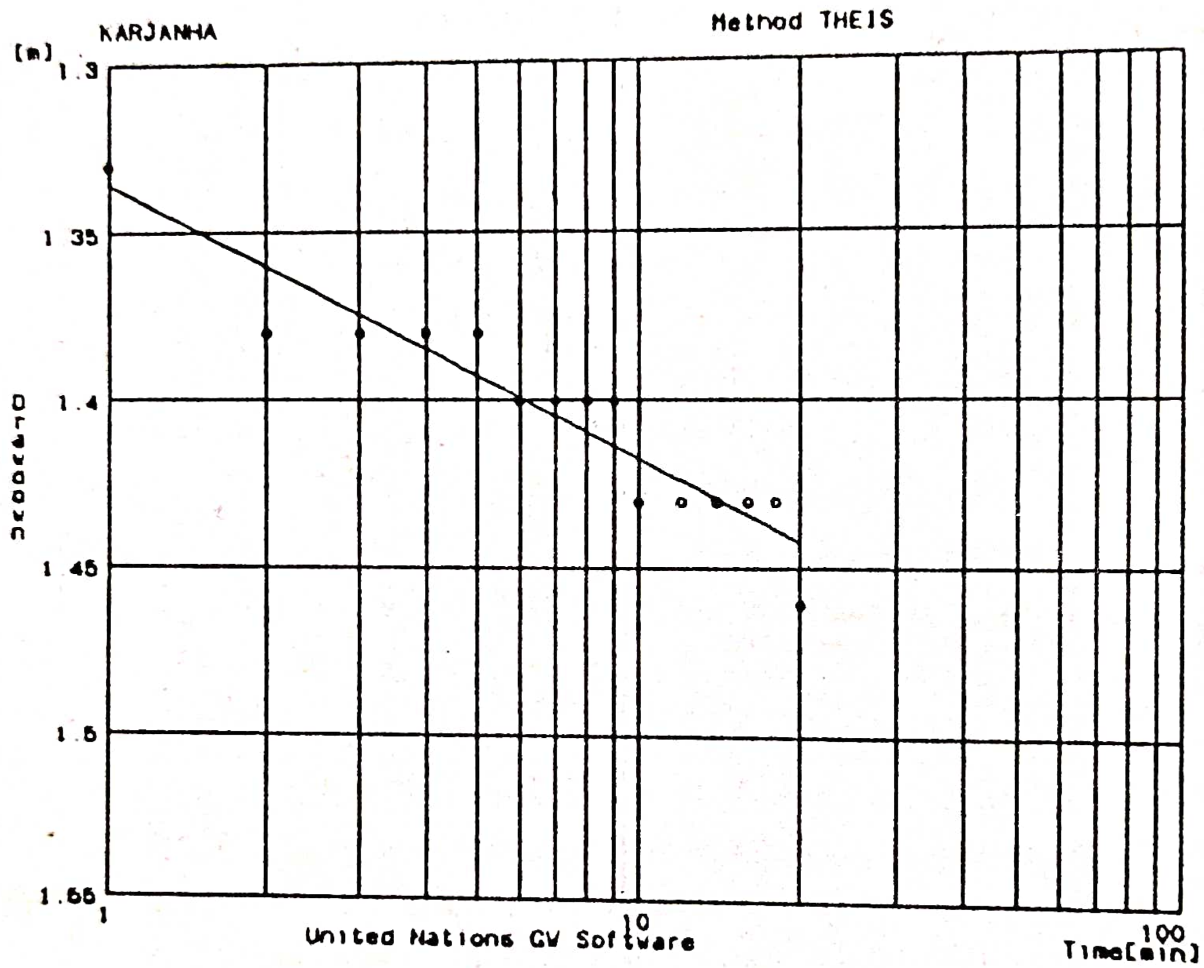
B 26. Log of DTW at Bhulkia



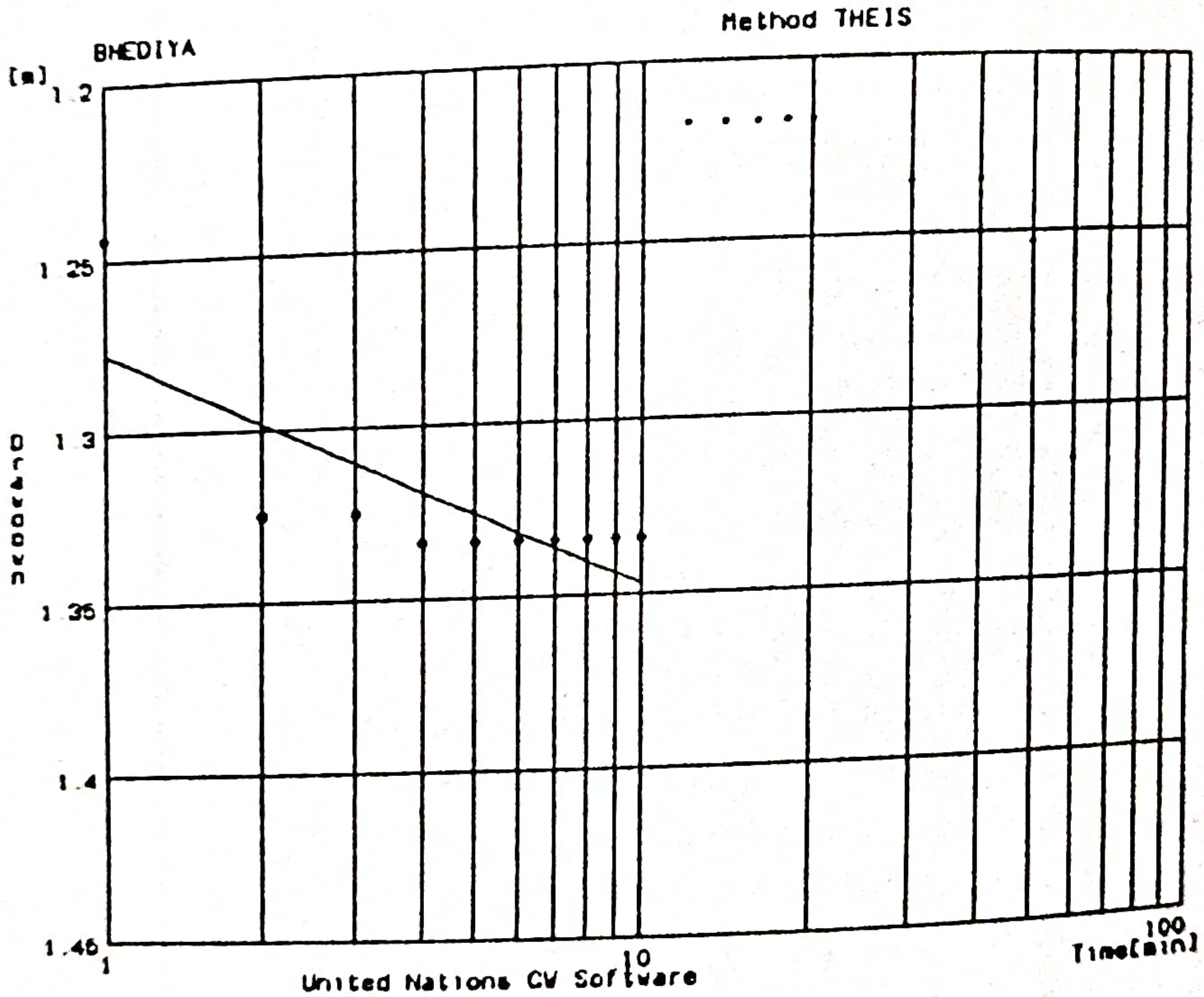
C 1. Pumping Test of UN 1



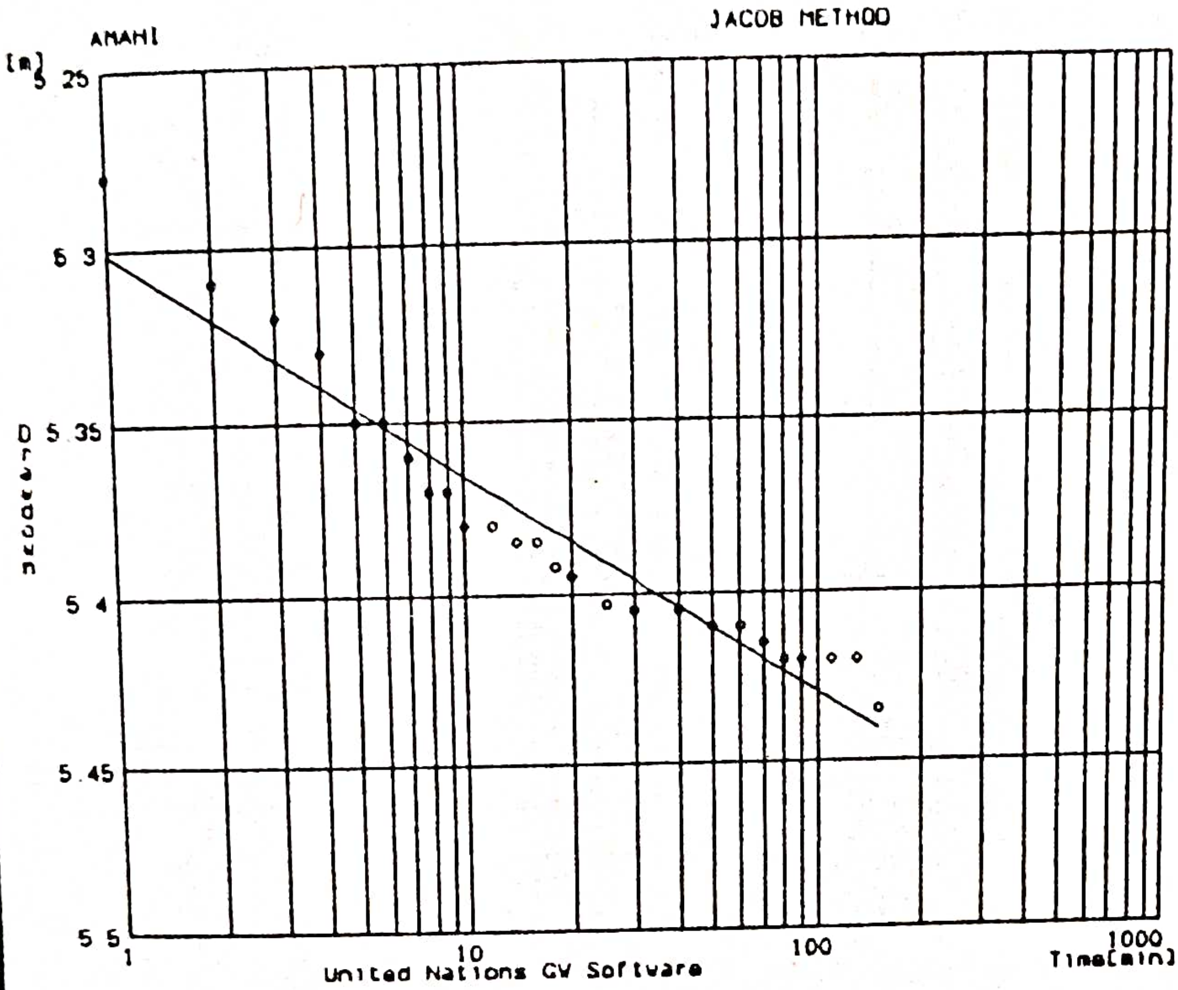
C 2. Pumping Test of UN 3



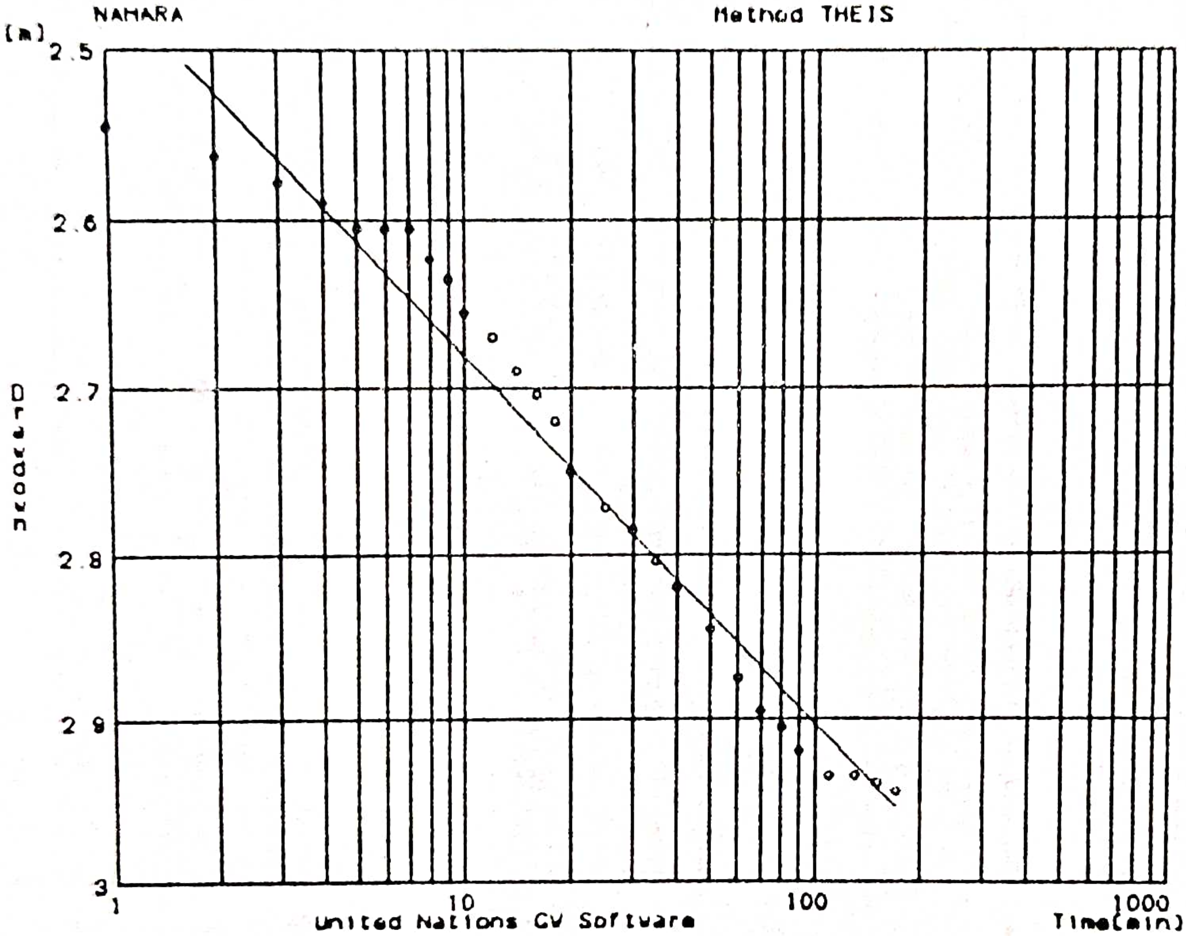
C 3. Pumping Test of UN 4



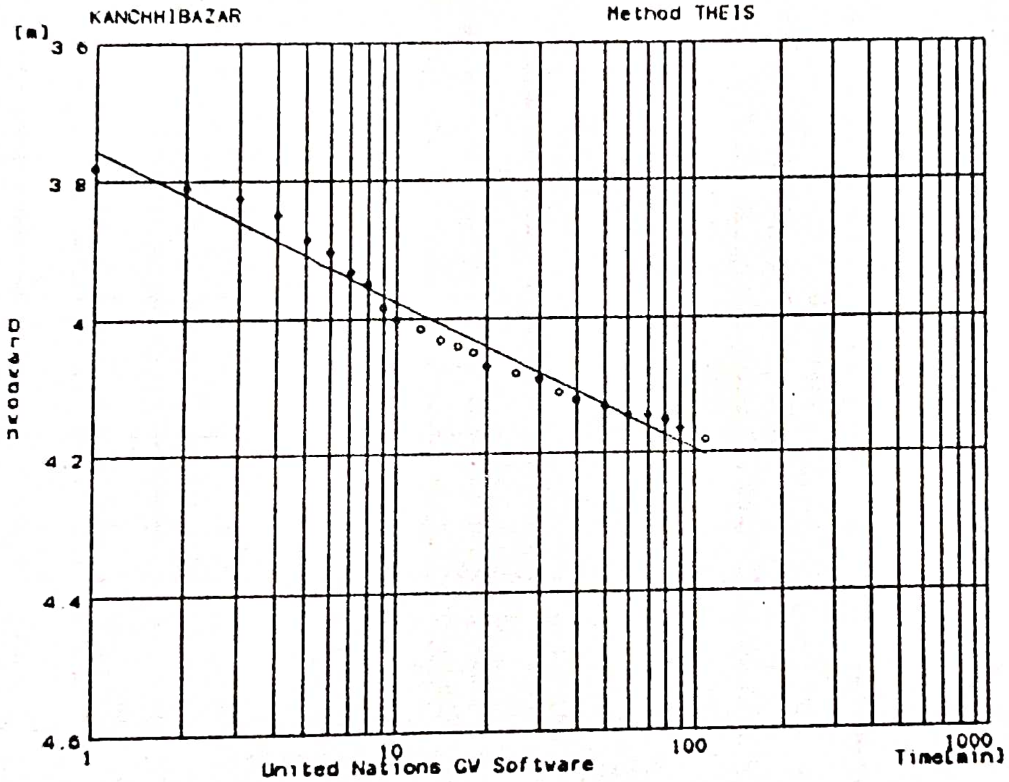
C 4. Pumping Test of UN 5



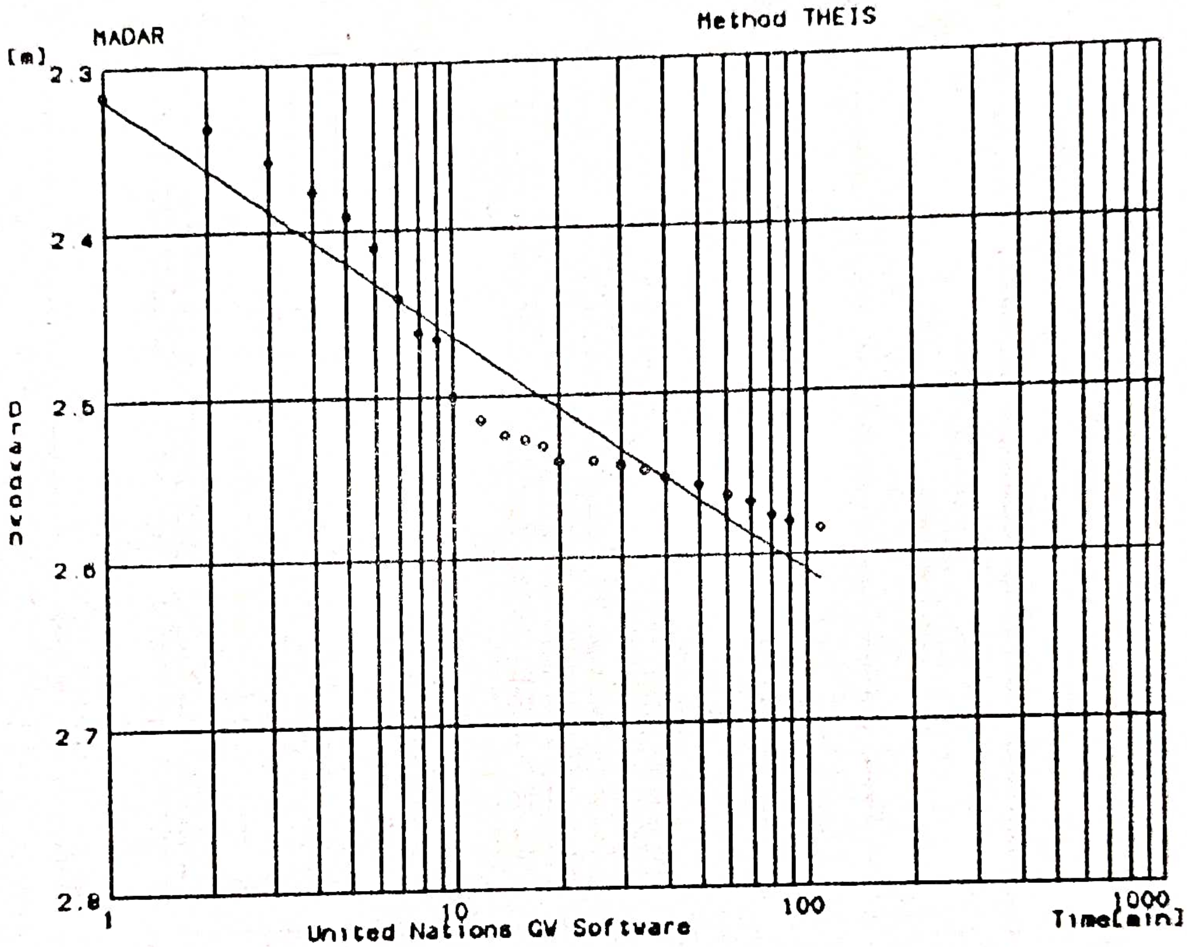
C 5. Pumping Test of UN 7



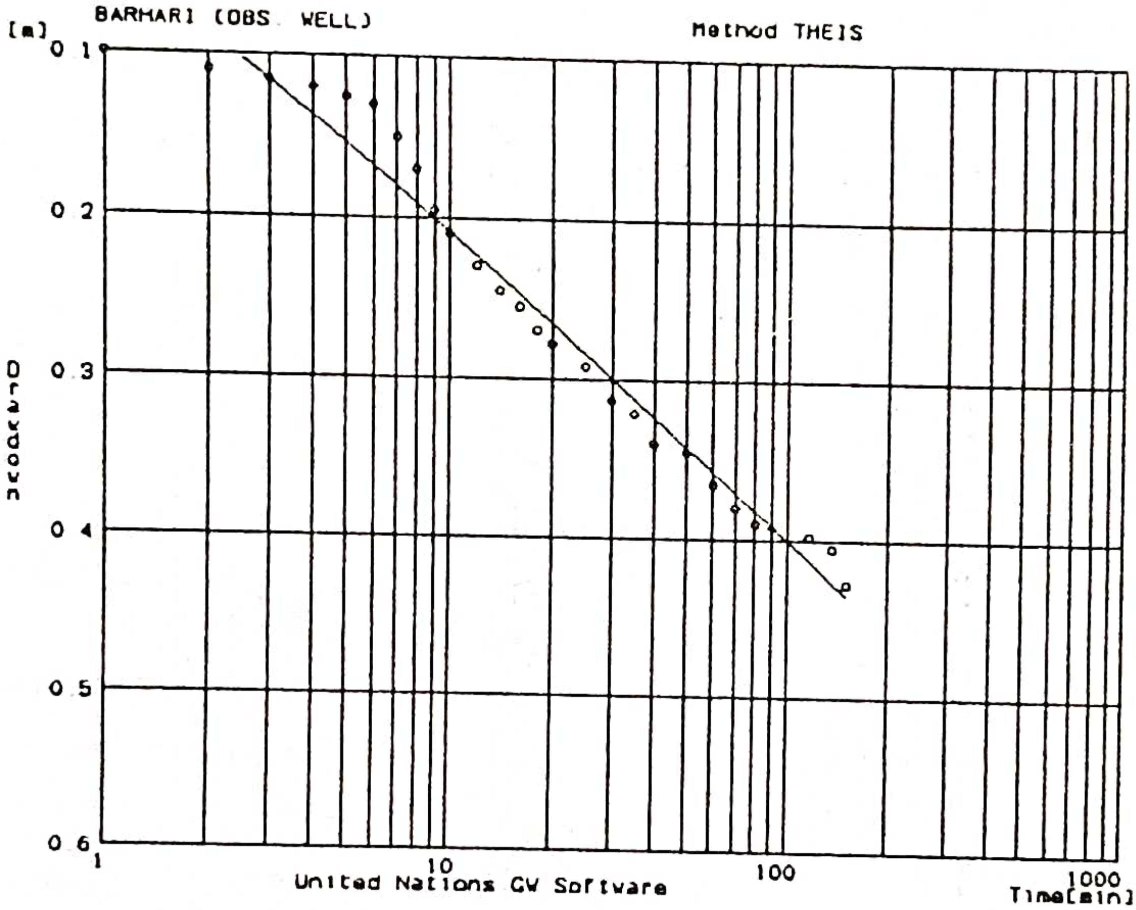
C 6. Pumping Test of UN 8



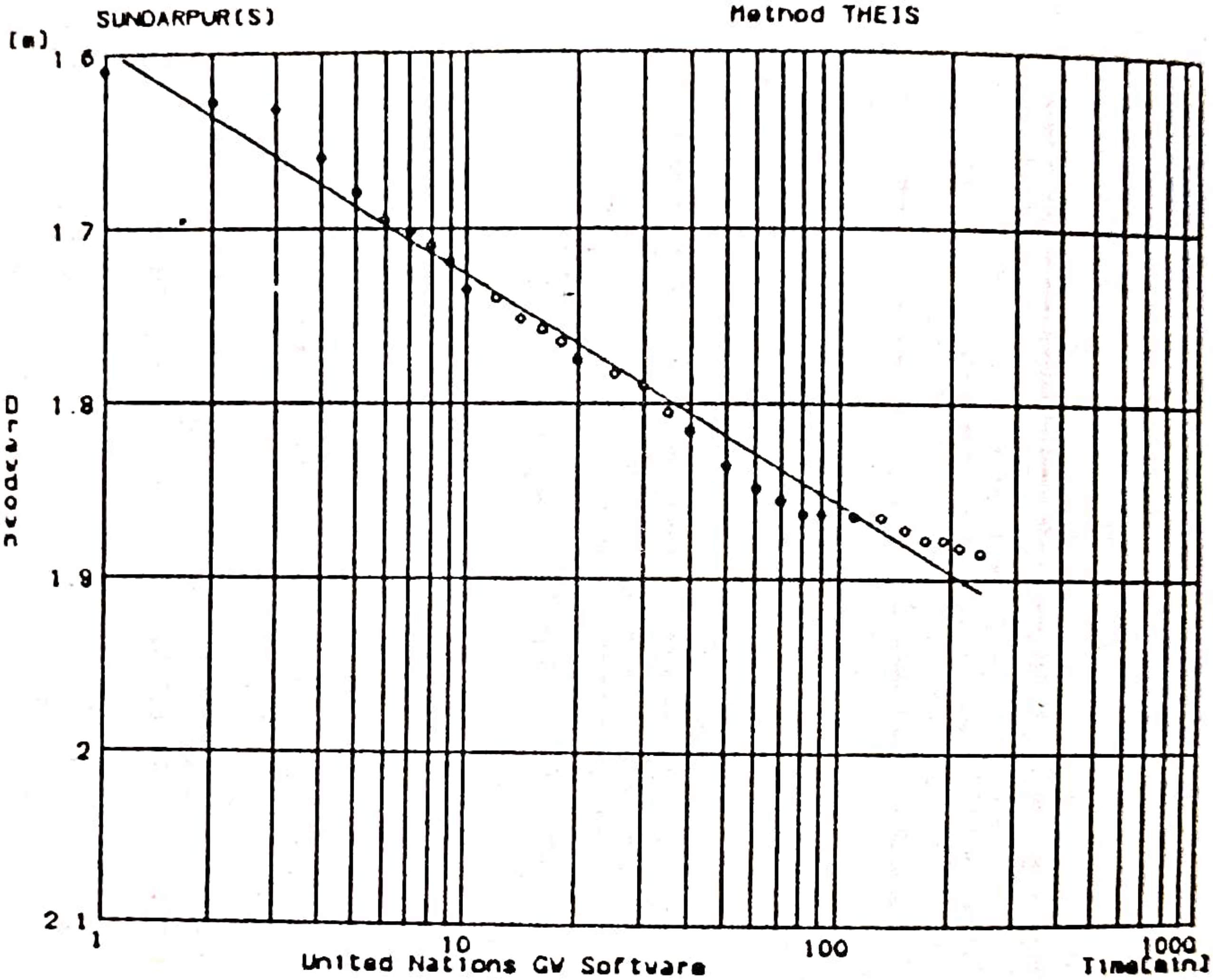
C 7. Pumping Test of UN 9



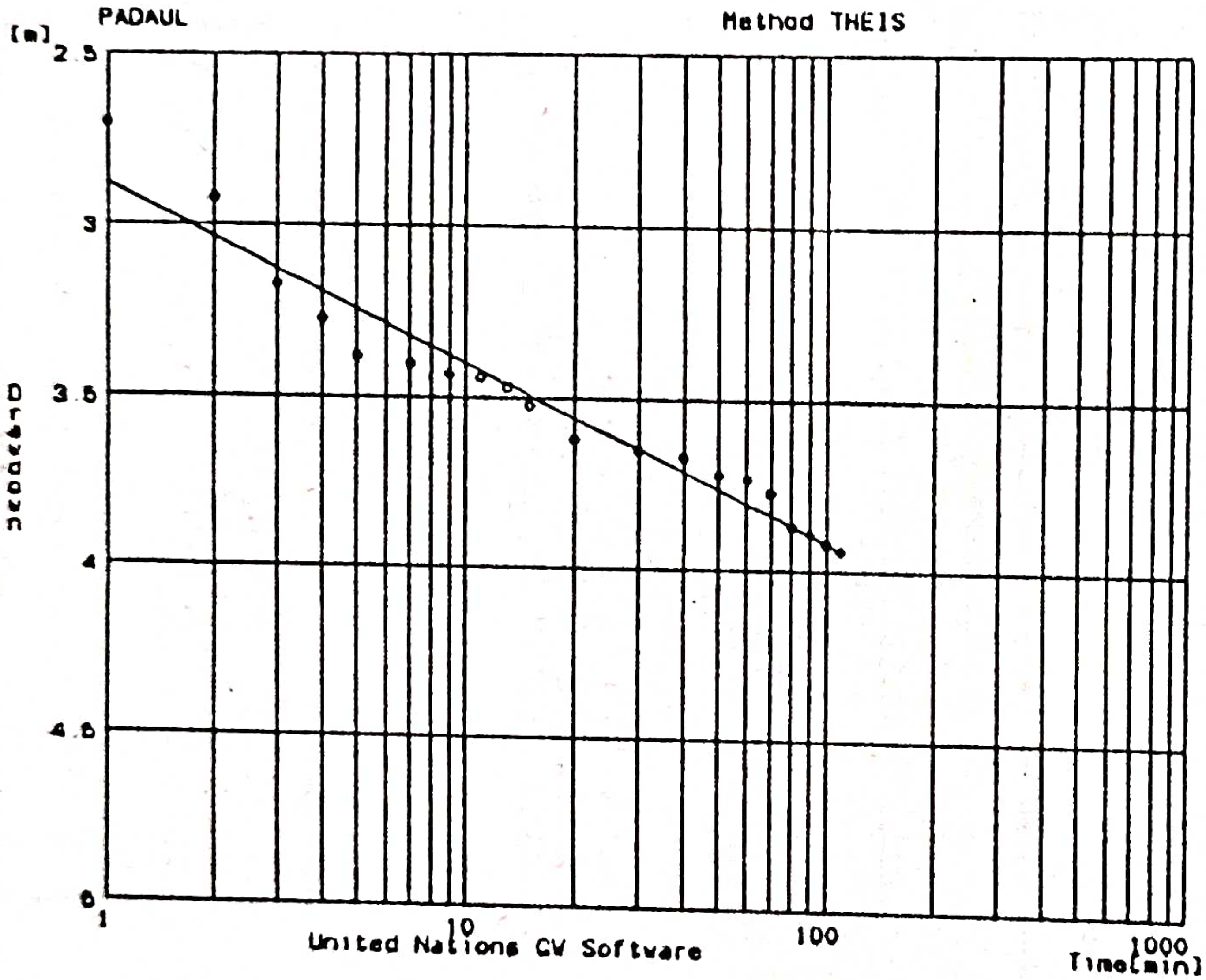
C 8. Pumping Test of UN 10



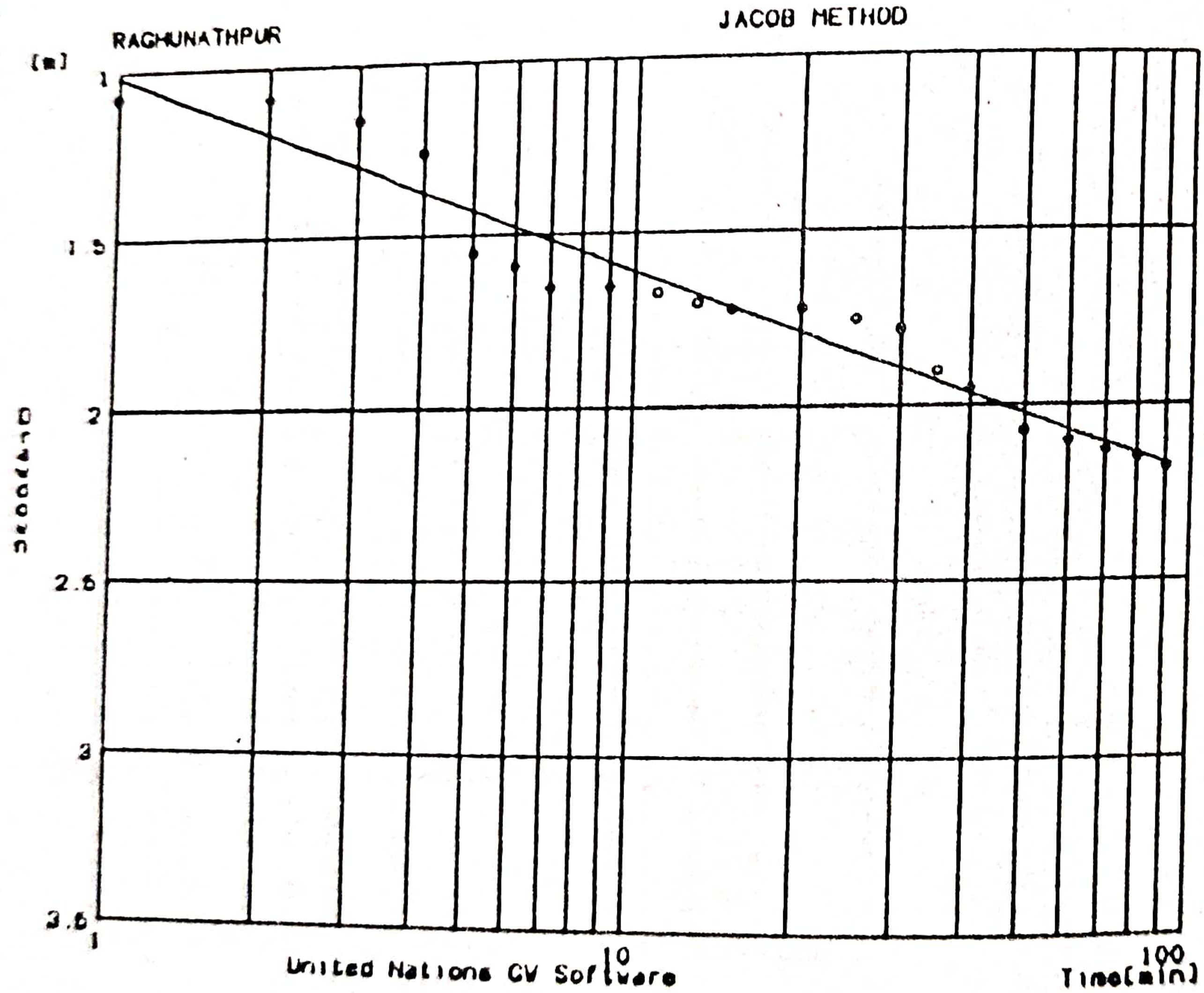
C 9. Pumping Test of UN 11



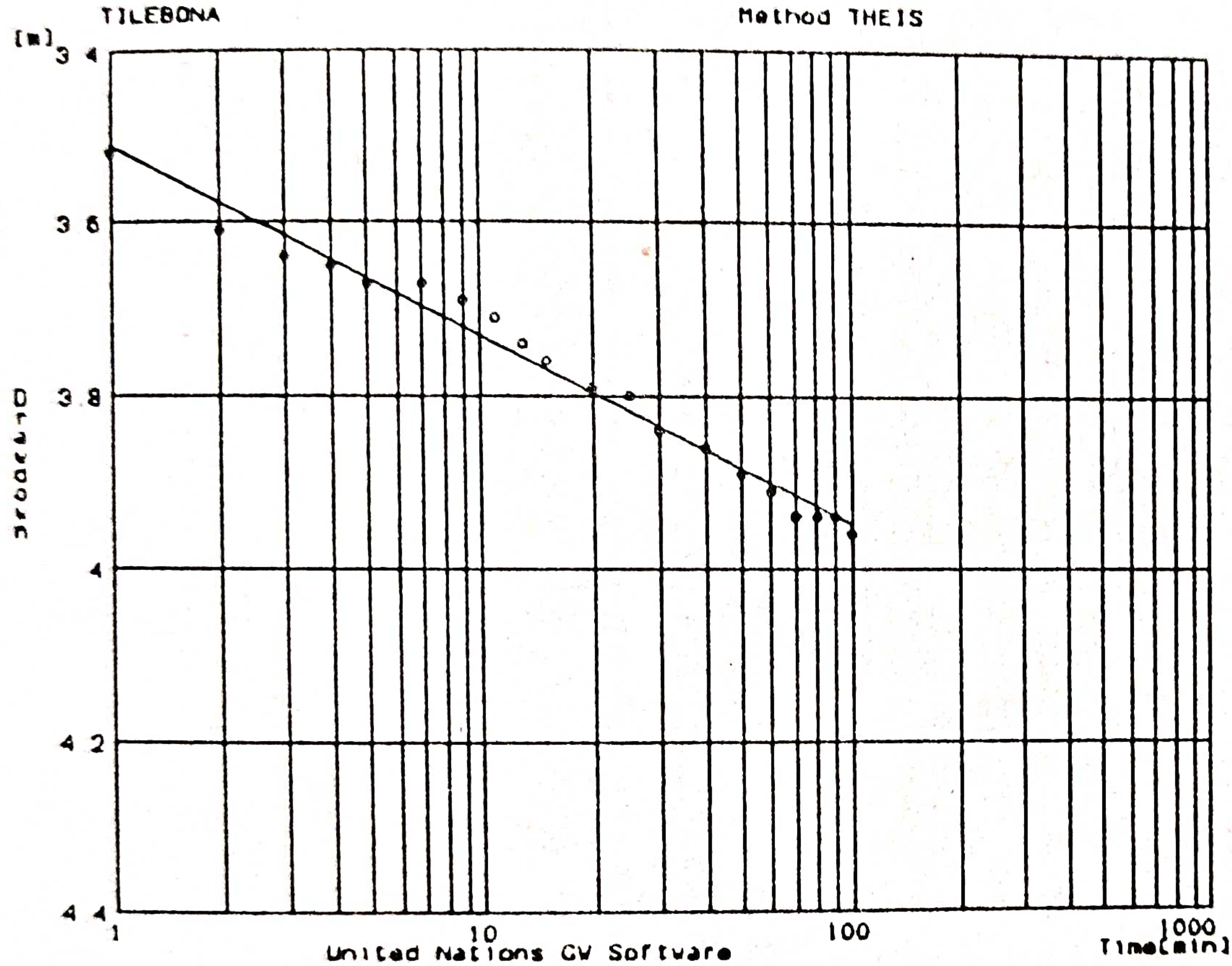
C 10. Pumping Test of UN 12



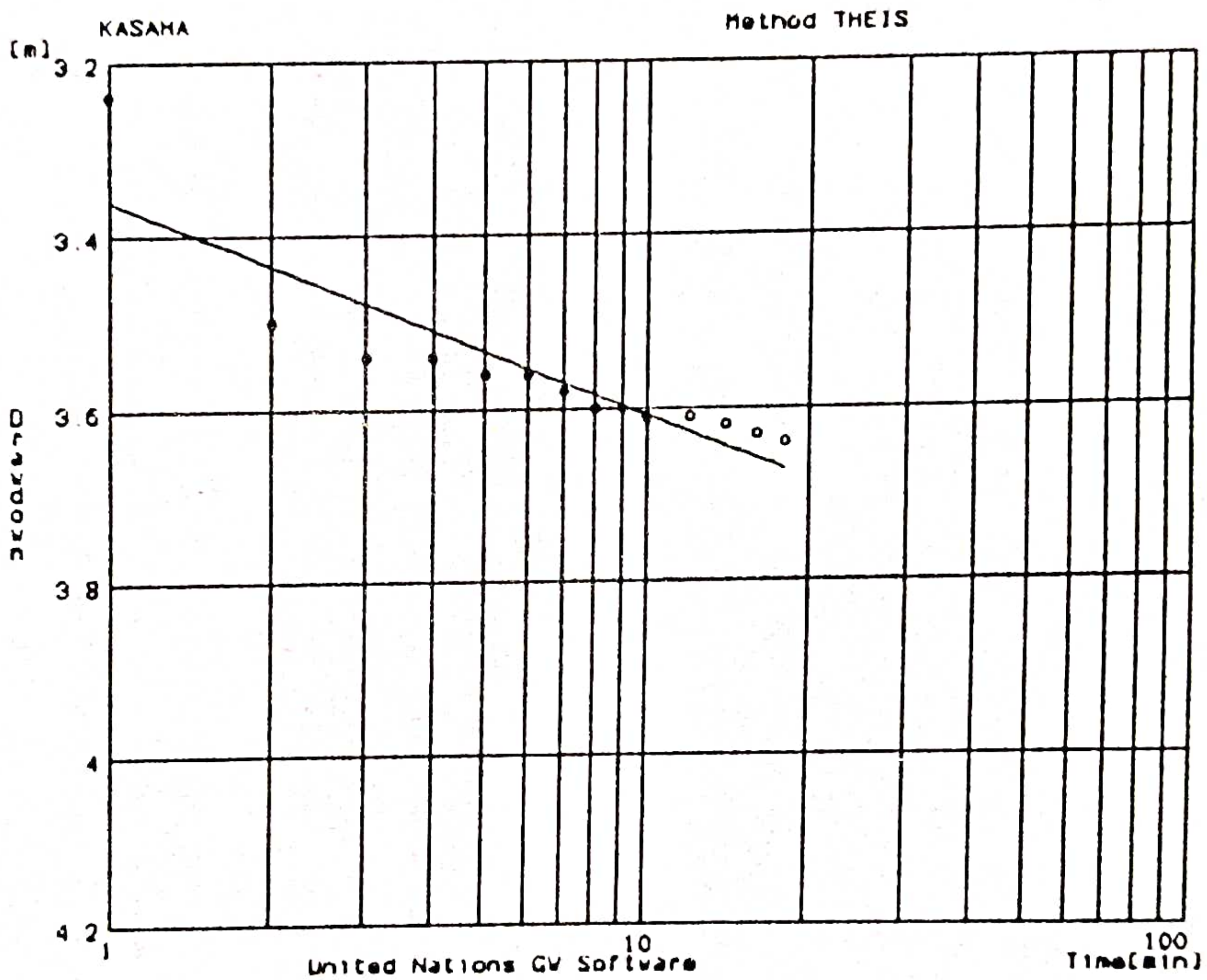
C 11. Pumping Test of UN 13



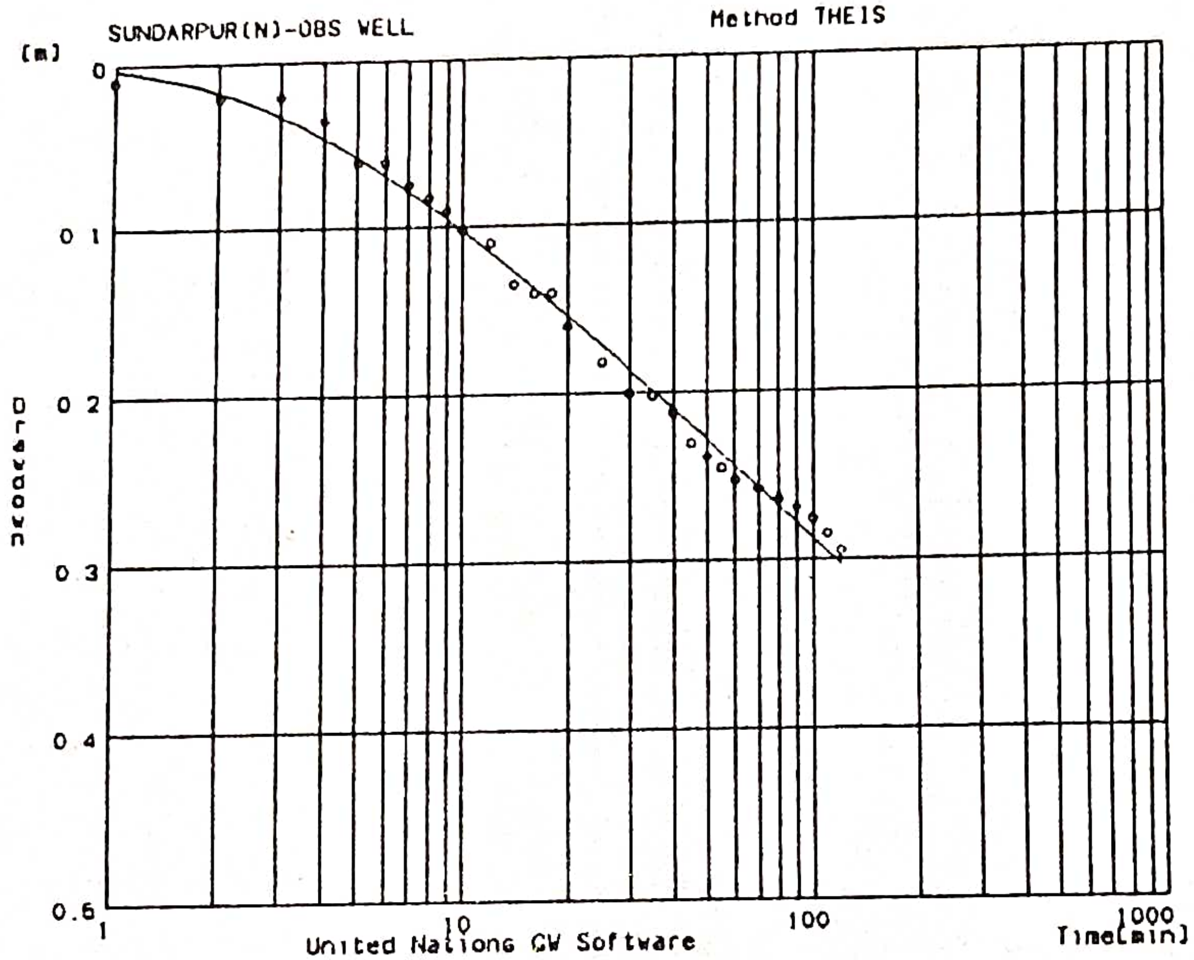
C 12. Pumping Test of UN 14



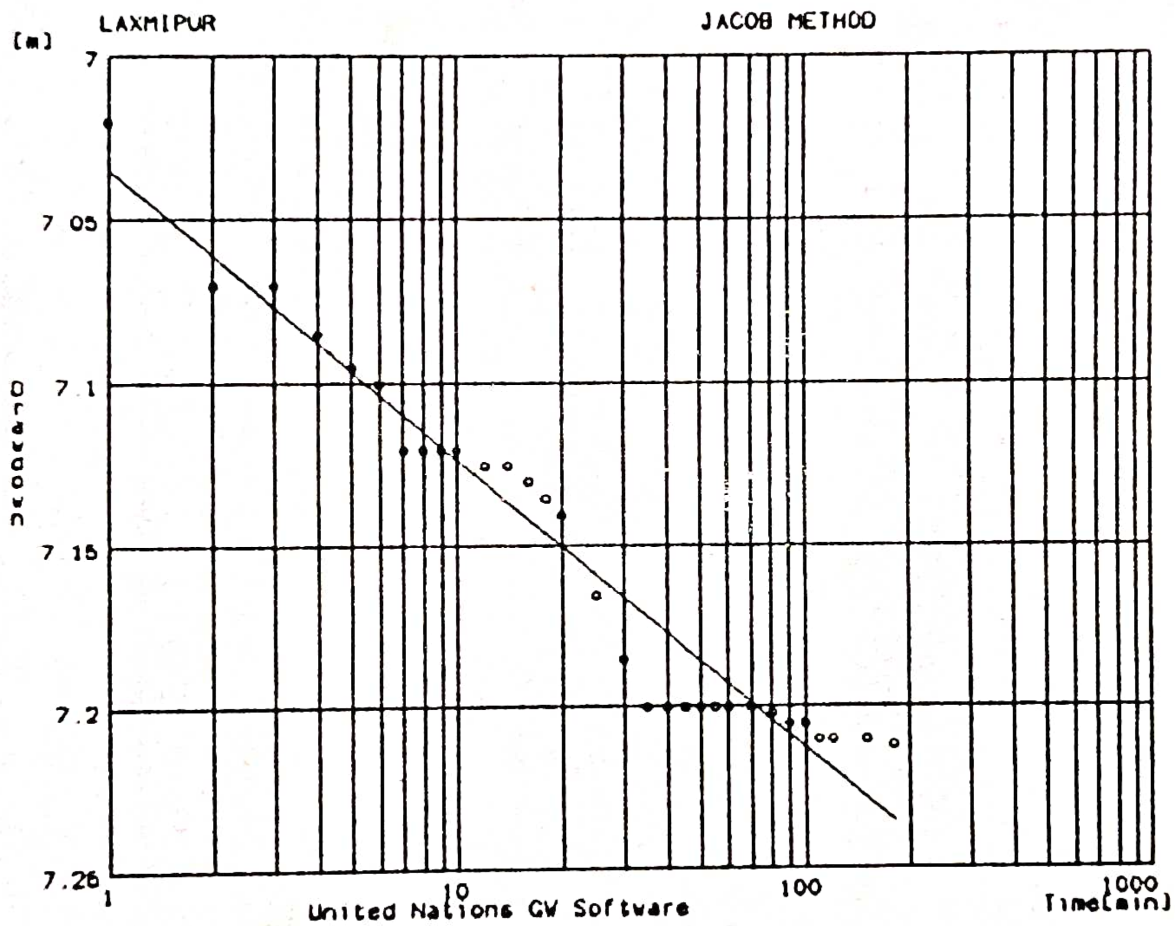
C 13. Pumping Test of UN 20



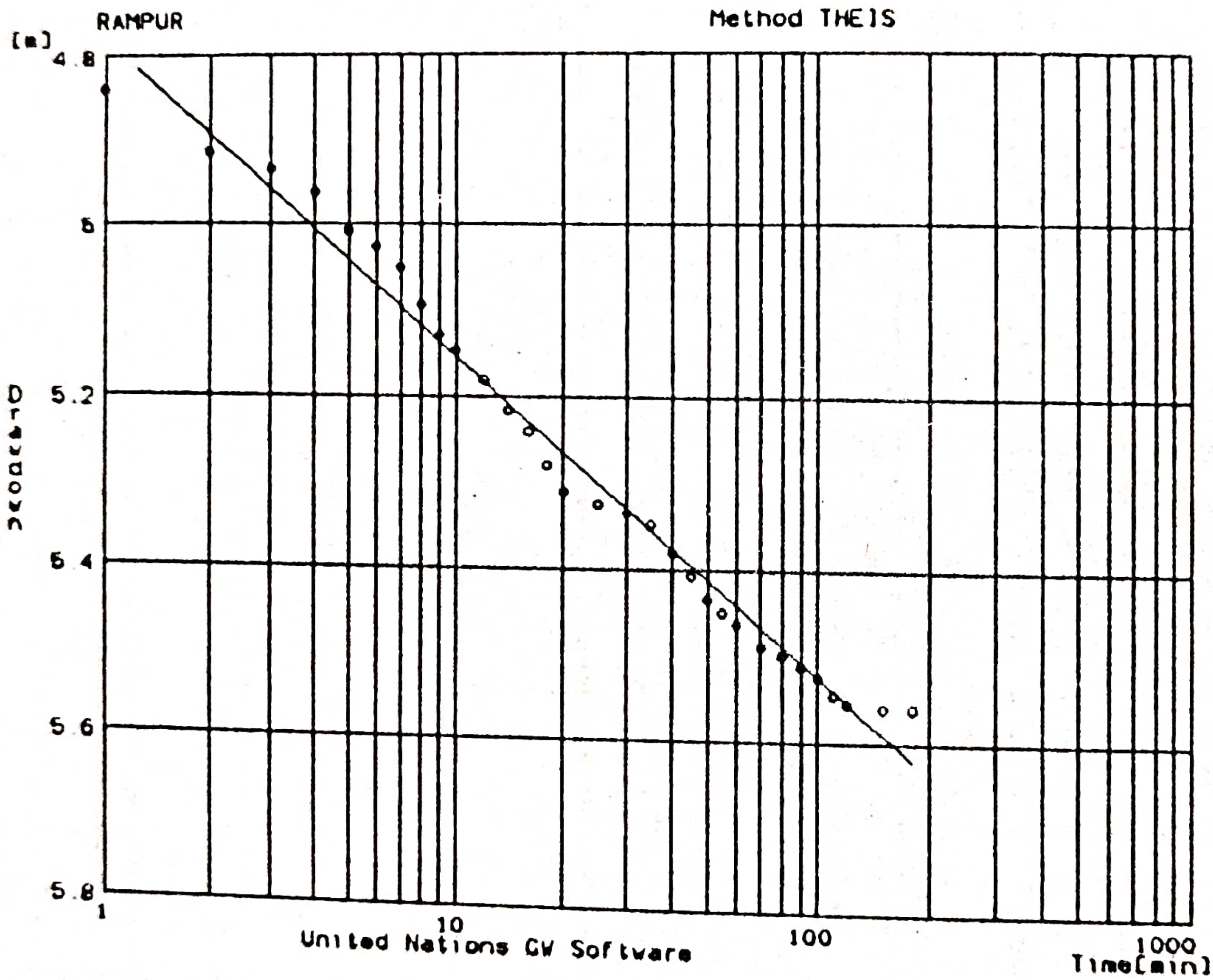
C 14. Pumping Test of UN 21



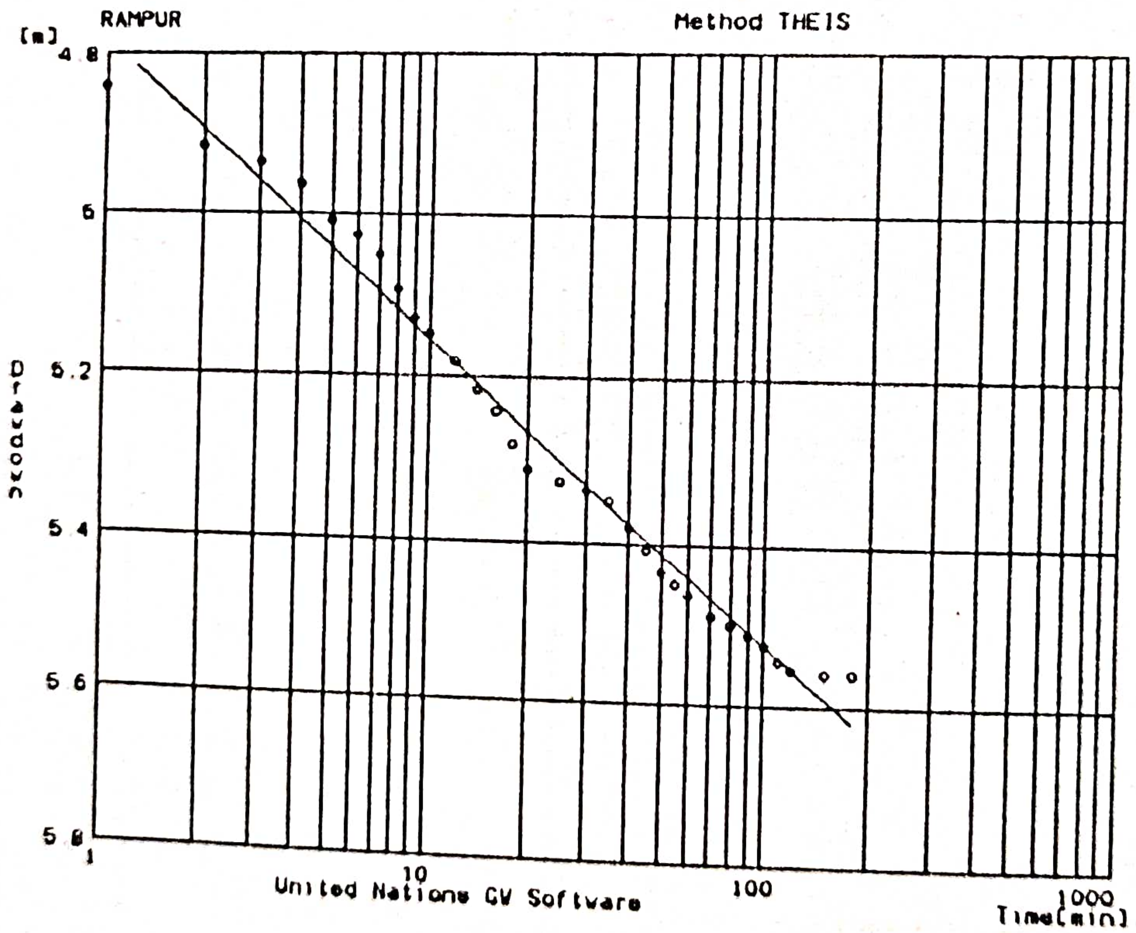
C 15. Pumping Test of UN 22



C 16. Pumping Test of UN 23



C 17. Pumping Test of UN 24



C 18. Pumping Test of Choharwa (Private) Well

APPENDIX D

Monthly Water Level Measurement Data in UN STWs in Siraha District

S. No	Village Name	X	Y	Elev. MSL (m) #	M.P. (m)	Year	Water Level Measurements in meters (BGL)											
							JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	MITHILESHWOR	425375	2964125	110.80	0.53	1990					2.46	1.88	1.12	0.66	0.18	0.71	1.24	1.73
						1991	1.93	2.13	2.18	2.23	2.54	2.54	1.62	0.71	0.56	0.61	1.07	1.27
2	BASBITTA	421250	2950250	76#	0.43	1990								0.51	0.46	0.76	1.02	1.60
						1991	1.85	2.13	2.23	2.25	2.90	2.46	1.92	0.91	0.56	0.81	1.17	1.37
3	KARJANHA	417625	2969375	100.75	0.35	1990					4.16	3.66	2.82	2.19	2.13	2.26	2.44	3.28
						1991	3.48	3.66	3.71	3.83	4.09	3.86	3.04	2.44	2.18	2.49	2.49	3.10
4	BHEDIYA	417500	2964250	90.43	0.45	1990						1.57	1.07		1.14	1.27	0.96	
						1991	3.35	3.53	4.01	4.17	3.91	2.79	2.23	1.63	1.40	1.17	1.32	1.63
5	BANDIPUR	417500	2974125	105.08	0.71	1990					5.54		3.56	2.84	2.01	1.83	1.93	3.48
						1991	3.66	3.81	4.27	4.52	4.62	4.80	4.59	2.11	1.88	2.46	2.44	2.62
6	AMAHI	449125	2958250	126.01	0.85	1990				5.59	6.2		5.56	5.49	0.04	3.48	3.45	5.26
						1991	5.51	5.79	5.51	6.27	6.50	6.53	6.35	5.31	5.21	5.44	5.39	5.49
7	NAHARA	447125	2943375	89.75	0.30	1990				3.20	2.26	2.29	1.42	0.41	0.33	0.61	0.76	1.55
						1991	1.78	1.98	2.08	2.15	2.36	1.68	1.03	0.30	0.20	0.46	0.86	1.07
8	KANCHHIBAZAR (Dhangadhi)	441625	2958500	129.67	0.42	1990					1.40	0.91	0.3	0.18	0.10	0.56	0.66	1.04
						1991	1.92	1.37	1.63	1.78	1.68	1.22	0.71	0.18	0.08	0.41	0.71	0.89
9	MADAR	418250	2945250	70.17	0.15	1990				1.6	2.29	2.13	1.98	0.25	2.87	0.3	0.41	1.6
						1991	1.98	2.08	213.2.1742.44			2.62	2.1311.29.0.41			0.51	0.74	0.96
10	BARHARI	436250	2958250	97.82	0.15	1990				2.18	2.31	1.88	1.77	0.71	0.71	0.86	0.91	1.78
						1991	1.96	2.13	2.21	2.24	2.39	2.54	1.92	1.27	1.07	1.12	1.27	1.40
11	SUNDARPUR(S)	441125	2943625	84.01	0.42	1990				5.36	5.44	5.41	4.95	3.53	3.53	4.52	4.67	5.64
						1991	6.33	6.10	6.20	6.29	6.81	5.94	5.00	4.37	4.06	4.11	4.34	4.57
12	PADAUL	446500	2941000	85.11	0.45	1990				1.96	2.08	2.06	1.75	0.51	0.43	0.40	0.61	1.19
						1991	1.52	1.83	1.90	2.13	2.39	2.29	1.57	0.71	0.40	0.48	0.86	0.96

X & Y = Landsat Coordinates, m = meter, # = elev. from topomap BGL = Below ground level

App. D...cont.

Monthly Water Level Measurement Data in UN STWs in Siraha District

S. No	Village Name	X	Y	Elev. MSL (m)	M.P. (m)	Year	Water Level Measurements in meters (BGL)											
							JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
13	RAGHUNATHPUR	449500	2952875	109.51	0.45	1990				4.62	4.22	6.05	5.53	3.73	3.43	1.93	2.75	2.02
						1991	2.64	3.07	3.81	4.04	4.19	4.37	4.39	2.11	1.98	2.08	3.02	3.40
14	KABILASI (Pokhariya)	433750	2949750	87.20		1990									2.5	3.4	4.0	4.2
						1991	1.42	1.52	1.63	1.78	2.08	2.44	1.47	0.66	0.30	0.41	0.71	0.96
15	RAMNAGAR	424750	2966750	112.19		1990								1.22				
						1991	3.63	3.78	3.81									
16	HAKPARA	425375	2949375	80.12	0.15	1990				1.65	1.75	1.75	1.22	0.51	0.61	0.46	0.30	1.63
						1991	1.98	2.08	2.36	2.41	2.62	3.05	1.70	0.74	0.56	0.71	1.07	1.32
17	TILEBONA	449125	2948625	99.76		1990				2.79	2.92	2.95	2.45	0.25	0.18	0.56	0.71	1.65
						1991	1.91	2.26	2.79	2.91	3.05	3.10	1.92	0.96	0.74	0.71	1.32	1.57
18	KASAHA	436000	2962000	140^	0.50	1990					4.67	4.90	4.09	3.45	2.79	1.83	2.06	4.11
						1991	4.88	5.33	4.42	4.47	4.70	5.36	5.28	4.37	4.22	4.09	4.39	3.96
19	SUNDARPUR(N)	441500	2949000	93.80	0.25	1990						1.22	0.61	0.53	0.18	0.76	0.86	1.40
						1991	1.63	1.83	1.88	1.95	2.23		0.91	0.38	0.25	0.30	0.71	1.02
20	LAXMIPUR	426150	2954750	91.70	0.20	1990					2.49	1.42	0.61	0.18	0.13	0.30	0.43	1.19
						1991	0.48	1.52	1.57	1.63	1.70	1.70	0.73	0:13	0.08	0.23	0.66	0.94
21	RAMPUR	441400	2953500	105.66	0.25	1990						1.52	0.96	0.41	0.30	0.89	1.47	1.63
						1991	1.91	2.18	2.23	2.35	2.49							
22	*LAHAN	449500	2952880			1990											0.45	1.52
						1991	1.75	1.85	2.18	2.27	2.16	2.64	2.05	0.07	0.30	0.30	1.22	1.52

* = Private STW, X & Y = Landsat Coordinates, m = meter, # = elev. from topomap BGL = Below ground level

App. D...cont.

Monthly Water Level Measurement Data in Private STWs and Dug Wells in Siraha District

S. No	Village Name	X	Y	Elev. MSL (m)	M.P. (m)	Year	Water Level Measurements in meters (BGL)											
							JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
25	*SUKHCHAINA	420500	2944130			1989	2.48	2.92	3.22	3.54	4.25	3.14	4.03	2.34	1.11	1.60	1.70	2.34
						1990	2.49	2.62	2.79	2.92	3.00	2.57	1.52	0.91	0.76	0.97	1.07	1.93
						1991	2.19	2.39	2.74	2.84	3.05							
26	+HANUMAN NAGAR	423418	2952410			1989	2.33	2.62	2.43	3.05	2.87	2.64	2.57		1.21	1.21	1.64	1.83
						1990	2.18	2.25	2.33	2.62	2.74	2.44	0.48	0.46	0.30	0.48	0.66	1.88
						1991	2.26	2.44	2.44	2.55	3.05	2.44	1.62	0.66	0.61	0.68	0.83	1.63
27	+ITARI	293950	2957630			1989		2.94	3.48	3.58	4.56	2.82	4.27	2.69	1.21	1.65	1.14	2.01
						1990	2.84	2.88	3.15	3.20	3.33	2.21	1.83	0.10	agl	0.15	0.56	1.88
						1991	2.13	2.36	2.74	2.88	3.15	1.09	0.65	0.07	1.02	0.08	0.56	0.66
28	+BHEDIYA	416525	2965380			1989		3.96	4.14	4.16	4.58	3.15	4.27	1.83	1.37	2.74	2.99	3.12
						1990	3.05	3.25	3.56	3.84	3.91			2.44	2.59	2.87	3.00	2.95
						1991	3.35	3.53	4.01	4.17	3.91	2.79	2.23	1.63	1.40	1.17	1.32	1.63
29	*MANHARWA	419113	2968100			1989	3.47	3.79	3.65	3.79	4.88	4.01	4.18	2.36	1.70	2.43	3.12	3.17
						1990	3.35	3.45	3.71	3.86	3.91	3.56	2.82	2.44	2.54	2.74	3.00	3.38
						1991	3.76	3.91	3.96	4.02	4.14	3.66	3.04	2.49	2.06	1.93	2.21	2.44
30	*RAMNAGAR	425062	29666580			1989	2.33	3.00	2.43	2.77	4.20	3.36	3.45	2.52	2.28	2.05	2.08	2.57
						1990	2.74	2.83	2.91	3.00	3.38	3.12	2.46	1.45	1.50	2.74	2.54	3.53
						1991	3.63	3.78	3.81									
31	*NARHA	426961	2961010			1989	0.96	1.65	1.90	2.06	2.26	1.83	1.83	0.83	0.40	0.30	0.86	1.22
						1990	1.40	1.53	1.96	1.83	2.23	1.83	1.22	0.43	0.25	0.40	0.61	1.29
						1991	1.52	1.65	1.93	2.10	4.14	1.98	1.26	0.61	0.10	0.35	0.99	1.23
32	*SANAITHA	422025	2959720			1989	1.09	1.32	1.75	1.88	2.82	1.27	2.52	1.02	0.30		0.30	0.79
						1990	0.99	1.22	1.52	1.52	2.26	0.76	0.00	0.00	0.00	0.00	0.30	0.66
						1991	0.97	1.22	1.42	1.55	1.65	2.01	1.01	0.35	0.25	0.35	0.66	0.86
33	*HARKATTI	432025	2946710			1989	0.83	1.40	1.65	2.21	2.44	1.55	2.08	0.32	0.62		1.14	1.40
						1990	1.62	1.93	2.24	2.08	1.32	1.57	0.10	agl	agl	agl	agl	0.61
						1991	1.22	1.22	1.29	1.37	2.49	1.75	1.16	0.10			0.10	0.41
34	*JANKINAGAR	436455	2944180			1989	5.13	5.49	6.93	7.17	7.50	5.54	7.37	4.67	2.79	2.74	3.53	4.27
						1990	4.57	5.36	5.72	5.18	5.31	5.28	4.67	3.48	3.35	3.41	3.66	5.92
						1991	6.20	6.25	6.40	6.40	6.81	5.59	4.92	4.14	3.86	3.96	4.14	4.37
35	*KALYANMA	435189	2954300			1989	2.79	3.23	3.30	3.31	3.51	3.40	3.05	1.70	1.06	2.64	1.93	2.74
						1990	2.92	3.02	3.09	3.15	3.35	3.28	2.74	1.65	1.60	0.86	2.13	2.90
						1991	3.05	3.35	3.40	3.47	3.76	3.76	2.86	1.93	1.40	1.47	1.63	1.83
36	*BETAUNA	431012	2958100			1989	2.03	1.96	2.31	2.44	2.93	2.49	2.61	0.43	0.68	0.99	1.57	2.34
						1990	2.44	2.54	3.10	2.87	2.63	2.92	2.26	1.32	1.09	1.45	1.52	2.31
						1991	2.54	2.74	3.05	3.13	3.56			1.57	1.02	1.17	1.40	1.63

* = Private STW, + = Dug Well, X & Y = Landsat Coordinates, m = meter, # = elev. from topomap,
BGL = Below ground level, agl = Above ground level.

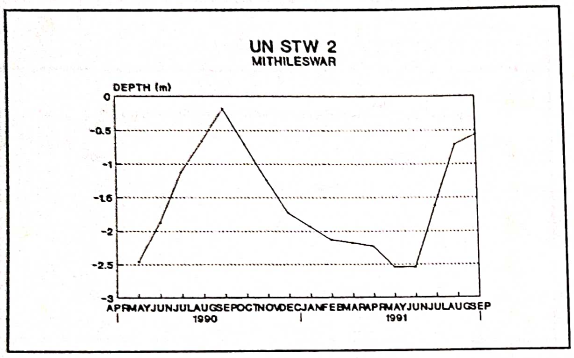
App. D...cont.

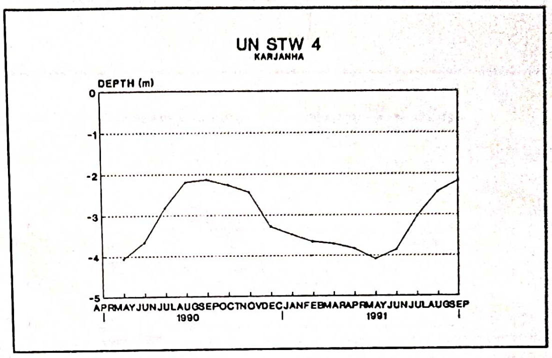
Monthly Water Level Measurement Data in Private STWs and Dug Wells in Siraha District

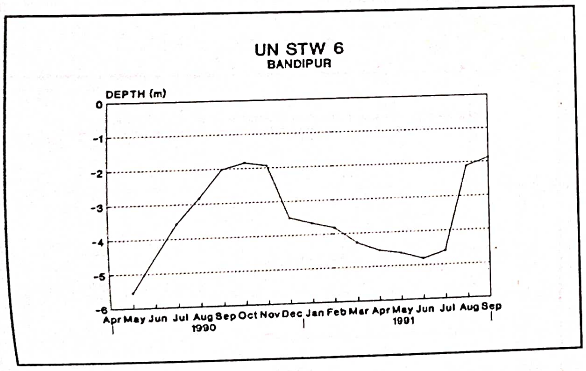
S. No	Village Name	X	Y	Elev MSL (m)	Year	Water Level Measurements in meters (BGL)											
						JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
37	+CHANDRALALPUR	431012	2965320		1989	5.41	7.11	7.41	7.85	8.46	10.98	11.13	7.11	6.55	5.99	6.25	6.66
					1990	7.01	7.27	7.98	8.89	11.38	11.23	11.33	10.01	9.50	6.58	6.50	7.19
					1991	7.65	8.18	10.97	11.94	12.23	10.72	8.58	7.42	7.19	7.70	8.05	6.93
38	*DHANGADHI	438087	2961140		1989	2.23	1.75	3.81	1.73	2.14	1.67	1.22	1.02	1.03	1.04	1.32	1.54
					1990	1.68	1.75	1.79	1.52	1.78	1.63	1.52	1.07	0.81	0.91	1.09	1.35
					1991	1.63	1.88	1.93	2.00	2.08	1.75	0.91	0.61	0.53	0.79	1.27	1.57
39	*JAGATPUR	443291	2942790		1989	3.55	4.09	5.03	4.95	5.26	3.66	4.04					1.83
					1990	2.17	3.35	3.56	3.76	3.86	3.66	2.13	1.67	1.73	1.65	1.78	2.84
					1991	3.18	3.35	3.48	3.48	3.86	4.06	3.27	1.96	1.32	1.47	1.63	1.88
40	*JAMATOL	446227	2937590		1989	~~9.99~~ 1.76	2.41	2.08	2.08	2.29	2.09	1.98	1.27	0.68	0.50	0.91	1.42
					1990	1.57	1.96	2.03	1.88	1.96	1.65	0.91	0.48	0.43	0.61	0.74	1.75
					1991	2.16	2.44	2.59	2.77	2.92	2.84	2.43	1.52	0.10	1.22	1.78	1.93
41	*PORTAHA	449367	2947470		1989		3.23	4.06	4.33	4.76	3.96	4.04	2.31	1.14	1.21	1.95	2.10
					1990	2.87	2.97	3.10	3.20	3.28	3.56	3.20	1.32	1.22	1.22	1.35	2.57
					1991	2.74	3.05	2.18	2.64	3.51	3.66	2.79	1.78	1.45	1.52	1.93	2.13
42	*BHAGWANPUR	448227	2941650		1989	2.56	2.92	2.84	3.28	3.54	3.02	3.22	1.40	0.91	0.50	1.62	2.31
					1990	2.54	2.64	2.84	3.10	3.28	3.05	2.44	1.27	1.17	1.58	1.78	2.41
					1991	2.57	2.79	2.90	3.05	3.40	2.74	3.09	1.52	1.32	1.47	2.01	2.21
43	+SIMALTOKI	442025	2964050		1989	12.04	13.92	15.01	16.16	16.97	17.88	17.40	16.97	14.38	9.75	9.88	10.80
					1990	11.97	12.96	14.15	15.24	16.56	17.30	16.89	15.70	15.70	10.36	10.59	11.48
					1991	11.84	12.91	13.36	14.91	15.27	11.89	11.30	10.39	10.42	12.32	11.41	12.19
44	+GOBINDAPUR	451645	2958990		1989	4.21	5.05	4.62	5.54	5.90	5.81	5.24	5.11	3.20	2.28	2.99	3.48
					1990	3.66	4.12	4.57			15.24	14.86	14.25	14.28	11.58	11.71	11.56
					1991	12.04	12.83	12.80	14.88	15.42	16.16	15.37	12.01	11.74	11.36	11.97	13.16
45	*SIRAHA	420379	2947970		1989	1.98	2.67	3.15	2.37	2.76	2.49	2.10	1.57	0.60	0.91	1.16	1.78
					1990	2.08	2.23	2.49	2.54								
					1991												
46	*BELHA	420886	2953920		1989	1.92	2.01	2.74	3.00	3.36	2.01	1.89	1.02	0.30	0.91	1.21	1.52
					1990	1.63	1.91	2.13	2.23								
					1991												

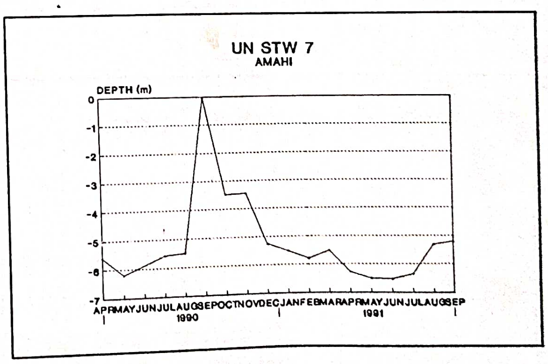
* = Private STW, + = Dug Well, X & Y = Landsat Coordinates, m = meter, # = elev. from topo map
BGL = Below ground level, agl = Above Ground Level

APPENDIX E. SELECTED HYDROGRAPHS









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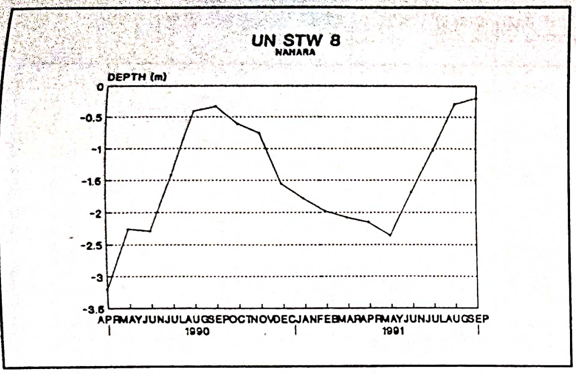

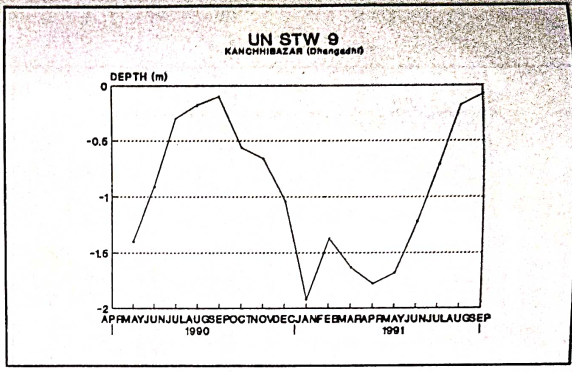

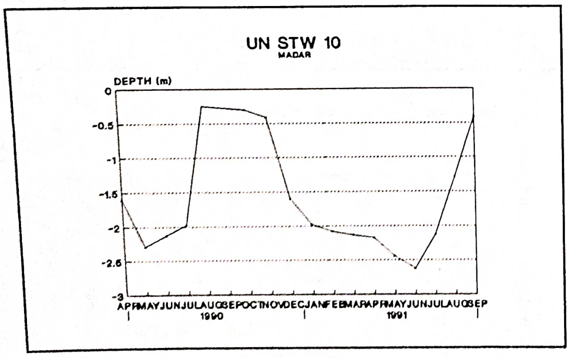

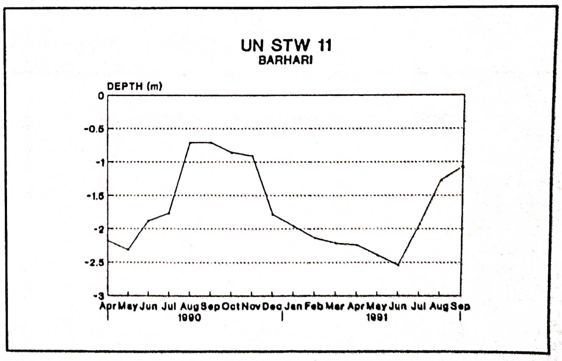

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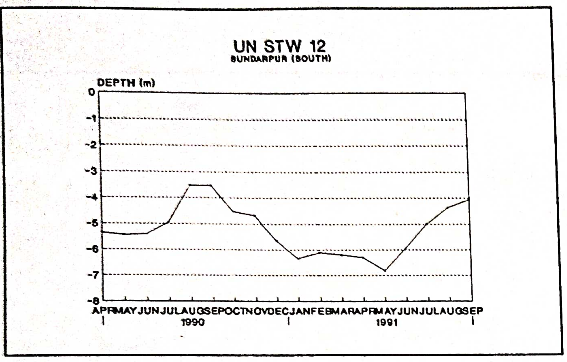

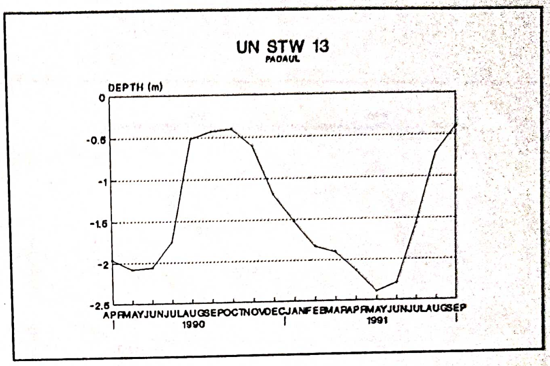

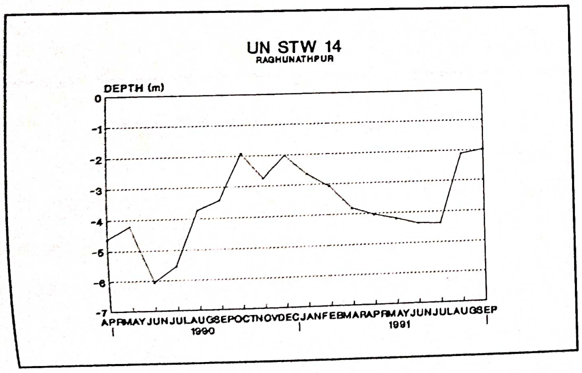

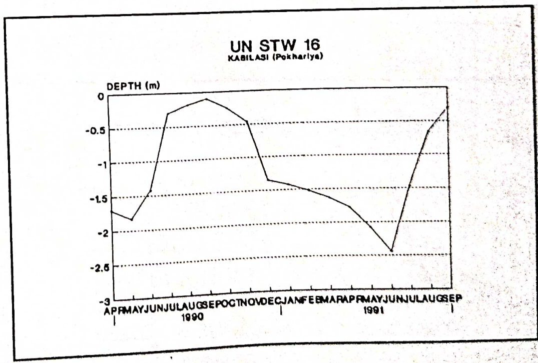

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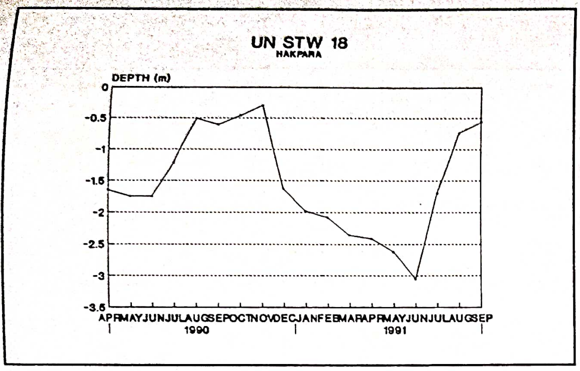

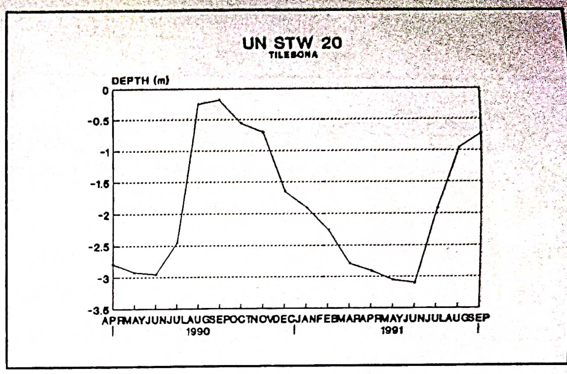

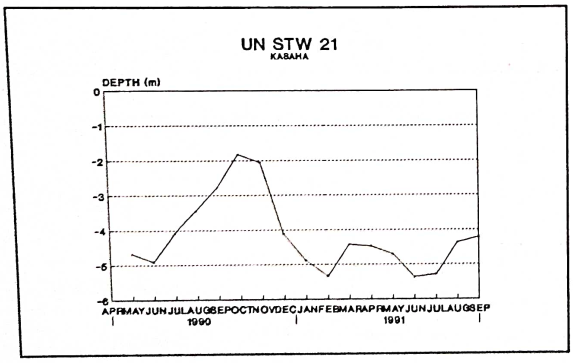

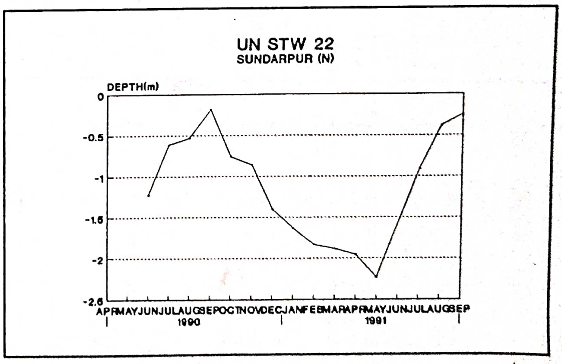

APPENDIX E. Contd...