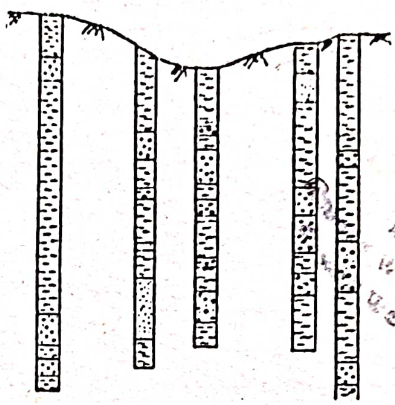
UNITED NATIONS DEVELOPMENT PROGRAMME
AND
HIS MAJESTY'S GOVERNMENT OF NEPAL
NEP/86/025

SHALLOW GROUND WATER INVESTIGATIONS IN TERAI

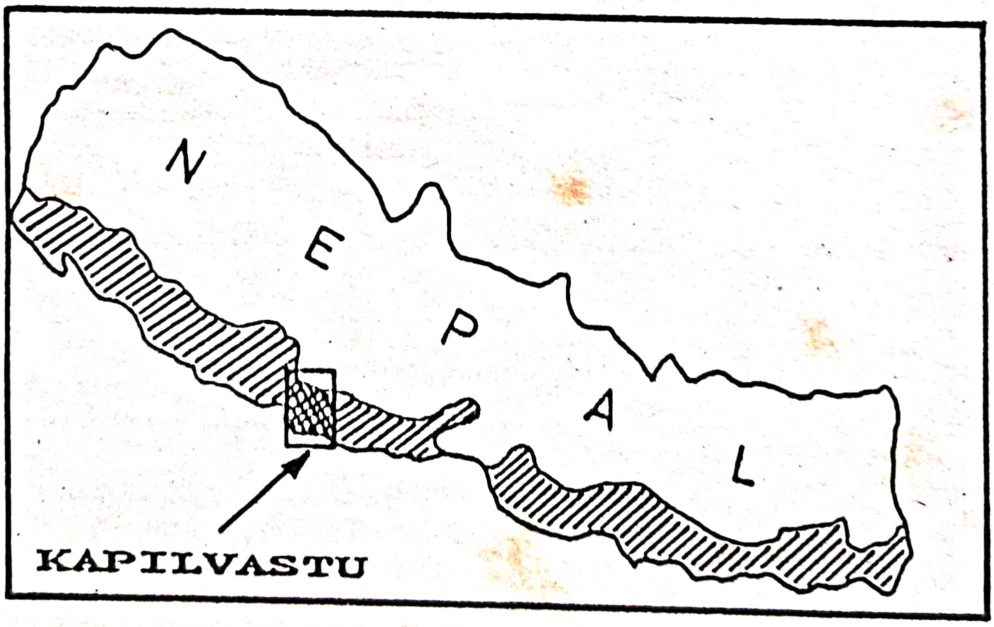
KAPILVASTU

SHALLOW WELLS DRILLING, TESTING AND MONITORING IN 1987/88

BASIC DOCUMENTATION AND PRELIMINARY INTERPRETATION



TECHNICAL REPORT NO. 7



KATHMANDU, JUNE 1989

GWRDB-UNDP PROJECT NEP/86/025

SHALLOW GROUND WATER EXPLORATIONS IN TERAI

TECHNICAL REPORT NO. 7

KAPILVASTU DISTRICT

SHALLOW WELLS DRILLING, TESTING AND MONITORING IN 1988/89

BASIC DOCUMENTATION AND PRELIMINARY INTERPRETATION

Executing Agency: United Nations Department of Technical Co-operation for Development

Prepared by:

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with assistance of **Dr. J.Karanjac**, Chief Consultant Hydrogeologist

KATHMANDU, JUNE 1989

EARLIER TECHNICAL REPORTS:

1. Bhairawa-Lumbini Ground Water Irrigation System Preliminary Mathematical Modelling. May 1988.

2. Shallow Ground Water Level Fluctuations in the Terai in 1987. Preliminary Report. May 1988.

3. **RAUTAHAT DISTRICT.** Shallow Wells Drilling, Testing and Monitoring in 1987/88. Basic Documentation and Preliminary Interpretation. November 1988.

4. RAUTAHAT DISTRICT. Mathematical Model of Shallow Ground Water System. December 1988.

5. **NAWALPARASI (WEST).** Shallow Wells Drilling, Testing and Monitoring in 1987/88. Basic Documentation and Preliminary Interpretation. March 1988.

6. NAWALPARASI (WEST). Mathematical Model of Shallow Ground Water System. March 1988.

ABBREVIATIONS:

UN/DTCD - United Nations Department of Technical Co- operation for Development

UNDP - United Nations Development Programme

USAID - United States Agency for International Development

GWRDB - Ground Water Resources Development Board

GDC - Groundwater Development Consultants (International) Ltd.

ADBN - Agricultural Development Bank of Nepal

ADB - Asian Development Bank

STW - Shallow Tube Well

DW - Dug Well

DTW - Deep Tube Well

MCM - Million Cubic Meters

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APPENDICES

1. BACKGROUND INFORMATION

1.1. 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 field-data collection, establishment of ground water data base, and to assessment of development potentials of shallow aquifers all over the Terai. The government counterpart agency is the Ground Water Resources Development Board (GWRDB) of the Department of Irrigation of the Ministry of Water Resources. The project's activities started in June 1987.

The immediate objectives of the project NEP/86/025 are the following.

(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 capacity of the GWRDB with regard to exploration, assessment and development of ground water.

The following project outputs are anticipated:

(a) Computerized data base with about 2000 shallow water points from all over the Terai. Information on lithology, hydrogeological parameters, water use, etc.

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

(c) Water level graphs (hydrographs) from selected observation points in a minimum period of one year.

(d) Reports on mathematical modelling.

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

1.2. Basis for this Report

This report is based on the following:

(a) NEP/86/025 project wells (for ease of reference called "project" wells) - 23 newly drilled shallow wells between January and June 1988.

(b) Some of shallow drilled wells for Ground Water Resources Investigations in Lumbini Terai by USAID/GWRDB in 1972

(c) Pumping tests conducted in project wells in 1988.

(d) Water level observations since May 1987.

(e) Groundwater Resources Development Strategies for Irrigation. Groundwater Development Consultants (UK), Ltd. 1987.

(f) Duba, D. 1982. Groundwater Resources in the Terai of Nepal.

(g) Tillson, D. 1985. Hydrogeological Technical Assistance to the Agricultural Development Bank of Nepal. ADB-UNDP report.

(h) Several Mission Reports by the Chief Consultant in this project.

(i) Several field trips by NEP/86/025 project staff.

1.3. Location, Size, Climate

Kapilvastu district belongs to the Western Region (in addition to Rupandehi and Nawalparasi districts). The district's Terai part occupies an area of 1500 km^2. According to Land Resources Mapping Project by Kenting Earth Sciences Ltd., completed in 1986 for the whole of Nepal, a total of 1040 km^2 of the Kapilvastu area is suitable for irrigation of wet season paddy and of diversified dry season crops. The location of Kapilvastu district within Nepal is shown in Figure 1. For the purpose of studying the shallow ground water system of the Terai, the contour line 150 m is considered to be the physical end of the Terai's Quaternary sediments. The main characteristics of climate in Kapilvastu district, as well as in the whole Terai, is monsoon rainfall which occurs between June and September and which delivers an average of 85% of the total annual rainfall. For the purpose of this report the data collected in three rainfall stations: **Taulihawa, Bhagwanpur** and **Patharkot** (Figure 1) are used. It is to be understood that the data are not officially cleared by the HMG Meteorological Service, but rather used in a draft form as an indication for the correlation between shallow water level fluctuation and the rainfall.

Although the Terai of Nepal is in subtropical zone, the mean monthly temperature reaches a low of 15.1 °C in January compared to a high of 30.7 °C in June.

Evolution of shallow ground water levels is heavily dependent on the distribution of rainfall. Most of the recharge to shallow aquifers comes from fan deposits near the Siwalik hills and mountains. The amounts of rainfall in the years 1987 and 1988 will be discussed in Section 4.2. The mean annual rainfall is close to 1900 mm and pan evaporation is about 1500 mm. Average monthly rainfall exceeds average evapotranspiration during only 4 months, June to September. Because of the large moisture deficit during the remaining months a second rice crop cannot be grown under normal conditions. The low winter temperatures preclude a third rice crop even with the addition of irrigation.

The major river in this district is Banganga which flows diagonally, from northeast to southwest, in the eastern half of the district. Unfortunately, there is no gauging station in this river. Therefore, its flow rate is not known.

2. PROJECT ACTIVITIES IN 1987/88

2.1. Drilling

Out of the total planned scope of drilling within this project, which amounts to about 200 shallow wells for the whole Terai, the program of drilling for Kapilvastu district was prepared about a year-and-half ago providing for drilling of 20 wells with an average drilling depth of 40 m. The total drilling metrage in Kapilvastu was estimated at 800 m. Here below the planned and actual implementation is shown:

Planned:	20 STW	Total drilling metrage: 800 m
Actual:	23 STW	Total drilling metrage: 1131 m

Both with respect to number of drilled wells and total drilled metrage, the implementation was above what had been programmed. The implementation compared to the design is illustrated in Figures 2 and 3. The map with locations of all "project" wells is shown in Appendix 1. Twenty three lithological logs with other well construction data are appended in the group of Appendices 3 (3/1 through 3/23). Lithological cross-sections are presented in Appendices 4 (4/2 through 4/6).

The actual number of wells in Kapilvastu district drilled by this project is 23. Two wells were abandoned. Average depth of completed wells was 50 m. However, most of the wells were deficient in the following:

(a) improper screen with 0.5 mm openings, low overall "porosity" of 11%;

(b) poor development which left behind a mud cake on the screen and prevented the water from entering the well. This has in turn resulted with unsuccessful pumping tests and less-than-expected transmissivity values for such kind of permeable formation.

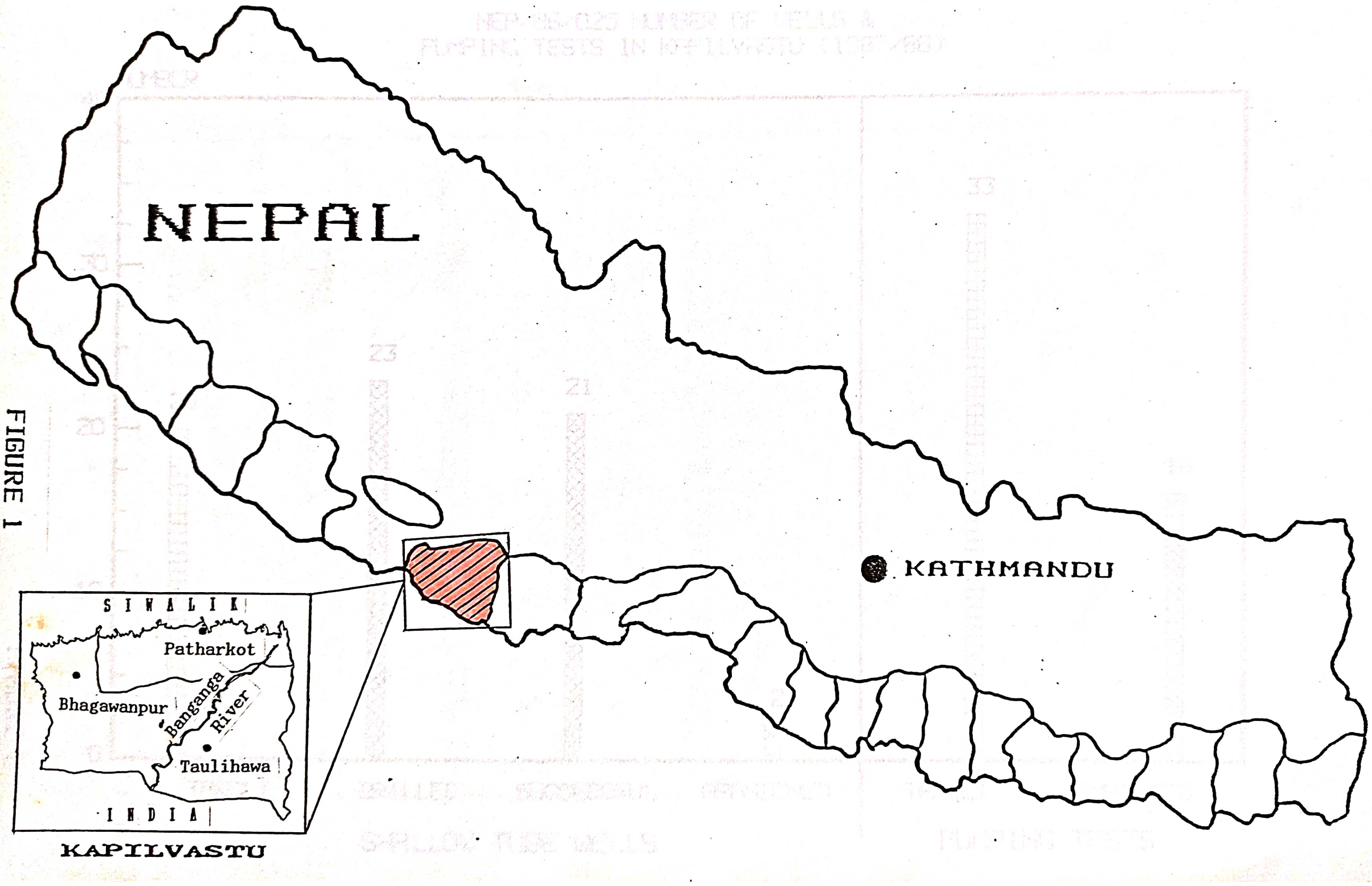

NEPAL
KATHMANDU
SIWALIK
Patharkot
Bhagawanpur
Banganga River
Taulihawa
INDIA
KAPILVASTU

FIGURE 1

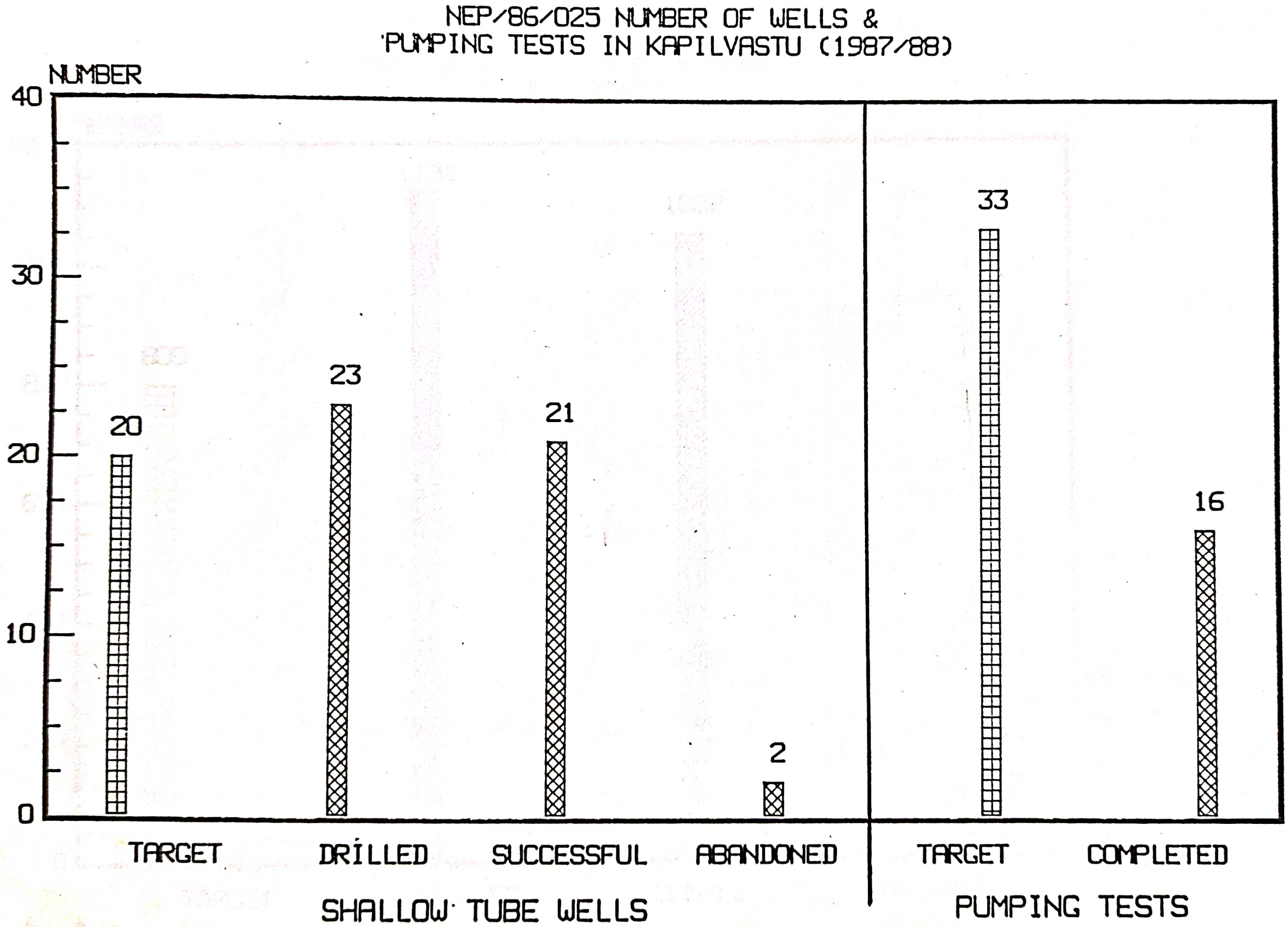

NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN KAPILVASTU (1987/88)
NUMBER
40
30
20
10
0
20
23
21
2
33
16
TARGET
DRILLED
SUCCESSFUL
ABANDONED
TARGET
COMPLETED
SHALLOW TUBE WELLS
PUMPING TESTS

FIGURE 2

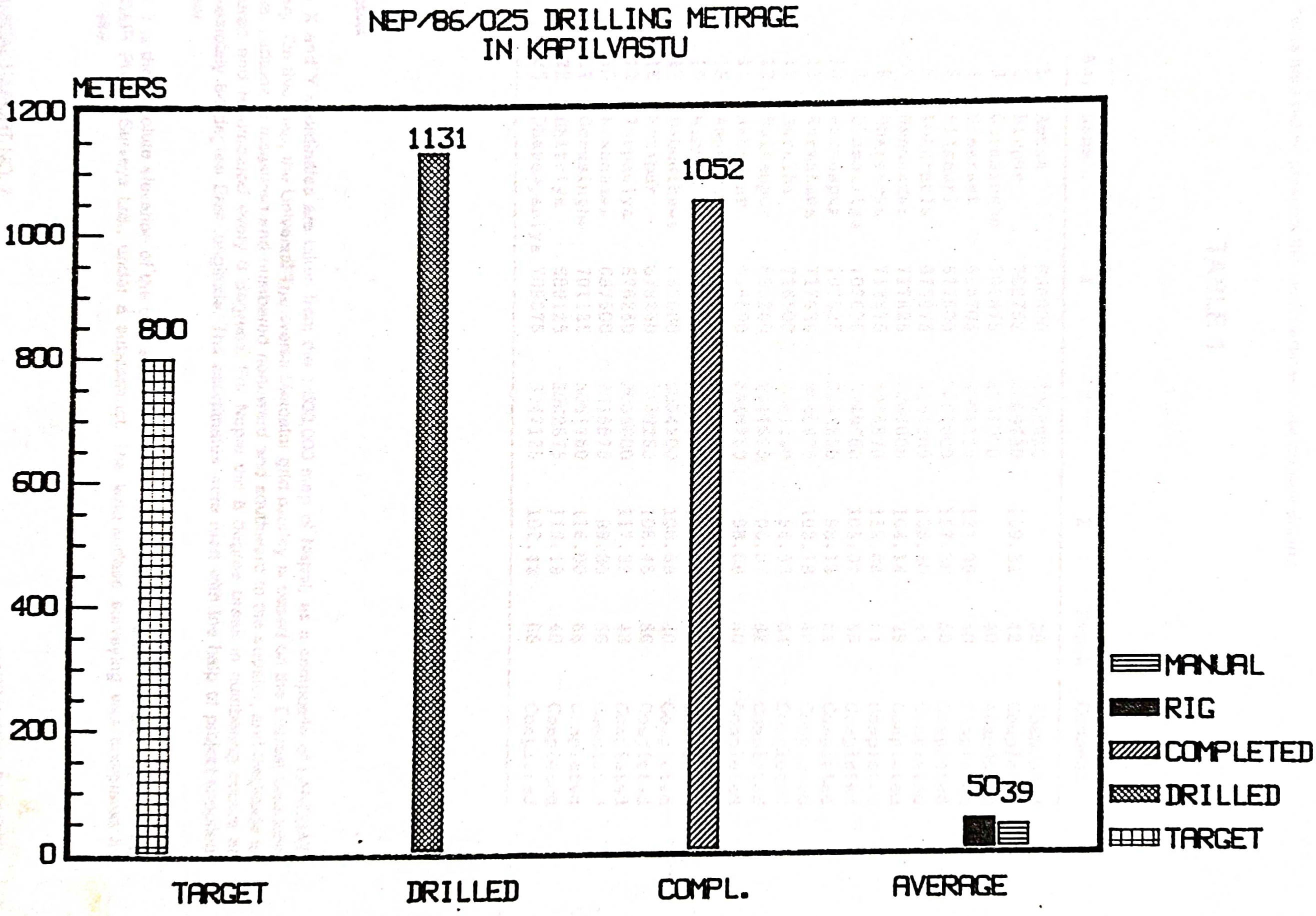

NEP/86/025 DRILLING METRAGE
IN KAPILVASTU
METERS
1200
1000
800
600
400
200
0
800
1131
1052
50
39
TARGET
DRILLED
COMPL.
AVERAGE
MANUAL
RIG
COMPLETED
DRILLED
TARGET

FIGURE 3

The table here below presents the most pertinent data on well drilling.

TABLE 1

No.	Name	X	Y	Z	Depth	Comment
1	Amuwa	696000	3058625		39	Abandoned
2	Birpur	702752	3069750	159.31	42	Completed
3	Gorusinghe	701875	3061000		40	Abandoned
4	Simarsat	695705	3064125	121.90	40	Completed
5	Bijgauri	677500	3064000	157.38	50	Completed
6	Loharaula	675875	3061250	135.40	44	Completed
7	Nandnagar	717625	3067000	164.14	29	Completed
8	Bharsarwa	712375	3055875	112.88	54	Completed
9	Dhamauliya	707625	3049750	105.07	55	Completed
10	Harnampur	707625	3043250	98.18	54	Completed
11	Karmahawa	717625	3046875	102.18	40	Completed
12	Auraiha	716500	3041250	96.53	34	Completed
13	Sultanpur	695250	3041875	96.07	62	Completed
14	Akbarpur	696500	3046750	98.68	50	Completed
15	Amuwa	697500	3058750	111.86	68	Completed
16	Mahuwa	696250	3054750	106.74	50	Completed
17	Babudihawa	689500	3054500	108.59	40	Completed
18	Motipur	678250	3049250	106.46	66	Completed
19	Jurpaniya	676250	3055000	117.32	48	Completed
20	Kushahawa	687500	3045875	99.30	56	Completed
21	Gorusinghe	701125	3061750	116.00	68	Completed
22	Bhitriya	689125	3062875	119.19	40	Completed
23	Dharampaniya	709375	3047125	102.42	66	Completed

Notes.

(1) X and Y coordinates are taken from the 1:500,000 map of Nepal, as a composite of LANDSAT imagery. On that map, the Universal Transverse Mercator grid overlay is based on the Everest Geodetic System. Latitude is measured and numbered northward and southward to the equator; and longitude is measured and renumbered every 6 degrees. For Nepal the 6 degree break in numbering occurs at approximately 84 degree East longitude. The coordinates were read with the help of project-supplied digitizer.

(2) Z is the absolute elevation of the well above the mean sea level. The elevation was supplied by SWISSAIR Photo+Surveys Ltd., under a subcontract. The land-surface surveying was completed in April 1989.

The deepest well is 68 m deep (STW-21, Gorusinghe), and the shallowest only 29 m (STW-7, Nandnagar). Both the shallowest and deepest wells were drilled by drilling rig, using the same rotary-with-mud drilling method. In the case of the well STW-7, it was reported that 45 bags of bentonite were absorbed at that depth and no further progress in drilling could be made due to very hard formation. The well log indicates drilling through boulders, which is an evidence of the coarse-grained Bhabar formation. The well Nandnagar is located near the foothills of Siwalik hills in the very northeastern corner of the district. This well was constructed with 6" dia. pipe, whereas the rest of the project wells were with 4" dia. pipe.

Most of the wells are poorly constructed. This mostly refers to the screen used (Japanese-manufactured wire-wrapped screen with 0.5 mm opening and an estimated open area of 11%), but also to the method of drilling with plenty of bentonite and improper and inefficient development. Both factors contributed to extremely poor yield of wells, which is absolutely in contradiction with the lithology encountered. For example, the well STW-9, Dhamauliya, penetrated about 16 m of gravel. One would expect transmissivity of about 500 m^2/day. Yet, the pumping test showed transmissivity of only 55 m^2/day with discharge of 5 l/sec. Similarly, the well STW-10, Harnampur, reported 11.5 meters of gravel. Yet, its pump-test discharge was only 2.5 l/sec, which resulted with the transmissivity value of only 60 m^2/day.

Out of 23 drilled wells, 22 wells were constructed by a drilling rig, and only one well was drilled by indigenous (manual) methods of drilling (depth - 39 m). This hole was abandoned due to pipe lowering problem. It may be too early to conclude on advantages and disadvantages of a particular method of shallow wells constructions in the Terai. Manually-drilled wells have a better control over lithology of penetrated strata; likewise, they are cleaner and pumping tests are more reliable because aquifers and well screens are less clogged than in bentonite-drilled wells. However, these advantages fade when the total depth of penetration is taken into account. In the Kapilvastu district the only manually-drilled well, STW-1 in Amuwa, was abandoned due to construction problems, although it penetrated 7 m of gravel and sand. The well was redrilled by a rig to the depth of 68 m, and successfully completed. Regrettably, due to misinterpretation of instructions, the well was screened from 61.0 to 66.5 m, eliminating thus the well from the "shallow well" category. Consequently, its transmissivity was low (25 m^2/day) in spite of 9 m of sand and gravel in the upper part of the well.

On the other hand, the well in Nandnagar, drilled by a rig, could not penetrate through boulders and other hard rocks. It is questionable whether a manually-drilled well would do any better, considering the locally available equipment.

As a conclusion of the drilling program in Kapilvastu district the following may be inferred. The drilling of shallow wells should be done with as little as possible bentonite mud. The screens should be best pre-packed with gravel, or alternatively the drilling diameter should be minimum 10 inches to accommodate 4 or 6-in casing and minimum 4-in gravel pack. In an exploration- drilling project as in this UN assistance project, the first saturated sand-and-gravel layer should be screened to offer the possibility of testing and monitoring the first directly recharged zone. In a water-supply and/or irrigation well, all permeable layers within the depth of drilling should be screened to produce as much water as available.

More attention should be given to well development. Screens with slot opening less than 1.0 mm should not be used. Better supervision of drilling and development activities is needed to produce better wells.

2.2. Testing Shallow Wells

The program specified the testing by pump of 33 shallow wells (20 newly drilled. and 13 to be selected from existing shallow wells). Out of this, only sixteen wells had been tested. It was reported that only three existing shallow wells were selected for pumping test, because other suitable-for-testing wells are concentrated in Chappargaon (northeastern part of Kapilvastu) and Chanauta (western part of the district) areas and the scattered ones are of less than 4 inches in diameter in which testing by centrifugal pump is not possible. For the location of all tested wells see Appendix 1 - the location map of all project wells and wells with pumping tests. In order to produce the transmissivity map of Kapilvastu, transmissivity values from five USAID shallow tubewells were also taken into consideration.

Out of 21 completed wells only 13 were pump tested. In some of the wells, the static water level at the drilling time was too deep to permit the testing with a centrifugal pump which normally has suction head limited to about 7 meters. For example, the wells Nandnagar (STW-7) and Kushahawa (STW-20) could not be tested immediately after the construction because the level was below 6 m from the land surface. But the same wells could have been tested in August when level rose to about 4 m from the ground level, see Appendices 10/1 and 10/3. Other wells Bharsarwa (STW-8), Auraiha (STW-12), Akbarpur (STW-14), Motipur (STW-18) and Dharampaniya (STW-23) were not tested in spite of their water levels always within 5 m from ground level.

All pumping test interpretations are appended to this report in the group of Appendices 5. The interpretation is based on the proprietary UN/DTCD computer program which includes a measure of appropriate formula fit (standard deviation).

In running pumping tests the following problems have been identified:

(a) Pumping equipment not adequate for all situations. The suction range of centrifugal pump limited to about 7 m below the pump discharge point restricts the possible dynamic depth of pumping. Pump discharge is fluctuating during the test.

(b) Pump discharge measuring instrumentation unreliable. When results by two methods of measurement are compared, the match is sometimes more than 20% off. 200-l barrel is probably better than "V"-notch weir. The best would have been a 3-in flowmeter with direct reading of the flowrate in liters per second.

(c) Measurements of water level during the pumping and/or recovery periods are sometimes questionable (late, improvised).

In most tested wells the duration of pumping was 100 minutes. In one project well Loharaula (STW-6) the time of testing was only 9 minutes for no obvious reason. The duration of testing in ADBN well at Bhalwar was 60 minutes. It has been noticed that the dynamic levels were stabilized within the pumping duration of 100 minutes, so the test duration of about one and half hour seems to be sufficient. What would have been very useful is to have had observation wells included in the testing program. For that reason the "project" wells should have been located nearby existing shallow drilled wells which could have been used as observation wells during the test.

2.3. Monitoring Water Levels

In Technical Report No. 2 three maps from Kapilvastu district were presented showing the maximum and minimum depths to water table in 1987 and the rise of water levels between the minimum and maximum of 1987. In May 1987, water levels were monitored in dug wells. The network of observation wells in May 1987 is shown in Appendix 2 (circles filled with a cross). Each newly drilled "project" well was included into the monitoring network. The idea was to gradually replace the original network of dug wells with newly drilled wells of which lithology is known, transmissivity eventually calculated and land surface elevation surveyed. This "new" monitoring network is also shown in Appendix 2. As of the month of May 1988, both networks are still under observations but, soon, only newly drilled wells shall remain under active monthly observations.

Depth to water levels is observed in bimonthly intervals from May 1987 to May 1988, then onwards it was changed to once-a-month. In the month of May 1988, the network included 26 dug wells and 6 project drilled wells, in June 1988 it contained 26 dug wells and 20 project drilled wells and from July onwards the network has been continuing with 26 dug wells and 21 project drilled wells. It is recommended that the observations continue with 21 existing "project" wells, plus selected four older STWs, to make the total network of 25 wells.

The evolution of water table in shallow aquifers of the Kapilvastu Terai is illustrated with several appendices in this report (Appendices 8: depths to water table in May 1989, June and October 1988, the rise of water table between June and October 1988, and the rise of water table between May and September 1987). In 1987, most of dug wells showed maximum and minimum depths to water table in the months of May and September, respectively, whereas in 1988 those are one month delayed. Individual hydrographs for some monitored wells (18 project drilled wells and 12 dug wells) are presented in Appendices 10 and 11.

3. SHALLOW AQUIFER LITHOLOGY AND AQUIFER PARAMETERS

3.1. Lithology

Project wells have penetrated through the upper 50 or so meters of an alluvial sequence, which is commonly known as the Terai Plain. The Plain is composed of interlocked alluvial deposits of the wider Ganges Plain and that of fans, channels, flood plains of numerous rivers flowing from the Siwalik Range and across the Terai Plain, as well as colluvial deposits at the foothills of the above range. The most prominent lithological-morphological unit is the Bhabar Zone.

The Bhabar Zone is a stretch of torrential deposits nearby Siwalik hills, being composed of outwash, boulders, cobbles, gravel and sand, and characterized by extremely poor sorting. Because it was formed as a result of river fan and colluvial deposition, the Bhabar Zone is not continuous. Between fans the Bhabar is often not present.

Very high permeabilities of the Bhabar sediments have been reported (50 to 200 meters per day) in other districts. Tillson in his 1985 report speculates about the area occupied by the Bhabar sediments in Kapilvastu district. His estimate is 200 km^2.

The bulk of the Terai sedimentary basin belongs to Holocene alluvium which includes present day alluvial deposits, channel sand-and-gravel deposits, outwash deposits. Due to their fluviatile origin and constant shifting of stream channels, these deposits are crossbedded, eroded, reworked, and redeposited.

The lithology of the shallow ground water system in Kapilvastu district is known from some 23 "project" wells and 32 USAID wells. Some of USAID wells were used to produce lithological cross sections presented in Appendices 4/2 through 4/6. GDC report (1987) indicated rather inferior lithology in Kapilvastu. "From a combination of USGS data, the interpretation of piezometry, and later Kapilvastu holes, it is fairly obvious that western Kapilvastu has no deep aquifer of any potential and that its shallow aquifer may also be marginal. In the eastern part of the district, which covers about 40% of the gross area, there is a block within which the shallow tube well development becomes properly viable and deep tube well development marginal or even acceptable in the northeastern subunit of the block. This is actually the area of extension of the Rupandehi deep aquifer." The current drilling program absolutely supports such comment.

There was no attempt to connect permeable layers in lithological cross sections. This is a "risky" undertaking in Quaternary deposits near to the foothills of sediment-supplying mountains and in an area cross-cut by many present rivers and buried channels. It is believed that the lithology of the upper 30 or so meters is rapidly changing over very small distances. Present-day and past-time rivers have been changing their streambeds; they have been either depositing or eroding sediments, leaving behind either coarse sediments or impermeable fine deposits.

Out of the total drilled metrage in 23 "project" wells of 1131 m, 362 m are sand and gravel deposits. This means that about 32% in an average shallow well is composed of sand and/or gravel. (An "average" well in this drilling program was 49 m deep, out of which 15.7 m were composed of permeable, and 33.3 m of impermeable deposits.) The percentage of permeable materials in Kapilvastu district (32%) is much less when compared to Nawalparasi (48%) or Sunsari (56%); it is also less than in Rautahat district (39%).

One of common earlier interpretations is that going from north to south the lithology of shallow aquifer becomes less favorable for ground water accumulation because grain size becomes finer. When lithological cross-sections are consulted (Appendices 4), that statement becomes less obvious.

The northern zone belongs to Bhabar formation, and streams cutting the Siwalik hills must have contributed permeable materials. The Bhabar formation normally contains the greatest proportion of coarse grained material but it is poorly sorted and generally overlain by silty and to some extent clayey deposits. Greater depths to water table, especially in pre-monsoon seasons, make the upper portion of the permeable sequence unsaturated, so that a portion of otherwise favorable lithology is of no use for accumulating and storing ground water. As will be clear from the text that follows, in spite of favourable lithology this northern part is less favourable zone for shallow ground water development.

The sudden changes of lithology are best illustrated with the zone at Gorusinghe village. Two wells are characteristic: STW-3 and STW-21. The distance between the wells is less than one kilometer. Yet, the well STW-3 has no permeable layer down to 40 m depth. The other well, STW-21, shows 15 m of gravel and sand within the same depth.

With the above comments in mind, and will all reservations with respect to quality and quantity of information, one may conclude that in Kapilvastu district in most places there is a chance of getting at least 5 to 7 meters of sand and/or gravel within a depth of 30 m from ground level and that a shallow well to supply drinking water to villages can be constructed without too much uncertainty. It is difficult to say whether large-capacity irrigation wells can be forecast with equal certainty without a more detailed exploration program.

The chances of finding excellent aquifers at shallow depths are tied to locating buried channels in which coarse sediments have been deposited.

3.2. Hydrogeological Parameters

Hydrogeological parameters of shallow aquifers were obtained from thirteen pumping tests run on "project" wells, three on existing ADBN wells and five USAID shallow wells. The wells used in this interpretation are shown in Appendix 6, which is the map of transmissivity. In the same time, this report contains a group of appendices (Appendix 5) with 16 pumping tests. Each test is interpreted in the same way, using a rather objective computer match between field data and theory. A comparison was made between the classical non-leaky theory of Theis and Jacob with the leaky-aquifer theory of Hantush. The result with lower standard deviation, or a better fit, was accepted. Except in one test,the classical Jacob interpretation produced quite a good fit. In one test, the better fit was obtained by Hantush Inflection Point Method.

The transmissivity of shallow aquifer is shown in Appendix 6 (the transmissivity map). The map is the creation of a computer contouring program, which interpolates and extrapolates random individual values. This inter-extrapolation process is based on only 21 values which is not sufficient to accurately describe the whole Terai part of the district. There are also some reservations as to the quality and accuracy of reported pumping tests, considering poor development, fluctuations in pumping rates, and inaccurate water level measurements. Likewise, since not all wells were drilled to the same or similar depth, the distribution of transmissivity cannot be taken as absolutely correct. The interpretation shall be attempted with information in hands.

There is a clear distinction between two patches in north-western and north-eastern parts and rest of the study area. Two wells in each patch have shown good transmissivities: Bijgauri (325 m^2/day) and Loharaula (473 m^2/day) in the north-western and Bhalwar (599 m^2/day) and Motipur (750 m^2/day) in the north- eastern part. Both areas belong to the Bhabar zone in which the lithology may be favourable but the depth to water table prohibitive. Except these two parts, the rest of the area is with much lower transmissivity.

Transmissivities, aquifer thicknesses, hydraulic conductivities and the lithology of project drilled and USAID wells are presented in the table on the next page.

It can be seen in the table that out of 18 wells, only in 6 wells the conductivity has matched with corresponding lithology. Hydraulic conductivities of less than 10 m/day are characteristic for fine-grained sand, while a coarse-grained sand with some proportion of gravel should have conductivities between 20 and 70 m/day. One can easily conclude that either the reported lithology is not correct or the well is not properly constructed and/or not developed in most of the cases.

The transmissivities are low in the southern part of the district, which may confirm the earlier statement that the lithology becomes less favourable from north to south. The lowest transmissivities are in the central part of the district (Babudihawa, 3 m^2/day from 5.5 m of gravel and sand). The wells located near the Nepal-India border (Shivnagar, Sultanpur, Harnampur) displayed also very low transmissivities, from 24 to 62 m^2/day.

TABLE 2

Well		Thickness (m)	Trans. (m2/day)	Conduct. (m/day)	Lithology
STW-4	Simarsat	5.0	25	5.0	S & G
STW-5	Bijgauri	10.0	325	32.5	S & G
STW-6	Loharaula	7.0	473	67.6	G
STW-9	Dhamauliya	16.0	54	3.4	G
STW-10	Harnampur	11.5	62	5.4	G
STW-11	Karmahawa	10.0	127	12.7	G
STW-13	Sultanpur	6.0	24	4.0	G
STW-15	Amuwa	7.5	26	3.5	S & G
STW-16	Mahuwa	5.5	33	6.0	S
STW-17	Babudihawa	5.5	3	0.5	G
STW-19	Jurpaniya	6.0	64	10.7	S & G
STW-21	Gorusinghe	18.0	99	5.5	S & G
STW-22	Bhitriya	11.0	49	4.5	S & G
USAID	Rehara	6.0	93	15.5	S & G
USAID	Motipur	10.0	750	75.0	G
USAID	Champapur	5.0	75	15.0	G
USAID	Dharamnagar	6.0	75	12.5	S & G
USAID	Shivnagar	5.0	162	32.4	G

Note: S = Sand, G = Gravel

4. FLUCTUATIONS OF SHALLOW WATER TABLE

4.1. Monitoring Network

Kapilvastu district is well covered with observation network. As shown in Appendix 2, in May 1987 when observations of shallow water table started (GDC) the network included 41 dug wells and continued only with 26 dug wells from July onwards. In May 1988 the network included 26 dug wells and 6 project drilled shallow tube wells. In June 1988, the network included 14 more project- drilled shallow wells. And from July 1988 onwards, observation is being done in 26 dug wells and 21 project drilled shallow wells. In fact, only project drilled shallow wells seem to be enough to represent the area under study, supported, for the time being, with some five or so older shallow tube wells.

4.2. Rainfall in Kapilvastu in 1987/88

To understand better the rise of shallow water levels from the driest month through the wettest month (either 1987 or 1988) one should look at rainfall in the June-September period. As shown in Figure 1,there are three rain gauging stations within the Terai portion of Kapilvastu district: Taulihawa in the east-central, Bhagwanpur in the north western and Patharkot in the north eastern parts.

The annual rainfall for the three stations is presented here below.

TABLE 3

	Rainfall in mm	
Stations	1987	1988
Taulihawa	1340	1489
Bhagwanpur	1507	1871
Patharkot	2261	2179
Average:	1703 mm	1845 mm

The comparison between average rainfall in 1987 and 1988 on monthly basis is shown in Figure 4. Average rainfall in 1988 was 142 mm higher than in 1987, but in both years the rainfall was less than long-term average which is about 1900 mm.

If only these three stations are considered in the two-year sequence, one may conclude that there is a trend of having more rain in north than in south, although the Patharkot raingauge, which is right at the Siwalik foothill, showed an opposite trend (82 mm less rain in 1988). In 1987, monsoon started in July and ended in October, whereas in 1988, it started in June and ended in September.

The monthly rainfall is plotted alongside water table fluctuations in Appendices 7 to indicate the relationship between the rainfall and water table rise and decline in the period from May 1987 through December 1988 for dug wells and from June 1988 through December 1988 for shallow tube wells. Although water level data are available through May 1989, the correlation with rainfall is possible only through December 1988, since rainfall data were not received beyond December 1988.

4.3. Shallow Ground Water System Hydrodynamics

Hydrodynamics of the shallow ground water system in Kapilvastu district in 1987 and 1988 is presented in Appendices 8/1 through 8/5; 9/1 through 9/3; 10/1 through 10/3; and 11/1 and 11/2. The group of Appendices 8 refers to the depth to water table in relative terms (pre-monsoon in 1989, pre- and post-monsoon in 1988, and rise of levels during this period in 1988 and 1987). Similar maps have been already presented in Technical Report No.2 for the year 1987.

APPENDICES

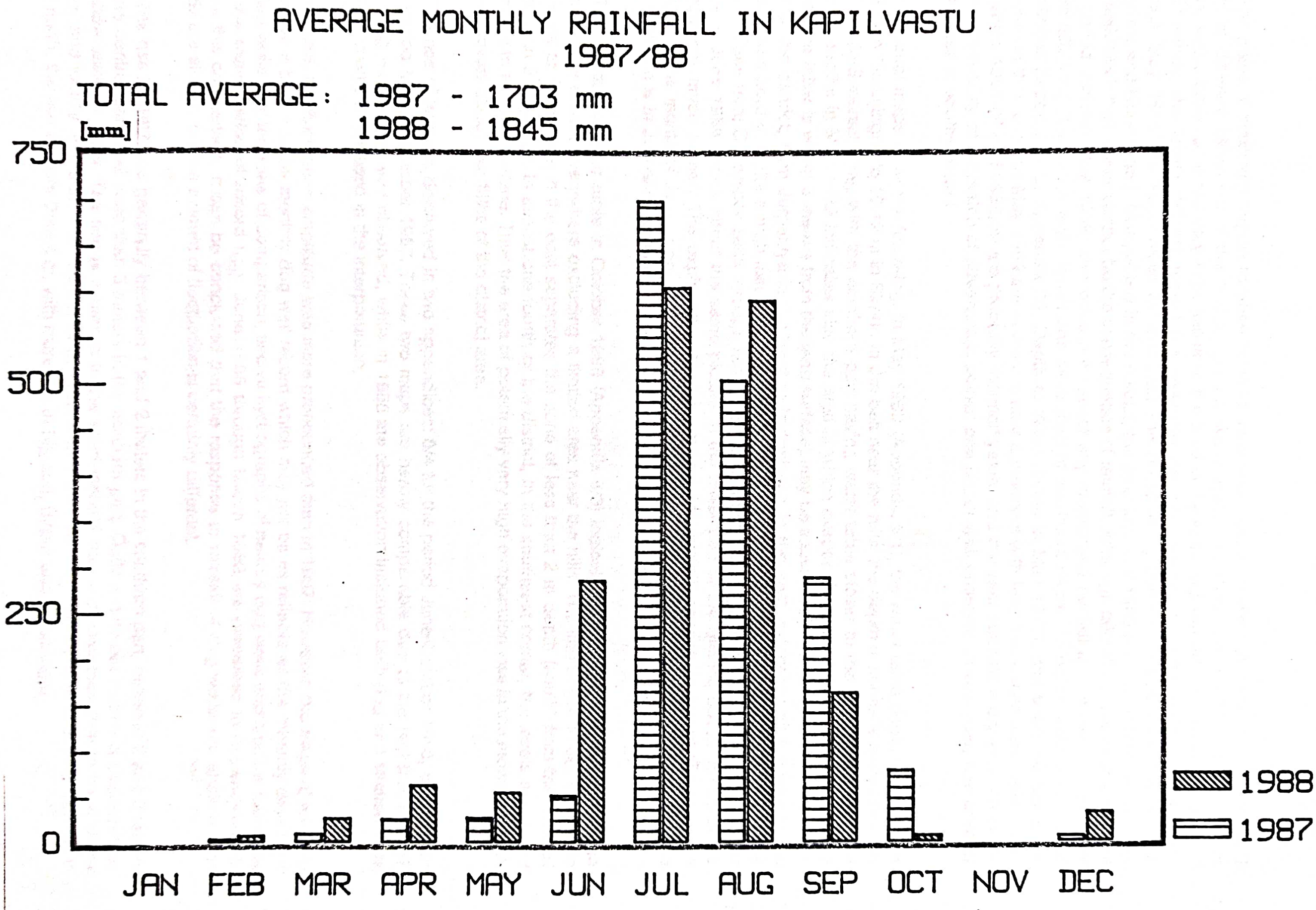

AVERAGE MONTHLY RAINFALL IN KAPILVASTU
1987/88
TOTAL AVERAGE: 1987 - 1703 mm
1988 - 1845 mm
[mm]
750
500
250
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1988
1987

FIGURE 4

The maps of maximum depths to water table in June 1988 and May 1989 (Appendices 8/2 and 8/1) point at different behaviour of the shallow ground water system in 1989 compared to 1988. In some wells, water table remained very high (close to the land surface) throughout the dry period of 1989. In other words, the levels did not repeat the seasonal decline normally experienced from November through May. (See also Appendices 7/1 and 7/2.) This is especially true for wells near the hills (Birpur, Simarsat and Nandnagar). Everywhere in the district, the May levels of 1989 are higher than June levels of 1988. Such high levels cannot be the consequence of rainfall. Although rainfall data are not known for the period January-May 1989, one does not expect any meaningful rainfall in that period that might eventually keep the levels high. When one more map of maximum depths to water table is consulted (Technical Report NO. 2, Appendix 33, Depth to Water Table in May 1977), one easily comes to the conclusion that levels in May 1989 are in much closer agreement with May 1989, than June 1988. Thus the years 1986/87 and 1988/89 are probably "normal" years, and the year 1987/88 a dry year. (There is also a possibility of mismatch of observation points: one Birpur well observed in one year, and another Birpur well in another year.)

Individual maps show the following. In May 1989 (Appendix 8/1), the water table depth ranged from 0.12 m in Gorusinghe to 10.12 m in Birpur. In the belt near the hills, the depth is normally more than 5 m (Loharaula-Simarsat line), with the southern part having water table closer to the ground surface. The map of depths in May 1989 indicates also the area in which evaporation loss directly from water table (when the latter is within 3 meters from the land surface) may be substantial. This is the area in the lower part of the district, from Jurpaniya in the west to karmahawa in the east, extending all the way to the Nepal-India border. Quite a high loss may be near Gorusinghe in which the water table is almost at the land surface from December 1988 through May 1989 (see Appendix 10/3). The map of depths to water table in June 1988 shows about the same picture in the lower part of the district, but in the north the depths are much higher. The explanation for this, except for rainfall, cannot be found. To be more intriguing, the month of June is not even the month of minimum water levels everywhere. In some wells the minimum is in July and October.

The depths to water table in October 1988 (Appendix 8/3) indicate that levels are very close to the land surface almost everywhere excluding a limited area near the hills. The line of wells from Bijgauri in the west to Bharsarwa in the east separates the zone of less than 2 m depth (south) from the zone of more than 2 m (north). In almost one fourth of the district, in the southeast corner, the levels are closer than 1 m to the land surface. Thus the area of potentially very high evaporation loss in the months of high levels covers about four fifths of the district area.

The rise of levels is displayed in two appendices: 8/4 for the period June-October 1988, and 8/4 for the period May-September 1987. These two maps are hardly comparable due to the fact that in 1987 only dug wells have been observed, while in 1988 the observation included both dug and shallow tube wells with only STWs used in the interpretation.

In 1988, the fluctuation amplitude was more pronounced than in 1987. However, the maps of levels in 1987 were based on bi- monthly dug well record which may not be as reliable as the monthly data from drilled wells. For the sake of comparison, twelve hydrographs of nearby dug wells and shallow tubewells for the same period of record from June 1988 through March 1989 are presented in Appendices 12. From this comparison, it can be concluded that the response to rainfall of dug wells and shallow tube wells are similar, but the amount of fluctuation is certainly different.

The rise in 1987 was generally between 1 and 2 meters in the southern part, between 2 and 3 meters in the central part, and more than 3 meters in the northern part. Quite a different picture is displayed by shallow wells in 1988. The rise is minimum in the south-central part with less than 2 m in most of the area, and locally less than 1 m. This area compares well with the dug well behaviour a year before. In the north, the rise is more than 4 m, with extremes in Bijgauri, Birpur and Nandnagar.

The rise of levels generally starts in the month of June as a direct response to June rainfall. The near-maximum water levels were established in the months of September/October 1988 and the decline started in October. Correlating the hydrographs with rainfall, it may be concluded that the high September/October levels are the response to rainfall of 1487 mm in the months of June, July and August. Soils were already wet because of about 300 mm of rain in June. Nearly equal distribution of rainfall in July and August helped to keep the water table high till October in spite of only 164 mm of rainfall in September.

Hydrographs of project drilled wells indicate in most cases the maximum depth to water table in 1989 less than that in 1988. The hydrographs of some 12 dug wells (more or less being representative for the whole area) are presented in group of appendices 11. It is indicative in most of them that maximum depth to water table in 1988 is higher than in 1987 or 1989. In other words, in the two-year sequence but with three dry seasons the absolute minimum of levels is in June-July 1988. Dug wells from central-north to central-south parts have minimum depth to water table higher in 1987 compared to 1988 which is different than in the rest of the study area. This could be due to distribution of rainfall in Kapilvastu. Rainfall recorded at Patharkot which is in the north of this area was 82 mm more than in 1988.

Another noticeable thing is that most of dug wells have shown maximum depth to water table in the month of June in 1988 whereas in 1987 it was in May. The explanation for this is the following: 1987 observations were based on bi-monthly intervals, so the actual month for maximum depth to water table is not known, but in the case of 1988 the data were from monthly intervals.

Appendices 9/1, 9/2, and 9/3, present water level contour maps in June and October 1988, and May 1989, respectively. As expected the general direction of ground water flow is from north to south. There is not so much difference in gradients of ground water flow in either of these three maps. The gradient of flow in the northern part is mostly about 0.003 or 3 meters per one kilometer. There is a change of gradient from contour line 110 (Bharsarwa). The gradient becomes gradually more gentle, first about 0.0015, and finally 0.0005 near the Nepal-India border in the southern corner. The change of gradient may be an indication of the change of transmissivity, which is should then be higher in southern compared to northern part. Yet, in the case of Kapilvastu district, the change of gradient is an indication of less water flowing through cross-section in the southern part. As mentioned earlier, the southern part is an area of very high evapotranspiration potential. Plenty of water coming from the north is released through evaporation process, so that less water flows through about the same transmissivity.

The map of contours in October 1988 is similar to the map in June, which means that the flow pattern is the same. In the northern-most part the difference in contours is more than 7 m whereas in the south it is less than 2 m.

The contour map of water levels in May 1989 is the newest status of levels and such it will be discussed in more details. Clearly the slope in the northern part, above the contour line 120, is steeper than in the southern part. The gradient between Bijgauri and Loharaula is 0.0033, between Birpur and Gorusinghe 0.0043, between Nandnagar and Bharsarwa 0.0037. The gradient is still steep between Loharaula and Jurpania, 0.0033. In the lower half, the gradient changes two or threefold. Between Bharsarwa and Harnampur the gradient is 0.0011; between Amuwa and Sultanpur it is 0.001; between Babudihawa and Kushahawa it is also 0.0011. The scale in which contour line maps are presented, and the fact that land-surface elevation at drilling sites had not been levelled but taken from topographic maps, precludes any better interpretation. It is difficult to conclude, e.g., on the relationship between the Banganga River and shallow ground water, although it is expected that ground water may be contributing to the river base flow if any. There may be some inflow across the western district border (India-Nepal), according to the curvature of contour lines. The ground water flow from the northwest (Bijgauri) is generally toward southeast, in direction of Motipur and Kushahawa. The water from Nandnagar flows mostly to south and southwest towards Karmahawa and Harnampur. The flow from Birpur is first toward Simarsat in southwest direction, then to Gorusinghe directly to the south.

The volume of shallow ground water flowing through any segment of the district can be calculated from the contour level maps and transmissivity maps. Yet, this will be deferred to the next chapter in which an attempt shall be made to assess the water balance.

5. ASSESSMENT OF WATER RECHARGE AND DISCHARGE

5.1. Preliminary Assessment from Basic Documentation

The following conclusions are drawn about the recharge and discharge of the ground water system in the reported area.

(1) The recharge comes from local infiltration of rainfall everywhere where more or less permeable surface permits. The percentage of infiltration may be high, but there may be plenty of rejected recharge in monsoon season because of oversaturation of the soil immediately underlying the land surface. This may be true in the lower part where water table in the monsoon season comes very close to the ground surface.

(2) In the Bhabar zone of Kapilvastu district, the water table is deeper compared to the southern parts. In addition to this, the fluctuation is also greater. However, due to coarser sediments, and presence of fan deposits, the percentage of recharge may be quite high. The percentage of direct rainfall recharge in Bhabar zone, according to Duba's (1982) calculations, appear to be very high in Lumbini zone. His estimate for all three districts within the zone is 43.7%. However, he overestimated rainfall (2490 mm). With rainfall about 1900 mm/year, and almost 200 km2 of Bhabar in the district, the input into the Bhabar sediments could be very high, 166 MCM (million cubic meters).

(3) The outflow of shallow ground water is mostly across the border into neighboring India. The outflow into India across the border is calculated approximately with gradients from Appendices 9/2 and 9/3, and transmissivities from Appendix 6. The length of outflow section is 50 km. The transmissivity is decreasing from 150 m^2/day near Shivnagar to 30 m^2/day in the middle of the section. The gradient is more or less similar (about 0.0008) in the outflow section. The volume of water that may be outflowing is about 3,600 m^3/day or 1.3 MCM/year (million cubic meters in one year): This is a small fraction of potential annual recharge from infiltrated rainfall. If, conservatively, only 10% of annual rainfall of 1900 mm infiltrate and recharge the shallow aquifer, the volume of recharge over an area of about 1500 km^2 could be about 285 MCM/year. The difference between this hypothetic recharge of 285 MCM and outflow into India of about 1.3 MCM is discharged through evaporation process (dominantly), into the Banganga and other rivers and withdrawals from dug and drilled wells (minor component at present).

(4) A rough estimate of the possibility of recharge is made by assuming the effective porosity of sand and gravel aquifers as 15% and considering that the average rise of water table during monsoon period is 3 m over an area of 1500 km^2. If one third of these 3 meters is composed of permeable deposits (the average percentage of permeable formation from total shallow depth was about 32, see Section 3.1) and reducing the rainfall to only the monsoon rainfall, say 1700 mm, the net result is about 225 MCM.

(5) It may be also considered that land surface is not permeable in the whole area. When thick clay deposits underlie the surface, there is no direct recharge by infiltrated rainfall.

Conservatively one may assume that the total recharge to shallow aquifer in Kapilvastu is about 200 MCM. The outflow into India is a very small fraction of that volume, so that most of ground water must be lost through evaporation process. This is the water that can be salvaged by carefully planned exploitation, provided that the lithology of shallow aquifer (that is its thickness and transmissivity) permit the ground water development by pumping.

5.2. Assessment of Water Balance by Mathematical Modelling

The volume of data appears to be sufficient to construct a preliminary model of Kapilvastu district. However, the quality of data is questionable, especially pumping test results and some water level monitoring data. The model, of a preliminary nature, can still be constructed provided some improvements are made in the data base in the period between June and October 1989. If and when this is accomplished the model can be prepared in one-month time (target: November 1989). To make the model as reliable as possible under the present situation, one needs to do the following:

(a) To run more pumping tests with correctly interpreted transmissivity values in existing ADBN or GWRDB shallow tube wells.

(b) To redevelop some of dubious wells, and to repeat the testing.

(c) To make an inventory of currently used shallow tube and dug wells with some control over withdrawals.

(d) To monitor water levels in the coming monsoon season, on a monthly or even bi-weekly basis, until October 1989,

The model may provide quantitative answers to the following:

(a) Recharge from rainfall in the Bhabar Zone and elsewhere.

(b) The importance and magnitude of the evapotranspiration process.

(c) The correct order of magnitude of hydrogeological parameters (permeability and transmissivity).

(d) The volume of outflow across the district boundary into India.

The aquifer system to be modelled (Appendix 13) has only one natural and three artificial boundaries. The natural boundary is the impermeable boundary in the north, being the physical termination of the shallow (and deep) ground water system of the Terai. The artificial boundaries of the district in the sense of the regional ground water system are the boundaries to the south and west (Nepal-India border) and east (district boundary with Rupandehi district).

The final outcome of the model could be the amount that can be annually developed by shallow wells considering the recharge, and the salvaged water on account of ground water evaporation.

The basis for the model calibration, i.e. for the verification of all system parameters, should be the rise of water levels from May through September 1988, correlated with rainfall, decline of water levels from September 1988 through May 1989, and again the rise of levels from May through October 1989. All four maps of water flow, i.e. in May 1988, October 1988, May 1989, October 1989, should be matched by the model.

Only at the end of the modelling study the water balance of the shallow ground water system and its development potential can be formulated. Without a comprehensive evaluation of the whole system, including all its components (recharge-flow-discharge), any quantification of the shallow ground water system behavior and development potential is only a speculation.

The main components of the model shall be the following:

(a) **Size.** Almost the whole Terai portion of the Kapilvastu district shall be modelled, with the India-Nepal state border as the south and west boundary, the contour line 150 m on its north, and the district boundary with Rupandehi on its east. The area involved in the model shall be about 35 km (north-south) by 51 km (west-east) (Appendix 13). The model corners shall have coordinates in X direction from 669000 to 720000, and in Y direction from 3038000 to 3073000. The discretization shall be 1000 m in each direction, creating a uniform mesh network of 1 km^2 each cell. Thus the model shall have 1785 cells.

(b) The model shall be two-dimensional. The geometry of the shallow ground water system shall demand the following data input for each cell: (i) land surface elevation, (ii) top of aquifer elevation, (iii) bottom of aquifer elevation, (iv) initial water level elevation. Other input matrices (one value for each cell) shall be the following: hydraulic conductivity of the shallow aquifer, storage coefficient of the shallow aquifer, recharge from rainfall infiltration, discharge through evapotranspiration process.

(c) Model calibration process shall have four stages: (i) steady-state calibration of modelled output in the month of May 1988 (minimum water levels), (ii) unsteady-state calibration of the period May 1988 - September 1988 (the rise of water levels as a consequence of monsoon rains and increased recharge), (iii) unsteady-state calibration of the period September 1988 through May 1989 (the decline of water levels after the end of monsoon), (iv) model verification in the monsoon season from May through October 1989.

(d) The model output shall be the following: (i) improved distribution of aquifer parameters (hydraulic conductivity, storage coefficient), (ii) sums of recharge from rainfall and the river, as well as of discharge through evaporation, and outflow across the southern and western border into India, (iii) assessment of available shallow water for increased development on account of avoiding evapotranspiration losses and eliminating the outflow into India.

6. CONCLUSIONS AND RECOMMENDATIONS

The objective of this report is to present technical information on the occurrence of shallow ground water in Kapilvastu district. It is presented in a form of a basic documentation with some preliminary interpretation.

The drilling program which was formulated about a year ago, was completed according to the expectations. Twenty three holes were drilled with the total drilling metrage of 1131 m. The average depth of newly completed wells is 50 m. Considering the lithology of shallow ground water system, this depth is probably adequate for the project purpose. Most of wells were not absolutely efficiently developed. It seems that too much bentonite was used, and the screen of only 0.5 mm openings and about 11% open area was found to be inadequate. As a consequence, pumping tests failed in such wells. Out of 23 drilled wells, 22 wells were constructed by a drilling rig, and only one well by indigenous (manual) methods of drilling. It may be too early to conclude on advantages and disadvantages of a particular method of shallow wells constructions in the Terai. Manually-drilled wells have a better control over lithology of penetrated strata; likewise, they are cleaner and pumping tests are more reliable because aquifers and well screens are less clogged than in bentonite- drilled wells. However, these advantages fade when the total depth of penetration is taken into account.

As a conclusion of the drilling program in Kapilvastu district the following may be inferred. The drilling of shallow wells should be done with as little as possible bentonite mud. The screens should be best pre-packed with gravel, or alternatively the drilling diameter should be minimum 10 inches to accommodate 4 or 6-in casing and minimum 4-in gravel pack. In an exploration- drilling project as in this UN assistance project, the first saturated sand-and-gravel layer should be screened to offer the possibility of testing and monitoring the first directly recharged zone. In a water-supply and/or irrigation well, all permeable layers within the depth of drilling should be screened to produce as much water as available.

More attention should be given to well development. Screens with slot opening less than 1.0 mm should not be used. Better supervision of drilling and development activities is needed to produce better wells.

In addition to lithology of shallow aquifers, which becomes known from the drilling operation, pumping tests provide most of knowledge on aquifer parameters. In the case of Kapilvastu, no one can be satisfied with the results of pumping tests. It is believed that least attention was given to the well development part. The quality of testing must be improved, as well as the accuracy of equipment used.

Moreover, the fact is that in seven project drilled wells pumping test have not been attempted. The explanation appended to field drilling report that depth of water level was unacceptable for centrifugal pumps does not stand since in five wells the depth to water table was at the time of drilling less than 5 m and in two wells the levels rose to within 4 m from the land surface in August 1988. In running pumping tests the following problems have been identified:

(a) Pumping equipment not adequate for all situations. The suction range of centrifugal pump limited to about 7 m below the pump discharge point restricts the possible dynamic depth of pumping. Pump discharge is fluctuating during the test.

(b) Pump discharge measuring instrumentation unreliable. When the results by two methods of measurement are compared, the match is sometimes more than 20%. 200-l barrel is probably better than "V"-notch weir. The best would have been a 3-in flowmeter with direct reading of the flowrate in liters per second.

(c) Measurements of water level during the pumping and/or recovery periods are sometimes questionable (late, improvised).

The interpretation of lithology on the basis of driller's log is sometimes difficult. The terminology such as "gravel and siltstone" has no sense in hydrogeology. Few percents of silty components in otherwise coarse-grained material may make the formation completely impermeable. Thus a large component of gravel has to be proved by pumping tests and matched with transmissivity values.

If pumping test results can be trusted, then the distribution of transmissivity can be interpreted in the following way. First, the lithology and permeability of shallow ground water system of Kapilvastu district is not as favourable as in other districts of Terai. There is a dominance of clay and silt sediments over permeable ones, at a ratio of 2 to 1. Except the north eastern and north western parts, in which the transmissivity is relatively acceptable (over 300 m^2/day), the rest of the area in Kapilvastu Terai is not at all suitable for intensive ground water development. Even individual wells for local water supply of a village demand a minimum transmissivity of at least 300 m^2/day. Except in the north-west around Bijgauri and Loharaula, and in the north-east near to Bhalwar and Motipur, nowhere else the transmissivity comes close to that minimum. Again, one must be cautious not to jump to conclusions since pumping test results are not always reliable.

It is clear that hydraulic conductivity values do not match with the corresponding lithology, which is the consequence of poor well construction (too much drilling mud, unsatisfactory well screens), and poor well development (late development with low- capacity pump, short duration of development, etc.). One of disadvantages of the drilling program is less-than-useful location of drilling sites for present purpose. This is to say that wells should have been located nearby an existing ADBN well which would have permitted the second well to act as observation well during pumping tests. Unfortunately, not in one single case this was possible and not one single value of storage coefficient had been produced.

The pump testing program in Kapilvastu district should be continued. There are many wells which lend themselves to testing. If remaining wells are tested after proper development, the wealth of information and knowledge about the district would be enormously improved. Likewise, the project wells which were poorly developed could be redeveloped properly and retested. Otherwise, there is always a possibility to be mislead when attempting to make assessment of ground water system balance, whether analytically or by means of mathematical models.

Kapilvastu district is well covered with water-level monitoring network. In the month of May 1989, the network includes 26 dug wells and 21 project drilled wells. Tentatively the proposed network for future monitoring shall include only 21 "project" drilled shallow wells. The continuing observation in some other wells will be helpful for comparison, but the number of such wells should be reduced to a maximum of five.

In most of the area the levels in June 1988 are within 6.0 m below the land surface. Only in the northern part it varies from 7 to 16 m. Between June and October 1988 the levels rose in central and southern areas by 1 to 3 m, whereas in the northern part the rise in levels vary from 4 to 7 m. The water levels started rising in the month of June as a direct response to June rainfall. The near maximum water levels were established in the months of September/October. The high September and October levels are the response to rainfall of 1200 mm in July and August.

The depths to water table in October 1988 indicate that levels are very close to the land surface almost everywhere excluding a limited area near the hills. The line of wells from Bijgauri in the west to Bharsarwa in the east separates the zone of less than 2 m depth (south) from the zone of more than 2 m (north). In almost one fourth of the district, in the southeast corner, the levels are closer than 1 m to the land surface. Thus the area of potentially very high evaporation loss in the months of high levels covers about four fifths of the district area.

There is not so much difference in gradients of ground water flow in either of contour maps of water levels produced in this report. The direction of shallow ground water flow is from north to south. The gradient of flow in the northern part is mostly about 0.003 or 3 meters per one kilometer. There is a change of gradient from contour line 110 (Bharsarwa). The gradient becomes gradually more gentle, first about 0.0015, and finally 0.0005 near the Nepal-India border in the southern corner. The change of gradient may be an indication of the change of transmissivity, which, then, should be higher in southern compared to northern part. Yet, in the case of Kapilvastu district, the change of gradient is an indication of less water flowing through cross- section in the southern part. As mentioned earlier, the southern part is an area of very high evapotranspiration potential. Plenty of water coming from the north is released through evaporation process, so that less water flows through about the same transmissivity.

Some preliminary evaluation on an assessment of shallow ground water is presented as follows:

(1) The recharge comes from local infiltration of rainfall everywhere where more or less permeable surface permits. The percentage of infiltration may be high, but there may be plenty of rejected recharge in monsoon season because of oversaturation of the soil immediately underlying the land surface.

(2) The Bhabar zone may be an important contributor to recharge of shallow aquifer. With rainfall about 1900 mm/year, and almost 200 km^2 of Bhabar in the district, the input into the Bhabar sediments could be very high, 166 MCM (million cubic meters), if Duba's estimate of Bhabar recharge is accepted. Yet, due to drilling problems encountered with coarse and hard materials and excessive depth of water, the Bhabar zone appears to be of marginal value for water development in spite of relatively acceptable transmissivity.

(3) The outflow of shallow ground water is mostly across the border into neighboring India. The outflow into India across the border is calculated approximately with gradients from contour maps produced in this report, and with transmissivities from pumping tests. With the length of outflow section is 50 km and average transmissivity of about 90 m^2/day (from 150 m^2/day near Shivnagar to 30 m^2/day in the middle of the section), and gradient of flow of about 0.0008, the volume of water that may be outflowing is about 3,600 m^3/day or 1.3 MCM/year (million cubic meters in one year). This is a small fraction of potential annual recharge from infiltrated rainfall. If, conservatively, only 10% of annual rainfall of 1900 mm infiltrate and recharge the shallow aquifer, the volume of recharge over an area of about 1500 km^2 could be about 285 MCM/year. The difference between this hypothetic recharge of 285 MCM and outflow into India of about 1.3 MCM is discharged through evaporation process (dominantly), into the Banganga and other rivers and withdrawals from dug and drilled wells (minor component at present).

(4) It may be also considered that land surface is not permeable in the whole area. When thick clay deposits underlie the surface, there is no direct recharge by infiltrated rainfall.

Conservatively one may assume that the total recharge to shallow aquifer in Kapilvastu is about 200 MCM. The outflow into India is a very small fraction of that volume, so that most of ground water must be lost through evaporation process. This is the water that can be salvaged by carefully planned exploitation, provided that the lithology of shallow aquifer (that is its thickness and transmissivity) permit the ground water development by pumping.

On the basis of the presented information, the feasibility of shallow ground water development in the reported area is as shown in Figure 5. It is difficult to interpret the area in terms of suitability for large-scale development. Nowhere in the district one can suggest even a limited zone that may be suitable for irrigation of a considerable area. The only way to describe the suitability for development is in relative terms. Of course, this interpretation does not go beyond the penetrated depth of, on average, 49 m.

The area in the north, the Bhabar zone, may be locally suitable for individual wells in places where water level is closer to the land surface. The land depressions should be the points of interest. The south-east and south-central parts are relatively more suitable for development, but on limited scale, in places where lithology is more favourable. This may be an area near the Banganga River or its local tributaries. The area in the west and central part may be good for individual wells only, for water supply of villages but not for irrigation.

Considering the water balance, the best development procedure would be to develop shallow ground water from the central area near Gorusinghe down to the India-Nepal state border (Sultanpur-Harnampur-Karmahawa). The development in that area would tend to lower the regional water table and salvage the water from being lost through evaporation. Yet, it is questionable how many wells one needs to drill in a zone of very low transmissivity to accomplish any substantial abstraction.

The number of shallow tube wells to develop available water cannot be assessed with the information available. Although more than 200 MCM annually recharge the shallow aquifer, an individual well can hardly pump more than 3-4 l/sec from very low transmissivity. If each well is pumped 120 days in dry season on a 12-hr per day basis, one well can hardly abstract more than about 18,000 m^3. Thus the number of wells should be as high as 11,000, which is certainly an extremely high number. In the case of Kapilvastu district this is not the question of availability of water, and the forecast of maximum permissible number of wells, but the question how many wells are required to abstract the water that may be available.

To bring more certainty into the process of planning the shallow ground water development in Kapilvastu district, it is recommended that additional exploration wells are drilled in the central and south-eastern corner, where water levels are close to the land surface. It goes without saying that careful attention should be given to their development and testing, much more than in the present project work.

FEASIBILITY FOR SHALLOW GROUNDWATER DEVELOPMENT

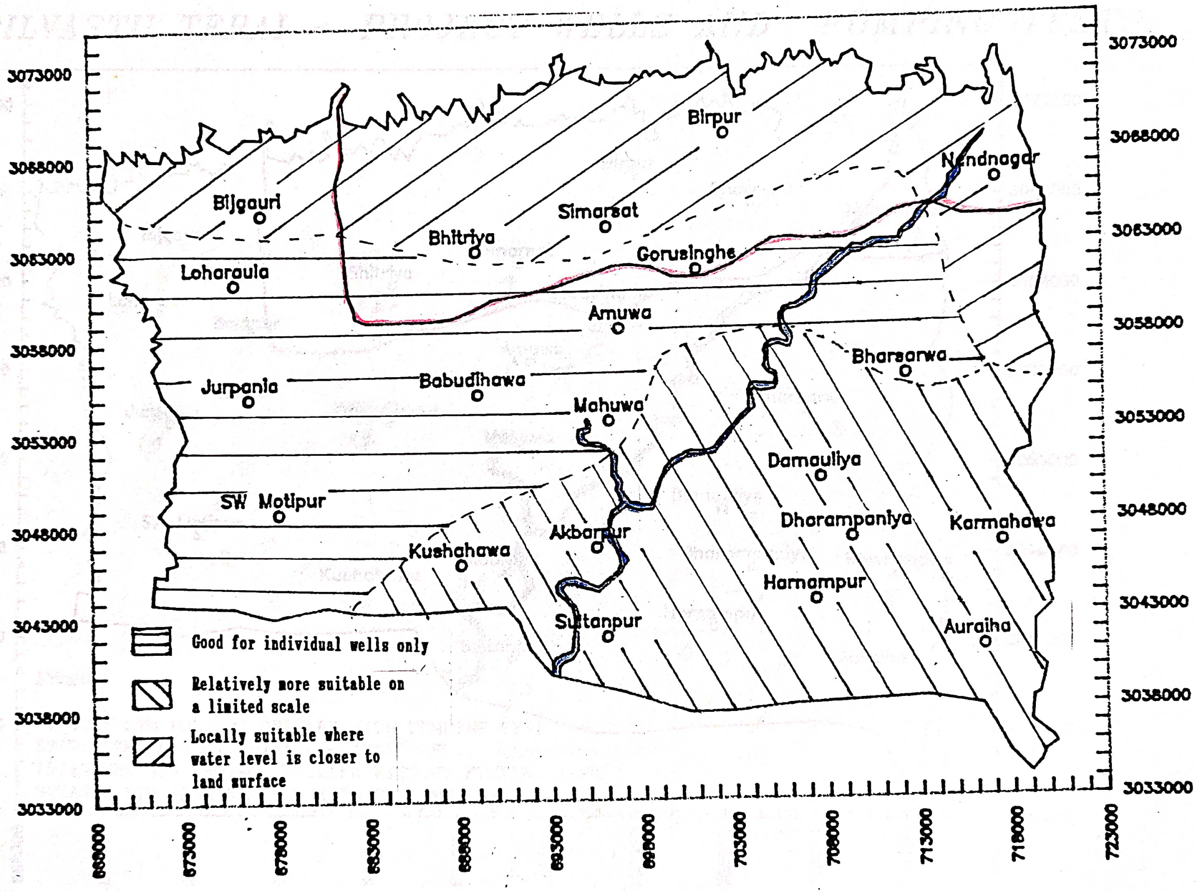
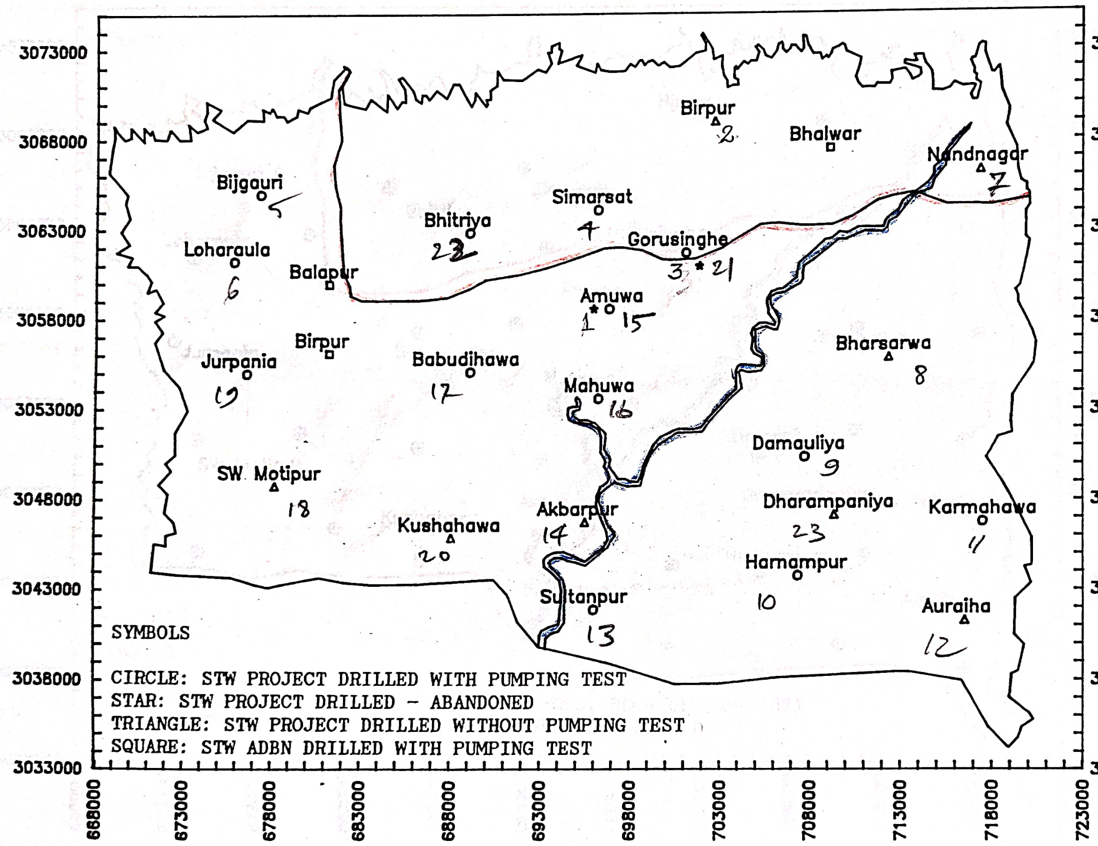


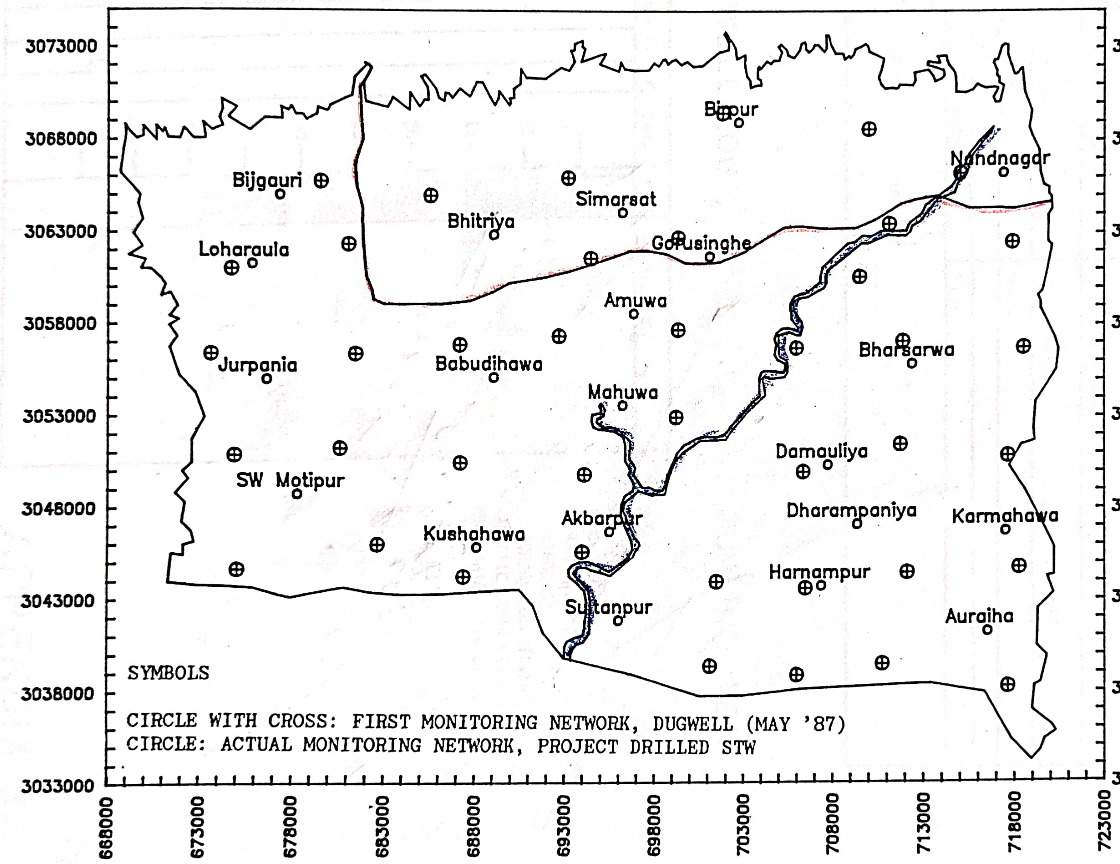
FIGURE 5

KAPILVASTU TERAI - PROJECT WELLS AND PUMPING TESTS



APPENDIX 1

KAPILVASTU TERAI – LOCATION MAP FOR MONITORING NETWORK



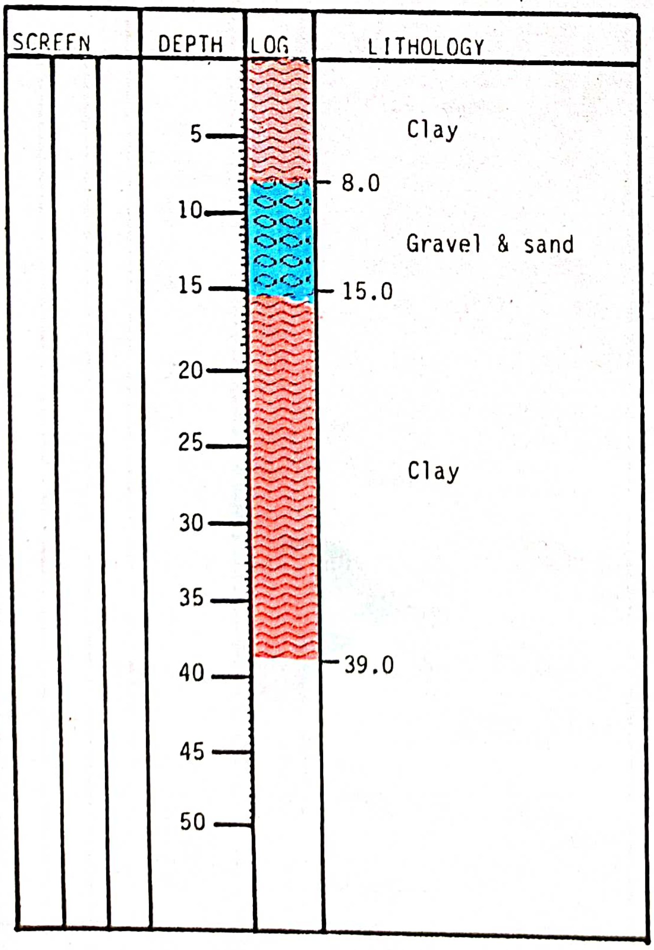
APPENDIX 2

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 1	LOCATION AMUWA
ELEVATION m	X = 696000 Y = 3058625
METHOD OF DRILLING	Manual
DRILLING DATES	
TOTAL DEPTH	39.0 m.
COMMENTS Abandoned	

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL:
DYNAMIC WATER LEVEL:

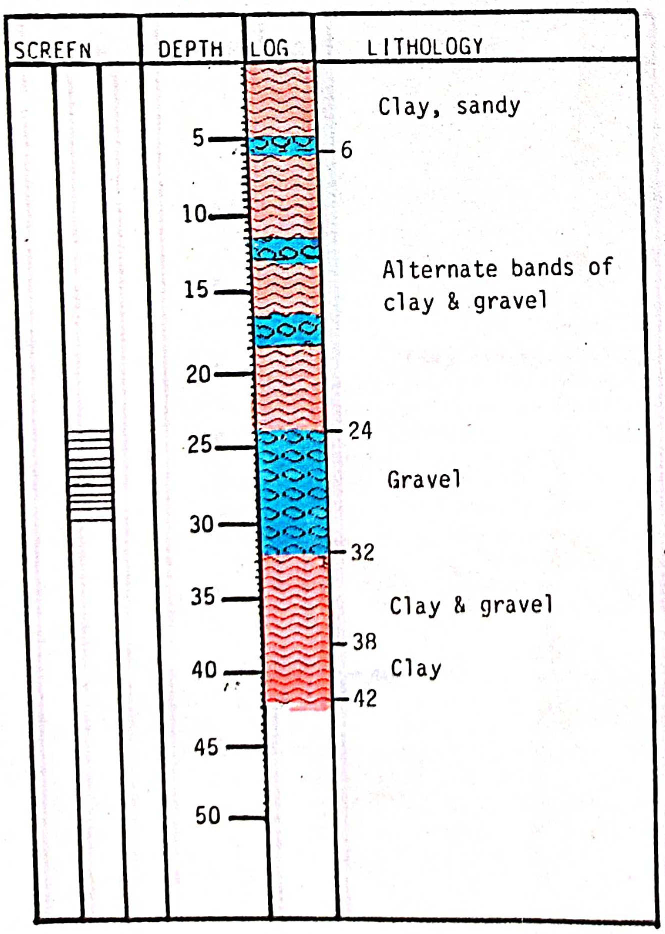
COMMENTS:

APPENDIX 3/1

KAPILVASTU

WELL NO. STW 2	LOCATION BIRPUR
ELEVATION 159.31 m	X = 702750 Y = 3069750
METHOD OF DRILLING	Rig
DRILLING DATES	28/01/88 - 31/01/88
TOTAL DEPTH	42 m.
COMMENTS	Screen position - 24.0 - 29.5 m. Screen type - Wire Wrapped M.P: 0.41 m.

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 13.36 m
DYNAMIC WATER LEVEL:

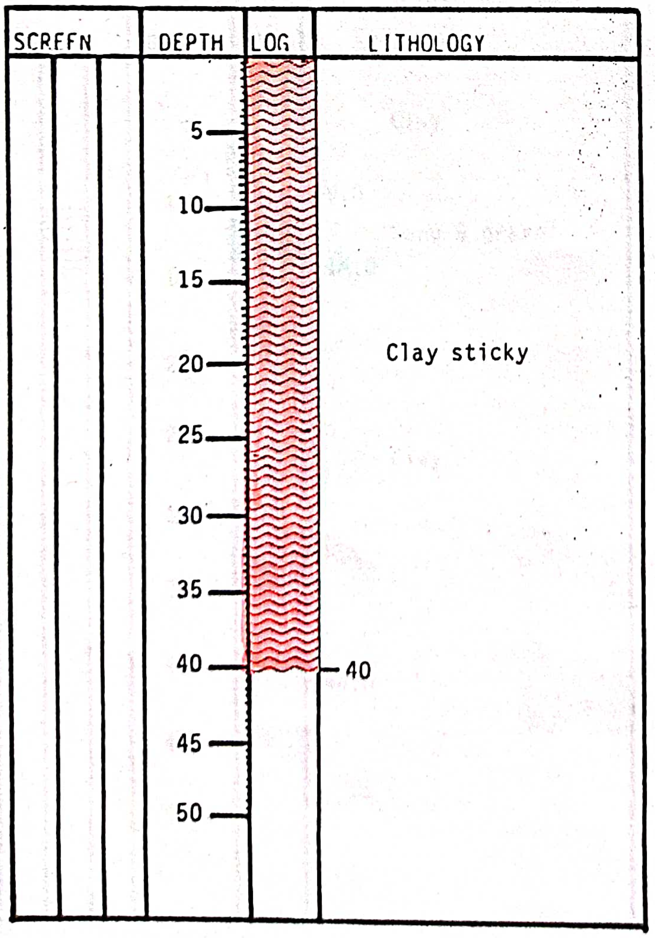
COMMENTS:

APPENDIX 3/2

KAPILVASTU

WELL NO. STW 3	LOCATION GORUSINGHE
ELEVATION m	X = 701875 Y = 3061000
METHOD OF DRILLING	Rig
DRILLING DATES	02/02/88 - 03/02/88
TOTAL DEPTH	40 m.
COMMENTS	Abandoned

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL:
DYNAMIC WATER LEVEL:

COMMENTS:

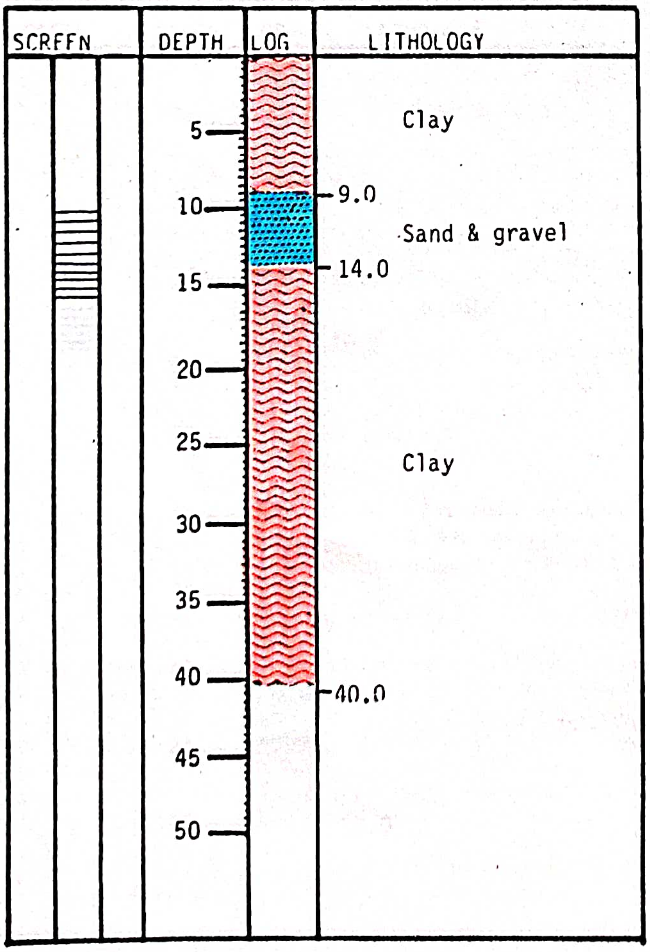
APPENDIX 3/3

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 4	LOCATION SIMARSAT	
ELEVATION 121.90 m	X = 695750	Y = 3064125
METHOD OF DRILLING	Rig	
DRILLING DATES	05/02/88 - 06/02/88	
TOTAL DEPTH	40 m.	
COMMENTS	Screen position - 10 - 15.5 m. Screen type - Wire Wrapped M.P: 0.46 m.	

WELL LOG



PUMPING TEST

DATE: 27/10/88
Q(l/s): 3.0
DURATION: 1 hr.50 min.
TRANSMISSIVITY: 25 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.24 m.
DYNAMIC WATER LEVEL: 5.93 m. (B.G.L)

COMMENTS:

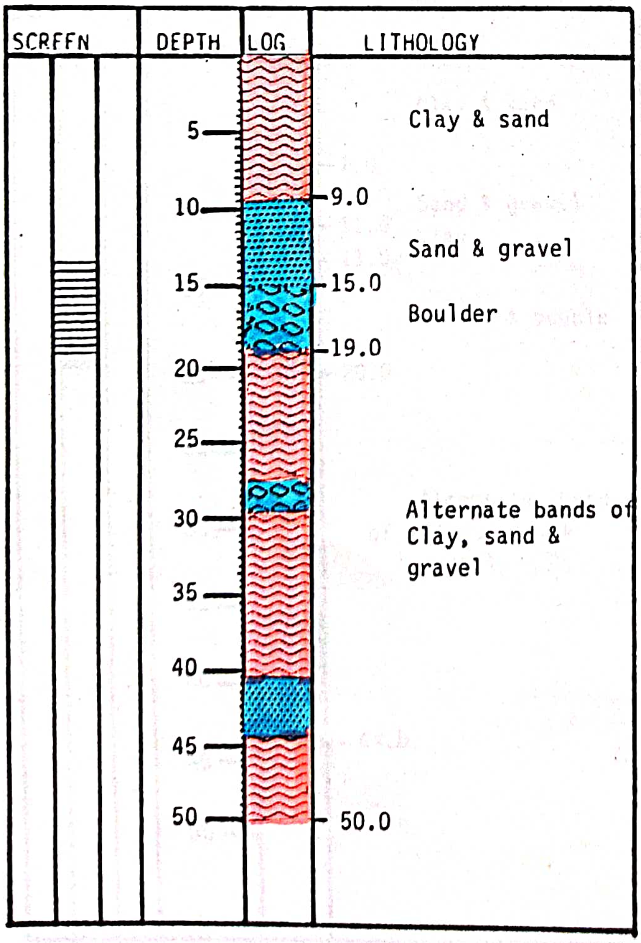
First pumping test on 16/05/88 with 0.5 l/s discharge had shown 30 m^2/day transmissivity.

APPENDIX 3/4

KAPILVASTU

WELL NO. STW 5	LOCATION BIJGAURI	
ELEVATION 157.38 m	X = 677500	Y = 3064000
METHOD OF DRILLING	Rig	
DRILLING DATES	22/03/88 - 24/03/88	
TOTAL DEPTH	50 m.	
COMMENTS	M.P: 1.12 m. Screen position - 13.5 - 19.0 m. Screen type - Wire Wrapped	

WELL LOG



PUMPING TEST

DATE: 28/10/88
Q(l/s): 12
DURATION: 2 hr. 10 min.
TRANSMISSIVITY: 325 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.59 m. (B.G.L)
DYNAMIC WATER LEVEL: 5.35 m.

COMMENTS:

Total duration of first pumping test on 25/03/88 was only 25 min and with fluctuation in discharge.

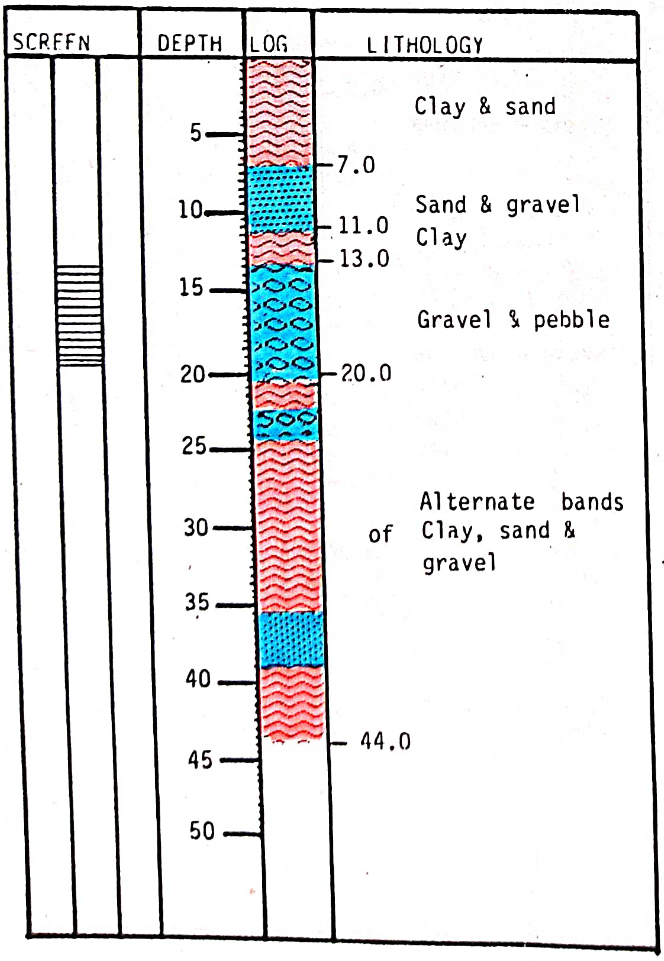
APPENDIX 3/5

GWRDB - UNDP NEP/85/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 6	LOCATION LOHARAULA
ELEVATION 135.40 m	X = 675875 Y = 3061250
METHOD OF DRILLING	Rig
DRILLING DATES	26/03/88 - 28/03/88
TOTAL DEPTH	44 m.
COMMENTS	M.P: 0.36 m. Screen position - 13.5 - 19.5 m. Screen type - Slotted pipe

WELL LOG



PUMPING TEST

DATE: 29/03/88
Q(l/s):12.0
DURATION: 9 min.
TRANSMISSIVITY: 475 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.87 m. (B.G.L)
DYNAMIC WATER LEVEL: 4.59 m.

COMMENTS:

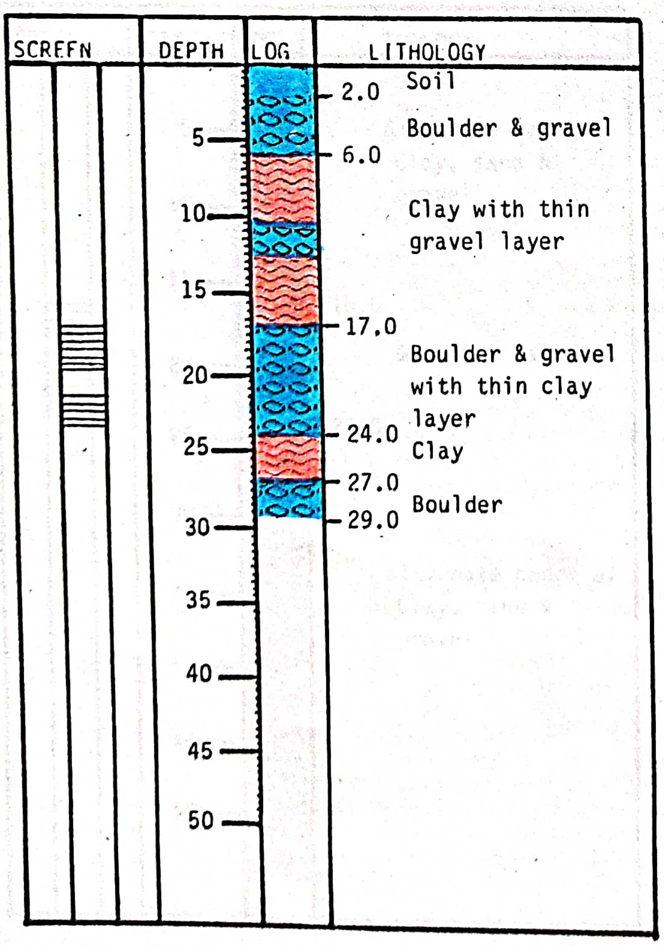
Fluctuation in water level noticed during the test.

APPENDIX 3/6

KAPILVASTU

WELL NO. STW 7	LOCATION NANDNAGAR
ELEVATION 164.14 m	X = 717625 Y = 3067000
METHOD OF DRILLING	Rig.
DRILLING DATES	05/04/88 - 09/04/88
TOTAL DEPTH	29 m.
COMMENTS	Screen position - 17 - 19.5, 21.5 - 23.5 Screen type - Slotted Pipe M.P: 1.09 m.

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 13.02 m.
DYNAMIC WATER LEVEL:

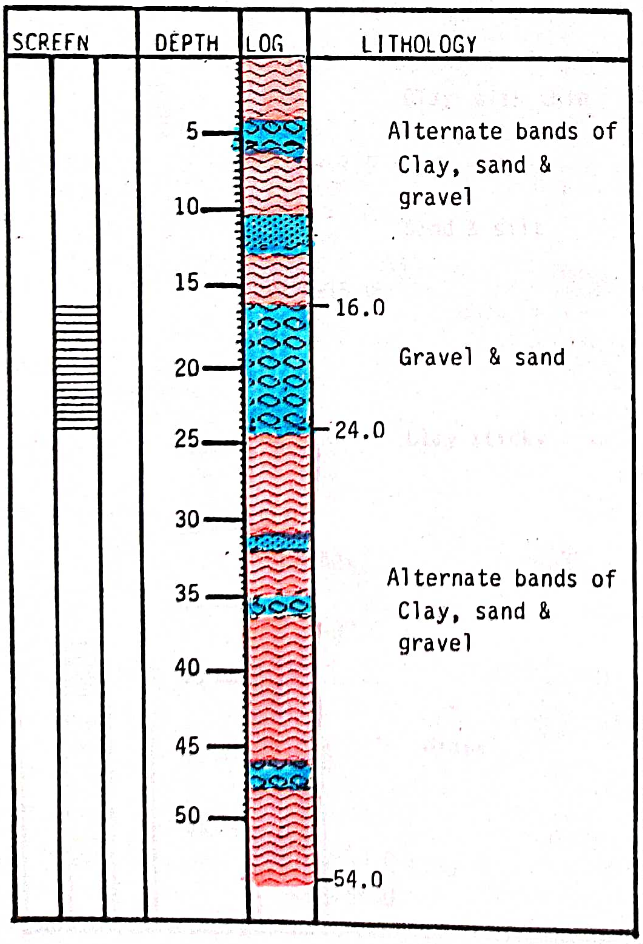
COMMENTS:

APPENDIX 3/7

KAPILVASTU

WELL NO. STW 8	LOCATION BHARSARWA
ELEVATION 112.88 m	X = 712375 Y = 3055875
METHOD OF DRILLING	Rig
DRILLING DATES	22/04/88 - 24/04/88
TOTAL DEPTH	54 m.
COMMENTS	Screen position - 16.0 - 24.0 m. Screen type - Wire Wrapped M.P: 0.4 m.

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.27 m.
DYNAMIC WATER LEVEL:

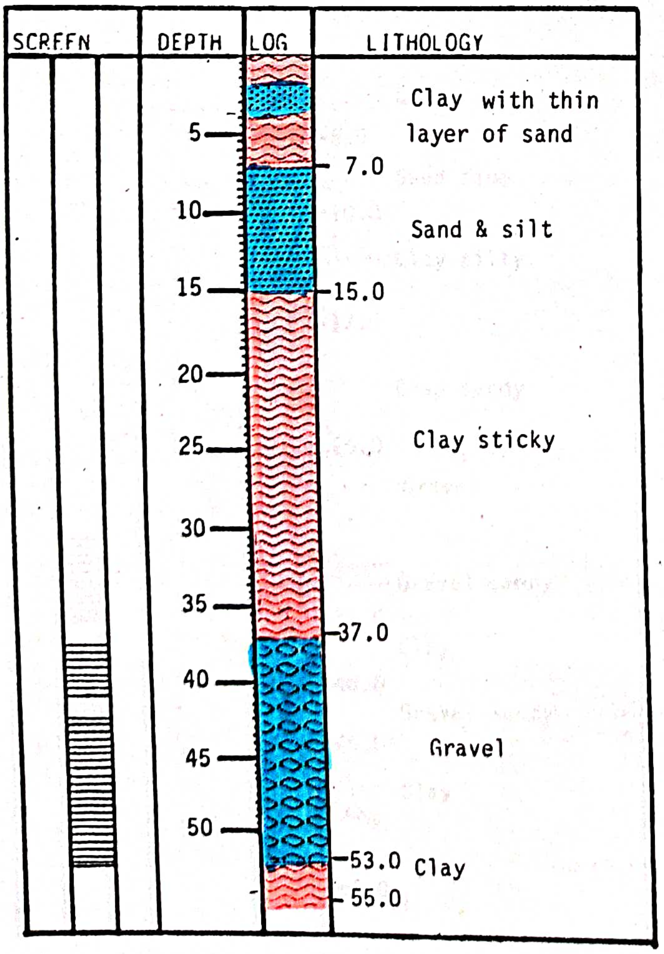
COMMENTS:

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 9	LOCATION DHAMAULIYA
ELEVATION 105.07 m	x = 707625 Y = 3049750
METHOD OF DRILLING	Rig
DRILLING DATES	27/04/88 - 29/04/88
TOTAL DEPTH	55 m.
COMMENTS	M.P: 0.41 m. Screen position 38.0 - 41.0, 42.5 - 53.5 m Screen type - Wire Wrapped

WELL LOG



PUMPING TEST

DATE: 14/10/88
Q(l/s): 5.0
DURATION: 1 hr. 50 min.
TRANSMISSIVITY: 55 m^2/day
METHOD: JACOB
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 1.69 m. (B.G.L)
DYNAMIC WATER LEVEL: 6.5 m.

COMMENTS:

First pumping test on 15/05/88 with 2.0 l/s discharge had shown 30 m^2/day transmissivity.

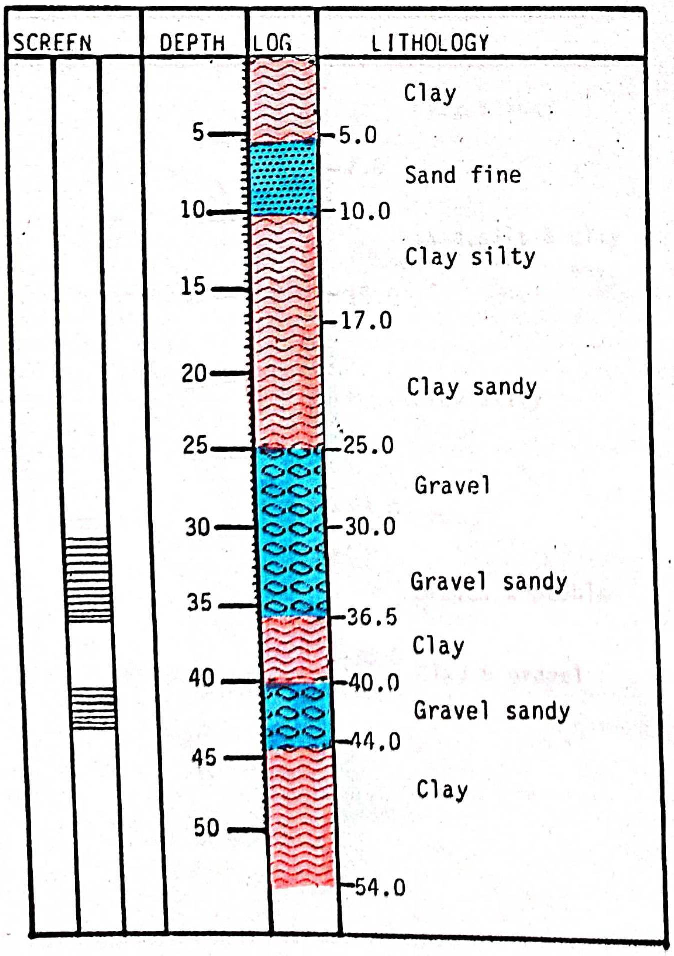
APPENDIX 3/9

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 10	LOCATION HARNAMPUR
ELEVATION 98.18 m	X = 707625 Y = 3043250
METHOD OF DRILLING	Rig
DRILLING DATES	01/05/88 - 03/05/88
TOTAL DEPTH	54 m.
COMMENTS	M.P: 0.39 m. Screen position - 30.5 - 36, 40.5 - 43 m. Screen type - Wire Wrapped

WELL LOG



PUMPING TEST

DATE: 05/05/88
Q(l/s): 2.5
DURATION: 1 hr. 40 min.
TRANSMISSIVITY: 60 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 1.75 m. (B.G.L)
DYNAMIC WATER LEVEL: 4.79 m.

COMMENTS:

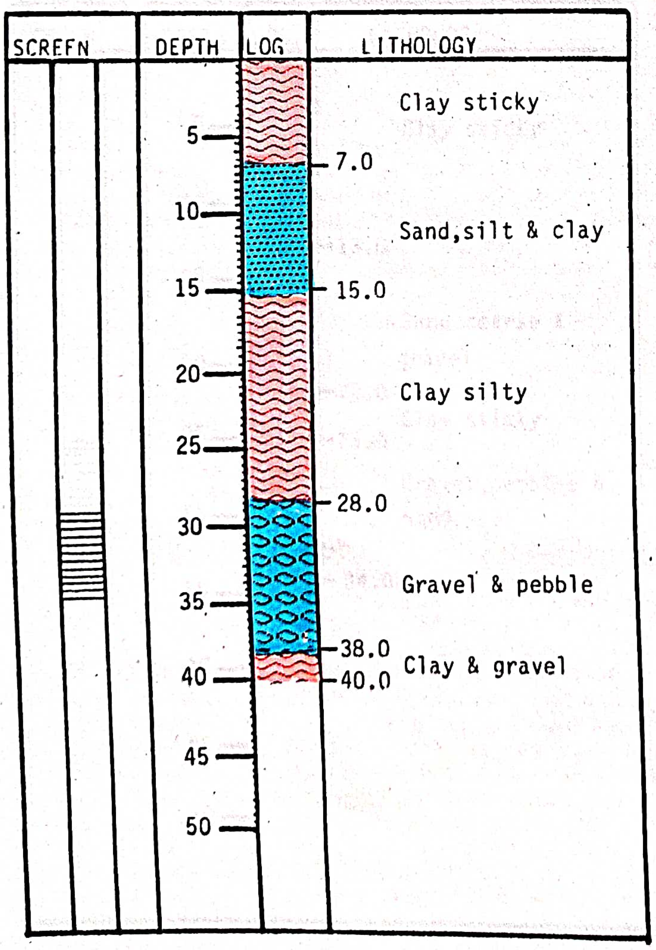
APPENDIX 3/10

GWRDB - UNDP NEP/85/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 11	LOCATION KARMAHAWA
ELEVATION 102.18 m	X = 717625 Y = 3046875
METHOD OF DRILLING	Rig
DRILLING DATES	07/05/88 - 08/05/88
TOTAL DEPTH	40 m.
COMMENTS	Screen position - 29.0 - 34.5 m. Screen type - Wire Wrapped M.P: 0.53 m.

WELL LOG



PUMPING TEST

DATE: 13/10/88
Q(l/s): 14
DURATION: 1 hr. 50 min.
TRANSMISSIVITY: 127 m^2/day
METHOD: Hantush Inflection Point
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.39 m. (B.G.L)
DYNAMIC WATER LEVEL: 4.76 m.

COMMENTS:

First pumping test on 11/05/88 with 4.5 l/s discharge had shown 152 m^2/day transmissivity.

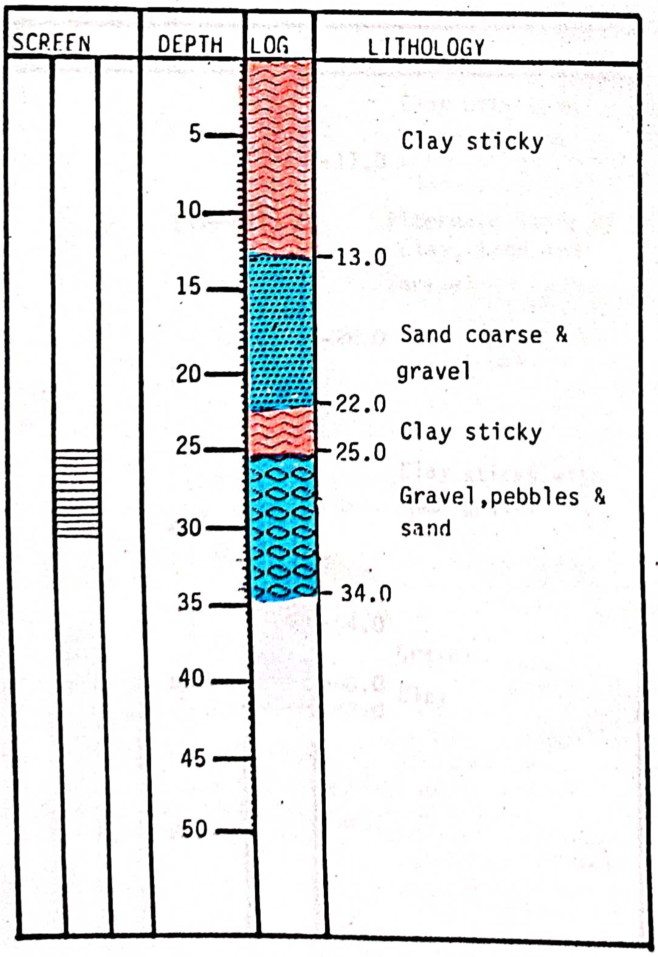
APPENDIX 3/11

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 12	LOCATION AURAIHA	
ELEVATION 96.53 m	X = 716500	Y = 3041250
METHOD OF DRILLING	Rig	
DRILLING DATES	07/05/88 - 08/05/88	
TOTAL DEPTH	34 m.	
COMMENTS	M.P: 0.32 m. Screen position - 25.0 - 30.5 m. Screen type - Wire Wrapped	

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL:
DYNAMIC WATER LEVEL:

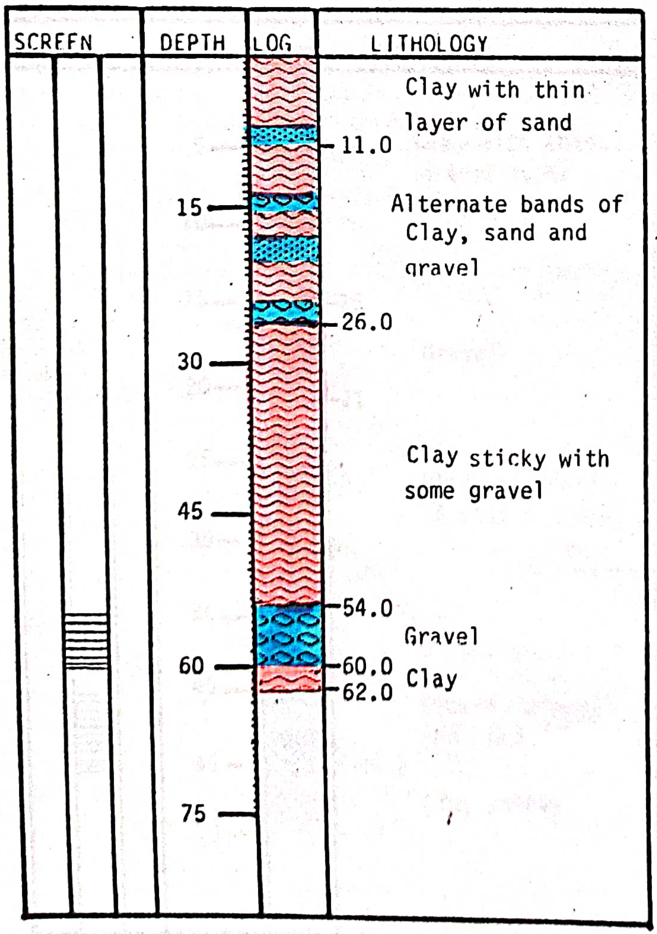
COMMENTS:

APPENDIX 3/12

KAPILVASTU

WELL NO. STW 13	LOCATION SULTANPUR	
ELEVATION 96.07 m	X = 695250	Y = 3041875
METHOD OF DRILLING	Rig	
DRILLING DATES	10/05/88 - 11/05/88	
TOTAL DEPTH	62 m.	
COMMENTS	M.P: 0.43 m. Screen position - 54.5 - 60.0 Screen type - Wire Wrapped	

WELL LOG



PUMPING TEST

DATE: 15/05/88
Q(l/s): 1.4
DURATION: 1 hr. 40 min.
TRANSMISSIVITY: 25 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.75 m.
DYNAMIC WATER LEVEL: 7.46 m. (B.G.L)

COMMENTS:

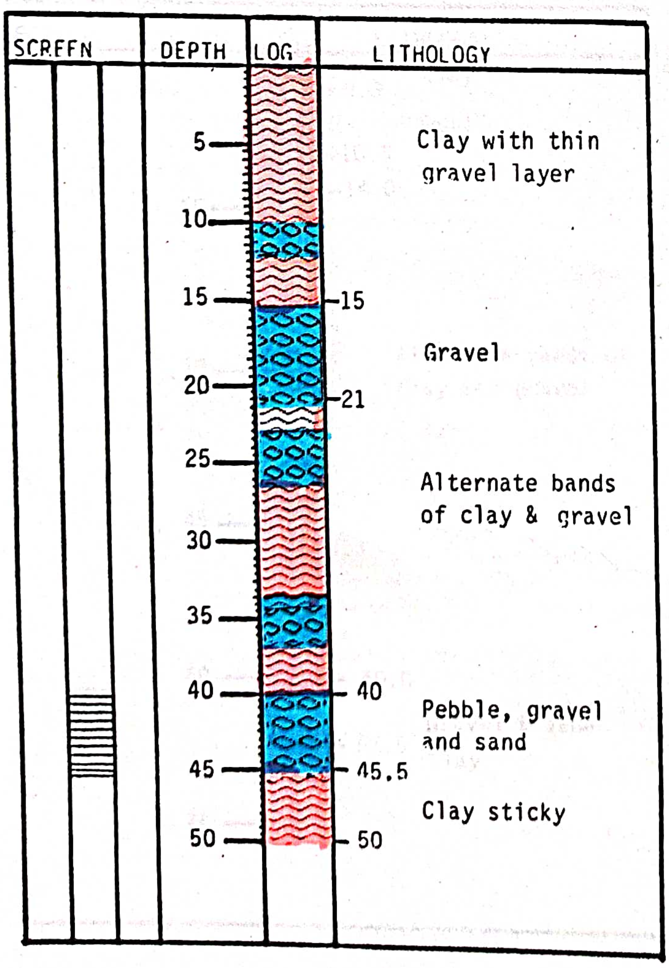
APPENDIX 3/13

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 14	LOCATION AKBARPUR
ELEVATION 98.68 m	X = 696500 Y = 3046750
METHOD OF DRILLING	Rig
DRILLING DATES	10/05/88 - 12/05/88
TOTAL DEPTH	50 m.
COMMENTS	M.P: 0.51 m. Screen position - 40 m - 45.5 m. Screen type - Wire Wrapped

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL:
DYNAMIC WATER LEVEL:

COMMENTS:

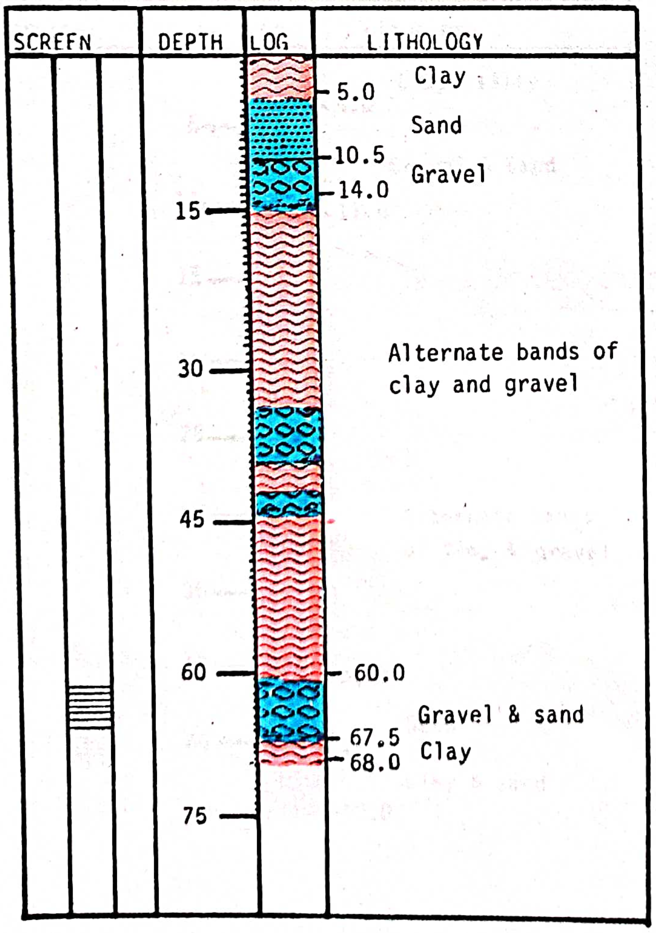
APPENDIX 3/14

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 15	LOCATION AMUWA	
ELEVATION 111.86 m	X = 697500	Y = 3058750
METHOD OF DRILLING	Rig	
DRILLING DATES	13/05/88 - 15/05/88	
TOTAL DEPTH	68 m	
COMMENTS	M.P: 0.47 m. Screen position - 61.0 - 66.5 m.	

WELL LOG



PUMPING TEST

DATE: 22/05/88
Q(l/s): 2
DURATION: 1 hr. 40 m.
TRANSMISSIVITY: 25 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 1.33 m. (B.G.L)
DYNAMIC WATER LEVEL: 6.43 m.

COMMENTS:

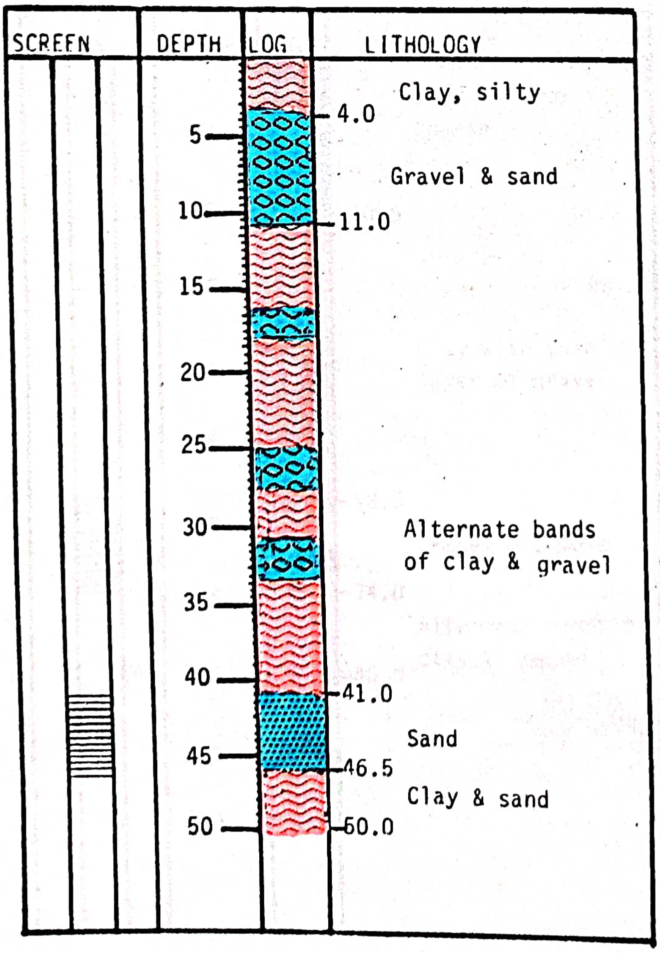
APPENDIX 3/15

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 16	LOCATION MAHUWA
ELEVATION 106.74 m	X = 696250 Y = 3054750
METHOD OF DRILLING	Rig
DRILLING DATES	15/05/88 - 16/05/88
TOTAL DEPTH	50 m.
COMMENTS	Screen position - 41 - 46.5 m. Screen type - Wire Wrapped M.P: 0.3 m.

WELL LOG



PUMPING TEST

DATE: 18/05/88
Q(l/s): 2.2
DURATION: 1 hr. 50 min.
TRANSMISSIVITY: 35 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 4.5 m.
DYNAMIC WATER LEVEL: 6.89 m. (B.G.L)

COMMENTS:

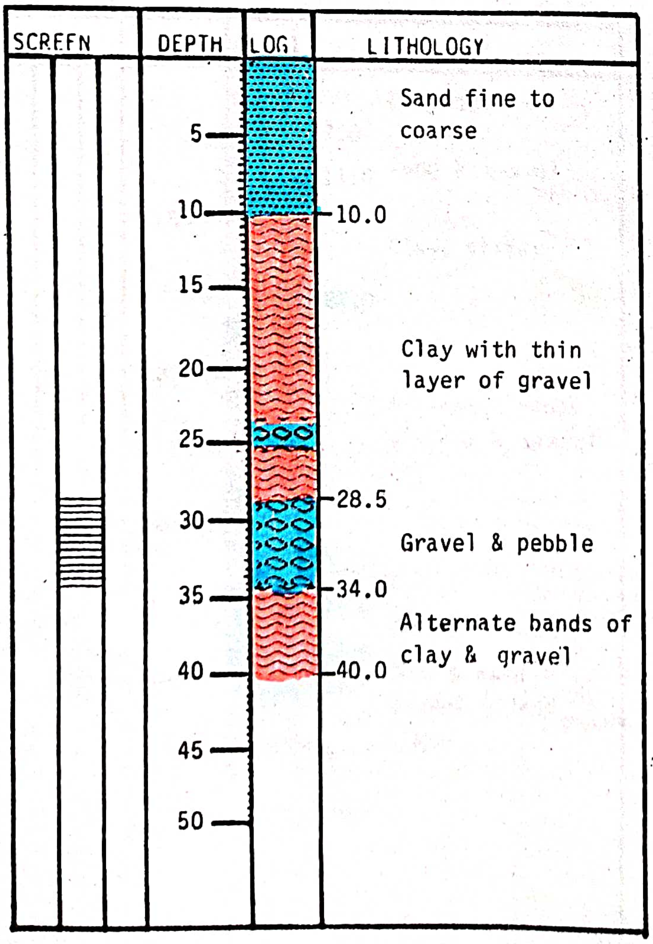
APPENDIX 3/16

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 17	LOCATION BABUDIHAWA	
ELEVATION 108.59 m	X = 689500	Y = 3054500
METHOD OF DRILLING	Rig	
DRILLING DATES	16/05/88 - 17/05/88	
TOTAL DEPTH	40 m.	
COMMENTS	Screen position - 28.5 - 34 m. Screen type - Wire Wrapped M.P: 0.44 m.	

WELL LOG



PUMPING TEST

DATE: 25/05/88
Q(l/s): 0.25
DURATION: 1 hr 40 min.
TRANSMISSIVITY: 3 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.68 m. (B.G.L)
DYNAMIC WATER LEVEL: 7.54 m

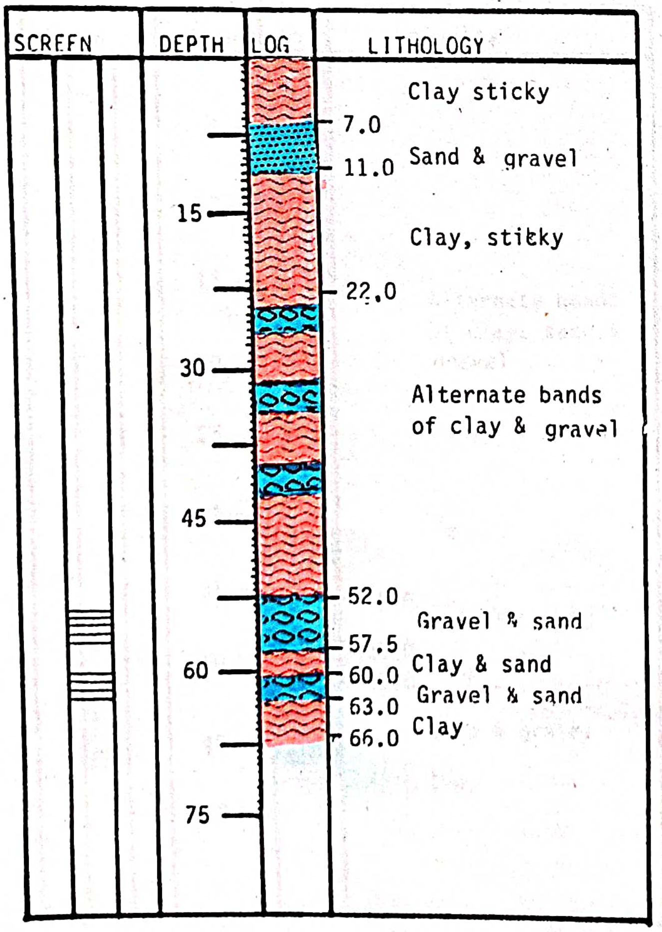
COMMENTS:

APPENDIX 3/17

KAPILVASTU

WELL NO. STW 18	LOCATION MOTIPUR
ELEVATION 106.46 m	X = 678250 Y = 3049250
METHOD OF DRILLING	Rig
DRILLING DATES	20/05/88 - 21/05/88
TOTAL DEPTH	66 m.
COMMENTS	Screen position - 54-57, 60-63 m. Screen type - Wire Wrapped M.P: 0.48 m.

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 4.90 m.
DYNAMIC WATER LEVEL:

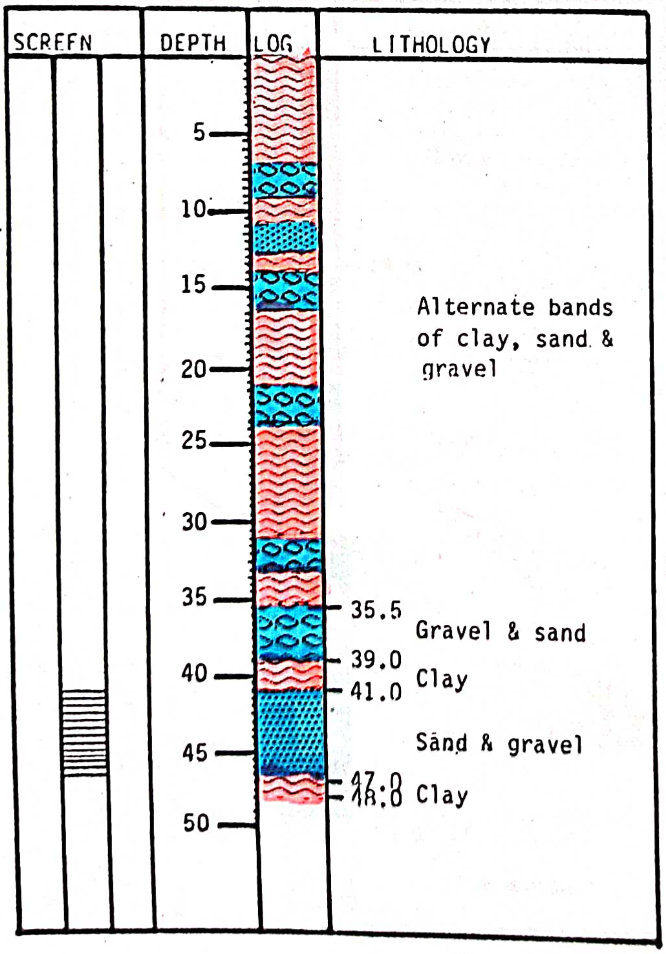
COMMENTS:

APPENDIX 3/18

KAPILVASTU

WELL NO. STW 19	LOCATION JURPANIYA
ELEVATION 117.32 m	X = 676250 Y = 3055000
METHOD OF DRILLING	Rig
DRILLING DATES	20/05/88 - 21/05/88
TOTAL DEPTH	48 m.
COMMENTS	Screen position - 41.0 m - 46.5 m. Screen type - Wire Wrapped M.P: 0.79 m.

WELL LOG



PUMPING TEST

DATE: 05/10/88
Q(l/s): 5
DURATION: 1 hr. 50 min.
TRANSMISSIVITY: 65 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 0.99 m. (B.G.L)
DYNAMIC WATER LEVEL: 4.91 m.

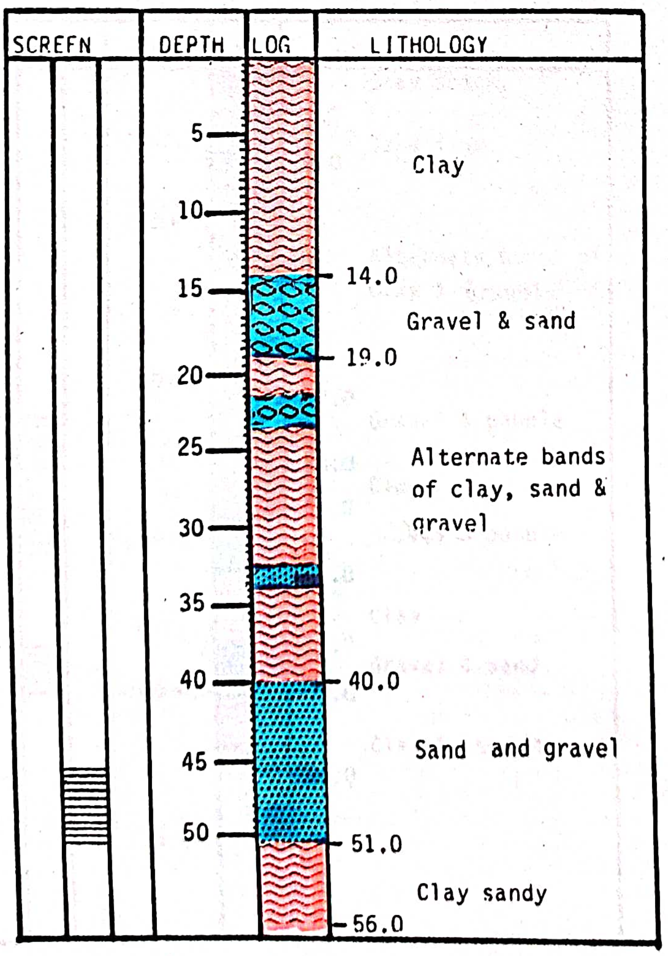
COMMENTS:

First pumping test on 27/05/88 with 1.7 l/s discharge had shown 36 m^2/day transmissivity.

KAPILVASTU

WELL NO. STW 20	LOCATION KUSHAHAWA
ELEVATION 99.30 m	X = 687500 Y = 3045875
METHOD OF DRILLING	Rig
DRILLING DATES	23/05/88 - 25/05/88
TOTAL DEPTH	56 m.
COMMENTS	M.P: 0.52 m. Screen position - 45.5 - 51 m. Screen type - Wire Wrapped

WELL LOG



PUMPING TEST

DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL:
DYNAMIC WATER LEVEL:

COMMENTS:

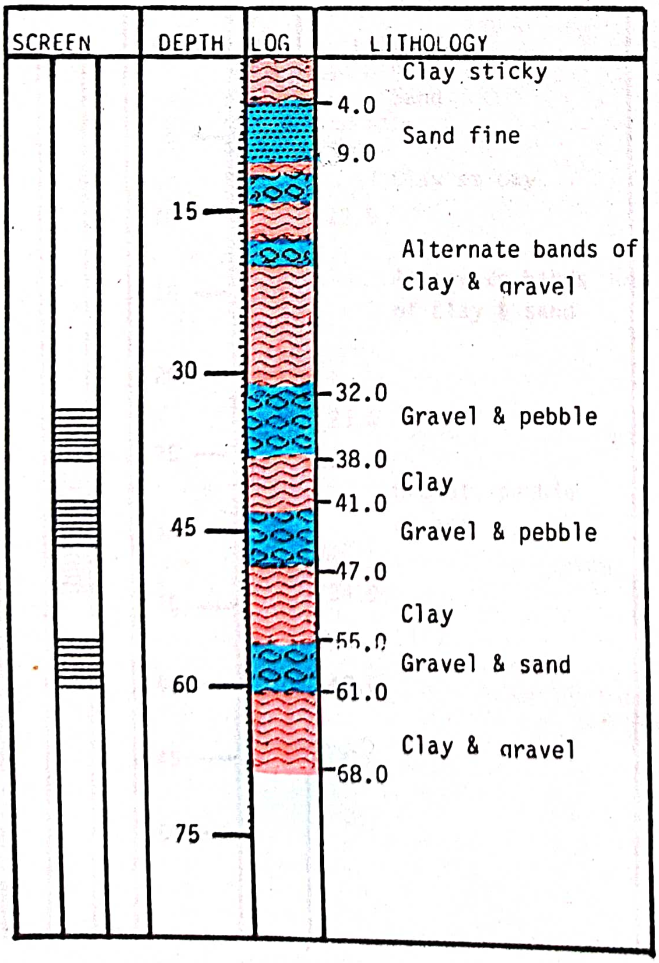
APPENDIX 3/20

GWRDB - UNDP NEP/86/025
SHALLOW GROUNDWATER EXPLORATION IN TERAI

KAPILVASTU

WELL NO. STW 21	LOCATION GORUSINGHE
ELEVATION 116 m	X = 701125 Y = 3061750
METHOD OF DRILLING	Rig
DRILLING DATES	26/05/88 - 28/05/88
TOTAL DEPTH	68 m.
COMMENTS	Screen position 32.5 - 38.0, 41.0 - 46.5, 55.0-60.5 m. Screen type - Wire Wrapped M.P: 0.48 m.

WELL LOG



PUMPING TEST

DATE: 01/10/88
Q(l/s): 11
DURATION: 2 hrs.
TRANSMISSIVITY: 100 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 0.62 m. (B.G.L)
DYNAMIC WATER LEVEL: 4.82 m.

COMMENTS:

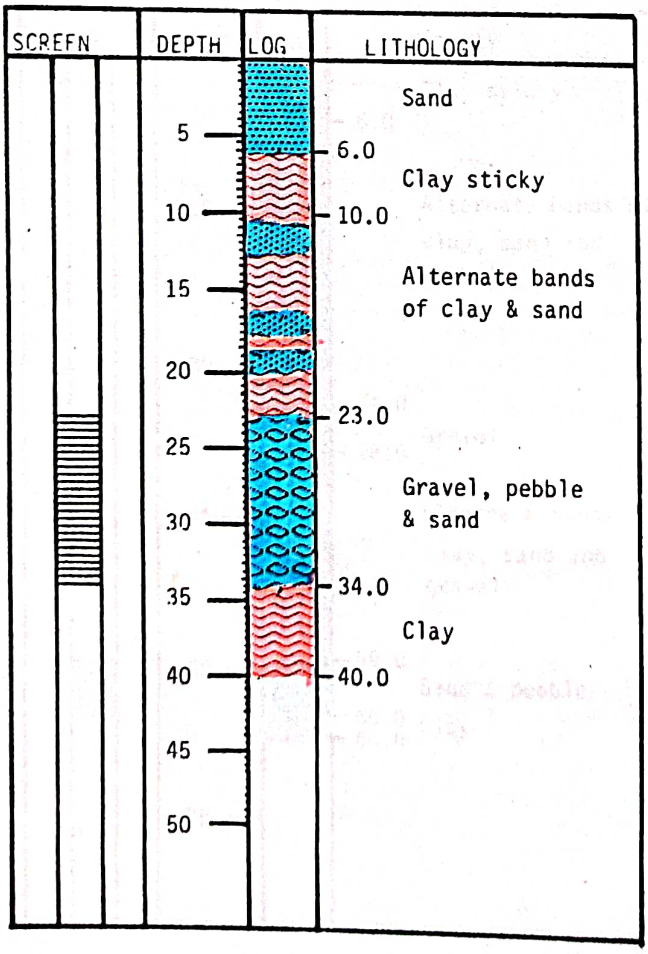
First pumping test in May 1988 with 4 l/s discharge had shown 46 m^2/day transmissivity.

APPENDIX 3/21

KAPILVASTU

WELL NO. STW 22	LOCATION BHITRIYA
ELEVATION 119.19 m	X = 689125 Y = 3062875
METHOD OF DRILLING	Rig
DRILLING DATES	26/05/88 - 29/05/88
TOTAL DEPTH	40 m.
COMMENTS	Screen position: 23 - 34 m. Screen type : Wire Wrapped M.P: 0.38 m.

WELL LOG



PUMPING TEST

DATE:
Q(l/s): 2
DURATION: 1 hrs. 50 min.
TRANSMISSIVITY: 50 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.47 m. (B.G.L)
DYNAMIC WATER LEVEL: 5.38 m.

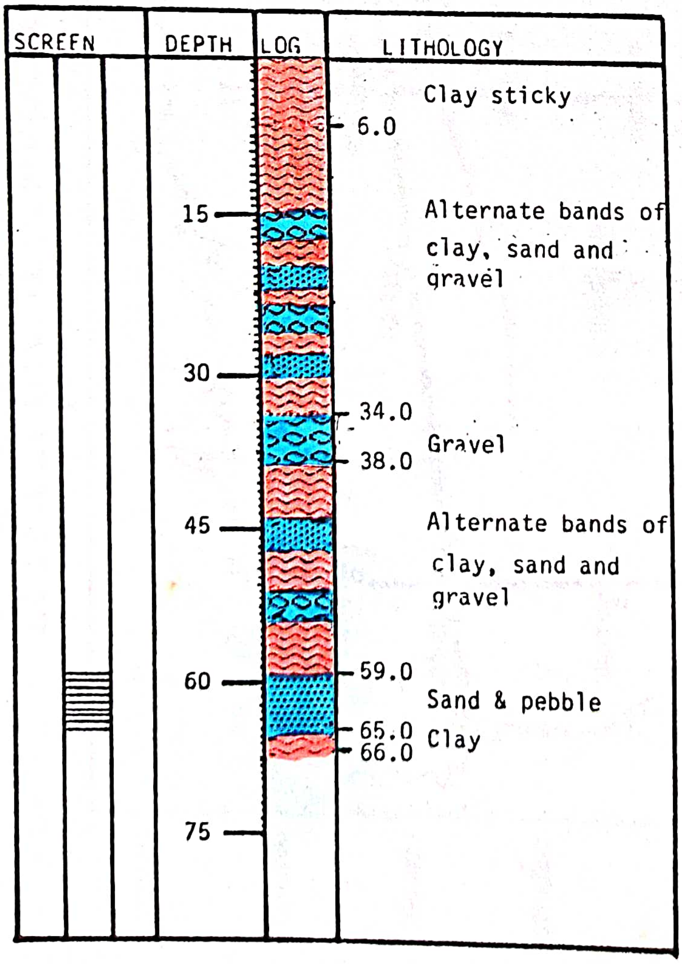
COMMENTS:

APPENDIX 3/22

KAPILVASTU

WELL NO. STW 23	LOCATION DHARAMPANIYA	
ELEVATION 102.42 m	X = 709375	Y = 3047125
METHOD OF DRILLING	Rig	
DRILLING DATES	31/05/88 - 01/06/88	
TOTAL DEPTH	66 m.	
COMMENTS	M.P: 0.83 m. Screen position - 59.5 - 65 m. Screen type - Wire Wrapped	

WELL LOG



PUMPING TEST

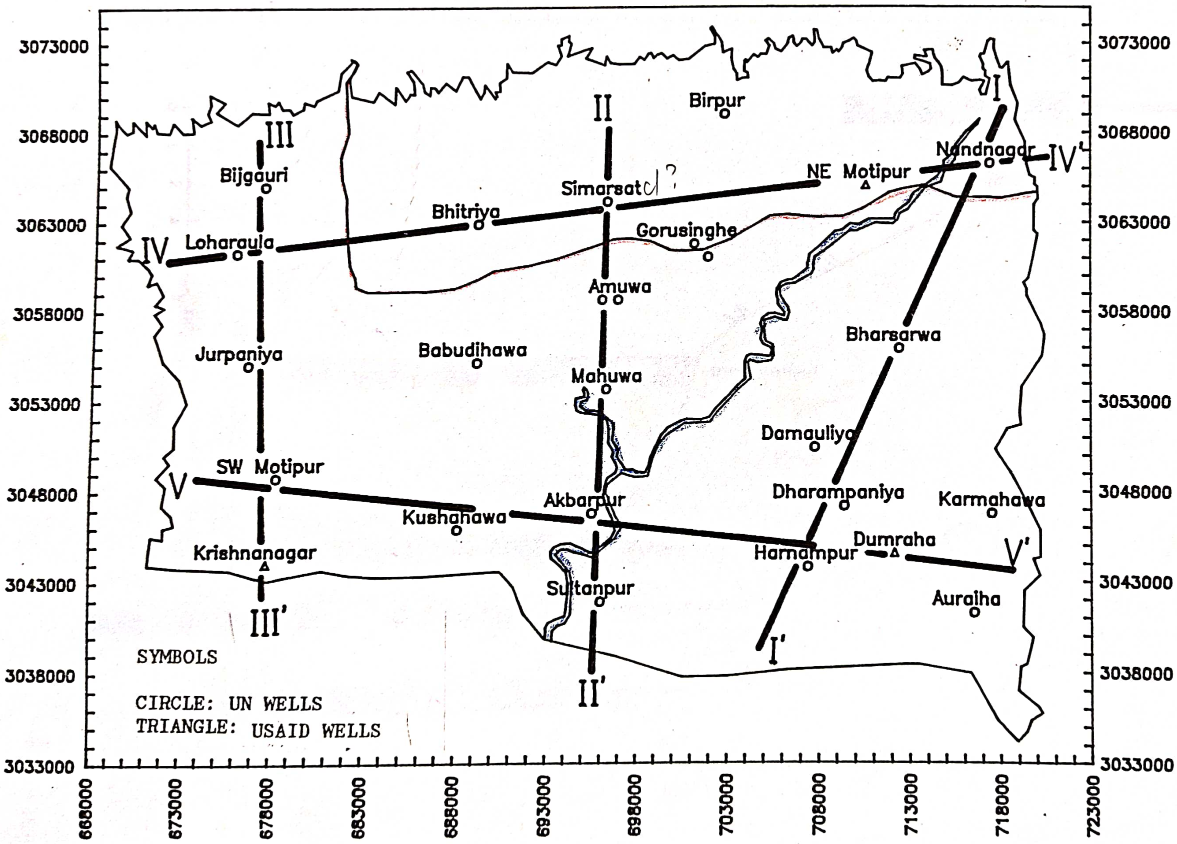
DATE:
Q(l/s):
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL:
DYNAMIC WATER LEVEL:

COMMENTS:

APPENDIX 3/23

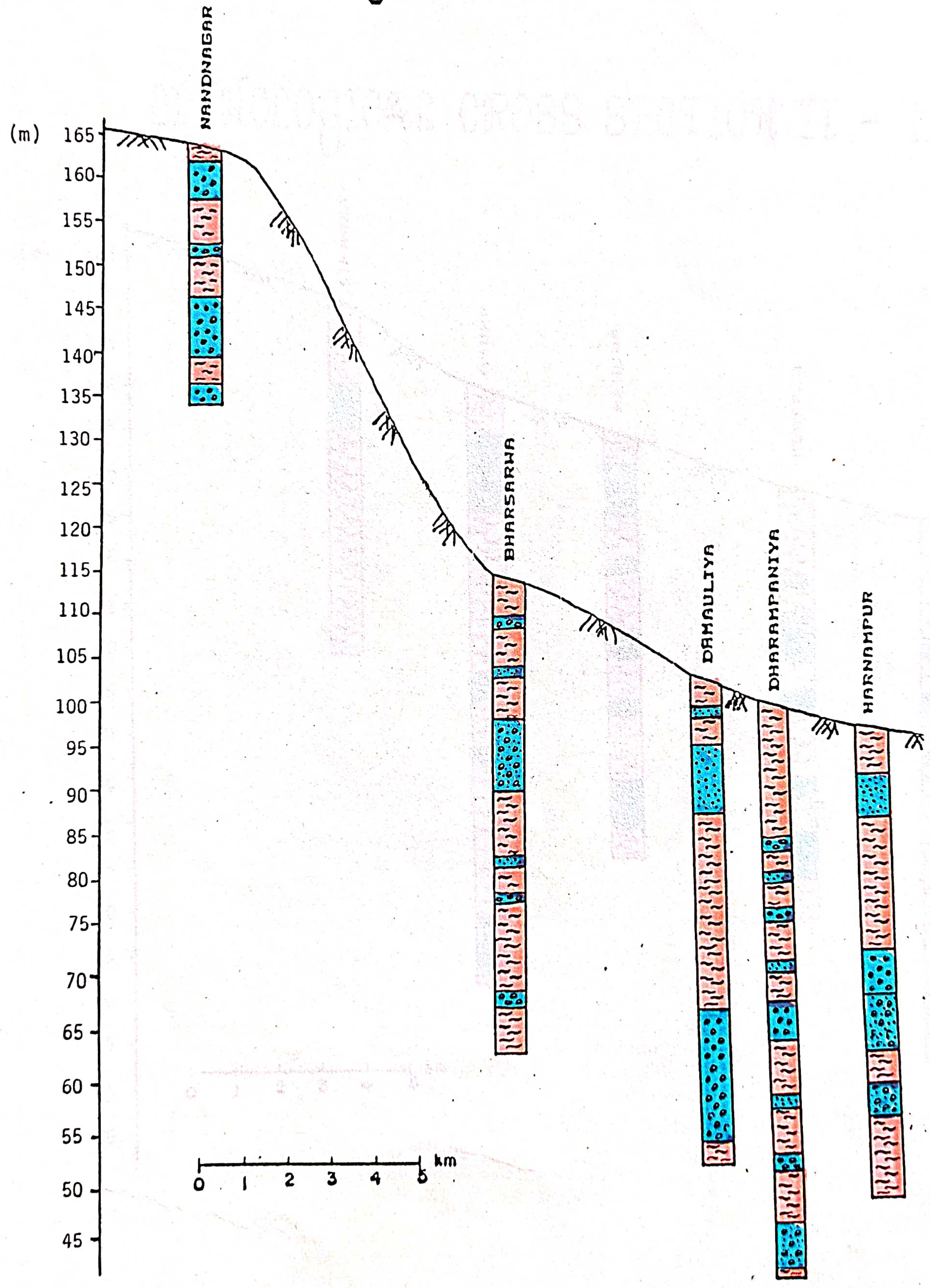
KAPILVASTU - LOCATION OF WELLS

LITHOLOGICAL CROSS SECTIONS (I - V)



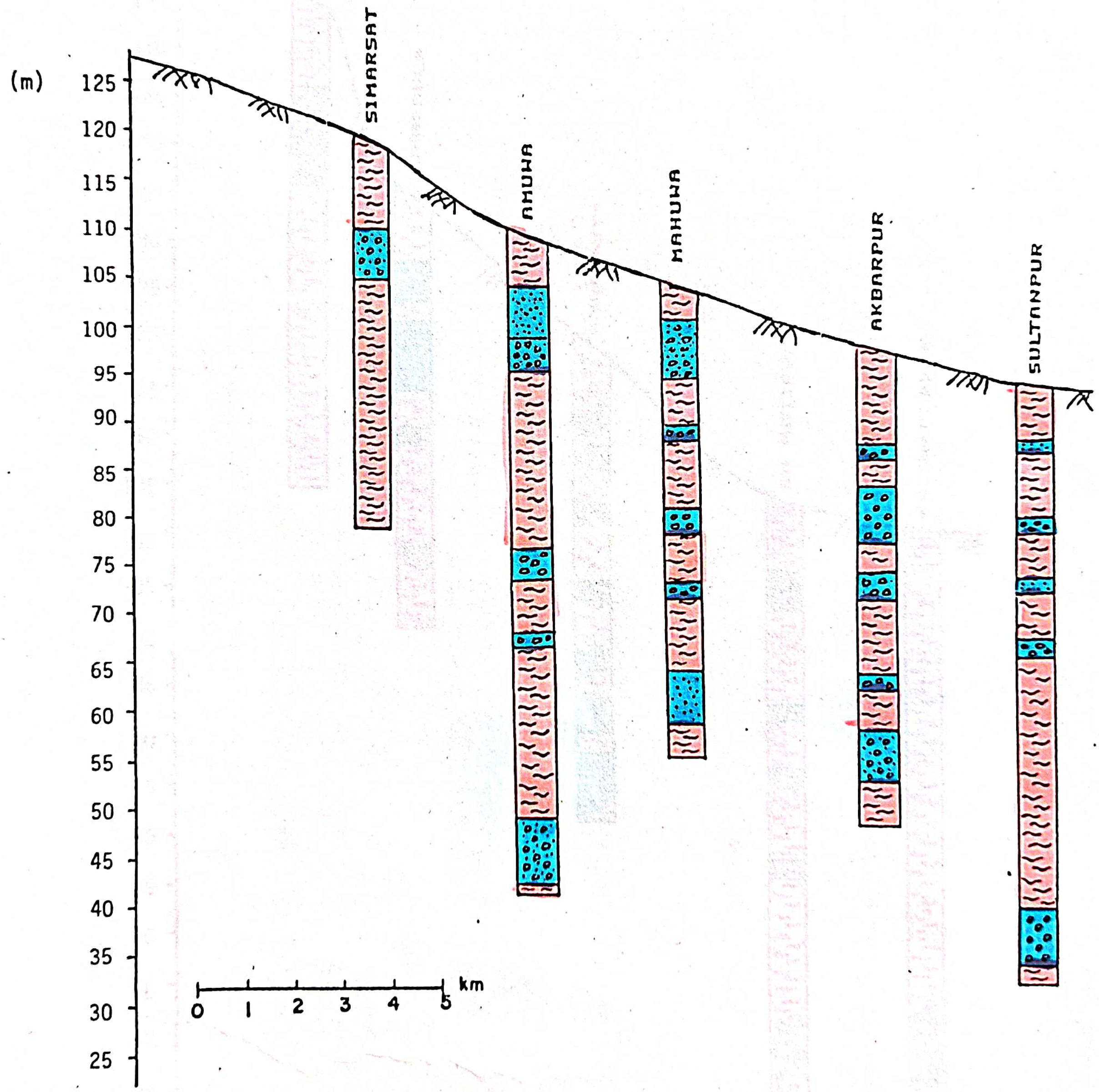
APPENDIX 4/1

LITHOLOGICAL CROSS SECTION I - I'



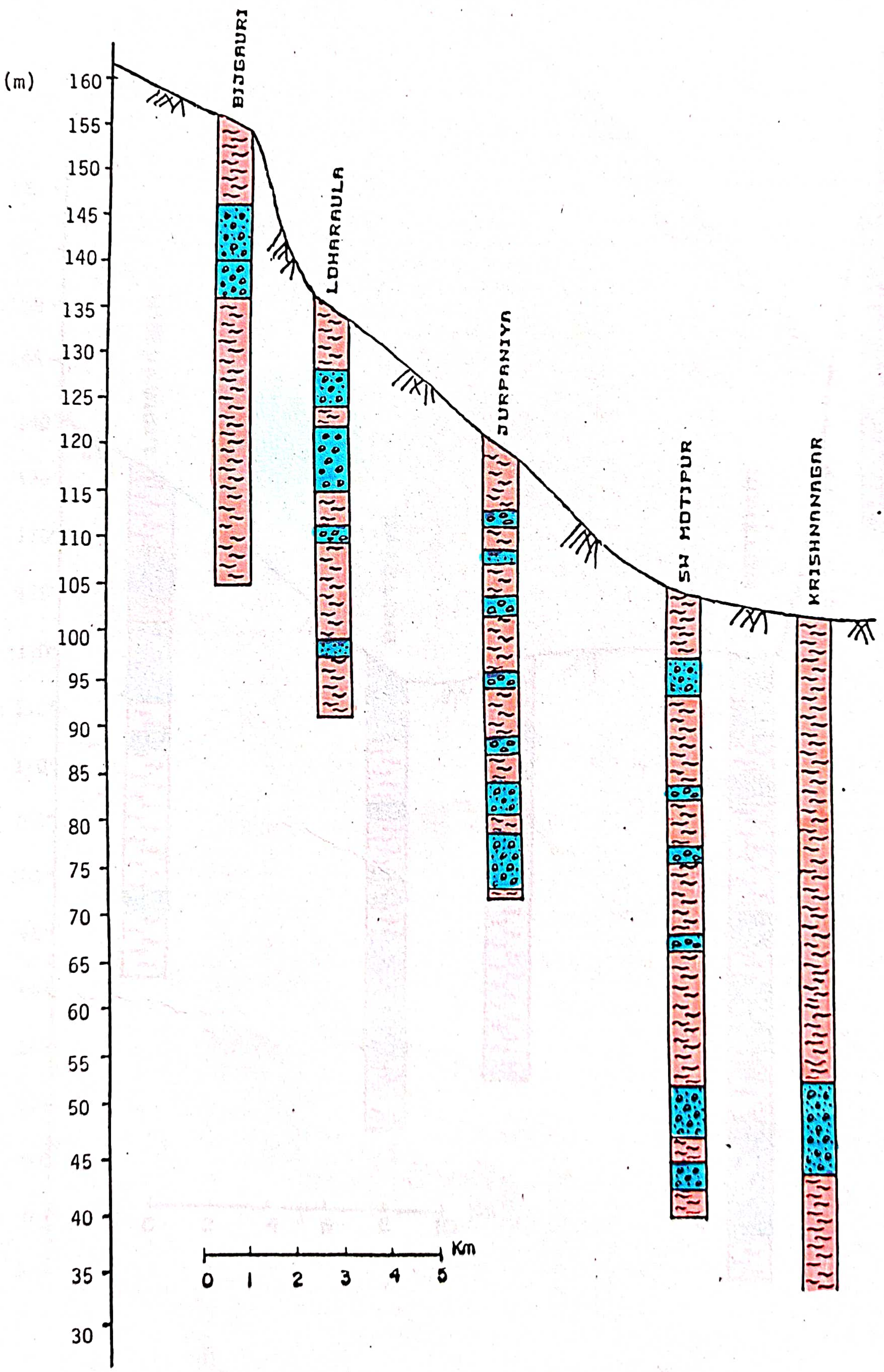
APPENDIX 4/2

LITHOLOGICAL CROSS SECTION II - II'



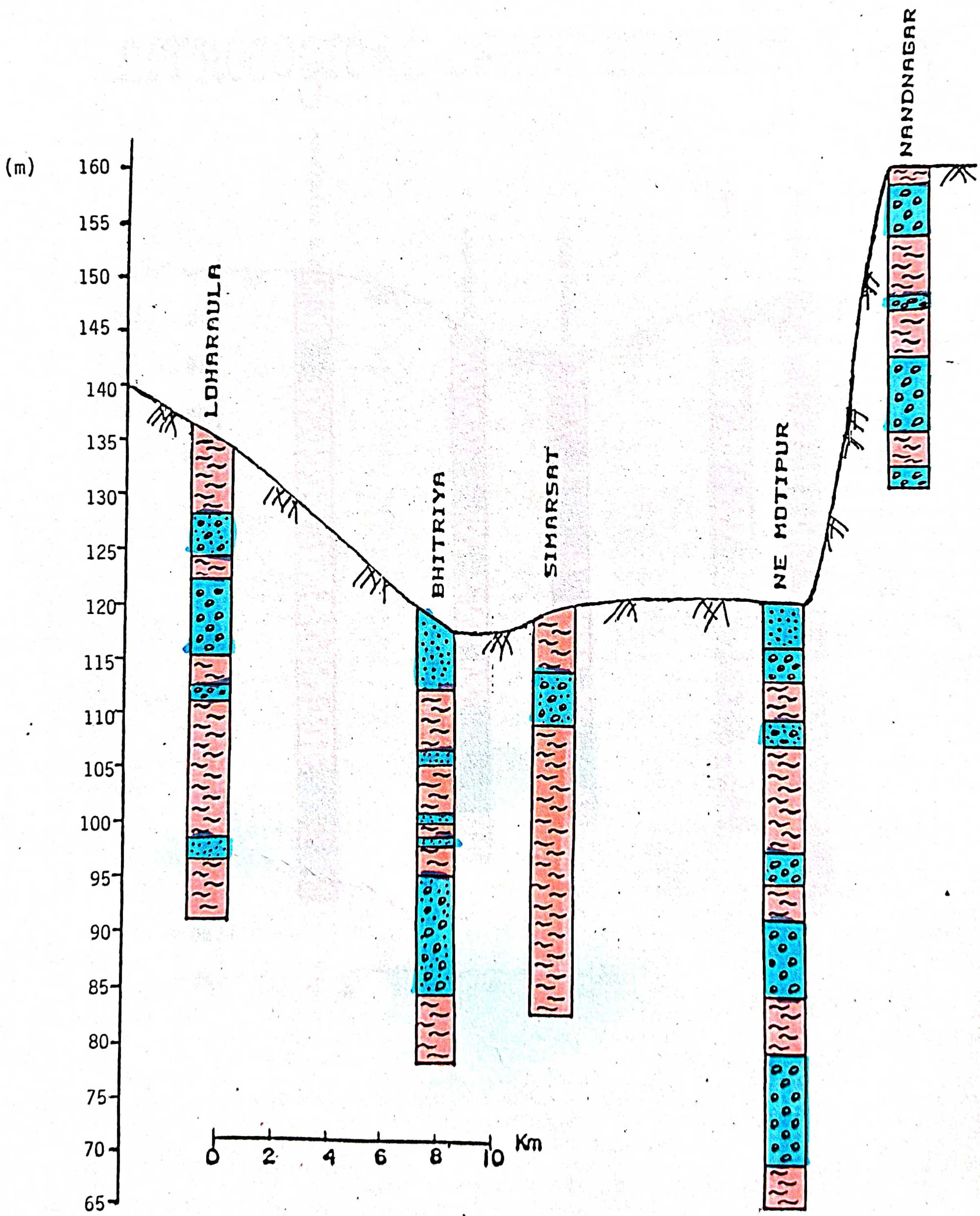
APPENDIX 4/3

LITHOLOGICAL CROSS SECTION III - III'



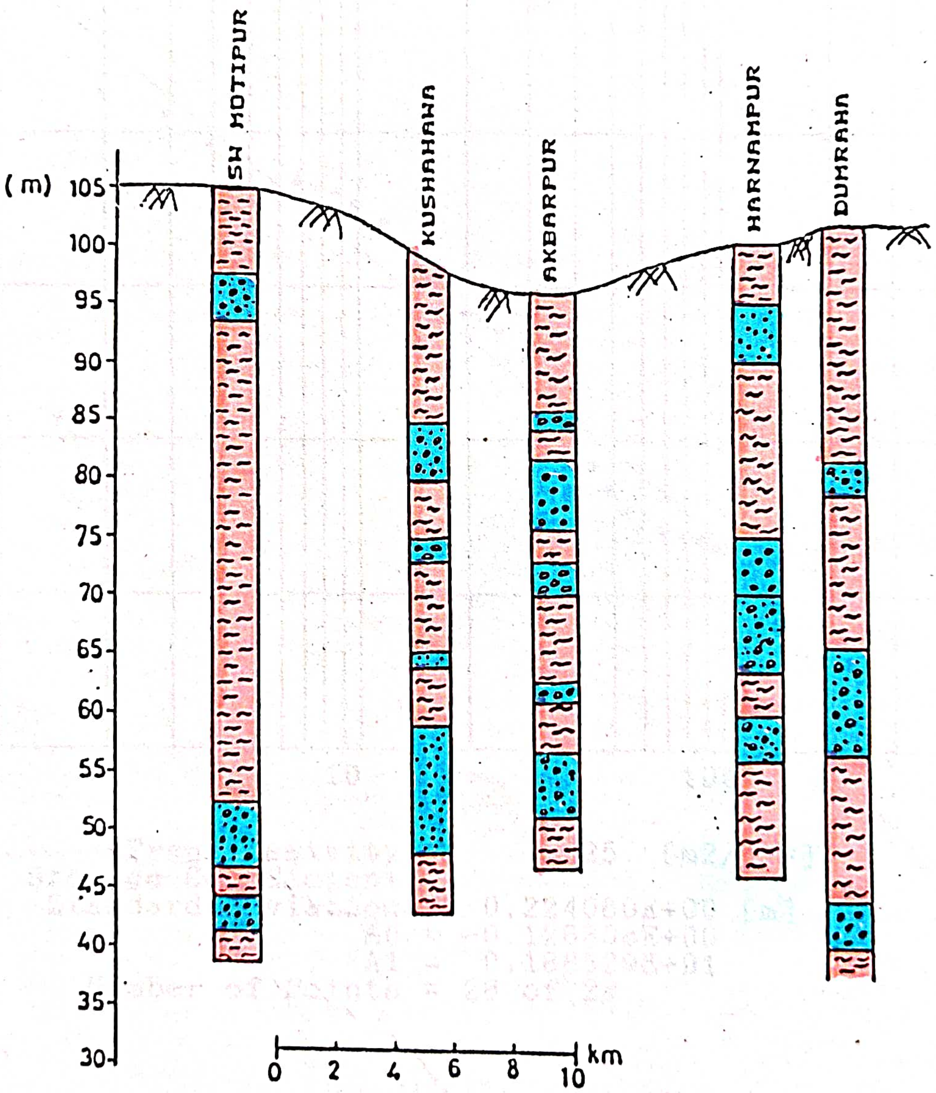
APPENDIX 4/4

LITHOLOGICAL CROSS SECTION IV - IV'



APPENDIX 4/5

LITHOLOGICAL CROSS SECTION V – V'

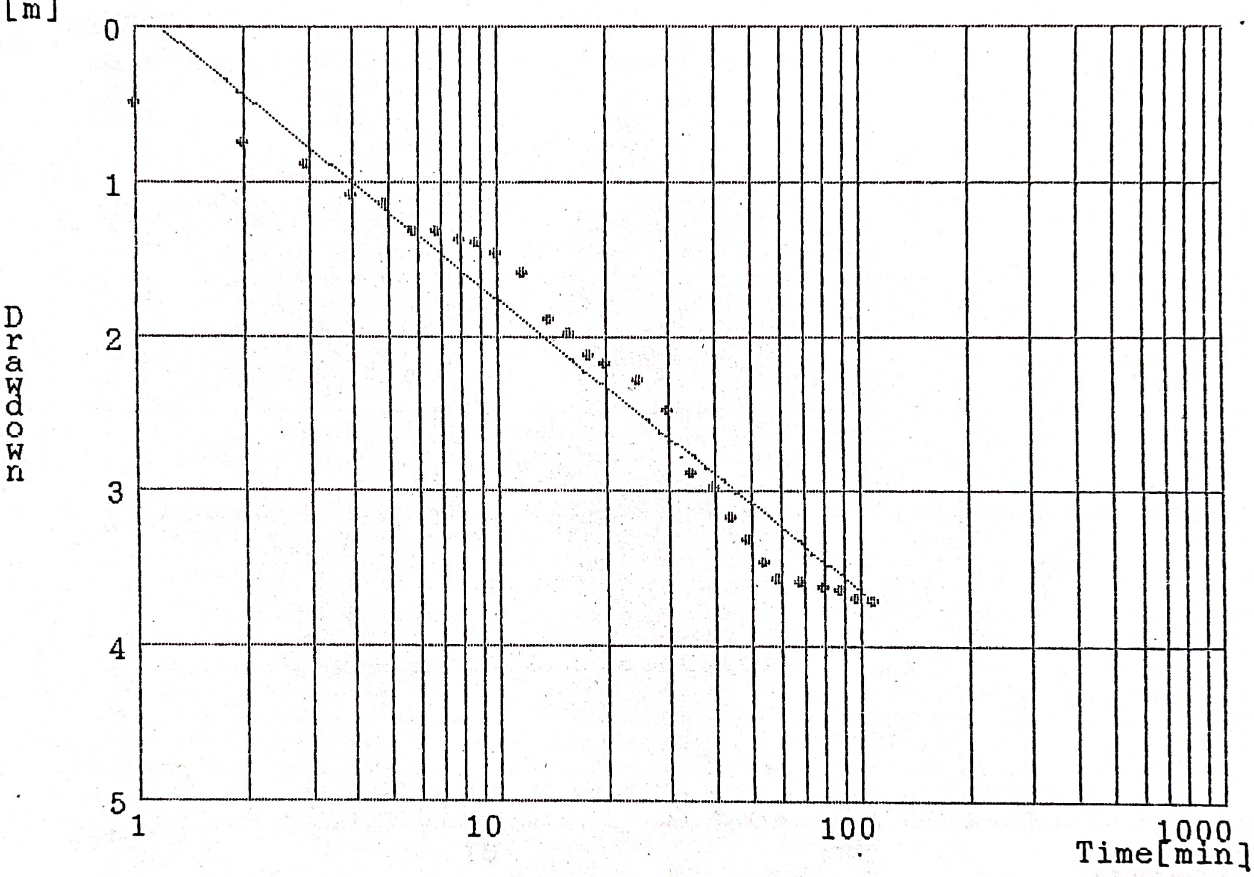


Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 4 SIMARSAT

Constant Pumping Rate = 3.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.70 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 25. [m2/day]
Storage Coefficient =
Standard Deviation = 0.224080E+00 [m]
A0 = -0.128808E+00
A1 = 0.188529E+01
Number of Points = 28 of 28

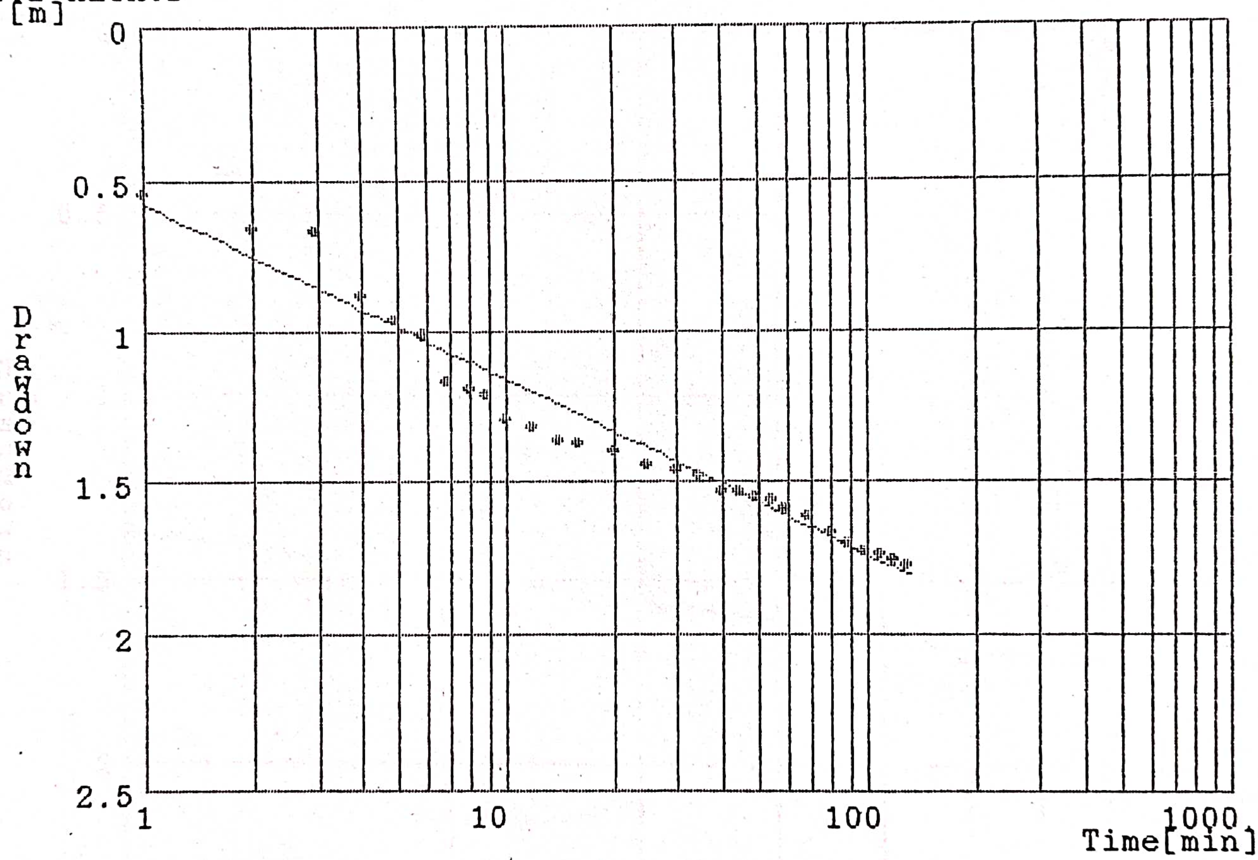
APPENDIX 5/1

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 5 BIJGAURI

Constant Pumping Rate = 12.000 [L/S]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.71 [m]
Well Type = STANDARD

JACOB METHOD



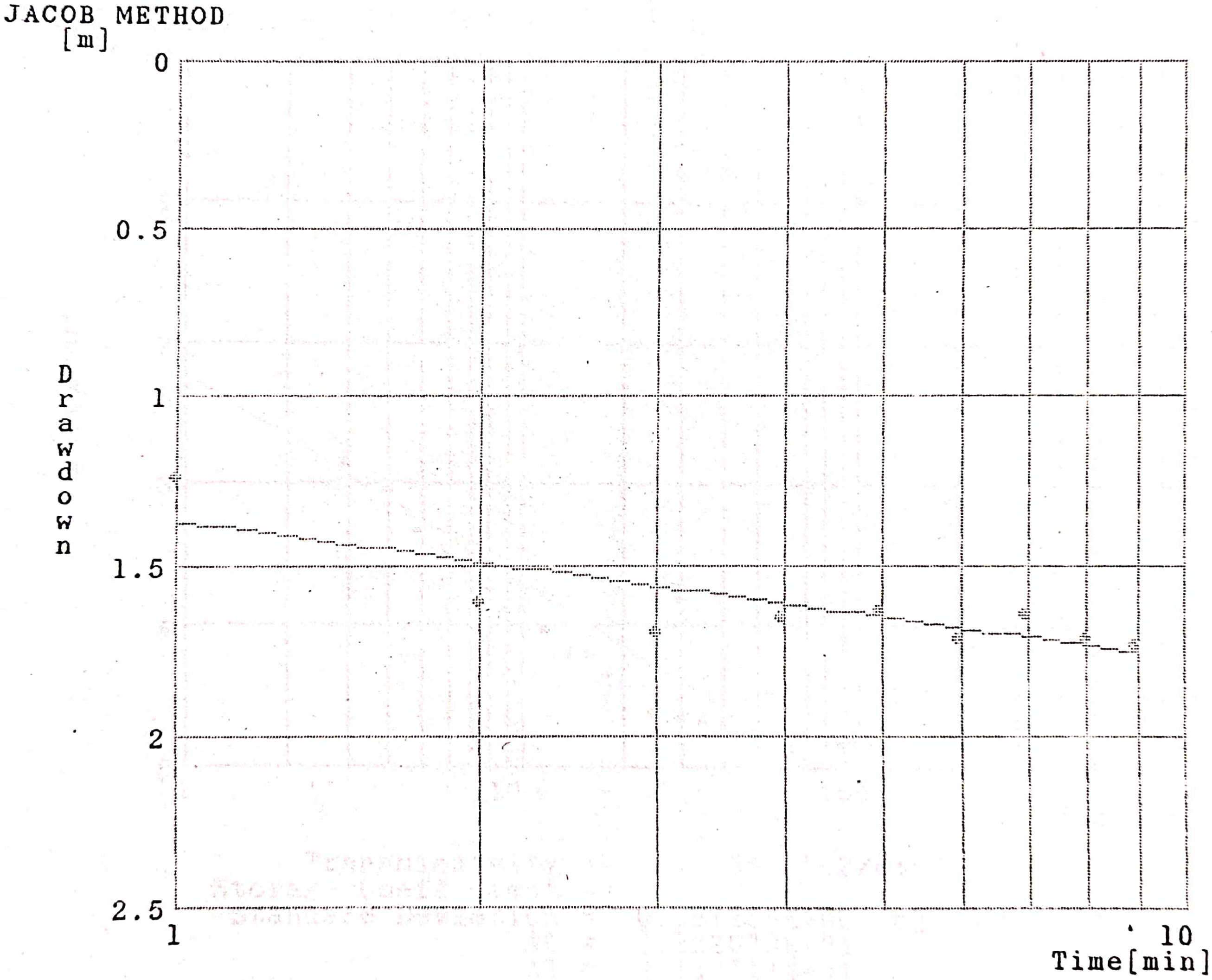
Transmissivity = 325. [m2/day]
Storage Coefficient =
Standard Deviation = 0.684702E-01 [m]
A0 = 0.573236E+00
A1 = 0.583334E+00
Number of Points = 29 of 29

APPENDIX 5/2

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 6 LOHARAULA

Constant Pumping Rate = 12.000 [L/S]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.23 [m]
Well Type = STANDARD



Transmissivity = 473. [m2/day]
Storage Coefficient =
Standard Deviation = 0.0772 [m]
A0 = 0.136432E+01
A1 = 0.401297E+00
Number of Points = 9 of 9

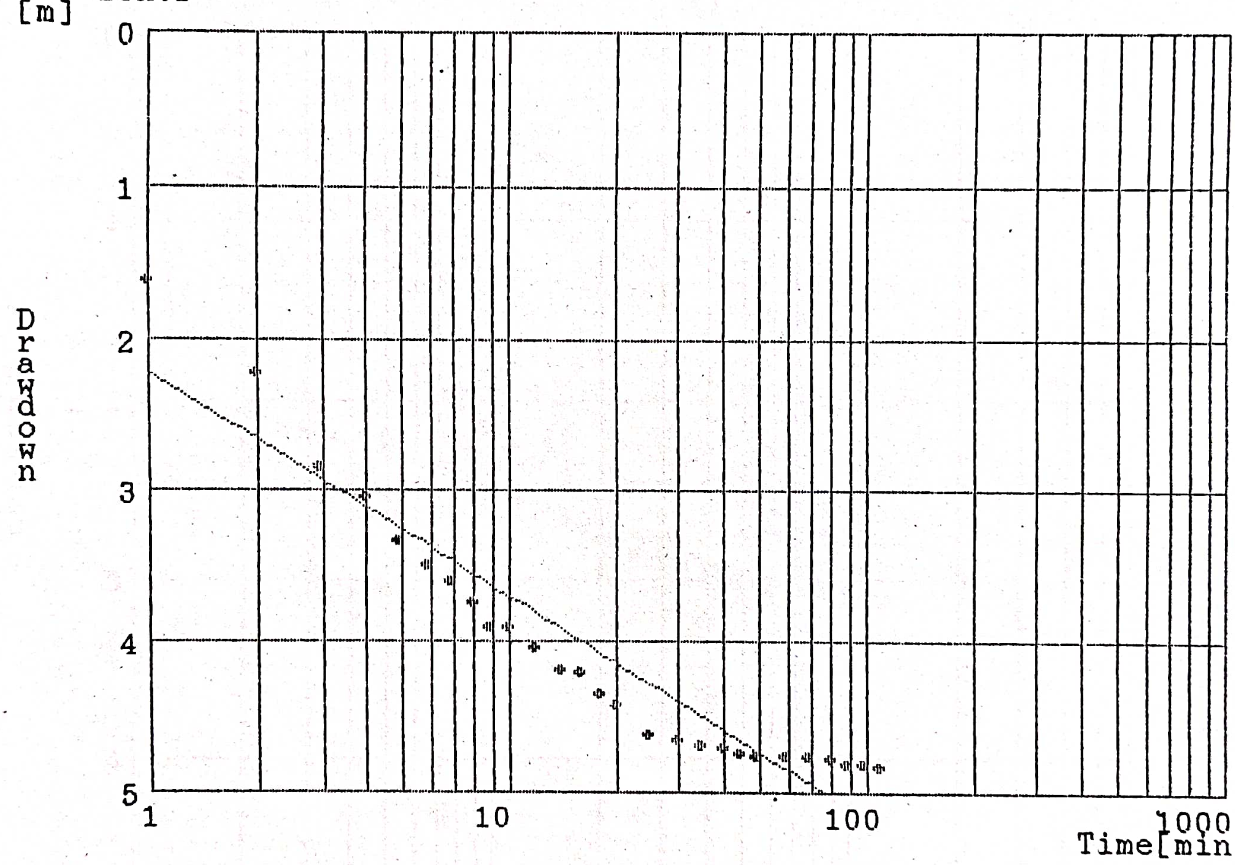
APPENDIX 5/3

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 9 DHAMAULIYA

Constant Pumping Rate = 5.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.10 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 54. [m2/day]
Storage Coefficient =
Standard Deviation = 0.257289E+00 [m]
A0 = 0.222009E+01
A1 = 0.147717E+01
Number of Points = 27 of 27

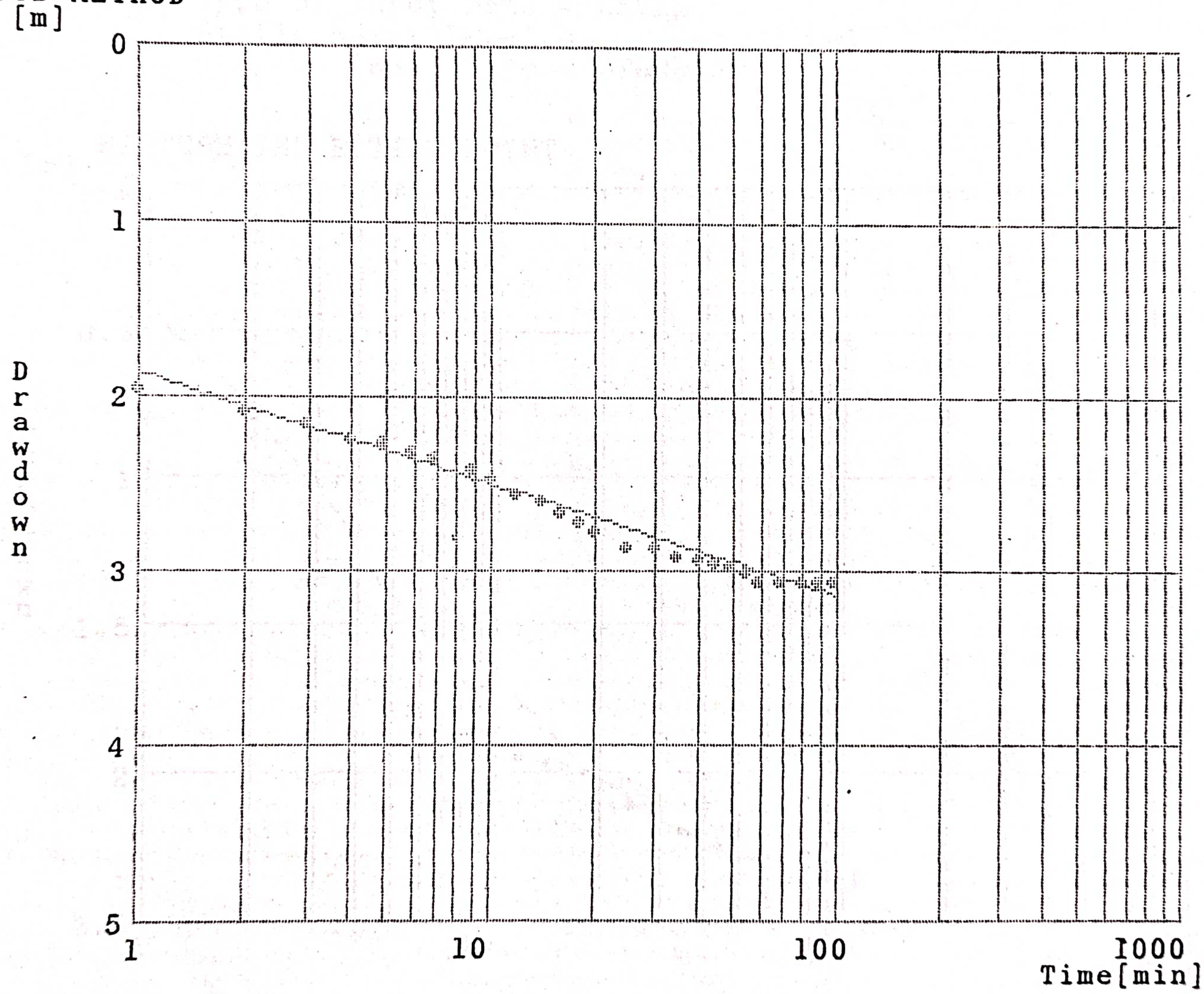
APPENDIX 5/4

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 10 HARNAMPUR

Constant Pumping Rate = 2.500 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.14 [m]
Well Type = STANDARD

JACOB METHOD



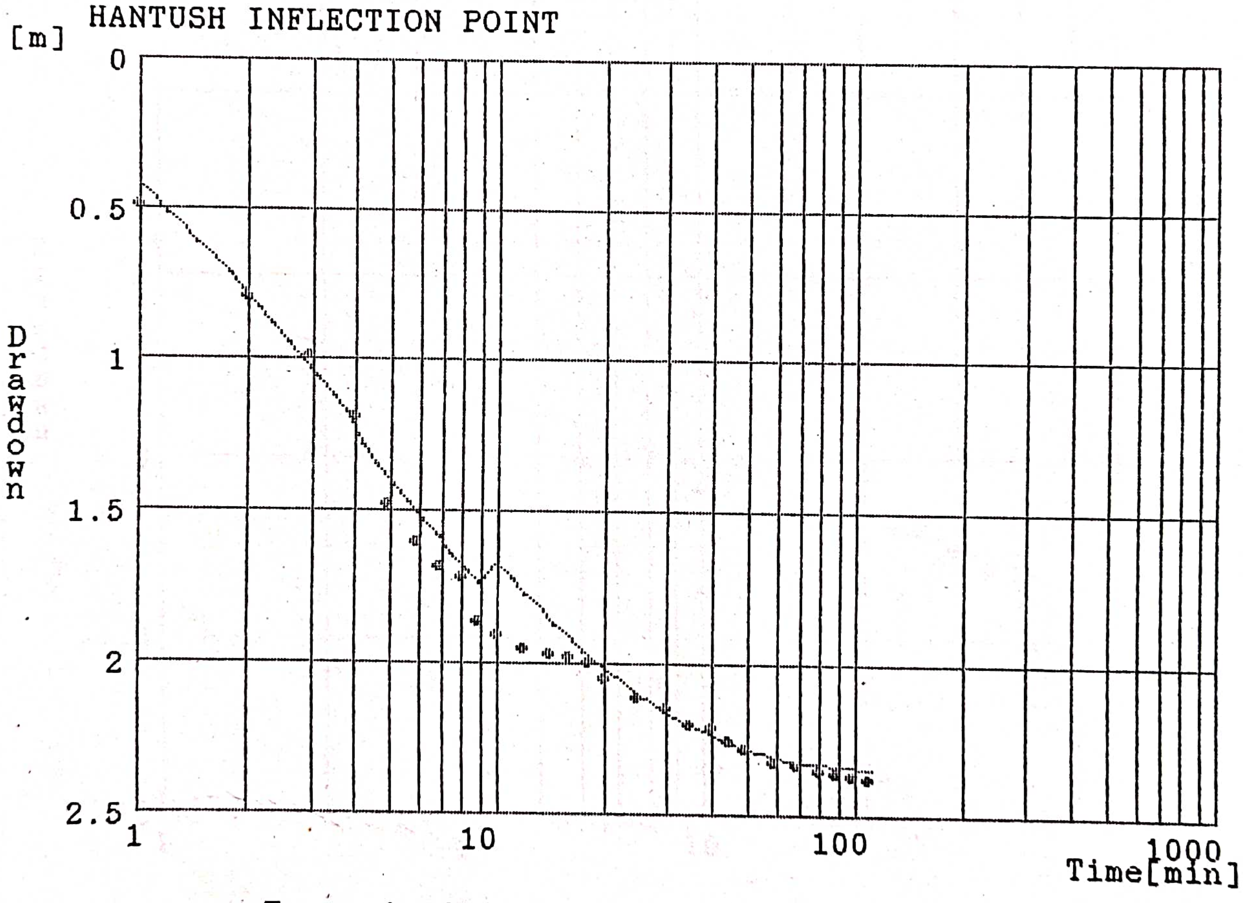
Transmissivity = 62. [m2/day]
Storage Coefficient =
Standard Deviation = 0.0496 [m]
A0 = 0.185688E+01
A1 = 0.640611E+00
Number of Points = 26 of 27

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 11 KARMAHAWA

Constant Pumping Rate = 14.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.92 [m]
Well Type = STANDARD

HANTUSH INFLECTION POINT



Transmissivity = 127. [m2/day]
Storage Coefficient =
Standard Deviation = 0.0712 [m]
Leakance =3113.5774 [1/DAY]

Number of Points = 27 of 27

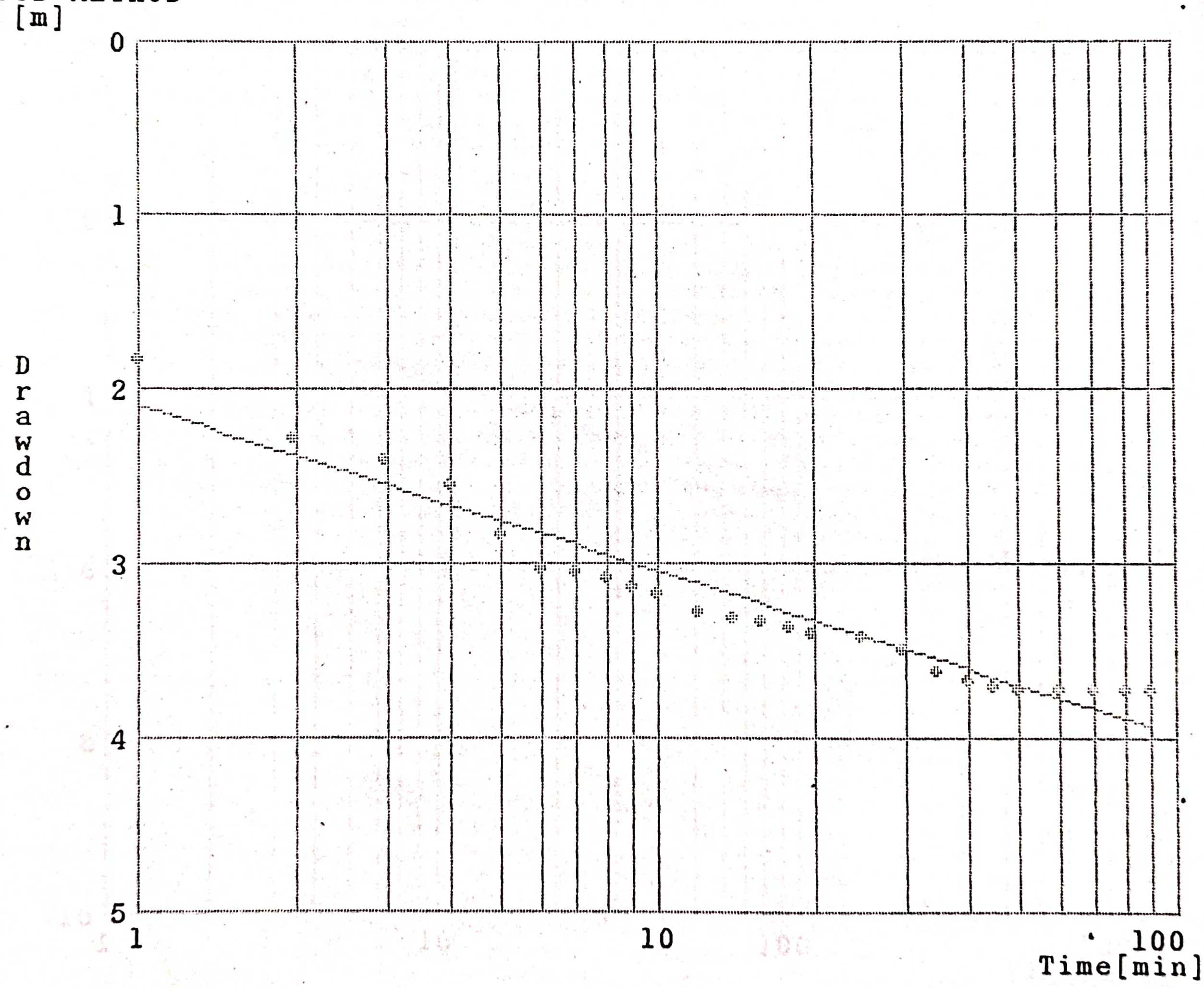
APPENDIX 5/6

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 13 SULTANPUR

Constant Pumping Rate = 1.410 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.18 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 24. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1255 [m]
A0 = 0.209264E+01
A1 = 0.944031E+00
Number of Points = 25 of 25

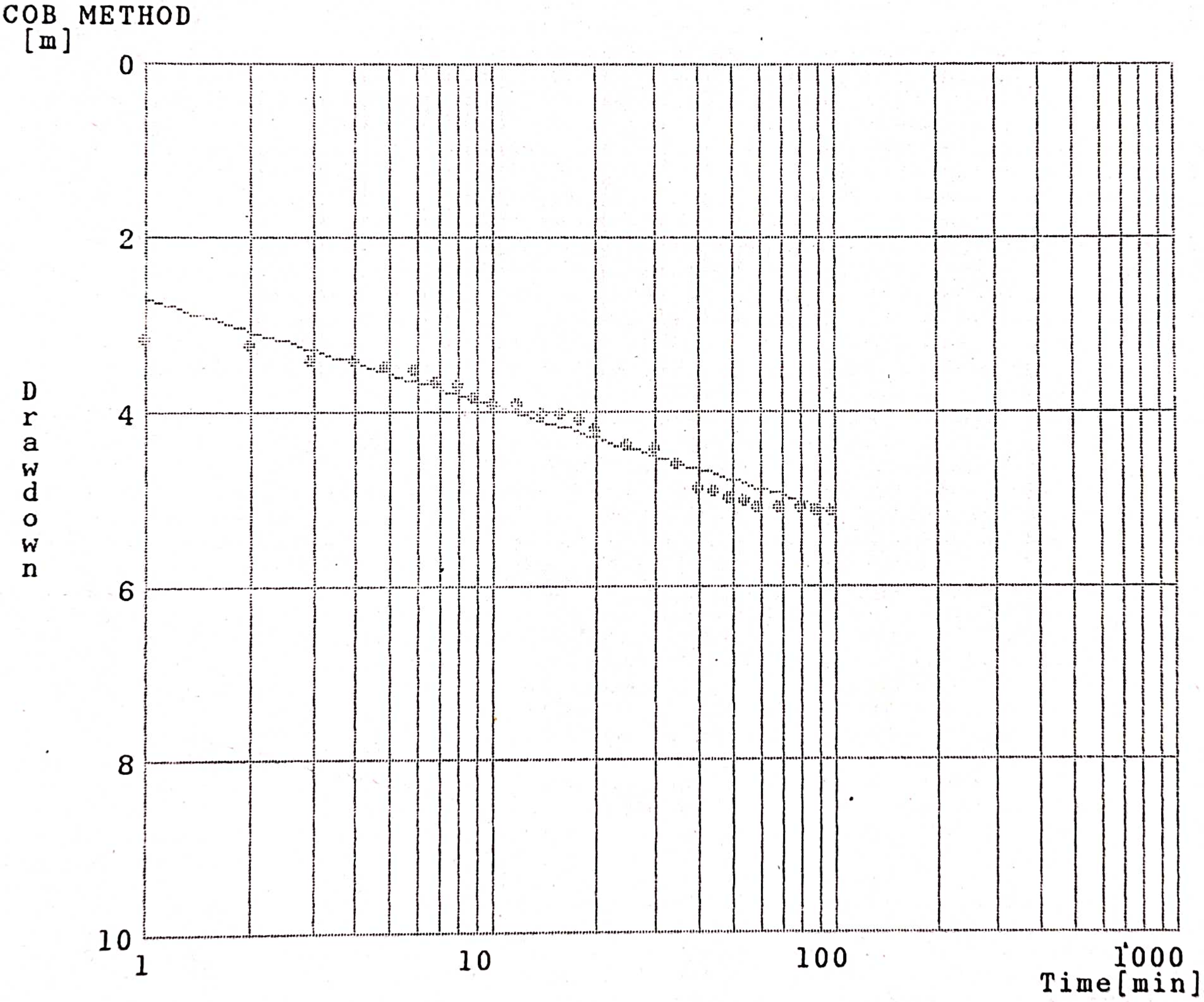
APPENDIX 5/7

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 15 AMUWA

Constant Pumping Rate = 2.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.80 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 26. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1494 [m]
A0 = 0.269389E+01
A1 = 0.122466E+01
Number of Points = 27 of 27

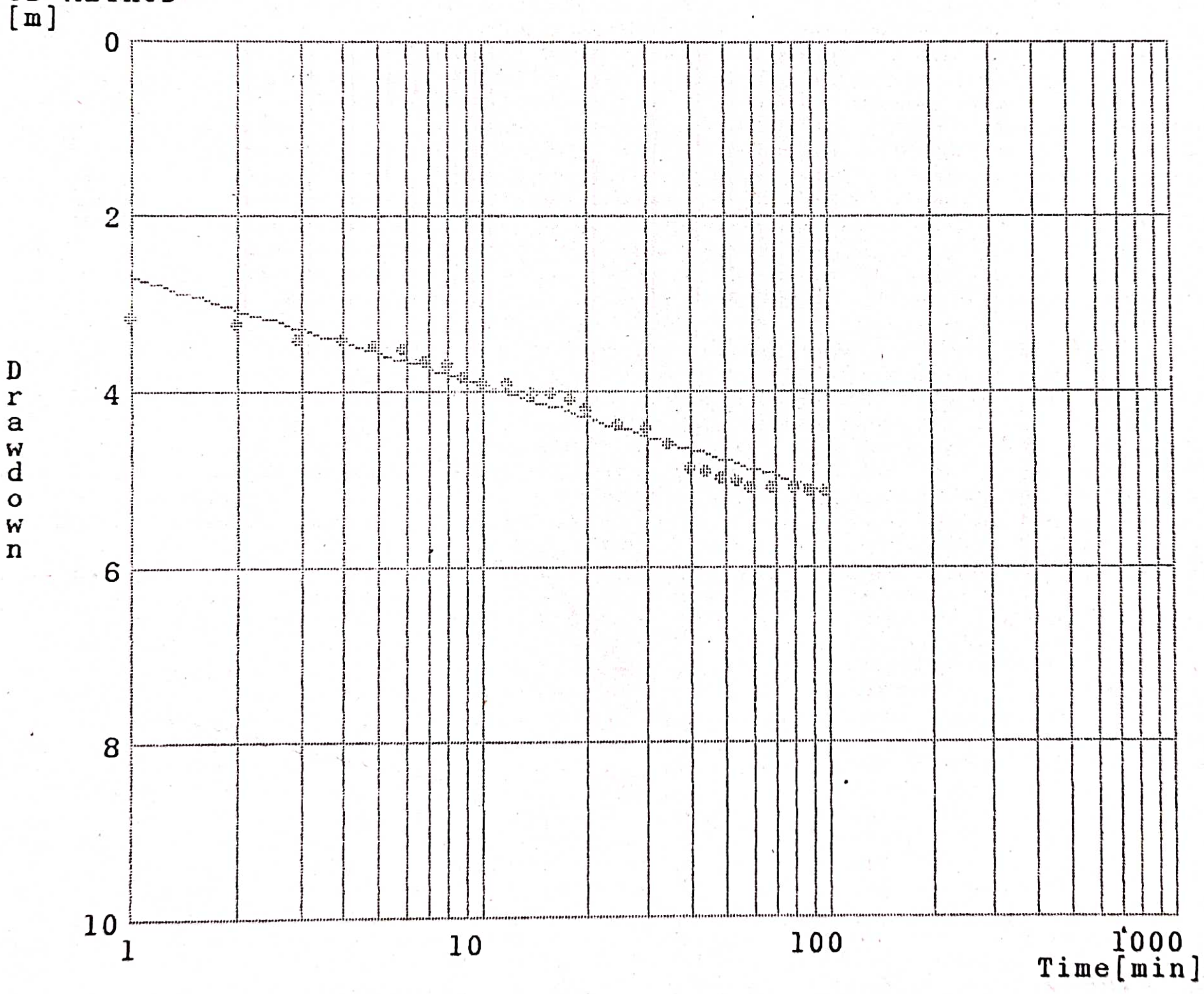
APPENDIX 5/8

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 15 AMUWA

Constant Pumping Rate = 2.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.80 [m]
Well Type = STANDARD

JACOB METHOD



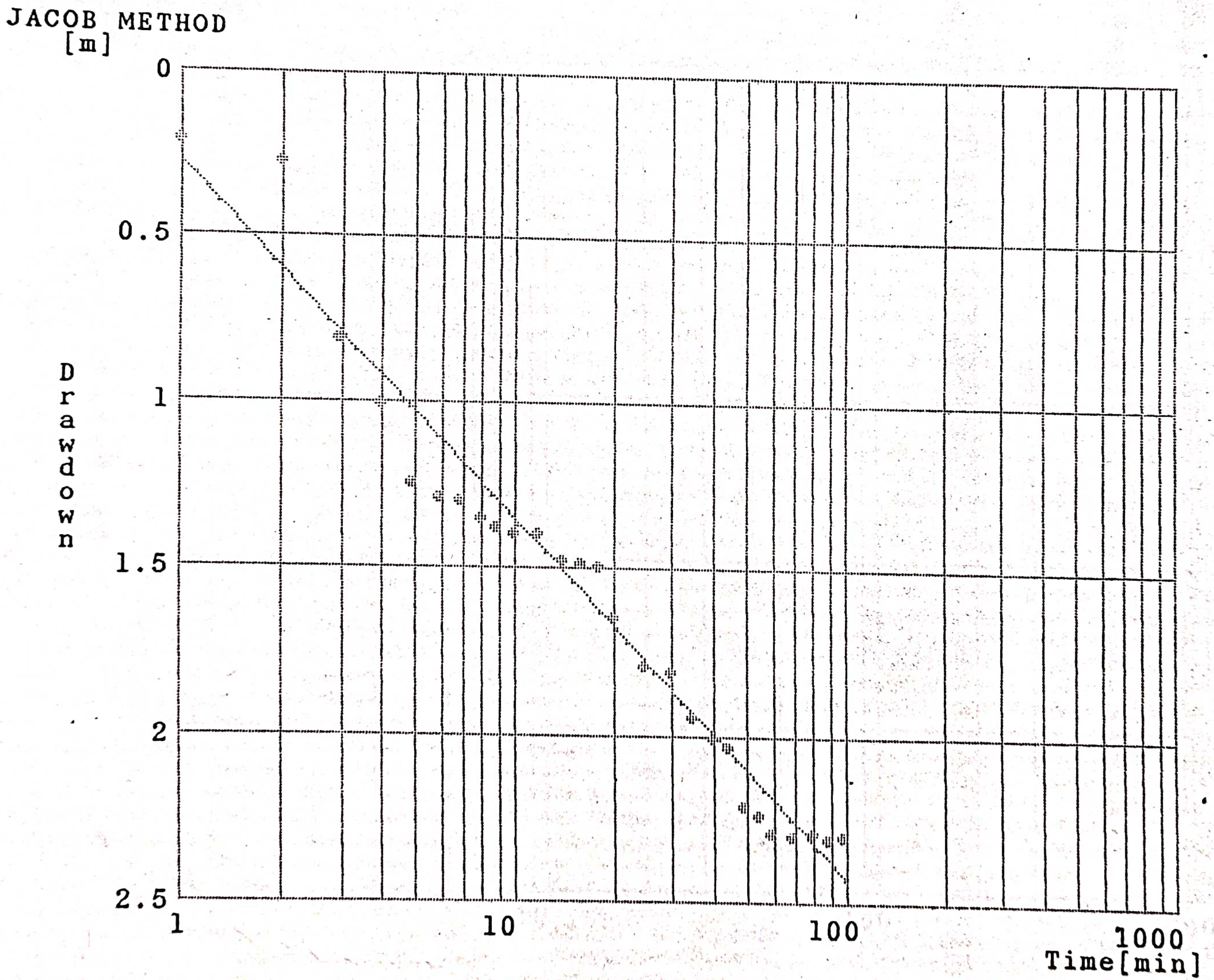
Transmissivity = 26. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1494 [m]
A0 = 0.269389E+01
A1 = 0.122466E+01
Number of Points = 27 of 27

APPENDIX 5/8

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 16 MAHUWA

Constant Pumping Rate = 2.2 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.90 [m]
Well Type = STANDARD



Transmissivity = 33. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1080 [m]
A0 = 0.273006E+00
A1 = 0.107631E+01
Number of Points = 27 of 27

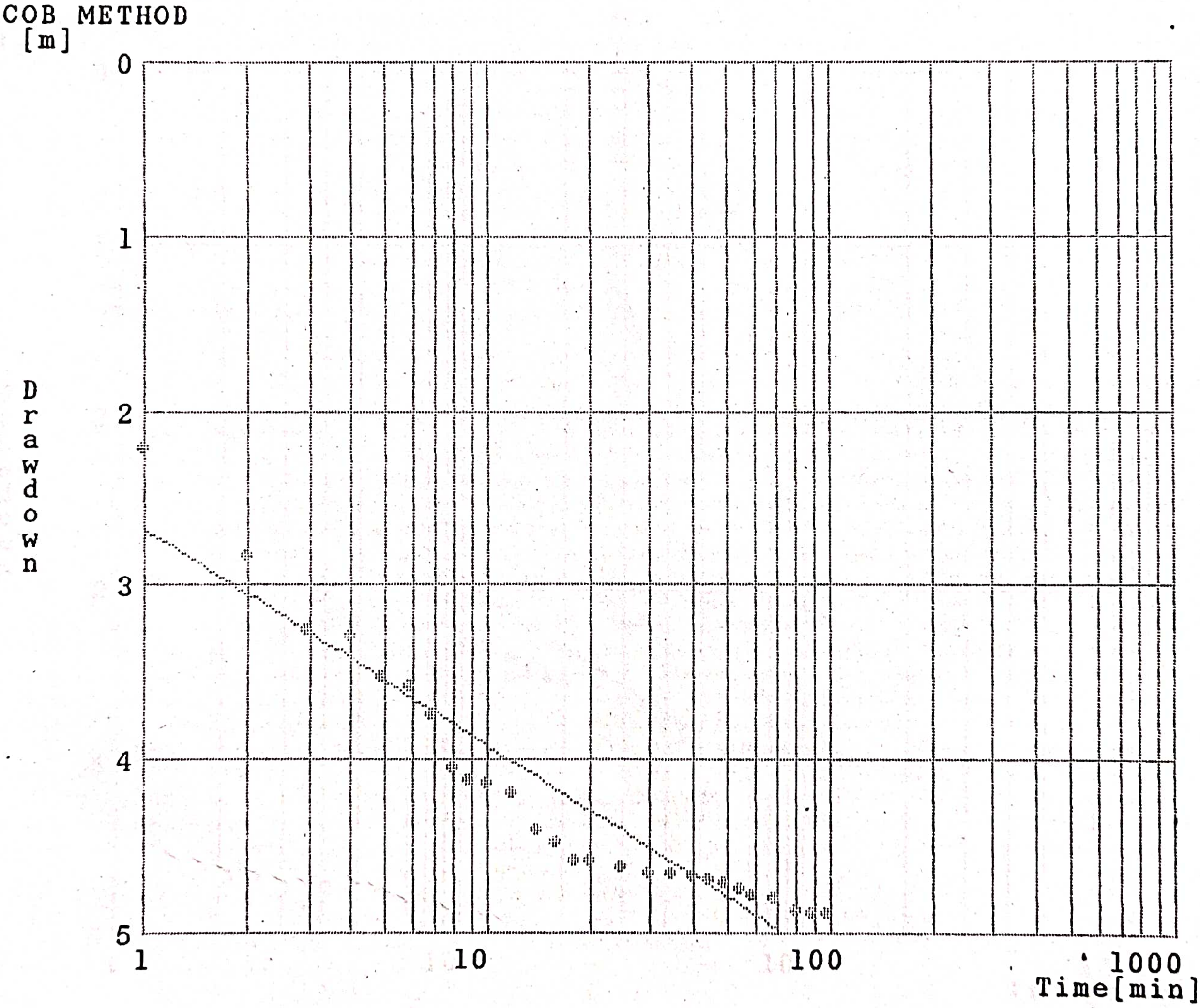
APPENDIX 5/9

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 17 BABUDIHAWA

Constant Pumping Rate = 0.250 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.12 [m]
Well Type = STANDARD

JACOB METHOD



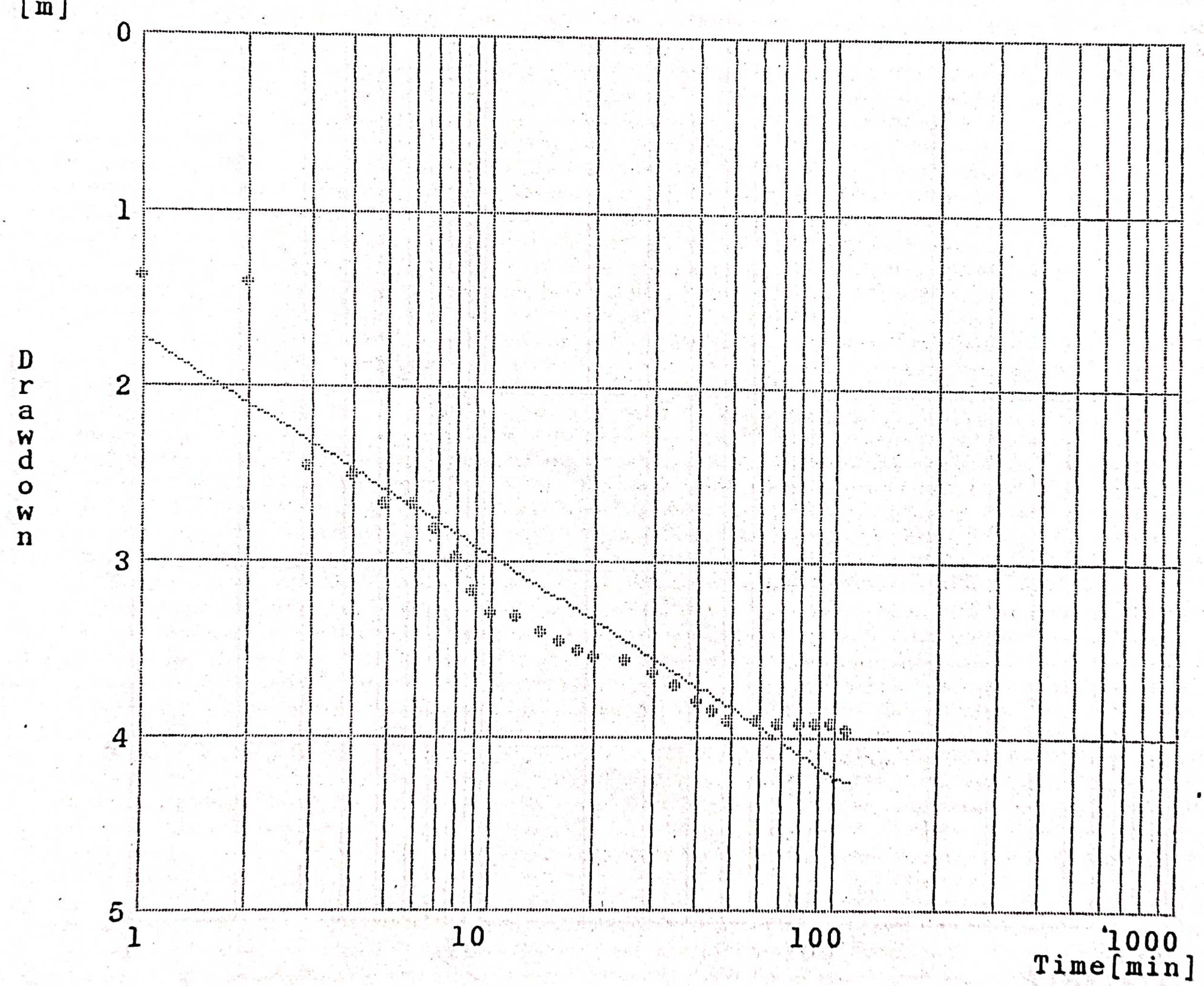
Transmissivity = 3. [m2/day]
Storage Coefficient =
Standard Deviation = 0.2069 [m]
A0 = 0.267365E+01
A1 = 0.124296E+01
Number of Points = 27 of 27

Project : NEP/86/025 KAPILVASTU
Organization : UNDP/GWRDB

Test : STW 19 JURPANIYA

Constant Pumping Rate = 5.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.78 [m]
Well Type = STANDARD

JACOB METHOD



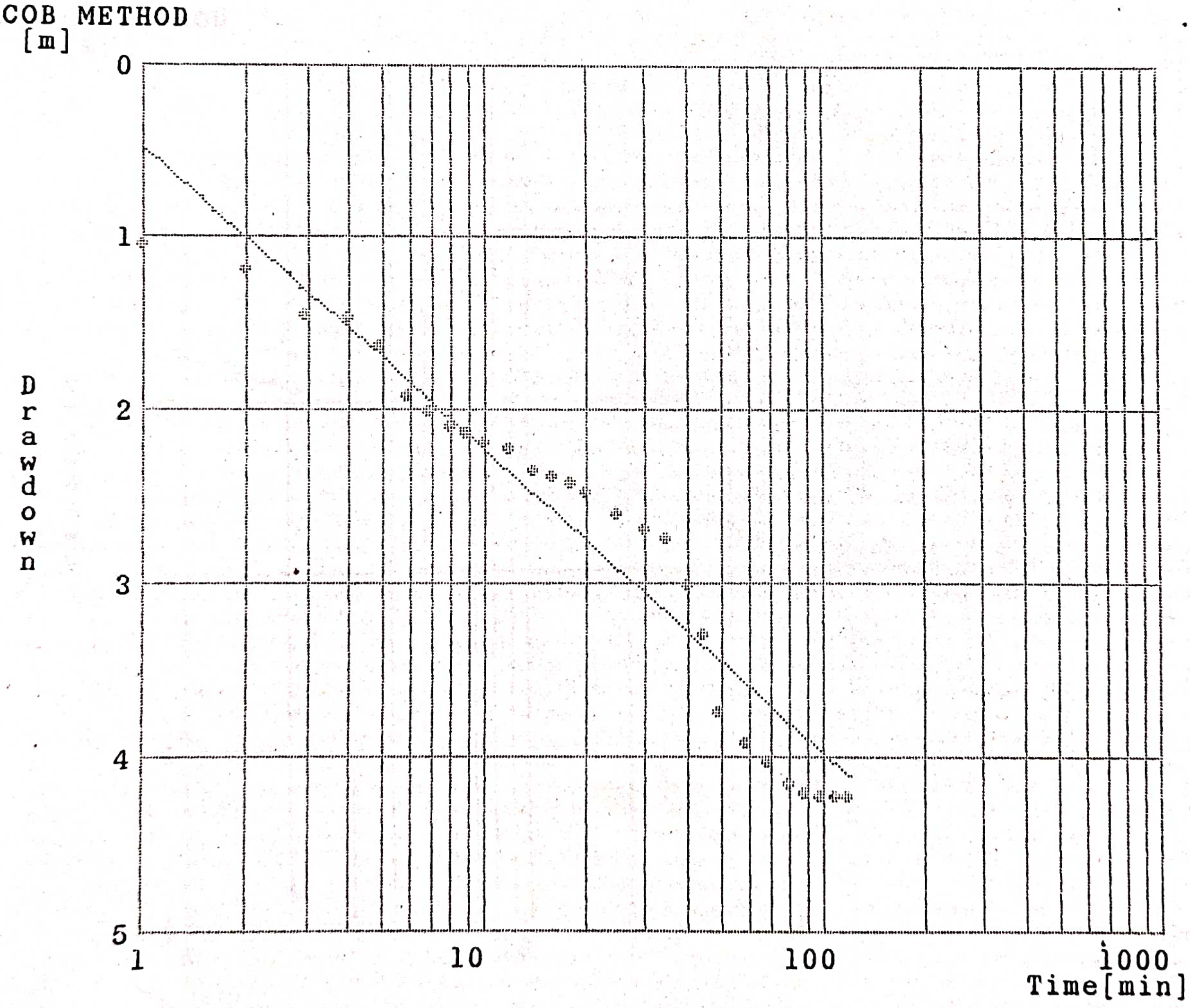
Transmissivity = 64. [m2/day]
Storage Coefficient =
Standard Deviation = 0.2260 [m]
A0 = 0.172101E+01
A1 = 0.124347E+01
Number of Points = 27 of 27

Project : NEP/86/025 KAPILVASTU
Organization : UNDP/GWRDB

Test : STW 21 GORUSINGHE

Constant Pumping Rate = 11.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.10 [m]
Well Type = STANDARD

JACOB METHOD



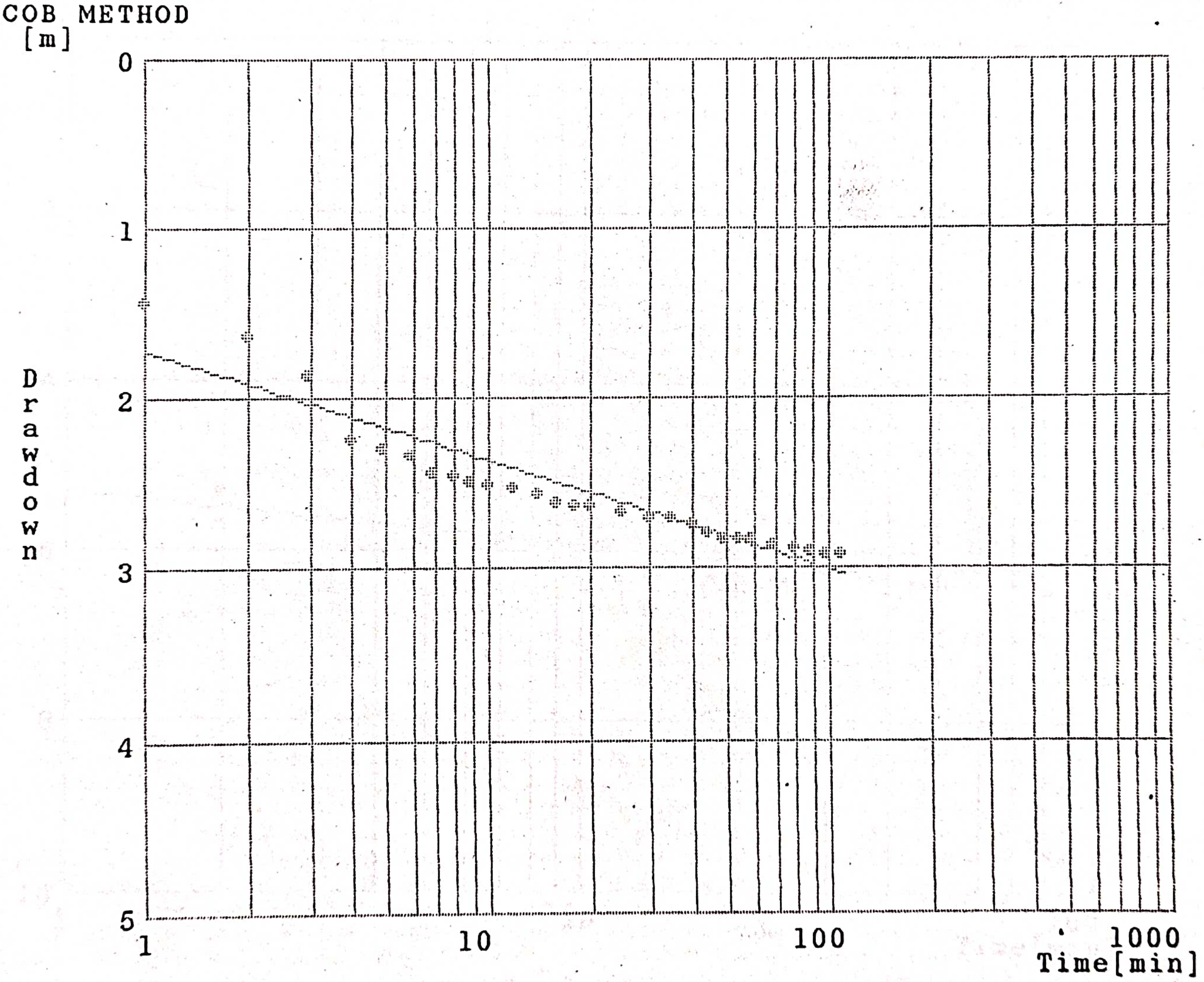
Transmissivity = 99. [m2/day]
Storage Coefficient =
Standard Deviation = 0.2492 [m]
A0 = 0.479214E+00
A1 = 0.174921E+01
Number of Points = 28 of 28

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW 22 BHITRIYA

Constant Pumping Rate = 2.000 [l/s]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.85 [m]
Well Type = STANDARD

JACOB METHOD



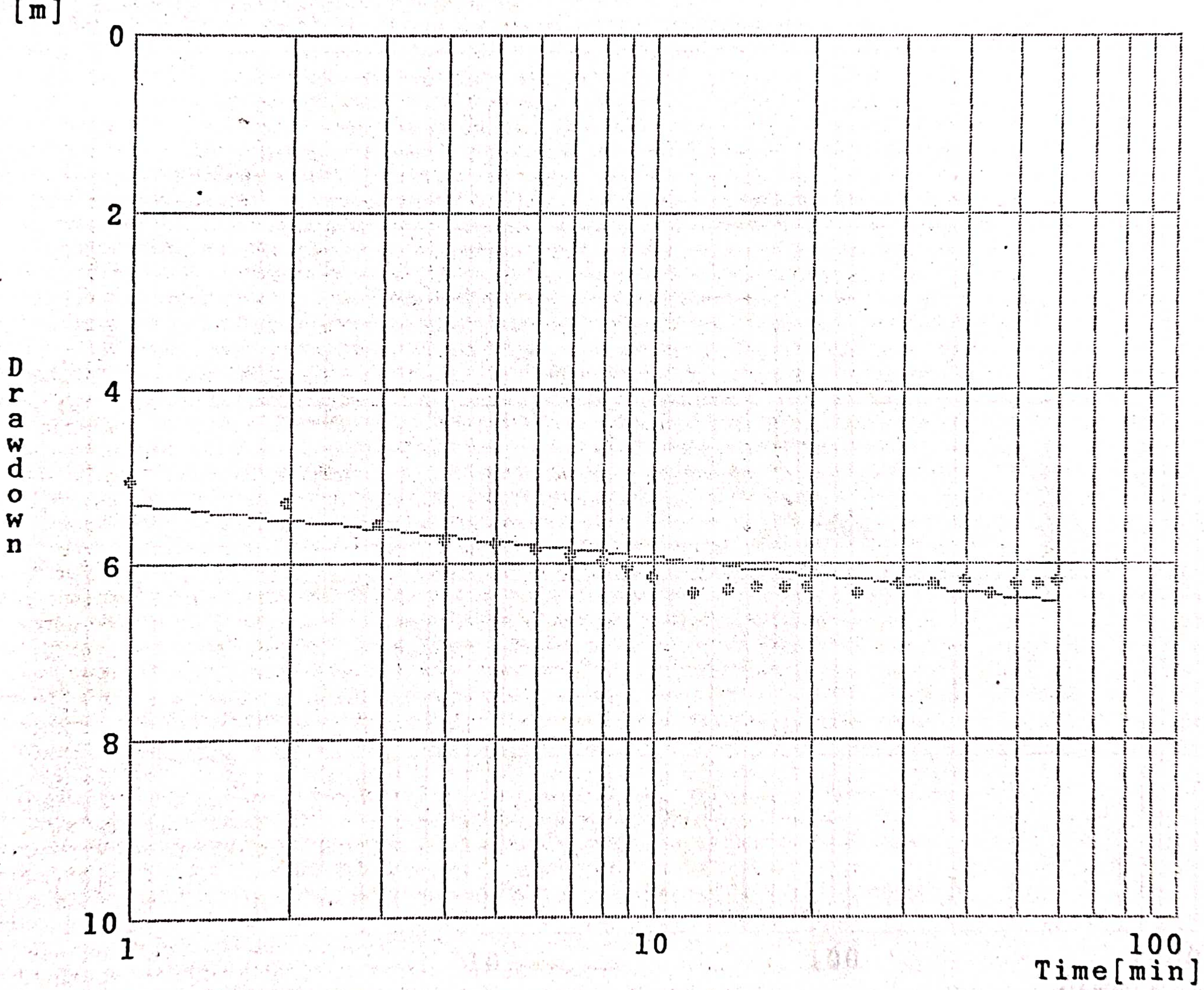
Transmissivity = 49. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1215 [m]
A0 = 0.171770E+01
A1 = 0.645071E+00
Number of Points = 28 of 28

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW (ADBN) BHALWAR

Constant Pumping Rate = 24.000 [L/S]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -0.99 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 599. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1655 [m]
A0 = 0.530072E+01
A1 = 0.633451E+00
Number of Points = 23 of 23

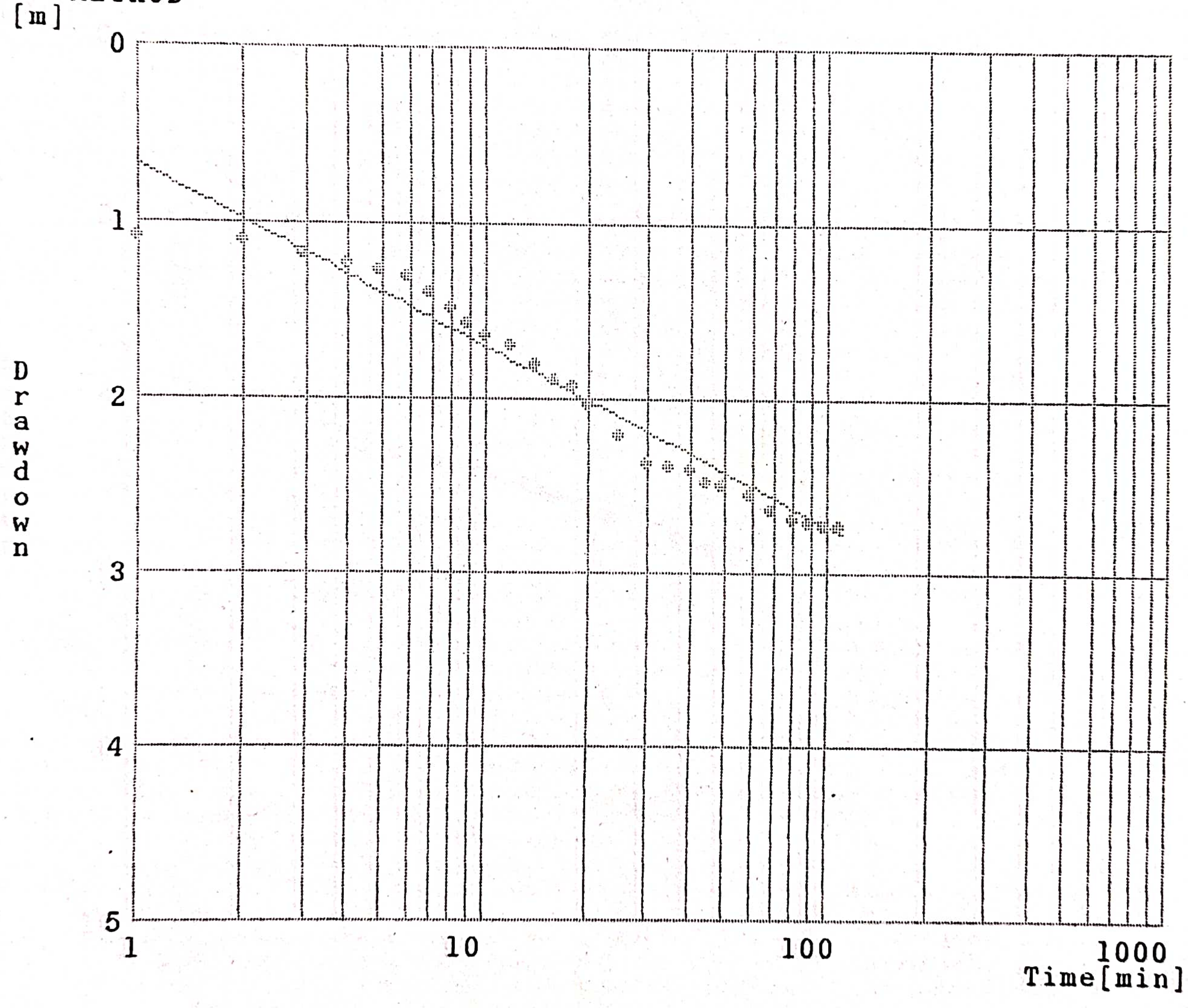
APPENDIX 5/14

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW (ADBN) BIRPUR

Constant Pumping Rate = 2.500 [L/S]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.82 [m]
Well Type = STANDARD

JACOB METHOD



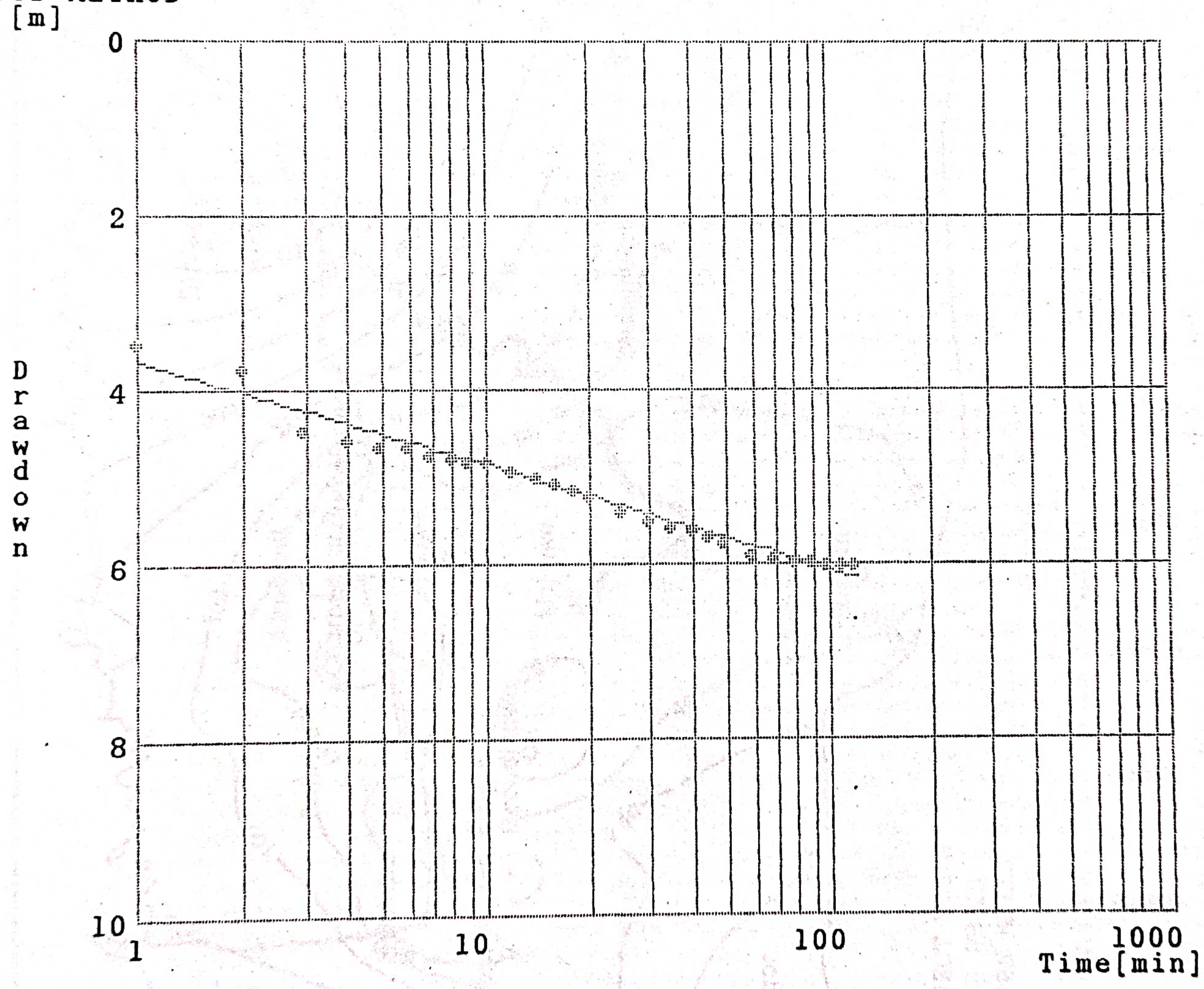
Transmissivity = 38. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1199 [m]
A0 = 0.666970E+00
A1 = 0.102784E+01
Number of Points = 27 of 27

Project : NEP/86/025 (KAPILVASTU)
Organization : UNDP/GWRDB

Test : STW (ADBN) BALAPUR

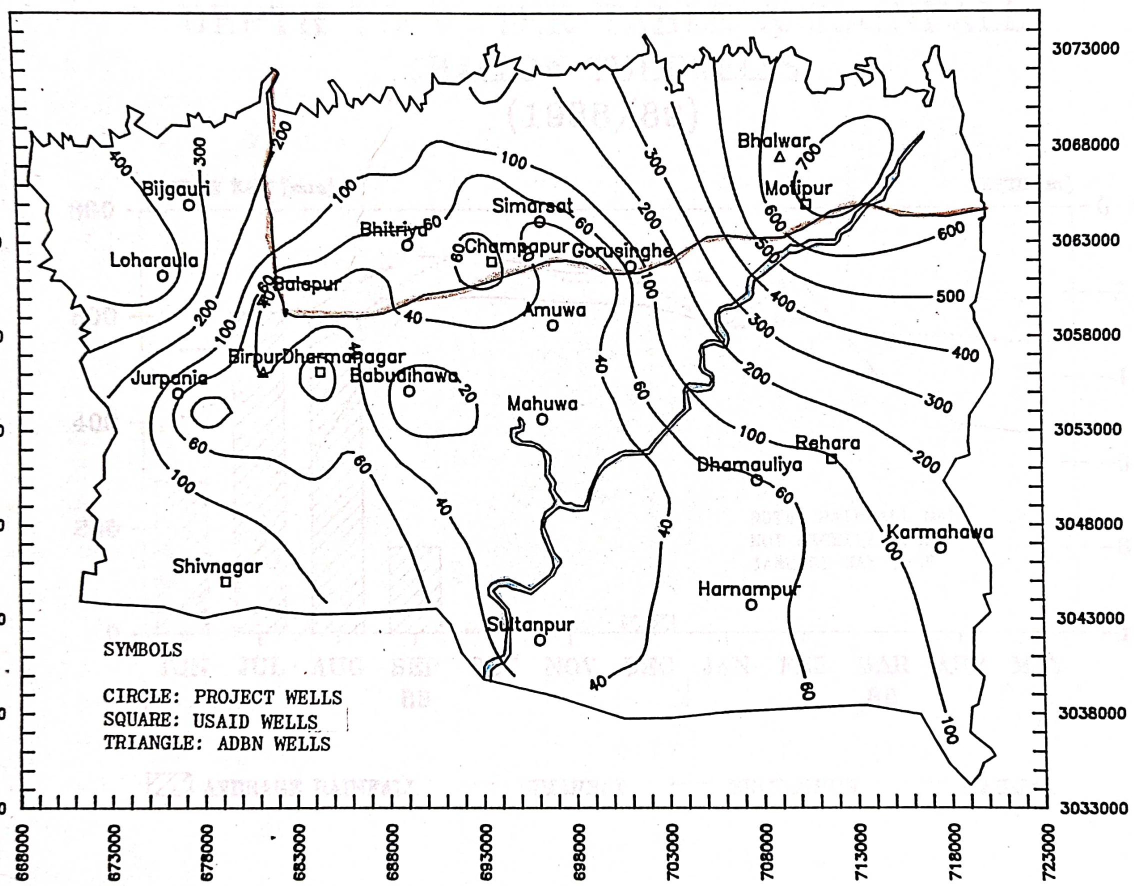
Constant Pumping Rate = 0.7 [L/S]
Distance from Observation Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 0.75 [m]
Well Type = STANDARD

JACOB METHOD



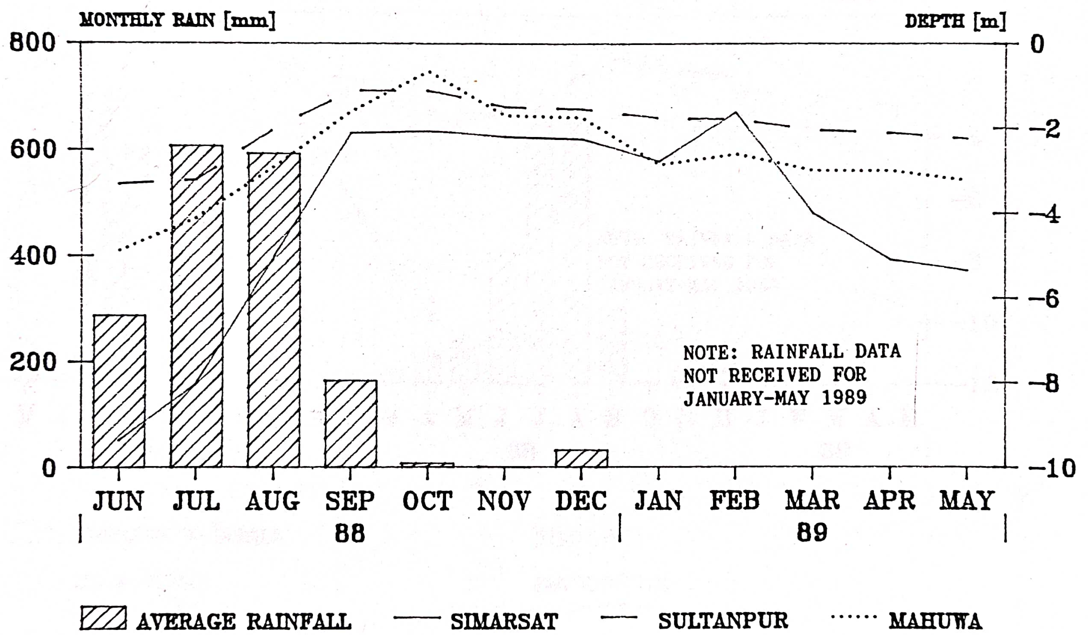
Transmissivity = 9. [m2/day]
Storage Coefficient =
Standard Deviation = 0.1014 [m]
A0 = 0.365917E+01
A1 = 0.119435E+01
Number of Points = 28 of 28

KAPILVASTU TERAI - TRANSMISSIVITIES (M2/DAY)



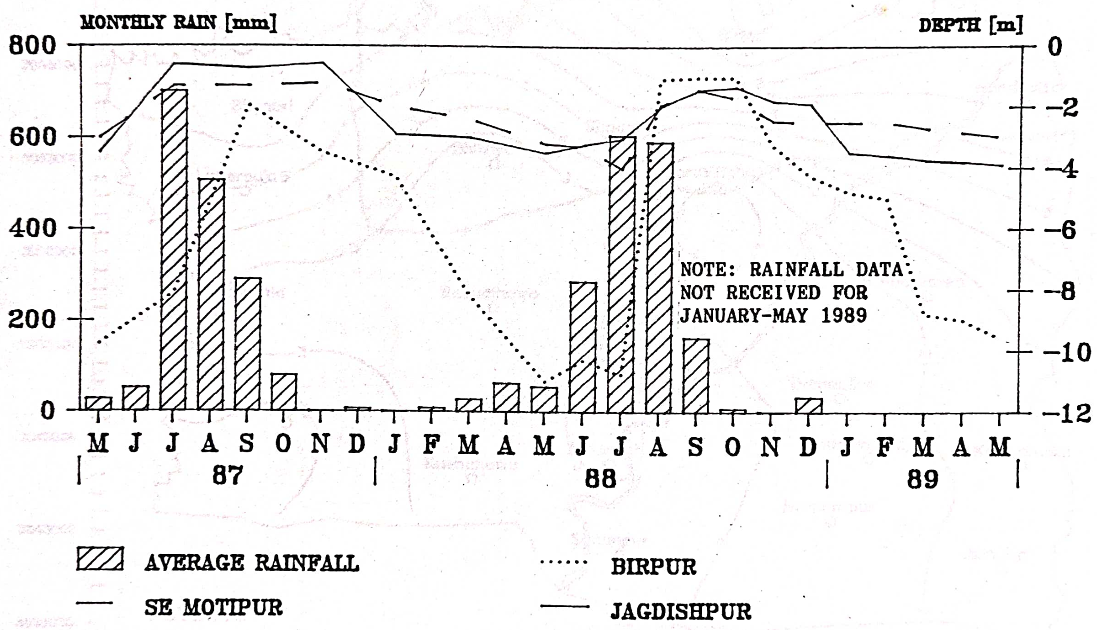
APPENDIX 6

DEPTH TO WATER TABLE & RAINFALL
SHALLOW TUBEWELLS
(1988/89)



APPENDIX 7/1

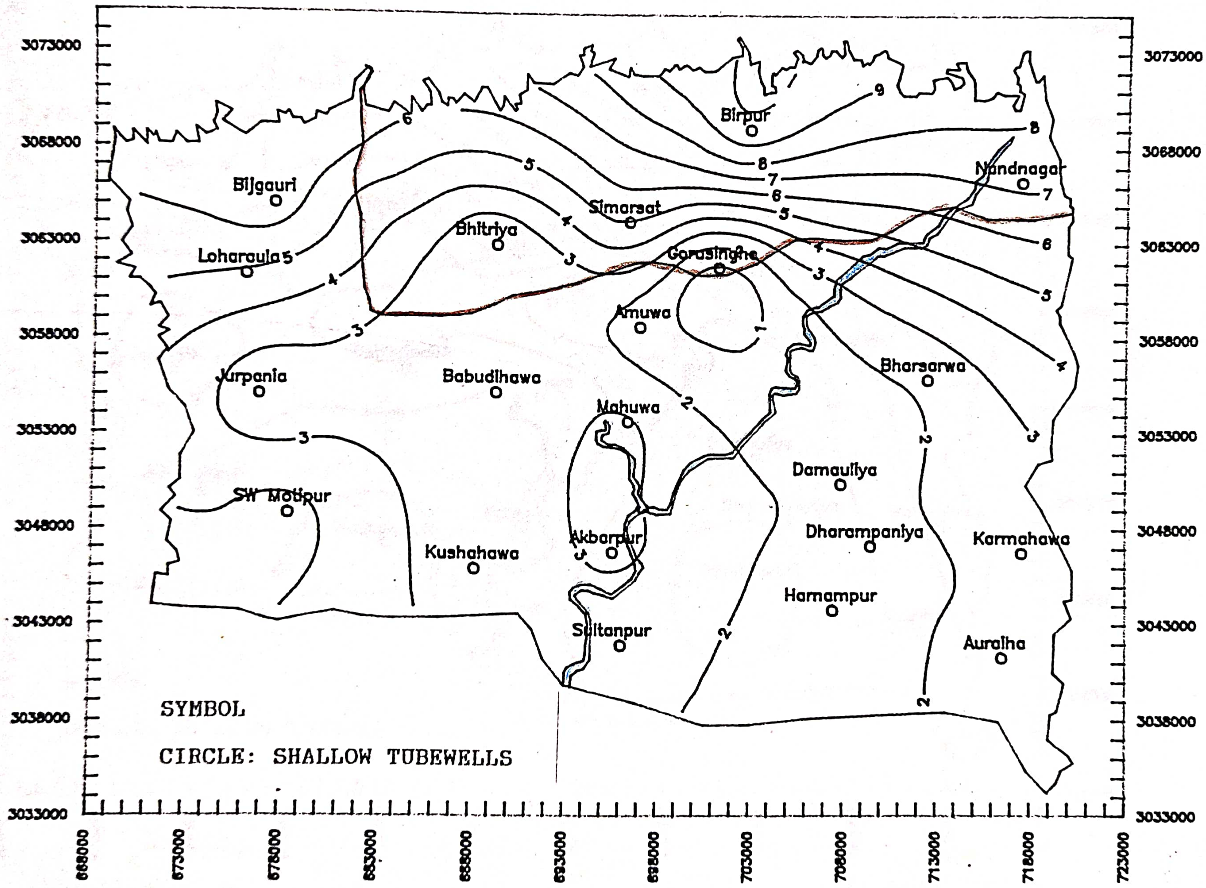
DEPTH TO WATER TABLE & RAINFALL
DUGWELLS
(1987, '88 & '89)



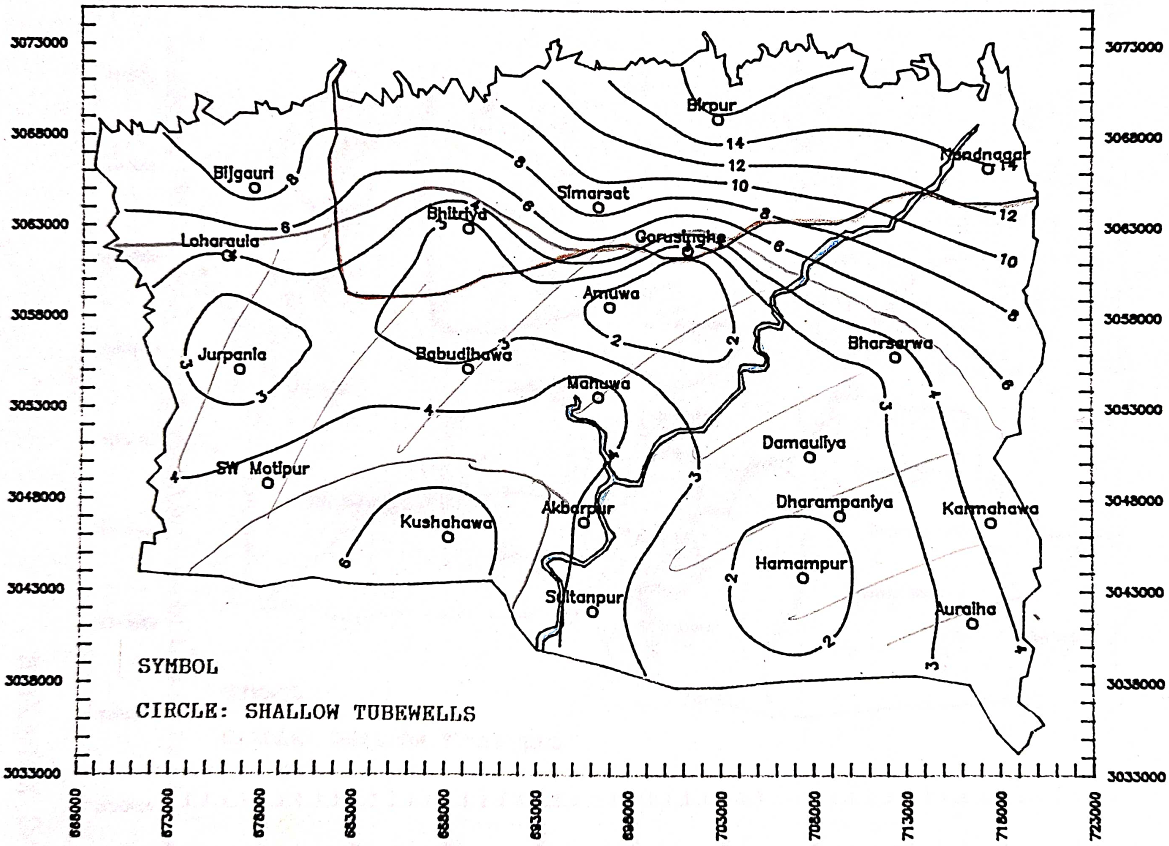
APPENDIX 7/2

APPENDIX 8/1

KAPILVASTU TERAI - DEPTH TO WATER TABLE MAY 1989

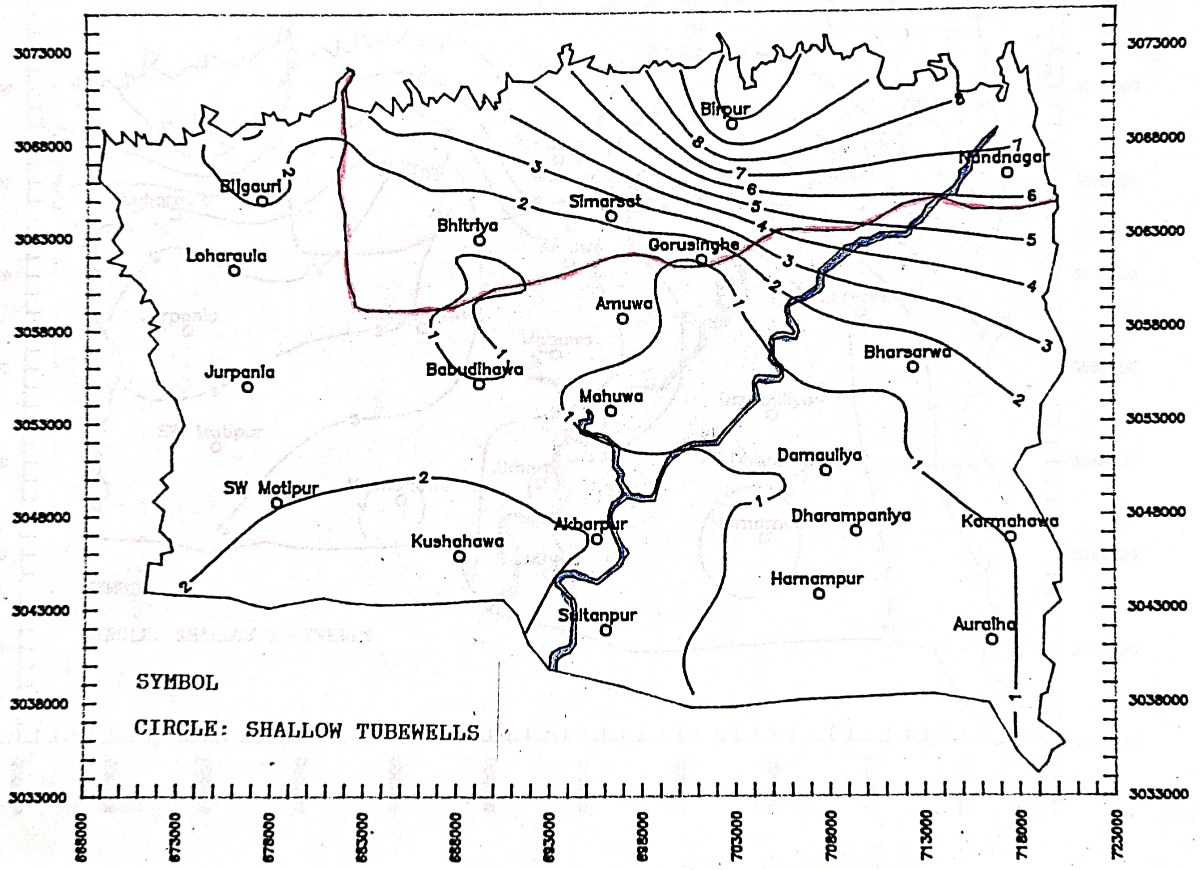


KAPILVASTU TERAI - DEPTH TO WATER TABLE JUN 1988



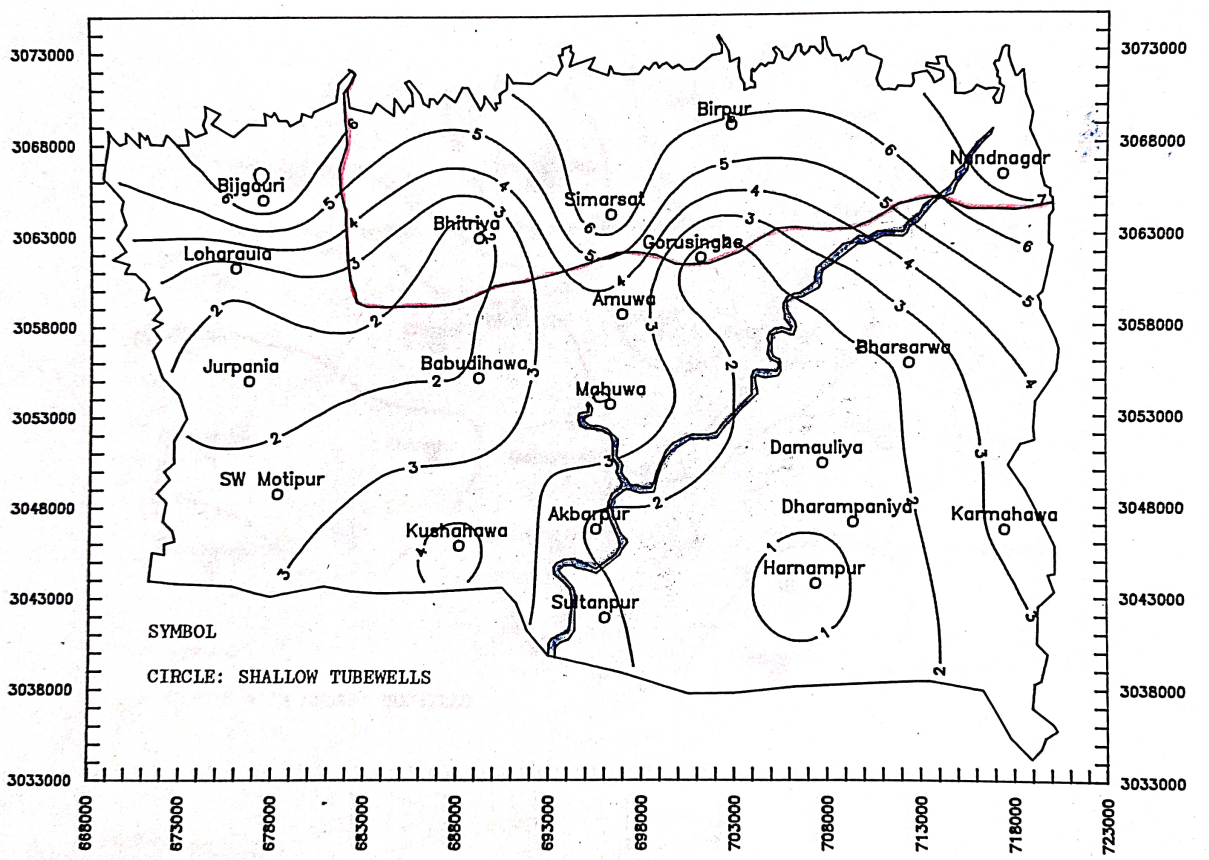
APPENDIX 8/2

KAPILVASTU TERAI - DEPTH TO WATER TABLE OCT 1988



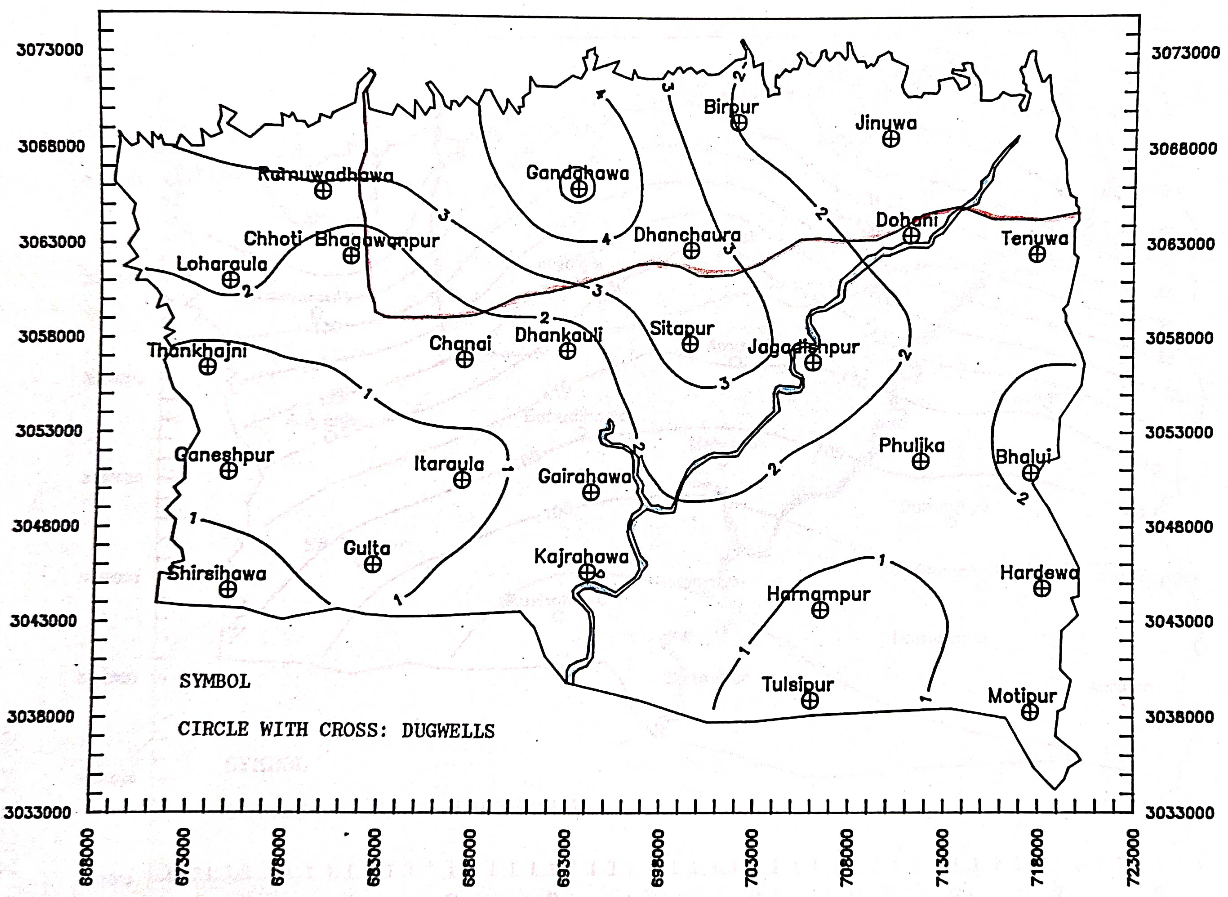
APPENDIX 8/3

KAPILVASTU TERAI - RISE OF WATER TABLE JUN-OCT 1988



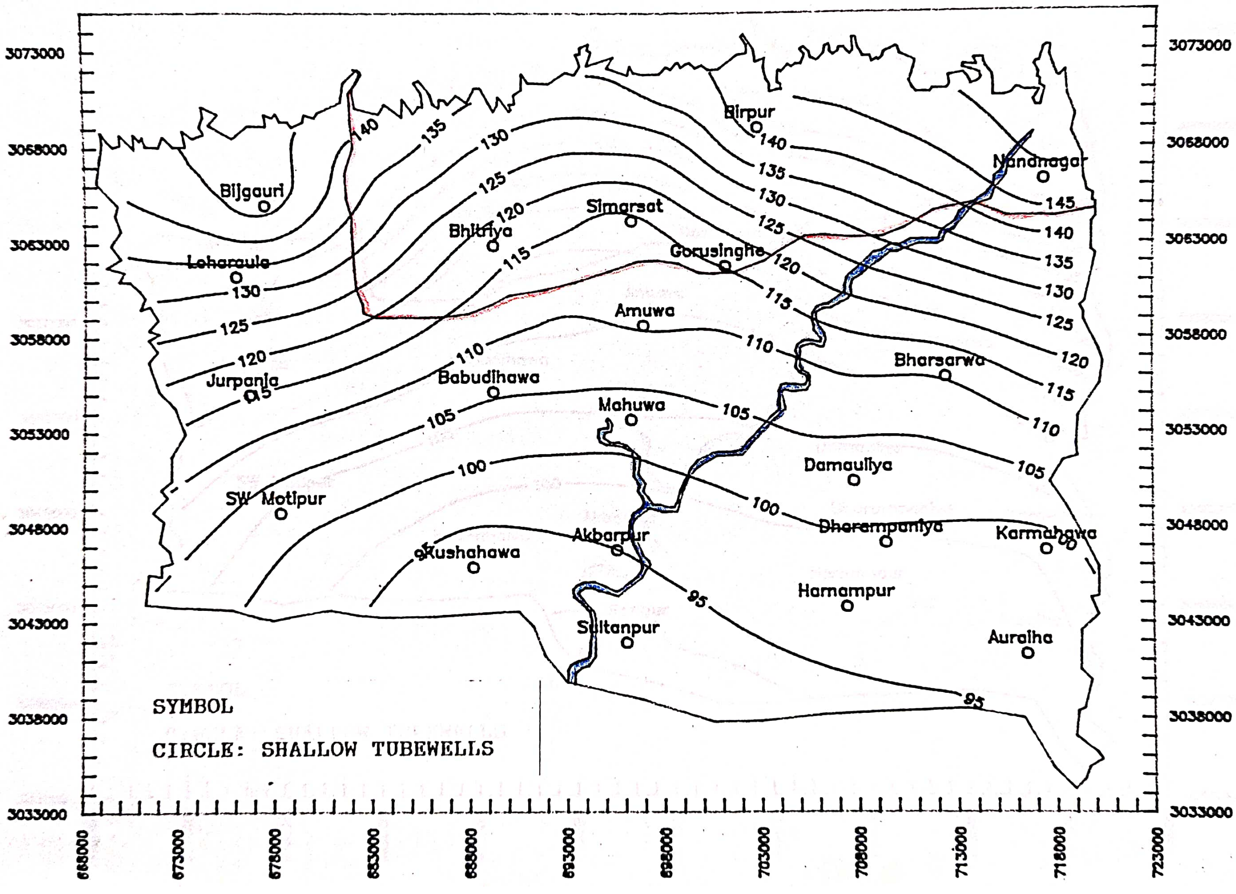
APPENDIX 8/4

KAPILVASTU TERAI - RISE OF WATER TABLE MAY-SEP 1987



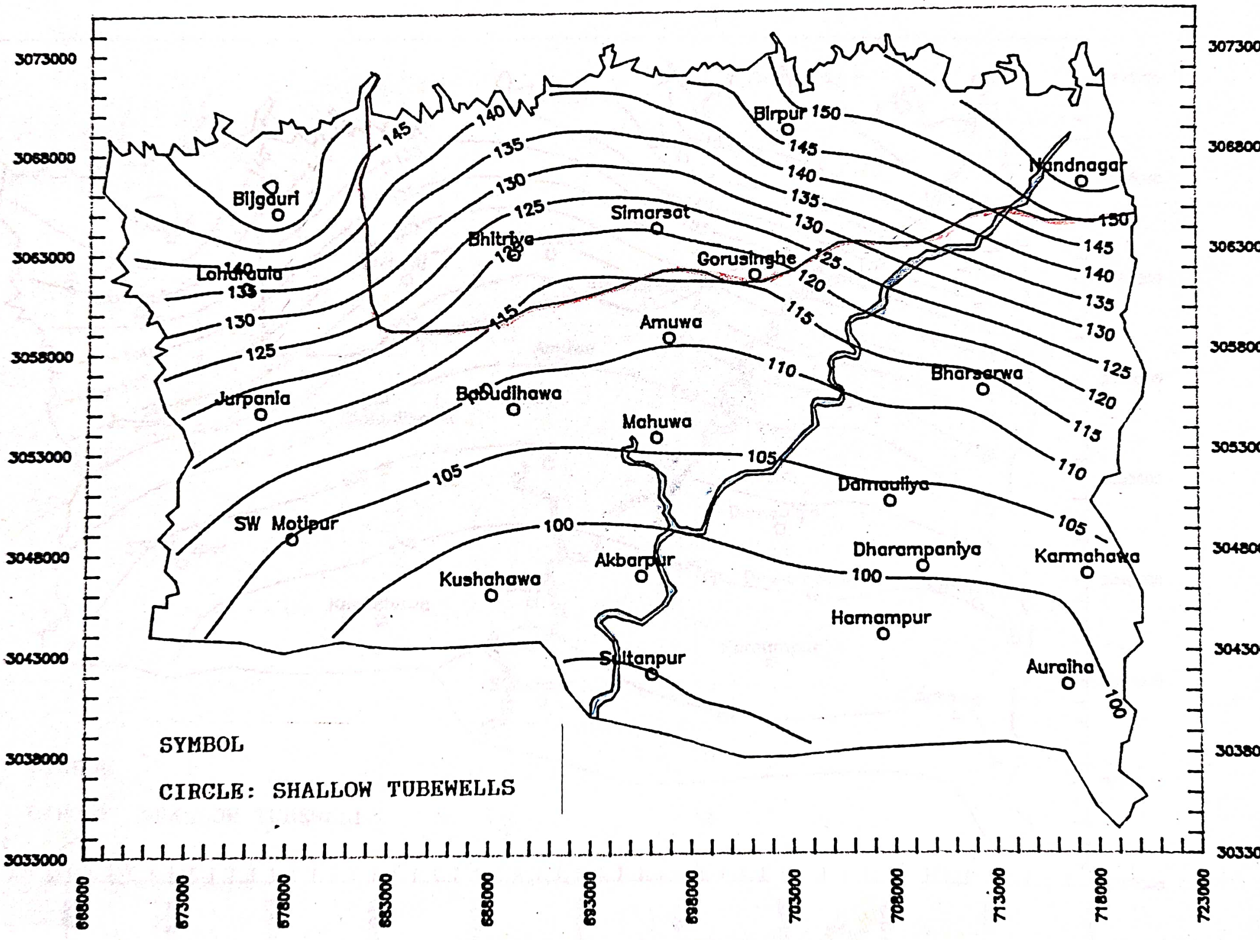
APPENDIX 8/5

KAPILVASTU - WATER LEVEL CONTOUR MAP JUN 1988



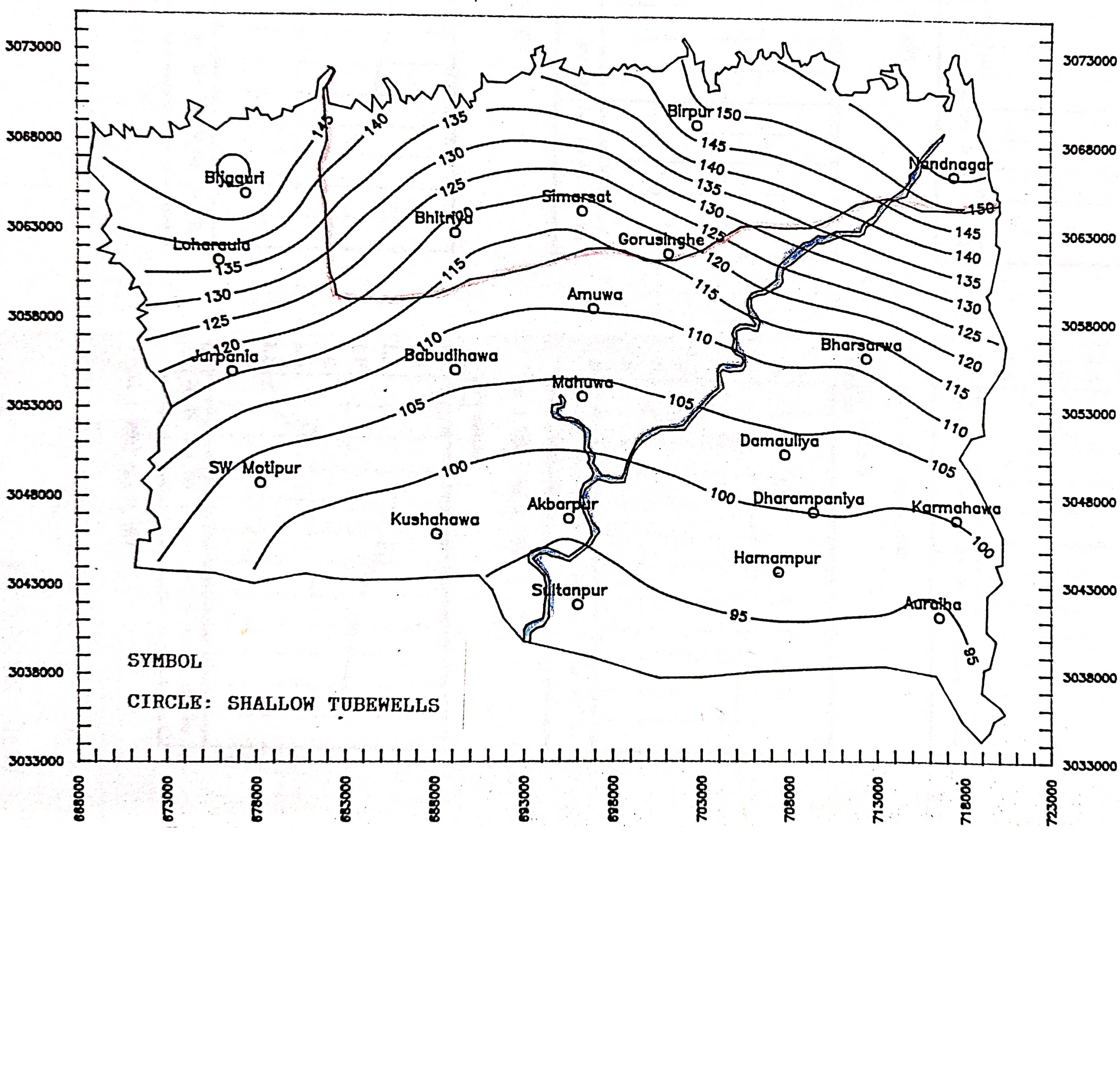
APPENDIX 9/1

KAPILVASTU - WATER LEVEL CONTOUR MAP OCT 1988



APPENDIX 9/2

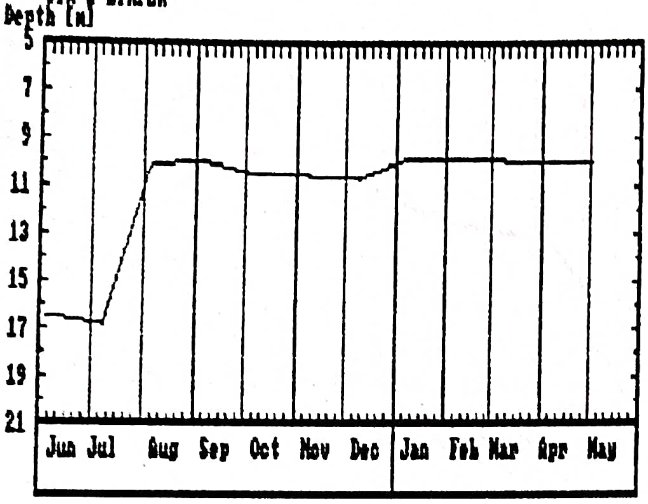
KAPILVASTU - WATER LEVEL CONTOUR MAP MAY 1989



APPENDIX 9/3

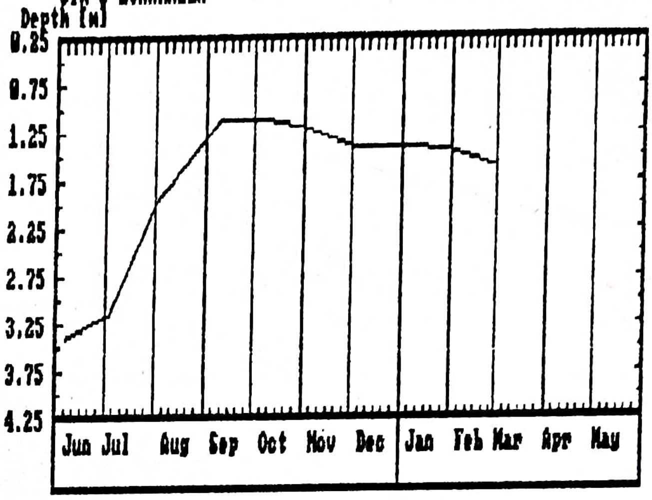
HYDROGRAPHS

STW-2 BIRPUR



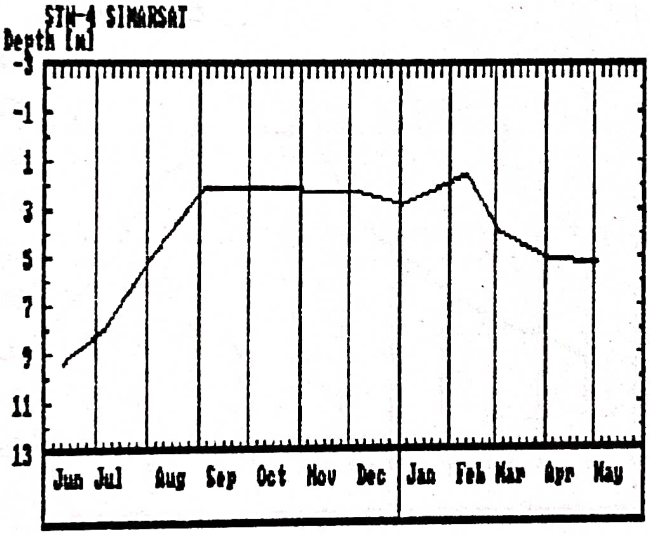
Jun 1, 1988 -- May 31, 1989

STW-6 LOHARAULA



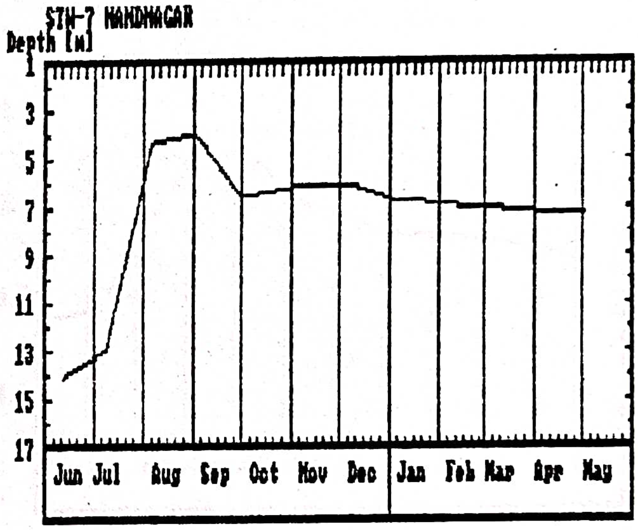
Jun 1, 1988 -- May 31, 1989

STW-4 SIMARSAT



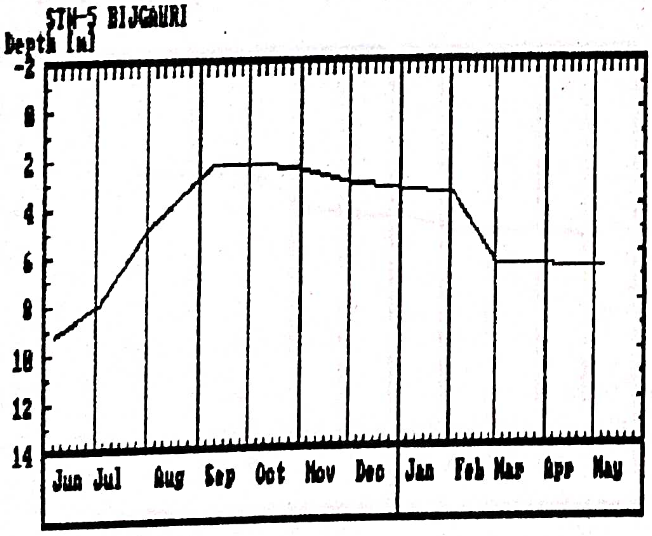
Jun 1, 1988 -- May 31, 1989

STW-7 NANDNAGAR



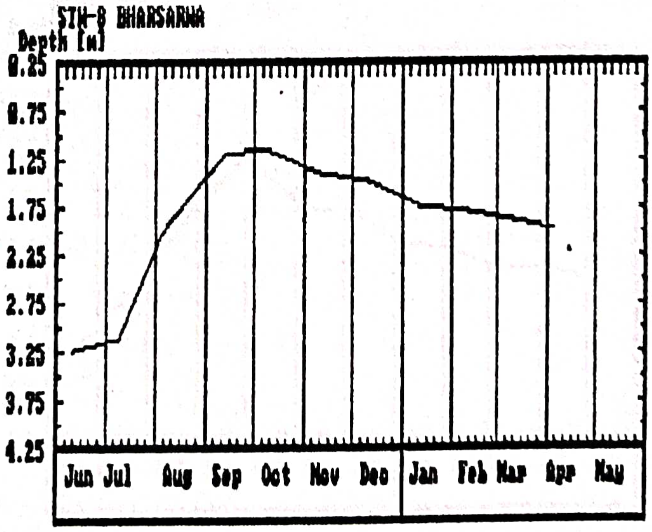
Jun 1, 1988 -- May 31, 1989

STW-5 BIJGAURI



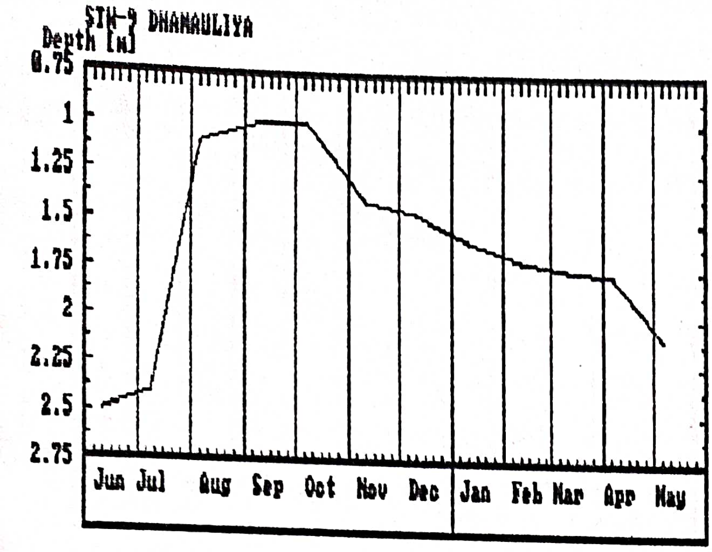
Jun 1, 1988 -- May 31, 1989

STW-8 BHARSARWA

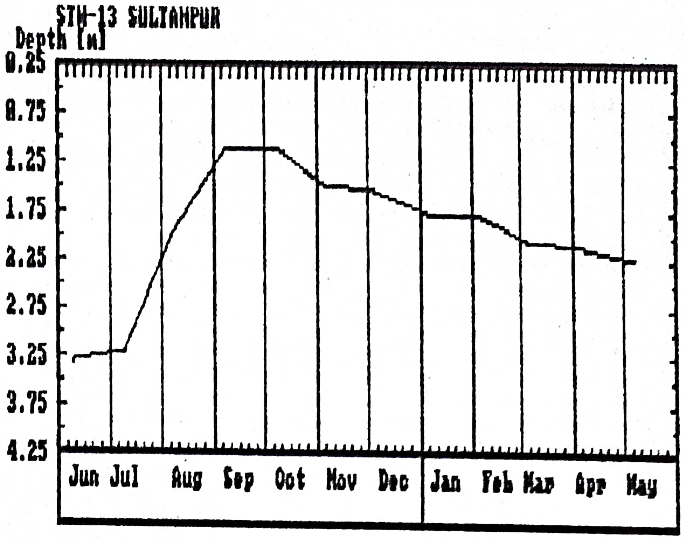


Jun 1, 1988 -- May 31, 1989

HYDROGRAPHS



Jun 1, 1988 -- May 31, 1989



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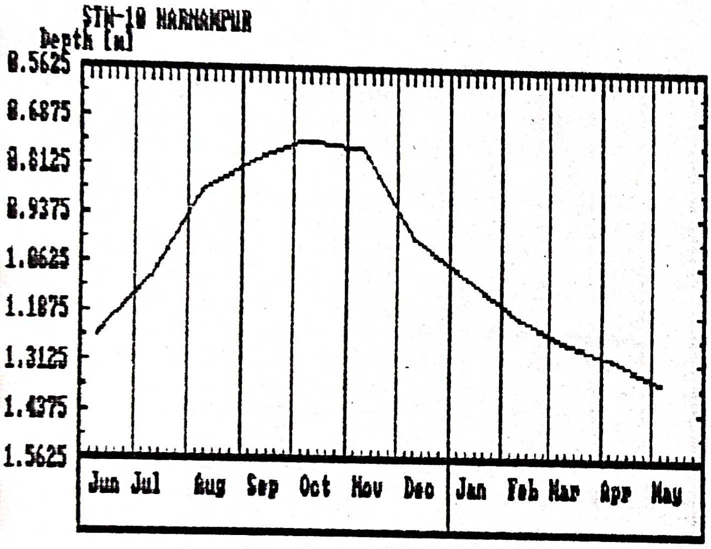

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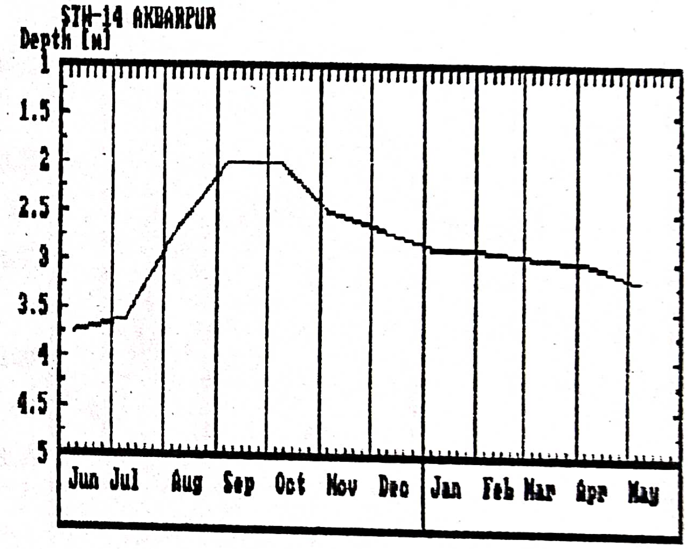

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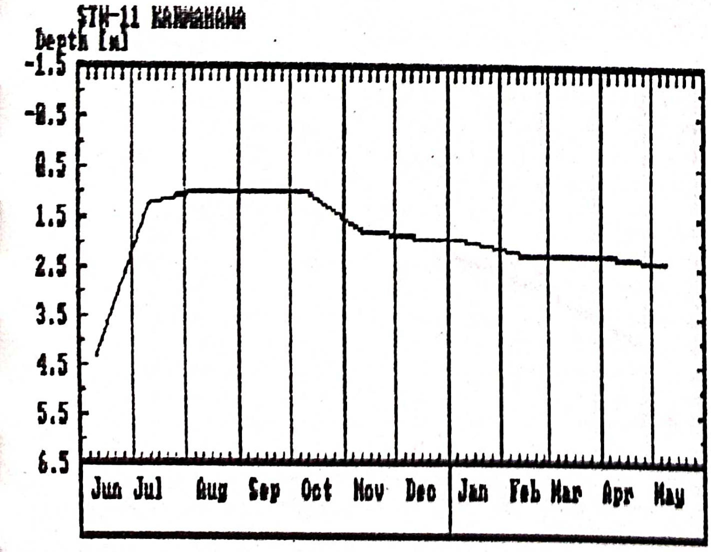

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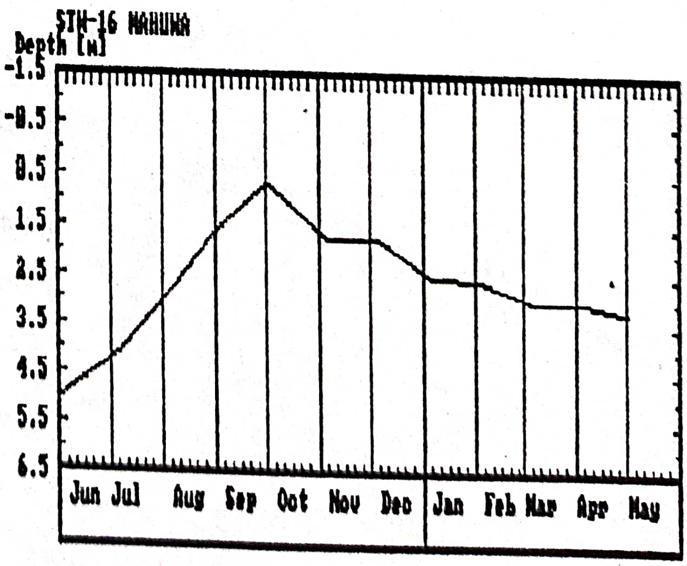
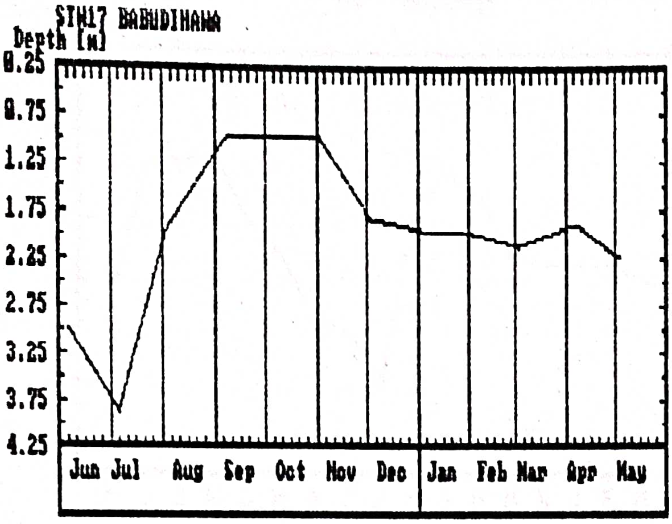


Jun 1, 1988 -- May 31, 1989

HYDROGRAPHS



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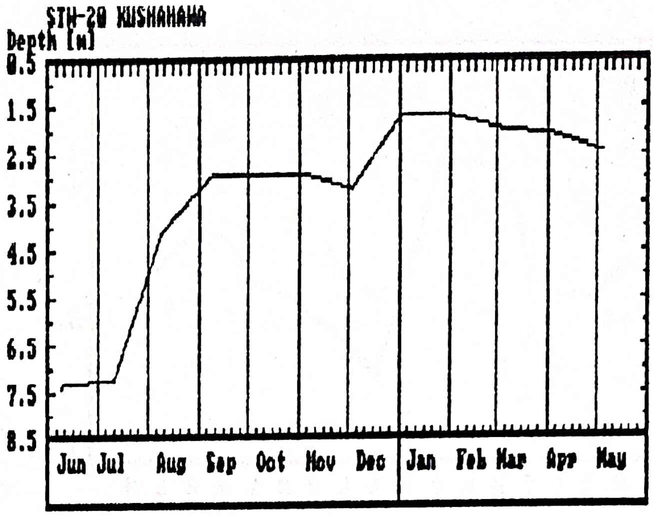

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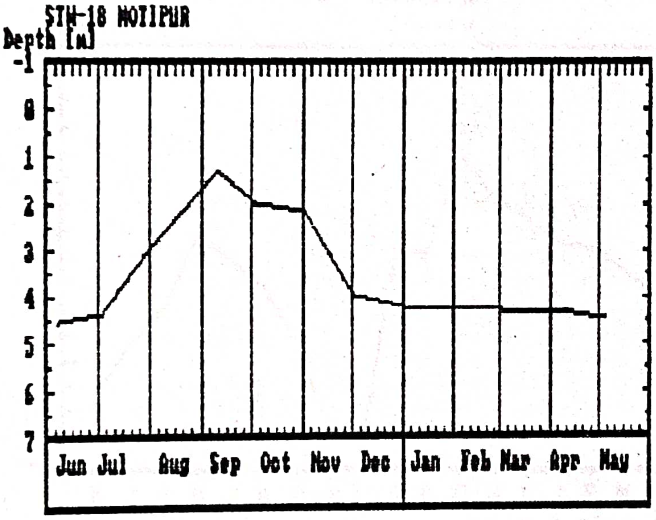

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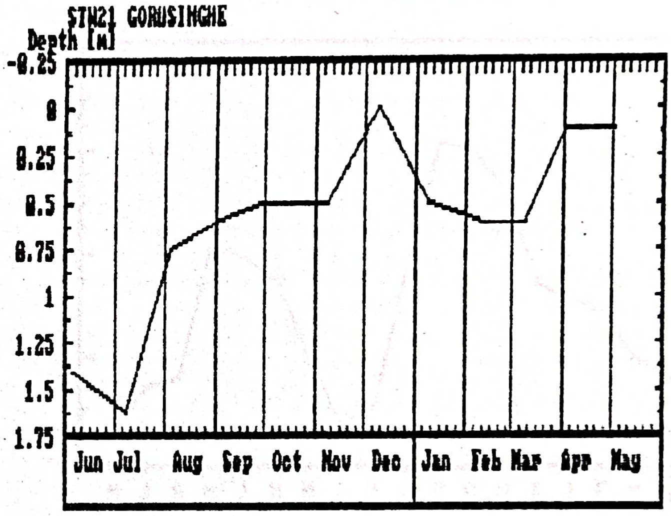

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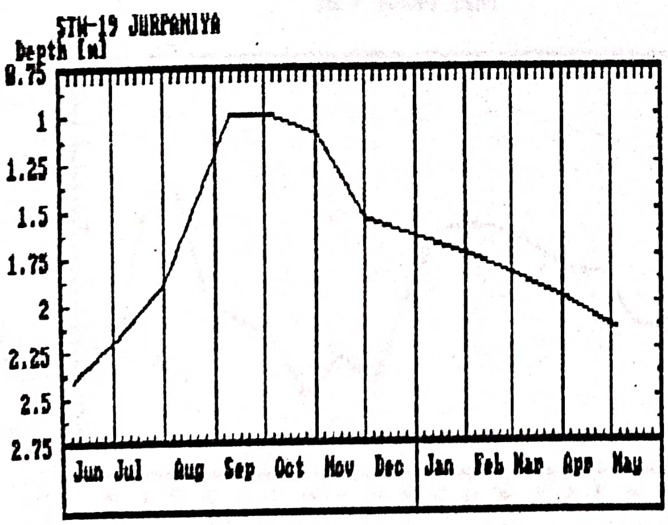

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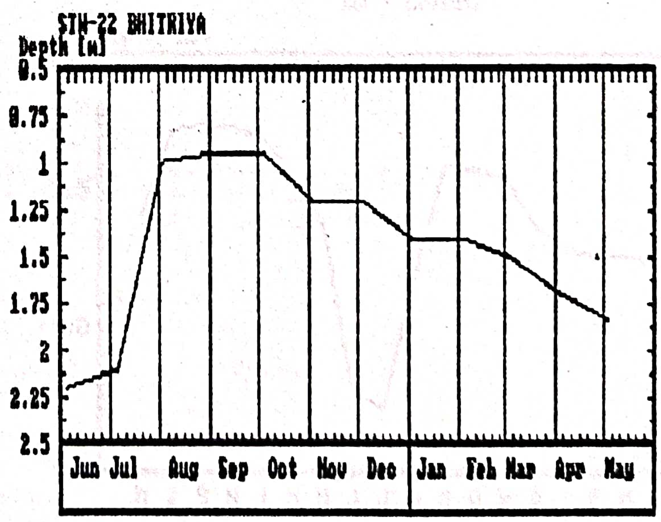
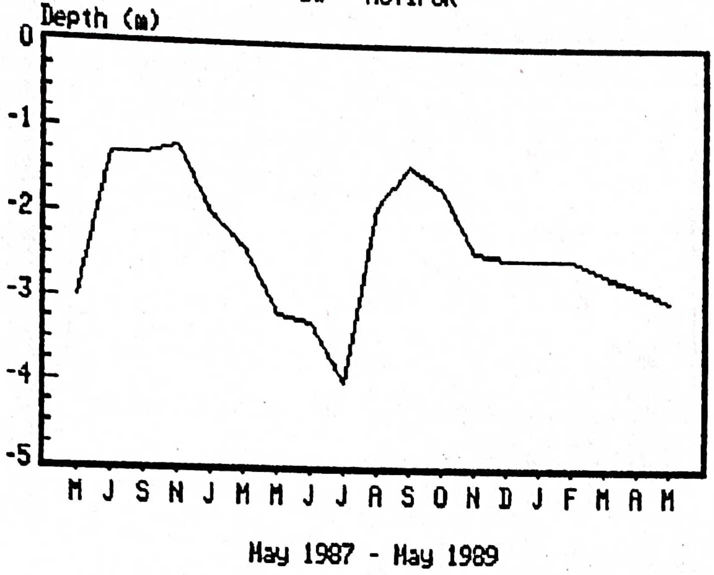


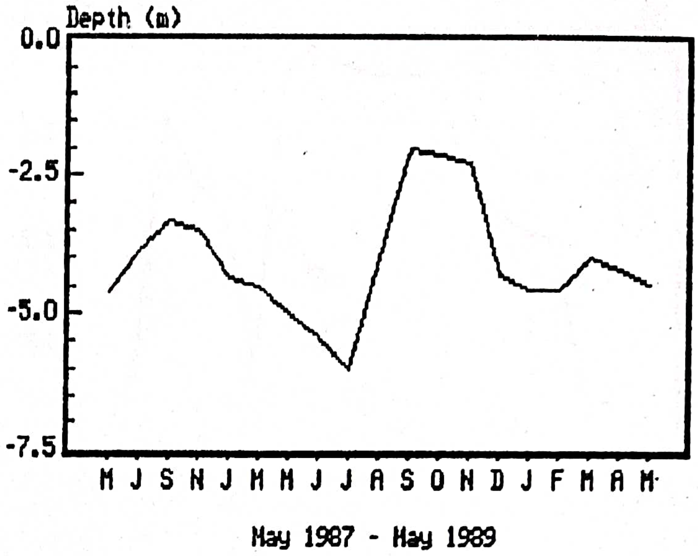
Jun 1, 1988 -- May 31, 1989

HYDROGRAPHS

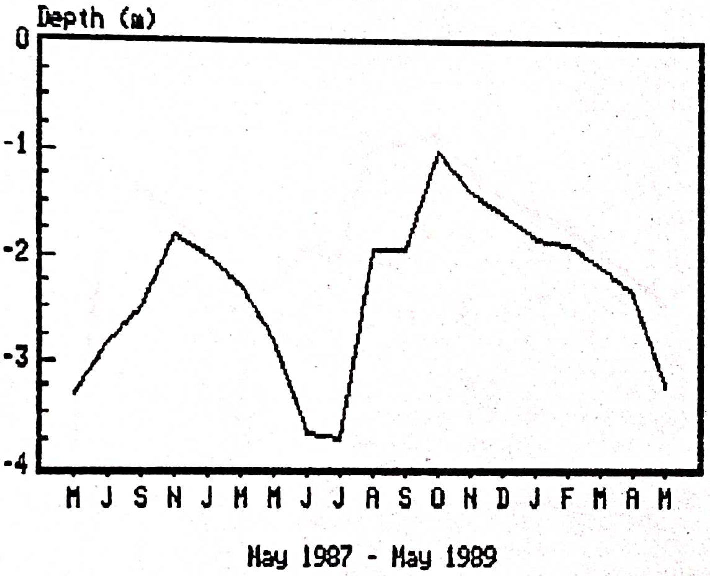
DW - MOTIPUR



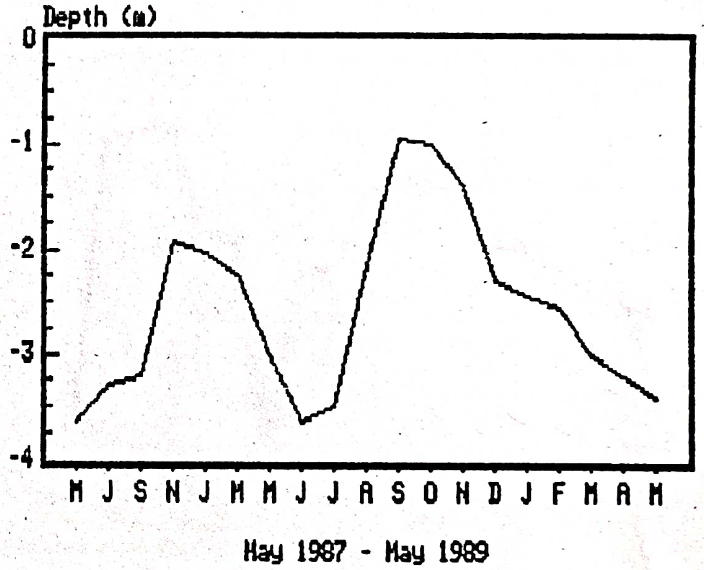
DW - SHIRSIHAWA



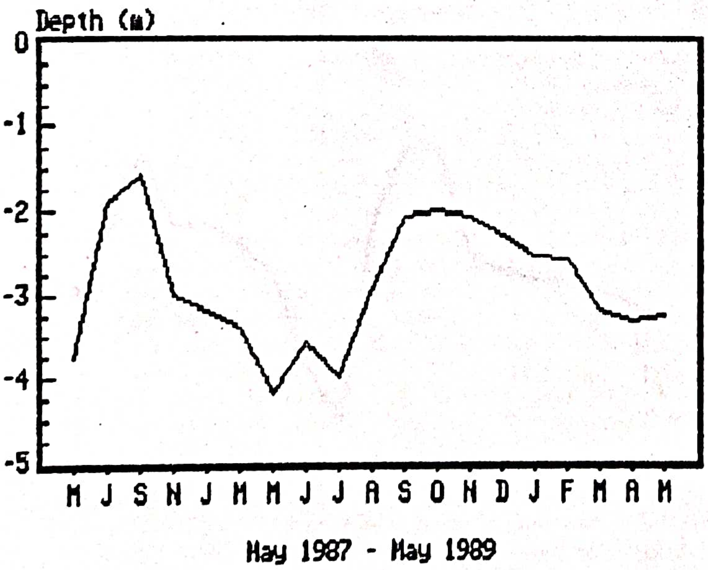
DW - HARNAMPUR



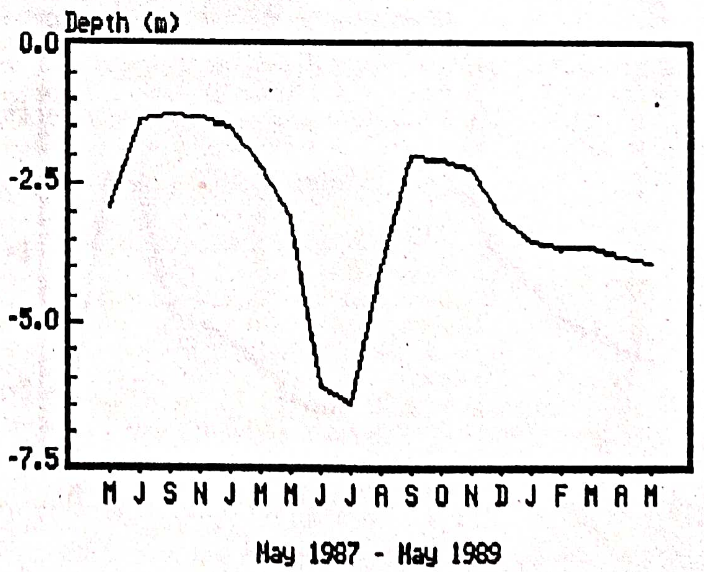
DW - THANKHAJNI



DW - KAJRAHAWA

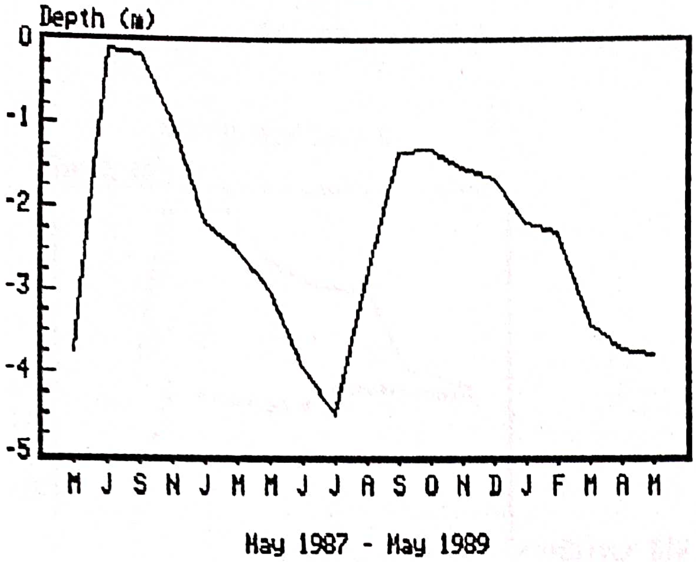


DW - CHANAI

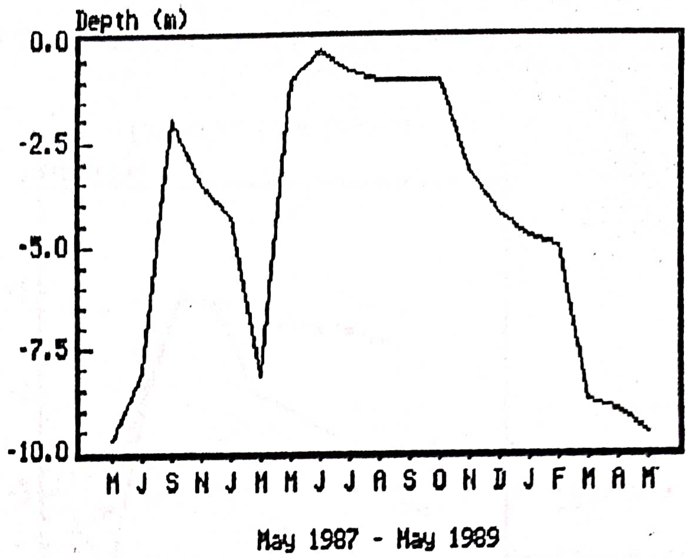


HYDROGRAPHS

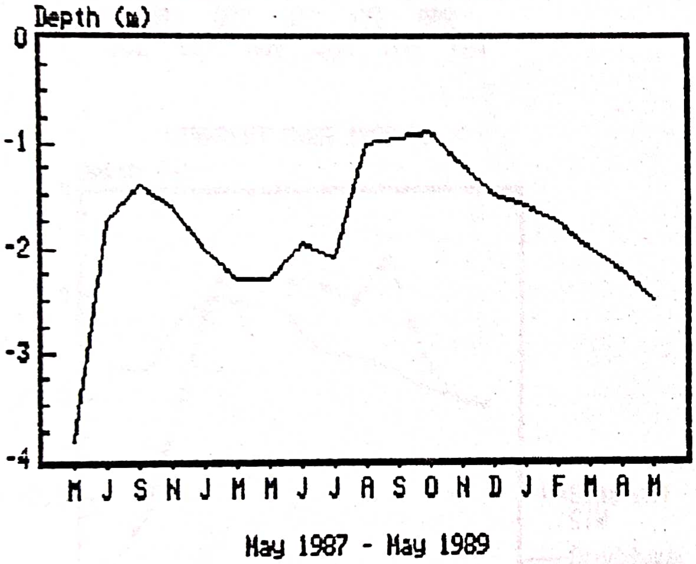
DW - SITAPUR



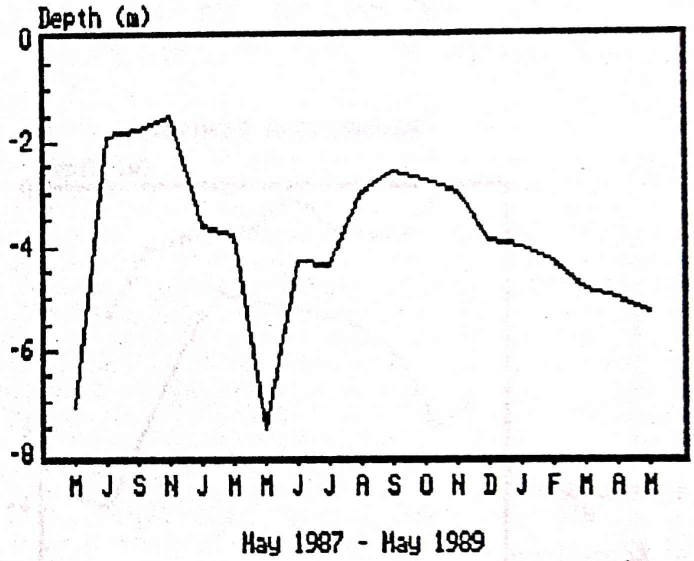
DW - BIRPUR



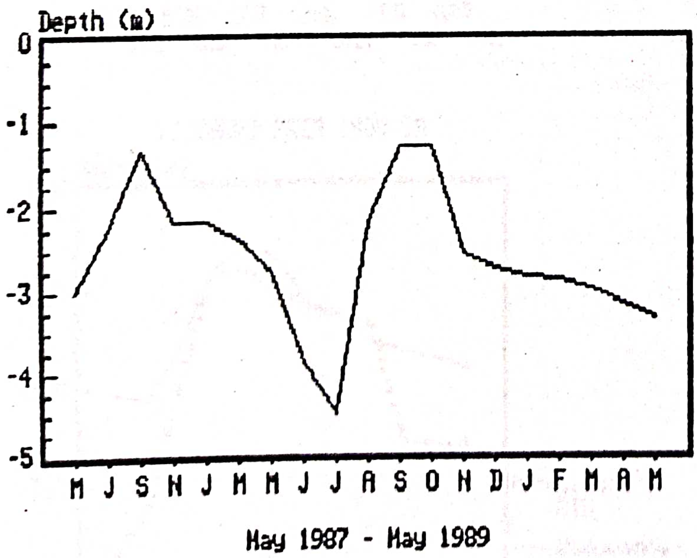
DW - BHALUI



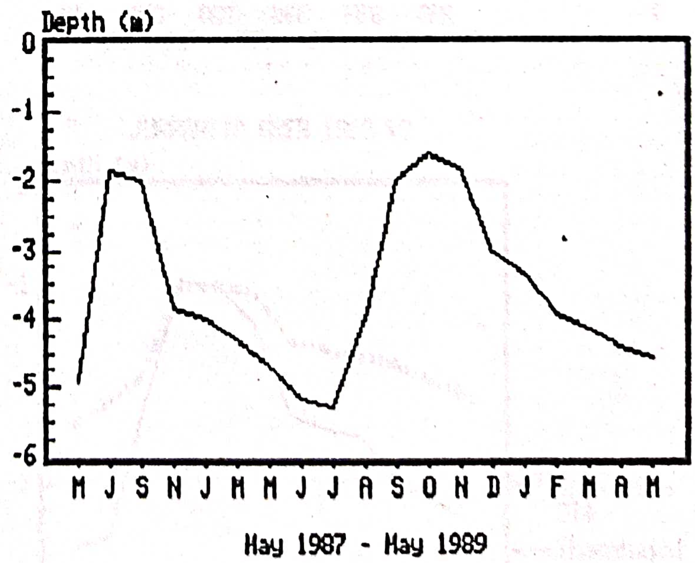
DW - GANDAHAWA



DW - DOHANI

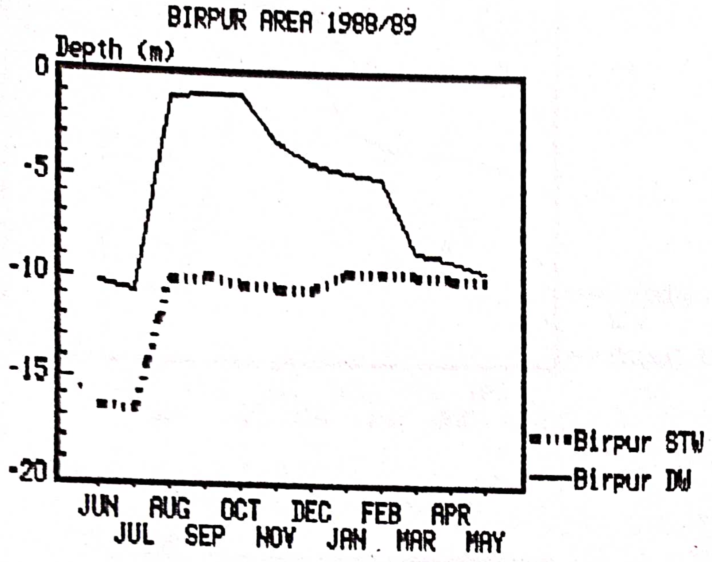


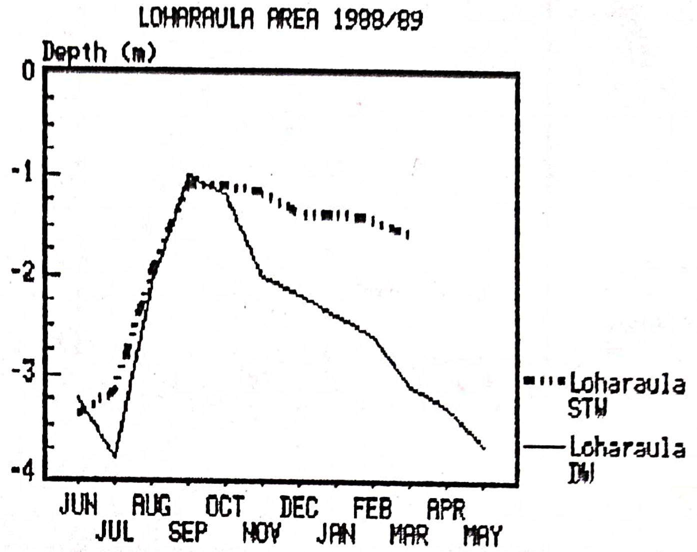
DW - RAMUWADHAWA

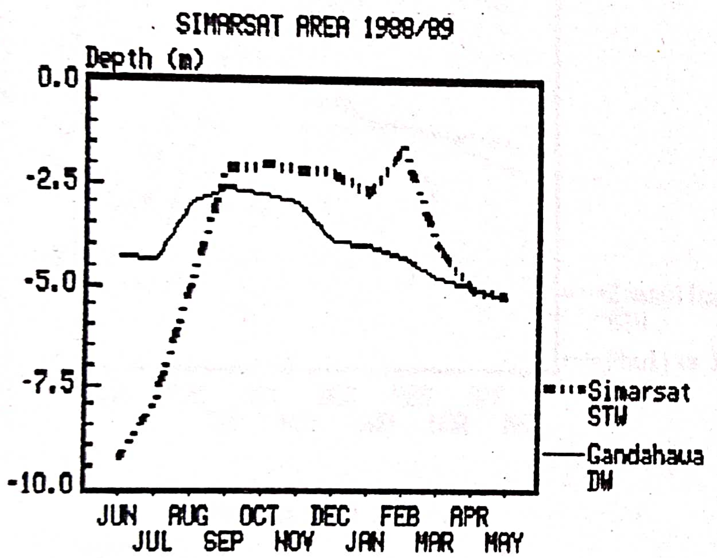


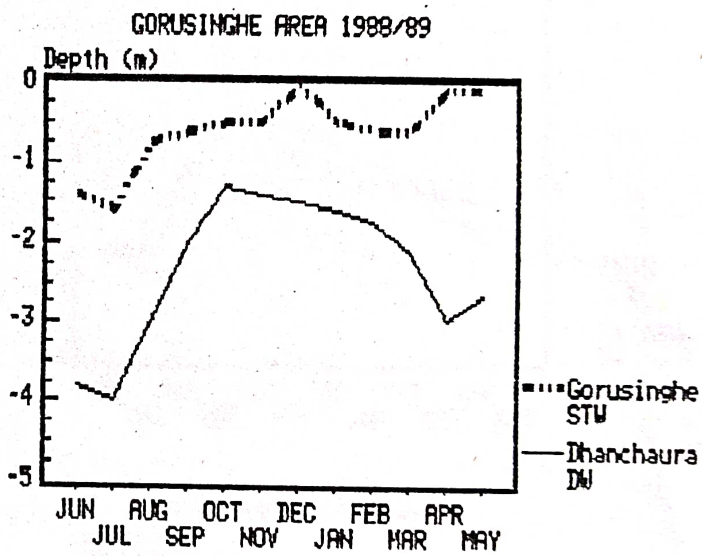
APPENDIX 11/2

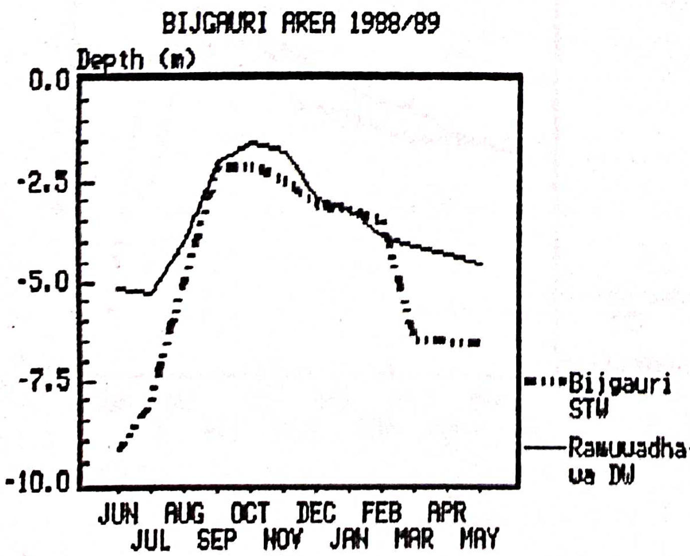
COMPARISON OF HYDROGRAPHS

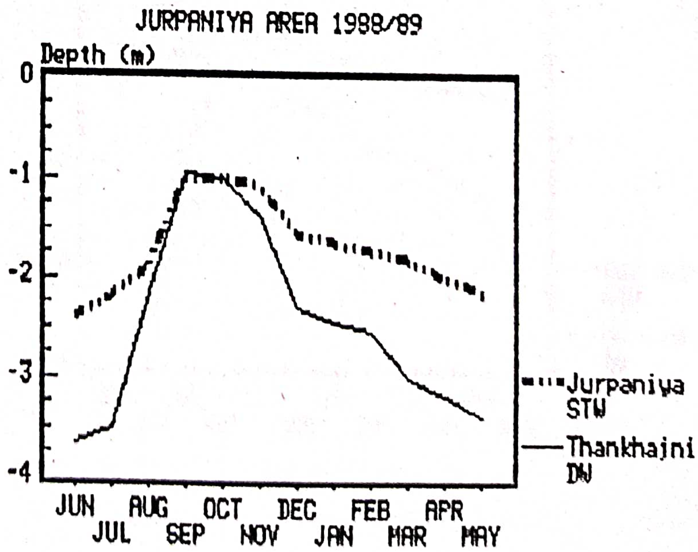




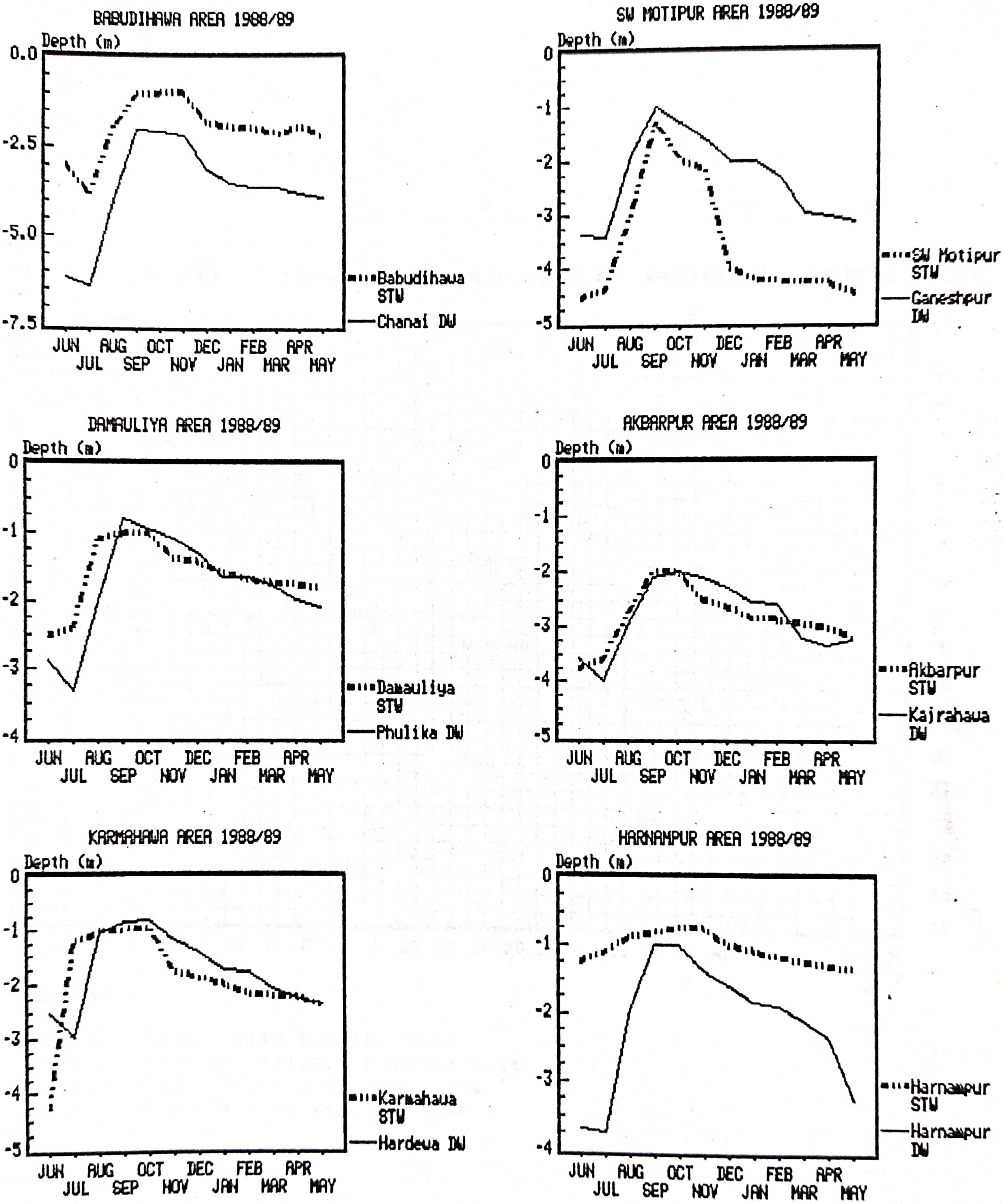




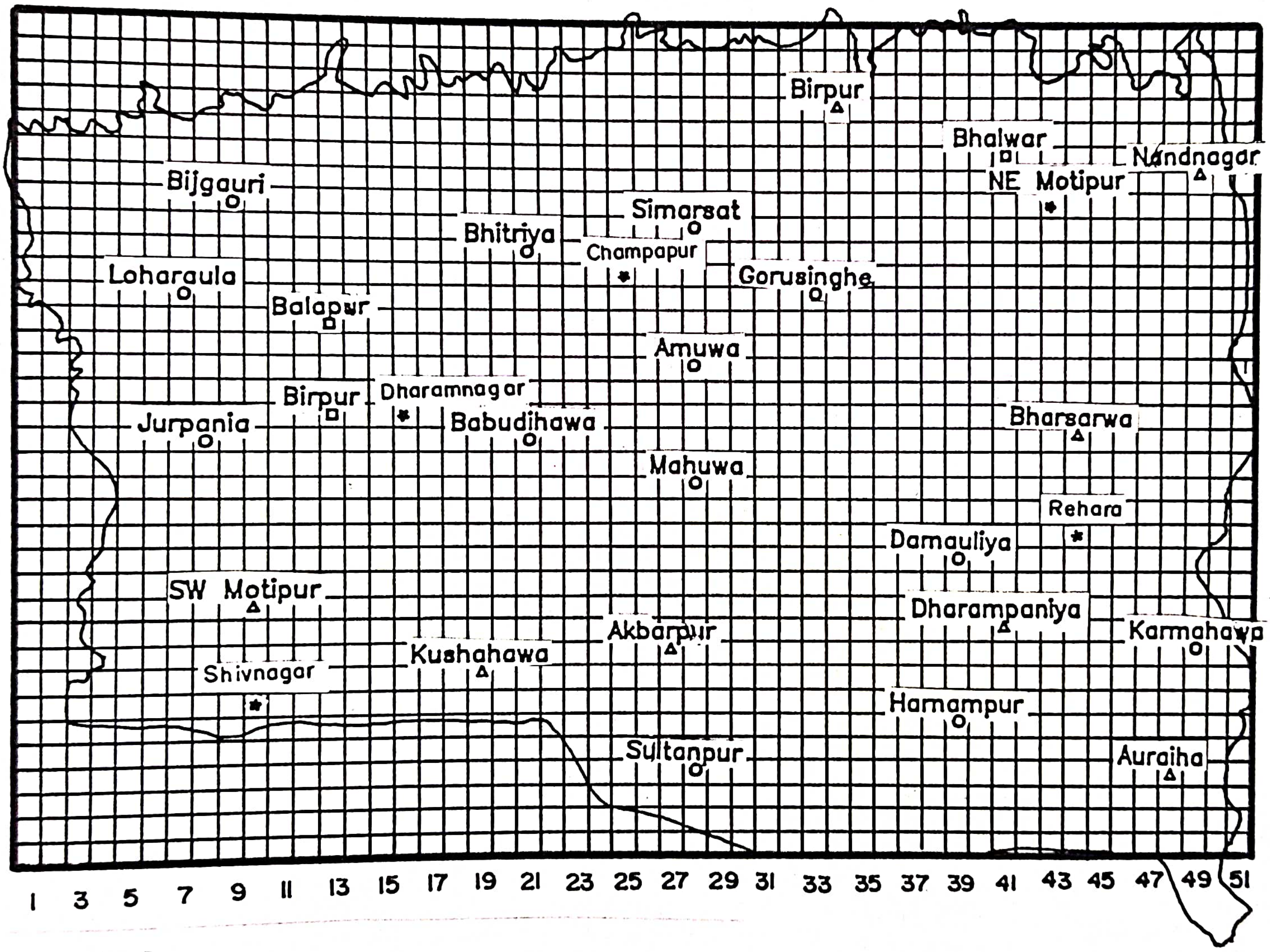




COMPARISON OF HYDROGRAPHS



KAPILVASTU – MATHEMATICAL MODEL NETWORK



Symbols:

Circle: UN STW with Pumping Test
Triangle: UN STW without Pumping Test
Square: ADBN STW only Pumping Test
Star: USAID STW with Pumping Test