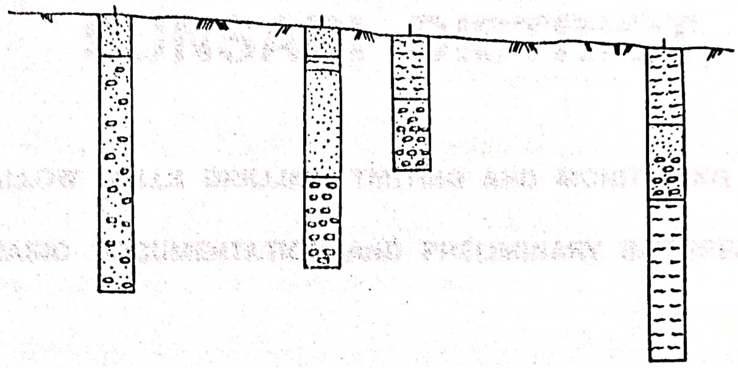
UNITED NATIONS DEVELOPMENT PROGRAMME
AND
HIS MAJESTY's GOVERNMENT OF NEPAL
NEP/86/025

SHALLOW GROUND WATER INVESTIGATIONS IN TERAI

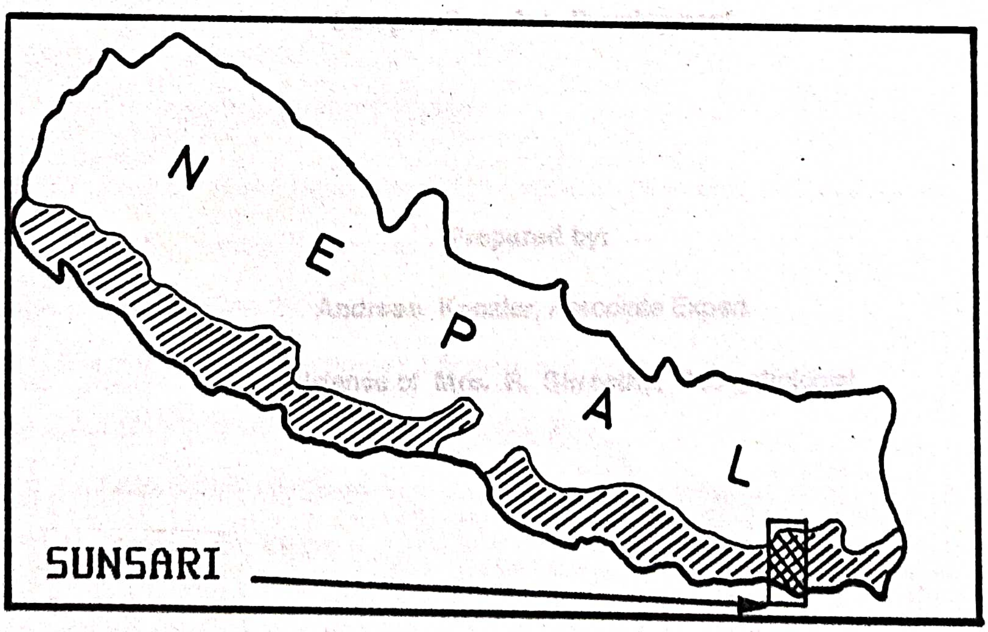
SUNSARI

SHALLOW WELLS DRILLING, TESTING AND MONITORING IN 1988/89

BASIC DOCUMENTATION AND PRELIMINARY INTERPRETATION



TECHNICAL REPORT NO.10



KATHMANDU, JUNE 1989

GWRDB-UNDP PROJECT NEP/86/025

SHALLOW GROUND WATER EXPLORATIONS IN TERAI

TECHNICAL REPORT NO. 10

SUNSARI 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:

Andreas Kanzler, Associate Expert

with assistance of **Mrs. R. Shrestha**, Geohydrologist

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 DISTRICT (WEST). Shallow Wells Drilling, Testing and Monitoring in 1987-89. Basic Documentation and Preliminary Interpretation. March 1989.

6. NAWALPARASI DISTRICT (WEST). Mathematical Model of Shallow Ground Water System. March 1989.

7. KAPILVASTU DISTRICT. Shallow Wells Drilling, Testing, and Monitoring in 1987-88. Basic Documentation and Preliminary Interpretation. June 1989.

8. DANG VALLEY. Shallow Wells Drilling, Testing and Monitoring in 1987/88. Basic Documentation and Preliminary Interpretation. June 1989.

9. DEUKHURI VALLEY. Shallow Wells Drilling, Testing and Monitoring in 1987/88. Basic Documentation and Preliminary Interpretation. June 1989.

ABBREVIATIONS:

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

UNDP - United Nations Development Programme

GWRDB - Ground Water Resources Development Board

GDC - Groundwater Development Consultants (International) Ltd.

ADBN - Agricultural Development Bank of Nepal

ADB - Asian Development Bank

MCM - Million cubic meters

TABLE OF CONTENT

APPENDICES

1. Project Wells and Pumping Tests Location Map

2. Location Map for Monitoring Network

3. Well Logs and Lithology of Project Wells (3/1 through 3/17)

4. Lithological Cross-Sections

4.1. Location of Wells for Cross-Sections
4.2. Cross-Section I-I'
4.3. Cross-Section II-II'
4.4. Cross-Section III-III'
4.5. Cross-Section IV-IV'
4.6. Cross-Section V-V'

5. Pumping Tests

5.1. DTW Tarahara
5.2. DTW Jhumka
5.3. STW 3 - Kushaha
5.4. STW 5 - Amahibela
5.5. STW 6 - Ramnagar
5.6. STW 7 - Bhokraha
5.7. STW 9 - Lauki I (Pumped well)
5.8. STW 9 - Lauki I (Obs. well)
5.9. STW 10 - Satyajhoda
5.10. STW 11 - Prakashpur
5.11. STW 12 - Lauki II
5.12. STW 13 - Inarwa
5.13. STW 16 - Kalabanjar (Pumped well)
5.14. STW 16 - Kalabanjar (Obs. well)

6. Map of Transmissivity of Shallow Aquifer

7. Depth to Water Table in Selected Wells and Rainfall

8. Depths to Water Table in 1987-1989

8.1. Rise of Water Table May-June 1987
8.2. May 1988 - Maximum Depth
8.3. September 1988 - Minimum Depth
8.4. Rise of Water Table from May through September 1988
8.5. Depth to Water Table in May 1989

FIGURES

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" - 17 new shallow wells drilled between October 1988 & January 1989.

(b) Shallow wells drilled by GWRDB for farmer, financed by ADBN in 1982/83.

(c) Deep tube wells, drilled between 1976 and 1982 by GWRDB. As most of this wells are "shallow", two pumping test results could be used to recognize the aquifer characteristic of the first layer.

(d) Pumping tests conducted in "project" wells between December 1988 and February 1989.

(e) Water level observations since May 1987.

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

(g) Duba, D. 1982: Groundwater resources in the Terai of Nepal.

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

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

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

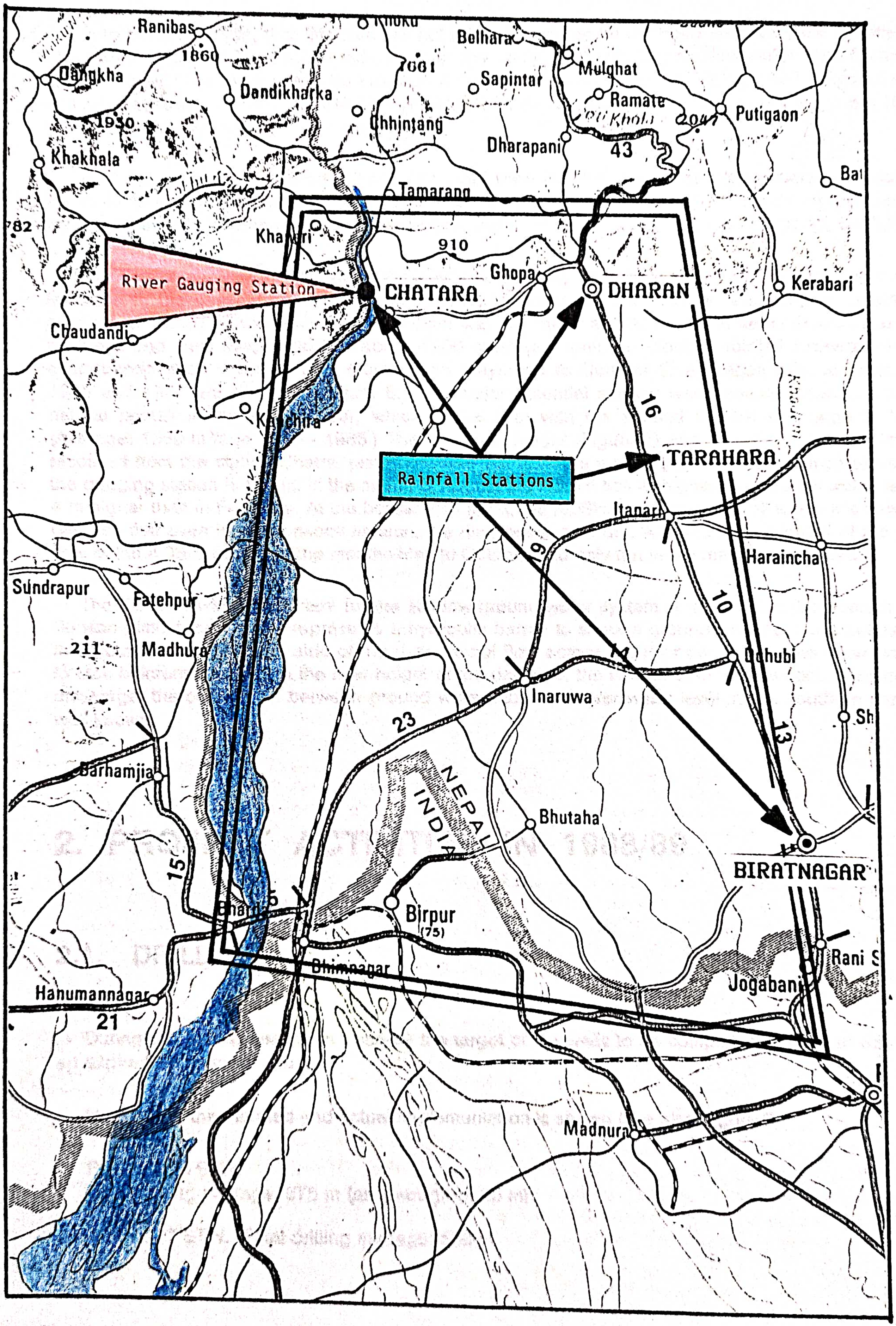
1.3 LOCATION, SIZE, CLIMATE, RIVER FLOW

Sunsari district belongs to the Eastern Region (together with Siraha, Saptari, Morang and Jhapa districts). The location of Sunsari within Nepal is shown in Figure 1. More detailed the area under study is shown in Figure 2 (the double-line polygon). The district area is about 1240 km^2, out of this, 100 km^2 are counted to the BHABAR ZONE.

The area under study in this district is in total: 1000 km^2. The contour line of 150 m is considered to be the physical end of the Terai Quaternary sediments. The main characteristic of the climate in Sunsari district, as well as in the whole Terai, is monsoon rainfall which occurs here between May and September and which delivers an average of 85% of the total annual rainfall. The monsoon usually sets in at the eastern part of the country.

For the purpose of this report, the data were collected in four rainfall stations: DHARAN, TARAHARA and CHATRA in 1987, and TARAHARA and BIRATNAGAR in 1988 (BIRATNAGAR is located in MORANG-District, but only 2.5 km east of the SUNSARI-District border).

FIGURE 1



River Gauging Station
CHATARA
DHARAN
TARAHARA
BIRATNAGAR
Rainfall Stations
Ranibas
Belhara
Mulghat
Dangkha
Dandikharka
Sapintar
Ramate
Putigaon
Chhintang
Dharapani
Khakhala
Tamarang
Ghopa
Kerabari
Chaudandi
Itanari
Haraincha
Sundrapur
Fatehpur
Madhura
Inaruwa
Duhubi
Barhamjia
Bhutaha
NEPAL
INDIA
Birpur
Bhimnagar
Hanumannagar
Jogabani
Madnura

FIGURE 2

It is to be understood, that the data are not officially cleared by the HMG Meterological Service, but rather used in a draft form as an indication for the correlation between shallow water level fluctuation and the rainfall. The same has to be said about the data on evaporation in 1985 & 1987 collected in the meterological station in TARAHARA (Figure 3) as well as for temperature data during the years 1986 - 1988, collected in BIRATNAGAR (Figure 5.)

The Terai in Nepal is located in the subtropical zone and the mean monthly temperature reaches a low of 17°C in January compared to a high of 29°C in June and/or July. The highest daily temperature are usually in April, but then the gap between day and night temperature is still very high (Figure 5.)

Evolution of shallow ground water is heavily dependent on the distribution of rainfall. Most of the recharge to the shallow aquifers comes from fan deposits near the Siwalik hills and mountains.The amounts of rainfall will be discussed in Section 4.2. The mean annual rainfall is about or more than 1900 mm/year and pan evaporation is about 1400 mm/year. Average monthly rainfall exceeds average evapotranspiration during 5 to 6 month, from May/June to October (Evaporation data at Tarahara in 1985 and 1987 are shown in Figure 6.) The major potential surface water source for supplementing natural rainfall is the KOSHI river, which is the river with the second highest discharge in NEPAL (Average: 1550 m^3/s in 1977 - 1985.) The river flow height (Figure 7) and river discharge (Figure 8) is recorded from the station Chatra, just at the flow out from the mountains. The land surface elevation at the gauging station is 170 m. In the month of August the KOSHI has its highest water level which is about 4 m higher than in February. At the border with India, the KOSHI is dammed up by a one kilometer long dam, so that even in premonsoon season, the river never gets dry. Almost ninety percent of the annual flow of the KOSHI occurs in the months May to October and only ten in the remaining 6 months.

The KOSHI River is important for the shallow ground water system of the Terai in the western part of Sunsari district, because it represents a hydraulic barrier to shallow groundwater flow. It is believed that the ground water from one side of the river cannot flow across the river course into the other side. Due to lack of information about the river height at the damside, the time of opening the floodgates and their discharge, the connection between ground water table and river water level in this southern part is not well known.

2. PROJECT ACTIVITIES IN 1988/89

2.1. DRILLING

During the drilling season in 1988/89 the target of the wells to be completed in Sunsari was 15, with an aspired depth to 45 - 50 m.

Here below the planned and actual implementation is shown (see also Figure 9):

Planned: 15 STW.
Total drilling metrage: 675 m (an average of 45 m).

Actual: 17 STW. Total drilling metrage: 558 m.

Although with respect to number of drilled wells the implementation was somewhat higher than the actual planning, but it was below expectations in the sense of drilled metrage. The implementation compared to the design is illustrated in Figures 9 and 10. The map with locations of all "project" wells is shown in Appendix 1. Seventeen lithological logs with other well construction data are appended in the group of Appendices 3 (3/1 trough 3/17). Lithological cross-sections are presented in Appendices 4 (4/2 trough 4/6).

The actual number of drilled wells in Sunsari district by this project is 17.

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

TABLE 1.

No.	Name	X	Y	Depth (m)	Comment
1	Khanar	527000	2945125	36.6	manual
2	Chandbela	522000	2944750	36.6	manual
3	Kushaha	522625	2932875	40.2	manual
4	Shimariya	523750	2932875	41.2	manual
5	Amahibela	518125	2927750	24.4	manual
6	Ramnagar	510875	2932125	21.3	manual
7	Bhokraha	508375	2947875	41.8	rig
8	Devanganj	513000	2925875	18.3	manual
9	Lauki I	506500	2941875	13.7	manual
10	Satyajhoda	516000	2936375	16.8	manual
11	Prakashpur	510625	2952000	19.5	rig
12	Lauki II	506500	2941875	36.9	rig
13	Inarwa	515125	2943625	50.9	rig
14	Jhumka	520375	2949250	57.0	rig
15	Tarahara	528125	2953375	44.5	rig
16	Kalabanjar	518125	2958250	25.9	rig
17	Singiyahi	515000	2954250	32.0	rig

Note. 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 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 numbered every 6 degrees. For Nepal the 6 degree break in numbering occurs at approximately 84 degree East longitude.

In all the wells the used screen was made of slotted pipe and all wells (also the manually constructed ones) are surrounded by gravel pack. More than half the wells are constructed by "manual methods" by local contractors, which are using the so called "sludge" method. By this method, no well stabilizing bentonite is used (only some kilogram of cow-dung) in contrast to wells drilled by rig machine, where almost 20 to 30 bags of bentonite or baryte were used contrary to given recommendations. In general, manually-drilled wells have a better control over lithology of penetrated strata, if the drilling contractor is trained to describe the penetrated layers in a correct way. Manually drilled wells are cleaner and the results of the pumping tests are more reliable because aquifers and well screens are not clogged by bentonite. However, these advantages fade, when the total depth of penetration is far from the aspired drilling depth. The average drilling depth of these wells is 28 m (Figure 10.) The shallowest well is Lauki I with only 13.7 m (this well was repeated nearby with rig (Lauki II)). But the well No 4 Shimariya, which is 41.2 m deep is a good example that it is possible also by manual method to drill up to a sufficient depth. As a conclusion of the drilling program in Sunsari district, the following may be inferred: the drilling of shallow tube 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 (0.25 m) to accommodate 4 or 6-in (0.10 or 0.15 m) casing and minimum 4-in (0.10 m) gravel pack. In an exploration-drilling project, such as 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 (However, in that case the screen should be set deep enough so that during pumping test the water level is always above the screen 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 original program for testing shallow wells in Sunsari intended pump testing of 15 newly drilled and 6 shallow wells to be selected from existing shallow wells. Ten wells had been succesfully tested. In two pumping tests one observation well was available and the test produced the values of storage coefficient in addition to transmissivity. For the location of all tested wells see Appendix 2 - the map of all project wells and two former drilled and pump-tested wells (Tarahara, 1982; and Jhumka, 1978) executed under GWRDB.

Out of 17 newly drilled "project wells", in 7 wells the pumping test could not be executed successfully for various reasons: (a) in two wells the discharge was two low and the pump stopped immediately after starting, (b) in one well the fluctuation started 5 min after starting the pump and the evaluated result is therefore not reliable, (c) the water table in one well was below the suction limit of the centrifugal pump, (d) one well was self flowing, (e) in two wells the results are far beyond any possibility for a realistic interpretation, that human error during the test has to be assumed (e.g. 15,000 m^2/day in well No 8 Devanganj with 16 m of sand and gravel).

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 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 (0.076 m) 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 condition of the water level indicator often does not guarantee a correct reading (battery low, wires broken).

In most tested wells the total duration of pumping was between 3 and 4 hours. In half of the pumping tests, the time span used in evaluation was less than one hour. In general dynamic water levels stabilized rather quickly so that under the consideration of an average transmissivity of about 2000 m^2/day, the duration of couple of hours was sufficient.

Only in two cases the water level measurements in an observation well were appropriate for evaluation. Not enough attention was paid to locating the drilling site within an adequate distance to an existing shallow well (50 to 100 m).

2.3 MONITORING WATER LEVELS

In Technical Report No.2 three maps from Sunsari 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 only in dug wells. The network of observation wells in May 1987 is shown in Appendix 2 (circles filled with a cross). From July 1987 onwards, 23 wells (partly dug wells and shallow tube wells) were selected for the transition until the final network consisting mainly of "project" wells will be established.

This "new" monitoring network is also shown in Appendix 2. As of the month of May 1989, both networks are still under observations but soon, only newly drilled wells shall remain under active monthly observations. Some "old" wells shall be retained to fill the gap and provide the continuity for presenting long-time hydrographs (starting from May 1987). The observation network for the future will consist of about 22 wells.

Depth to water levels is observed in monthly intervals. In April 1989, all 17 "project" wells are observed for the first time completely. Individual hydrographs of 14 "old" wells covering one full monsoon period in 1988 are shown in Appendix 10. Likewise three selected hydrographs and the comparison with rainfall from May 1987 to May 1989 is shown in Appendix 7.

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 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 the 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 Zone have been reported (50 to 200 meters per day) in other districts. Tillson (1985) speculates about the area occupied by the Bhabar sediments for each of the Terai districts. In his report the Bhabar Zone in Sunsari is about 100 km^2, which is some more than half the average of all Terai districts.

The bulk of 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 Sunsari district is known from at least 17 "project" wells and from about 30 wells drilled in 1976 and 1978, but mainly in 1982/83 by GWRDB drilling program. These wells were designed as Deep Tube Wells, but reached only a drilling depth of 32 m in some cases.

There was no attempt to connect the 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 crosscut 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 17 "project" wells of 558 m, 312 m are sand and gravel deposits. This means that about 56 % in an average shallow well is composed of sand and/or gravel. (An "average" well in this district under this program was 32.8 m deep, out of which 18.4 m were composed of permeable and 14.4 m of impermeable deposits.)

One of common earlier interpretations is that going from north to south, the lithology of shallow aquifer becomes less favorable for ground water accumulations because grain size becomes finer. It is questionable whether this is true for the upper 30 or so meters; in other districts e.g. Nawalparasi (west) and also in Rautahat district (see Technical Report No.5 and No.3), the grain size distribution seems also not as simple as supposed. As shown in the lithological cross sections I - I', II - II', and III - III'(from north to south, see Appendices 4/2, 4/3, 4/4), some wells close to the Nepal - Indian border show lithology of great promise. For example the well Lauki II has 36 m of sand and gravel and moreover the drilling ends in aquifer; the well Ramnagar shows about 16 m of sand and gravel and terminates also in this aquifer; and the well Amahibela shows nearly 20 m of sand and gravel and terminates in aquifer. The zone near the Koshi river is supposed to be characterized with more sand and gravel than clay, even if there are no wells very close to the river bank which could prove this assumption (during every monsoon a belt of about 4 km length east of the downstream river is flooded). Except of a tongue-shaped north-south extending area in the north- and middle-eastern part of Sunsari, the complete rest is very permeable mostly from the surface to the drilling depth. Only in this eastern part the wells show thick clay layers, Khanar: 31 m, Kushaha: 30.5 m, Shimariya: 33.4 m of clay. Even the well Kalabanjar (II - II') in the very northern part shows from the top to 16 or so meter an impermeable clay layer, although this part of the district belongs to the Bhabar formation , where normally streams cutting the Siwalik hills should have contributed permeable material. This Bhabar formation contains in general the greatest proportion of coarse grained material but it is poorly sorted and normally overlain by silty and to some extend clayey deposits. As the maps of deepest and highest water level shows (Appendix 9), the water table is not, as typically expected very deep in an east - west trending belt near the Siwalik hills, but the wells with the deepest water levels are arranged in an 25 or so km long strip (see Appendices 8/2 and 8/3) between Baklauri and Babiya.

Considering the lithology of the shallow aquifer in Sunsari, one may conclude that almost everywhere the chances of getting at least 5 to 8 m of sand and/or gravel deposits are very good, and that a shallow well to supply drinking water to villages can be constructed without much uncertainty. As it is indicated by this very small number of wells, large capacity irrigation wells can be constructed all over the district, except in this tongue-shaped north - south trending area in the eastern part of the district. A more detailed exploration drilling and pumping test program would certainly bolster this supposition.

3.2. HYDROGEOLOGICAL PARAMETERS

Hydrogeological parameters of the shallow aquifer were obtained from nine pumping tests run on "project" wells and two in former drilled and pump tested GWRDB-wells (Tarahara, 1982; Jhumka, 1978). 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 (Appendices 5) with some 13 pumping tests. Each is interpreted in the same way, using a rather objective computer match between field data and theory. Out of the results between the classical non-leaky theory of Theis and Jacob, the result with the lower standard deviation, or a better fit was accepted. In no case the leaky aquifer theory of Hantush was fitting. Except in three cases the Jacob method could be used - perhaps a longer testing, with more drawdown during the test, would have changed the above conclusion. However longer testing would have required a higher pumping rate during the test, higher decline of the level which could eventually drop to below the suction reach of centrifugal pumps that were used in testing. There is very little doubt that numerous permeable layers are mutually interconnected either vertically (leakage through semipermeable beds) or latterally (see lithological cross-sections in Appendices 4). The short-term testing as applied in this project has resulted in transmissivity values that are representative only for the layer directly being screened and tested.

The transmissivity of the upper 35 or so meters (with an average depth of about 33 m as reported earlier) is shown in Appendix 6 (the transmissivity map). The map is a creation of a computer contouring program, which interpolates and extrapolates random individual values. This inter-extrapolation process is based on only 13 values which is by far insufficient for an accurate description of the whole district. As mentioned earlier, several more wells are available for pumping tests, but due to static water levels below 6 meters and low discharge which let the pump stop after a few seconds and inappropriate pumping equipment the pumping was postponed. With 21 pumping tests in the Sunsari district, which was the target of the program, the transmissivity distribution would have been much more accurate.The interpretation shall be attempted with information in hands.

There is not a clear distinction between northern (with high transmissivity) and southern part (with low transmissivity), as one could expect.

In the northern part, two wells have shown high transmissivities (STW 16 **Kalabanjar** well: 2392 m^2/day, obs.well: 4933 m^2/day, and DTW **Tarahara** with 2582 m^2/day). The well Tarahara was planned as a deep tube well, but the drilling stopped after 31.5 in gravel and sand. Likewise the "project" well Kalabanjar stopped after only 26 m in gravel.

South of these two wells, the values of the transmissivity are decreasing over the wells **Prakaspur** (1600 m^2/day) and **Jhumka** (1960 m^2/day) to an NW-SE belt with transmissivities which are in this area not expected: **Bhokraha**: 1200 m^2/day and **Inarwa**: 800 m^2/day. This belt is also indicated by the following wells (Appendices 8/2 and 8/3):

(a) **Chandbela**: pumping test could not be evaluated because of immediate drop of water table (under 8.3 m), discharge only 4.5 l/s. Aquifer: 10.6 m sand.

(b) **Khanar**: no pumping test due to low discharge. Aquifer: 5.2 m sand out of total drilling depth of 36.6 m.

(c) **Shimariya**: no pumping test due to low discharge. Aquifer: 7.9 m sand & sand with gravel by a total drilling depth of 41.2 m.

Taking these wells also in account by drawing the contour map of transmissivity, the picture of the actual map gets even worse in the middle eastern part of the district: transmissivity values of around 300 - 600 m^2/day are than expected in this area.

Leaving this belt of lower transmissivity to the south, the transmissivity is strongly increasing, indicated by the following pumping tests:

(a) Lauki I & II (average transmissivity around 2200 m^2/day), aquifer is 35.7 m sand and gravel, but drilling stopped herein.

(b) Satyajhoda transmissivity shows the highest value in the whole district of 4300 m2/day, even with only 8.3 m of sand & gravel - in which the drilling stopped.

(c) Kushaha transmissivity is 2500 m^2/day from 9.7 m of sand and gravel.

The most southern east corner shows lower transmissivity, but which is only indicated by the pump test of Amahibela with 1100 m^2/day from 20 m of sand and gravel aquifer.

In the whole south-west end of the district (west of Lauki), no well is drilled, no pumping test is conducted and no water level informations are available, so that all map interpolations are pure speculation.

Coming to hydraulic conductivities, the picture is strongly distorted, due to lack of information about the real thickness of the aquifer in most of wells.

Ten out of eleven pumping test ran in wells in which drilling stopped in aquifer. So especially the hydraulic conductivity values in the following table has to be treated with this knowledge in mind.

TABLE 2

Symbol	Well Name	Thickness (m)	Trans. m2/day	Conduct. m/day
STW 3	Kushaha	10.0	2500	250
STW 5	Amahibela*	21.5	1100	51
STW 6	Ramnagar*	16.5	2000	120
STW 7	Bhokraha*	39.0	1200	31
STW 9/12	Lauki I & II*	37.0	2000	54
STW 10	Satyajhoda*	8.5	4300	505 (?)
STW 11	Prakaspur*	15.0	1600	106
STW 13	Inarwa*	46.5	900	19
STW 16	Kalabanjar*	9.5	2400	250
DTW	Tarahara*	29.0	2600	89
DTW	Jhumka*	39.0	2000	51

Note: The "*" symbol points at a partially penetrating well. There are two values of storage coefficient obtained:

STW 9/12 **Lauki I & II**: 0.67 which is much to high, but confirms the observation of the lithological log, that the aquifer is unconfined and the sand appears on the landsurface.

STW 16 **Kalabanjar**: 0.0042 which indicates semiconfined to confined conditions and which fits also with the observations of the lithological log: 16.5 m clay is overlyining the gravel aquifer.

These values in general are representative only for a temporary hydraulic state during the pumping test, and should not be taken for hydrogeological parameters of the aquifer.

4. FLUCTUATIONS OF SHALLOW WATER TABLE

4.1. MONITORING NETWORK

Sunsari district is well covered with observation network, except in the south-west area downstream the river. As shown in Appendix 2, in May 1987 when observations of shallow water table started (GDC) the network included 62 dugwells. In May 1988 the network included 18 shallow tube wells and 4 dug wells. In May 1989 the network included 14 "project"-drilled shallow tube wells, 9 shallow tube wells and 1 dug well of the former monitoring network. This number shall be reduced to 17 "project" shallow tubewells and 5 shallow tube wells out of the former network; so that the final network in Sunsari shall have a total of 22 wells.

4.2. RAINFALL IN SUNSARI IN 1987/88

To understand better the rise of shallow water levels from May through the month of September (either 1987 or 1988) one should look at rainfall in June-September period. As shown in Figure 2, there are three rain gauging stations in the Sunsari district and one more 2 km east of the eastern district border so that the measured amount of rainfall in that station is definitely representative for the district area in the south-east. As one can see from Figure 3 (1987, upper half), that especially in the month of August 1987 there are big differences in the measured data, although the two stations Tarahara (August 87: 1326 mm) and Chatra (August 87: 739 mm) are only 21 km far, so that this great differences in rainfall measurement should be rechecked. For further calculations it seemed to be sensible to take the average amount of rainfall out of the three stations Dharan, Tarahara and Chatra which is shown in Figure 4 in graph and table. Thereafter the average total rainfall 1987 in Sunsari was 2655 mm/year, which is 16.3 % above the mean average of 2222 mm/year (taken between 1976 and 1986 in Chatra). Especially the strong rain of 1000 mm/month in August 1987 and 530 mm/month in September are contributing to this rainy year. Compared to that, the year 1988 was "drier" with 2088 mm/year which means 6.5 % less than the annual average. The average measurement in 1988 (Figure 4) was taken from the stations Tarahara and Biratnagar Airport. One can see from the graph, that the rain in premonsoon season (up to June) in the more northern rain gauge station Tarahara is almost double the amount of Biratnagar, but as soon as the monsoon starts the picture reverse to a 1/4 - 1/3 higher amount in the more southern station Biratnagar.

4.3. SHALLOW GROUND WATER SYSTEM HYDRODYNAMICS

Hydrodynamics of the shallow ground water system in Sunsari district in 1987, 1988 & 1989 is presented in Appendices 8/1 through 8/5. The group of Appendices 8 refers to the depth to water table in relative terms (pre-monsoon, post monsoon, rise of levels in 1987 and 1988). Similar maps have been already presented in Technical Report No.2 for the year 1987. Actually, Appendix 8/1 is directly taken from that report.

There are two maps of maximum depth to water table presented in this report: May 1988 and May 1989. It is not wise to compare these two maps directly, as one is based on information of 18 STW & 4 dug wells (May 1988) and the second on 15 newly drilled "project" wells (May 1989).

The May map in 1988 shows the following. The deepest water levels are found in wells which are located in a NNE - SSW belt in the central part of the district. Herein are 5 wells with a water table deeper than 6 m (Baklauri, 7.32 m; Pakali, 7.87 m; Jhumka, 6.48 m; Balaha, 7.09 m; Inarwa, 6.53 m). The shallowest water table is found in Hansphosa with 1.07 m. The interesting thing is , that Hansphosa is located only 3 km east of Pakali, which was the well with the deepest water table. This behaviour can be explained, with the help of the map of water table in 1989 (Appendix 8/5.) There the "project" well Tarahara, which is only 4 km NE of Hansphosa is the only well in which piezometric head is above the land surface, and it is discharging with approximately 3 - 4 l/s.

The water table in the southern part of the district shows in May 1988 a quite uniform depth of about 3 to 4 m (Appendix 8/2). There are no information about the water table in the western part of the district in a range 8 to 10 km east of the Koshi River due to lack of wells. The picture in May 1989 is in general not much different - the deepest water table with 8.76 m (STW 14 Jhumka) is found in this NNE - SSW belt, described above. Discarding the flowing well Tarahara, the most shallow water table in May 1989 is observed in Khanar with 1.45 m. The water table in the complete southern part is in a range between 3 and 4 m as in 1988, except the well Kushaha with 5.07 m which is probably the result of a higher land surface elevation around this well.

Inspite of a comparatively uncommon high amount of rainfall in April 1988 (210 mm), the water table started rising with a delay of at least one month not before end of May (June data not available). May is still the month with the lowest water table under the land surface (see Appendix 7 in which water table is correlated with rainfall).

In the monsoon season of 1988 the water table rose generally between 1 and 3 m in the whole area (see Appendix 8/4). The rise is the greatest in the central part of the NNE - SSW belt with about 16 by 7 km extension. Herein the water table rose in some places for more than 4 m. The least rise is to be observed in the SE - corner of the district and in the NW - part, here especially shown by the well Dhanpuri (May 1988: 3.71 m and September 1988: 3.49 m). In 1988 (Appendix 8/4) the picture is different than a year before (Appendix 8/2), as the fluctuation amplitude was more pronounced in 1987. However, the maps of levels in 1987 (especially in May) were based mostly on dug well record, which may not be as reliable as the data from drilled wells. For the sake of comparison, three hydrographs together with the monthly rainfall are shown in Appendix 7. The water table of these three dug wells shows quite a different behaviour: well Baklauri has a very high amplitude in 1988 (over 3.5 m) - in 1987 the rise of water table was apparently only 2 m, but there is no record about the month of April which could have had already a rise of the water table. Well Devanganj shows a very mild amplitude with rise and decline of generally 1 to 1.5 m (except the rise between May and September 1987 with 2.1 m). Well Bhokraha with water table generally very close to the surface shows its strongest rise in monsoon 1987 from 2.74 m in May up to the land surface in July.

4.4. CONTOUR MAPS

The elevations of newly drilled wells ("project wells") were taken from topographic map Rajbiraj sheet No. 72J-B. The map scale is 1:125,000. In a flat terrain such as the Terai of Nepal, the map presents land surface elevations as point values rounded to one meter rather than as contour lines. It is regrettable that the project could not complete its own surveying program. The accuracy of "reading" land surface elevations at well sites is probably several meters. The maps of water table contours, as presented in Appendices 9/1 and 9/2 are generally correct, showing the right gradient and flow pattern. At well sites the actual elevations could be different but this will not affect the interpretation. (For evaluation of available shallow ground water resources by means of mathematical models, it is almost indispensable to have a better control over actual land surface elevations at observation wells.)

(Well site elevations reported in Appendices 3 - Well Logs and Lithology) are also taken from topographic map.)

Both maps of contours, in May 1988 (Appendix 9/1) and September 1988 (Appendix 9/2), show the following flow pattern:

(1) The flow is from north (notably northeast) to south. The water table contours toward the SAPTA KOSHI River although extrapolations are controlled by the river stages. There are areas without information which are left blank (northeastern and southwestern corners).

(2) The flow gradient is steepest along the eastern district boundary, starting with some 0.0035 in the upper part between contours 90 an 115 m,. continuing with 0.0017 between contours 80 and 90 m, and terminating with 0.0012 between contours 65 and 80 m. The average slope in May 1988 from Hansphosa in the north to Amahi in the south is about 0.0019 , i.e. 48 meters decline of head over the distance of 25 kilometers. Exactly the same slope is in the month of September 1988.

The interpretation of the contour maps alone indicate that either the transmissivity of the northern half of the district is less than the transmissivity of the lower half (steeper gradient times lower transmissivity gives the same product as milder gradient times higher transmissivity) or that less water is flowing through the souther part toward India due to evaporation from shallow water table. The first assumption is partly confirmed by the map of transmissivity (Appendix 6) showing high transmissivity in the south-central part. The second assumption is dismissed (partly) by deep water table in southern part of the district (deeper than 3 m) which eliminates any larger loss of shallow water to evaporation. What is certain is that the highest transmissivities are found in the central part between Balaha-Babiya-Duhabi-Harinagar in which the flow gradient is mildest and in which center is located the well Satyajhoda with transmissivity over 4000 m^2/day.

5.0 ASSESSMENT OF WATER RECHARGE AND DISCHARGE

5.1. PRELIMINARY ASSESSMENT FROM BASIC DOCUMENTATION

The flow pattern as presented in May and September 1988 leads to the following conclusions about the recharge, discharge and flow in the ground water system in reported area.

(1) With the average transmissivity of about 2500 m^2/day in the northern part (Kalabanjar-Tarahara, Appendix 6) and flow gradient of some 0.0025, the total ground water flow across the section of 20 km (Sapta Koshi River - Dhanpuri - Hansphosa) can be about 125,000 m^3/day (1447 l/sec). This water comes mostly from recharge from hill sides (Bhabar zone, fan deposits, underflow from hills).

(2) In the southern part, toward India-Nepal border, the transmissivity of 2000 m^2/day and flow gradient of some 0.001 produce the total flow over a section of 15 km (Harinagar- Raniganj) equal to 30,000 m^3/day (347 l/sec).

(3) Through the whole section of some 33 km (from the point where SAPTA KOSHI river leaves Nepal to Duhabi village), with an average transmissivity of 2500 m^2/day and average flow gradient of 0.001 m/m, the flow could be as high as 82,500 m^3/day (956 l/sec).

There is some 40,000 m^3/day unaccounted for. The water that is mostly recharge in the north may (a) evaporate on its way to the south (near the river banks the water table can be closer than 3 m even in May), (b) get lost through direct outflow into the SAPTA KOSHI River (in May, a portion of river flow is base flow, which is ground water contribution), (c) can be consumed by shallow tube and dug wells by local farmers.

5.2. ASSESSMENT OF WATER BALANCE BY MATHEMATICAL MODELLING

There appears to be enough data to construct a preliminary model of the Sunsari district. To make the model more than preliminary, one needs the following:

(a) Absolute elevations of the KOSHI River at sites where it enters and leaves the Terai of Nepal.

(b) Water levels monitored in missing zones (northeastern and southwestern corner).

(c) More pumping tests with correctly interpreted transmissivity values.

(d) Inventory of currently used shallow tube and dug wells with some control over withdrawls.

The model may provide quantitative answers to the following:

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

(b) The connection with the SAPTA KOSHI in minimum and maximum flow conditions.

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

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

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

The aquifer system to be modelled (Appendix 11) has two natural and two artificial boundaries. The natural ones are the impermeable boundary in the north, being the physical termination of the shallow (and deep) ground water system of the Terai, and the western boundary being represented as a constant-head line coinciding with the SAPTA KOSHI River. The artificial boundaries of the district in the sense of the regional ground water system are the boundaries to the south (Nepal-India border) and east (district boundary with Morang district). Even the northern boundary is only partly natural, since the Terai plain extends beyond that boundary, yet at higher elevation than 150 m.

The final outcome of the model could be the amount that can be annually developed by shallow wells considering the recharge, the induced flow from the river, 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, and decline of water levels from September 1988 through May 1989. The two maps of water flow, i.e. Appendices 9/1 and 9/2, 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 Sunsari district shall be modelled, with the SAPTA KOSHI River on its western boundary, India-Nepal state border as the south boundary, the contour line 150 m on its north, and the district boundary with Morang on its east. The area involved in the model shall be about 35 km (northwest-southeast) by 41 km (northeast-southwest) (Appendix 11). The discretization shall be 1000 m in each direction, creating a uniform mesh network of 1 km^2 each cell.

(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. The elevation of the SAPTA KOSHI River cells shall also be required.

(c) Model calibration process shall have three 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).

(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, outflow into the river if any, and outflow across the southern border into India, (iii) assessment of available shallow water for increased development on account of avoiding evapotranspiration losses and inducing the river recharge.

6. CONCLUSIONS AND RECOMMENDATIONS

The objective of this report is to present technical information on the occurrence of shallow ground water in Sunsari district. It is given in a form of a basic documentation, which shall be used for future evaluation of the ground water system (mathematical modelling); however, some preliminary interpretation is also included herein.

The drilling program which was formulated about a year ago, was completed according to the expectations. Seventeen holes were drilled with the total drilling metrage of 558 m. The average depth of newly completed wells is 32.8 m. Considering the lithology of shallow ground water system, this depth is probably adequate for the project purpose. Within the upper 33 meters about 56% are composed of permeable formations (sand and gravel). Quite a high presence of gravel is noted. This makes the Sunsari district favourable for shallow ground water development. Only eight successful tests have been performed. Out of 17 drilled wells, 8 wells were constructed by a drilling rig, and only 9 wells by indigenous (manual) methods of drilling ("sludge" method).

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 Sunsari drilling project the local contractor was capable of producing manually-drilled well 41.2 m deep. Yet some wells were very shallow (13.7 m, 16.8 m, 18.3 m).

As a conclusion of the drilling program in Sunsari 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. Although not to be absolutely satisfied with the results of pumping tests, they did produce the values of transmissivity and, in two cases, storage coefficient. The quality of testing must be improved, as well as the accuracy of equipment used.

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.

According to lithology and transmissivity of investigated shallow aquifer, both the lithology and transmissivity are very favourable all over the district. Lithology is dominated by coarse materials (gravels), the transmissivity is high (between 1500 and 4500 m^2/day). (The same conclusion can be safely "extrapolated" to the area near the SAPTA KOSHI River in which information is missing.) One should expect considerable drilling problems with cobbles and boulders all over the area.

Since aquifer percentages and permeabilities are high there is no obvious distinction between so-called deep and shallow aquifers.

From individual points (not absolutely conclusive), two zones may be singled out. The first is a high-transmissivity area in the central-south part, near Satyajhoda and Kushaha, extending toward Biratnagar in Morang. The transmissivity is over 2500 m^2/day reaching over 4000 m^2/day in Satyajhoda. The second is slightly less favourable zone than the rest in the west-central part, between Inarwa and Bhokraha. Inarwa well is the only location with less than 1000 m^2/day transmissivity.

The hydraulic conductivities of shallow aquifer materials in the whole district are about 75 m/day, exceptionally several hundred meters per day (Satyajhoda, over 500 m/day). The values of about 80-100 m/day are characteristic for clean coarse-grained sand with gravel. The values over 100 m/day indicate greater proportion of clean gravel over sand.

The pump testing program in Sunsari district should be continued. There are many wells which lend themselves to testing. Most of hand-pump equipped wells (drilled by ADBN) could be easily tested. If out of 500 shallow drilled wells 20 are tested, the wealth of information and knowledge about the district would be enormously improved.

Sunsari district is well covered with water-level monitoring network. In the month of May 1989, the network includes 14 project-drilled wells, 9 STWs from ADBN program, and 1 dug well. Tentatively the proposed network for future monitoring shall include 17 "project" drilled shallow wells, plus five wells equipped with hand pump from the old program. The final network in Sunsari district could have about 22 shallow tube wells. Three wells should be drilled near the Sapta Koshi River to the depth of some 20 m, to provide a base for evaluating the connection between shallow aquifer and the river.

In most of the area the levels in May 1988 are deeper than 3.0 m under the land surface. There is a zone in central part of deep water table. The depth to water table in September 1988 is still high, about 2-3 m. This is favourable in the sense that the evaporation process, which in other Terai districts can be responsible for quite a loss of water, is of minor importance in Sunsari.

Between May and September 1988 the levels rose in most of the area between 2 and 3 m, and in some parts only 1 m. The rise of levels started in early June as a direct response to June rainfall. The near-maximum water levels were established by the end of August. The decline started in September. The high July and August levels are the response to rainfall in excess of 1100 mm/60 days. The rainfall in September of 164 mm in Sunsari is not sufficient to keep the water at such high levels and the levels slowly but steadily decline.

As expected the general direction of ground water flow is from north to south. The maps of water level contours are not as accurate as one would desire since land surface elevations of observation wells were not surveyed but taken from topographic map. Yet the general conclusions about the flow pattern shall not be affected by this definite disadvantage.

The flow pattern as presented in May and September 1988 leads to the following conclusions about the recharge, discharge and flow in the ground water system in reported area.

(1) With the average transmissivity of about 2500 m^2/day in the northern part (Kalabanjar-Tarahara, Appendix 6) and flow gradient of some 0.0025, the total ground water flow across the section of 20 km (Sapta Koshi River - Dhanpuri - Hansphosa) can be about 125,000 m^3/day (1447 l/sec). This water comes mostly from recharge from hill sides (Bhabar zone, fan deposits, underflow from hills).

(2) In the southern part, toward India-Nepal border, the transmissivity of 2000 m^2/day and flow gradient of some 0.001 produce the total flow over a section of 15 km (Harinagar- Raniganj) equal to 30,000 m^3/day (347 l/sec).

(3) Through the whole section of some 33 km (from the point where SAPTA KOSHI river leaves Nepal to Duhabi village), with an average transmissivity of 2500 m^2/day and average flow gradient of 0.001, the flow could be as high as 82,500 m^3/day (956 l/sec).

There is some 40,000 m^3/day unaccounted for. The water that is mostly recharge in the north may (a) evaporate on its way to the south (near the river banks the water table can be closer than 3 m even in May), (b) get lost through direct outflow into the SAPTA KOSHI River (in May, a portion of river flow is base flow, which is ground water contribution), (c) be consumed by shallow tube and dug wells by local farmers.

Although an assessment of shallow aquifer water balance is not attempted in this report, some preliminary evaluation is presented. A parallel study is being currently run by this project in which a mathematical model is under construction and testing. The model shall provide some answers to the following: (a) recharge from rainfall in the Bhabar Zone and elsewhere, (b) the connection with the Sapta Koshi River in minimum and maximum flow conditions, (c) the importance and magnitude of evapotranspiration process, (d) the correct order of magnitude of hydrogeological parameters, (e) the volume of outflow across the district boundary into India.

The following is concluded from the flow pattern in May and September 1988, and from all other information collected for this report:

(1) The district is dominated by the past and present course of the SAPTA KOSHI River and its piedmont fan. The net effect of wide area occupied by the KOSHI river deposits is that aquifer percentages and permebilities are high and that no obvious distinction can be made between deep and shallow aquifers.

(2) The recharge comes from local infiltration of rainfall everywhere where more or less permeable surface permits.

(3) The Bhabar zone is an important "contributor" in the reported area.

(4) The outflow of shallow ground water is generally across the border into neighboring India, and locally to the SAPTA KOSHI River.

(5) The outflow into India across the border is calculated approximately with gradients from Appendices 9/1 and 9/2, and transmissivities from Appendix 6. The volume of water that may be outflowing is about 80,000 m^3/day or 29 MCM/year (million cubic meters in one year). This is quite a high percentage of potential annual recharge from infiltrated rainfall. If, conservatively, only 10% of annual rainfall of 2222 mm infiltrate and recharge the shallow aquifer, the volume of recharge over an area of about 900 km^2 could be about 200 MCM/year. The difference between this hypothetic recharge of 200 MCM and outflow into India of about 29 MCM is discharged through evaporation process (dominantly), and the rest is outflowing into the SAPTA KOSHI River (locally very high) or is withdrawn from dug and drilled wells (unknown component at present).

For a better understanding of the relationship between the SAPTA KOSHI River and shallow aquifer the following program of investigations is recommended:

(a) Drilling of three wells near the left bank of the river, to the depth of only 10-15 m.

(b) Continuous monitoring of water table in these new wells in one year period. Description and measurement of river stage in the same period at the site of the first upstream well. It is important that the river flood stage is correctly monitored.

(c) Establishment of one additional river-stage gauging station at the south (near the Nepal-India border), and measuring surface water elevation during a pre-monsoon and monsoon season. Measuring of river discharge in the dry season.

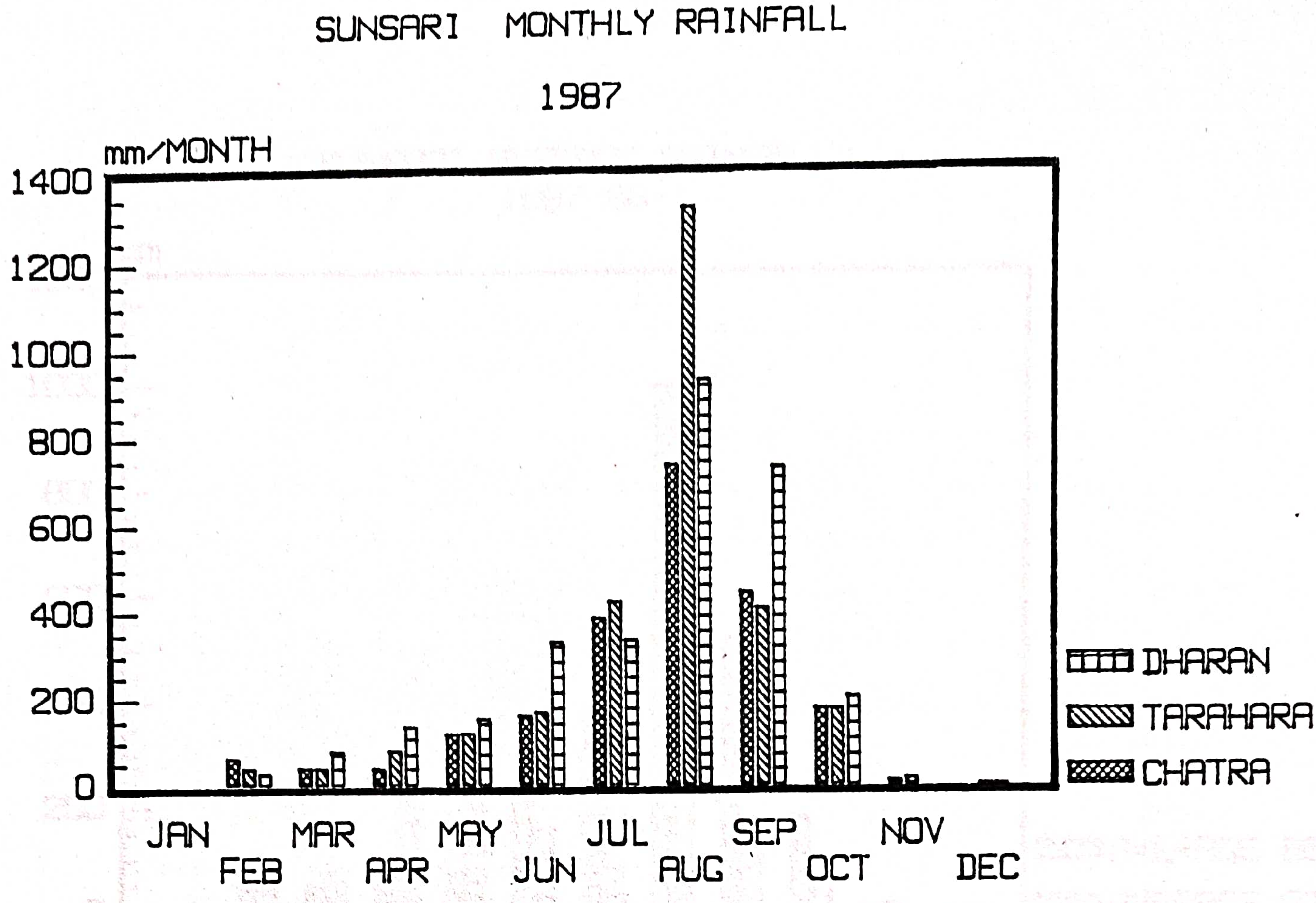
(d) Correlation of water table in three new wells (recommended at a) with the river level height.

(e) Calculation of the base flow at upstream and downstream station, if established, in the dry season.

Finally, on the basis of the presented information, there appear good prospects of developing shallow ground water resource in almost whole district area, except in the north, at the foot of hills where water table may be too deep and/or large boulders can create drilling problems.

To complete this investigations it is recommended to do the following:

(a) Perform pump tests in the wells that have been drilled but not tested.
(b) Test several existing ADBN-financed wells.
(c) Use turbine pumps which can lower dynamic depth during pumping to minimum 12 m.
(d) Drill three very shallow wells parallel to the left bank of the SAPTA KOSHI River, at a distance not greater than 100 m from the river.
(e) Continue with monitoring of water table in 22 wells (17 project-drilled, 5 hand-pump equipped). The frequency of monitoring in the June-September period should be biweekly. In the rest of the year once-a-month measurement suffices.
(f) Establish correct altitudes of newly drilled wells by land- surface surveying.


SUNSARI MONTHLY RAINFALL
1987
mm/MONTH
1400
1200
1000
800
600
400
200
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
DHARAN
TARAHARA
CHATRA

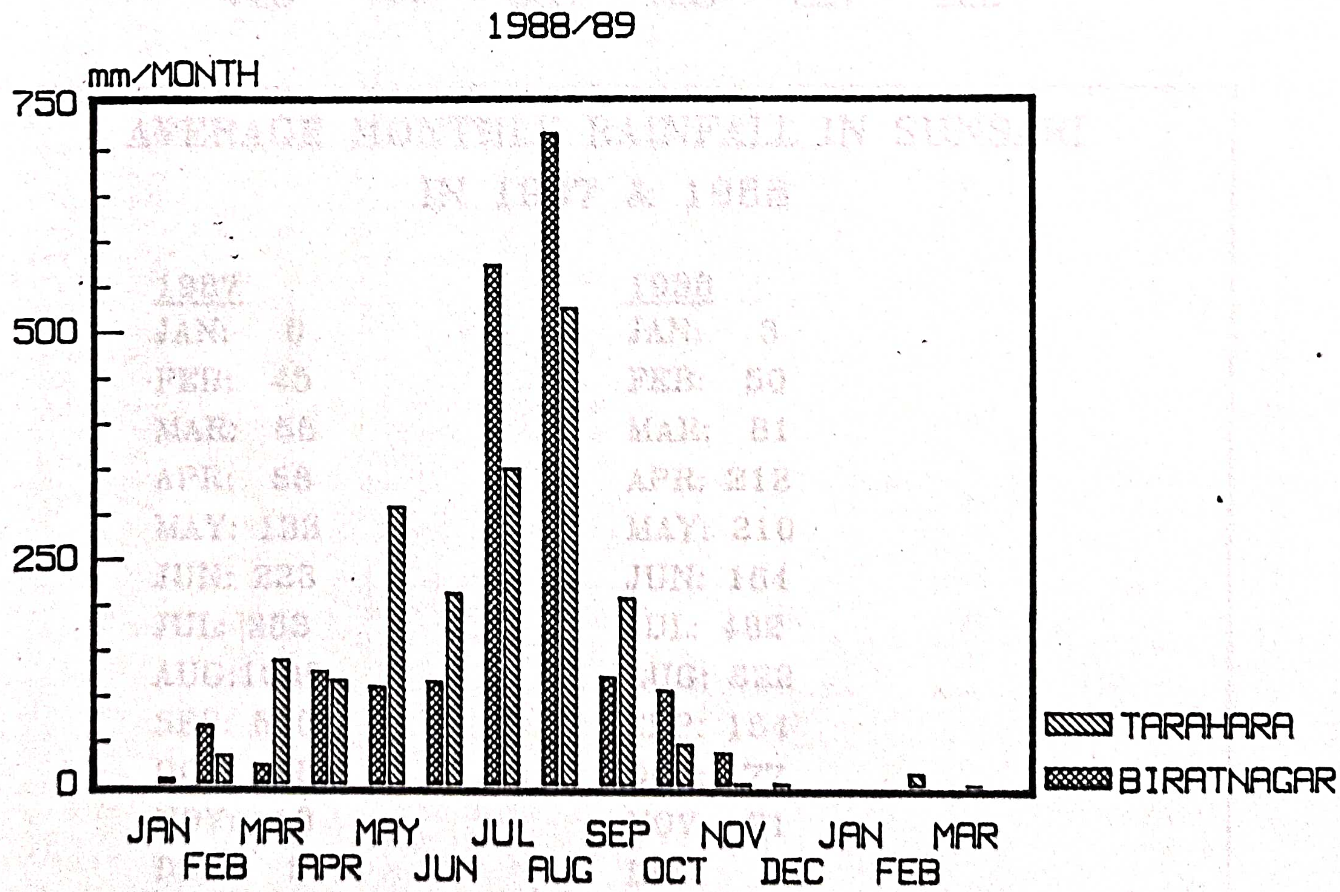
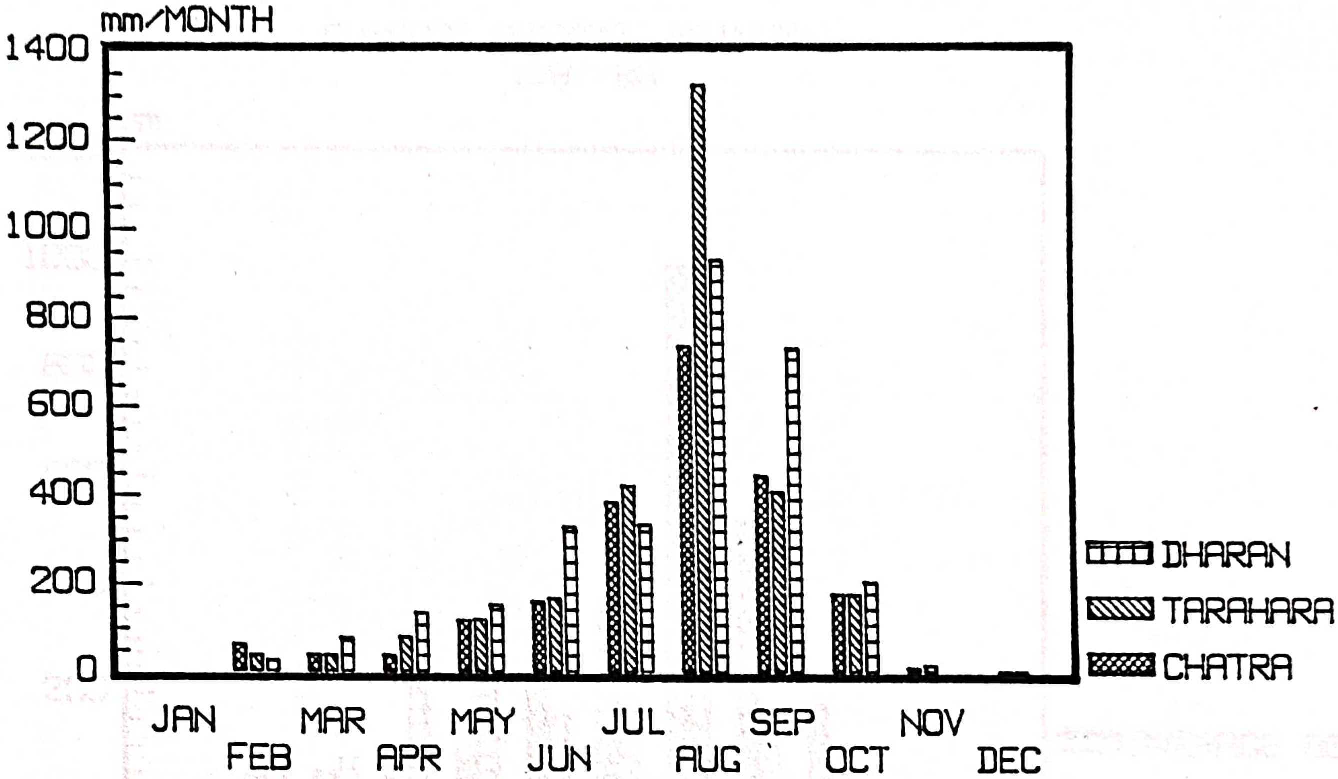

1988/89
mm/MONTH
750
500
250
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
TARAHARA
BIRATNAGAR

FIGURE 3

SUNSARI MONTHLY RAINFALL

1987



1988/89

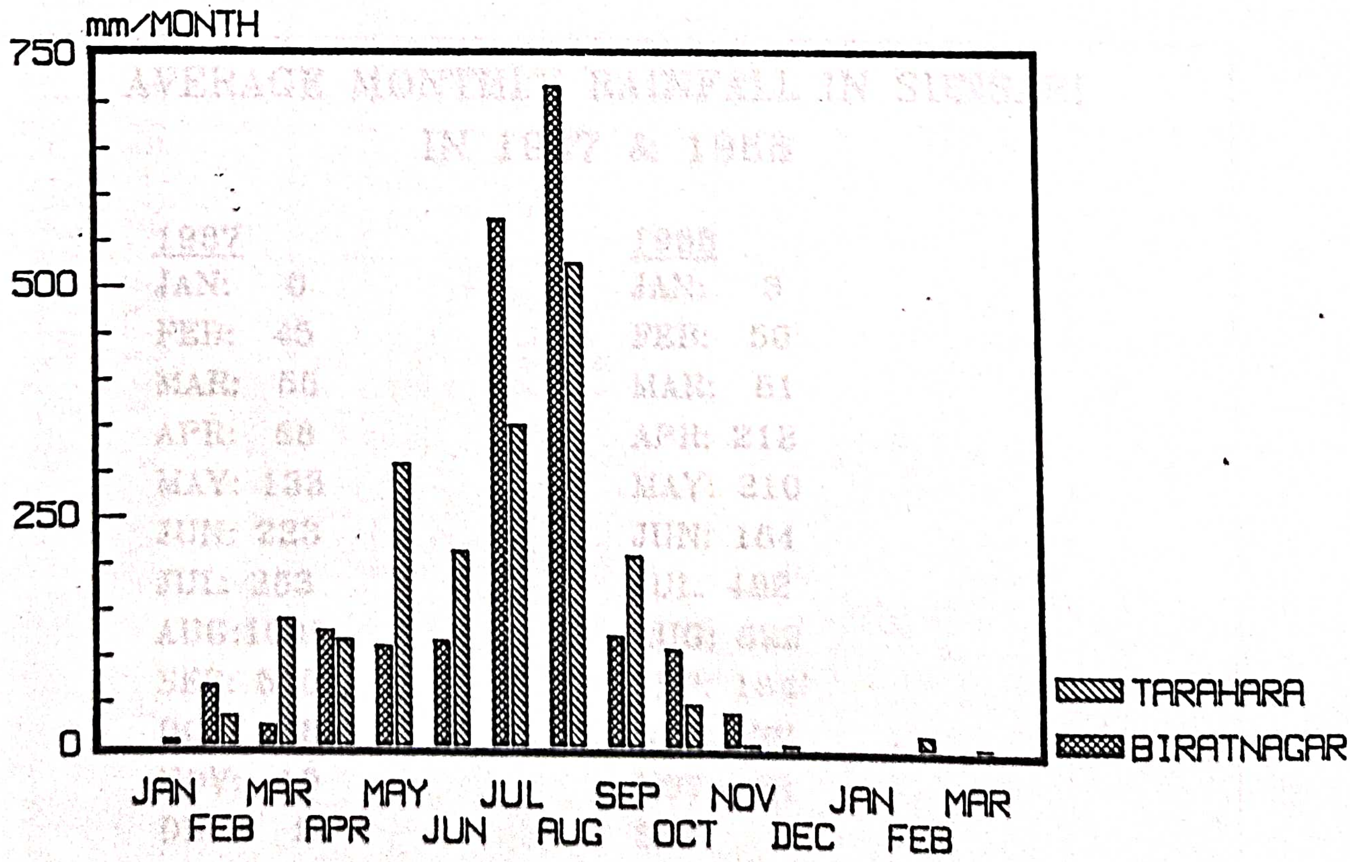
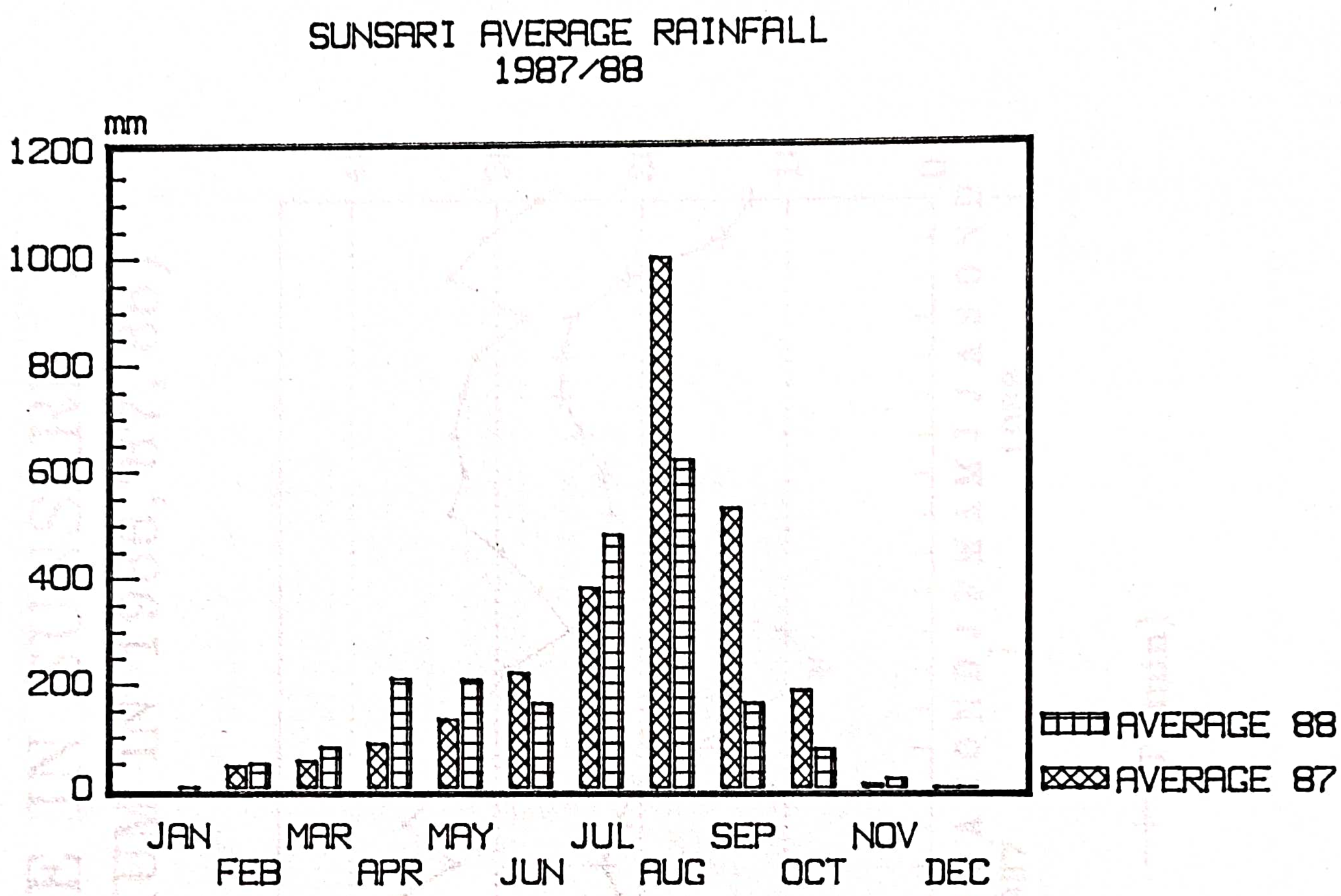


FIGURE 3



AVERAGE MONTHLY RAINFALL IN SUNSARI IN 1987 & 1988

1987		1988	
JAN:	0	JAN:	3
FEB:	45	FEB:	50
MAR:	55	MAR:	81
APR:	88	APR:	212
MAY:	133	MAY:	210
JUN:	223	JUN:	164
JUL:	383	JUL:	482
AUG:	1000	AUG:	622
SEP:	530	SEP:	164
OCT:	188	OCT:	77
NOV:	10	NOV:	21
DEC:	2	DEC:	2
TOTAL:	2655 mm/year	TOTAL:	2088 mm/year

[mm/MONTH]

FIGURE 4

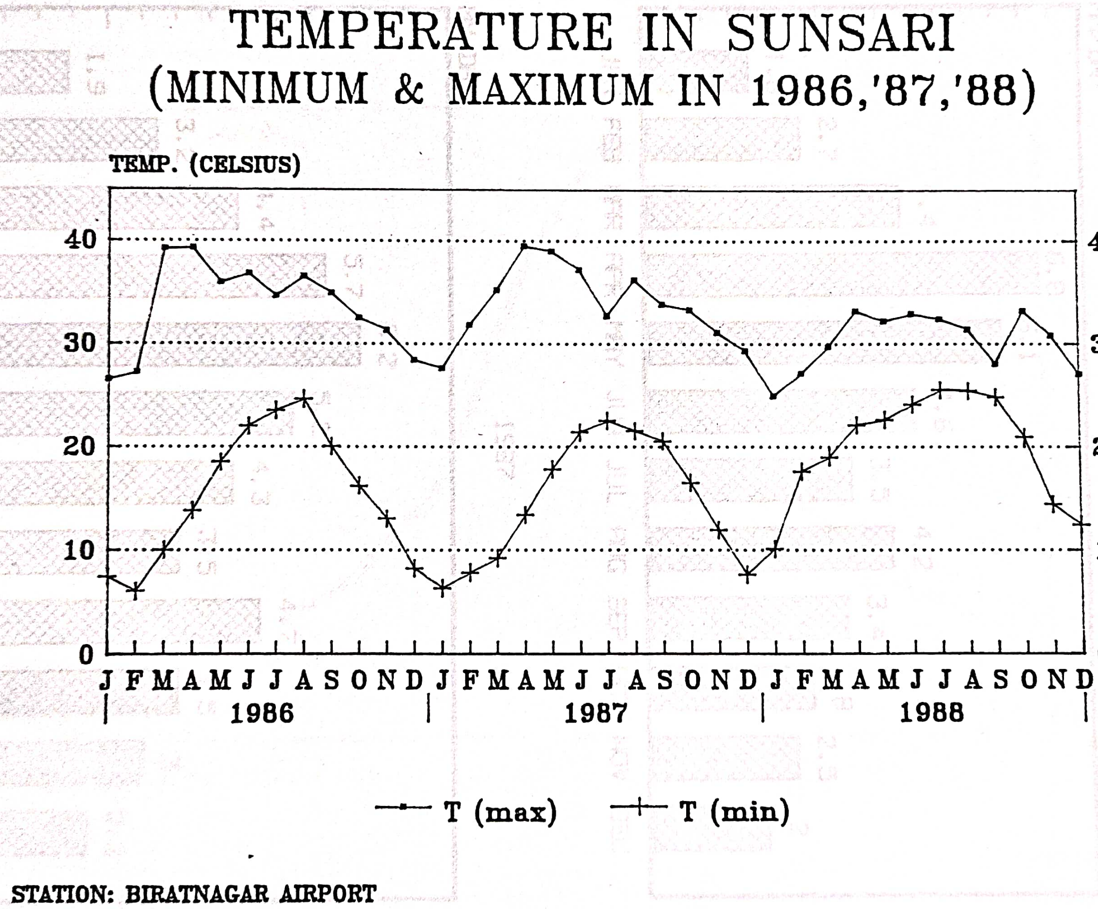
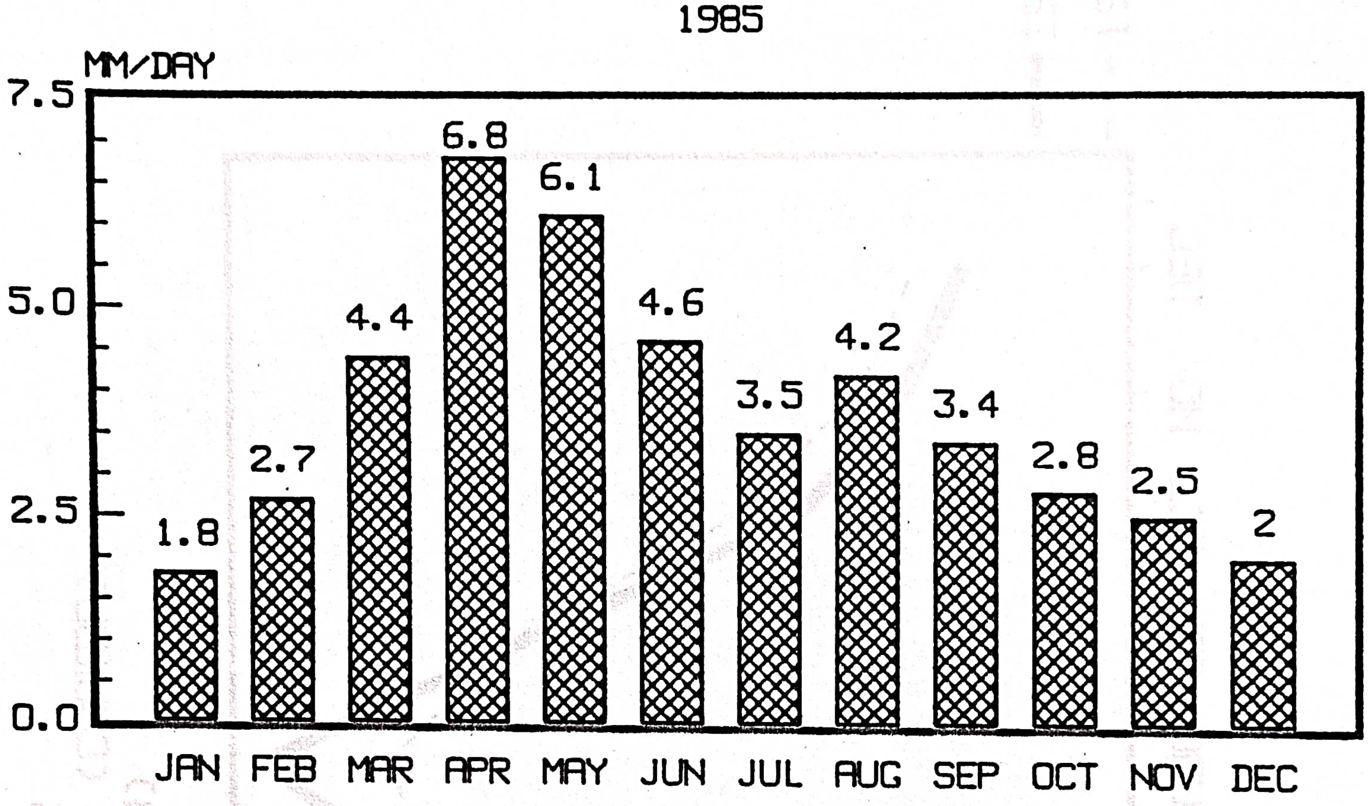

TEMPERATURE IN SUNSARI
(MINIMUM & MAXIMUM IN 1986,'87,'88)
TEMP. (CELSIUS)
40
30
20
10
0
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1986
1987
1988
T (max)
T (min)
STATION: BIRATNAGAR AIRPORT

FIGURE 5

SUNSARI DAILY EVAPORATION IN MM
STATION TARAHARA



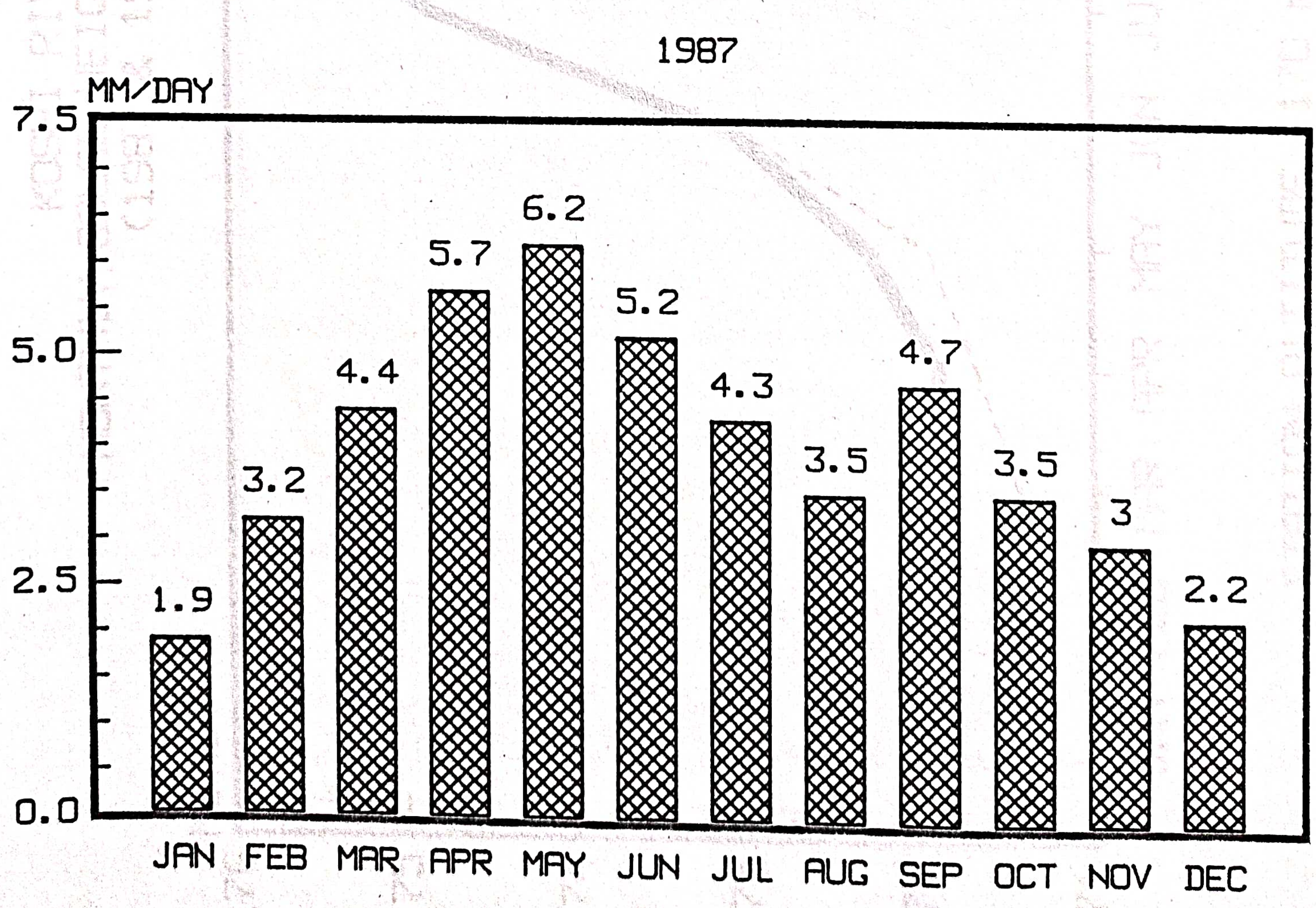
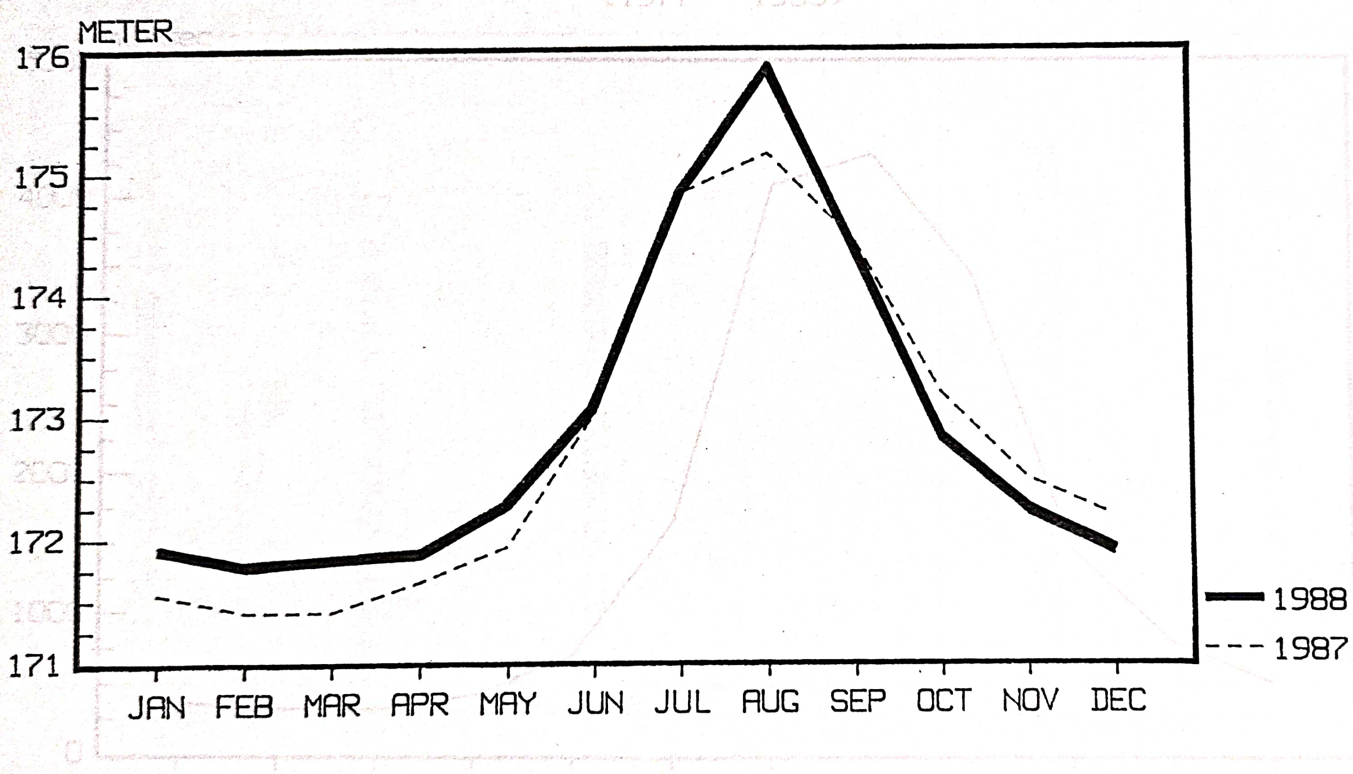


FIGURE 6

KOSHI RIVER
MONTHLY GAUGE HEIGHT (CHATRA)
(1987 & 1988)



STATION ALTITUDE: 170 m

FIGURE 7

KOSHI RIVER
AVERAGE MONTHLY DISCHARGE
(1977 - 1985)

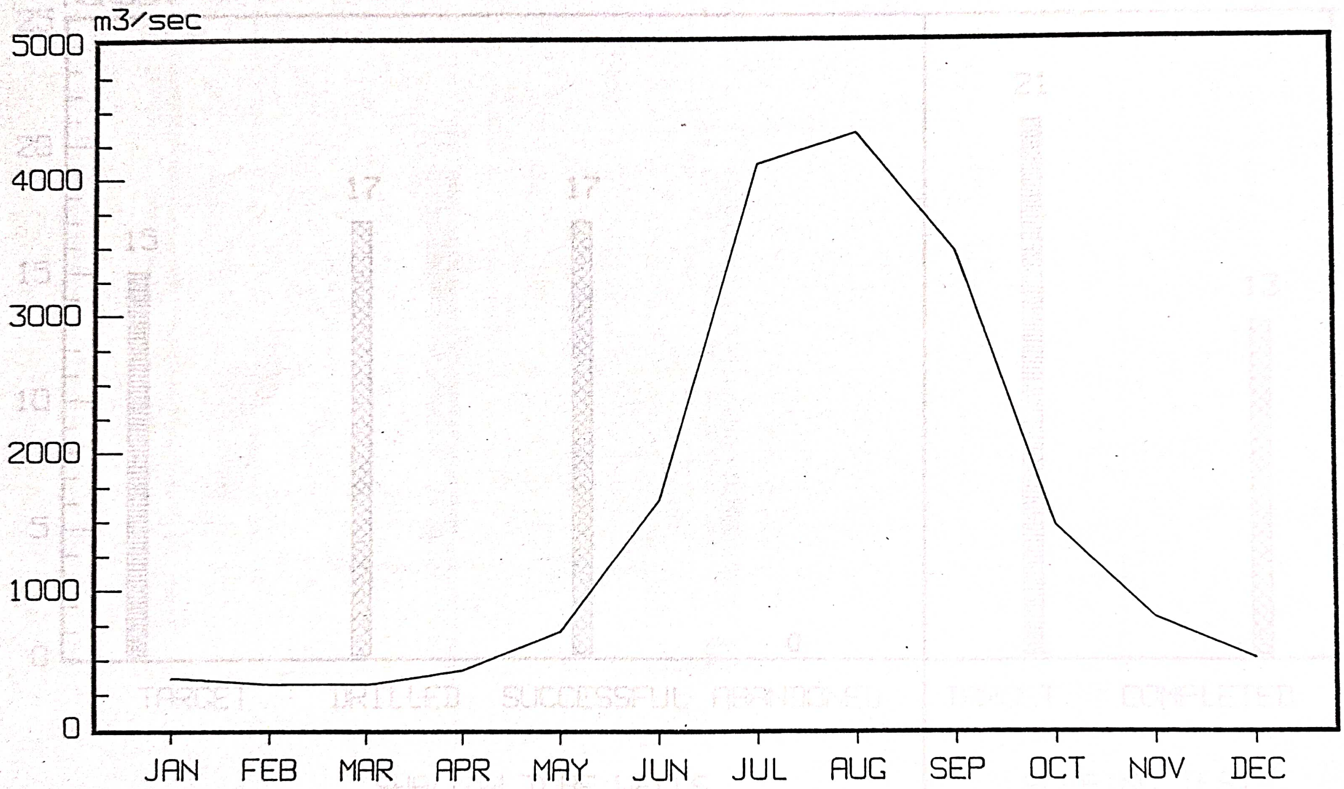


FIGURE 8

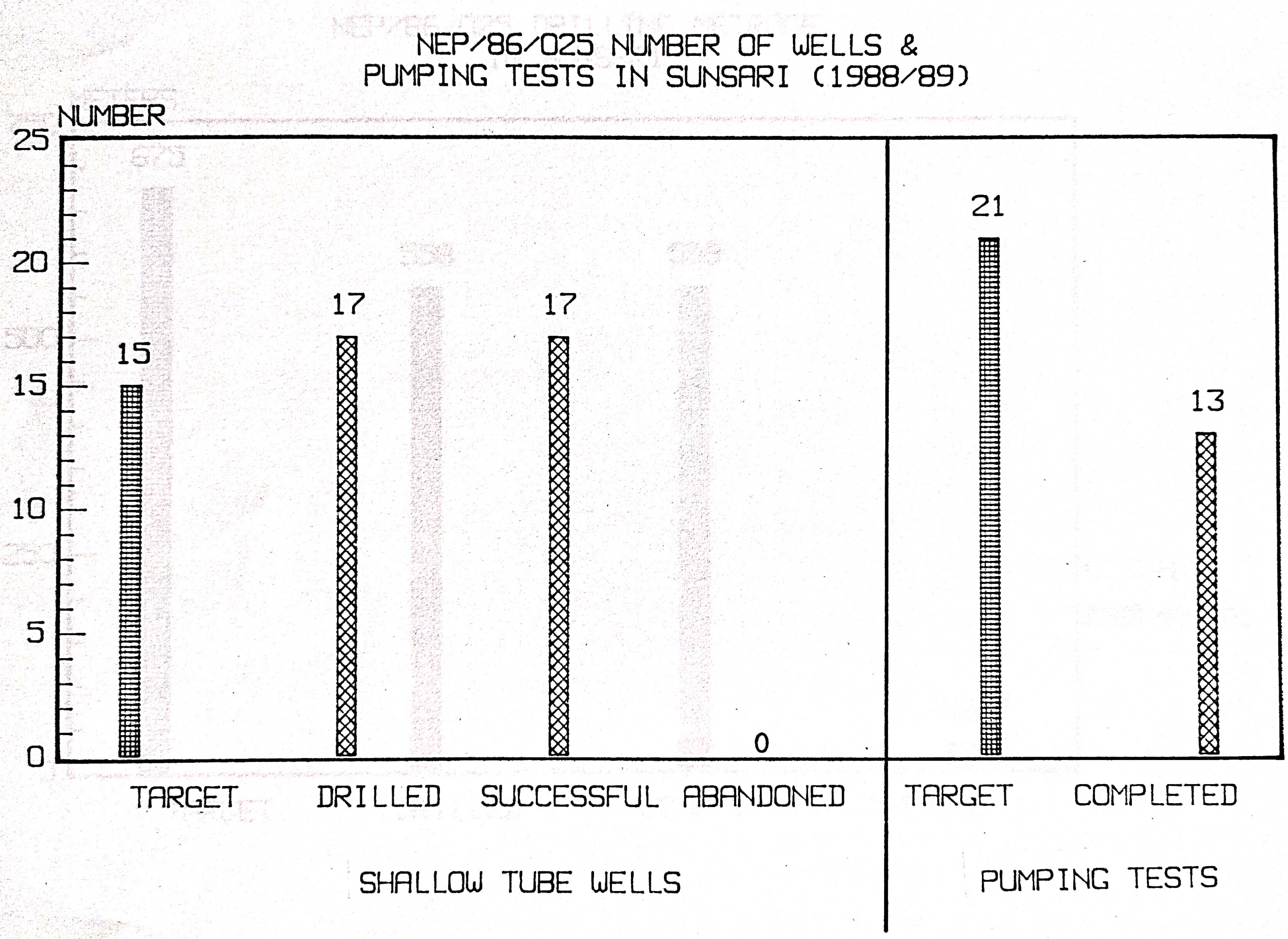

NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN SUNSARI (1988/89)
NUMBER
25
20
15
10
5
0
15
17
17
0
21
13
TARGET
DRILLED
SUCCESSFUL
ABANDONED
TARGET
COMPLETED
SHALLOW TUBE WELLS
PUMPING TESTS

FIGURE 9

NEP/86/025 DRILLING METRAGE
IN SUNSARI

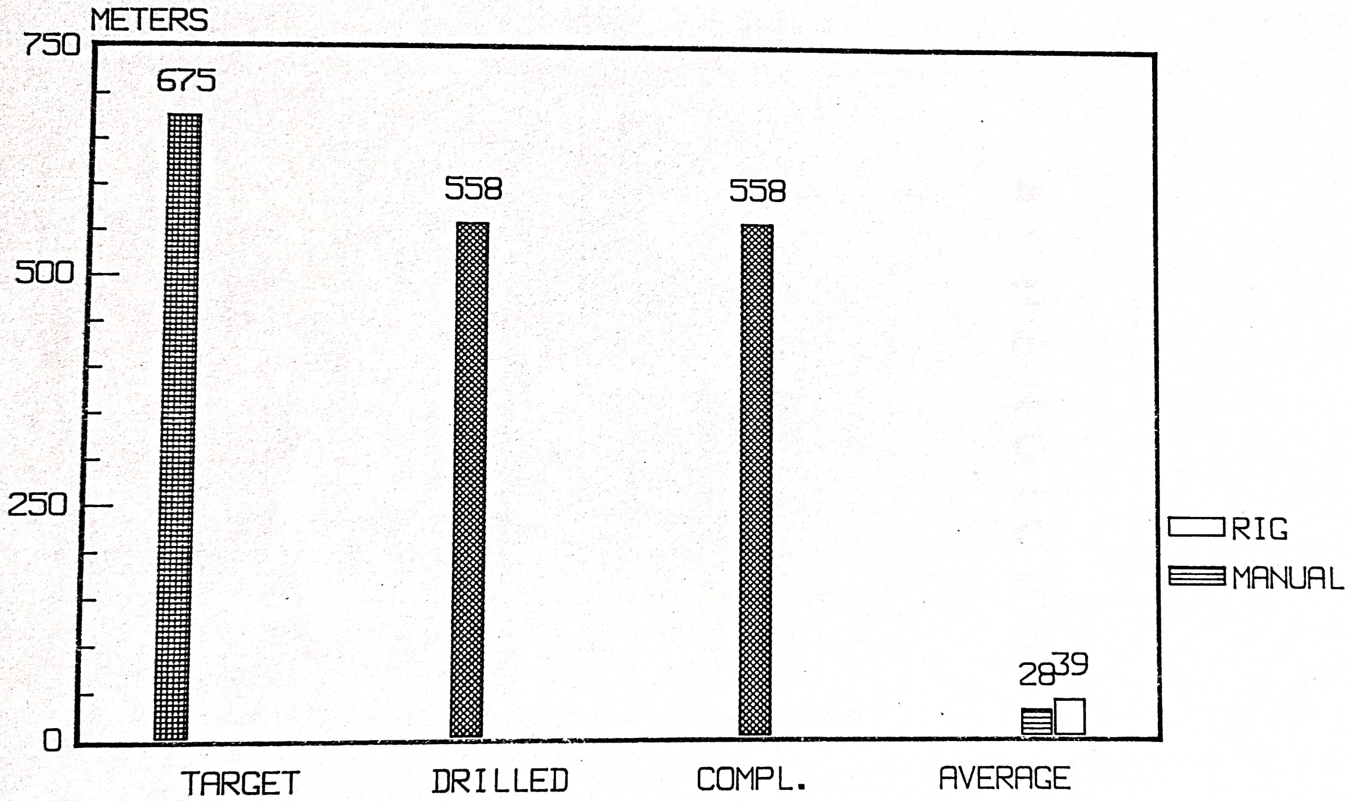
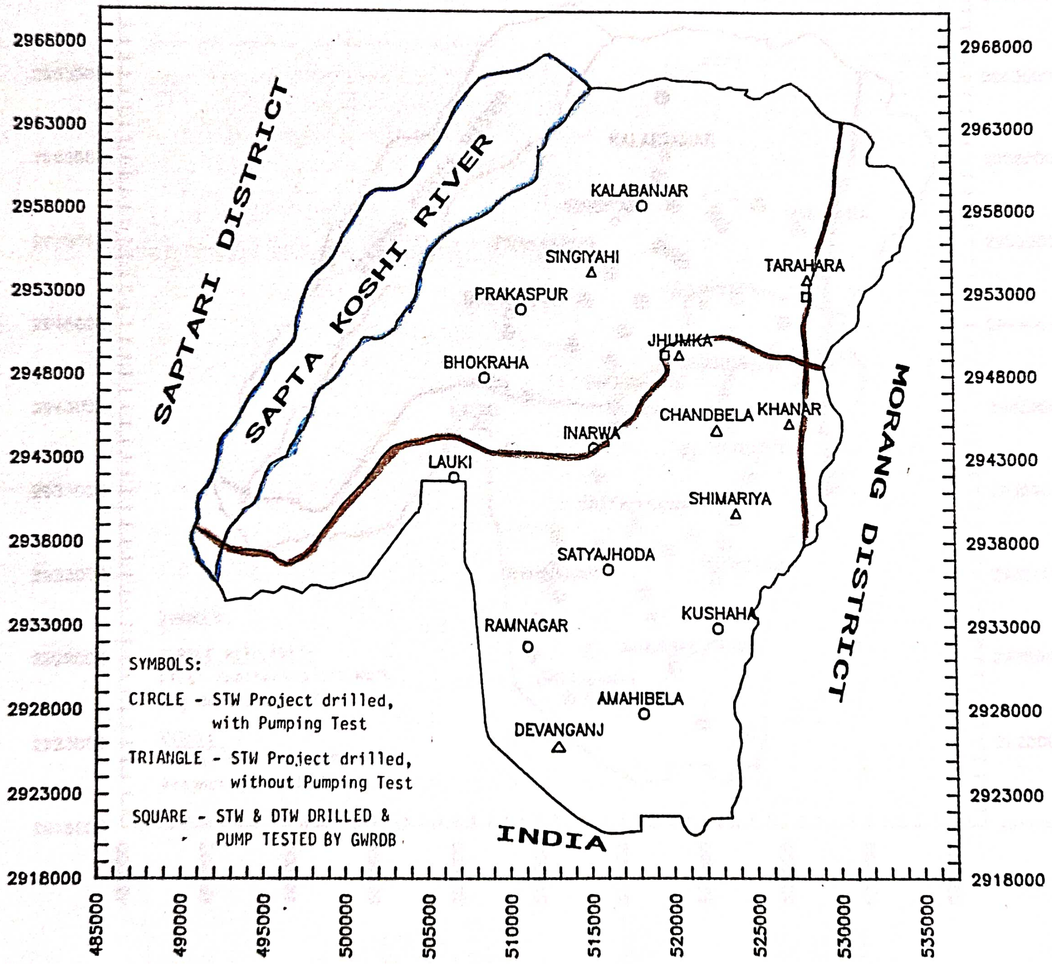


FIGURE 10

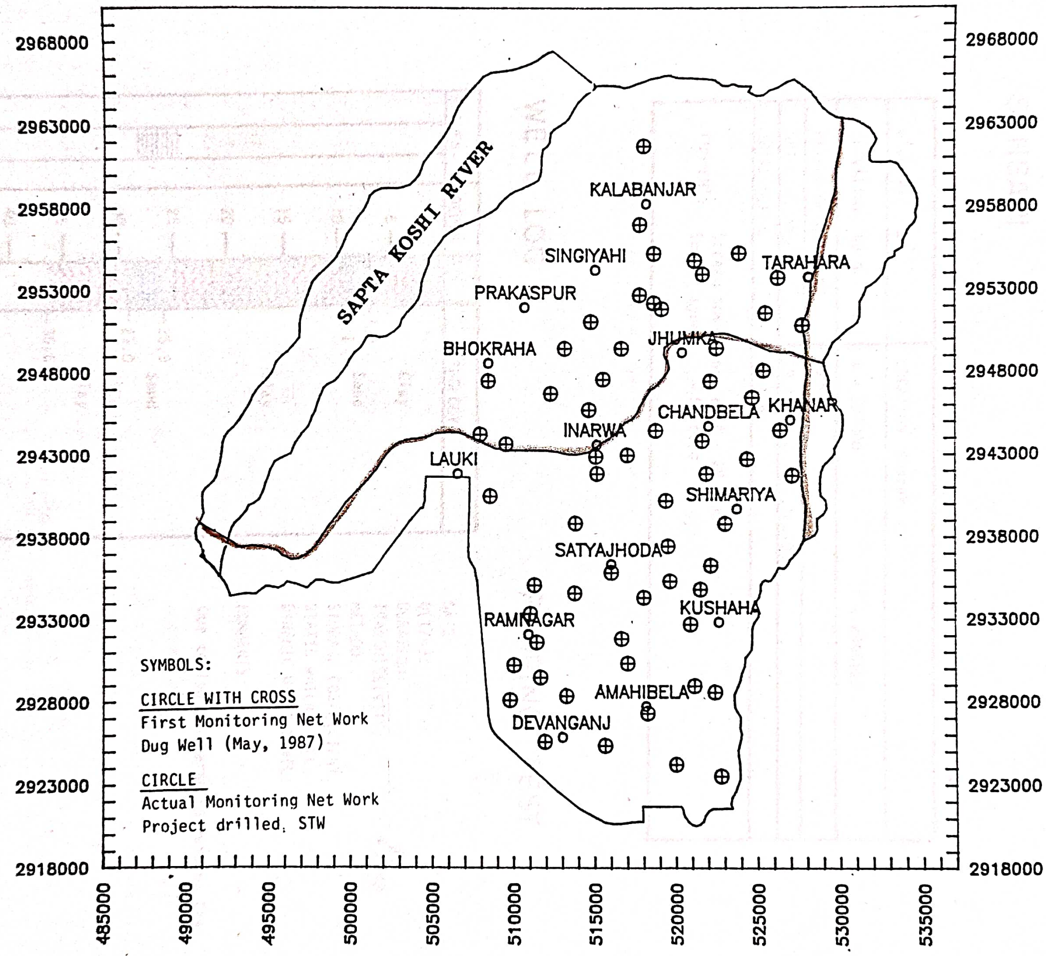
APPENDICES

SUNSARI PROJECT WELLS AND PUMPING TESTS



APPENDIX 1

SUNSARI LOCATION MAP FOR MONITORING NETWORK

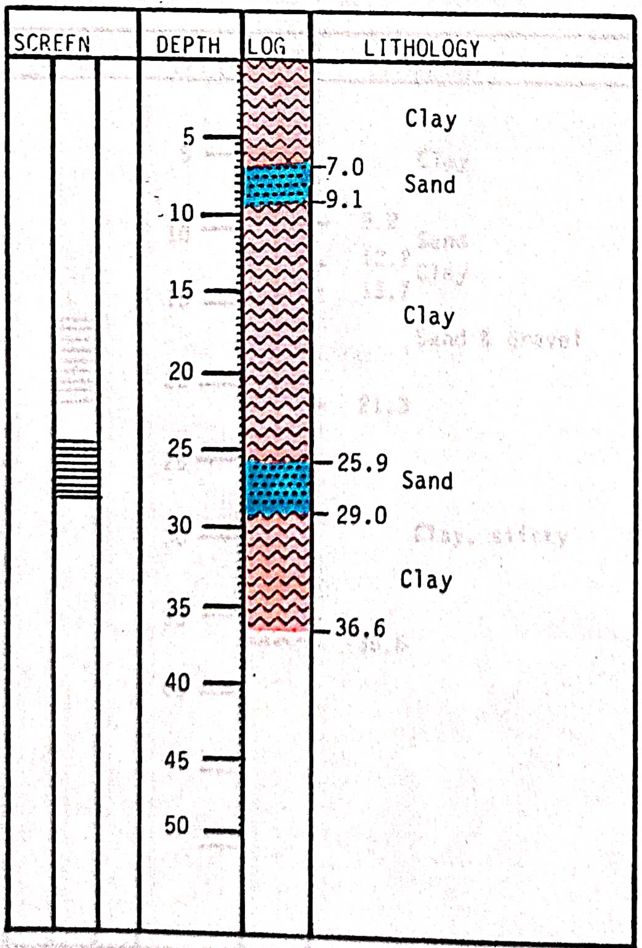


APPENDIX 2

SUNSARI

WELL NO. 1	LOCATION Khanar
ELEVATION 98.5 m	X = 527000 Y = 2945125
METHOD OF DRILLING	Manual
DRILLING DATES	12.10.1988 - 15.10.1988
TOTAL DEPTH	36.6 m.
COMMENTS	Screen position - 25.4 - 28.1 m. Screen type - Slotted

WELL LOG



PUMPING TEST

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

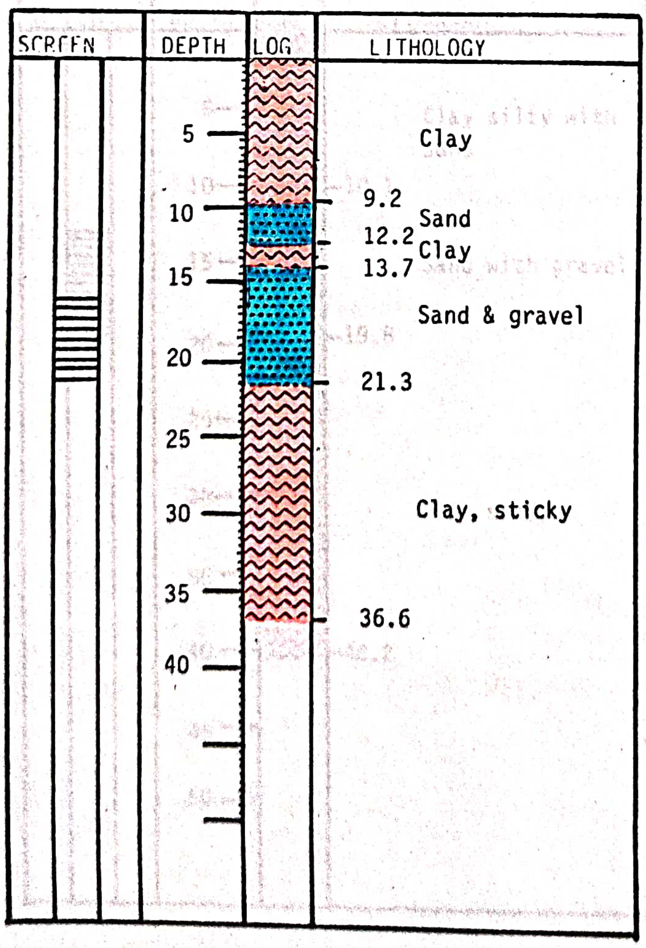
COMMENTS:

Due to low discharge no Pumping Test.

SUNSARI

WELL NO. 2	LOCATION Chandbela
ELEVATION 93.0 m	X = 522000 Y = 2944750
METHOD OF DRILLING	Manual
DRILLING DATES	1.11.88
TOTAL DEPTH	36.6 m.
COMMENTS	Screen position - 15.2 - 21.3 m. Screen type - Slotted

WELL LOG



PUMPING TEST

DATE: 22.12.1988
Q(l/s): 4.5
DURATION: 5 min.
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 5.38 m(B.G.L)
DYNAMIC WATER LEVEL: 7.78 m(B.G.L)

COMMENTS:

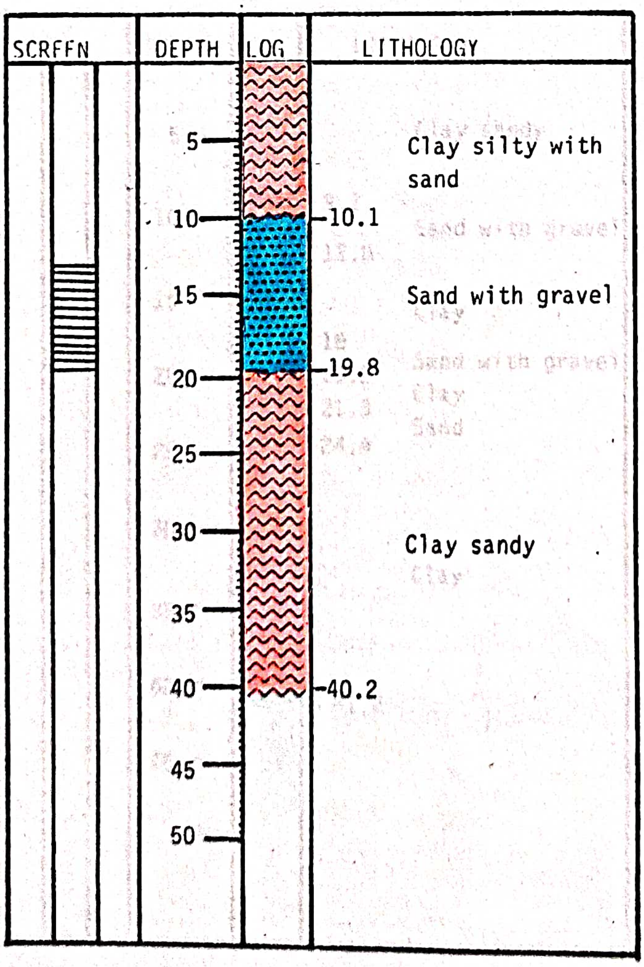
Due to short duration of P.T. not evaluatable.

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

SUNSARI

WELL NO. 3	LOCATION Kushaha
ELEVATION 77.0 m	X = 522625 Y = 2932875
METHOD OF DRILLING	Manual
DRILLING DATES	19.11.1988 - 22.11.1988
TOTAL DEPTH	40.2 m.
COMMENTS	Screen position - 13.3 - 19.4 m. Screen type - Slotted

WELL LOG



PUMPING TEST

DATE: 1.12.1988
Q(l/s): 15
DURATION:35 min.
TRANSMISSIVITY: 2500 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.39 m(B.G.L)
DYNAMIC WATER LEVEL:5.54 m(B.G.L)

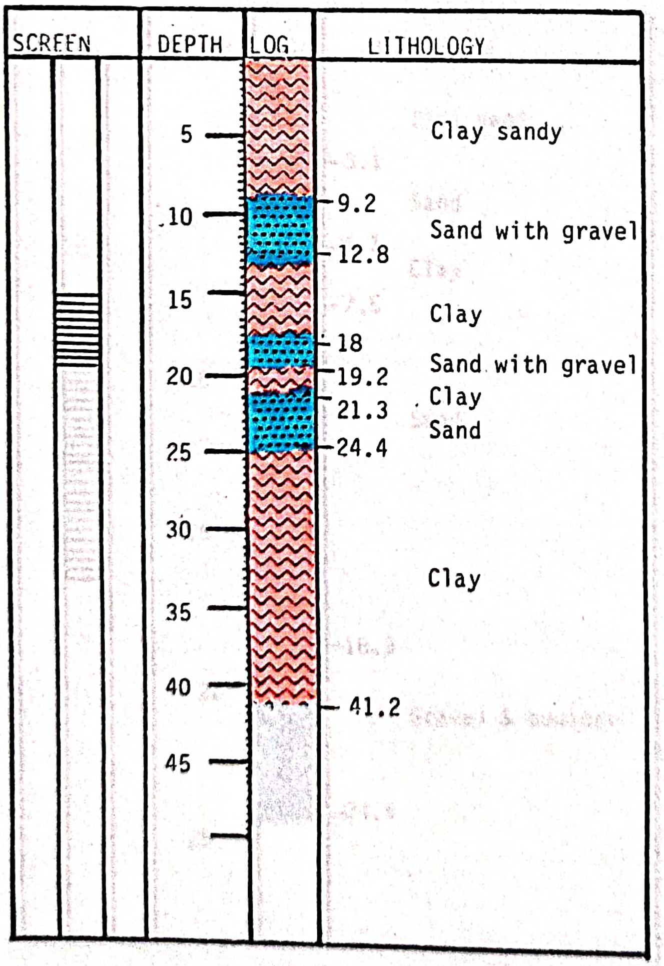
COMMENTS:

APPENDIX 3/3

SUNSARI

WELL NO. 4	LOCATION Shimariya
ELEVATION 83.2 m	X = 523750 Y = 2932875
METHOD OF DRILLING	Manual
DRILLING DATES	29.11.1988 - 4.12.1988
TOTAL DEPTH	41.2 m.
COMMENTS	Screen position - 15.2 - 19.2 m. Screen type - Slotted

WELL LOG



PUMPING TEST

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

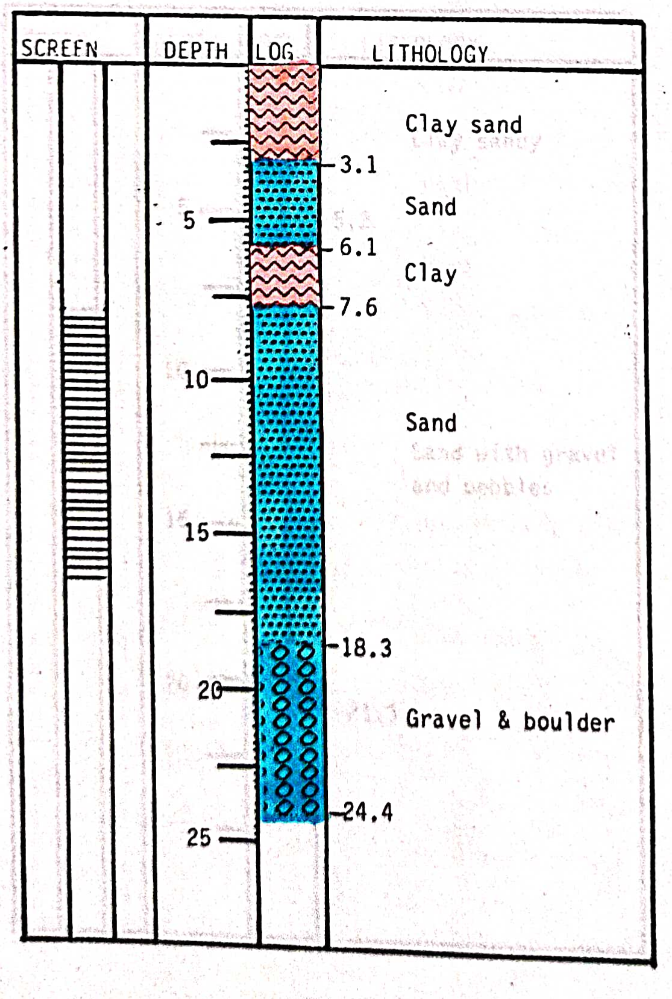
COMMENTS:

Due to low discharge, no pumping test.

SUNSARI

WELL NO. 5	LOCATION Amahibela
ELEVATION 69.8 m	X = 518125 Y = 2927750
METHOD OF DRILLING	Manual
DRILLING DATES	7.12.1988
TOTAL DEPTH	24.4 m.
COMMENTS	Screen position - 8.7 - 17.8 m. Screen type - Slotted

WELL LOG



PUMPING TEST

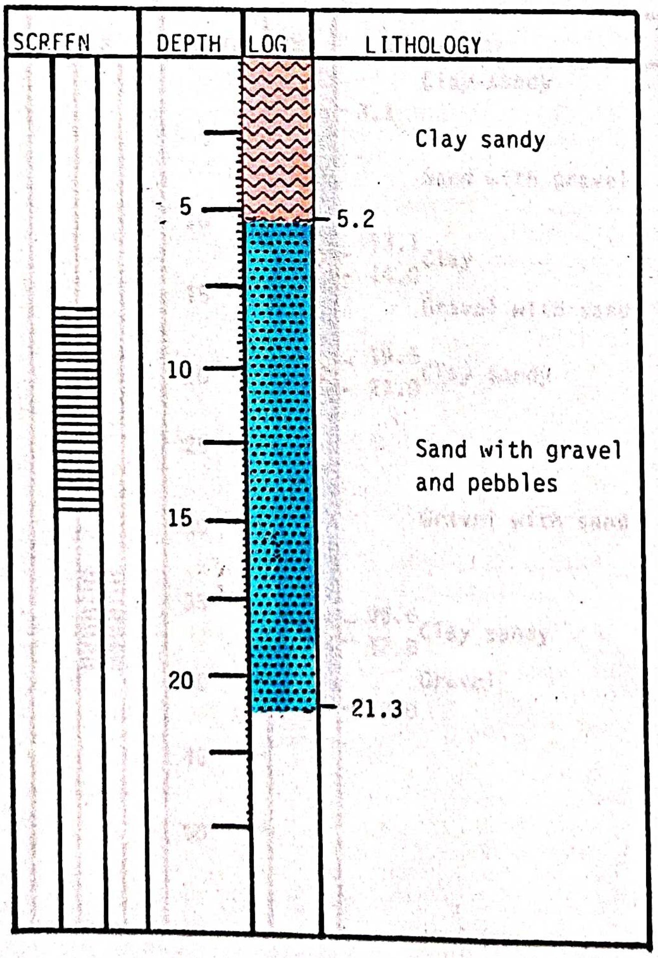
DATE: 12.2.1989
Q(l/s): 18.5
DURATION: 100 min.
TRANSMISSIVITY: 1100 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.11 m(B.G.L)
DYNAMIC WATER LEVEL: 5.03 m(B.G.L)

COMMENTS:

SUNSARI

WELL NO. 6	LOCATION Ramnagar	
ELEVATION 72 .6 m	X = 510875	Y = 2932125
METHOD OF DRILLING	Manual	
DRILLING DATES	13.12.1988 - 18.12.1988	
TOTAL DEPTH	21.3 m.	
COMMENTS Screen position - 8.7 - 14.8 m. Screen type - Slotted		

WELL LOG



PUMPING TEST

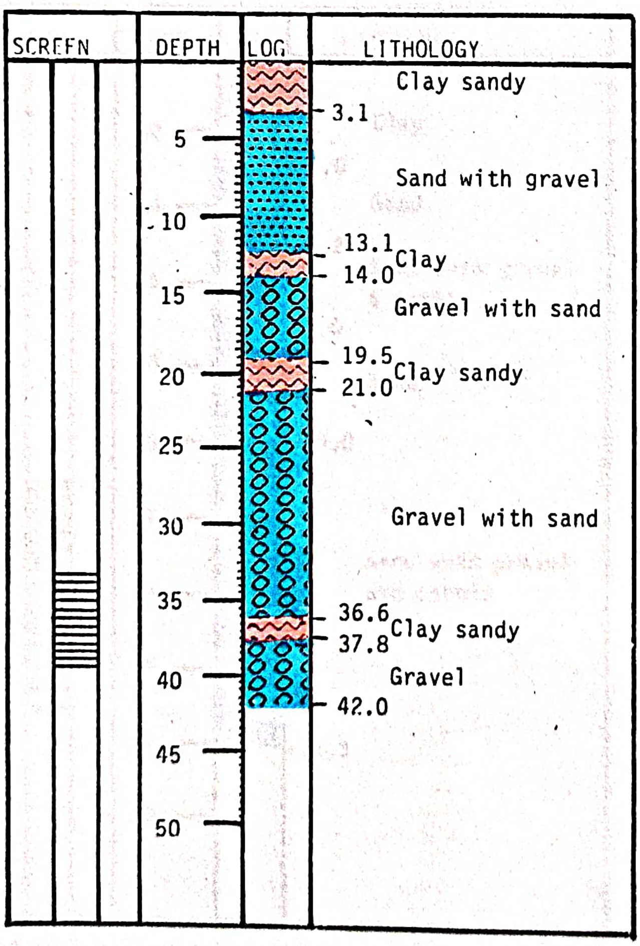
DATE: 24.12.88
Q(l/s): 20
DURATION: 35 min.
TRANSMISSIVITY: 2000 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.93 m (B.G.L)
DYNAMIC WATER LEVEL: 6.54 m (B.G.L)

COMMENTS:

SUNSARI

WELL NO. 7	LOCATION Bhokraha
ELEVATION 83.5 m	X = 508375 Y = 2947875
METHOD OF DRILLING	Rig
DRILLING DATES	15.12.1988
TOTAL DEPTH	41.8 m.
COMMENTS	Screen position - 33.5 - 39.6 m. Screen type - Slotted

WELL LOG



PUMPING TEST

DATE: 26.12.1988
Q(l/s): 20
DURATION: 3 hrs.
TRANSMISSIVITY: 1200 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.51 m(B.G.L)
DYNAMIC WATER LEVEL: 5.78 m(B.G.L)

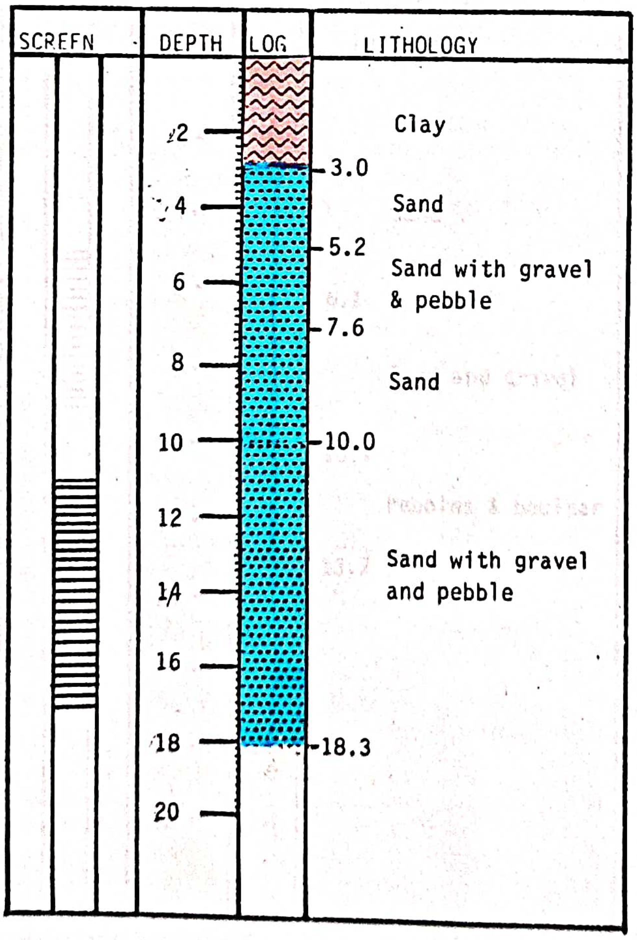
COMMENTS:

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

SUNSARI

WELL NO. 8	LOCATION Devanganj
ELEVATION 69.7 m	X = 513000 Y = 2925875
METHOD OF DRILLING	Manual
DRILLING DATES	17.12.1988 - 20.12.1988
TOTAL DEPTH	18.3 m.
COMMENTS	Screen position - 11.7 - 17.8 Screen type - Slotted

WELL LOG



PUMPING TEST

DATE: 23.12.1988
Q(l/s): 24
DURATION: 30 min.
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.03 m (B.G.L)
DYNAMIC WATER LEVEL: 4.04 m (B.G.L)

COMMENTS:

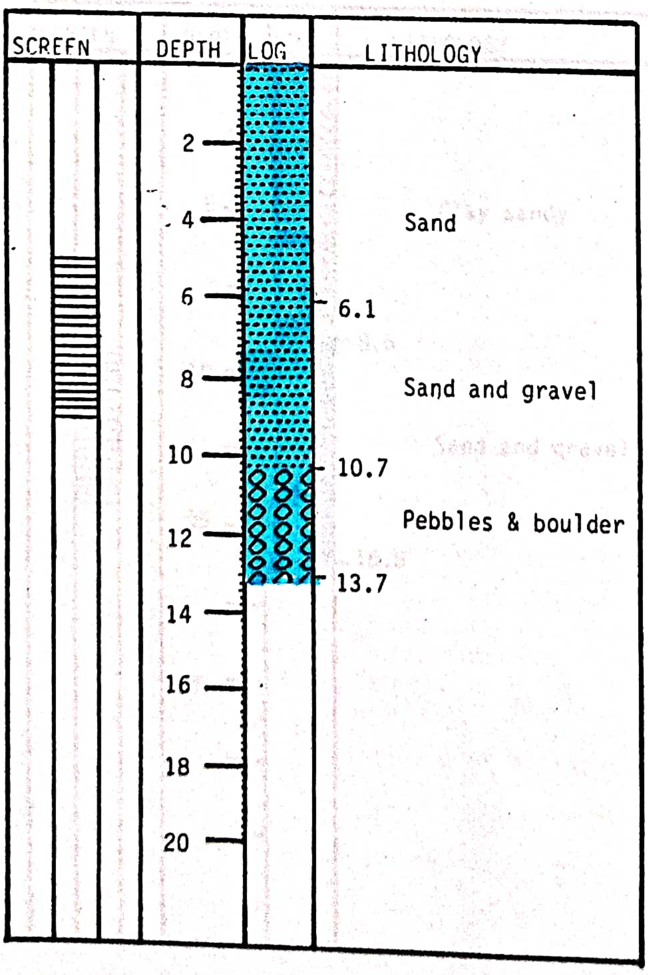
The result of the evaluation is not reliable, shows transmissivity of over 15 000 m^2/day (mistake in measuring the water table)?

APPENDIX 3/8

SUNSARI

WELL NO. 9	LOCATION Lauki - I
ELEVATION 80.5 m	X = 506500 Y = 2941875
METHOD OF DRILLING	Manual
DRILLING DATES	20.12.1988
TOTAL DEPTH	13.7 m.
COMMENTS	Screen position 5.6 - 9.1 m. Screen type - Slotted 14.2 m. far a rig drilled well was constructed (=STW 12)

WELL LOG



PUMPING TEST

DATE: 25.12.1988
Q(l/s): 20
DURATION: 35 min
TRANSMISSIVITY: 2400 m^2/day
METHOD: Theis
STORAGE COEFFICIENT: 0.6734
STATIC WATER LEVEL: 1.14 m.(B.G.L)
DYNAMIC WATER LEVEL:4.14 m (B.G.L)

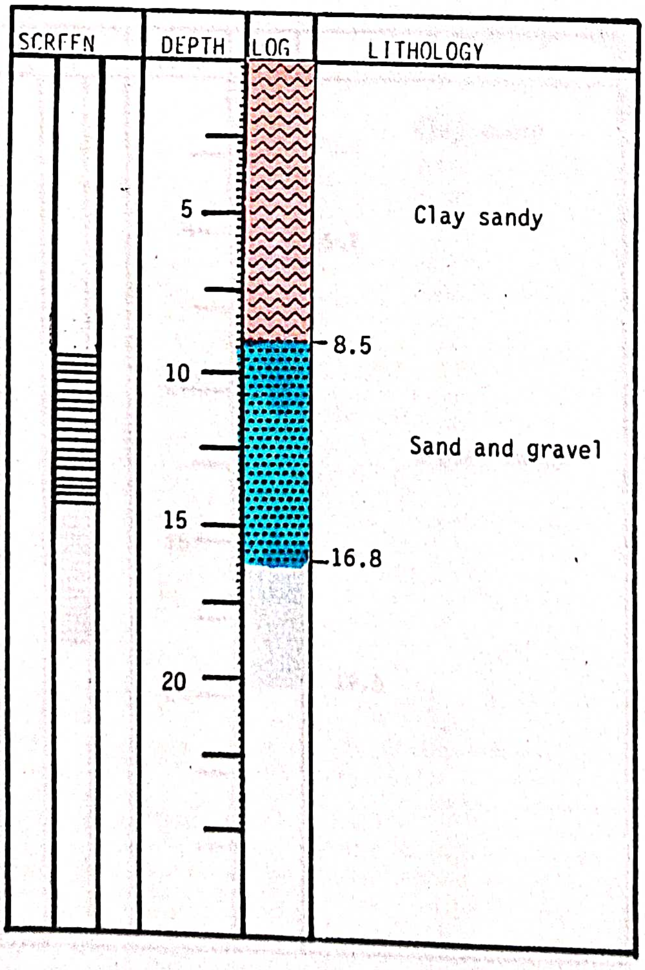
COMMENTS:

The 14.3 m. far observation well (H.P) shows Transmissivity of 2800 m^2/day.

SUNSARI

WELL NO. 10	LOCATION Satyajhoda	
ELEVATION 77 .3 m	X = 516000	Y = 2936375
METHOD OF DRILLING	Manual	
DRILLING DATES	21.12.1988 - 25.12.88	
TOTAL DEPTH	16.8 m.	
COMMENTS	Screen position 8.7 - 14.8 m Screen type Slotted	

WELL LOG



PUMPING TEST

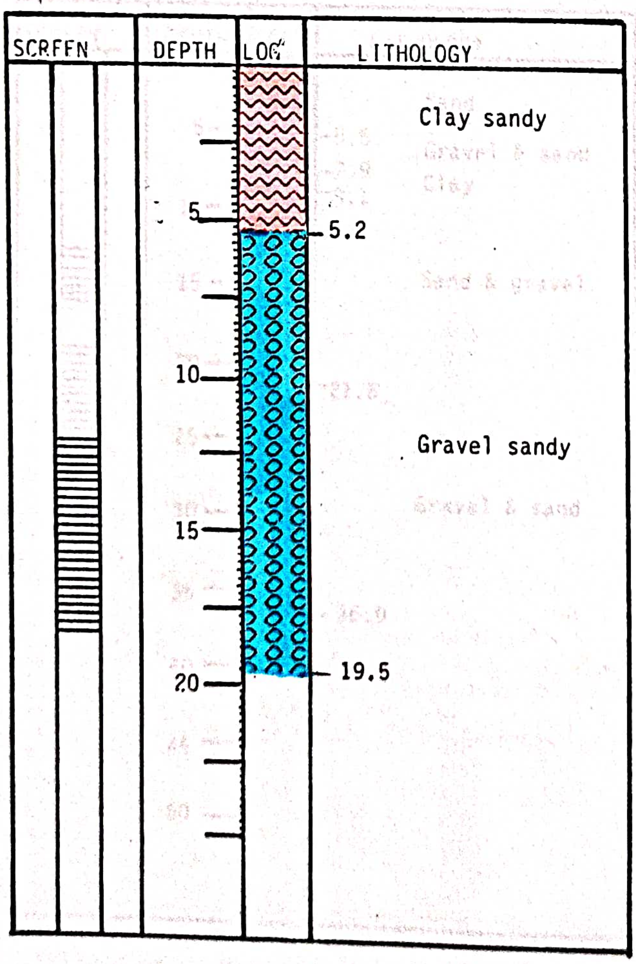
DATE: 28.12.1988
Q(l/s): 20
DURATION: 100 min.
TRANSMISSIVITY: 4300 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.58 m(B.G.L)
DYNAMIC WATER LEVEL: 5.48 m(B.G.L)

COMMENTS:

SUNSARI

WELL NO. 11	LOCATION Prakashpur
ELEVATION 89.0 m	X = 510625 Y = 2952000
METHOD OF DRILLING	Rig
DRILLING DATES	24.12 - 27.12.1988
TOTAL DEPTH	19.5 m.
COMMENTS	Screen position - 12.2 - 18.3 m. Screen type - Slotted

WELL LOG



PUMPING TEST

DATE: 31.12.1988
Q(l/s): 22
DURATION: 60 min.
TRANSMISSIVITY: 1600 m^2/day
METHOD: Theis
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 2.56 m(B.G.L)
DYNAMIC WATER LEVEL: 4.16 m(B.G.L)

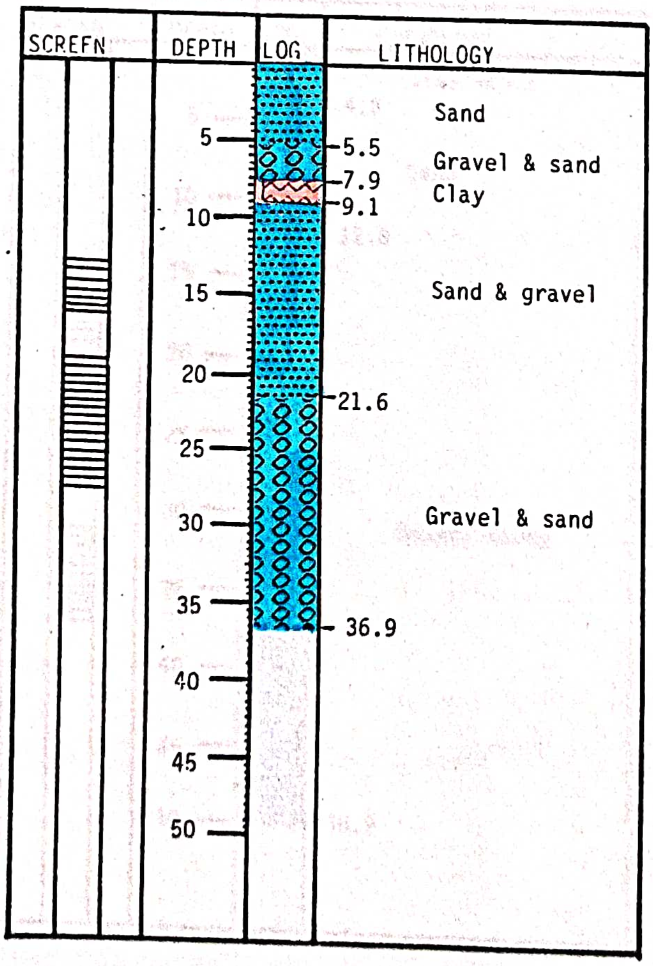
COMMENTS:

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

SUNSARI

WELL NO. 12	LOCATION Lauki - II
ELEVATION 80.5 m	X = 506500 Y = 2941875
METHOD OF DRILLING	Rig
DRILLING DATES	28.12.1988 - 31.12.1988
TOTAL DEPTH	36.9 m.
COMMENTS	Screen position 13.7 - 16.5 m., 19.5 - 28.7 m Screen type Slotted Well is 14.2 m. for from Well No. 9.

WELL LOG



PUMPING TEST

DATE: 1.1.1989
Q(l/s): 20
DURATION: 100 min.
TRANSMISSIVITY: 1600 m^2/day
METHOD: Theis
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 1.01 m(B.G.L)
DYNAMIC WATER LEVEL: 5.55 m(B.G.L)

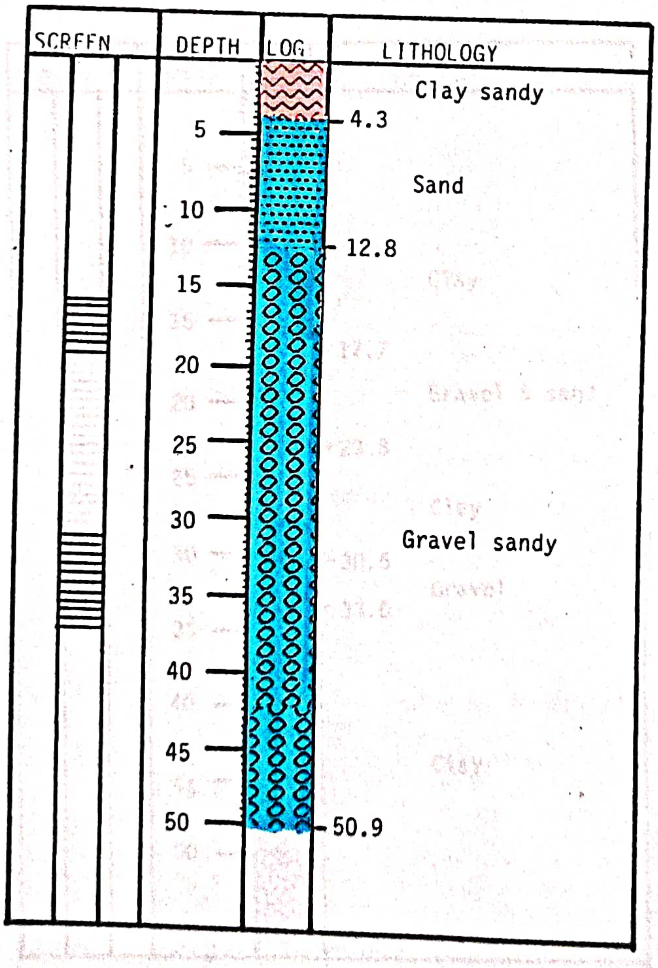
COMMENTS:

APPENDIX 3/12

SUNSARI

WELL NO. 13	LOCATION Inarwa
ELEVATION 83.1 m	X = 515125 Y = 2943625
METHOD OF DRILLING	Rig
DRILLING DATES	1.1.89 - 7.1.89
TOTAL DEPTH	50.9 m.
COMMENTS	Screen position - 16.3 - 19.4 m., 31.6 - 37.7 m., Screen type - Slotted

WELL LOG



PUMPING TEST

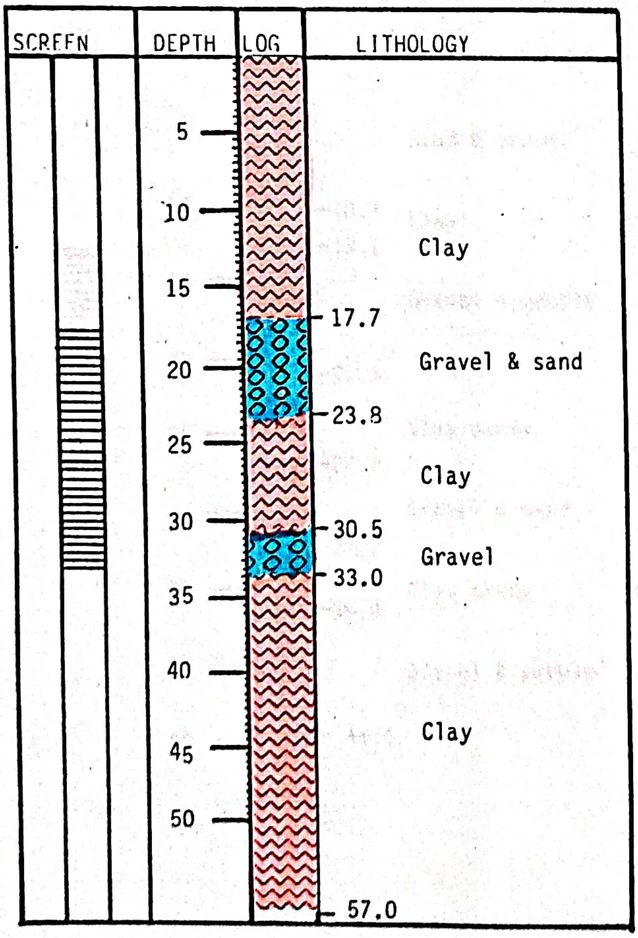
DATE: 12.1.1989
Q(l/s): 21
DURATION: 50 min
TRANSMISSIVITY: 900 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.47 m(B.G.L)
DYNAMIC WATER LEVEL: 4.97 m(B.G.L)

COMMENTS:

SUNSARI

WELL NO. 14	LOCATION Jhumka
ELEVATION 102.0 m	X = 520375 Y = 2949250
METHOD OF DRILLING	Rig
DRILLING DATES	7.1.1989 - 10.1.1989
TOTAL DEPTH	57.0 m.
COMMENTS	Screen position 17.8 - 29.9 m., 30.0 - 33.1 m. Screen type - Slotted

WELL LOG



PUMPING TEST

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

COMMENTS:

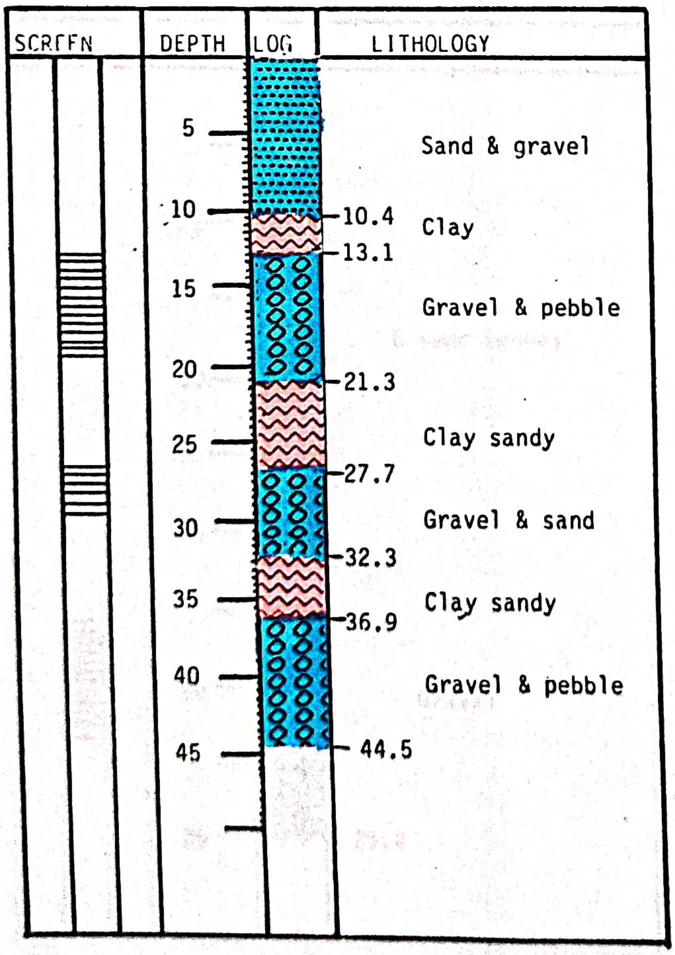
Due to deep water table,

no pumping test. (greater than 8 m)

SUNSARI

WELL NO. 15	LOCATION Tarahara	
ELEVATION 145.0 m	X = 528125	Y = 2953375
METHOD OF DRILLING	Rig	
DRILLING DATES	12.1.1989	
TOTAL DEPTH	44.5 m.	
COMMENTS	Screen Position 13.1 - 19.2 m., 26.8 - 29.9 m. Screen Type - Slotted Pipe	

WELL LOG



PUMPING TEST

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

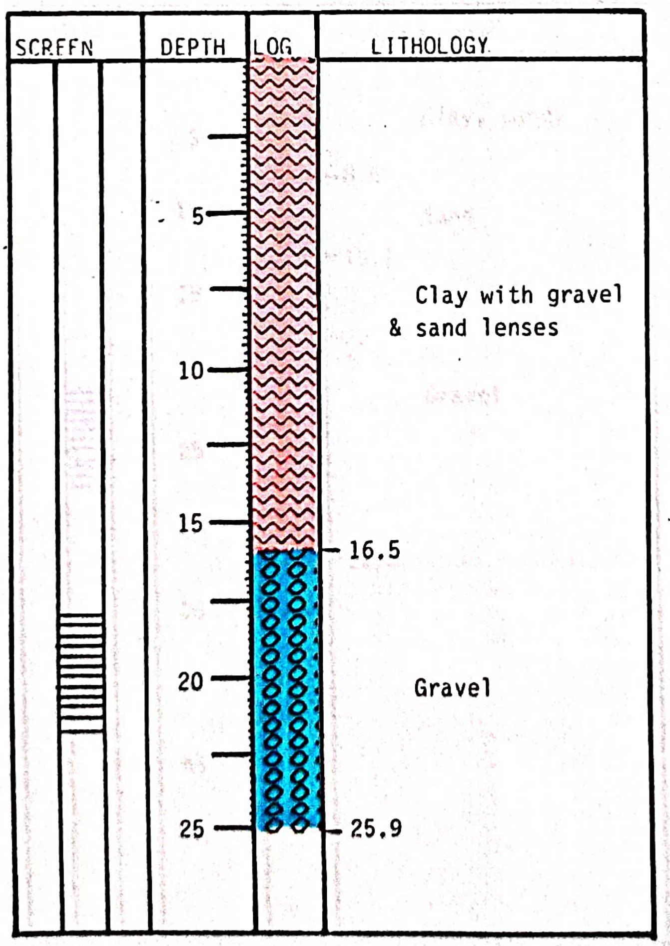
COMMENTS:

Self flowing well.

SUNSARI

WELL NO. 16	LOCATION Kalabanjar	
ELEVATION 118.0 m	X = 518125	Y = 2958250
METHOD OF DRILLING	Rig	
DRILLING DATES	18.1 - 20.1.1989	
TOTAL DEPTH	25.9	
COMMENTS	Screen Position - 17.7 - 23.8 m. Screen Type - Slotted	

WELL LOG



PUMPING TEST

DATE: 15.2.1989
Q(l/s): 12
DURATION: 140 min.
TRANSMISSIVITY: 2400 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT: 0.000421
STATIC WATER LEVEL: 5.95 m. (B.G.L)
DYNAMIC WATER LEVEL: 7.25 m.(B.G.L)

COMMENTS:

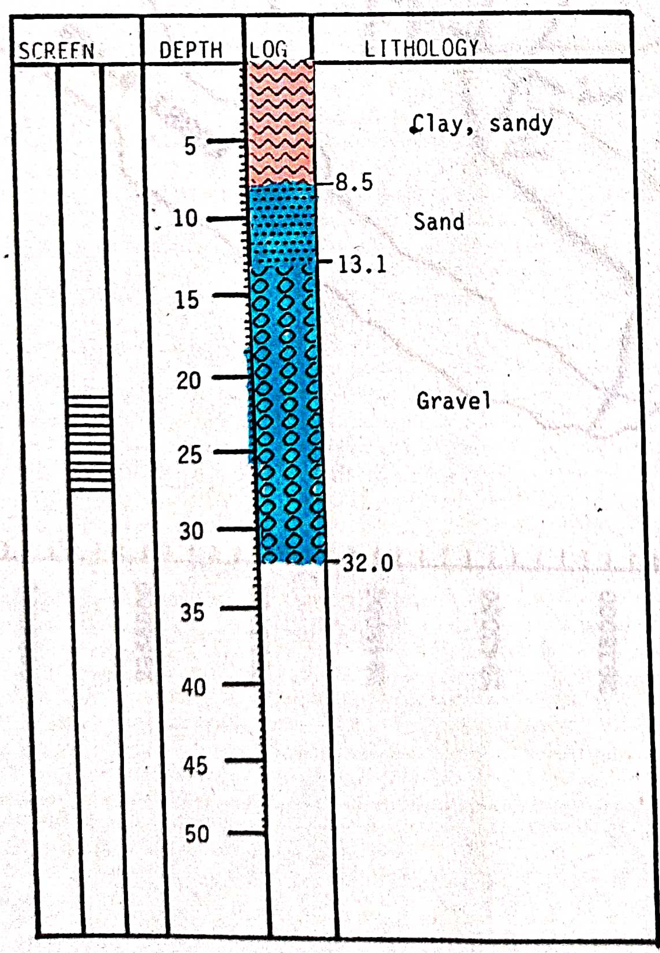
The 62.9 m. far Observation Well shows 4900 m^2/day

APPENDIX 3/16

SUNSARI

WELL NO. 17	LOCATION Singiyahi	
ELEVATION 100.0 m	X = 515000	Y = 2954250
METHOD OF DRILLING	Rig	
DRILLING DATES	21.1.1988	
TOTAL DEPTH	32.0	
COMMENTS Screen position 21.3 - 27.4 m.		

WELL LOG



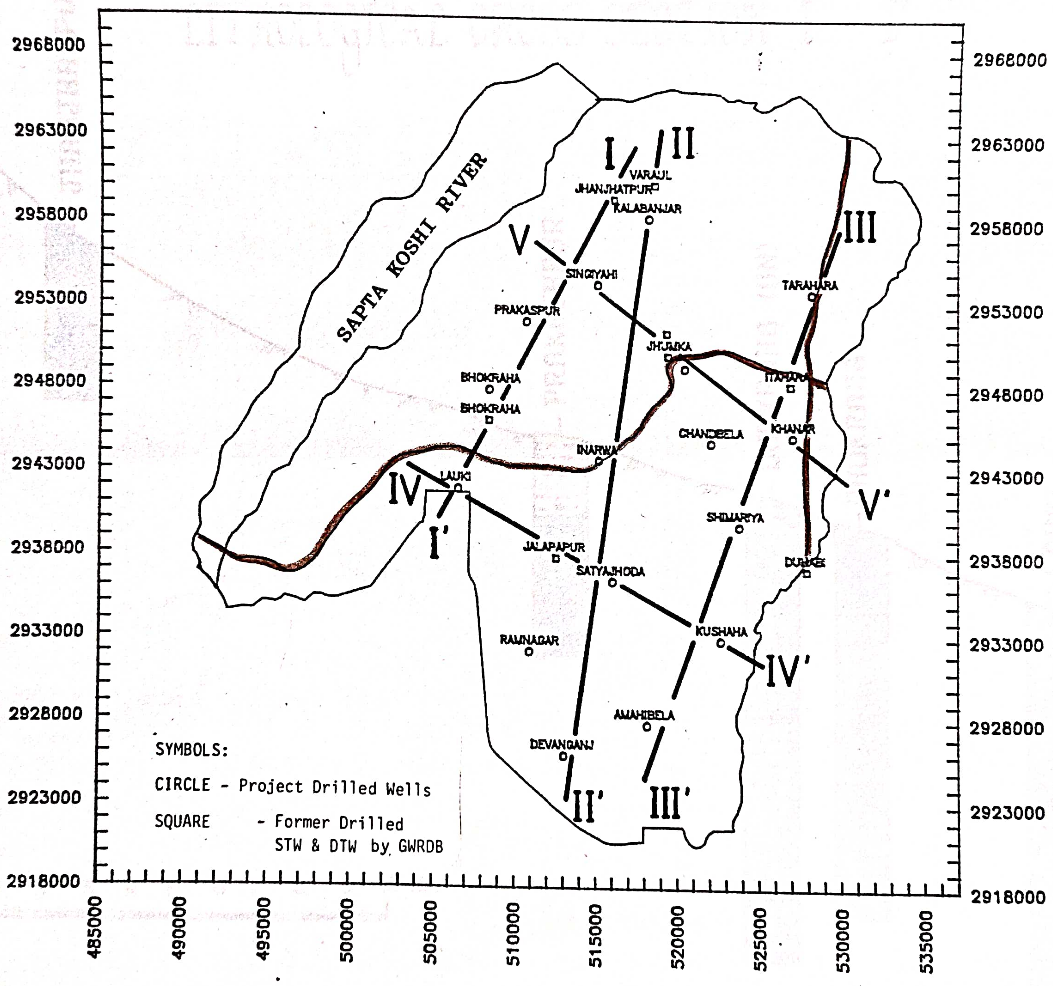
PUMPING TEST

DATE: 16.2.89
Q(l/s): 12
DURATION:
TRANSMISSIVITY: m^2/day
METHOD:
STORAGE COEFFICIENT:
STATIC WATER LEVEL: 3.31 m(B.G.L)
DYNAMIC WATER LEVEL: 7.9 m (B.G.L)

COMMENTS:

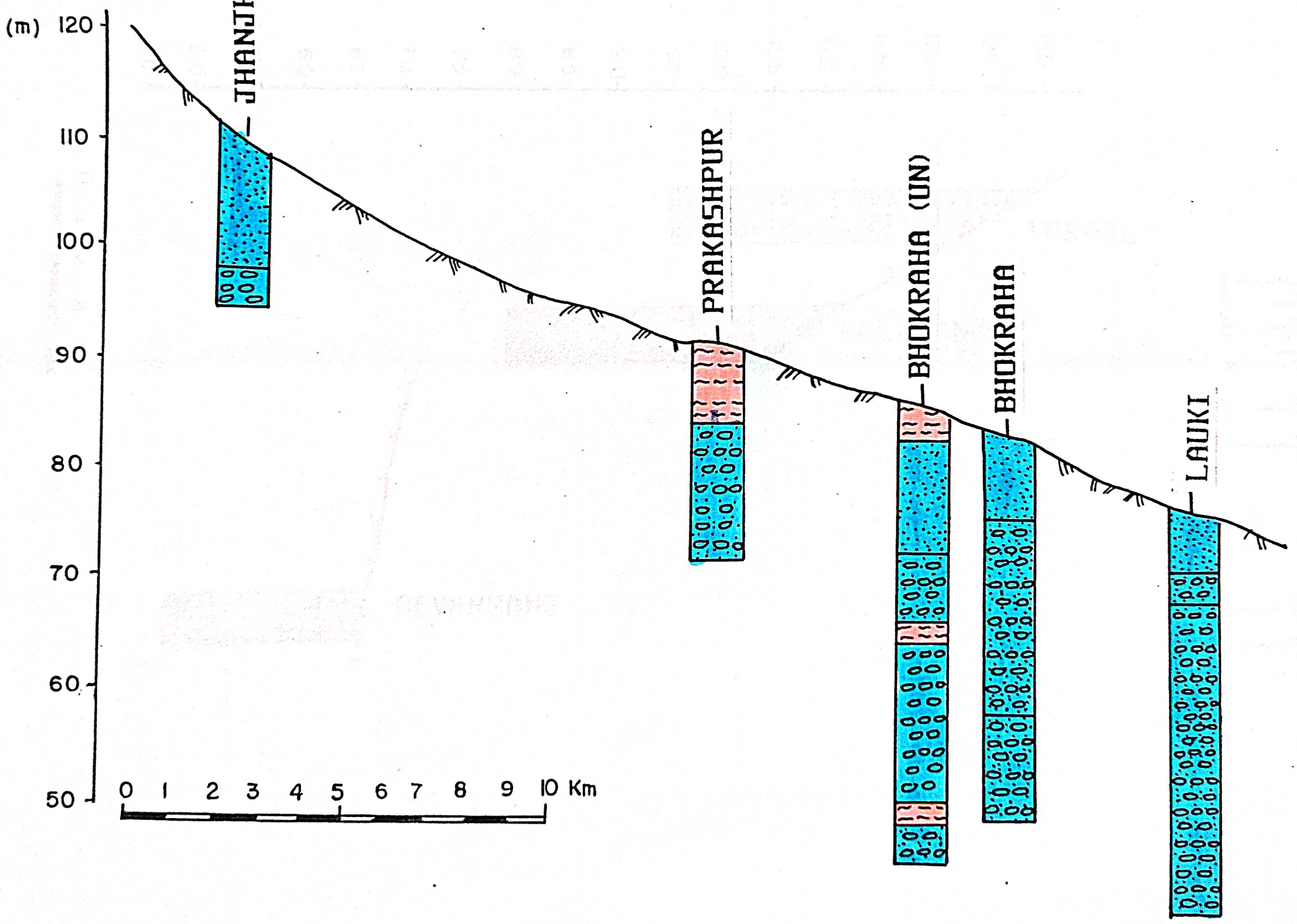
The transmissivity of the well shows 313 m^2/d the observation well shows 7165 m^2/day

SUNSARI LITHOLOGICAL CROSS SECTIONS



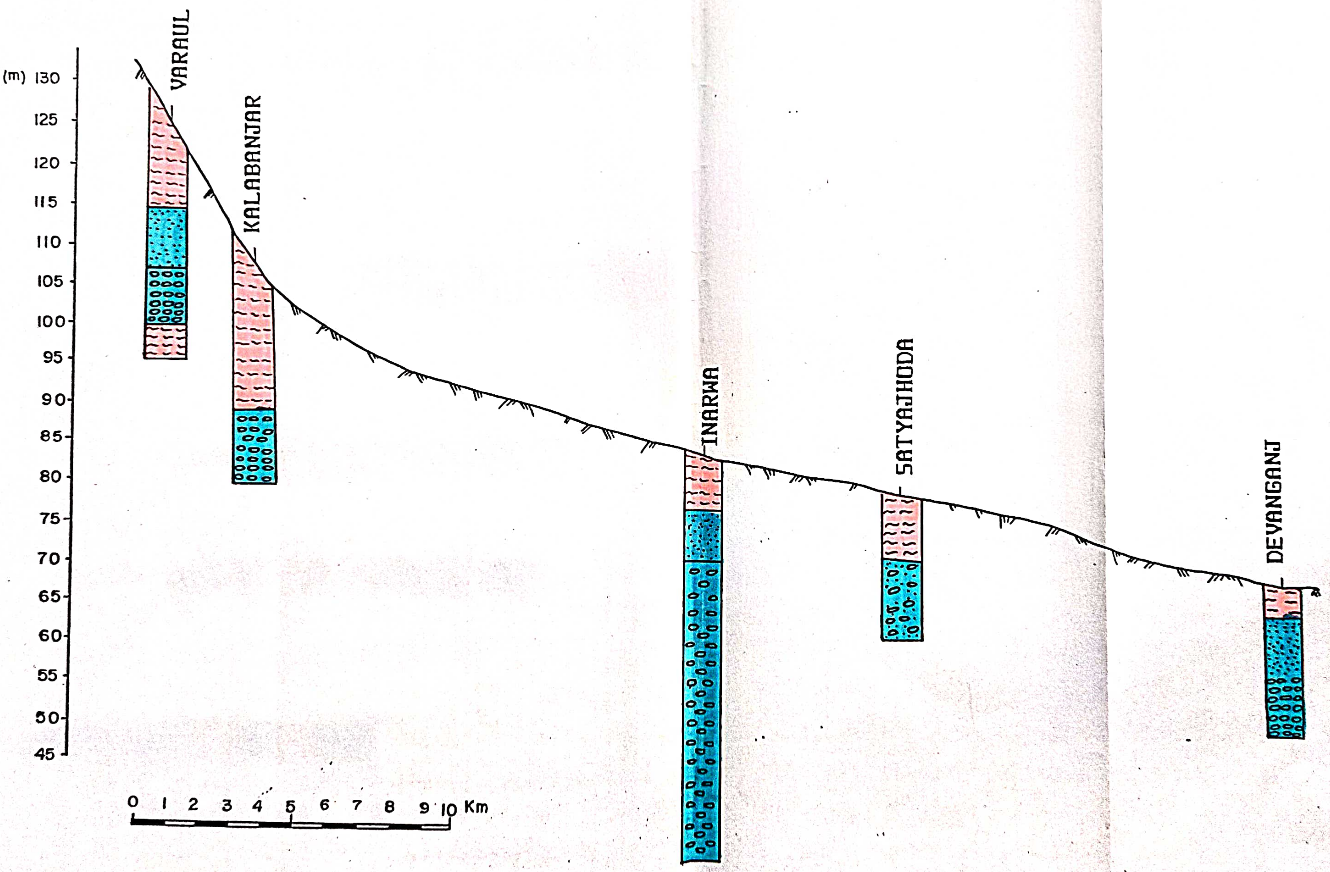
APPENDIX 4/1

LITHOLOGICAL CROSS SECTION I – I'



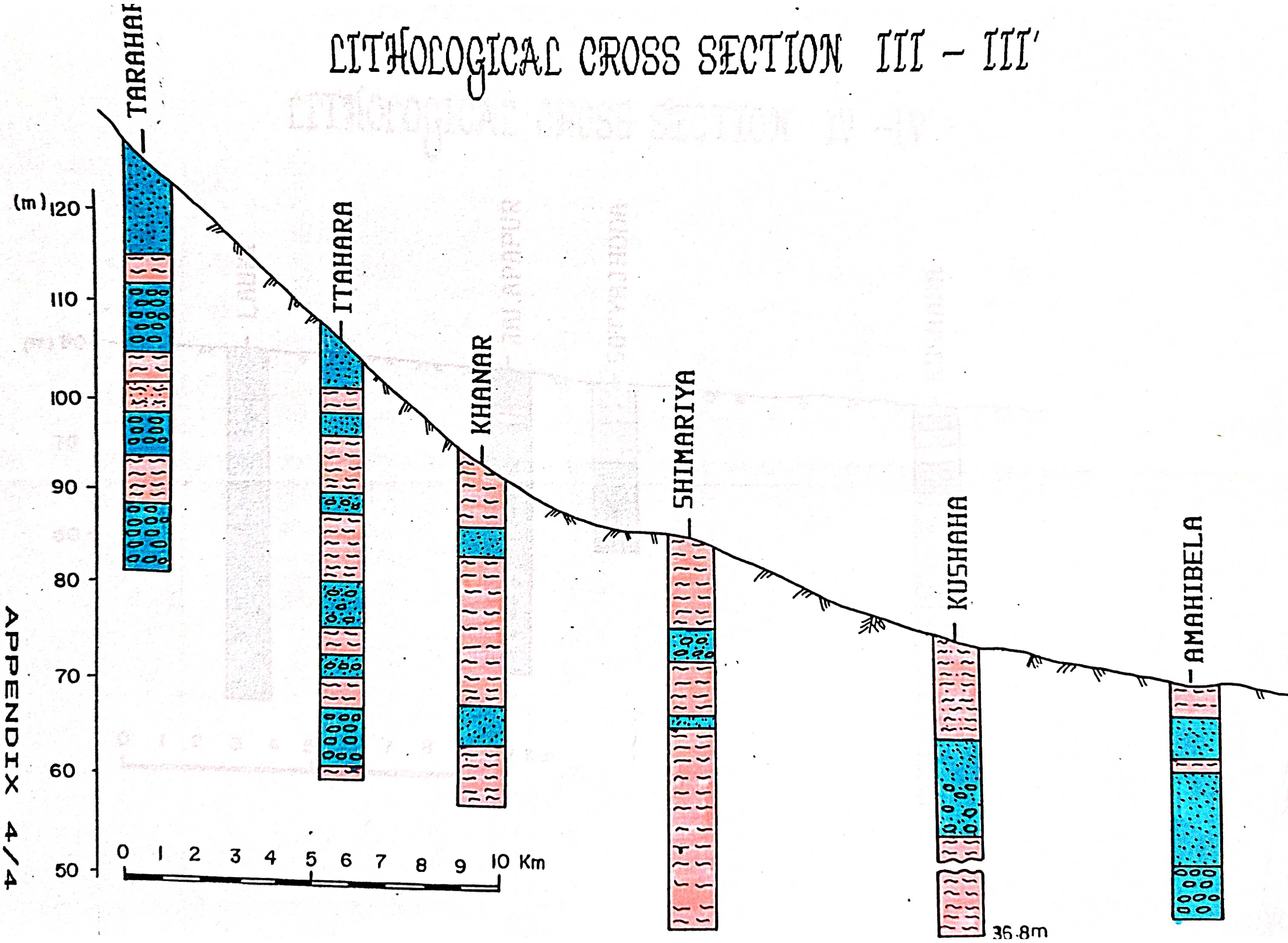
APPENDIX 4/2

LITHOLOGICAL CROSS SECTION II – II'



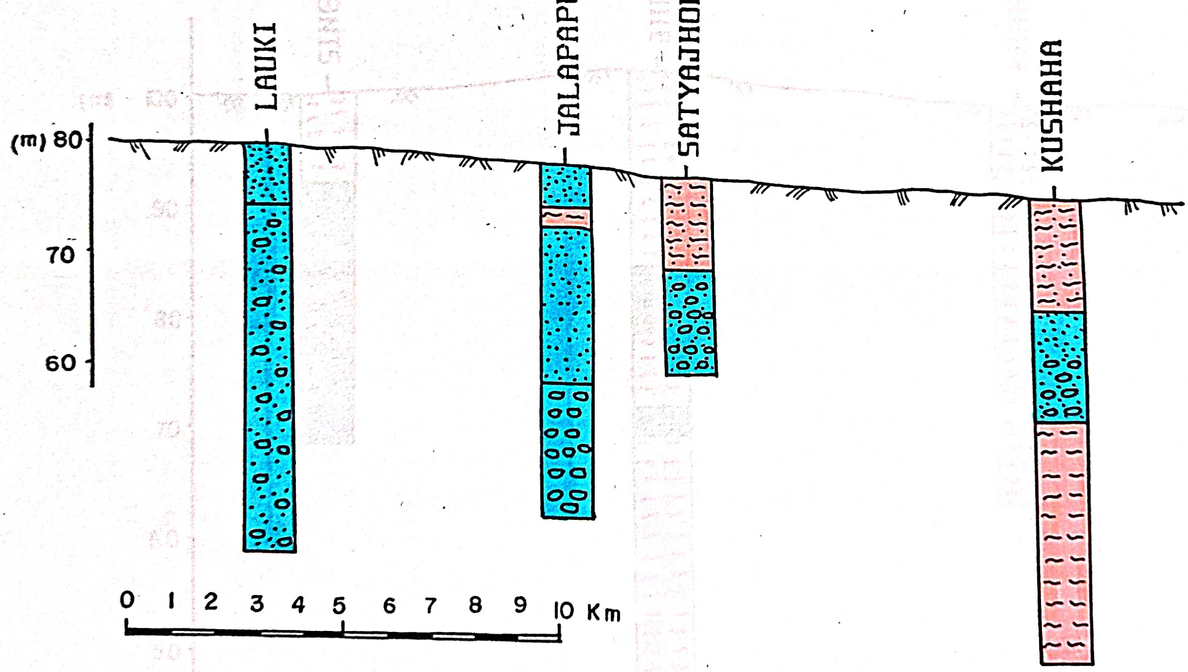
APPENDIX 4/3

LITHOLOGICAL CROSS SECTION III – III'



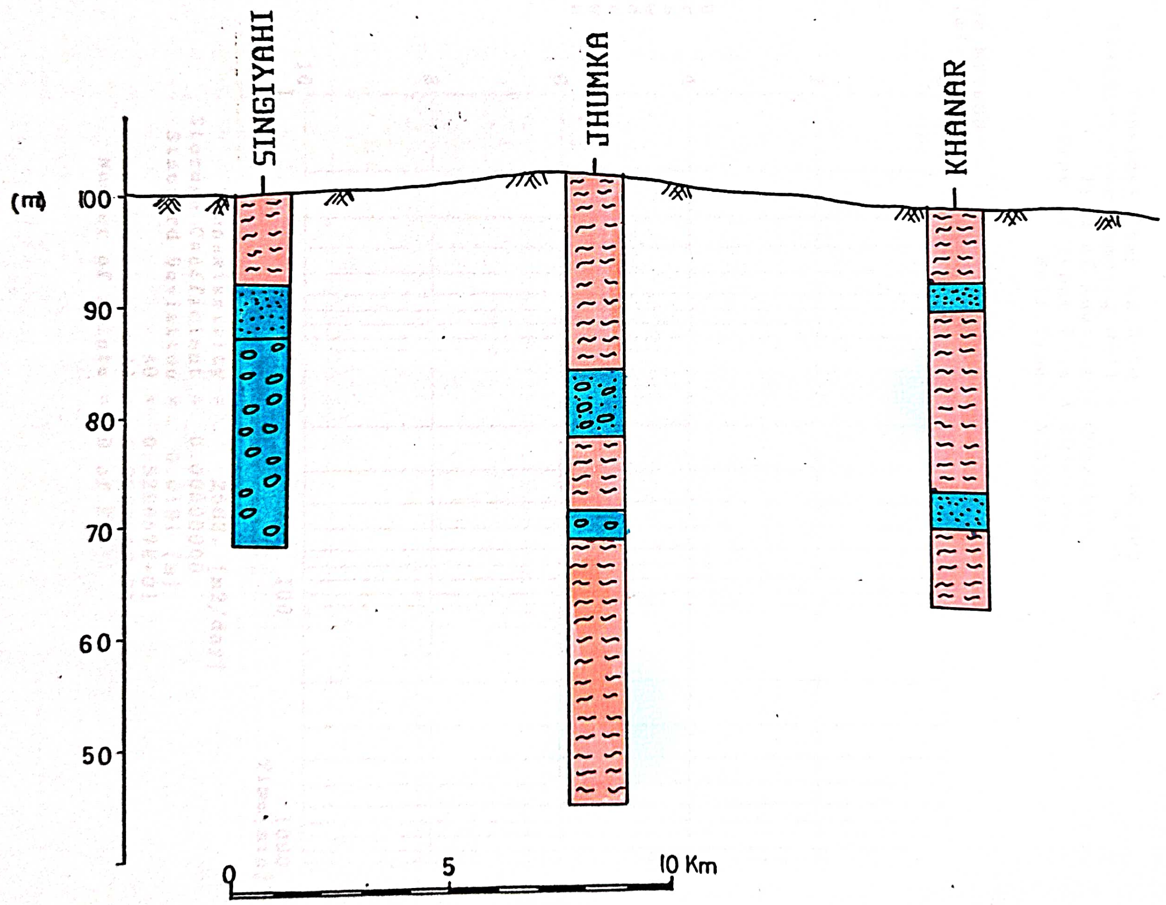
APPENDIX 4/4

LITHOLOGICAL CROSS SECTION IV -IV'



APPENDIX 4/5

LITHOLOGICAL CROSS SECTION V – V'



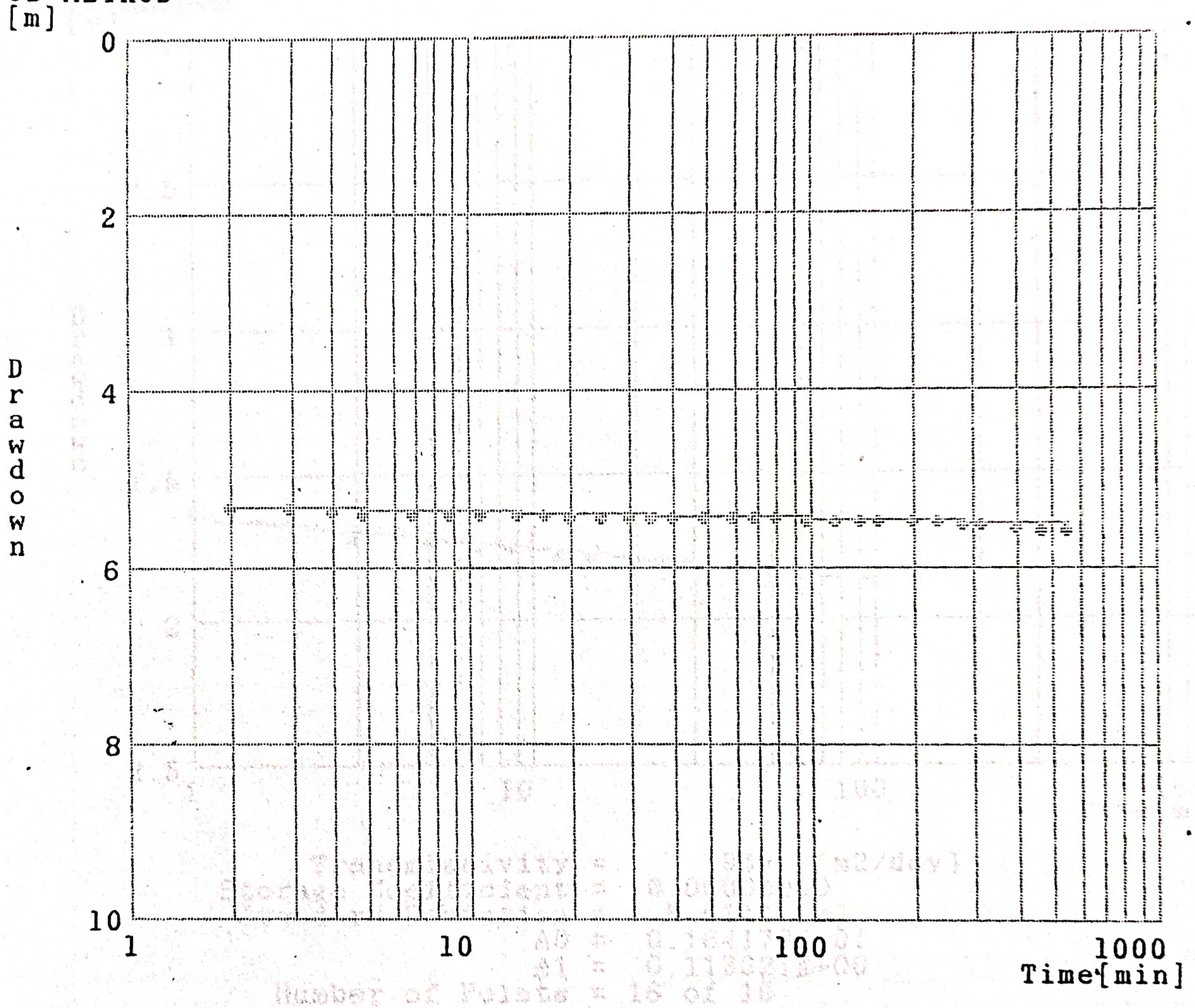
APPENDIX 4/6

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

Test : DTW TARAHARA

Constant Pumping Rate = 13.500 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

JACOB METHOD



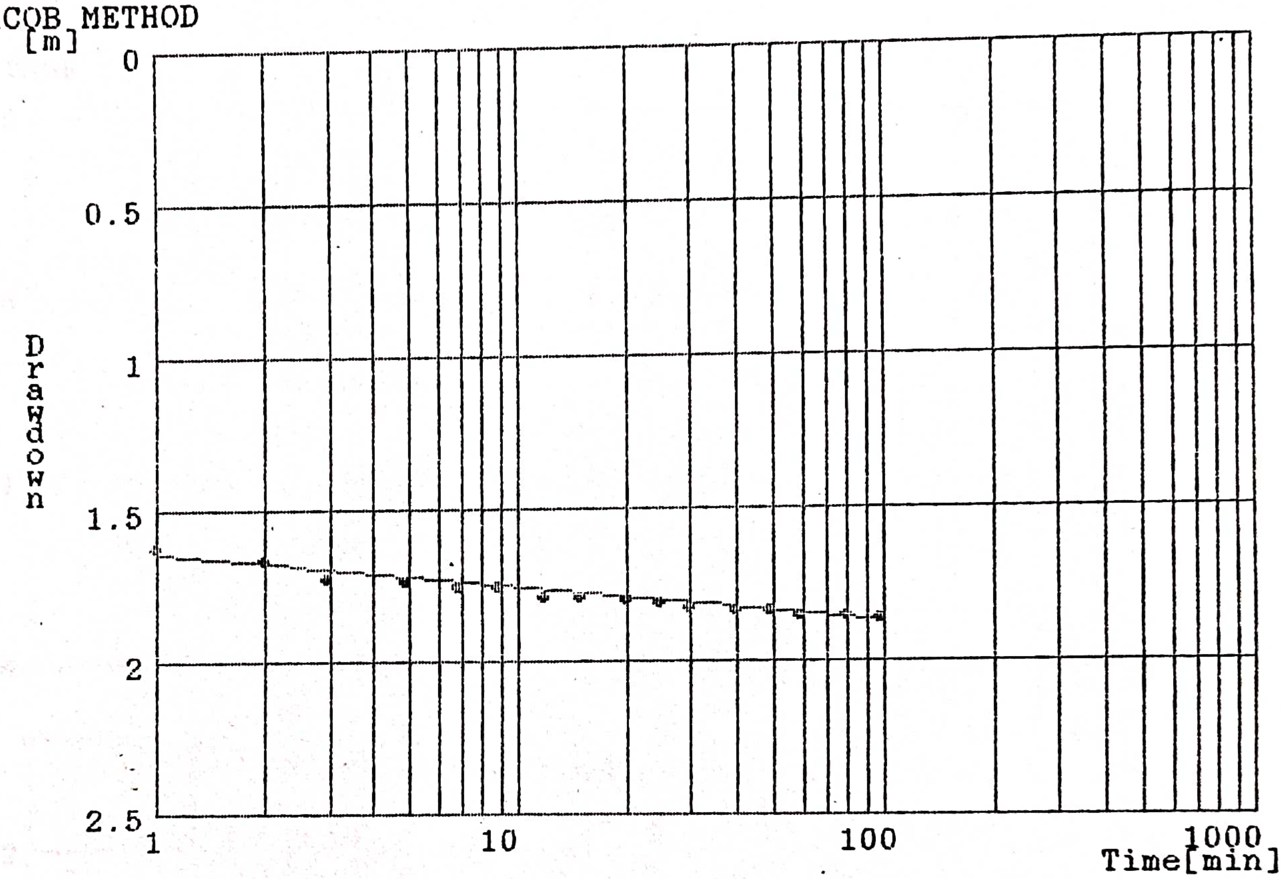
Transmissivity = 2582. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0191 [m]
A0 = 0.528057E+01
A1 = 0.826774E-01
Number of Points = 29 of 29

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

Test : DTW JHUMKA

Constant Pumping Rate = 14.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

JACOB METHOD

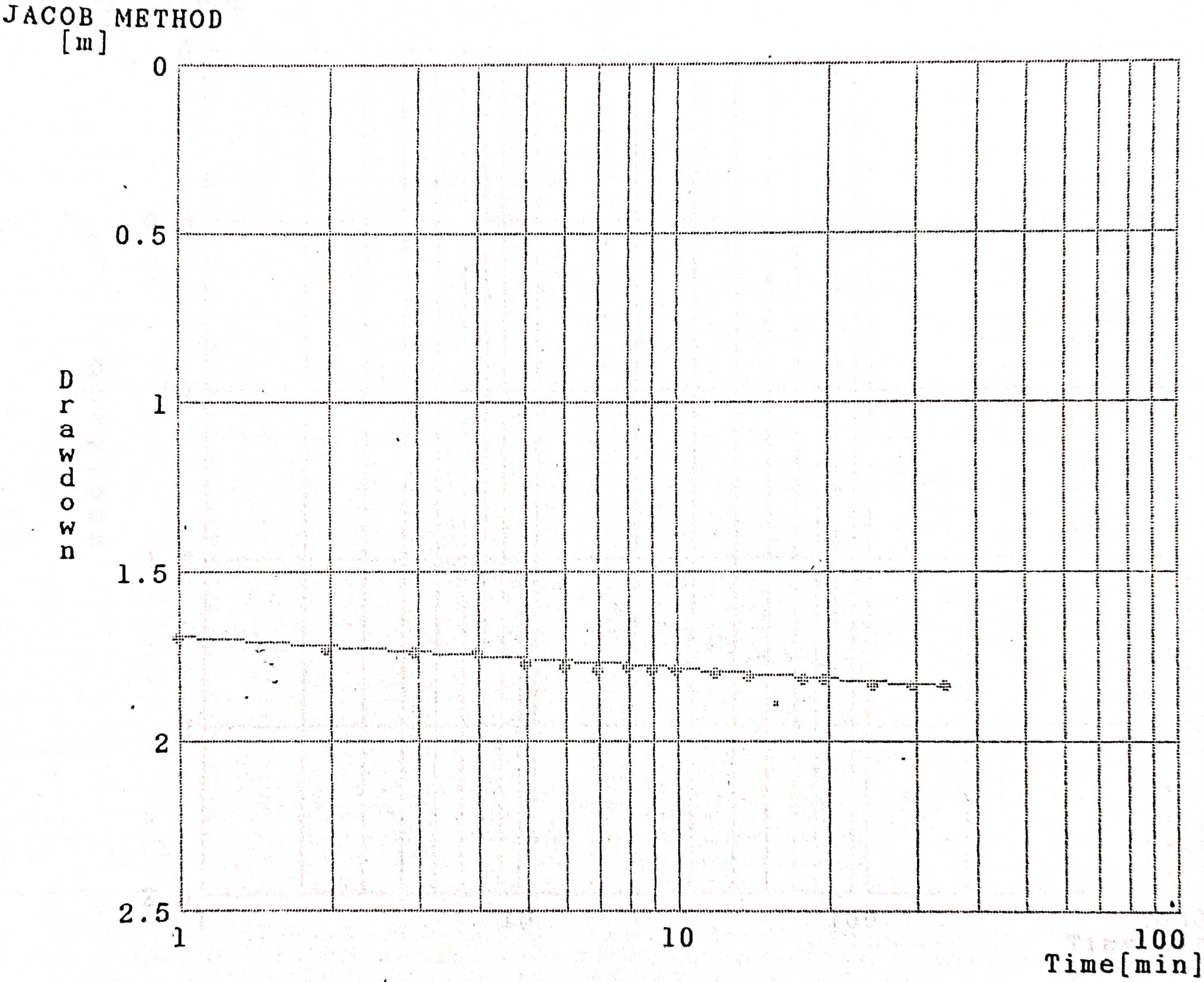


Transmissivity = 1959. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0141 [m]
A0 = 0.164173E+01
A1 = 0.113021E+00
Number of Points = 16 of 16

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

Test : STW 3 KUSHAHA

Constant Pumping Rate = 15.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 10.00 [m]
Type of Input Data = LEVEL
Static Water Level = -3.80 [m]
Well Type = STANDARD



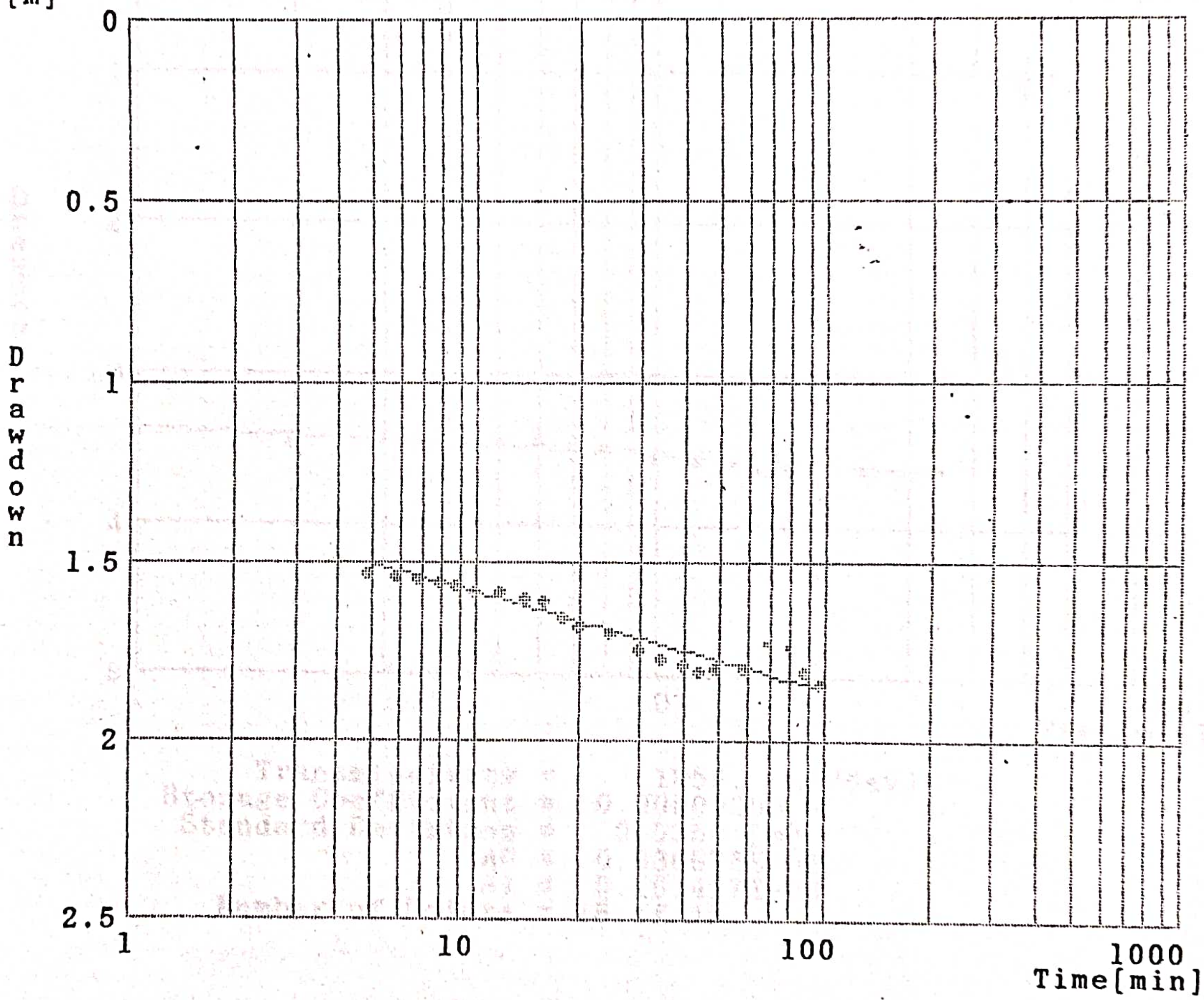
Transmissivity = 2488. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0086 [m]
A0 = 0.168841E+01
A1 = 0.953152E-01
Number of Points = 17 of 18

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

Test : STW 5 AMAHIBELA

Constant Pumping Rate = 18.500 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 22.00 [m]
Type of Input Data = LEVEL
Static Water Level = -3.54 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 1074. [m2/day]

Standard Deviation = 0.0223 [m]
A0 = 0.131098E+01
A1 = 0.272244E+00
Number of Points = 20 of 22

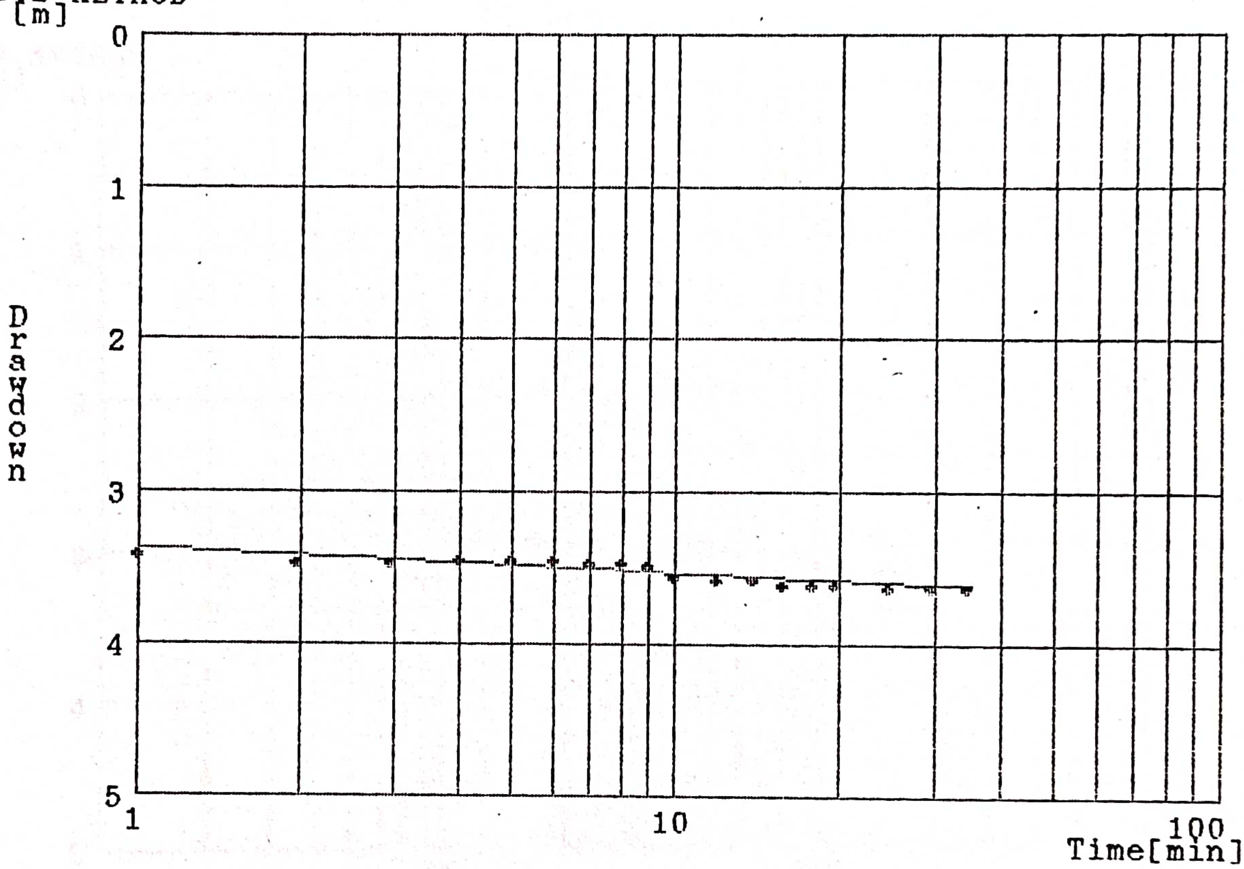
APPENDIX 5/4

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

Test : STW 6 RAMNAGAR

Constant Pumping Rate = 20.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

JACOB METHOD



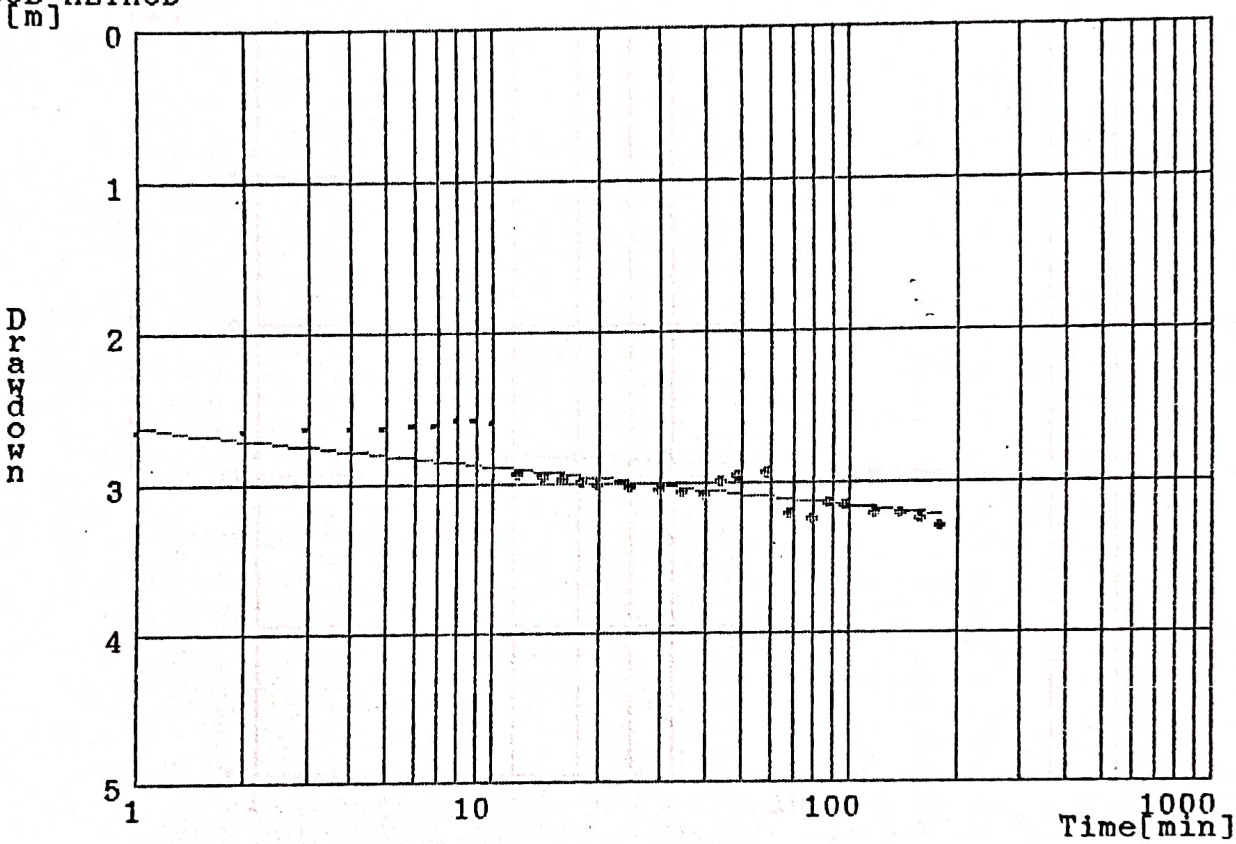
Transmissivity = 1959. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0350 [m]
A0 = 0.336675E+01
A1 = 0.161427E+00
Number of Points = 18 of 18

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

Test : STW 7 BHOKRAHA

Constant Pumping Rate = 20.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.28 [m]
Well Type = STANDARD

JACOB METHOD



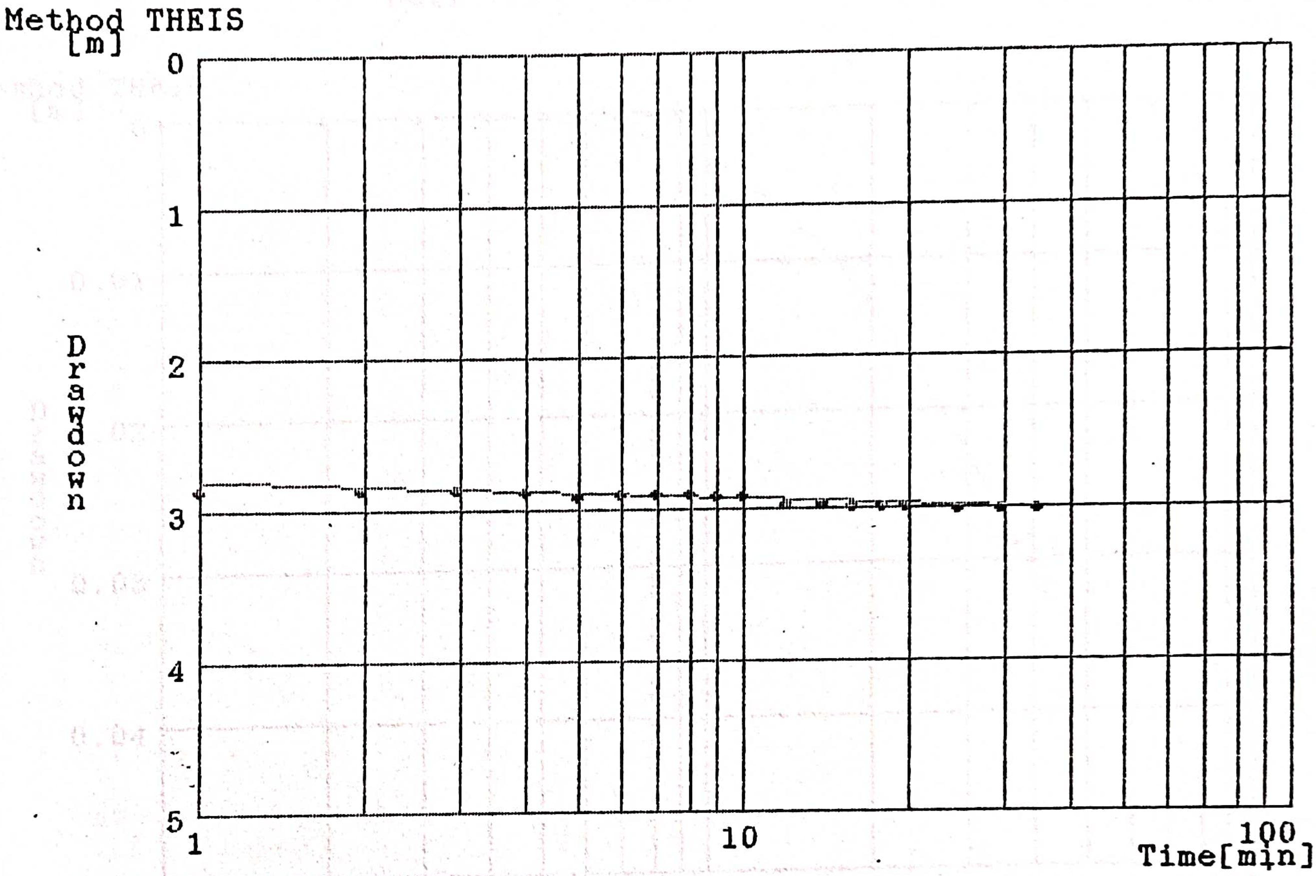
Transmissivity = 1203. [m2/day]

Standard Deviation = 0.0622 [m]
A0 = 0.262190E+01
A1 = 0.262850E+00
Number of Points = 20 of 30

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

Test : STW 9 LAUKI I

Constant Pumping Rate = 20.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.70 [m]
Well Type = STANDARD



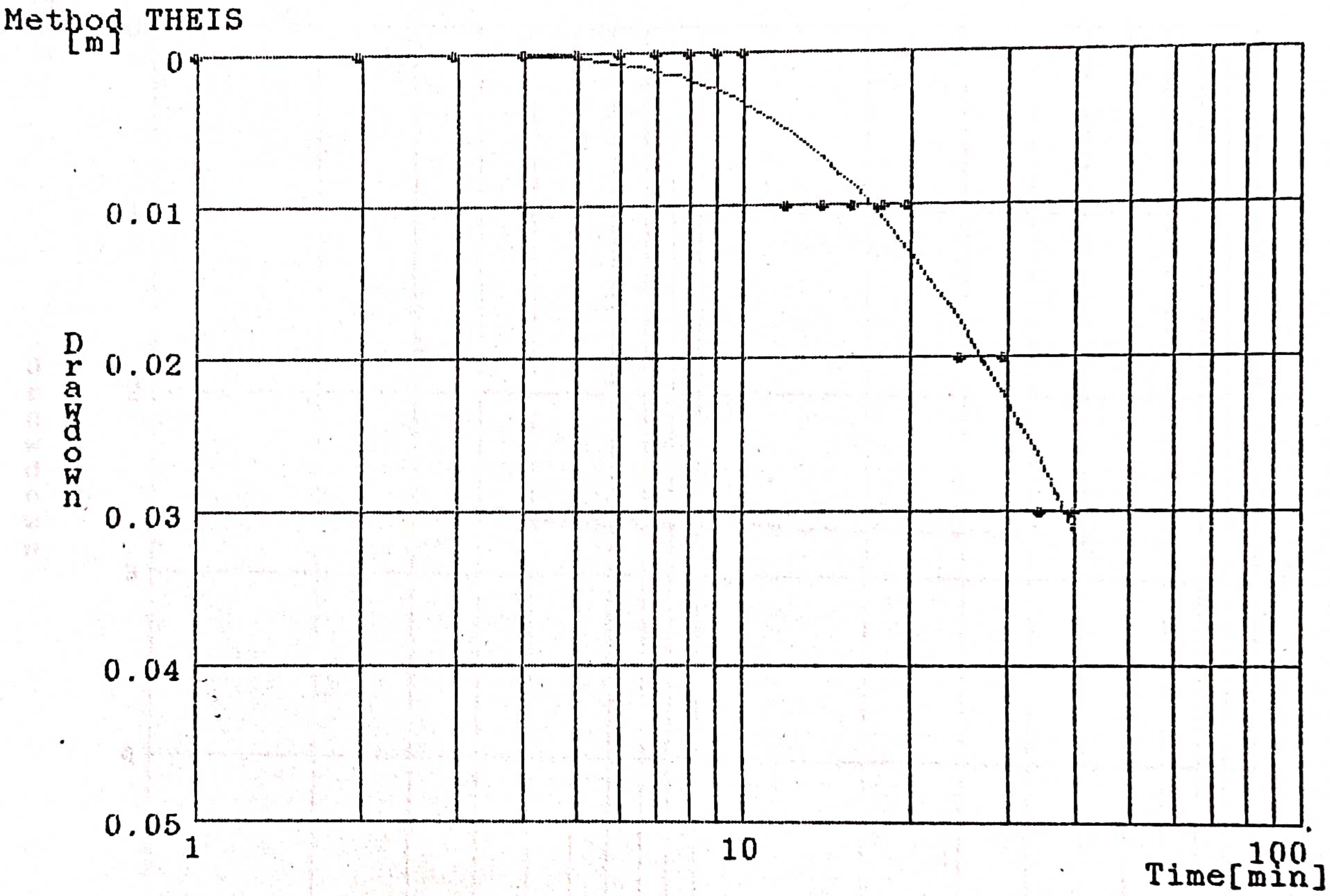
Transmissivity = 2372. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0208 [m]

Number of Points = 18 of 18

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

Test : STW 9 LAUKI I (OBS.)

Constant Pumping Rate = 20.000 [L/S]
Distance from Pumping Well = 14.30 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.94 [m]
Well Type = STANDARD



Transmissivity = 2761. [m2/day]
Storage Coefficient = 0.67346334
Standard Deviation = 0.0022 [m]

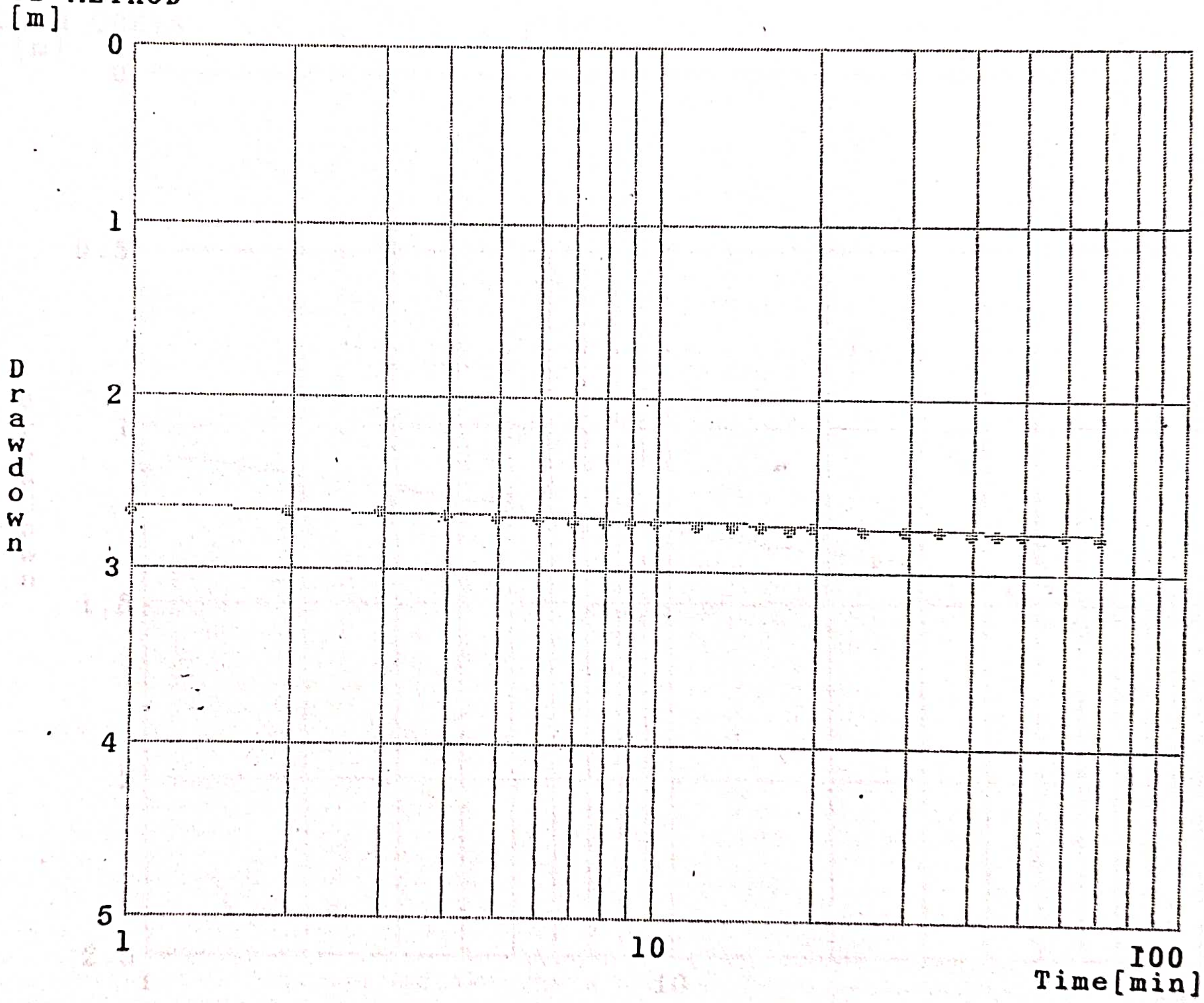
Number of Points = 19 of 19

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

Test : STW 10 SATYAJHODA

Constant Pumping Rate = 20.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.18 [m]
Well Type = STANDARD

JACOB METHOD



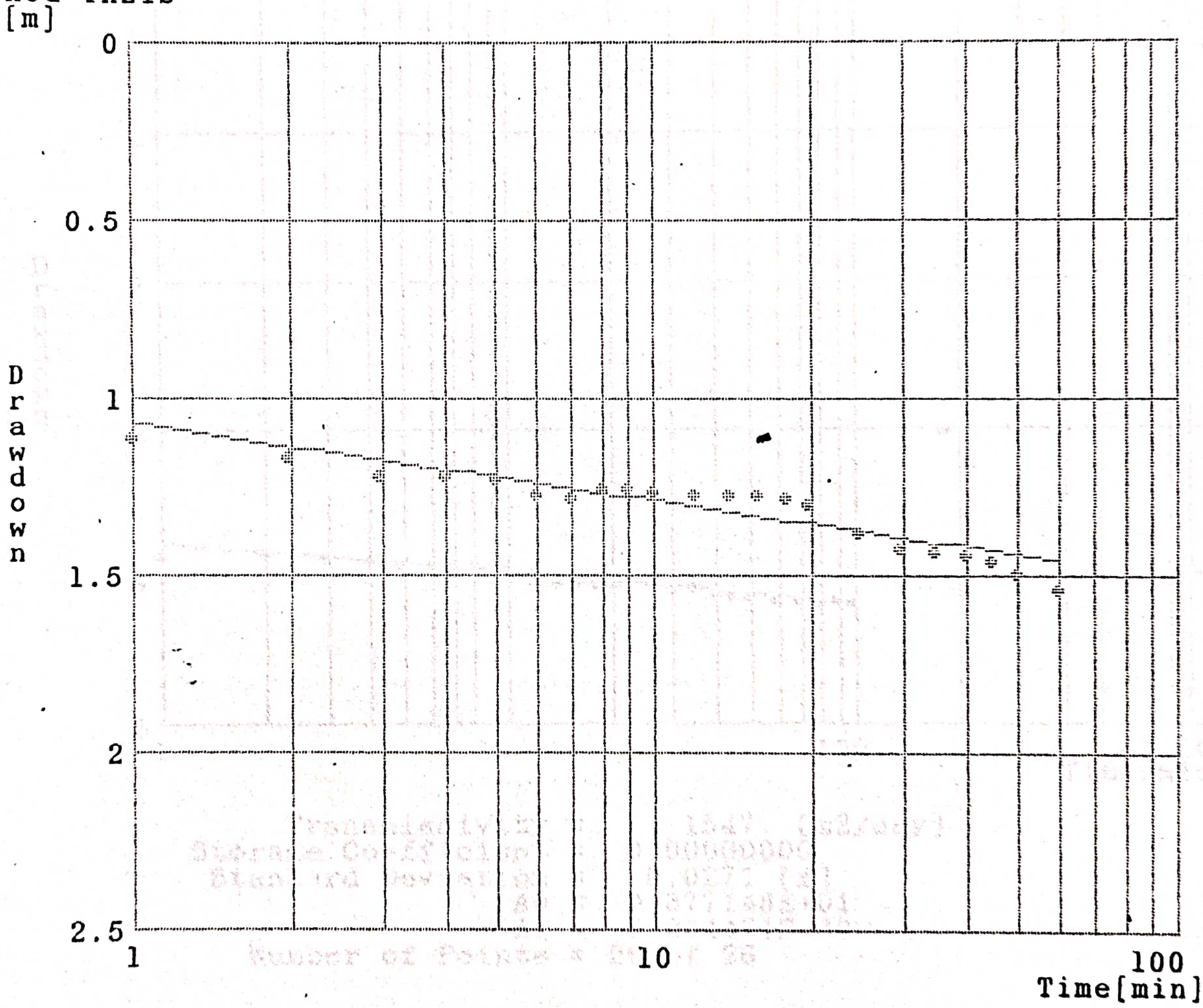
Transmissivity = 4327. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0075 [m]
A0 = 0.263841E+01
A1 = 0.730780E-01
Number of Points = 23 of 23

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

Test : STW 11 PRAKASHPUR

Constant Pumping Rate = 22.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 19.00 [m]
Type of Input Data = LEVEL
Static Water Level = -3.01 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 1602. [m2/day]

Standard Deviation = 0.0388 [m]

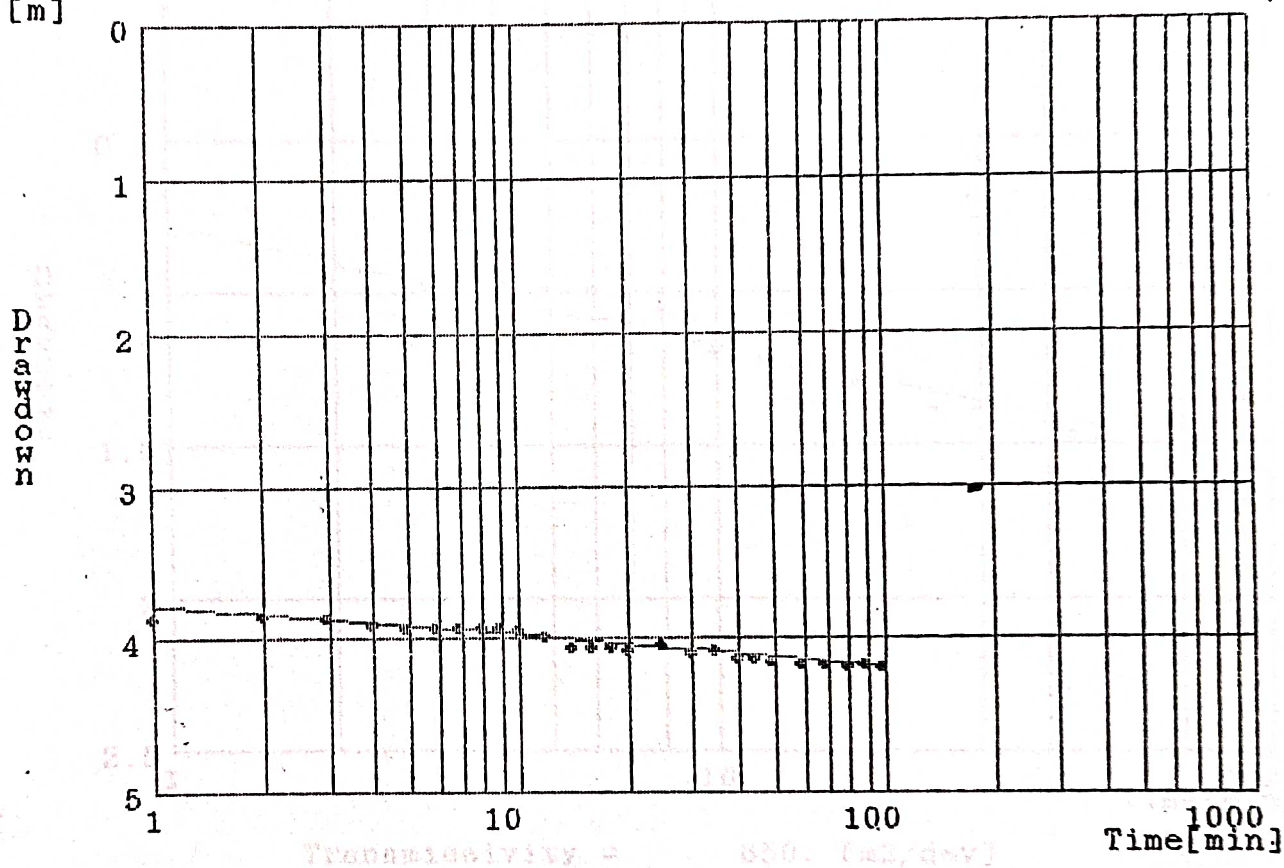
Number of Points = 22 of 22

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

Test : STW 12 LAUKI II

Constant Pumping Rate = 20.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 35.00 [m]
Type of Input Data = LEVEL
Static Water Level = -1.67 [m]
Well Type = STANDARD

JACOB METHOD

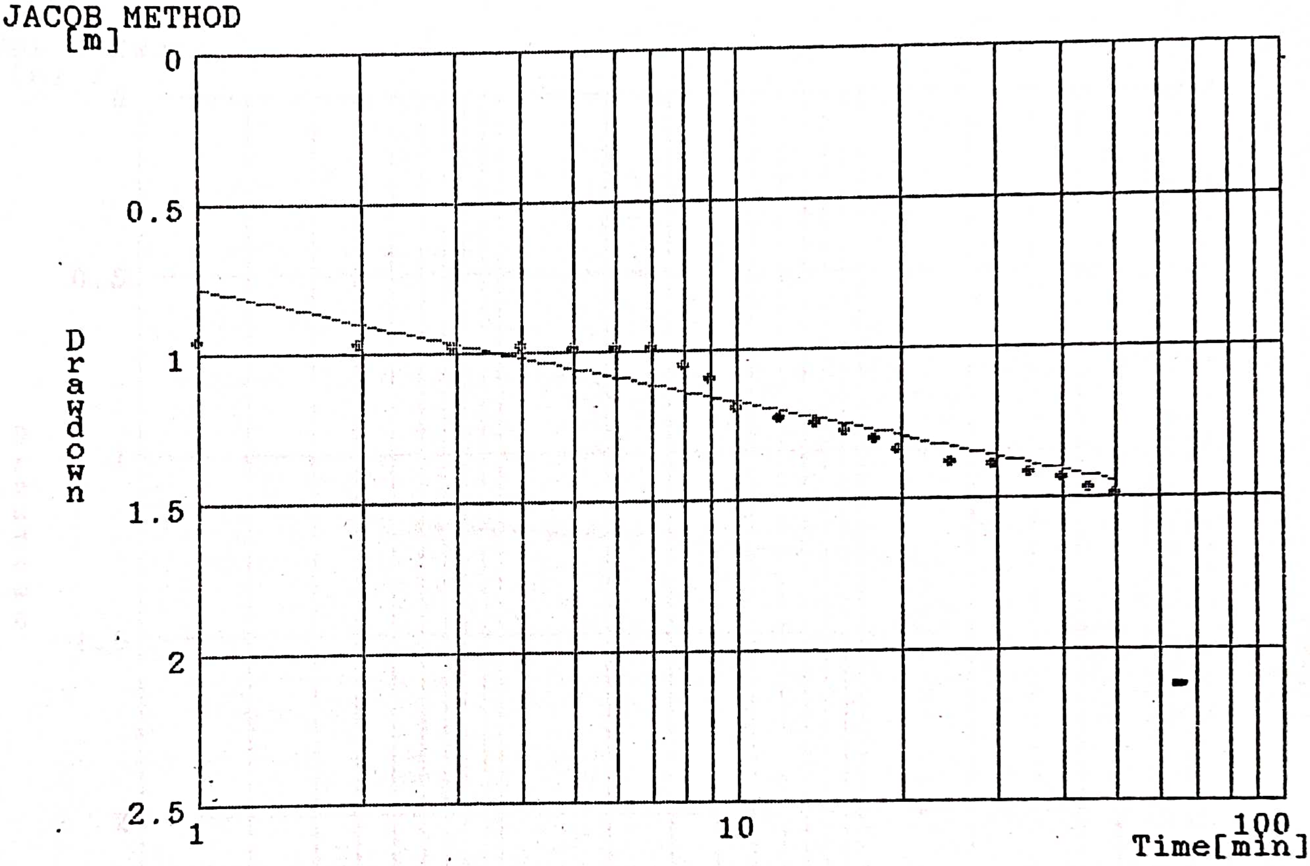


Transmissivity = 1547. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0271 [m]
A0 = 0.377148E+01
A1 = 0.204471E+00
Number of Points = 26 of 26

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

Test : STW 13 INARWA

Constant Pumping Rate = 21.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 46.00 [m]
Type of Input Data = LEVEL
Static Water Level = -4.05 [m]
Well Type = STANDARD



Transmissivity = 850. [m2/day]

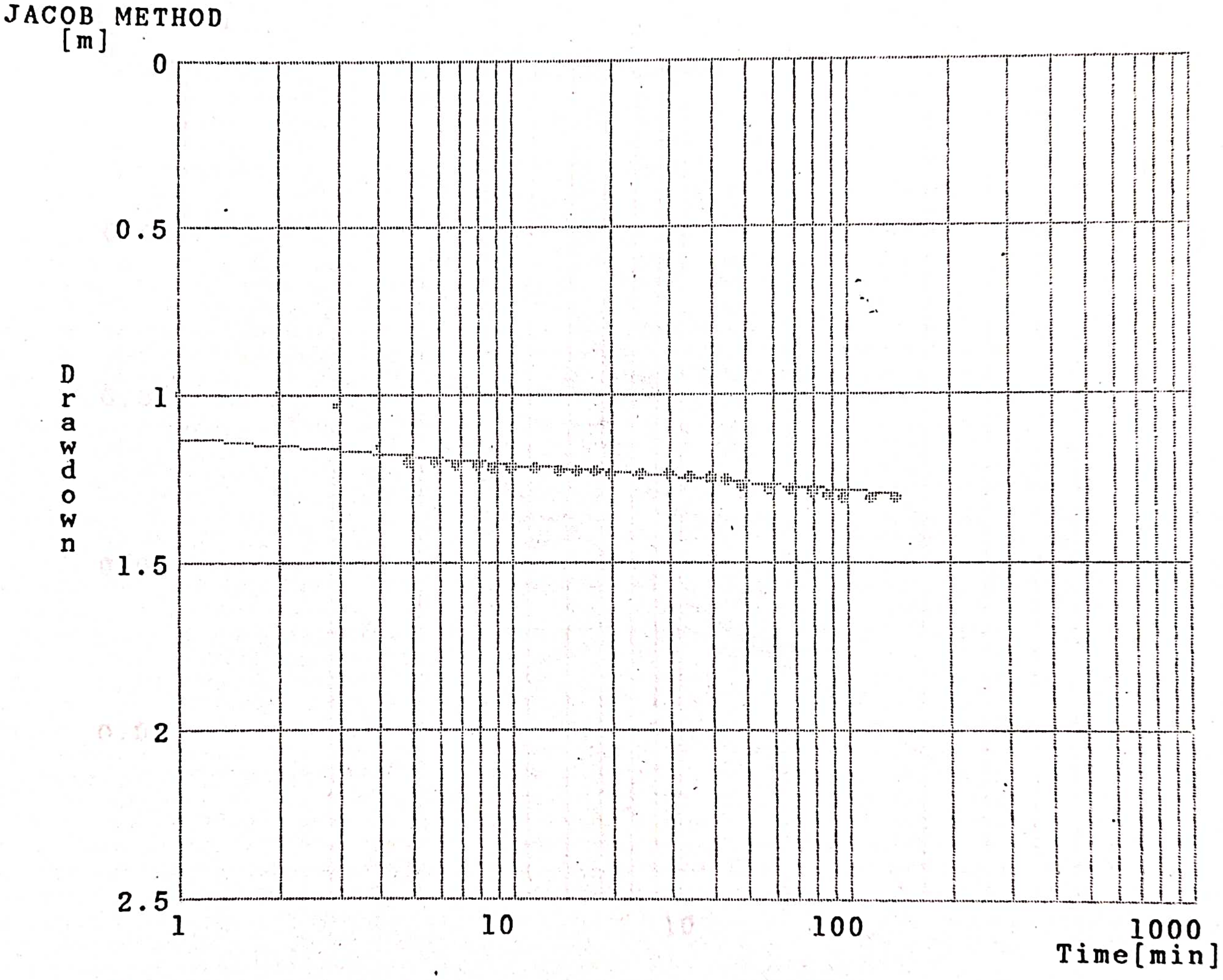
Standard Deviation = 0.0655 [m]
A0 = 0.780586E+00
A1 = 0.390449E+00
Number of Points = 21 of 21

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

Test : STW 16 KALABANJAR

Constant Pumping Rate = 12.000 [L/S]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -6.55 [m]
Well Type = STANDARD

JACOB METHOD

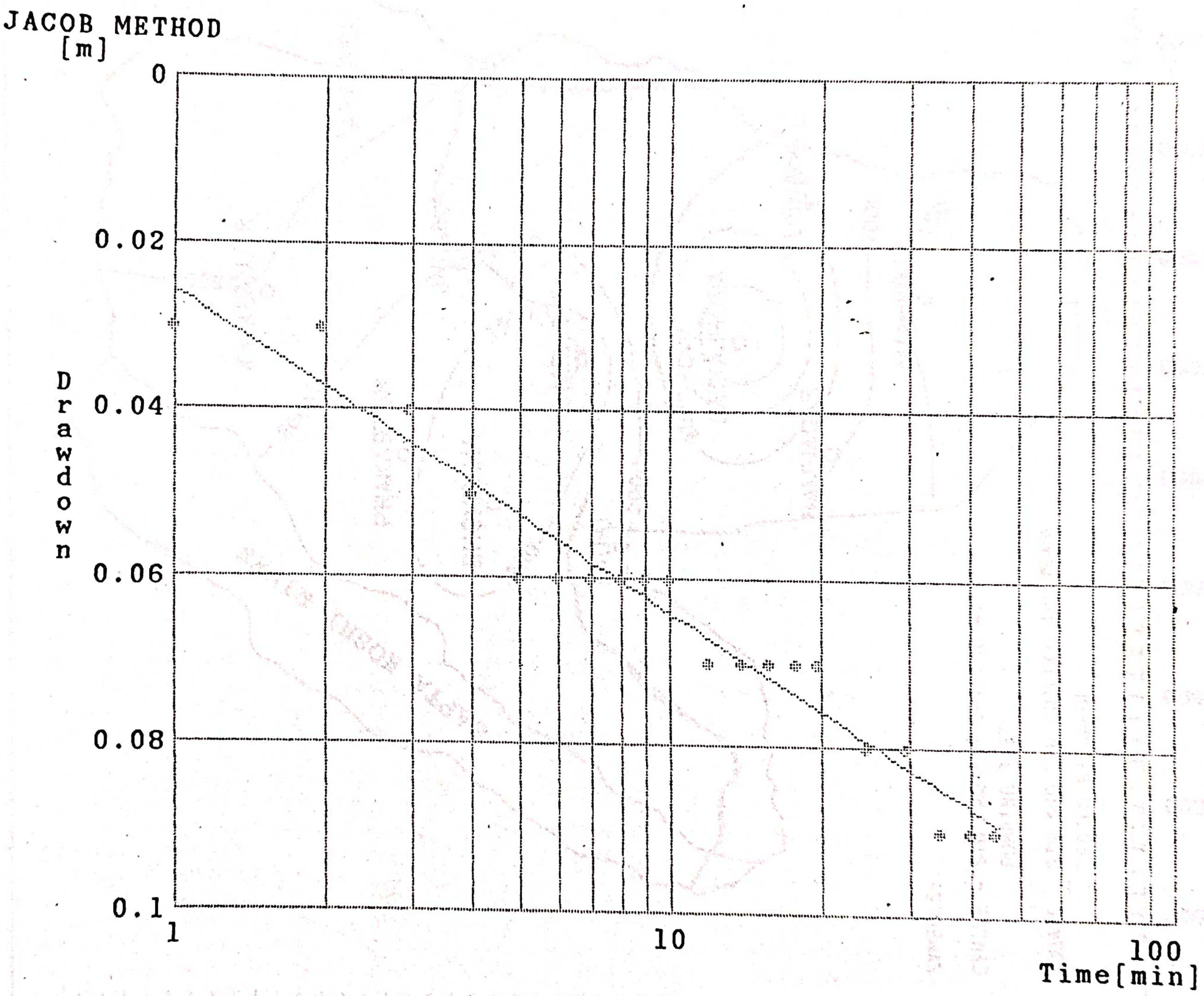


Transmissivity = 2392. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0071 [m]
A0 = 0.112680E+01
A1 = 0.793355E-01
Number of Points = 24 of 28

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

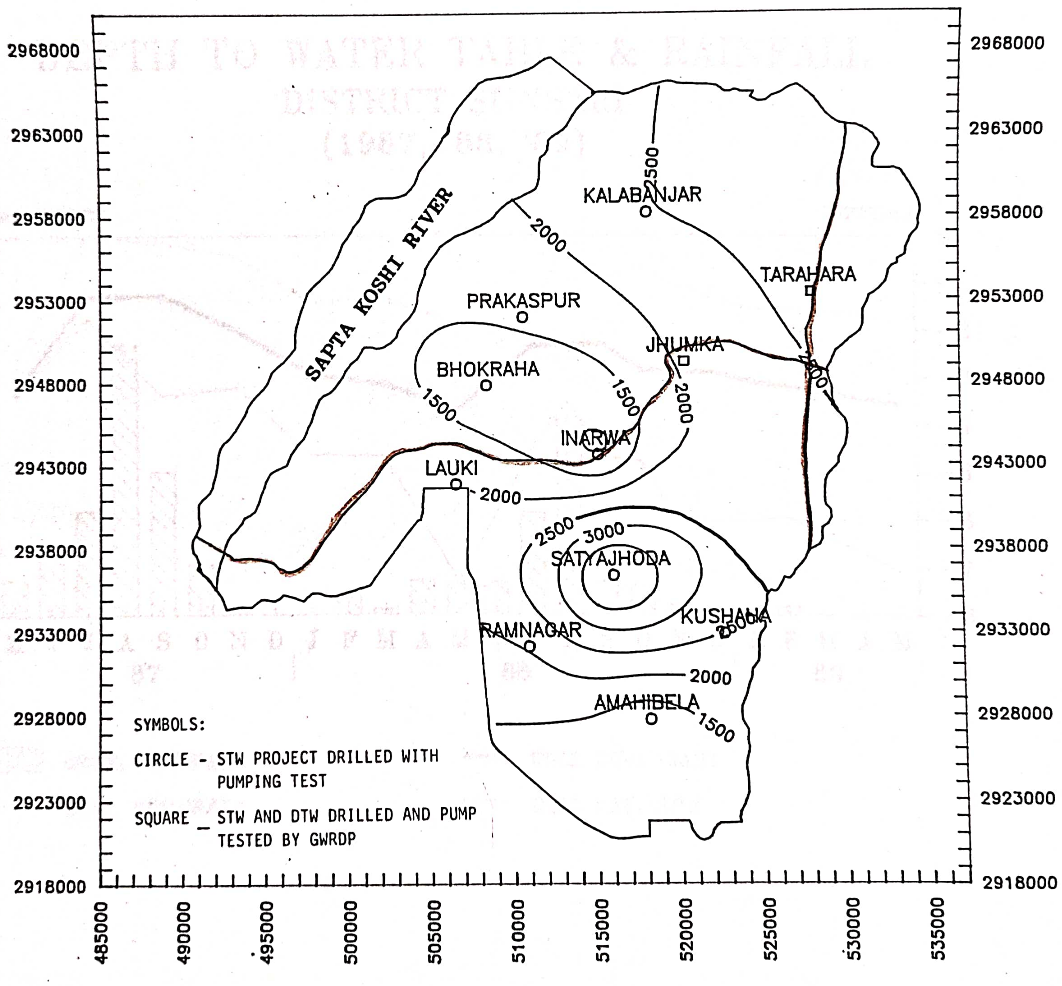
Test : STW 16 KALABANJAR (OBS.)

Constant Pumping Rate = 12.000 [L/S]
Distance from Pumping Well = 62.90 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -6.51 [m]
Well Type = STANDARD



Transmissivity = 4933. [m2/day]
Storage Coefficient = 0.00042117
Standard Deviation = 0.0038 [m]
A0 = 0.256131E-01
A1 = 0.384637E-01
Number of Points = 20 of 20

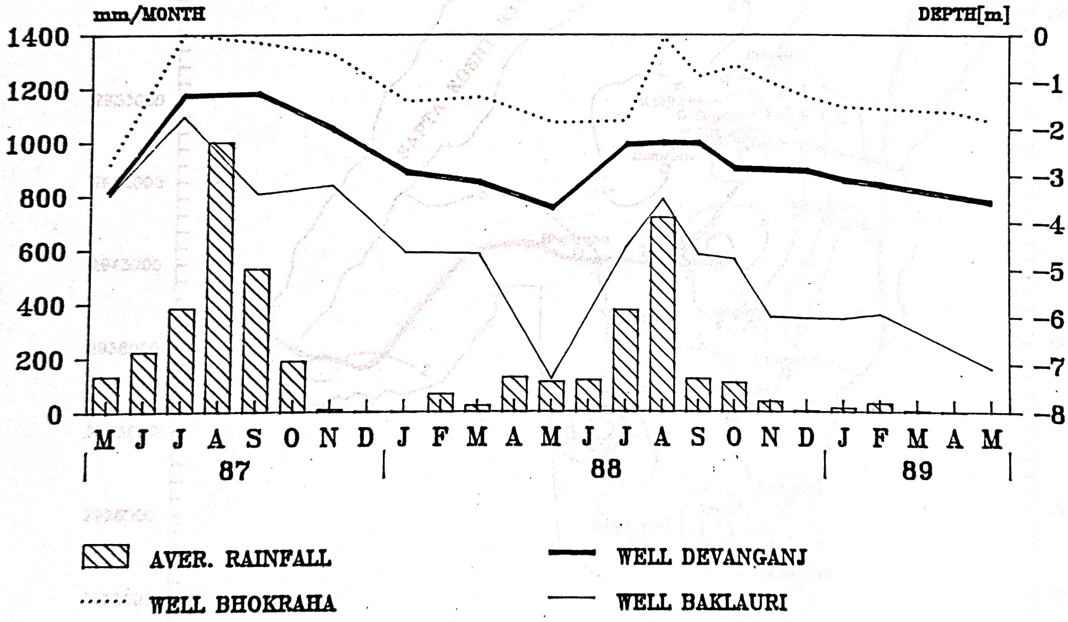
SUNSARI TRANSMISSIVITIES (M2/DAY)



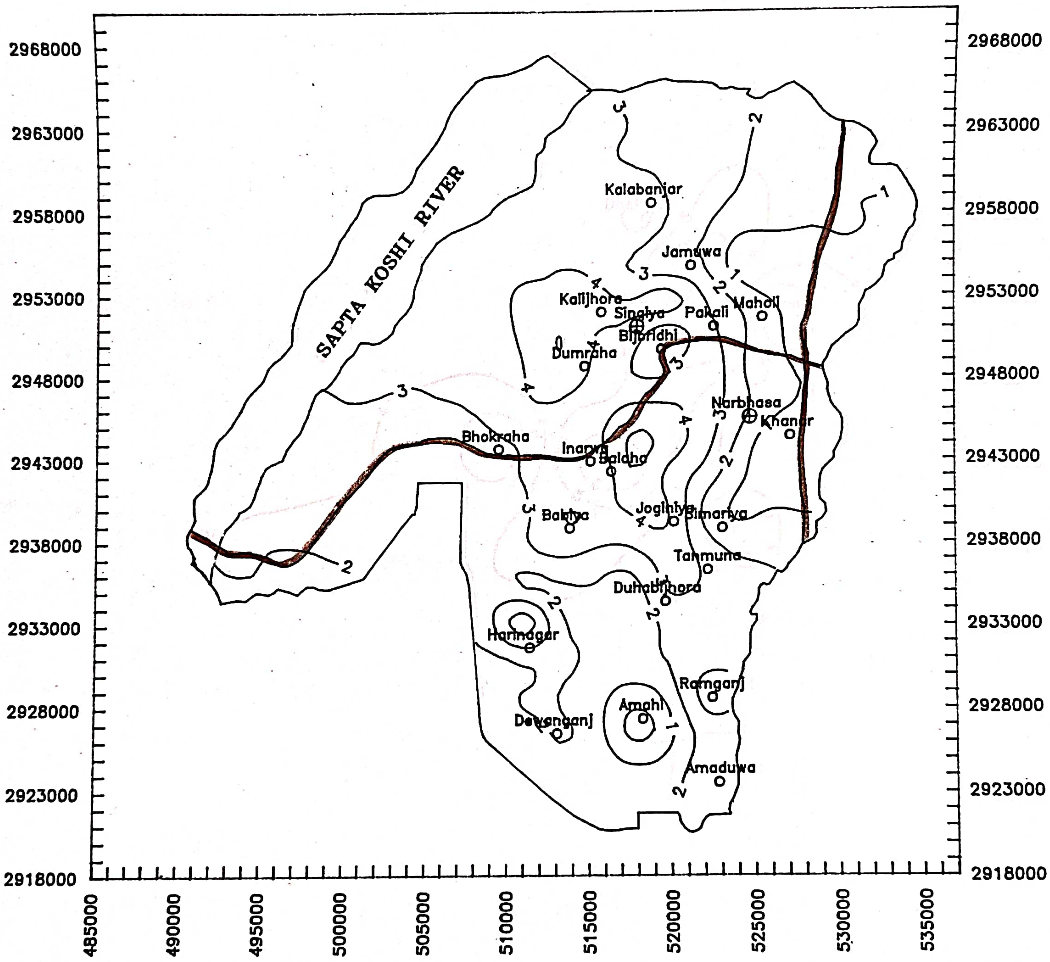
APPENDIX 6

APPENDIX 7

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



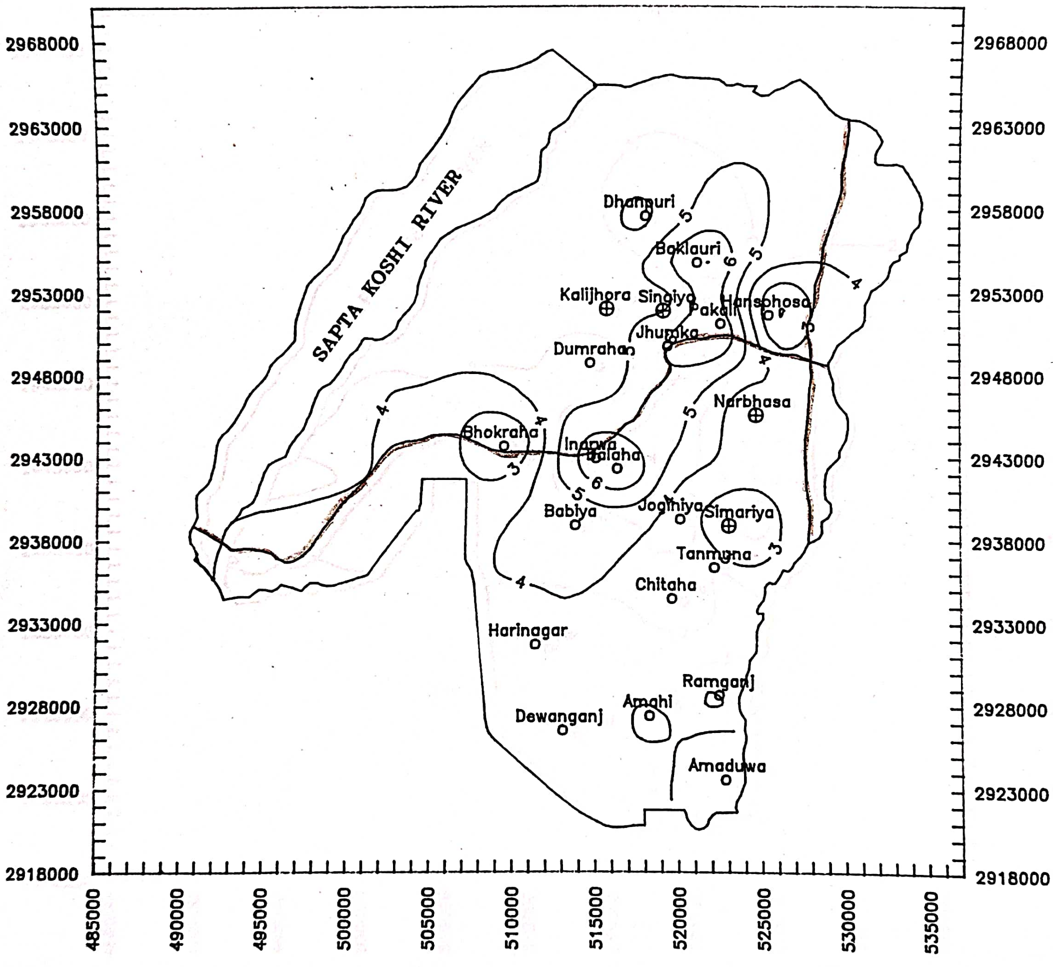
SUNSARI RISE OF WATER TABLE MAY – JULY 1987



APPENDIX 8/1

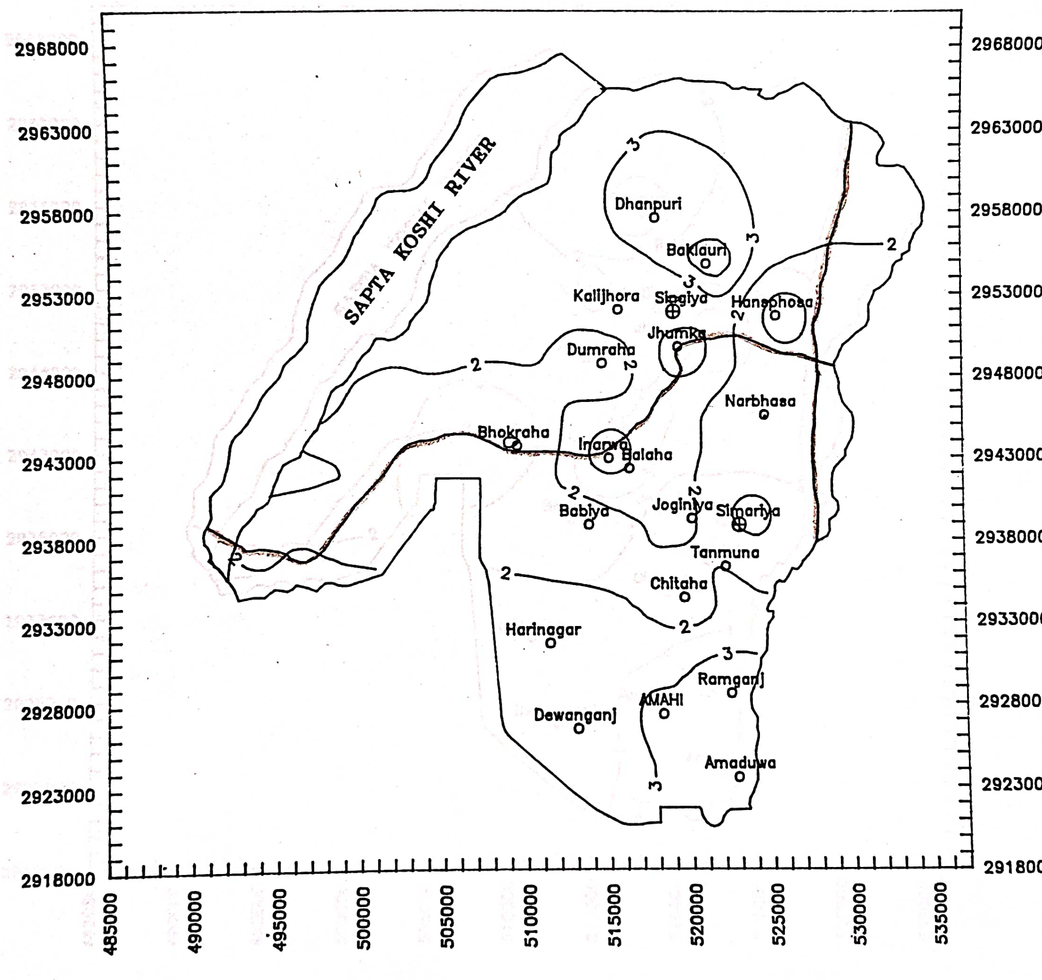
APPENDIX 8/2

SUNSARI DEPTH TO WATER TABLE MAY 1988

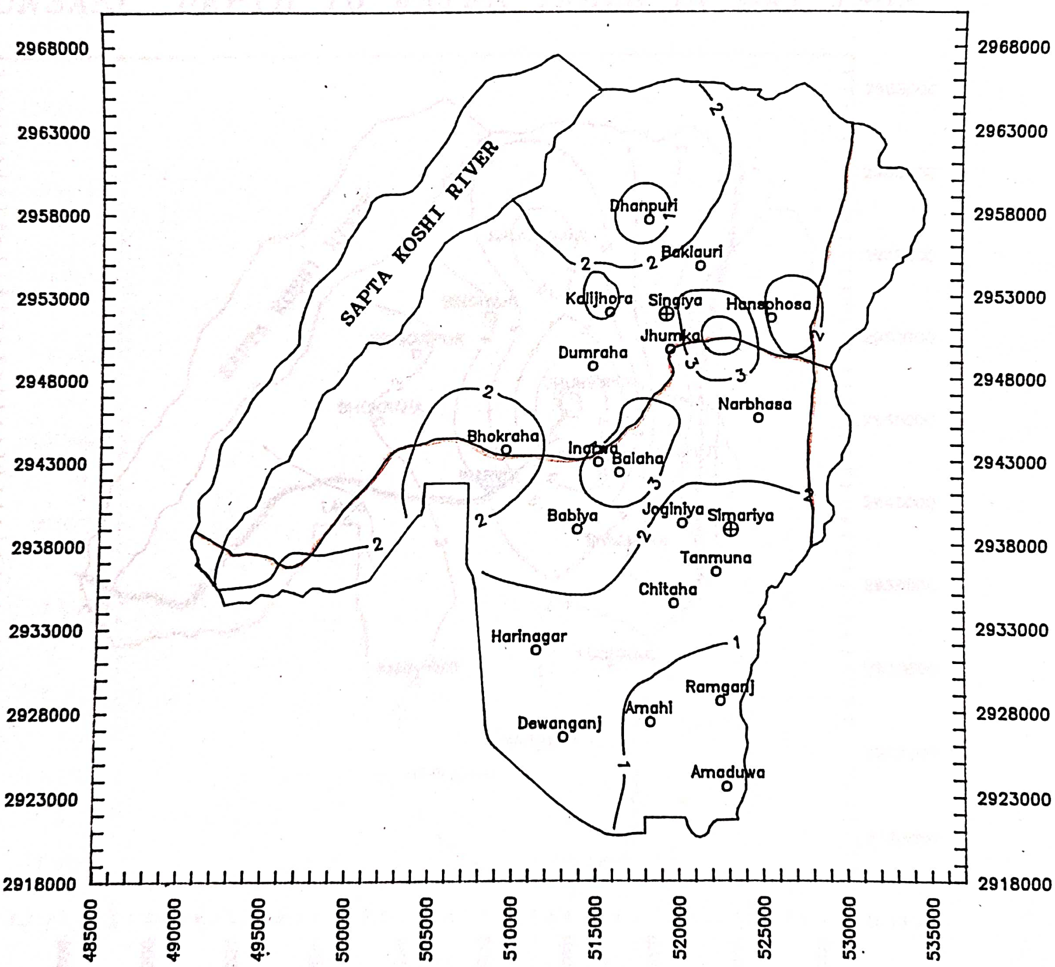


APPENDIX 8/3

SUNSARI DEPTH TO WATER TABLE SEP 1988

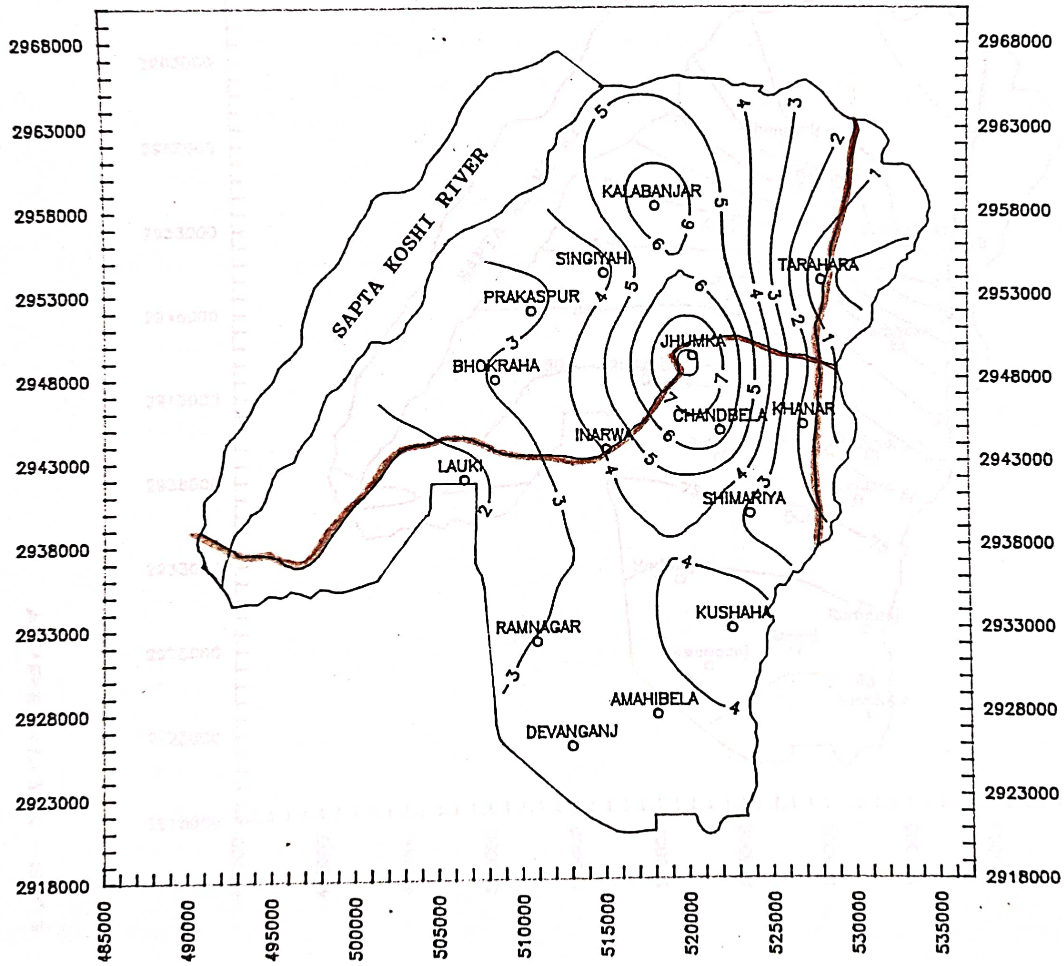


SUNSARI RISE OF WATER TABLE MAY - SEP 1988



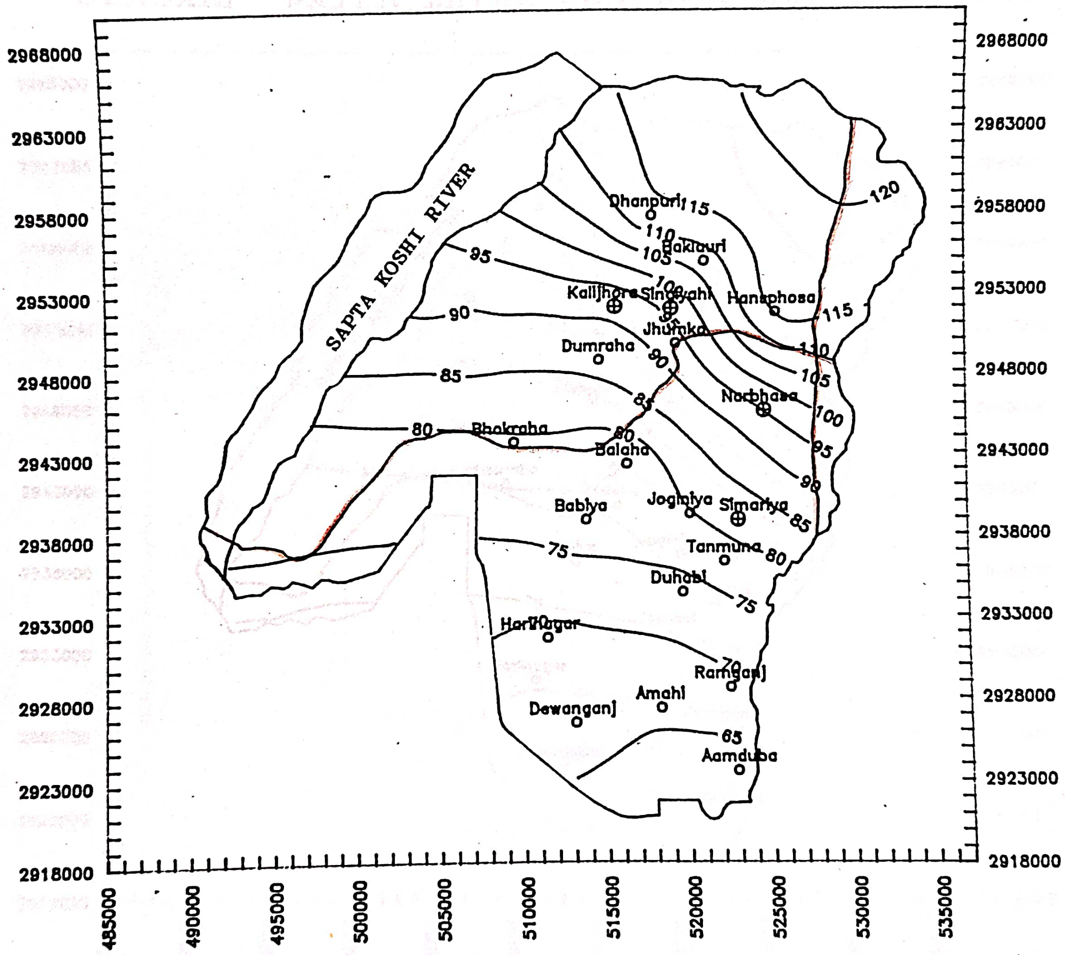
APPENDIX 8/4

SUNSARI DEPTH TO WATER TABLE IN MAY 1989



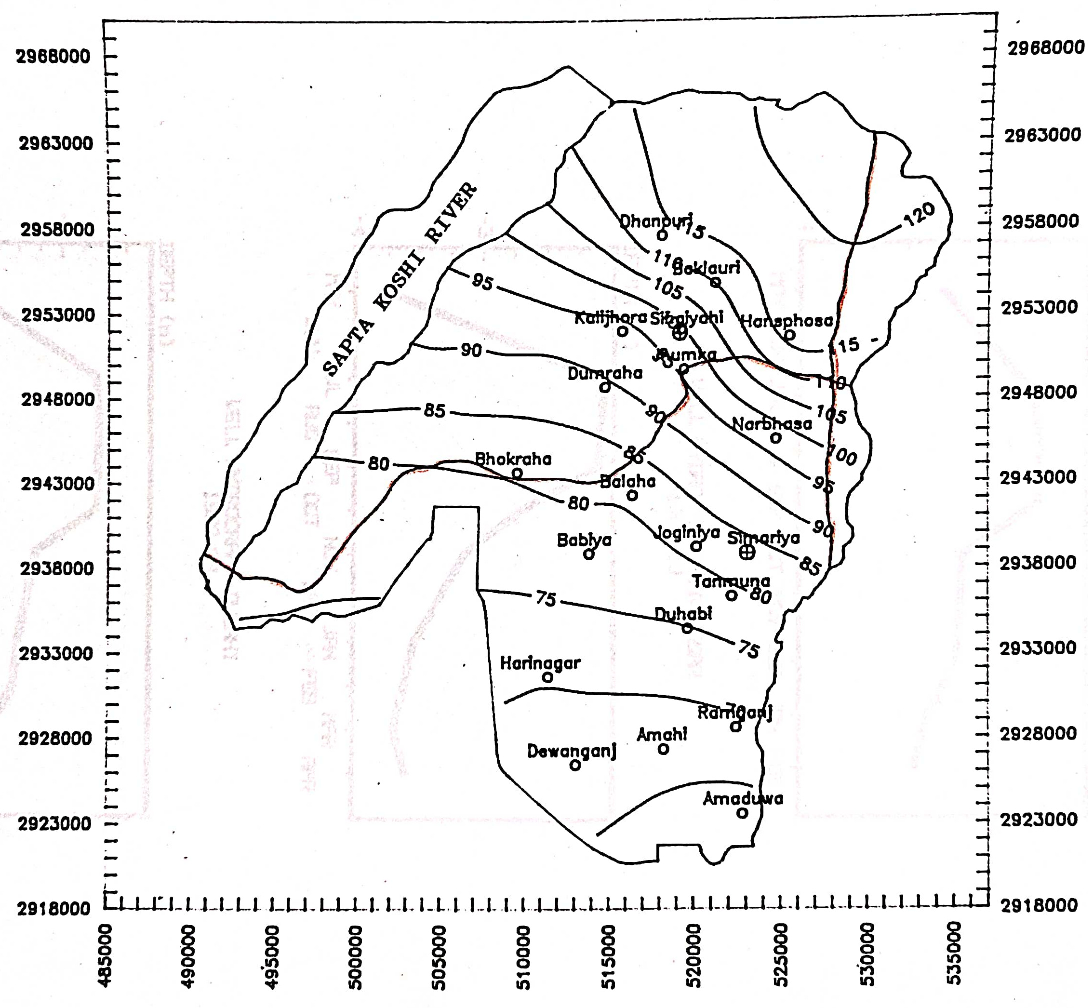
APPENDIX 8/5

SUNSARI WATER LEVEL CONTOUR MAP MAY 1988



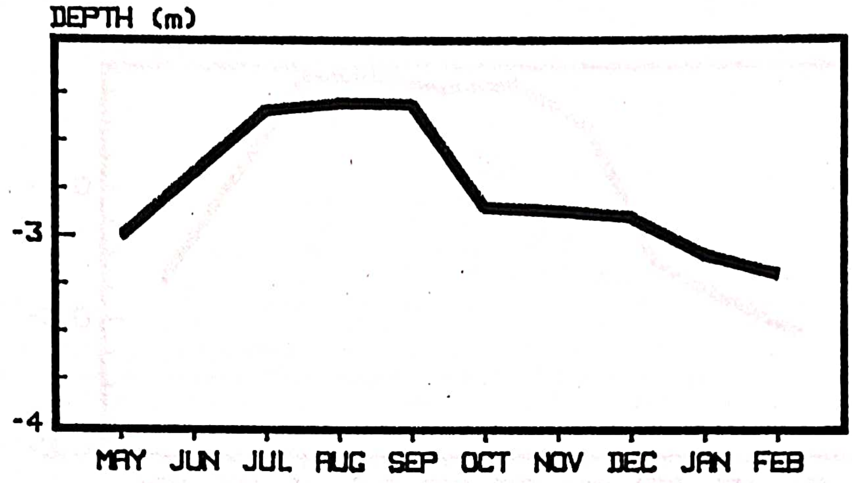
APPENDIX 9/1

SUNSARI WATER LEVEL CONTOUR MAP SEP 1988

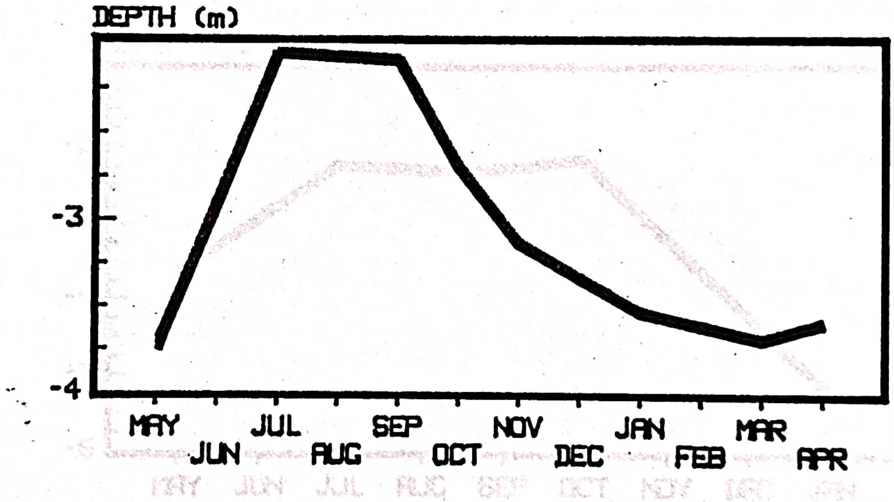


APPENDIX 9/2

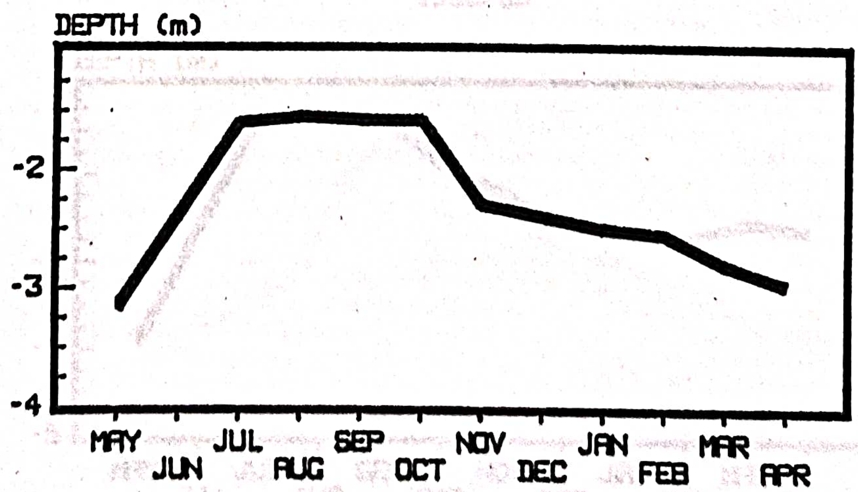
WELL HYDROGRAPH DEVANGANJ
1988/89



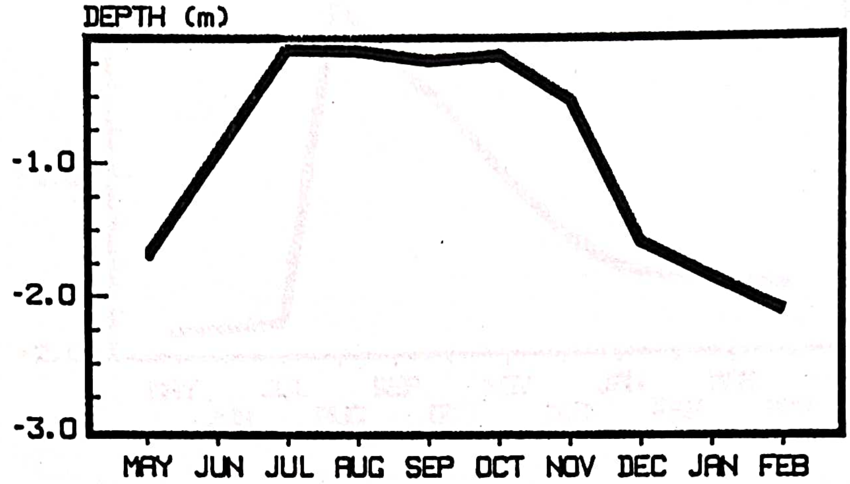
WELL HYDROGRAPH HARINAGAR
1988/89



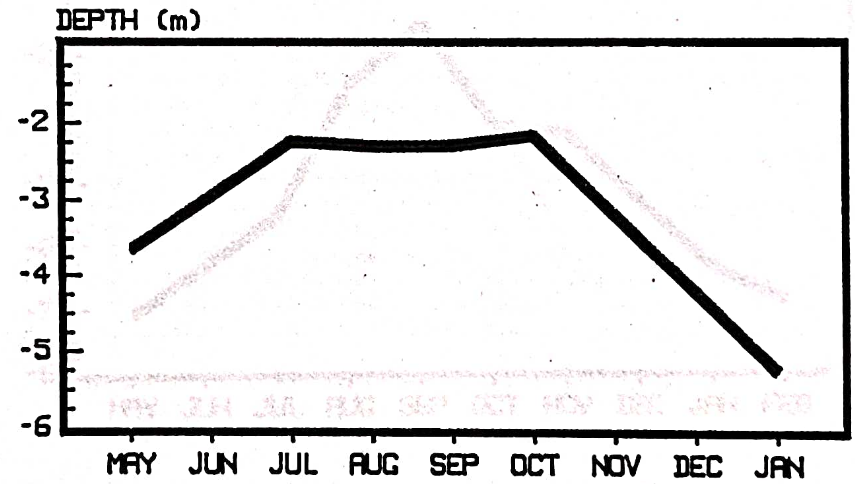
WELL HYDROGRAPH DUBAHI
1988/89



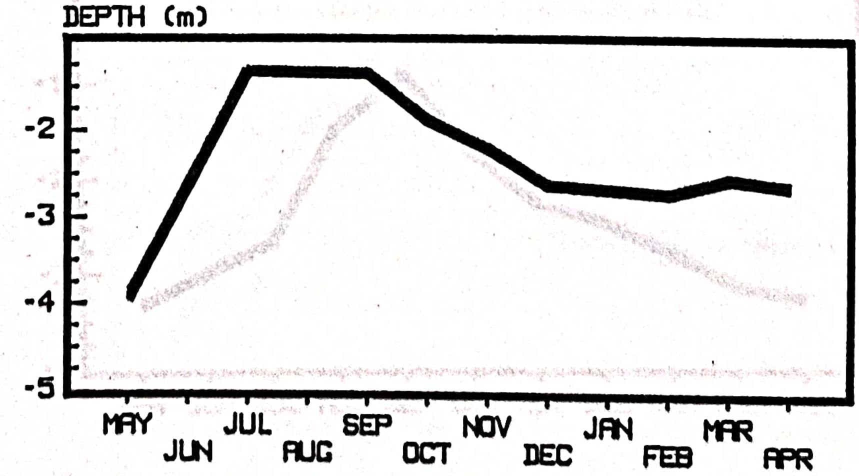
WELL HYDROGRAPH SIMARIYA
1988/89



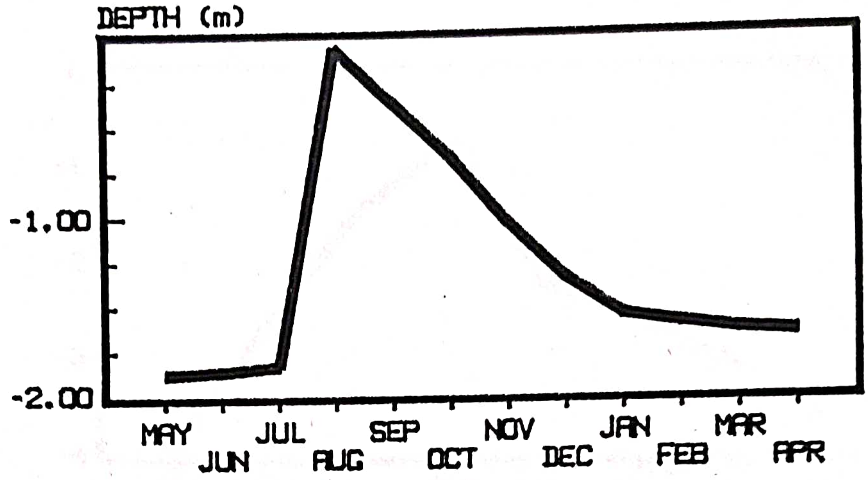
WELL HYDROGRAPH JOGINIYA
1988/89



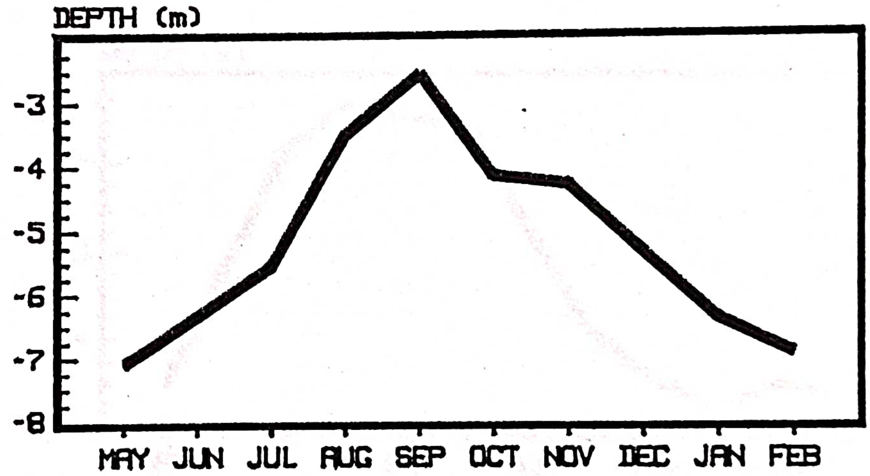
WELL HYDROGRAPH BABIYA
1988/89



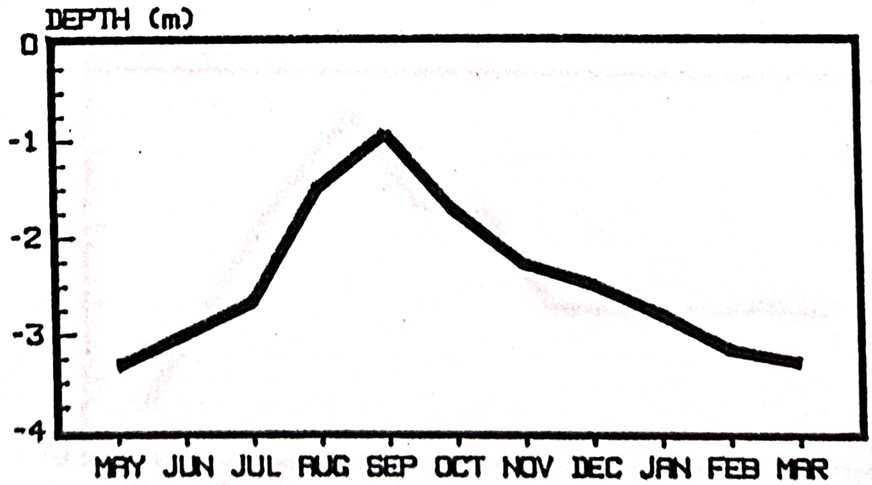
WELL HYDROGRAPH BHOKRAHA
1988/89



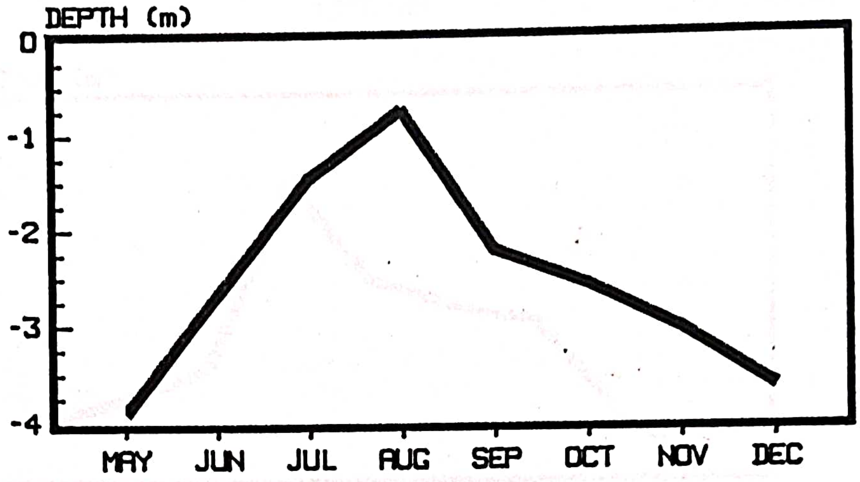
WELL HYDROGRAPH BALAHA
1988/89



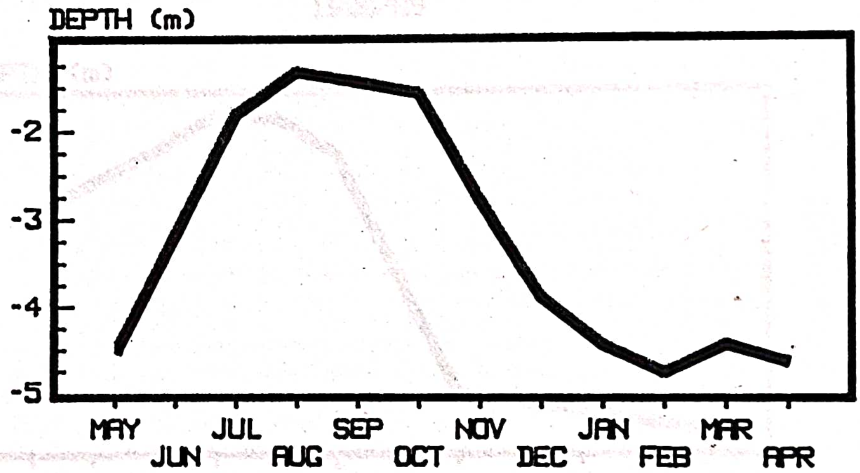
WELL HYDROGRAPH NARBASA
1988/89



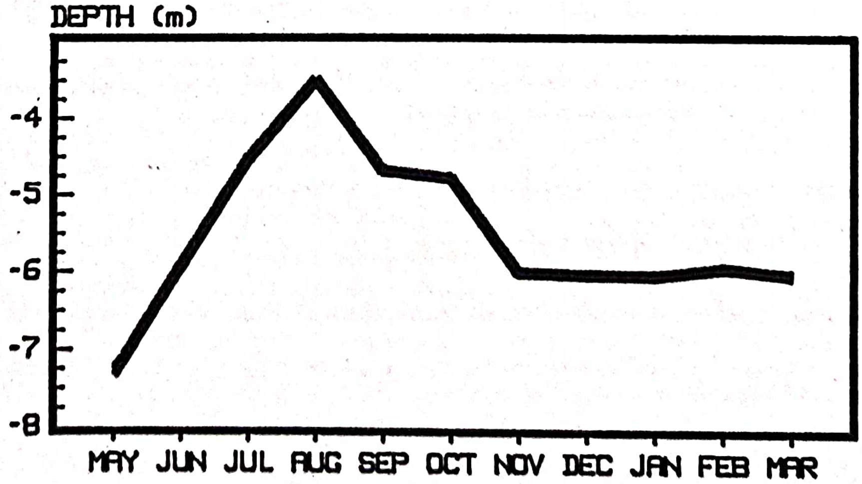
WELL HYDROGRAPH KALIJHORA
1988

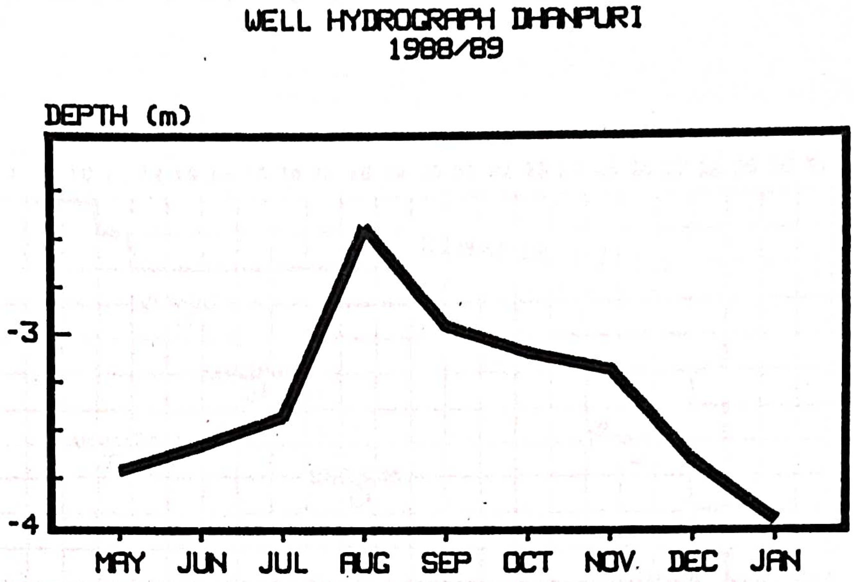


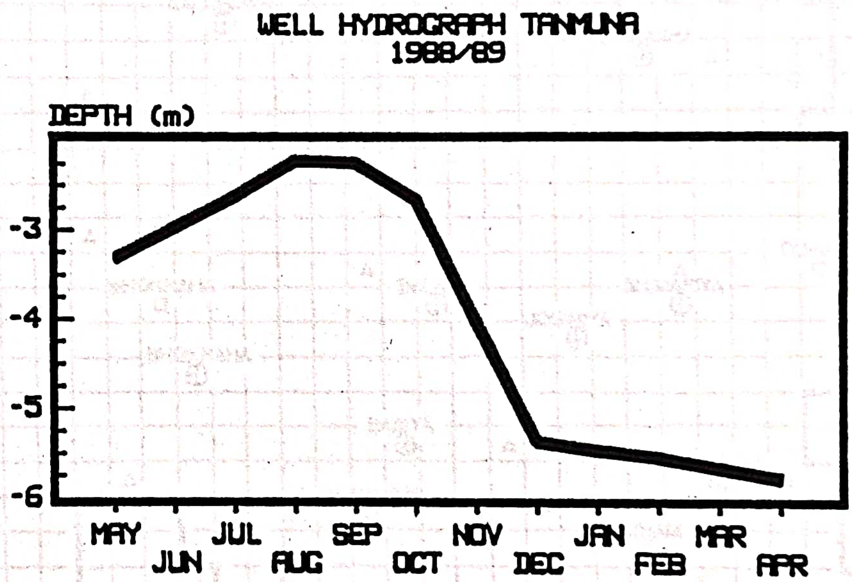
WELL HYDROGRAPH SINGIYA
1988/89



WELL HYDROGRAPH BAKLAURI
1988/89




WELL HYDROGRAPH DHANPURI
1988/89
DEPTH (m)
-3
-4
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN


WELL HYDROGRAPH TANMUNA
1988/89
DEPTH (m)
-3
-4
-5
-6
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR

SUNSARI: MATHEMATICAL MODEL NETWORK