United Nations Development Programme

and

His Majesty's Government of Nepal Project

NEP/86/025

SHALLOW GROUND WATER INVESTIGATIONS IN TERAI

TECHNICAL REPORT No. 16

JHAPA DISTRICT

SHALLOW WELLS DRILLING, TESTING AND MONITORING IN 1987-89

BASIC DOCUMENTATION AND PRELIMINARY INTERPRETATION

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

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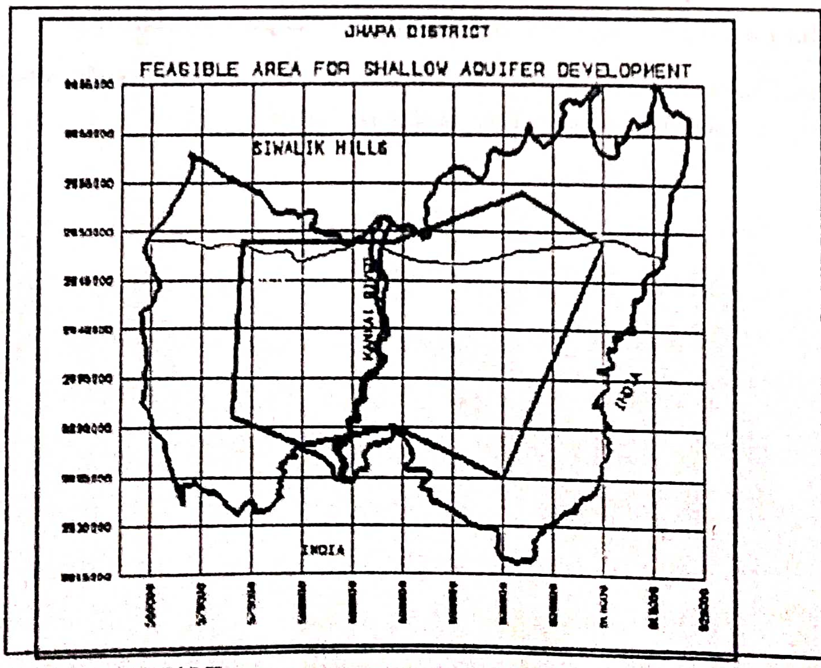
EXECUTIVE SUMMARY

The objective of this report is to present technical information on the occurrence of shallow ground water in Jhapa district. The report is given in a form of Basic Documentation with some preliminary interpretation.

The basis for the report are newly drilled 21 shallow project wells and compiled data from 16 deep tube wells drilled by GWRDB in 1983-89. The report follows an established format of presenting lithological data (in 37 well logs and 7 lithological cross sections including both shallow and deep wells). In addition to drilling, data from 16 pumping tests are processed and interpreted. As a general conclusion both shallow and deep aquifers are present in Jhapa district in every part of the district. The percentage of permeable layers in 21 shallow project-drilled wells is about 58.9% (374 m of permeable sediments out of total 635 m drilled metrage). This is compared with similar percentages in other districts as follows. The highest percentage in all currently interpreted districts of the Terai under NEP/86/025 project is in Jhapa. The Jhapa shallow aquifer is closely followed by Sunsari (56%), Deukhuri (53%), Dang (48%), Nawalparasi (48%). Rautahat district with 39%, Morang with 38%, Kapilvastu with 32%, and Rupandehi with 30%, show much less permeable formations. As a whole the shallow aquifer of Jhapa district has quite acceptable transmissivity, on average between 500 and 800 m^2/day. (This transmissivity would have even higher had the wells been properly constructed and developed.) The transmissivity is minimum (less than 300 m^2/day) in eastern part, near the Mechi River, and increases towards the central part where it reaches a maximum of about 1100 m^2/day. The transmissivity above 500 m^2/day is considered sufficient for water supply and small-scale irrigation. In parts with transmissivity above 1000 m^2/day (central) medium- to large-scale irrigation might be also feasible, provided levels are not too deep, what apparently they are not. An average shallow well drilled to about 30 m depth, shall have about 17 meters of sand with gravel, and about 13 meters of clay.

Jhapa district is well covered with water level observation network. The number of 18 wells is believed adequate for Jhapa district. The observation of water levels in existing network should continue. Newly drilled wells should be protected against vandalism.

Overall, the shallow ground water system of Jhapa district has very high development potential. Its lithology is favorable, hydrogeological characteristics reflected in transmissivity and hydraulic conductivity are likewise favorable. Water levels are not too deep in the months when pumping is needed for irrigation. Yet, one may delineate a more promising area for shallow aquifer development, such as shown in figure here below. The area within polygon is about 840 km2.



The recharge, taken as a conservative value, could be minimum about 271 MCM per year. Out of this very little (12 MCM) is lost through natural down-gradient outflow toward south, that is to India. By far the greatest percentage of recharge and natural flow is intercepted by evaporation and lost. Medium-scale shallow ground water development is both feasible and beneficial.

Intensive abstraction of shallow water shall lower water table to depths from which there will be no evapora-

tion. Water logging, which may happen in peak monsoon months at present, shall be prevented because water levels shall be deep enough to leave above an unsaturated zone capable of accepting additional rain water.

If the recharge values are not overestimated, at least one half of 271 MCM could be salvaged and abstracted through a system of carefully located wells. With an average agricultural demand of about 1 l/sec over 100 days for one hectare, or 8640 m^3/ha, 135 MCM sustained yield would imply irrigation of about 15600 ha or 156 km^2, that is 15.6% of the total area of Jhapa declared as irrigable.

Without a mathematical model it is difficult to come to maximum development potential figures. The recharge in Bhabar zone infiltrates partly to shallow aquifer, but also contributes to the recharge of deep aquifer. At present the deep aquifer is fully saturated and underpiezometric head, but its annual exchange of water is minor compared to that of shallow aquifer. Water cannot evaporate from deep aquifer, it is not feeding rivers. Its water is flowing down-the-gradient toward south. With transmissivity of 1000 m^2/day, and gradient of 0.001, through the same outflow section of 40 km the volume of 14.6 MCM can flow annually. This volume is nevertheless a minor component of water balance of shallow aquifer, although it comes from the same 271 MCM of estimated recharge.

The volume of data appears to be sufficient to construct a preliminary model of Jhapa district. The total network shall be 54x43 uniform square cells of 1 km^2 each, that is the total model area shall be 2322 cells or square kilometers. The model boundaries are natural (north, east), and artificial (west, south). In the north the shallow aquifer disappears. In the east the Mechi River makes a constant-head boundary. The boundary to the west shall be taken as the end of shallow aquifer, or beyond the district to the west the transmissivity shall be zero. This is also a no-flow across boundary, implying no exchange of shallow water between Jhapa and neighboring district of Morang. The only really artificial boundary in this model shall be the southern boundary, i.e. the south border with India. Yet, there one may assign either constant heads or constant outflow using data reported herein. The calibration may start with steady state in pre-monsoon season of 1989, and continue with unsteady-state in monsoon season of 1989, that is from May through September 1989. Model verification may cover the period of one year from May 1989 through May 1990. The whole work may take one month including report writing. The target date for working on the model could be June-August 1990, when additional water level data, until May 1990, shall become available.

The model output shall be the following:

(a) Correct values of recharge from rainfall over permeable portion of the district.

(b) Modified distribution of hydrogeological parameters, such as transmissivity, effective porosity.

(c) Every component of water balance quantified, notably recharge and evaporation.

(d) Proposals for future extensive shallow aquifer development and impact of various pumping scenarios.

The final outcome of the model shall be the number, location, spacing, pumping rate of shallow wells in most promising areas, and the consequence of extensive pumping over a period of some 5 years.

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EARLIER TECHNICAL REPORTS:

1. **Bhairawa-Lumbini** Ground Water Irrigation System Preliminary Mathematical Modelling. May 1988.
2. Shallow Ground Water Level Fluctuations in the Terai in 1987. Preliminary Report. May 1988.
3. **RAUTAHAT DISTRICT.** Shallow Wells Drilling, Testing and Monitoring in 1987/88. Basic Documentation and Preliminary Interpretation. November 1988.
4. **RAUTAHAT DISTRICT.** Mathematical Model of Shallow Ground Water System. December 1988.
5. **NAWALPARASI (WEST).** Shallow Wells Drilling, Testing and Monitoring in 1987/88. Basic Documentation and Preliminary Interpretation. March 1989.
6. **NAWALPARASI (WEST).** Mathematical Model of Shallow Ground Water System. March 1989.
7. **KAPILVASTU DISTRICT.** Shallow Wells Drilling, Testing and Monitoring in 1987/89. Basic Documentation and Preliminary Interpretation. June 1989.
8. **DANG VALLEY.** Shallow Wells Drilling, Testing and Monitoring in 1987/89. Basic Documentation and Preliminary Interpretation. June 1989.
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10. **SUNSARI.** Shallow Wells Drilling, Testing and Monitoring in 1988/89. Basic Documentation and Preliminary interpretation. June 1989.
11. **RUPANDEHI DISTRICT.** Deep Wells Drilling, Testing and Monitoring in 1969-89. Basic Documentation and Preliminary Interpretation. August 1989.
12. **MORANG.** Shallow Wells Drilling,Testing and Monitoring in 1987/89. Basic Documentation and Preliminary Interpretation. September1989.
13. SHALLOW WATER LEVEL FLUCTUATION MAPS 1987 - 1989. September 1989.
14. **RUPANDEHI.** Shallow Wells Drilling, Testing and Monitoring in 1987/89. Basic Documentation and Preliminary Interpretation. September 1989.
15. **MAHOTTARI.** Shallow Wells Drilling, Testing and Monitoring in 1987/1989. Basic Documentation and Preliminary Interpretation.

ABBREVIATIONS:

UN/DTCD - United Nations Department of Technical Co-operation for Development
UNDP - United Nations Development Programme
USAID - United States Agency for International Development
GWRDB - Ground Water Resources Development Board
GDC - Groundwater Development Consultants (International) Ltd.
ADBN - Agricultural Development Bank of Nepal
STW - Shallow Tube Well
DTW - Deep Tube Well
MCM - Million Cubic Meters

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. The government implementing agency is Ground Water Resources Development Board of the Department of Irrigation, Ministry of Water Resources. The project is designed as a four-and-half year project primarily oriented to field-data collection, establishment of ground-water data bases, and to assessment of development potentials of shallow aquifers all over the Terai. The project started in June 1987.

The project is to produce the following tangible outputs:

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

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

(c) Water level graphs 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.

(f) Assessment of shallow aquifer development potentials in each of districts.

1.2. Objectives of this Report

This Report is a routine presentation of most of compiled and collected data, from on-going UNDP/UNDTCD project and earlier sources. Prior to reporting on shallow aquifers in Jhapa district, the following districts have been reported already: Rautahat, Nawalparasi, Dang and Deukhuri, Kapilvastu, Sunsari, Morang, Rupandehi, and Mahottari. Also, there is a report on deep aquifers of Rupandehi district. (See Earlier Technical Reports at the beginning of the report.)

This Report is designed as a Basic Documentation report, which incorporates all available information on groundwater system under one cover. The format of presentation is the one selected by the UN project NEP/86/025 for shallow wells, and provides for consistency of reporting. The emphasis is on "raw" information about lithology, pumping tests, water levels (heads). The interpretation that is offered herein, is neither complete nor very detailed. It is preliminary interpretation, which shall be finalized in Project's Final Report. However, this interim report can be used by hydrogeologists and planners, especially in ADBN, for preparing the programs of increased shallow aquifer exploitation in Jhapa district.

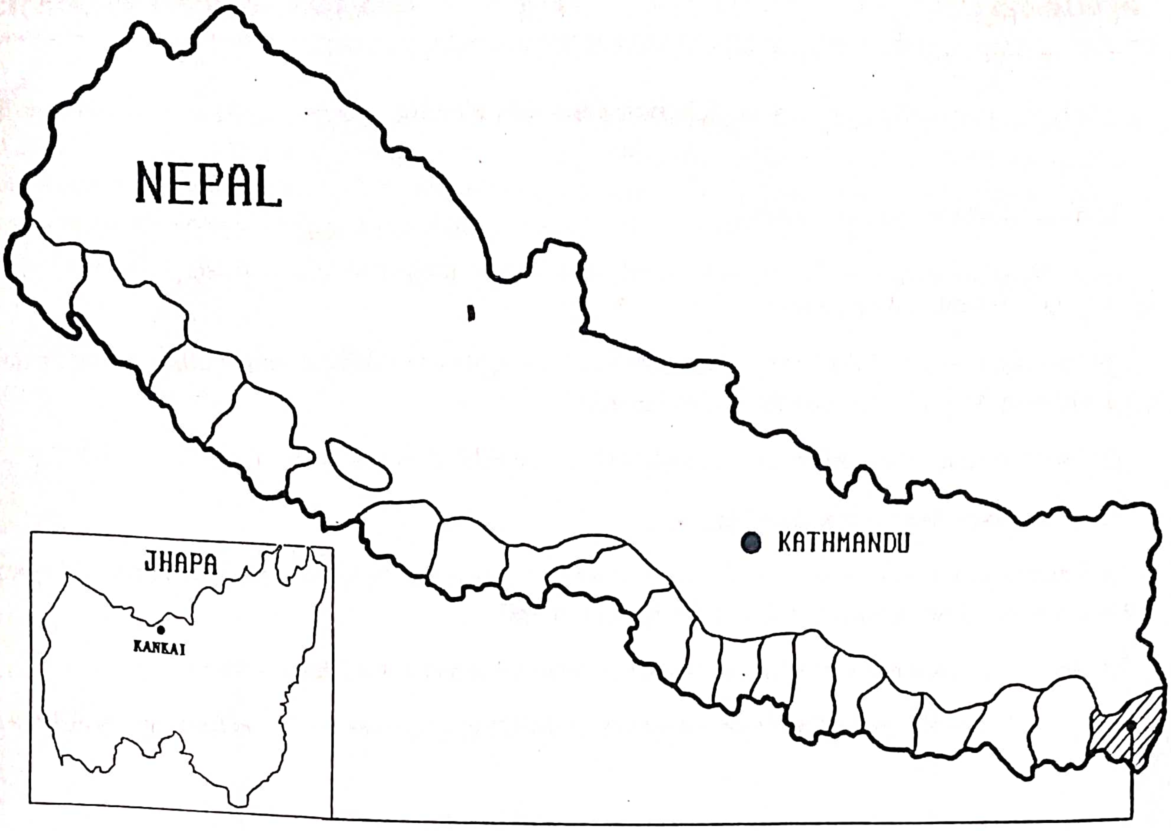


FIGURE 1.

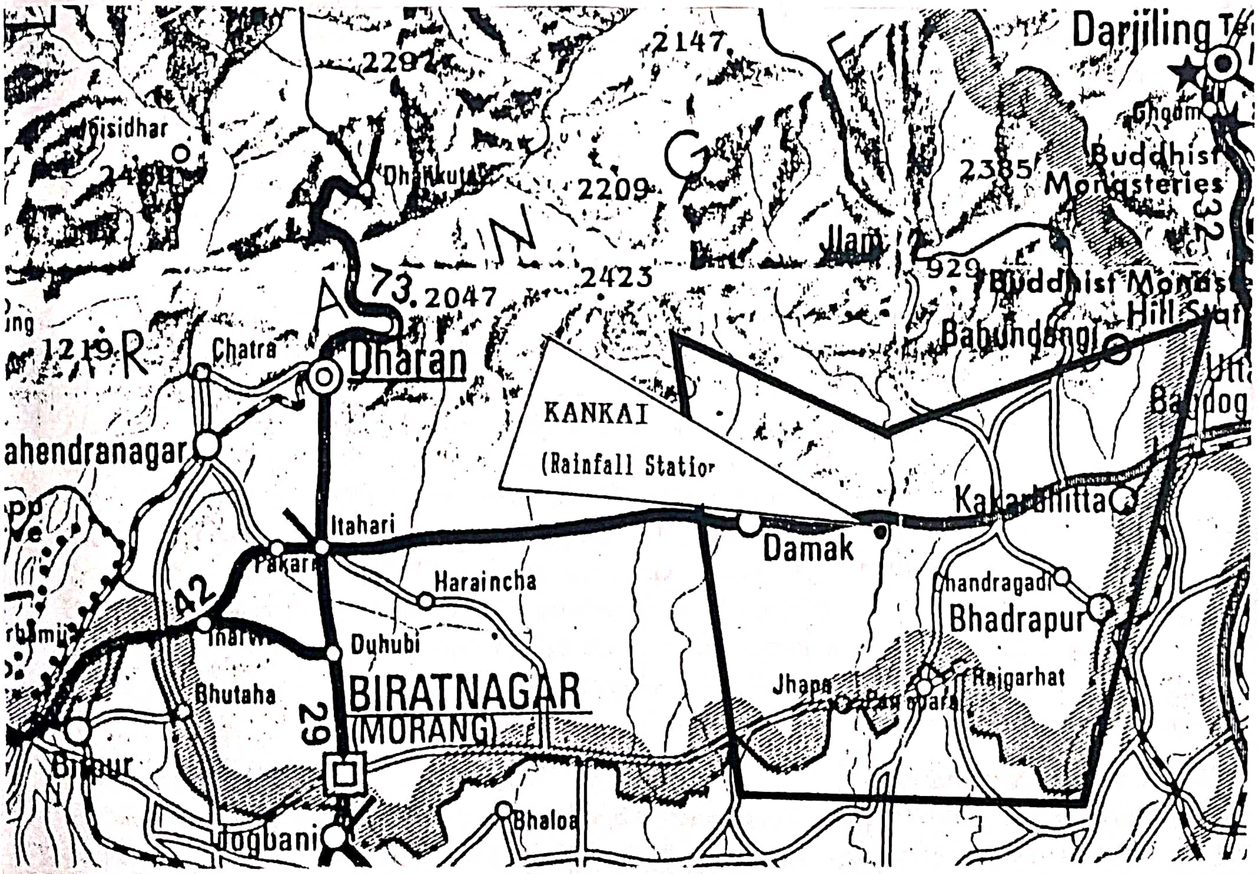


FIGURE 2.

1.3. Basis for this Report

This report is based on the following:

(a) NEP/86/025 project wells (for ease of reference called "project wells"); 21 newly drilled shallow wells between March 1989 and January 1990.

(b) Deep tube wells (DTW) drilled for ground water investigation by GWRDB and Drinking Water Project in the period from May 1983 through April 1989 (16 wells).

(c) Pumping tests conducted in "project wells" (14), in "ADBN" or private wells (5).

(d) Water level observations since May 1987.

(e) Study of groundwater resources development strategies for irrigation in the Terai, as compiled and reported by Groundwater Development Consultants (UK), Ltd. in 1987.

(f) Several technical reports on the occurrence of deep aquifers in Terai (Duba, Tillson).

(g) First Mission Report by Chief Consultant in NEP/86/025 project (July 1987), and field trips by NEP/86/025 project staff.

1.4. Location, Size and Climate

Jhapa district belongs to the Eastern Region of Nepal. To the west of Jhapa is Morang district and to the east is India. The western boundary between Jhapa and Morang is the Ratuwa Khola, and eastern boundary between India and Jhapa is the Mechi River, which is one of the major rivers of Nepal. According to Tillson, the area of Jhapa district is about 1565 km^2 The Terai part of this district is 1400 km^2, out of which the Bhabar Zone is 100 km^2 (other sources estimate the Bhabar to be more than 250 km^2). The Bhabar zone is built of fan-shaped deposits of mixed composition, with coarse fragments intertwined with finer sediments' The coarse sediments result from river deposition after sharp loss of transportation energy at the exit from Siwalik hills. The length of the district is 46 km from east to west and its width is 29 km from north to south. The location of Jhapa district within Nepal is shown in Figure 1. For the purpose of studying the shallow ground water system of the Terai, the contour line 150 m is considered to be the physical end of the Terai's Quaternary sediments.

The main characteristics of climate in Jhapa district, as well as in the whole Terai, is monsoon rainfall which occurs between June and September and which delivers an average of 85% of the total annual rainfall. For the purpose of this report the data collected in Kankai rainfall station are used. Some of recent information on rainfall is a "raw" material, not officially cleared by the HMG's Meteorological Service. It is used as an indication for the correlation between shallow water level fluctuations and rainfall. Although the Terai of Nepal is in subtropical zone, the mean monthly temperature reaches a low of 15.1 °C in January compared to a high of 30.7 °C in June. The information that is available on climate includes daily and monthly evaporation, mean monthly temperature, mean monthly humidity, plus daily rainfall, from Biratnagar or nearby station in Sunsari district (Tarahara). Average annual rainfall in Kankai is 2729 mm, for the period from 1985 through 1988. Especially, the year 1987 was excessively wet (3521 mm). The location of the Kanaki rainfall station is shown in Fig.2. Average evaporation from free water surface is about 1500 mm. Average monthly rainfall exceeds average evapotranspiration during only 4 months, June to September.

There are several rivers that cross the district from north to south, carrying water and supplying sediment from higher Mahabharat Range or Himalayas. The major streams, which are mostly intermittent or with low flow rate before the monsoon, are (from west to east): Mawa Khola, Kawal Nadi, Kankai Nadi, Saranamati Nadi, Charghaere Nadi, Haidiya Nadi, Ninda Khola and Mechi Nadi. Among the rivers that flow inside the district the Kankai is the major stream having an average discharge of 8 m^3/sec. These rivers originate from Mahabharat Hills and flow towards south. For appreciating the recharge to shallow aquifer of Jhapa district, it is important to note that the west-east Siwalik hills range is intersected by major or smaller rivers in the district at least in nine places. This is on average one river entering the Jhapa Terai in every 5 km.

2. PROJECT ACTIVITIES IN 1987/89

2.1. Drilling

The drilling of shallow wells in this UN project is programmed for about 200 shallow tube wells (STW) all over Terai districts. Out of this, the designed number for Jhapa was 23, and 21 wells have been actually drilled. The drilling started in March 1989, and terminated in jANUARY 1990. The total drilled metrage is 635 m, or an average well is 30.3 m deep. The performance related to expectations is shown in Figure 3. The officer-in-charge of drilling was Mr. Prem Karki. His work in drilling and reporting to project's office in Kathmandu is here acknowledged.

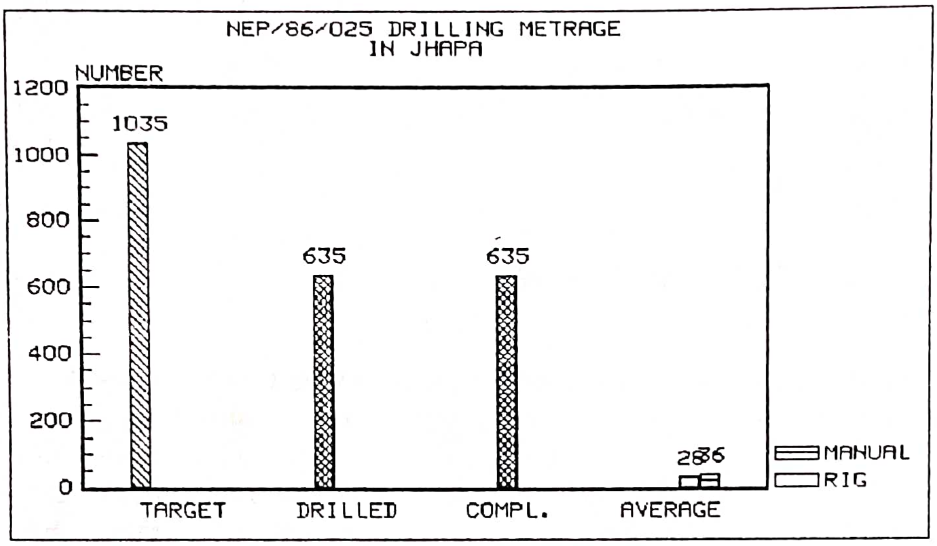


Fig. 3. Drilling Performance in Jhapa District

It is important to note that out of 21 wells only six were drilled by classical rotary drilling rig, using mud and drill rods. Fifteen wells were drilled by indigenous method, that is manually. As will be discussed in next chapter, within shallow 30 meters of Jhapa aquifers, there is plenty of large-size gravel (pebble) which normally creates problems in drilling.

Evidently the manual method of drilling as applied to Jhapa is successful in overcoming difficulties normally experienced in drilling through hard gravel and pebble. The average depth of wells drilled manually is 28 m and of those drilled by rig 36 m. The depth of wells drilled by rig varies from 25 m (STW13- Bareghare) to 44 m (JPUN7-Kankai) and by manual method from 15.2 m (STW5-Lakhanpur) to 36.6 m (STW8-Gwaldubba, STW10-Keradhap and STW14-Sangambasti).

In general, it has been found that manual drilling is successful so manual drilling is superior to bentonite-mud drilled wells. Pumping test results are more reliable, well losses are minor component of aquifer losses. Manually-drilled wells are also reported to be cheaper. The only disadvantage is that they are frequently terminated inside a permeable formation, although instructions for drilling specify that the well should be terminated in at least 2 m of clay below the last permeable layer. This happened in well STW-3 (Gherabari: total depth 29.9 m; sand and boulders), STW-4 (Phulbari: total depth 16.8 m, sand and pebble), STW-5 (Lakhanpur: total depth 15.2 m, sand and gravel), STW-9 (Hukkagachhi: total depth 35.1 m, sand). However, out of six rig-drilled wells two wells also have terminated in permeable formations: STW-1 (Prithvinagar) in "gravel and sand" at depth of 35.1 m, and STW-13 (Bareghare) in "gravel medium" at depth of 25.9 m. The conclusion is that gravel and pebble shall create equal problems to manually as well as to rotary-rig drilled wells. If manual drilling is cheaper, if the driller can penetrate to 40 m depth, the preference should be given to manual method.

The map with locations of all "project" wells is presented as Appendix 1. The scale of the map is small, making t an index map. The numbers along map borders are X and Y coordinates in meters. Thus one centimeter in the nap is about 3 kilometers in nature, or the scale is close to 1:300,000. The map in Appendix 1 also shows the ocations of four ADBN-financed STWs, in which pumping tests have been made and results reported herein.

This report presents also the lithology at 16 deep wells drilled by GWRDB in 1983-89. All together 37 lithological logs are appended to this report in Appendices 3, to illustrate the lithology of both deep and shallow aquifer in Jhapa. This is a diversion from earlier reports in which the attention was given to shallow aquifer only. It is believed that reports of this kind ("Basic Documentation") shall be more useful for future reference if all information is presented.

Table 1 presents general information on all wells documented in this report (21 "project wells", 16 DTWs). Project wells are sequentially numbered from STW-1 through STW-21, and deep wells from DTW-1 through DTW-16. The same sequential number appears in the group of Appendices 3, and in location map in Appendix 4/1. The map is the basis for locating lithological cross sections and individual wells in cross sections (Appendices 4/2 through 4/14).

TABLE 1. General Drilling Data On STWs and DTWs

No.	WELL NAME	X	Y	Z	DEPTH	SCREEN
1	JPD1	568200.	2949800.	126.00	88.40	17.0
2	JPD2	604200.	2948200.	130.00	125.00	20.0
3	JPD3	585900.	2949500.	120.00	85.90	8.7
4	JPD4	575700.	2941300.	100.00	137.20	17.7
5	JPD5	572800.	2933900.	85.00	137.20	12.4
6	JPD6	573000.	2926700.	71.00	137.20	0.0
7	JPD7	607900.	2942200.	105.00	148.40	18.1
8	JPD8	607700.	2934600.	84.00	146.30	24.4
9	JPD9	599400.	2938900.	95.00	146.30	36.2
10	JPD10	591500.	2943400.	103.00	144.80	24.1
11	JPD11	606000.	2930500.	81.00	155.50	0.0
12	JPD12	593000.	2932900.	79.00	167.70	33.2
13	JPD13	586100.	2929900.	75.00	158.50	0.0
14	JPD14	569875.	2950875.	132.00	72.30	7.3
15	JPD15	598375.	2952750.	162.00	73.10	33.4
16	JPD16	615688.	2947625.	120.00	159.70	67.0
17	JPS1	606625.	2930875.	81.00	35.10	9.1
18	JPS2	608593.	2933875.	81.00	21.30	5.8
19	JPS3	594500.	2923250.	66.00	29.90	6.1
20	JPS4	592500.	2939100.	94.00	16.80	4.8
21	JPS5	571500.	2947625.	121.00	15.20	3.2
22	JPS6	570625.	2940875.	101.00	27.40	3.1
23	JPS7	585625.	2949000.	120.00	43.90	10.2
24	JPS8	571500.	2934125.	86.00	36.60	6.1
25	JPS9	572250.	2927625.	73.00	35.10	7.3
26	JPS10	575250.	2944875.	113.00	36.60	7.6
27	JPS11	602625.	2947875.	128.00	38.10	9.1
28	JPS12	580200.	2945375.	113.00	34.80	6.2
29	JPS13	599750.	2953375.	183.00	25.90	6.1
30	JPS14	606750.	2926125.	69.00	36.60	6.0
31	JPS15	581000.	2936000.	85.50	35.10	6.2
32	JPS16	593625.	2944125.	112.00	38.10	6.0
33	JPS17	614125.	2947375.	121.00	32.00	9.3
34	JPS18	572500.	2929375.	75.00	27.40	4.6
35	JPS19	599400.	2937900.	95.00	28.96	9.0
36	JPS20	600400.	2918000.	63.00	22.87	7.6
37	JPS21	600200.	2935600.	84.00	18.60	6.0

Number of wells in data base:	37
Total drilled depth in data base:	2719.8
Average depth per well:	73.5
Total screened interval:	524.9
Average screened interval:	14.2
Number of wells with screen:	34
Number of wells w/out screen:	4

NOTES (for TABLE 1):

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

(2) Z is the absolute elevation of the well above the mean sea level. All the elevations were taken from topographic maps at scale 1:125,000 (unsatisfactory) and 62,500 (better). The error in higher parts of the district, that is north of main west-east highway, could be as high as 10 meters. In the lower-lying area, toward south, the accuracy is probably within one meter or two. For the reporting purpose this may be acceptable. For modeling the shallow ground water system, the accuracy of water-well land- surface elevation in flat terrains should be +/- 0.5 m, and in steeper parts +/- 1 m.

The total drilling depth of all 16 DTWs drilled by GWRDB in 1983- 89 is 2,081 m, and an average "deep" well is 130 m deep. The deepest well has penetrated to the depth of 168 m (DTW-12, Rajgadhat).

The statistics for "project wells" (shallow tube wells) is shown below.

Number of wells in data base:	21
Total drilled depth in data base:	635.9
Average depth per well:	30.3
Total screened interval:	139.4
Average screened interval:	6.6
Number of wells with screen:	21
Number of wells w/out screen:	0

2.2. Testing Shallow Wells

The program of test pumping called for testing of all newly drilled wells, plus some 5 existing wells. Thus the total number of wells to be pump tested was 23. Out of this the project tested 19 wells: 14 shallow tube wells drilled by UN Project and 5 in ADBN STW (private wells).

Among tested wells, two wells (STW 6 and STW 13) show unreliable results due to high fluctuation of water level during pumping. Eliminating these two, and one private well, the total number of acceptable pumping tests appears to be only 16. The performance of this project activity compared to the designed expectations is shown in Figure 3. In only five pumping tests a nearby existing well was used as an observation well, providing for the possibility of evaluating storage coefficient or effective porosity of shallow aquifer in addition to its transmissivity. The instructions prior to selecting drilling and testing sites were to have an observation well within 50 meters. The reasons for not performing pumping tests in five project wells are as follows:

pumping tests a nearby existing well was used as an observation well, providing for the possibility of evaluating storage coefficient or effective porosity of shallow aquifer in addition to its transmissivity. The instructions prior to selecting drilling and testing sites were to have an observation well within 50 meters. The reasons for not performing pumping tests in five project wells are as follows:

STW-1, Prithvinagar ... deep water table (greater than 6 m)
STW-3, Gherabari ...... location not accessed due to lack of fuel
STW-10, Keradhap ...... drawdown excessive
STW-18, Gauriganj ..... not sand-free well
STW-9, Hukkagachhi .... not sand-free well

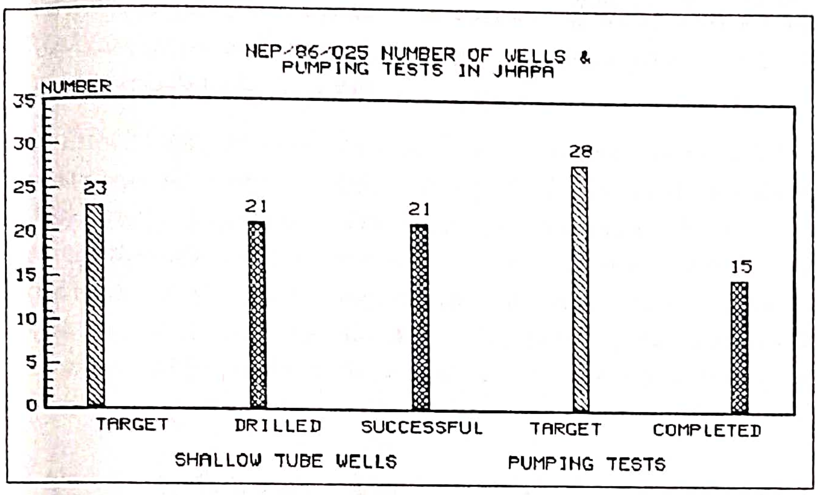


Fig.4. Number of Wells and Pumping Tests

Partial failure of pumping test portion of field activities is due to the following:

(a) Unable to make sand-free well. This may be a consequence of poor well design and improper gravel packing. Also well development of short duration and improper methodology should be blamed for failure.

(b) High drawdown. The pumping equipment used cannot regulate the discharge. The well should be developed properly.

(c) Because of pumping near the limit of suction pump range, the pump discharge rate was fluctuating in some tests, which made the interpretation difficult.

The duration of test of less than 60 minutes is hardly worth interpretation. The total testing time of all 12 tests in "project" wells was equal to 2210 minutes, or about 180 minutes per one well. This would have been acceptable, provided each well had been tested for an equivalent period of time. However, some wells were tested only 30 minutes, and some 300 minutes. In ADBN wells, the time was more even: a total of 440 minutes for 4 wells, or an average testing time of 110 minutes per well, which is quite acceptable.

2.3. Monitoring Water Levels

Water level observations started in the spring of 1987 in more than 100 shallow and dug wells. This was a part of depth-to-water data collection campaign for GDC's report "Study of Groundwater Development Strategies for Irrigation in the Terai", which was released in December 1987. Most of these wells were retained in monitoring network until recent days. Most of them do not produce a continuous record, some months or periods are missing, and some wells are eliminated from monitoring network due to vandalism and wells' failure. The newly drilled "project" wells are replacing dug wells and earlier shallow wells from observations.

On the basis of various sources, maps of depths to water table are produced in several technical reports. Technical Report No. 2, dated May 1988, presented pre-monsoon and post-monsoon depths to water in 1987, and the rise of levels in the monsoon period. Technical Report No. 13, is an update of the Report No. 2, which corrects some of early errors and extends the period of presentation through June 1989. Both reports contain the maps from Jhapa district as well. Likewise, each of district Basic Documentation reports presents current maps of depth to water and water level contour maps in absolute elevations above sea level.

The map in Appendix 2 is monitoring network location map. Points are shown in two categories: (a) former network with which observations started (star), (b) current network of project wells only (small circle). It is believed that 21 project wells are sufficient to describe the evolution of water levels in Jhapa district. Yet, seven carefully selected shallow wells from the early period of observation should be retained in the network to provide for correlation and continuity. A proposal shall be given in text to follow.

3. SHALLOW AQUIFER LITHOLOGY AND AQUIFER PARAMETERS

3.1. Lithology

The lithology of shallow and intermediate-deep aquifers in Jhapa district is known from 37 lithological logs, prepared for the same number of drilled wells. All these logs are appended to this report in Appendix 3 (sequentially, 1 through 37). There is a map, Appendix 4/1, which shows the location of each of 37 wells uniquely identified with a number from STW 1 through 21 and DTW 1 through 16. The presentation of lithology of the district is based on lithological cross sections, Appendices 4/2 through 4/14, prepared exclusively for this report. The lithological well logs and cross sections are prepared by a UN/DTCD proprietary computer program, authored by J.Karanjac and D.Braticevic.

Prior to discussion of lithology in cross sections, the same UN computer program was used to analyze the percentage of permeable layers within the drilled depth in each well in data base, both shallow and deep. Additionally, only shallow wells have been processed. The program permits the user to define the depth of penetration within which one wants to analyze the proportion of permeable versus impermeable formations. For this report all wells, both deep and shallow, have been analyzed first, followed by the same analysis for shallow wells only. In the first case, the depth of analysis was declared as 400 m, guaranteeing that all drilled layers shall be accounted for, while in the second case, the depth was declared as 43 m. The information is shown in Table 2 below.

TABLE 2. Thickness And Percent Of Permeable Layers In STW And DTW

WELL NAME	DEPTH	PERMEABLE	PERCENT
JPUN1	35.1	26.2	74.6
JPUN10	36.6	15.6	42.6
JPUN11	38.1	22.6	59.3
JPUN12	34.8	20.7	59.5
JPUN13	25.9	22.6	87.2
JPUN14	36.6	14.7	40.2
JPUN15	35.1	19.6	55.8
JPUN16	38.1	24.4	64.0
JPUN17	32.0	21.0	65.6
JPUN18	27.4	10.9	39.8
JPUN2	21.3	9.8	46.0
JPUN3	29.9	27.5	92.0
JPUN4	16.8	14.7	87.5
JPUN5	15.2	12.1	79.6
JPUN6	27.4	18.2	66.4
JPUN7	43.9	18.7	42.6
JPUN8	36.6	14.8	40.4
JPUN9	35.1	17.9	51.0
JPUN20	22.9	13.7	60.0
JPUN19	29.0	18.9	65.3
JPUN21	18.6	9.5	50.8
JPD1	88.4	67.3	76.1
JPD10	144.8	69.9	48.3
JPD11	155.5	45.5	29.3
JPD12	167.7	116.2	69.3
JPD13	158.5	123.5	77.9
JPD14	72.3	7.1	9.8
JPD15	73.1	67.1	91.8

JPD16	159.7	108.1	67.7
JPD2	125.0	93.0	74.4
JPD3	85.9	35.4	41.2
JPD4	137.2	89.4	65.2
JPD5	137.2	69.2	50.4
JPD6	137.2	80.2	58.5
JPD7	148.4	65.8	44.3
JPD8	146.3	70.1	47.9
JPD9	146.3	70.3	48.1

```
DEPTH OF CALCULATION:   400.0
     Cumulative depth down to selected range: 2719.8
Total permeable thickness in selected range: 1552.2
  Average percentage of permeable materials:   57.1%
```

As a check only STWs have been processed. The statistical summary is shown below.

```
DEPTH OF CALCULATION:   43.0
     Cumulative depth down to selected range:  635.4
Total permeable thickness in selected range:  374.1
  Average percentage of permeable materials:   58.9%
```

One may conclude that the participation of permeable layers is about the same in shallow part as well as in deeper part. In other words, no matter how deep is a well, on average it will have about 57 to 59% of permeable formations.

Cross-Section I-I' (Deep aquifer: Appendix 4/2) cuts the northern portion of the district, at elevations above 132 m. This is a west-east section, coinciding with the Mahendra highway. Both shallow and deep wells are jointly shown. The cross section displays lithology of upper 170 meters or so. This is an area close to Bhabar zone. As mentioned before, the Bhabar in Jhapa is reported to occupy about 100 km^2. The wells DTW 1, DTW 14 (north west) DTW 3 (central), STW 11, DTW 2, STW 17 and DTW 16 (east) fall into this section, parallel to Mahendra highway. The aquifer shown in this section varies from 17 m to 80 m (Appendix 4/2). However, the real Bhabar is north of the Mahendra highway. Water levels in two out of three wells are not too deep: 3.42 m in October 1989 in STW 11, and 1.92 m in the same month in STW 17.

To gain more details in the upper part of aquifer sequence, that is within 60 meters from land surface, a similar representation of lithology along the same section line is shown in Appendix 4/3 (Section I-I', Shallow aquifer). Evidently, sand and gravel layers dominate.

Cross-Section II-II' (Deep aquifer: Appendix 4/4) cuts the southern part of the district from west to east. Two shallow wells (STW 8 and STW 14) and two deep wells (DTW 5 and DTW 13) are shown. The content of sand and gravel in south-western part varies from 14.8 m in STW-8 (from the depth of 36.6 m) to 61 m in DTW 5 (out of total depth of 137.2 m). In this area the prospect of getting a good well is better going deeper. DTW 13, which is located in the central part near the River Kankai, shows higher percentage of sand, gravel and pebble (120 m). STW 14 is located in the south-eastern part of the section, near the River Mechi. It shows 14.7 m of sand, gravel and pebble, which is less than average of all shallow wells. Its October 1988 water level is above ground level, which proves that the uppermost 2.7 m of clay are effectively sealing the shallow aquifer from the ground surface.

The lithological cross section II - II' (Shallow Aquifer, Appendix 4/5) details the lithology of upper 50 or so meters along the same section line as II-II' (Deep aquifer). Its western part represented by STW 8, Gwaldubba, is inferior (14.8 m of sand and gravel and transmissivity likewise very small, less than 500 m^2/day). In the east (STW 14, Sangambasti), shallow aquifer is also represented by 14.7 m of gravel and transmissivity of that area is also rather low, that is 300 m^2/day similar to western side (Appendix 6). In the central part(DTW 13, Jhapa), the upper 45 meters are absolutely dominated by gravel and some sand, with a transmissivity around 1000 m^2/day, according to Appendix 6. Since this well is located near the Kankai River at elevation of 75 m, and permeable layers extend all the way to the land surface, one may expect the connection between the shallow aquifer and the Kankai Nadi.

Cross-Section III-III' (Deep aquifer: Appendix 4/6) cuts diagonally from north-west to south-east. Seven wells are projected on this section line (DTW 14, STW 5, STW 10, DTW 4, STW 15, DTW 13, and STW 3), with a range of land surface elevations from 132 to 66 m. The depth of penetration and illustration is between 15.2 (STW-5) and 158 m (DTW-13). Each of wells has at least one good permeable layer, which is overlain and underlain by extensive and continuous clay layers. The well STW-5, Lakhanpur in the north with 12.1 m of sand and gravel has 600 m^2/day transmissivity. The middle part of the cross section, around STW 15 (Panchgachhi), and deep well DTW 13 (may have connection between shallow aquifer and the Kankai River). Appendix 4/7 (Shallow aquifer) shows the shallow aquifer for the sake of detailed presentation. It appears that the lower half of the cross section is more promising, although the shallow aquifer is quite well represented everywhere.

Cross-Section IV-IV' (Appendix 4/8) is a north-south cut through the upper 15 to 35 meters (STW 5 and STW 9, respectively), showing shallow aquifer, and from 72 meters (DTW 14) to 137 meters (DTW 6), showing deep aquifer. The elevation varies from 132 to 71 meters. There is plenty of gravel along the whole cross section. The thickness of sand and gravel decreases from north to south. Transmissivity varies around 500 to 600 m^2/day. The middle portion of this cross-section shows a rather inferior lithology in its shallow part (STW 6, STW 8 and DTW 5). The very south well, STW 9, indicates a good shallow aquifer between 9.1 and 12.2, and from 28.1 to 32.3 meters, with transmisisivity of about 500 m^2/day. As in other cross sections, the shallow aquifer is amplified in Appendix 4/9.

Cross-Section V-V' (Appendix 4/10) is a north-south line in the central part of the district, which cuts through both shallow and deep aquifer. There is plenty of gravel and sand in the north (DTW 4 and STW 4), the content of which decreases going down towards south. However, the well STW-3 in the south, near the Nepal-India border, shows a remarkably permeable lithology (Appendix 4/11: Shallow Aquifer). The transmissivity is highest, 1000 m^2/day, in the central portion (STW-4 and DTW-12) of the section (Appendix 6) and decreases towards north and south. In well STW-4 there is a sequence of good permeable layers, with the thickness of 14.7 m out of 16.8 m drilled depth. Unfortunately, the project-drilled shallow well, STW 4 at Phulbari, was also terminated in sand and pebble at depth of 16.8 m, although more permeable layers were underneath. The shallow portion along the same section line is shown in Appendix 4/11.

Cross section VI-VI' (Deep aquifer: Appendix 4/12) cuts from the north to south. Shallow wells (STW-2, STW-1, and STW-14) represent the shallow aquifer, and deep wells (DTW-7, DTW-8, and DTW-11) the deep aquifer. Its depth of presentation is about 155 meters (from +105 m land surface in DTW-7 to minimum elevation of +69 m in STW-14). The lithology of shallow well STW-1 is identical to deep well DTW-11 at the same location, which may indicate that the well STW-1 was not needed in that particular location (see Appendix 4/13). Water levels in shallow wells Maheshpur (STW-2) and Sangambasti (STW-14) are both above ground level after monsoon. The transmissivity varies from 500 m^2/day (north) to 300 m^2/day (south). The impression about this northern part of the district is that at any level of depth one may encounter sand and gravel layers which contain ground water.

Cross-Section VII-VII' (Appendix 4/14) is lithological cross section cutting through north-east to south-west direction (DTW- 16, STW-17, DTW-7, DTW-9, DTW-12, and DTW-13). It is created by five deep wells and one shallow well. The whole section displays quite a high content of permeable layers. In the north east the thickness of sand and gravel is 21 m in shallow well, but clearly, the gravel layers continues beyond the shallow well depth. Actually the best layer is found in DTW-16 at interval 33- 7 m. The thickness of sand and gravel is also very high in DTW- 13, which is located at the south at an altitude of 75 m near the Kankai River. The transmissivity, which starts at about 300 m^2/day in the north and increases towards south-west up to 1000 m^2/day, offers another view of the development potential in southern part of the district. There is good aquifer in central part (wells DTW-7, DTW-9, DTW-12, and DTW-13) all over the drilled depth. As a general conclusion both shallow and deep aquifers are present in Jhapa district in every part of the district. The percentage of permeable layers in 18 shallow project-drilled wells is about 58.7% (332.0 m of permeable sediments out of total 565.9 m drilled metrage). This is compared with similar percentages in other districts as follows. The highest percentage in all currently interpreted districts of the Terai under NEP/86/025 project is in Jhapa. The Jhapa shallow aquifer is closely followed by Sunsari (56%), Deukhuri (53%), Dang (48%), Nawalparasi (48%). Morang district with 38%, Rautahat with 39%, Rupandehi with 30%, and Kapilvastu with 32% show much less permeable formations. Only these districts have been evaluated and reported until now. An average shallow well drilled by this project in Jhapa district would be 31.4 meters deep; it would have about 18.4 m of permeable and 13.0 m of impermeable layers, and would have an average screened interval 6.5 meters.

3.2. Hydrogeolpgical Parameters

Hydrogeological parameters of the shallow aquifer of Jhapa district were obtained from pumping tests run on 11 "project" wells and 5 ADBN wells (both under this project and in the "past"). The wells used in this interpretation are shown in Appendix 6, which is the map of transmissivity. Each of 16 test-pumped well is shown with either a circle (UN "project" STWs) or a square (ADBN STWs). In the same time, this report contains a group of appendices (Appendix 5) with each of individual 16 tests shown graphically with field-observed data and computer-fitted data. The computer program used in this interpretation is the UN- proprietary program developed by J.Karanjac and D.Braticevic.

The map of transmissivity is a creation of another computer program which interpolates and extrapolates random values. In the case of Jhapa district it appears that the aerial coverage is acceptable. Missing wells are in central southern part, especially in district corners. Likewise, one or more test-pumped wells would be welcome between location Bareghare and Ghailadubba (see Appendix 1, central-north), near Hukkagachhi (south-west), Sitapuri (west). The test at Ghailadubba in central-north should be repeated. The transmissivity of 280 m^2/day is not in line with the lithology at this site. It was not accepted for the construction of transmissivity map. To construct the transmissivity map more correctly, three wells from neighboring Morang district have also been taken into account. (The shallow aquifers of Jhapa and Morang districts make one system, which does not respect administrative boundaries.)

It is noted that most of wells are not properly constructed for testing with pump discharges of 10-15 l/sec. With casing diameter 100 mm, and open screen area about 15%, with pump discharge between 10 and 15 l/sec, the minimum length of well screen is about 8 m. This requirement is in line with recommendations for maximum or critical velocity of water entering the screen. When critical velocity is surpassed there is a danger of sand inflow, instability of gravel pack, and additional well losses may reduce overall efficiency of the well. This is interpreted in lower transmissivity during pump test than reported.

As an example the following calculation is offered. Open screen area in a well screened with 100 mm screen, with 15% openings, is about 0.047 m^2/m of screen. In a coarse-grained aquifer with hydraulic conductivity about 80 m/day, the critical (maximum permissible) entrance velocity is 3 cm/sec. If a well is to be pumped at 10 l/s, the minimum screen length must be 7.07 meters. This requirement had not been met in some wells.

As a whole the shallow aquifer of Jhapa district has quite acceptable transmissivity, on average between 600 and 800 m^2/day. (This transmissivity would have even higher had the wells been properly constructed and developed.) The transmissivity is minimum (less than 300 m^2/day) in eastern and south-eastern parts, near the Mechi River, and increases towards the central and north-central part where it reaches a maximum of about 1200 m^2/day. It is also high in the north-west, toward Morang district. (In Morang, near the district border, some wells show the transmissivity in excess of 2500 m^2/day.)

The transmissivity above 500 m^2/day is considered sufficient for water supply and small-scale irrigation. In parts with transmissivity above 1000 m^2/day (central) large-scale irrigation might be also feasible, provided levels are not too deep, what apparently they are not.

Most important hydrogeological data are presented in Table 3.

TABLE 3. Transmissivities and Permeabilities

Well	Location	Transmissivity m^2/day	Thickness m	Permeability m/day
STW-2	Maheshpur	621 (329)	5.2	119.4
STW-4	Phulbari	1139 (4833)	14.7	77.5
STW-5	Lakhanpur	601	12.1	49.7
STW-7	Kankai	1068	14.1	75.7
STW-8	Gwaldubba	294 (525)	9.1	32.3
STW-11	Buttabari	1005 (654)	9.8	102.6
STW-12	Satashi	588 (515)	11.9	49.4
STW-14	Sangambasti	178	5.8	30.7
STW-15	Panchgachhi	811	8.4	96.5
STW-16	Ghailadubba	280	13.1	21.3
STW-17	Satigatta	211	9.0	23.4
STW-19	Goldhap-4	445	15.8	28.2
PRW-1	Dasaharatpur	527		
PRW-2	Pathariya	453		
PRW-3	Topgacchi-3	380		
PRW-4	Gaurigung	909 (1642)		
PRW-5	Dharampur	483 (99)		

Average: 600 m^2/day

The results are more or less expected, with some minor inconsistencies. Hydraulic conductivities, or permeabilities, about 20 m/day indicate fine to medium grained sand. Conductivities between 30 and 70 m/day are characteristic for medium to coarse grained sand. Higher than that indicates coarse sand with more or less gravel component. (Gravel itself does not contribute too much to overall permeability. Coarse sand and gravel may have about the same value of permeability.) The values above 100 m/day are exceptional indicating an excellent permeability and high development potential.

In the western side there is some ambiguity in interpretation. Project well Sitapuri, STW-6, which is not shown in Appendix 6 because its test was eliminated, was pump-tested for only 18 minutes. This was clearly insufficient. Its low transmissivity may be questioned so pumping test was discarded. Another well, Gwaldubba (STW-8) has only 3 m of gravel with sand, and the rest is sand fine to coarse. However one of its screens was completely misplaced, that is placed opposite clay (19.5-22.6 m). With a better well design this well would have produced higher transmissivity than reported 294 m^2/day. (Actually, the observation well nearby produced the transmissivity of 525 m^2/day, or twice higher than the pumped well itself. Thus, one may conclude that the western part of the district has at least 500-600 m^2/day from upper 30 meters.

In the north, the well STW-13 (Bareghare), which has one of the best lithologies, with 22.6 m of gravel out of 25.9 drilled meters, did not produce pump-test results due to high fluctuation of water level during pumping. Considering that two wells south of this well have transmissivities of 1005 and 1068 m^2/day, that is the best in the district, one may extend the zone of high transmissivity to the Bareghare well as well. Anyway, the pumping test at Bareghare should be repeated.

In the very center of the district is a well, STW-4 Phulbari, located near the eastern bank of the Kankai River. It displays the highest transmissivity of all tested wells, 1139 m^2/day. It was drilled entirely through gravel and sand. However, another well in the same central part 5 km to the north, Ghailadubba (STW-8), also encountered plenty of gravel (24.4 m), but the test produced a mediocre transmissivity of only 280 m^2/day. Careful interpretation of the test may indicate much higher transmissivity had the test been run correctly. The slope of test points in first 20 minutes indicate the transmissivity of over 1500 m^2/day. There is a sharp break of slope after 20 minutes, indicating probably a higher pumping rate than reported. The test results are not reliable and the convergence of transmissivity contour lines toward low transmissivity in Ghailadubba (see Appendix 6) should be better eliminated. It appears that the whole central part between Phulbari-Kankai-Bareghare-Buttabari has the transmissivity above 1000 m^2/day.

The eastern part of the district shows constantly low transmissivity. The well STW-17 at Satigatta at north-east has plenty of gravel (9.0 m within screened portion of the well, and 21 m all together). Evidently the upper 12 m of gravel have been cut off by clay seal from the rest of aquifer. Even the well Sangambasti (STW-14) drilled in the south-east corner should have much higher transmissivity than reported 178 m^2/day. Only the well STW-2 at Maheshpur may have lower transmissivity than the rest of district, with only 5.2 meters of sand with some gravel.

Such distribution of transmissivities in shallow aquifer of Jhapa district leads us to declare the shallow aquifer of Jhapa as very good for shallow aquifer development in most of places.

Transmissivities are high enough to suggest irrigation on a moderate scale sustained entirely by shallow aquifer. Withe drilling going somewhat deeper, say to 60-70 m, large-scale irrigation may also be feasible.

Since only five observation wells were available during testing, only five values of storage coefficient, or effective porosity in the case of unconfined aquifer, were obtained. Fortunately all are acceptable. The storage parameters are shown in Table 4.

TABLE 4. Storage Coefficients in Jhapa District

Well	Location	Storage Coefficient
STW-2	Maheshpur	0.0003
STW-4	Phulbari	0.0019
STW-8	Gwaldubba	0.00009
STW-11	Buttabari	0.018

The first three values would be representative for confined aquifers, while the fourth value is more characteristical for semiconfined to unconfined aquifer. It is an established fact that in semiconfined aquifers the testing should continue for many hours and days to produce a meaningful value of storage coefficient. These parameters are only good indication of the type of shallow aquifer, which, in this case, is mostly semiconfined.

4. FLUCTUATIONS OF SHALLOW WATER TABLE

4.1. Monitoring Network

Jhapa district is well covered with water level observation network, for clarity called monitoring network. As mentioned earlier first measurements of depth to water started in May 1987 by GWRDB observers for the GDC "Study of Groundwater Development Strategies for Irrigation in the Terai". More than 120 dug and shallow wells were included into the network. Water level observations in many of these dug and shallow wells continued beyond the end of the GDC study. At least in 20 wells there is a more or less continuous record until August 1989 (see Appendices 10). Locations of this early network are shown in Appendix 2 with star. Gradually some of these wells were abandoned for various reasons, mostly subjective. In December 1989 alltogether 32 wells have been monitored, out of which 17 are private hand pump and dug wells, and 15 are "project" shallow tube wells. Since by December 1989 18 project wells have been drilled, three wells are not under observation. One of these three is damaged, and for other two there is no explanation!

Since 21 wells drilled under this project were completed by February 1990, there is no need to monitor levels in dug wells or in shallow wells with unknown lithology. The number of 18 wells is believed adequate for Jhapa district. It is regretful that some of project wells drilled in early 1989 were not included into the network immediately after their completion. As of July 1989 all project wells are under monthly observation. Yet for the sake of continuity and comparison it is suggested that for some time, a year or two, eight existing wells are retained in the network: Sonapur (north-west), Bhalugaon (central-west), Tulachan (south- center), Bavantoli (south-east), Rajgadh (south-center), Amarbasti (south-east), Chandragadhi (east), and Duwagadhi (north-east). Thus the monitoring network would consist of 18 new wells and 8 existing, or a total of 26 wells.

4.2. Rainfall in Jhapa District in 1987-89 Correlated With Water Levels

Since most of recharge that reaches shallow aquifer of Jhapa or any district of Terai comes directly from rainfall, it is important to correlate the rise of shallow levels with rainfall in the monsoon season. For this reason the project attempts to obtain timely rainfall records from nearby, representative, rainfall stations. For Jhapa, the representative station is in Kankai. Thanks to understanding of the HMG's Department of Meteorology, the project is getting "raw" data in time to include them into the report. The data are used only for technical reasons, for producing meaningful comparison between selected hydrographs and rainfall in the same period. The data are used with an understanding that they have not yet been cleared by HMG's Department of Meteorology and released for public use.

Three wells Sonapur (north-west), Goldhap (center-east) and Ghodmara (south-east) are chosen for the comparison of water levels with the rainfall. The hydrographs produced in Appendix 7 indicate the following.

(a) The rise of levels in 1987 started in March following the first pre-monsoon rains (in March, April and May a total of 326.5 mm of rain fell in Kankai). Since the levels in March and April of 1987 had not been observed, the minimum level on the record, although not necessarily the real annual minimum, is in the month of May. (The minimum level means the maximum depth of water table from the land surface.)

(b) The rainfall in 1988 was again early, that is in April when 143 mm of rain fell, followed by 220 mm of rain in May. The total rainfall during March, April and May is 442.8 mm out of 2538.8 mm (see Appendix 7. and table here below). This early rainfall has an immediate response in the rise of shallow water levels. There is no any significant time lag in water level response. As a consequence, in 1988 the minimum water levels were in March.

(c) In 1989 significant rainfall starts in May with 420.7 mm, with negligible rainfall in March and April. In this year the minimum water levels are as expected, in May. Extremely high rainfall in September 1989 did not result in excessive rise of water table beyond the month of August.

(d) While minimum water levels are normally in any year in every well all over the area always in the same month, whether March or May, this is not true for maximum levels (or closest to land surface). Maximum levels may be in the middle of the monsoon season (say, July), although, normally they tend to be in September-October period. The heavy monsoon rain is a local phenomenon, and depending on antecedent rain (or soil moisture conditions), it may or may not contribute much to shallow aquifer recharge. Thus the maximum level in a well depends on location of that well, its lithology, and rainfall in preceding months. It appears that maximum water levels are most often in September, with some deviations. For example in Sonapur in 1987 the maximum is in July, again in Sonapur in 1988 the maximum is in October. In Ghodmara, in 1988 the level is at the surface from July through September. In the same well, in 1989 the maximum is also in September. In that sourthern part, near the Indian border, water head (not table) is normally above land surface at the end of the monsoon season. Water level in the centrally located well Goldhap reaches almost to the surface at the end of monsoons in 1987, 1988, and 1989. Such high levels (at or above land surface) are a consequence of extremely wet years (1987, 1988, 1989). Without knowing exact lithology of the surface layer through which water table moves, it is difficult to explain why the maximum in Sonapur in 1988 was in October.

(e) The same rainfall does not produce everywhere the same amount of water level rise. The rise is a consequence of several factors: (i) actual amount of local rainfall, (ii) permeability and infiltration capacity of near-the-surface layer, (iii) lithology of layer through which water table fluctuates. Table 3 shows monthly rainfall in Kankai in 1987-89 period.

Fig. 5.1

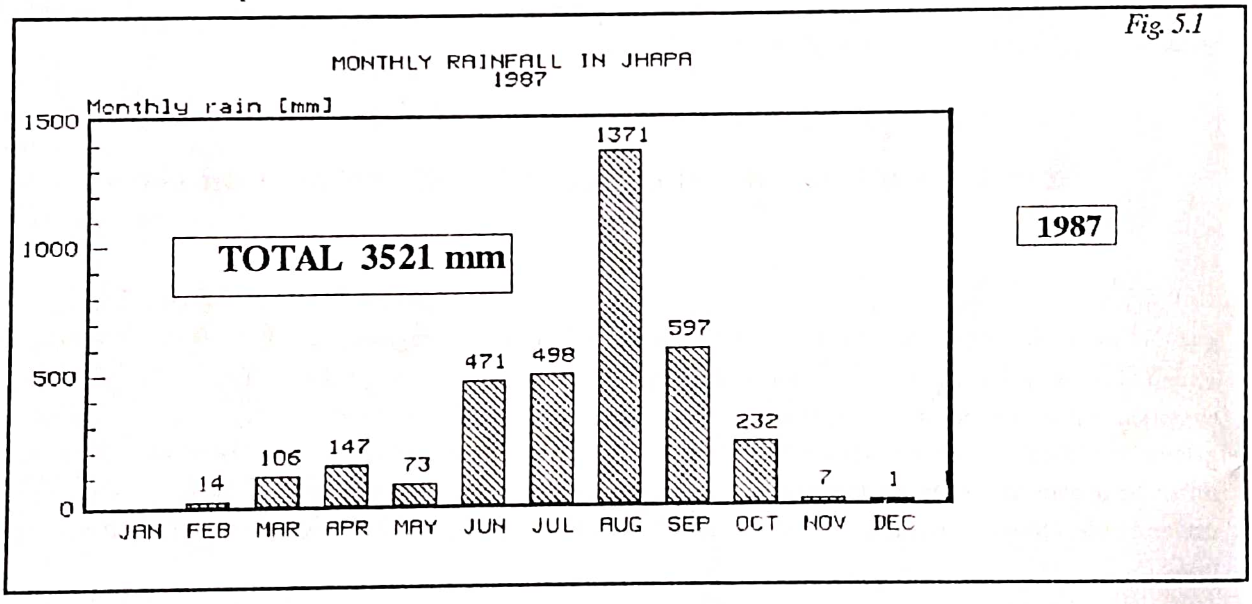


TABLE 5. Rainfall at Kankai Station

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1987	0	14	107	148	74	472	499	1371	597	232	7	0	3521
1988	26	28	80	143	220	126	798	696	289	98	32	3	2539
1989	18	23	5	4	421	558	784	637	1141	99	45	3	3737

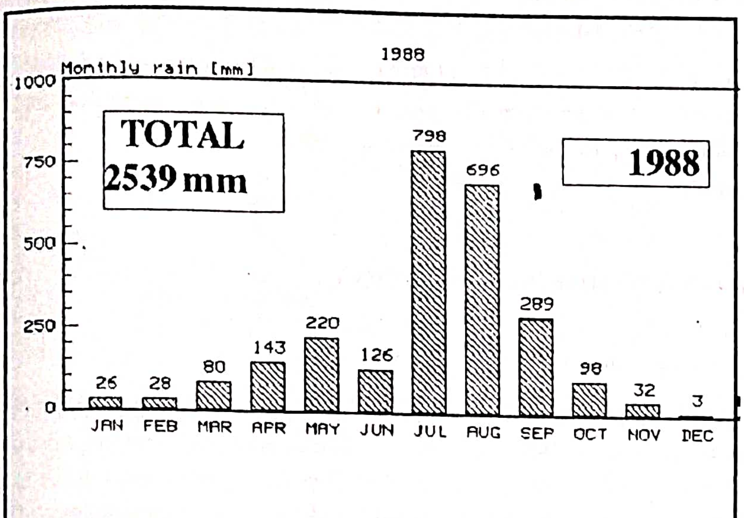


Fig. 5.2

All three years, 1987 through 1988 are the years with rainfall above long-term average: (a) in 1987 due to excessive August rainfall, which, in terms of ground water recharge, is partly rejected; (b) in 1988 due to high pre-monsoon rains in April, May and June; (c) in 1989, on account of extreme September rain, which is also partly rejected in terms of ground water recharge. The computation of water balance in Chapter 5 shall assume conservative values, which are much lower than rainfall in 1987- 89: 1800 mm for Jhapa, 2000 mm for near-the-hills areas. In conjunction with analysis of hydrographs at individual wells as shown in Appendices 10, it is important to note rainfall in April and May 1988, and September 1989.

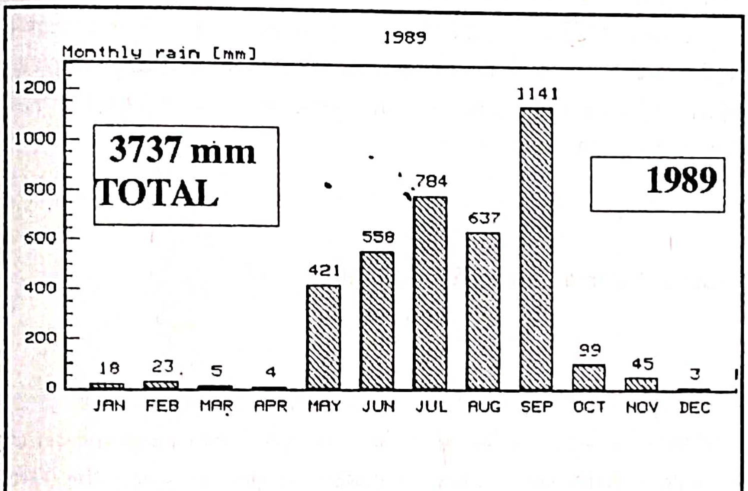


Fig. 5.3

4.3. Shallow Ground Water System Hydrodynamics

Hydrodynamics of the shallow ground water system of Jhapa district is presented in Appendices 8/1 through 8/7, and in Appendices 10. The group of Appendices 8 refers to the depth to water table from land surface in relative terms (pre-monsoon, post-monsoon, rise of levels in 1987, 1988). Similar maps have been prepared for Technical Report No. 2 on the basis of 1987 observations in early monitoring network (dug and ADBN shallow wells). An update of that report has been released by the project as Technical Report No. 13, which included the year 1988 and pre- monsoon period of 1989. (There will be one more update of the same set of maps near the end of the project, that will include only the seasons of 1988, 1989, and 1990, based on project wells.) The last two maps in Appendices 8 present water level contour maps in absolute terms, in elevations above mean sea level, for the month of May 1989 and September 1989. In 1989, these two maps correspond to the month of deepest water levels (pre-monsoon), and to the month in which water is the least deep in relation to the land surface. General observation for the month of May, of either 1988 or 1989, is that shallow aquifer levels in their lowest configuration are not that deep. The maximum depth is in Hukkagachhi (south-west), normally about 5 m below land surface (see Appendix 8/2, as well as maps in Appendices 8/2 and 8/5). In most of the district, in the month of May the levels are only between 2.5 and 3.5 m deep, which also indicates that the storage capacity of shallow aquifer is high preventing more decline of levels prior to onset of monsoons. Even at higher elevations (wells Anarmani, Sonapur), the maximum levels are less than 3.44 and 2.39 m below land surface.

In the month of generally highest levels, September 1988 (Appendix 8/3), levels are close to land surface. In almost whole district in September 1988 the levels were between 0.0 (Ghodmara) and 1.96 m (Amarbasti) from the land surface. Only in Hukagachhi levels in September are still about 3.22 m deep.

The fluctuation of levels is very moderate, from 0 m in the central part to over 3 m in western part. In the most of area the rise between May and September 1988 is of order of magnitude 0.3 to 1.86 m. This also indicates that the storage capacity of shallow aquifer is high, it is unconfined, its volume is uniformly distributed all over the district. Lithology of shallow aquifer as discussed in 3.1., transmissivity as discussed in 3.2., and rise and decline of water levels, all this points at rather high development potential of shallow aquifer in Jhapa.

4.4. Water Level Contour Maps in 1989

Only two maps are presented, one for May 1989 (Appendix 8/8), another for September 1989 (Appendix 8/9). The maps lack precision due to the fact that well points had not been surveyed. Altitudes are taken from topographic map at scale 1:62,500 and 1:125000. Contour maps clearly show the direction of ground water movement. It is, as expected, from north to south. The picture is about the same in May and in September, except that the whole flow net is higher in September compared to May for the amount of rise of water levels. (As demonstrated earlier, this rise is not too high, at most 1.5 meters in most of the district.) Contour lines are grouped closer one to the other in the north part. This is an indication of more water flowing through the northern and central belt than through southern, provided transmissivities are about the same or higher in the north. On the other hand, if the same amount of water would be flowing, than steeper gradient (which is indicated by denser grouping of contour lines) would mean less transmisisivity in the north which is not the case. Thus a plausible explanation of such a contour map is the following. More water flows in the north, from Bhabar zone toward south. When land surface topography changes, somewhere near the center of the district, water cannot flow further, it emerges at the surface or near it and evaporates. Water logging may occur in some places in September.

4.5. Fluctuation of Levels in Individual Wells

Hydrographs at 17 selected shallow wells are appended to this report as Appendices 10. Locations of these wells are shown in Appendix 9. None of project wells could be included at this time since the observation started too late, in spring 1989. However, these 17 wells provide for continuity. They are well spread all over the district. as shown in Appendix 8/10. The only missing continuous record is in the very center of the area, among wells Sonapur, Bhalugaon, Bansbari, Gauradaha, Jurapani. Likewise the record is missing in the area north of the Mahendra highway. In table 6 only maximum and minimum depths to water table shall be presented, along with maximum fluctuation in the whole period of observation. The fluctuation does not necessarily correspond to the" rise of levels between May and September", since in some localities neither minimum corresponds to May nor maximum to September.

TABLE 6. Fluctuation of Water in Shallow Wells (1988)

Well	Maximum Depth (m)	Minimum Depth (m)	Fluctuation (m)
Sonapur	2.39	1.72	0.67
Gauradaha	3.22	1.72	1.5
Jurapani	3.2	0.95	2.25
Hukagachhi	5.08	3.22	1.86
Bansbari	2.39	0.02	2.37
Bhalugaon	2.99	1.23	1.76

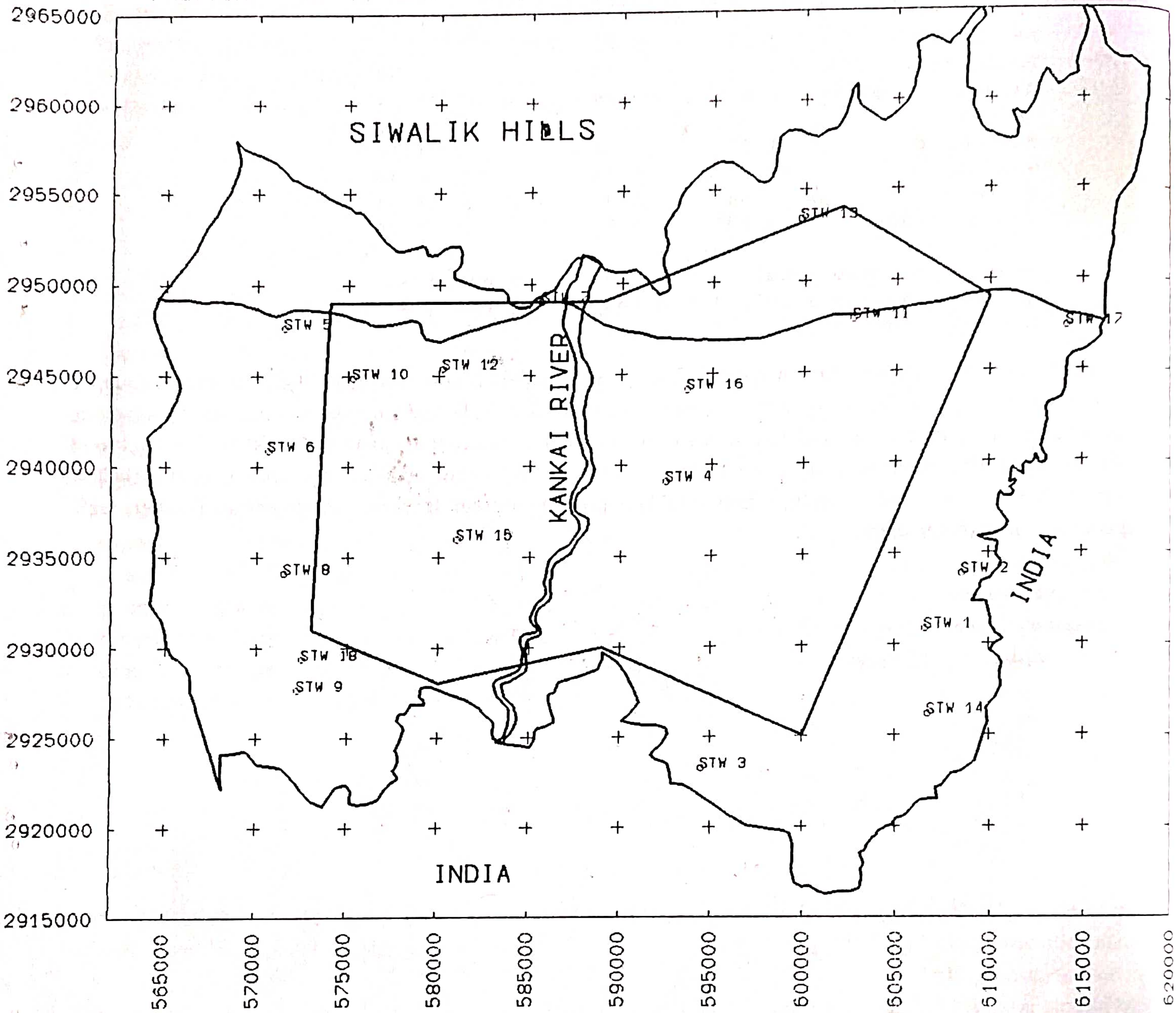
Gwaladhhuba	1.44	0.72	0.72
Dangibari	2.02	0.23	1.79
Ghodmarai	1.65	0.0	1.65
Bavantoli	2.21	0.21	2.00
Phulbari	2.34	0.79	1.55
Rajgadh	2.13	0.34	1.79
Amarbasti	4.33	1.96	2.37
Maheshpur	1.68	0.58	1.10
Goldhap	0.41	0.11	0.30
Anarmani	3.44	1.9	1.54
Chandragadhi	3.35	0.59	2.76

Average minimum level: 2.6 m below land surface
Average maximum level: 1.0 m below land surface
Average fluctuation: 1.6 m

It is very important to note that in many wells the rise of levels in March and April 1988 is direct consequence of unexpected high rainfall in these two months. This is evident in wells Goldhap, Sonapur and Ghadamara, Gauradaha, Jurapani, Hukagachhi, Bansbari and in other wells, in which the minimum in 1988 was in March, and the rise in April was 0.5 m or more. This also speaks in favor of suggesting high development potential of shallow aquifer. The recharge after March (80 mm) and April rainfall (143 mm) is almost instantaneous. The time lag is probably less than one month.

JHAPA DISTRICT

FEASIBLE AREA FOR SHALLOW AQUIFER DEVELOPMENT



APPENDIX 11

5. ASSESSMENT OF WATER RECHARGE AND DISCHARGE

5.1. Preliminary Assessment from Basic Documentation

The following may be concluded about recharge and discharge of the shallow ground water system in Jhapa district. The conclusions are drawn on the basis of information presented so far.

(1) The recharge comes mostly from local infiltration of rainfall. There are some zones in which extensive clay layer separates the first permeable layer from the land surface, preventing direct recharge from rainfall or surface water. Out of 37 wells in only 3 wells permeable layers come all the way to the ground surface. These wells are STW-3 (Gharebari), STW-10 (Keradhap) and STW-15 (Panchgachhi), with thickness of surface sand-and-gravel layer of 9.5, 1.5, and 15 m, respectively. Remaining 31 wells contain more or less impermeable clay and sandy clay, with an average thickness of about 4 m. According to such analysis, the land surface in the northern part appears to be relatively more permeable than the area in the south. However, an extensive clay layer, which can make the surface almost impermeable to any recharge reaching water table, may be present in about 60 % of the whole area. When each of these wells is located on the map, it becomes clear that impermeable surface is in the Hukkagachhi, Maheshpur, Sangambasti area, that is in southwest and in southeast. Thus, using the location of such wells as an indicator, one may accept that about 40% of the total area is permeable and 60% impermeable. Of course, this analysis holds as much as one trusts the lithological interpretation of local driller.

(2) The Bhabar zone is very extensive in Jhapa district. Reportedly it occupies more than 100 km2, although some sources estimate it at more than 250 km^2. Duba (1982) calculated the recharge to shallow aquifers. He distinguished between Bhabar zone and non-Bhabar. For Mechi zone, he came up with 30% of annual rainfall reaching shallow aquifer for non-Bhabar, and 39.3% for Bhabar sediments.

(3) The calculation of recharge shall be made with conservative values of rainfall of 2000 mm for Kankai and upper parts of the district, and 1800 for the lower part of the district. This is based on the fact that a part of extreme rain in monsoon season is rejected by soils and cannot infiltrate to become ground water. This is especially true for the month of August which is preceded by two rainy months after which soil moisture is above its infiltration capacity. With such conservative estimate of rainfall, the calculation may proceed as follows:

40% of area is permeable: 0.4 x 1716 km^2 = 686.4 km^2 (permeable)
100 km^2 is Bhabar, 586 km^2 is non-Bhabar
Recharge in Bhabar Zone:
100km^2 * 10^6 m^2/km^2 * 2.0 m/yr * 0.393 = 78.6 MCM (million cubic meters)
Recharge in Non-Bhabar zone:
586km^2 * 10^6 m^2/km^2 * 1.8 m/yr * 0.30 = 316.4 MCM (Million cubic meters)
TOTAL RECHARGE: = 395 MCM (Million cubic meters)

This is a tremendous amount of water that may eventually reach the aquifer. However, other evidence in this project's evaluation of potential recharge to shallow aquifer, notably by means of mathematical models, indicates that the percentage of recharge as estimated by Duba is too high. More conservative values should be used, for example 30% for Bhabar, but 20% for the rest of area. In this case, the Bhabar recharge could be as high as 60 MCM, and non-Bhabar recharge 211 MCM, or a total of about 271 MCM, which is still a very high potential.

(4) Water level contour maps (Appendices 8/8 and 8/9) indicate the discharge towards south, i.e. to neighboring India. The volume of outflow is quantified in the following way. An average transmissivity of shallow aquifer in the very south is about 500 m^2/day (see Appendix 6). The total length of the Nepal-India border between the rivers that make the Jhapa district boundary is about 40 km. The gradient of flow appears to be very mild in the south, five meters per three kilometer, or 0.00167. With such parameters the calculation is as follows:

$$500 * 40{,}000 * 0.00167 * 365 = \mathbf{12.2\ MCM}$$

Even if the gradient of the central part is taken into calculation, that is of 10 meters per 3.5 km, or 0.0028, still the total volume of outflow is very small, **16.8 MCM.**

There is a gross debalance between recharge and discharge, if and when only the outflow into India is taken as discharge. One glance at maps of depths to water table in either May or September points at areas in which water table is constantly close to land surface. The whole eastern part of the district has water levels within 2.0 meters from land surface in May 1988 (Appendix 8/2), and almost the whole district has water levels less than 0.5 to 1.5 m deep in September 1988 (Appendix 8/3).

The clear answer is that evaporation process must be a very strong mechanism for withdrawing shallow water. To demonstrate the importance of evaporation of water directly from water table the following calculation will suffice.

If throughout the year an average daily potential evaporation rate of 5 mm is taken (in Bhairawa it varies from 2.1 mm in January to 8.5 mm in May), and water level on average is at 1.0 m below land surface (in eastern part), then from one square kilometer can evaporate about 2000 m3/day when evaporation rate drops from 100% at free water (at land surface) to 40% at 1.0 m depth:

$$0.005\ \text{m/day} * 0.4 * 1{,}000{,}000\ \text{m}^2 = 2{,}000\ \text{m}^3\text{/day/km}^2$$

This is equivalent to about 0.73 MCM from one square kilometer. If 310 km^2 would have the same conditions, the total evaporation from that area would be equal to all recharge from rainfall, that is 271 MCM. Evidently this is much higher than outflow into India.

To conclude, the shallow ground water system of Jhapa district has very high development potential. Its lithology is favorable, hydrogeological characteristics reflected in transmissivity and hydraulic conductivity are likewise favorable. The recharge, taken as a conservative value, could be as high as 271 MCM per year. Out of this very little is lost through natural down- gradient outflow toward south, that is to India. By far the greatest percentage of recharge and natural flow is intercepted by evaporation and lost. Large-scale shallow ground water development is both feasible and beneficial.

Intensive abstraction of shallow water shall lower water table to depths from which there will be no evaporation. Water logging, which may happen in peak monsoon months at present, shall be prevented because water levels shall be deep enough to leave above an unsaturated zone capable of accepting additional rain water.

If the recharge values are not overestimated, at least one half of 271 MCM could be salvaged and abstracted through a system of carefully located wells. With an average agricultural demand of about 1 l/sec over 100 days for one hectare, or 8640 m^3/ha, 135 MCM sustained yield would imply irrigation of about 15600 ha or 156 km^2, that is 15.6% of the total area of Jhapa declared as irrigable.

Without a mathematical model it is difficult to come to maximum development potential figures. The recharge in Bhabar zone infiltrates partly to shallow aquifer, but also contributes to the recharge of deep aquifer. At present the deep aquifer is fully saturated and under piezometric head, but its annual exchange of water is minor compared to that of shallow aquifer. Water cannot evaporate from deep aquifer, it is not feeding rivers. Its water is flowing down-the-gradient toward south. With transmissivity of 1000 m^2/day, and gradient of 0.001, through the same outflow section of 40 km the volume of 14.6 MCM can flow annually. Although this is twice more than outflow through shallow aquifer, this is nevertheless a minor component of water balance of shallow aquifer, although it comes from the same 271 MCM of estimated recharge. Only when deep aquifer becomes subjected to heavy withdrawal, such as is the case of Bhairawa- Lumbini project in Rupandehi district, one may expect reversed picture.

On the basis of transmissivity values, lithology of shallow 30 meters, depth to water table in pre-monsoon season (maximum depth), and water table fluctuations, a tentative map illustrating the feasibility of shallow aquifer development has been constructed. The very favourable area covers mostly the central part of the district (about 840 km^2). However, with additional, correctly interpreted, pumping tests, there is a possibility of having this area extended, most notably in the north-western direction, all the way to the district border with Morang. The sketch of the most promising area is shown in Appendix 11.

5.2. Assessment of Water Balance by Mathematical Modeling

The volume of data appears to be sufficient to construct a preliminary model of Jhapa district. The missing information is in the north, above the highway. Likewise, unknown is the role of any river in the district. When designing the exploration program the project insisted on having one or more wells drilled very near the river (within 100 meters of non-flooded river bank). Thus a correlation of levels would have been established and the role of rivers evaluated. Also of great importance are correctly leveled wells. For modelling work, the precision of knowing water level in a well is at worst 0.5 m, considering the gradient of flow of 1 m per 1000 meters.

The model of Jhapa district may cover the district as shown in Appendix 12. It shall be oriented N-S, along rows, and W-E, along columns. In west-east direction the size shall be 54 km, i.e. from X coordinate 564000 to coordinate 618000. In north-south direction the size shall be 43 km, i.e. from Y coordinate 2916000 to 2959000. The total network shall be 54x43 uniform square cells of 1 km^2 each, that is the total model area shall be 2322 cells or square kilometers.

The model boundaries are two artificial and two natural. One of natural boundaries is in the north, where more or less impermeable foothills of the Siwalik range enclose the Terai portion of the district. Yet, even there should be boundary conditions such as inflow through river beds or as underflow of ground water from Siwalik hills. Likewise, the eastern boundary of the district and the model is the Mechi River, or the state boundary between India and Nepal. It may be represented as constant-head boundary, or no-flow across boundary. Since the flow system is such that the major direction of flow is from north to south, the western boundary, which is artificial, should pose no major problem. This boundary shall be taken as the end of shallow aquifer, or beyond the district to the west the transmissivity shall be zero. This is also a no-flow across boundary, implying no exchange of shallow water between Jhapa and neighboring district of Morang. In essence this is true. The only really artificial boundary in this model shall be the southern boundary, i.e. the south border with India. Yet, there one may assign either constant heads following maps in Appendices 8/8 and 8/9, and hydrographs of nearest wells, or constant outflow using transmissivity and gradients from maps in Appendices 6 and 8/8, 8/9.

The basis for model calibration should be maps of water levels in absolute elevations as shown in Appendices 8/8 and 8/9. The calibration may start with steady state in pre- monsoon season of 1989, and continue with unsteady-state in monsoon season of 1989, that is from May through September 1989. Model verification may cover the period of one year from May 1989 through May 1990. The whole work may take one month including report writing. The target date for working on the model could be June-August 1990, when additional water level data shall become available until May 1990.

The model output shall be the following:

(a) Correct values of recharge from rainfall over permeable portion of the district.
(b) Modified distribution of hydrogeological parameters, such as transmissivity, effective porosity.
(c) Every component of water balance quantified, notably recharge and evaporation.
(d) Proposals for future extensive shallow aquifer development and impact of various pumping scenarios.

The final outcome of the model shall be the number, location, spacing, pumping rate of shallow wells in most promising areas, and the consequence of extensive pumping over a period of some 5 years.

6. CONCLUSIONS AND RECOMMENDATIONS

The objective of this report is to present technical information on the occurrence of shallow ground water in Jhapa district. The report is given in a form of Basic Documentation with some preliminary interpretation.

The basis for the report are newly drilled 21 shallow project wells and compiled data from 16 deep tube wells drilled by GWRDB in 1983-89. The report presents lithological data in 37 well logs and in 7 lithological cross sections including both shallow and deep wells. In addition to drilling, data from 16 pumping tests have been processed and interpreted. Both lithological data and pumping test information are processed by computer using UN/DTCD proprietary software.

The drilling started in March 1989, and terminated in July 1989 (additional 3 wells were drilled in January 1990). The total drilled metrage is 635 m, or an average well is 30.3 m deep. It is important to note that out of 21 wells only six were drilled by classical rotary drilling rig, using mud and drill rods. Fifteen wells were drilled by indigenous method, that is manually. Within shallow 31 meters of Jhapa aquifers, there is plenty of large-size gravel (pebble) which normally creates problems in drilling. Evidently the manual method of drilling as applied to Jhapa is successful in overcoming difficulties normally experienced when drilling through hard gravel and pebble. Average depth of manually drilled well is 29.4 m. The deepest manually-drilled well is 36.6 m deep. Actually six manual wells reached the depth greater than 34 m, in spite of gravel.

The quality of manually drilled wells, provided that they have reached the designed depth and are not terminated in permeable formation, is superior to bentonite-mud drilled wells. Pumping test results are more reliable, well losses are minor component of aquifer losses. Manually-drilled wells are also reported to be cheaper. The conclusion is that gravel and pebble shall create equal problems to manually as well as to rotary-rig drilled wells. If manual drilling is cheaper, if the driller can penetrate to 40 m depth, the preference should be given to manual method.

Out of 16 pumping tests, in only five pumping tests a nearby existing well was used as an observation well, providing for the possibility of evaluating storage coefficient or effective porosity of shallow aquifer in addition to its transmissivity. In five "project" wells pumping test has not been made either because of deep water level, sand entry into the well, or fluctuation of pump discharge. One or more test-pumped wells would be welcome between location Bareghare and Ghailadubba (see Appendix 1, central-north), near Hukagachhi (south-west), Sitapuri (west). The test at Ghailadubba in central-north should be repeated. The transmissivity of 280 m^2/day is not in line with the lithology at this site.

It is noted that some of wells are not properly constructed for testing with pump discharges of 10-15 l/sec. With casing diameter 100 mm, and open screen area about 15%, with pump discharge between 10 and 15 l/sec, the minimum length of well screen is about 8 m. This requirement is in line with recommendations for maximum or critical velocity of water entering the screen. When critical velocity is surpassed there is a danger of sand inflow, instability of gravel pack, and additional well losses may reduce overall efficiency of the well. This is interpreted in lower transmissivity during pump test than reported.

As a general conclusion both shallow and deep aquifers are present in Jhapa district in every part of the district. The percentage of permeable layers in 21 shallow project-drilled wells is about 58.9% (374 m of permeable sediments out of total 635 m drilled metrage). This is compared with similar percentages in other districts as follows. The highest percentage in all currently interpreted districts of the Terai under NEP/86/025 project is in Jhapa. The Jhapa shallow aquifer is closely followed by Sunsari (56%), Deukhuri (53%), Dang (48%), Nawalparasi (48%). Rautahat district with 39%, Morang with 38%, Kapilvastu with 32%, and Rupandehi with 30%, show much less permeable formations. Only these districts have been evaluated and reported until now. An average shallow well drilled by this project in Jhapa district would be 30.3 meters deep; it would have about 17.8 m of permeable and 12.5 m of impermeable layers, and would have an average screened interval 6.5 meters.

As a whole the shallow aquifer of Jhapa district has quite acceptable transmissivity, on average between 500 and 800 m^2/day. (This transmissivity would have even higher had the wells been properly constructed and developed.) The transmissivity is minimum (less than 300 m^2/day) in eastern part, near the Mechi River, and increases towards the central part where it reaches a maximum of about 1100 m^2/day. The transmissivity above 500 m^2/day is considered sufficient for water supply and small-scale irrigation. In parts with transmissivity above 1000 m^2/day (central) large-scale irrigation might be also feasible, provided levels are not too deep, what apparently they are not.

Jhapa district is well covered with water level observation network. The number of 18 wells is believed adequate for Jhapa district. It is regretful that some of project wells drilled in early 1989 were not included into the network immediately after their completion. As of July 1989 all but three project wells are under monthly observation. Yet for the sake of continuity and comparison it is suggested that for some time, a year or two, eight existing wells are retained in the network: Sonapur (north- west), Bhalugaon (central-west), Tulachan (south-center), Bavantoli (south-east), Rajgadh (south-center), Amarbasti (south- east), Chandragadhi (east), and Duwagadhi (north-east). Thus the monitoring network would consist of 18 new wells and 8 existing, or a total of 26 wells.

The evolution of shallow water levels depends heavily on rainfall. Each of the last three years was an extremely wet event. The annual rainfall in 1989, e.g. is about 37% above long-term annual average. Early pre-monsoon rainfall of 1987 and 1988 has had an immediate response in the rise of shallow water levels. There is no any significant time lag in water level response. As a consequence of about 443 mm of rain in the March-May 1988 period, the levels starting rising from March, and not from May as is the normal case.

While minimum water levels are normally in any year in every well all over the area always in the same month, whether March or May, this is not true for maximum levels (or closest to land surface). Maximum levels may be in the middle of the monsoon season (say, July), although, normally they tend to be in September-October period. The heavy monsoon rain is a local phenomenon, and depending on antecedent rain (or soil moisture conditions), it may or may not contribute much to shallow aquifer recharge. Thus the maximum level in a well depends on location of that well, its lithology, and rainfall in preceding months. It appears that maximum water levels are most often in September, with some deviations. It is important to note that heavy September rainfall in 1989 (1141 mm) did not produce any significant rise of water levels. The soil was fully saturated and almost all September rainfall is rejected.

The same rainfall does not produce everywhere the same amount of water level rise. The rise is a consequence of several factors: (i) actual amount of local rainfall, (ii) permeability and infiltration capacity of near-the-surface layer, (iii) lithology of layer through which water table fluctuates.

General observation for the month of May, either 1988 or 1989, is that shallow aquifer levels in their lowest configuration are not that deep. The maximum depth is in Hukkagachhi (south-west), normally about 5.0 m below land surface. In most of the district, in the month of May the levels are only between 2.5 and 3.5 m deep, which also indicates that the storage capacity of shallow aquifer is high preventing more decline of levels prior to onset of monsoons. In the month of generally highest levels, September, levels are close to land surface. In almost whole district in September 1988 the levels were between 0.0 m and 3.2 m from land surface. The fluctuation of levels is very moderate, from 1 m in the east central part to over 3 m in western and eastern part. In most of the area the rise between May and September 1989 is of order of magnitude 0.5 to 2.0 m. Lithology of shallow aquifer, its transmissivity, and the rise and decline of water levels, all this points at high development potential of shallow aquifer in Jhapa.

Most of the district has very favorable conditions for shallow ground water development. The minimum levels in May are not more than 4 to 5 m below land surface, the transmissivity is above 500 m^2/day, and the recharge from rainfall reaches the shallow aquifer almost instantaneously. If one has to select which area should be given preference, than it is the whole district area excluding eastern part, that is a stretch parallel to the Mechi River of some 5 kilometers, and a southwestern corner. The total area is about 35 km wide by 24 km high, that is it occupies about 840 km^2, or about 60% of the Terai portion of Jhapa district. The location of the most promising area is shown in Appendix 11. The rest of the district area should not be discarded either. As discussed earlier, its transmissivity is probably higher than 300 m^2/day everywhere, and with drilling to about 40 m another permeable layer could be screened producing enough water for small to medium scale irrigation. Water level contour maps constructed for the months of May and September 1989, respectively, clearly show the direction of ground water movement. It is, as expected, from north to south. The picture is about the same in May and in September, except that the whole flownet is higher in September compared to May for the amount of the rise of water levels. The following may be concluded about recharge and discharge of the shallow ground water system in Jhapa district. The conclusions are drawn on the basis of information presented so far.

(1) The recharge comes mostly from local infiltration of rainfall, wherever the surface is permeable. According to analysis of land-surface permeability, the land surface in the northern part appears to be relatively more permeable than the area in the south. One may accept that about 40% of the total area is permeable and 60% impermeable. Of course, this analysis holds as much as one trusts the lithological interpretation of local driller.

(2) The Bhabar zone is very extensive in Jhapa district. Reportedly it occupies more than 100 km^2.

(3) The calculation of recharge is made with conservative values of annual rainfall of 2000 mm for Kankai and upper parts of the district, and 1800 for the lower part of the district. This is based on the fact that a part of extreme rain in monsoon season is rejected by soils and cannot infiltrate to become ground water. This is especially true for the month of August which is preceded by two rainy months after which soil moisture is above its infiltration capacity. With such conservative estimate of rainfall, the calculation may proceed as follows: using Duba's recharge percentages of 39.3% for Bhabar zone and 30% for non- Bhabar, the overall annual recharge to shallow aquifer could be as high as 434 MCM (million cubic meters). This is a tremendous amount of water. However, other evidence in this project's evaluation of potential recharge to shallow aquifer, notably by means of mathematical models, indicates that the percentage of recharge as estimated by Duba is too high. More conservative values should be used, for example 30% for Bhabar, but 20% for the rest of area. In this case, the Bhabar recharge could be as high as **60 MCM**, and non-Bhabar recharge **211 MCM**, or a total of about **271 MCM**, which is still a very high potential.

(4) Water level contour maps (Appendices 8/8 and 8/9) indicate the discharge towards south, i.e. to neighboring India. The volume of outflow is quantified and shown to be about **12.2 MCM** across the length of about 40 km. Even when a steeper flow gradient of the central part is accepted, that is 0.0028, the total volume of outflow is still very small, **16.8 MCM**.

There is a gross debalance between recharge and discharge, if and when only the outflow into India is taken as discharge. Much stronger discharging process is trough the evaporation from shallow water table. In most of the area water levels are constantly, year throughout, within 3 meters from the land surface, that is within the evaporation reach. A semiquantitative analysis indicates that from one square kilometer about 0.73 MCM can evaporate under prevailing field conditions. In other words the **total recharge of about 271 MCM could be lost through evaporation from an area of only 371 km^2**. Evidently this is much higher than outflow into India.

To conclude, the shallow ground water system of Jhapa district has very high development potential. Its lithology is favorable, hydrogeological characteristics reflected in transmissivity and hydraulic conductivity are likewise favorable. The recharge, taken as a conservative value, could be as high as 271 MCM per year. Out of this very little (12 MCM) is lost through natural down-gradient outflow toward south, that is to India. By far the greatest percentage of recharge and natural flow is intercepted by evaporation and lost. Medium-scale shallow ground water development is both feasible and beneficial.

Intensive abstraction of shallow water shall lower water table to depths from which there will be no evaporation. Water logging, which may happen in peak monsoon months at present, shall be prevented because water levels shall be deep enough to leave above an unsaturated zone capable of accepting additional rain water.

If the recharge values are not overestimated, at least one half of 271 MCM could be salvaged and abstracted through a system of carefully located wells. With an average agricultural demand of about 1 l/sec over 100 days for one hectare, or 8640 m^3/ha, 135 MCM sustained yield would imply irrigation of about 15600 ha or 156 km^2, that is 15.6% of the total area of Jhapa declared as irrigable.

Without a mathematical model it is difficult to come to maximum development potential figures. The recharge in Bhabar zone infiltrates partly to shallow aquifer, but also contributes to the recharge of deep aquifer. At present the deep aquifer is fully saturated and under piezometric head, but its annual exchange of water is minor compared to that of shallow aquifer. Water cannot evaporate from deep aquifer, it is not feeding rivers. Its water is flowing down-the-gradient toward south. With transmissivity of 1000 m^2/day, and gradient of 0.001, through the same outflow section of 40 km the volume of 14.6 MCM can flow annually. This volume is nevertheless a minor component of water balance of shallow aquifer, although it comes from the same 271 MCM of estimated recharge. The volume of data appears to be sufficient to construct a preliminary model of Jhapa district. There is some missing information, which can be filled with either repeated or new test pumping. Also all wells and some river points must be leveled. For modelling work, the precision of knowing water level in a well is at worst 0.5 m, considering the gradient of flow of 1 m per 1000 meters. The role of any river in the district is unknown. The water balance presented before does not consider any exchange between shallow aquifer and rivers. The real development potential from shallow aquifer may be much higher if induced recharge from rivers is taken into consideration.

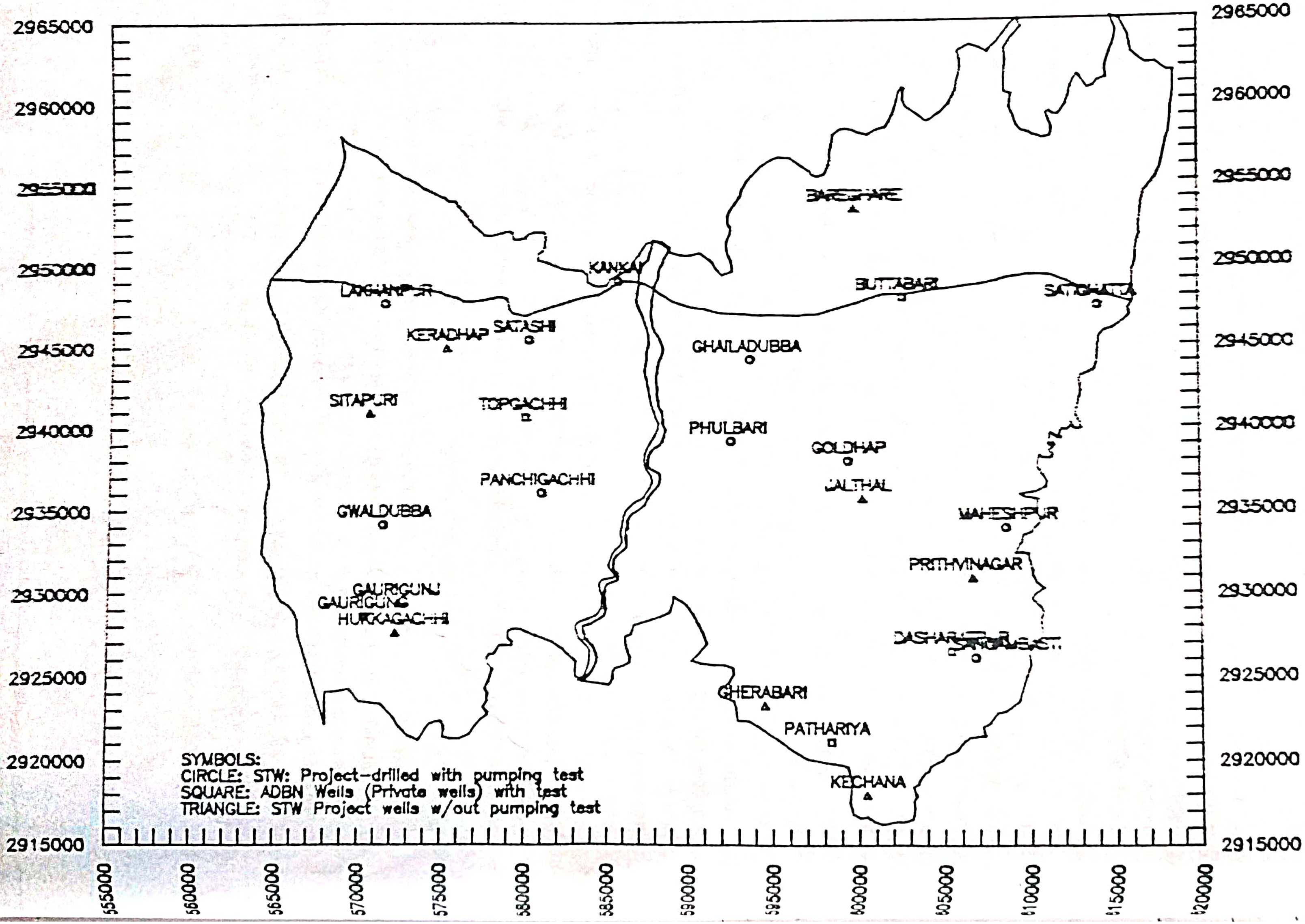
The model of Jhapa district may cover the district as shown in Appendix 11. The total network shall be 54x43 uniform square cells of 1 km^2 each, that is the total model area shall be 2322 cells or square kilometers. The model boundaries are natural (north, east), and artificial (west, south). In the north the shallow aquifer disappears. In the east the Mechi River makes a constant-head boundary. The boundary to the west shall be taken as the end of shallow aquifer, or beyond the district to the west the transmissivity shall be zero. This is also a no-flow across boundary, implying no exchange of shallow water between Jhapa and neighboring district of Morang. The only really artificial boundary in this model shall be the southern boundary, i.e. the south border with India. Yet, there one may assign either constant heads or constant outflow using data reported herein. The calibration may start with steady state in pre-monsoon season of 1989, and continue with unsteady-state in monsoon season of 1989, that is from May through September 1989. Model verification may cover the period of one year from May 1989 through May 1990. The whole work may take one month including report writing. The target date for working on the model could be June-August 1990, when additional water level data, until May 1990, shall become available.

The model output shall be the following:

(a) Correct values of recharge from rainfall over permeable portion of the district.
(b) Modified distribution of hydrogeological parameters, such as transmissivity, effective porosity.
(c) Every component of water balance quantified, notably recharge and evaporation.
(d) Proposals for future extensive shallow aquifer development and impact of various pumping scenarios.

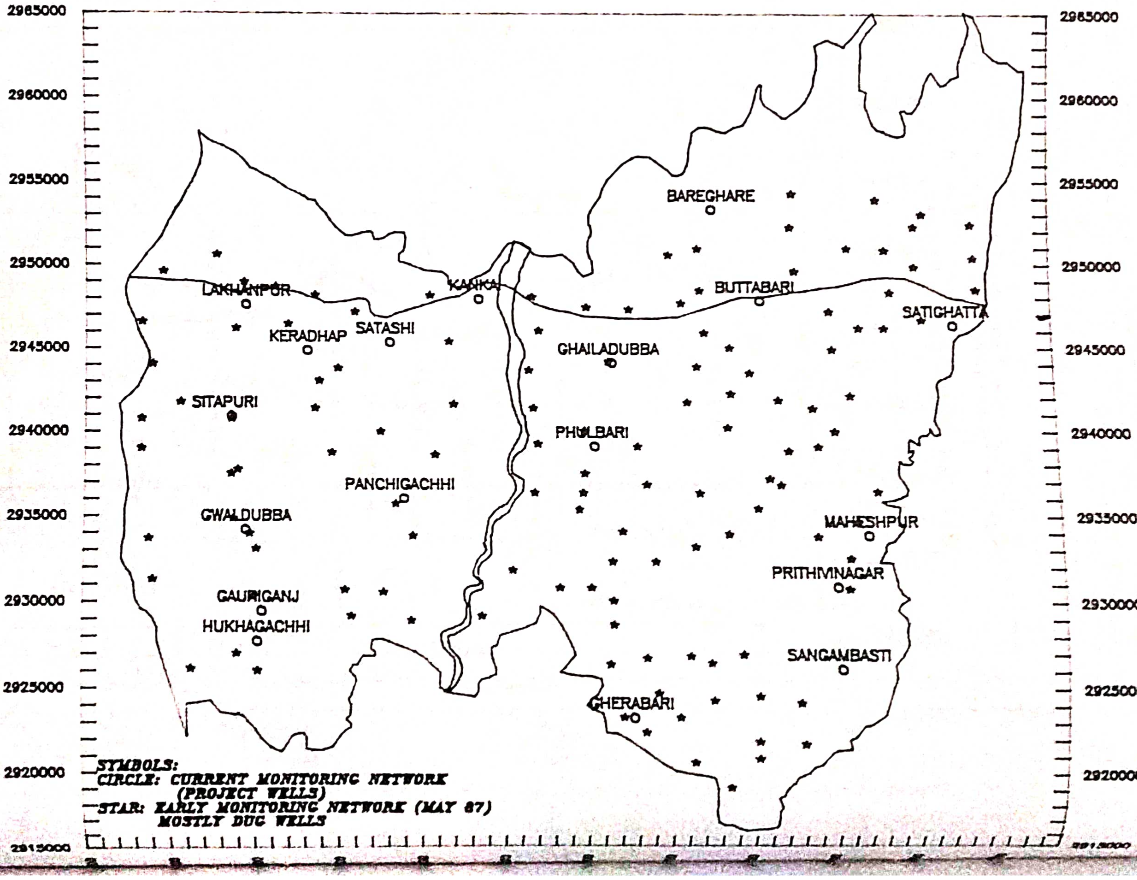
The final outcome of the model shall be the number, location, spacing, pumping rate of shallow wells in most promising areas, and the consequence of extensive pumping over a period of some 5 years.

JHAPA PROJECT WELLS AND PUMP-TESTED WELLS



APPENDIX 1

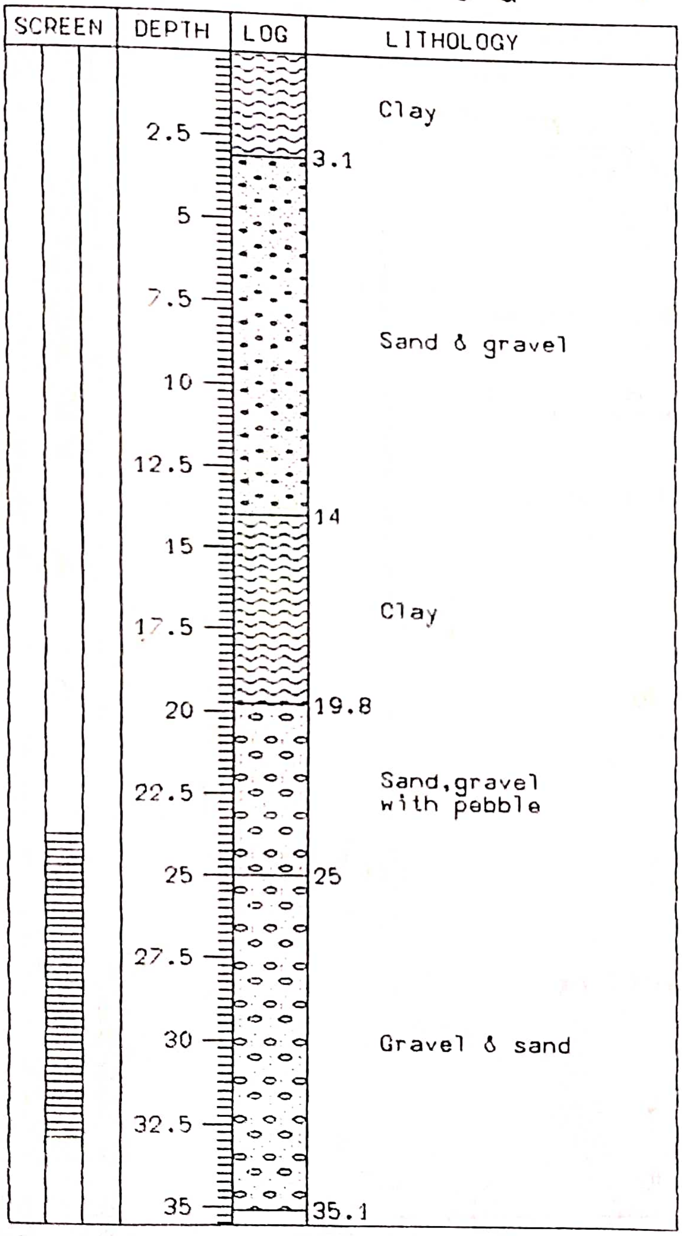
JHAPA MONITORING NETWORK LOCATION MAP



APPENDIX 2

Well No. STW 1	Location: PRITHVINAGAR
Elevation: 81	X = 606625 Y = 2930875
Method of Drilling: RIG	
Drilling Dates :	
Total Depth : 35.10	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 23.78 - 32.93 m DRILLED UNDER UNDP - PROJECT	

W E L L L O G

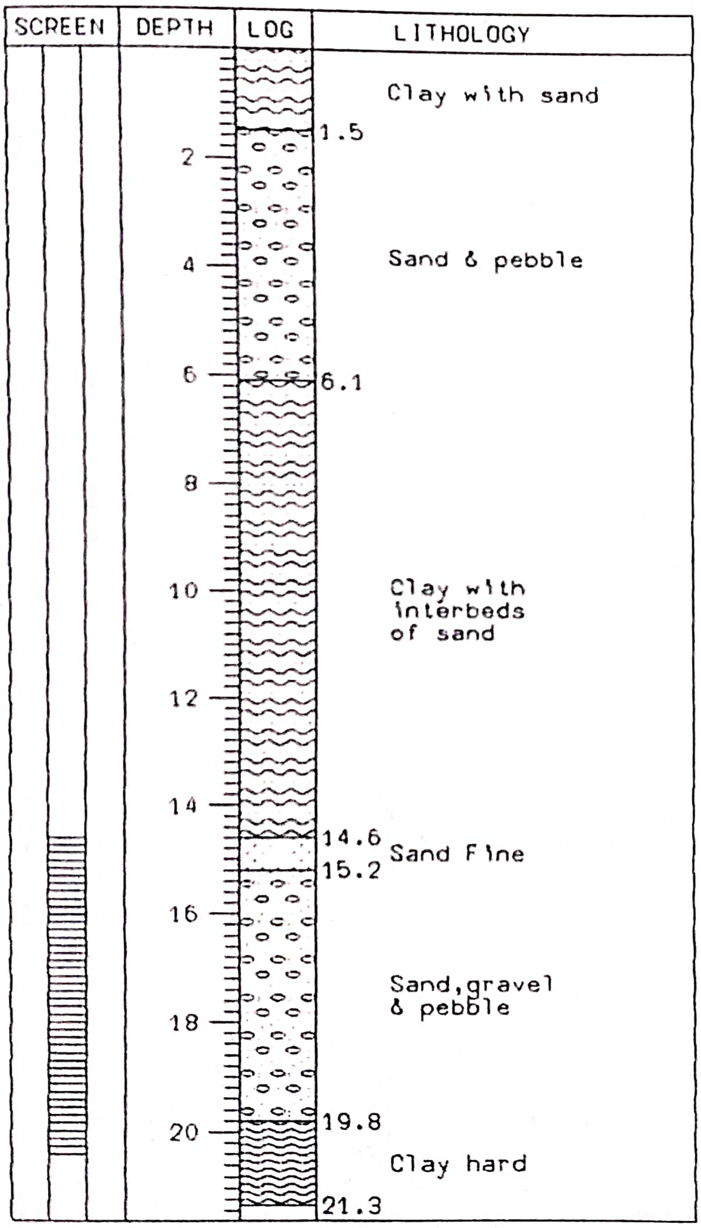


APPENDIX 3/1

GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW 2	Location: MAHESHPUR
Elevation: 81	X = 608593 Y = 2933875
Method of Drilling: MANUAL	
Drilling Dates : 5.3.1989 - 11.3.1989	
Total Depth : 21.30	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 14.6 - 20.4 m DRILLED UNDER UNDP PROJECT	

WELL LOG



PUMPING TEST

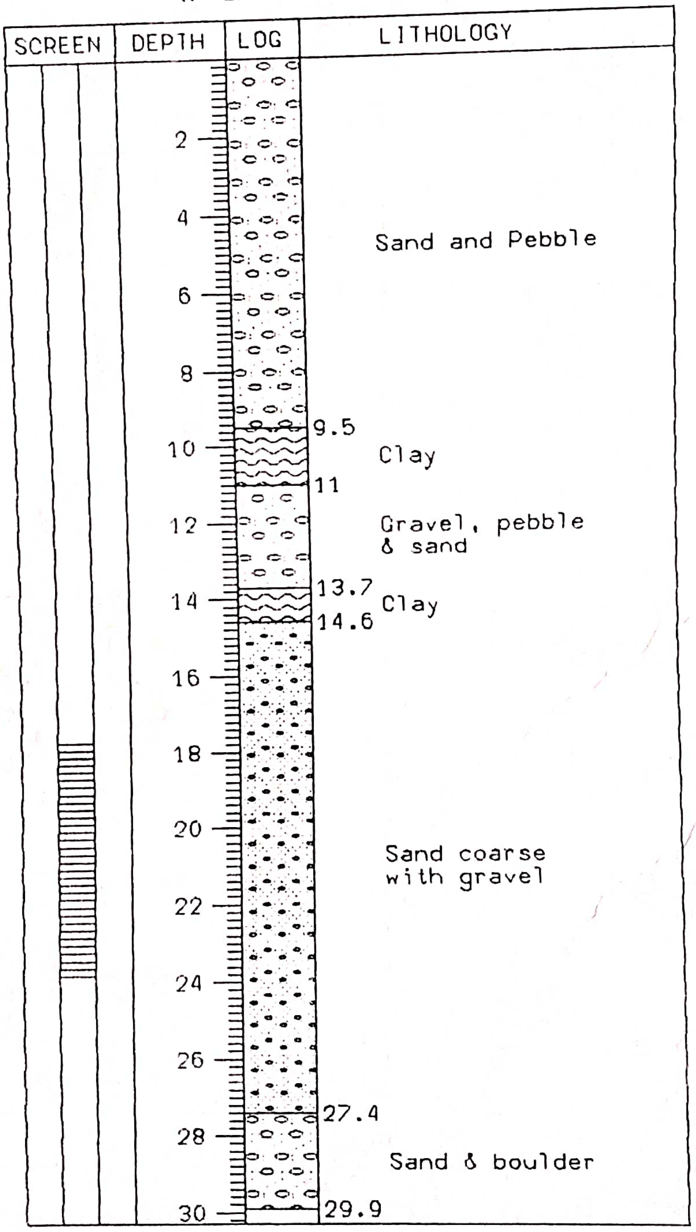
Date: 15.5.1989
Capacity: 7.5 l/s
Duration: 320 min
Transmiss.: 330 m2/day
Method : JACOB
Stor.Coeff.: 0.00031
SWL: 0.51 (B.GR.L)
DWL: 8.02 (B.GR.L)

APPENDIX 3/2

GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW 3	Location: GHERABARI
Elevation: 66	X = 594500 Y = 2923250
Method of Drilling: MANUAL	
Drilling Dates : 9.3.1989 - 15.3.1989	
Total Depth : 29.90	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 17.7 - 23.8 m DRILLED UNDER UNDP - PROJECT	

W E L L L O G

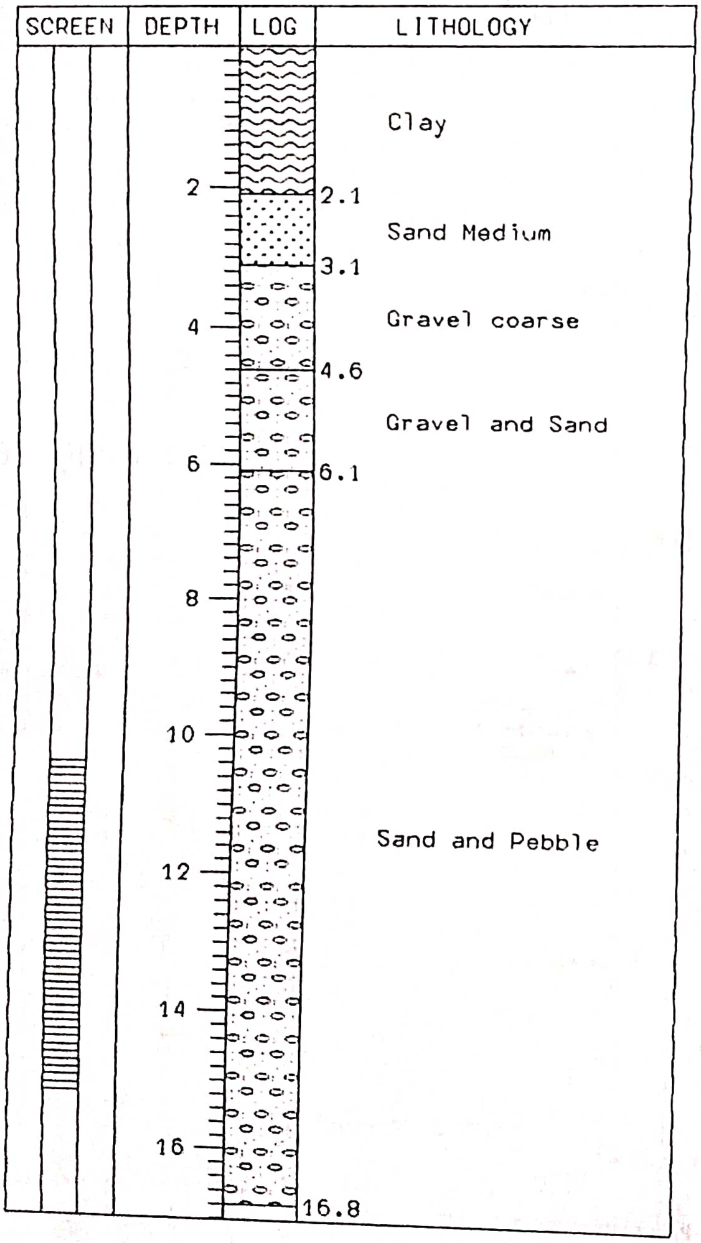


APPENDIX 3/3

GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW 4	Location: PHULBARI	
Elevation: 94	X = 592500	Y = 2939100
Method of Drilling: MANUAL		
Drilling Dates : 14.3.1989 - 18.3.1989		
Total Depth : 16.80		
Comments : SCREEN TYPE: SLOTTED TYPE SCREEN POSITION: 10.5 - 15.2 m DRILLED UNDER UNDP - PROJECT		

W E L L   L O G



PUMPING TEST

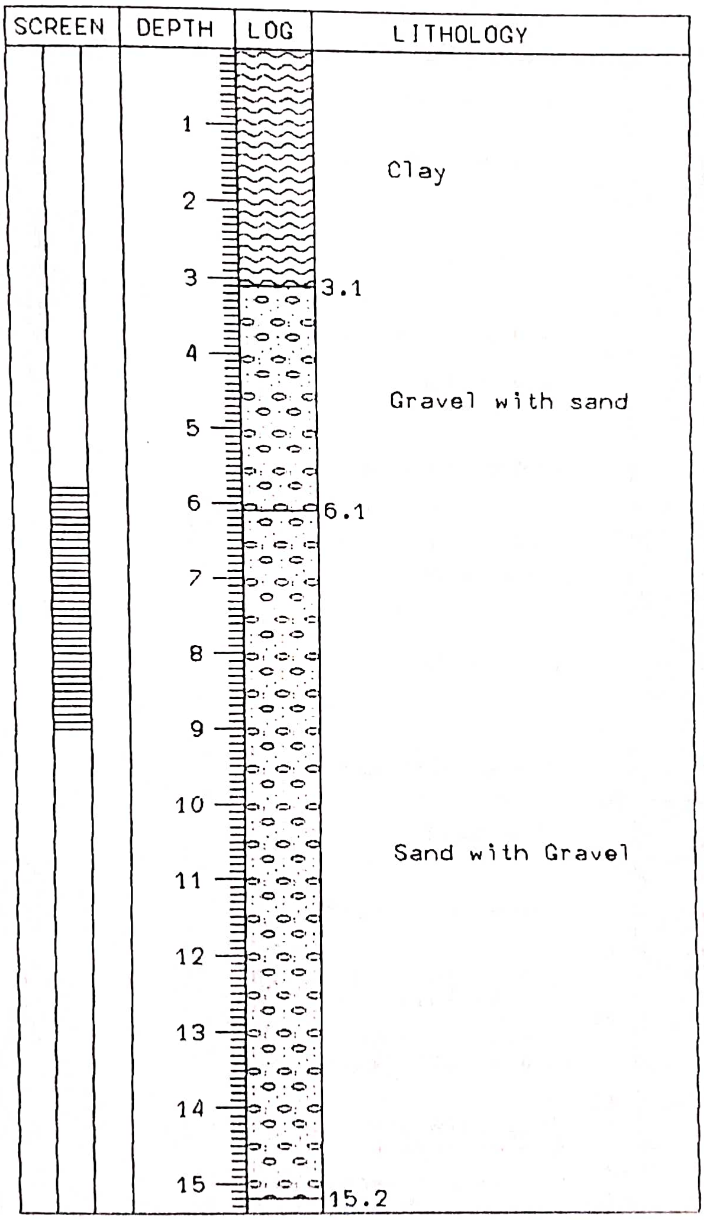
Date: 12.6.1989
Capacity: 15 l/s
Duration: 200 min
Transmiss.: 1200 m2/day
Method : THEIS
SWL: 2.32 (B.GR.L
DWL: 6.9 (B.GR.L

COMMENT:
Transmissivity in
observation well = 4800 m2/

APPENDIX 3/4

Well No. STW 5	Location: LAKHANPUR
Elevation: 121	X = 571500 Y = 2947625
Method of Drilling: MANUAL	
Drilling Dates : 7.6.1989 - 10.6.1989	
Total Depth : 15.20	
Comments : SCREEN TYPE: SLOTTED PYPE SCREEN POSITION: 5.8 - 9.0 m DRILLED UNDER UNDP - PROJECT	

WELL LOG

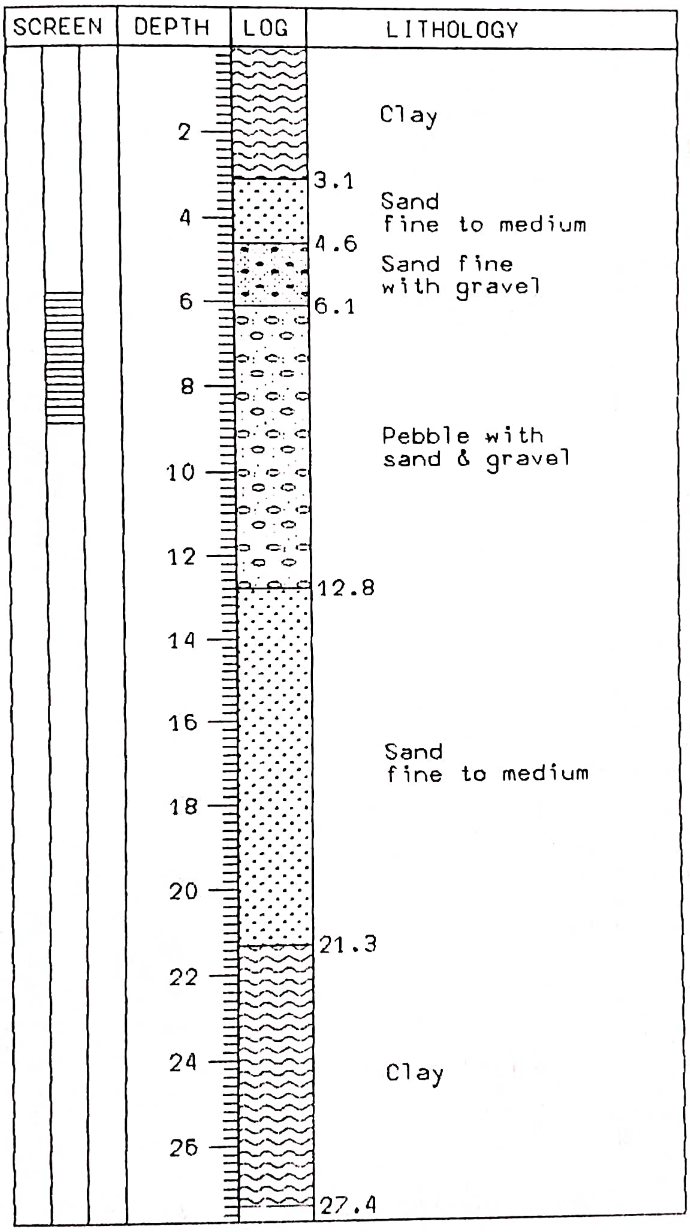


PUMPING TEST

Date: 12.6.1989
Capacity: 8.7 l/s
Duration: 120 min
Transmiss.: 600 m2/day
Method : THEIS
SWL: 2.56 (B.GR.L)
DWL: 8.51 (B.GR.L)

Well No. STW 6	Location: SITAPURI
Elevation: 101	X = 570625 Y = 2940875
Method of Drilling: MANUAL	
Drilling Dates : 9.6.1989 - 11.6.1989	
Total Depth : 27.40	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 5.8 - 8.8 m DRILLED UNDER UNDP - PROJECT	

W E L L   L O G

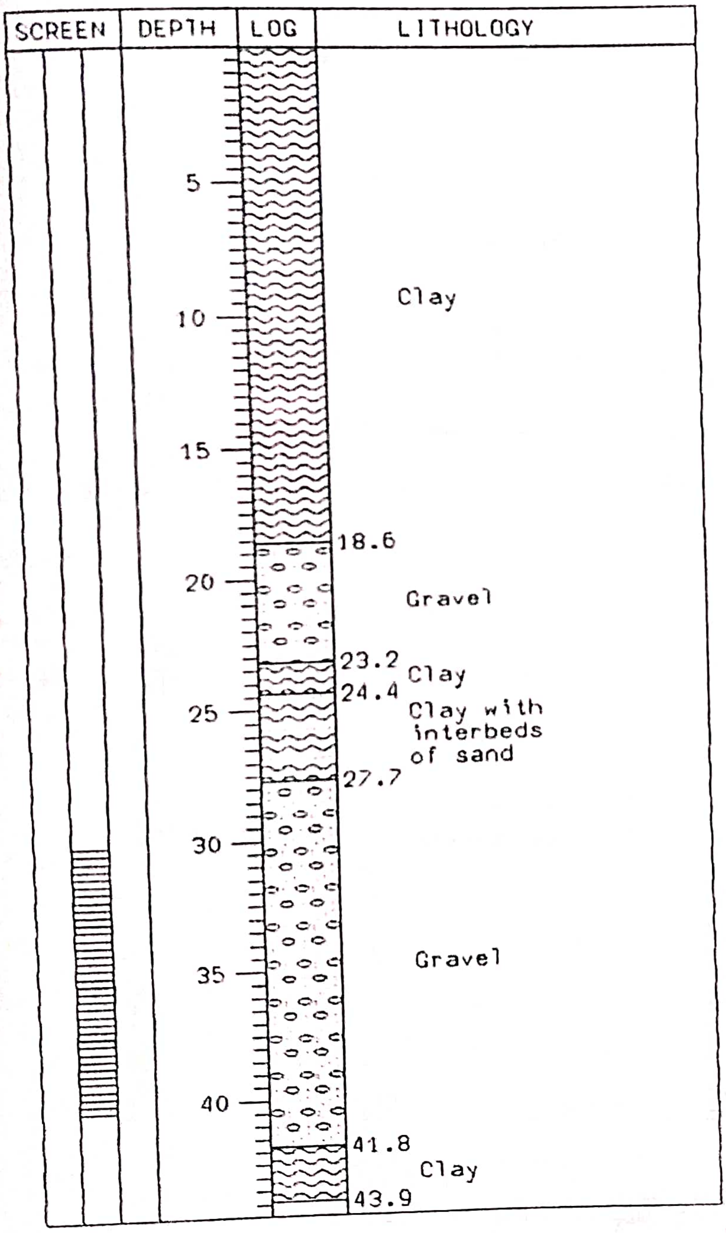


PUMPING TEST

SWL: 0.62 m (B.GR.L)

Well No. STW 7	Location: KANKAI
Elevation: 120	X = 585625 Y = 2949000
Method of Drilling: RIG	
Drilling Dates : 12.6.1989 - 13.6.1989	
Total Depth : 43.90	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 30.1 - 40.3 m DRILLED UNDER UNDP - PROJECT	

W E L L L O G

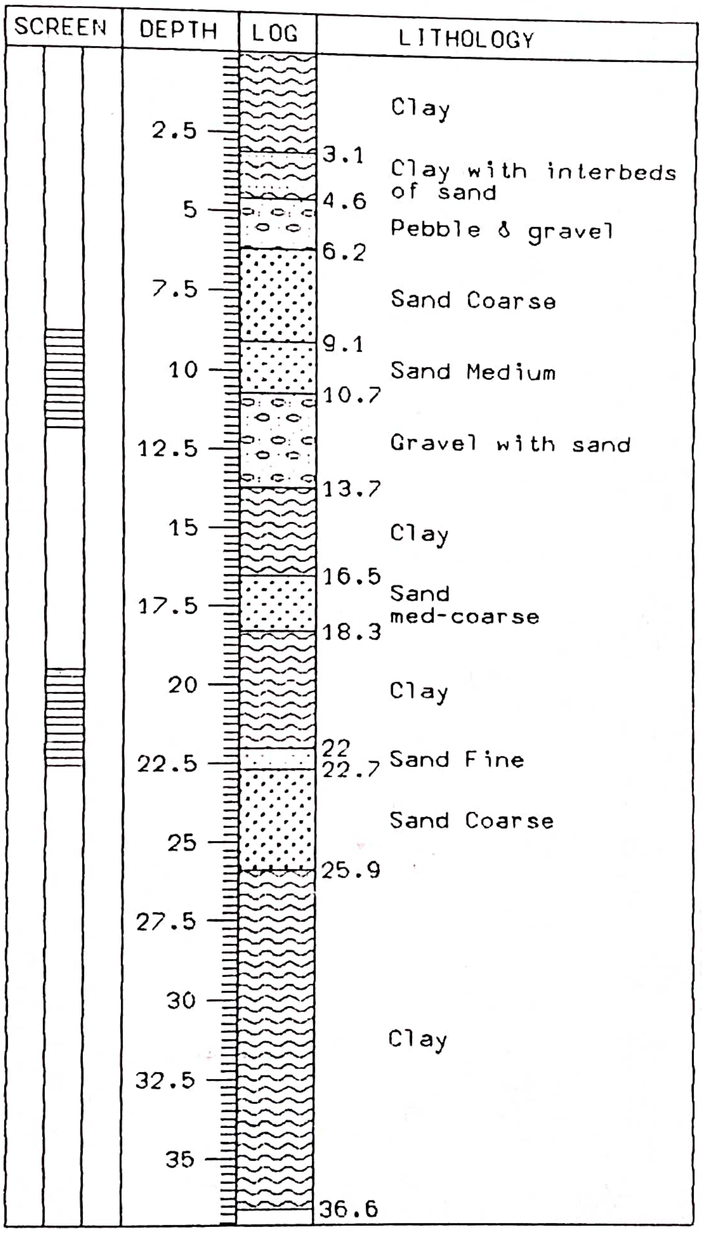


PUMPING TEST

Capacity: 8.3 l/s
Duration: 350 min
Transmiss.: 1070 m2/day
Method : THEIS
SWL: 6.70 m(B.GR.L)
DWL: 8.19 m(B.GR.L)

Well No. STW 8	Location: GWALDUBBA
Elevation: 86	X = 571500 Y = 2934125
Method of Drilling: MANUAL	
Drilling Dates : 11.6.1989 - 16.6.1989	
Total Depth : 36.60	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 8.8 - 11.9 m & 19.5 - 22.6 m DRILLED UNDER UNDP - PROJECT	

W E L L   L O G



PUMPING TEST

Date: 18.6.1989
Capacity: 6 l/s
Duration: 200 min
Transmiss.: 400 m2/day
Method : THEIS
Stor.Coeff.: 0.000091
SWL: 0.77 (B.GR.L)
DWL: 1.49 (B.GR.L)

COMMENTS:
Transmissivity in observation well = 530 m2/day

Well No. STW 9	Location: HUKKAGACHHI
Elevation: 73	X = 572250 Y = 2927625

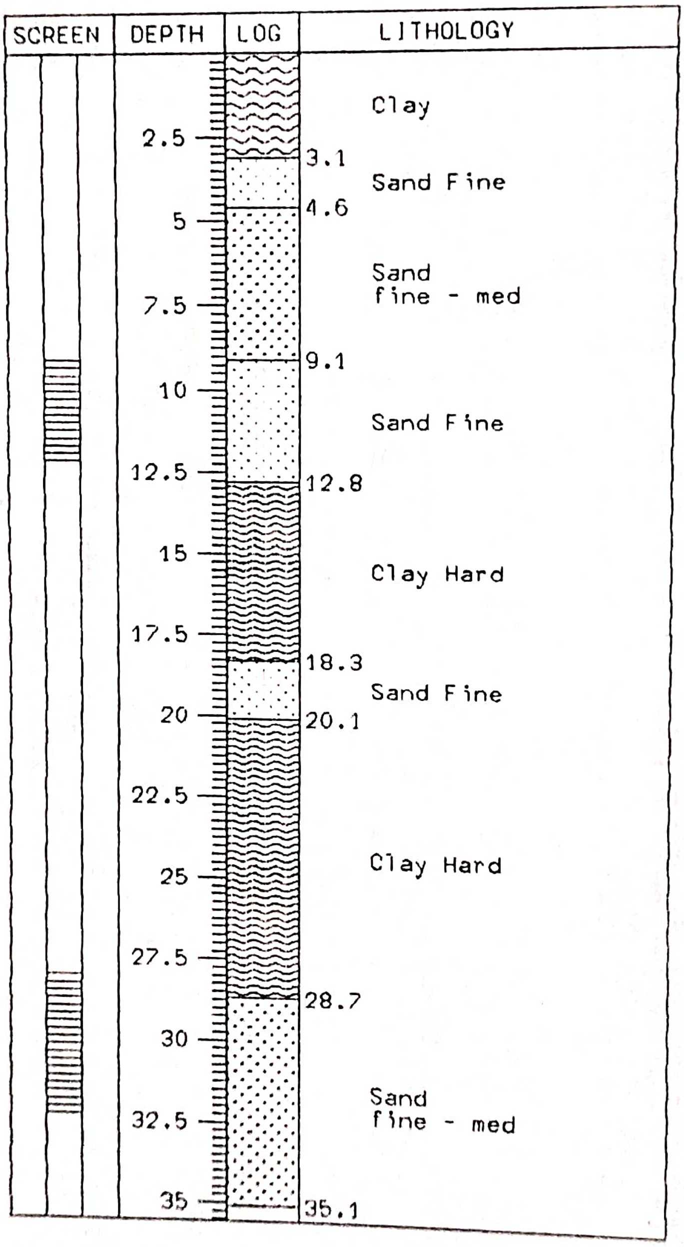
Method of Drilling: MANUAL

Drilling Dates : 17.6.1989 - 19.6.1989

Total Depth : 35.10

Comments : SCREEN TYPE: SLOTTED PIPE
SCREEN POSITION: 9.1 - 12.2 m
28.1 - 32.3 m
DRILLED UNDER UNDP - PROJECT

WELL LOG



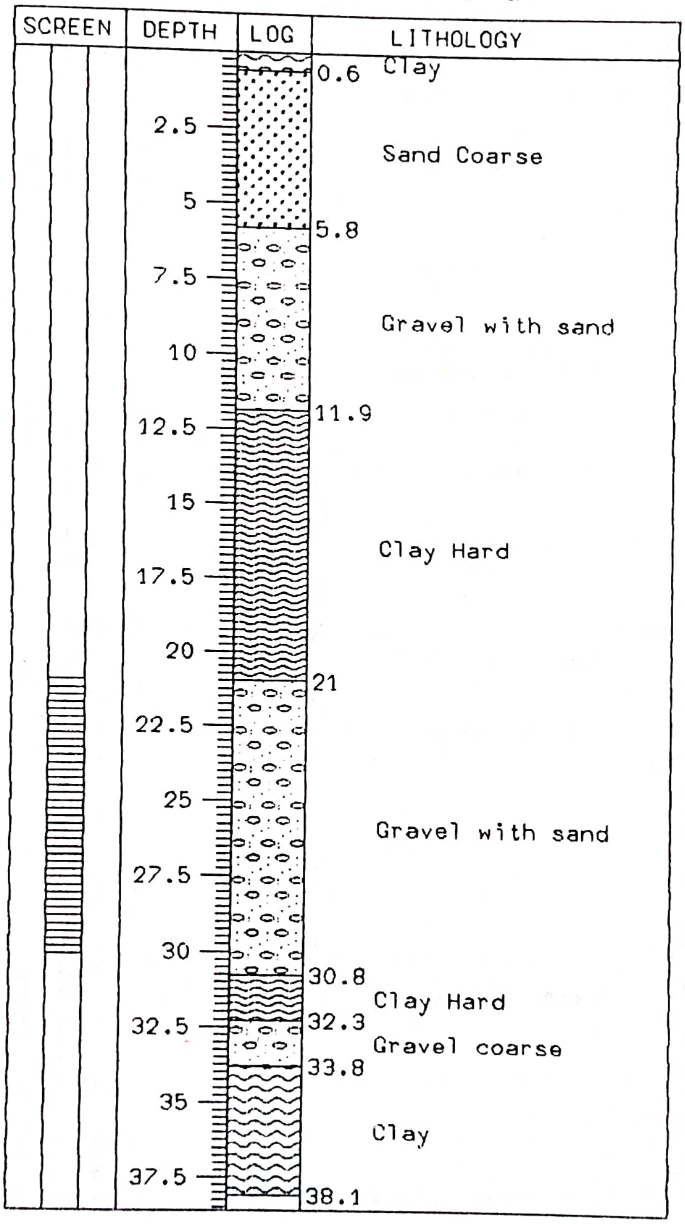
Well No. STW 10	Location: KERADHAP
Elevation: 113	X = 575250 Y = 2944875
Method of Drilling: MANUAL	
Drilling Dates : 17.6.1989 - 19.6.1989	
Total Depth : 36.60	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 11.9 - 15.9 m 7.4 - 21.0 m DRILLED UNDER UNDP - PROJECT	

WELL LOG

DEPTH (bottom of layer)	LITHOLOGY
1.5	Sand Fine
3.7	Clay
5.8	Sand Fine
6.4	Clay
8.2	Pebble with Sand and Gravel
10.1	Clay
12.2	Sand Fine
14.6	Sand Coarse
16.5	Clay
17.9	Sand Medium
21	Gravel coarse
22.9	Clay
24.1	Sand Coarse
36.6	Clay

Well No. STW 11	Location: BUTTABARI
Elevation: 128	X = 602625 Y = 2947875
Method of Drilling: RIG	
Drilling Dates : 20.6.1989 - 24.6.1989	
Total Depth : 38.10	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 21.0 - 30.1 m DRILLED UNDER - PROJECT	

WELL LOG



PUMPING TEST

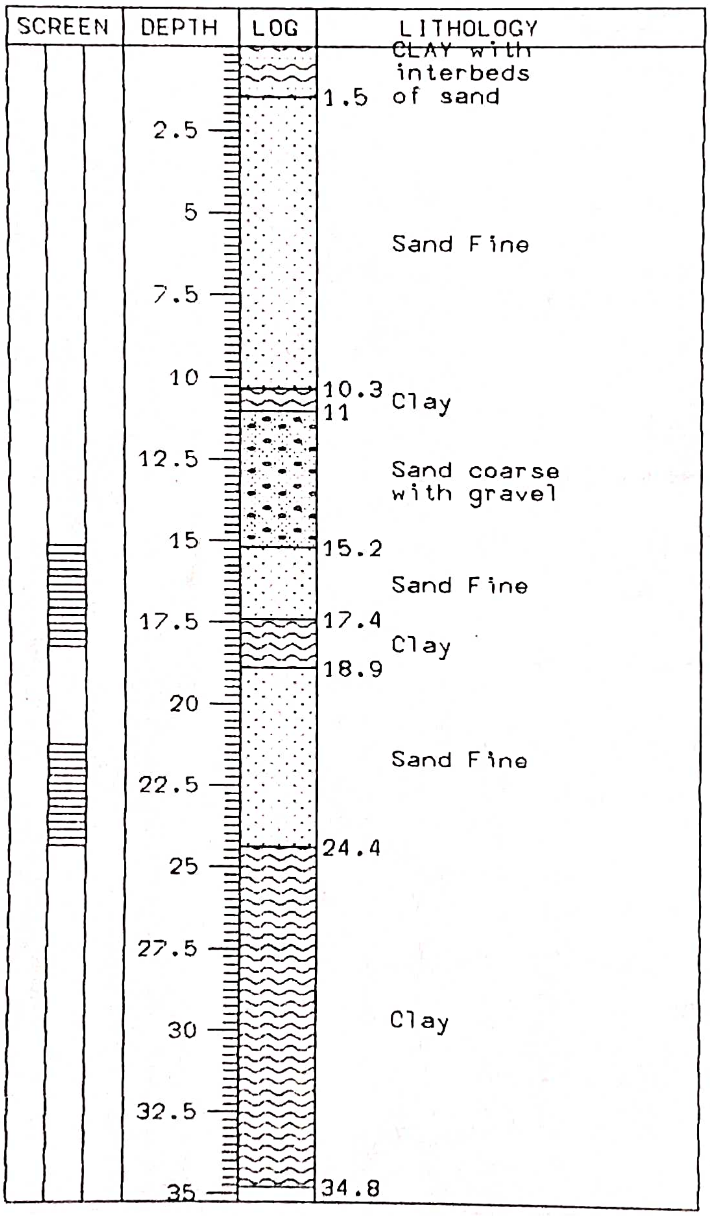
Date: 3.7.1989
Capacity: 20 l/s
Duration: 260 min
Transmiss.: 1000 m2/day
Method : THEIS
Stor.Coeff.: 0.018
SWL: 2.95 m(B.GR.L)
DWL: 3.56 m(B.GR.L)

Transmissivity in observation wells = 650 m2/day

GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW 12	Location: SATASHI
Elevation: 113	X = 580200 Y = 2945375
Method of Drilling: MANUAL	
Drilling Dates : 19.6.1989 - 24.6.1989	
Total Depth : 34.80	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 15.2 - 18.3 m 21.3 - 24.4 m DRILLED UNDER UNDP - PROJECT	

WELL LOG



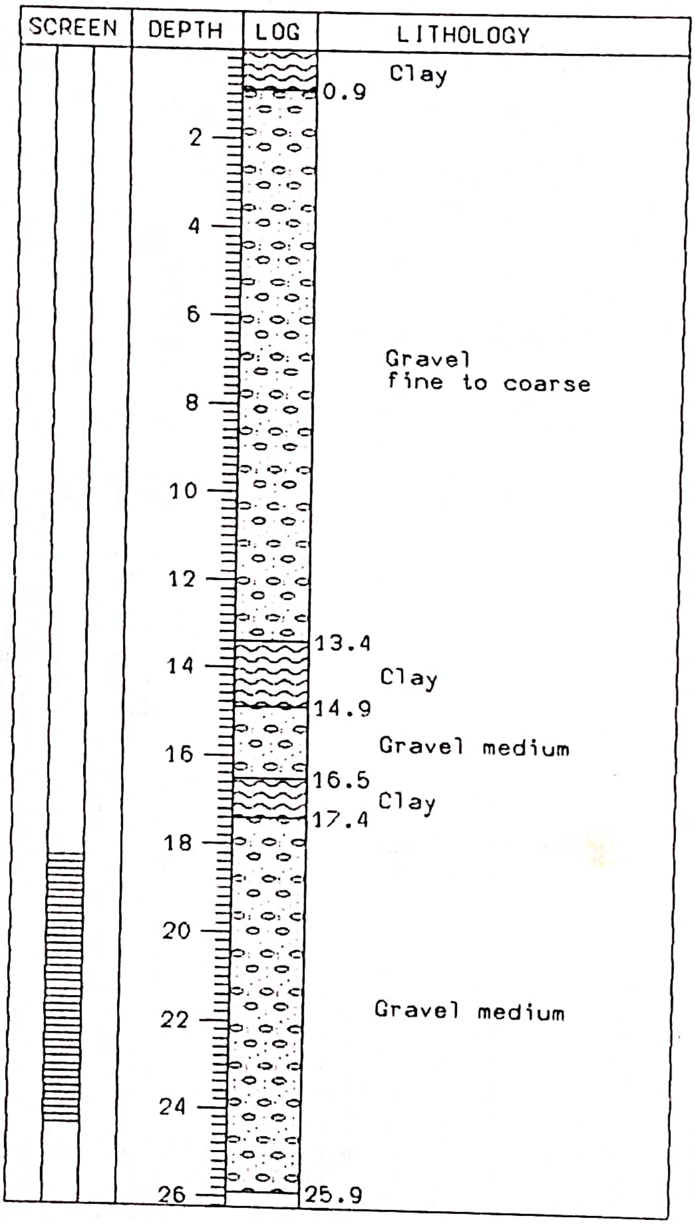
PUMPING TEST

Date: 8.7.1989
Capacity: 4 l/s
Duration: 230 min
Transmiss.: 580 m2/day
Method : JACOB
Stor.Coeff.: 0.0021
SWL: 0.58 m (B.GR.L.)
DWL: 0.99 m (B.GR.L.)

COMMENTS:
Transmissivity in observation well = 515 m2/day

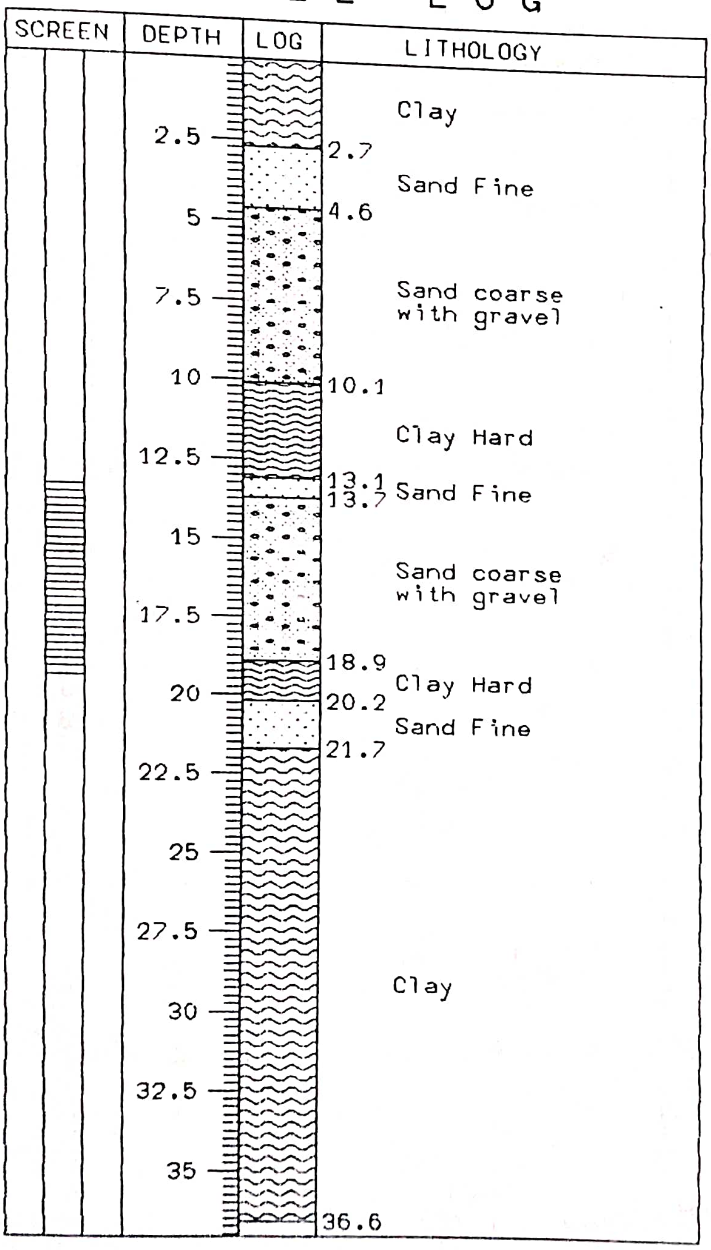
Well No. STW 13	Location: BAREGHARE
Elevation: 183	X = 599750 Y = 2953375
Method of Drilling: RIG	
Drilling Dates : 23.6.1989	
Total Depth : 25.90	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 18.3 - 24.4 m DRILLED UNDER UNDP - PROJECT	

W E L L   L O G



Well No. STW 14	Location: SANGAMBASTI
Elevation: 69	X = 606750 Y = 2926125
Method of Drilling: MANUAL	
Drilling Dates : 24.6.1989 - 28.6.1989	
Total Depth : 36.60	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 13.4 - 19.4 m DRILLED UNDER UNDP - PROJECT	

W E L L   L O G



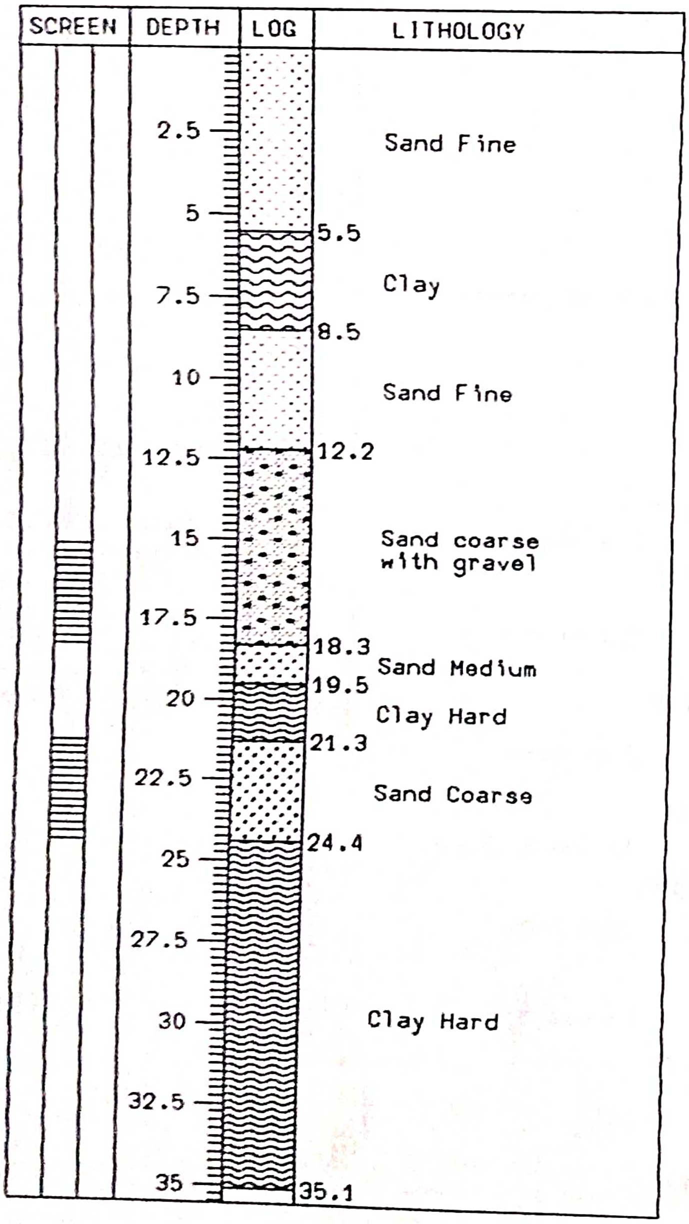
PUMPING TEST

Capacity: 5.4 l/s
Duration: 80 min
Transmiss.: 180 m2/DAY
Method : THEIS
SWL: 0.37 m (B.GR.L)
DWL: 8.78 m (B.GR.L)

GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW 15	Location: PANCHGACHHI
Elevation: 85.5	X = 581000 Y = 2936000
Method of Drilling: MANUAL	
Drilling Dates : 26.6.1989 - 29.6.1989	
Total Depth : 35.10	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 15.2 - 18.3m 21.3 - 24.4 m DRILLED UNDER UNDP - PROJECT	

WELL LOG

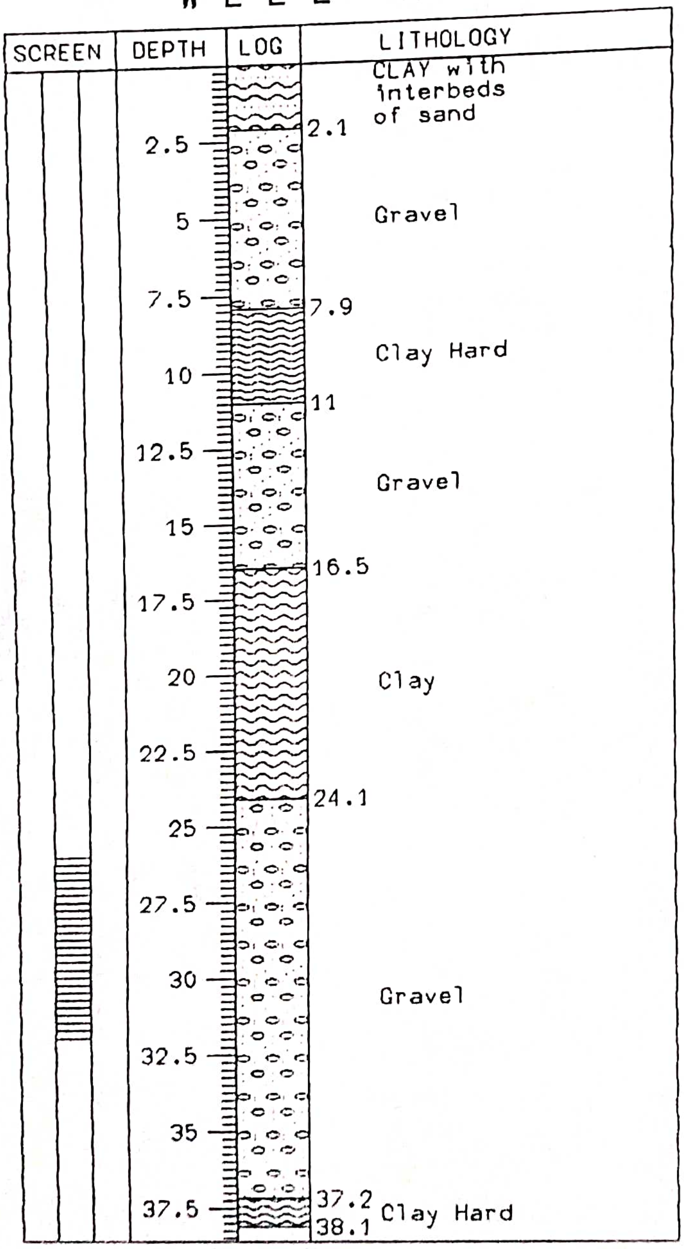


PUMPING TEST

Date: 9.7.1989
Capacity: 8 l/s
Duration: 140 min
Transmiss.: 810 m2/day
Method : RECOVERY
SWL: 1.57 m (B.GR.L)
DWL: 7.2 m (B.GR.L)

Well No. STW 16	Location: GHAILADUBBA
Elevation: 112	X = 593625 Y = 2944125
Method of Drilling: RIG	
Drilling Dates : 28.6.1989	
Total Depth : 38.10	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 25.9 - 31.9 m DRILLED UNDER UNDP - PROJECT	

WELL LOG



PUMPING TEST

Date: 16.6.1989
Capacity: 10.3 l/s
Duration: 200 min
Transmiss.: 280 m2/day
Method : THEIS
SWL: 0.08 m (A.GR.
DWL: 8.64 m (B.GR.

GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW 17	Location: SATIGATTA
Elevation: 121	X = 614125 Y = 2947375
Method of Drilling: RIG	
Drilling Dates : 2.7.1989	
Total Depth : 32.00	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 14.9 - 18.3 m 21.3 - 23.8 m 25.3 - 28.7 m DRILLED UNDER UNDP - PROJECT	

W E L L L O G

DEPTH	LITHOLOGY
0 - 1.2	Clay
1.2 - 13.2	Gravel coarse
13.2 - 14.9	Clay Hard
14.9 - 18.6	Gravel coarse
18.6 - 21.6	Clay Hard
21.6 - 23.8	Pebble & gravel
23.8 - 25.9	Clay Hard
25.9 - 29	Pebble & gravel
29 - 32	Clay

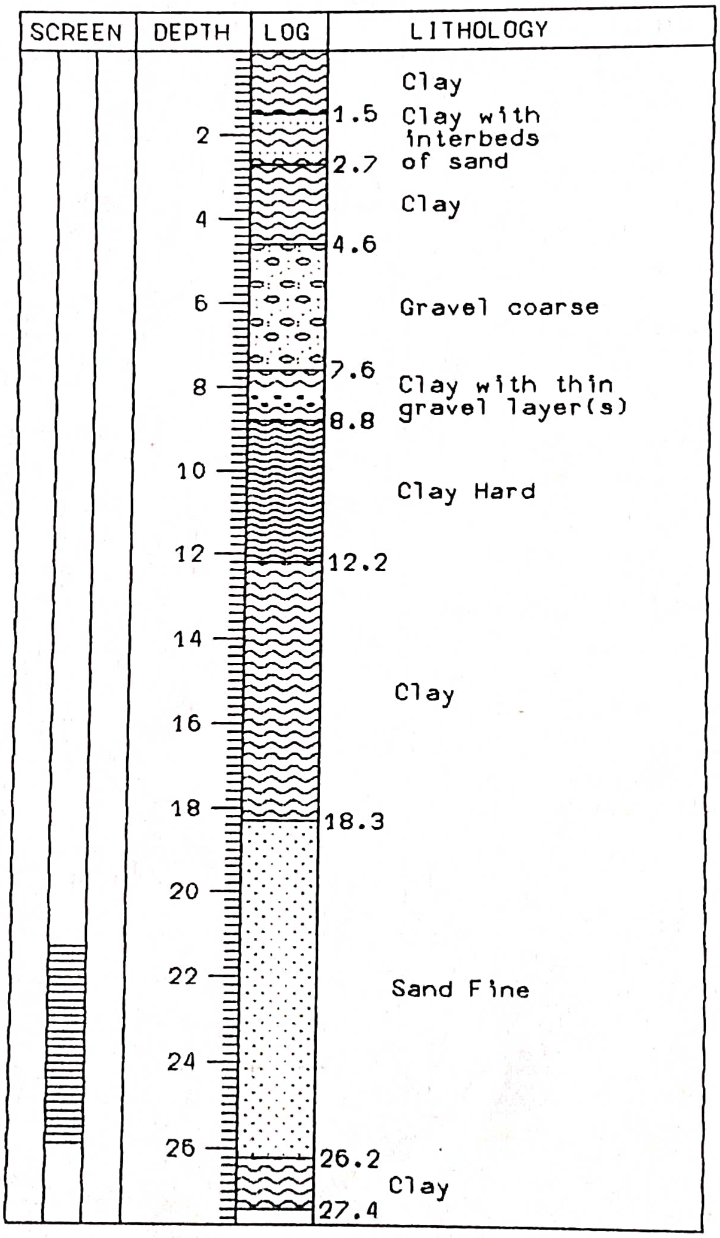
PUMPING TEST

Date: 10.7.1989
Capacity: 3 l/s
Duration: 160 min.
Transmiss.: 210 m2/day
Method : RECOVERY
SWL: 1.73 m (B.GR.L)
DWL: 8.00 m (B.GR.L)

APPENDIX 3/17

Well No. STW 18	Location: GAURIGUNJ
Elevation: 75	X = 572500 Y = 2929375
Method of Drilling: MANUAL	
Drilling Dates : 7.7.1989 - 12.7.1989	
Total Depth : 27.40	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 21.3 - 25.9 m DRILLED UNDER UNDP PROJECT	

WELL LOG



GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. STW-19	Location: GOLDHAP-4
Elevation: 95	X = 599400 Y = 2937900
Method of Drilling: MANUAL	
Drilling Dates : 5/1/90-13/1/90	
Total Depth : 28.96	
Comments : SCREEN TYPE: SLOTTED SCREEN POSITION:11.59-14.63,17.68-23.63m DRILLED UNDER UNDP PROJECT, DIA. 4-in	

W E L L L O G

Depth	Lithology
0 – 0.6	Sandy clay
0.6 – 3	Clay
3 – 6.1	Sand coarse with fine gravel
6.1 – 10.7	Gravel coarse
10.7 – 11.6	Clay
11.6 – 14.6	Sand fine to coarse with few gravel
14.6 – 16.8	Clay
16.8 – 25	Sand fine to coarse with gravel
25 – 25.9	Clay sandy
25.9 – 29	Clay

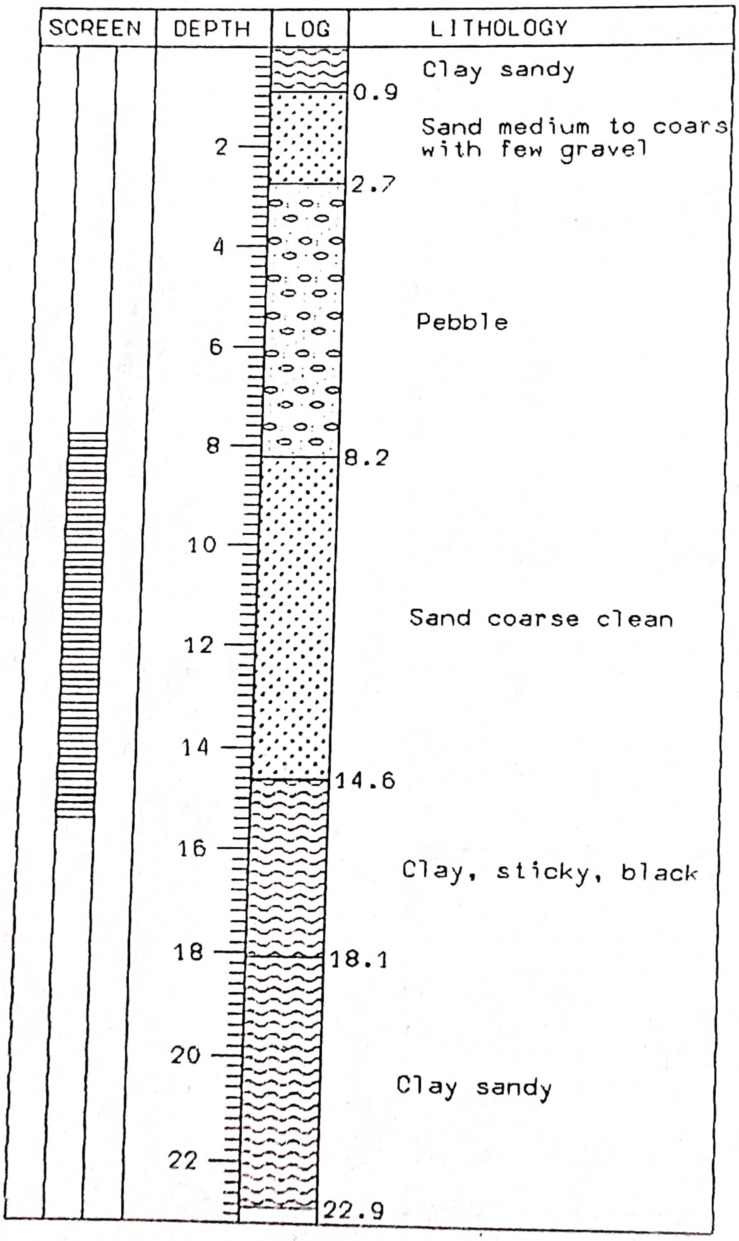
PUMPING TEST

Date: 22/1/1990
Capacity: 12 l/sec
Duration: 230 min.
Transmiss.: 445 m2/day
Method : Theis
SWL: 1.20 m
DWL: 6.12

MP 0.65 m
T from recovery 445 m2/d
T from pumping test
241 m2/day

Well No. STW-20	Location: KECHANA
Elevation: 63	X = 600400 Y = 2918000
Method of Drilling: MANUAL	
Drilling Dates : 20.1.90-24.1.90	
Total Depth : 22.87	
Comments : SCREEN TYPE: SLOTTED PIPE SCREEN POSITION: 7.77-15.4 m PUMP TEST ATTEMPTED BUT FAILED DUE TO LOW DISCHARGE	

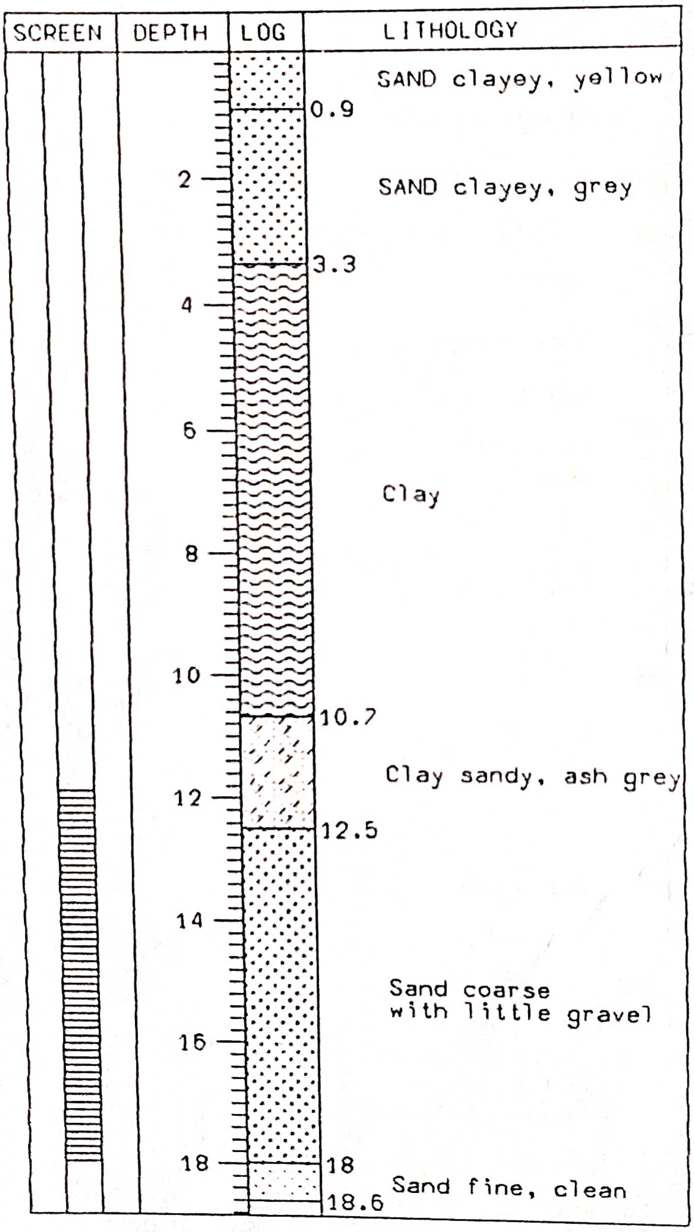
WELL LOG



GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

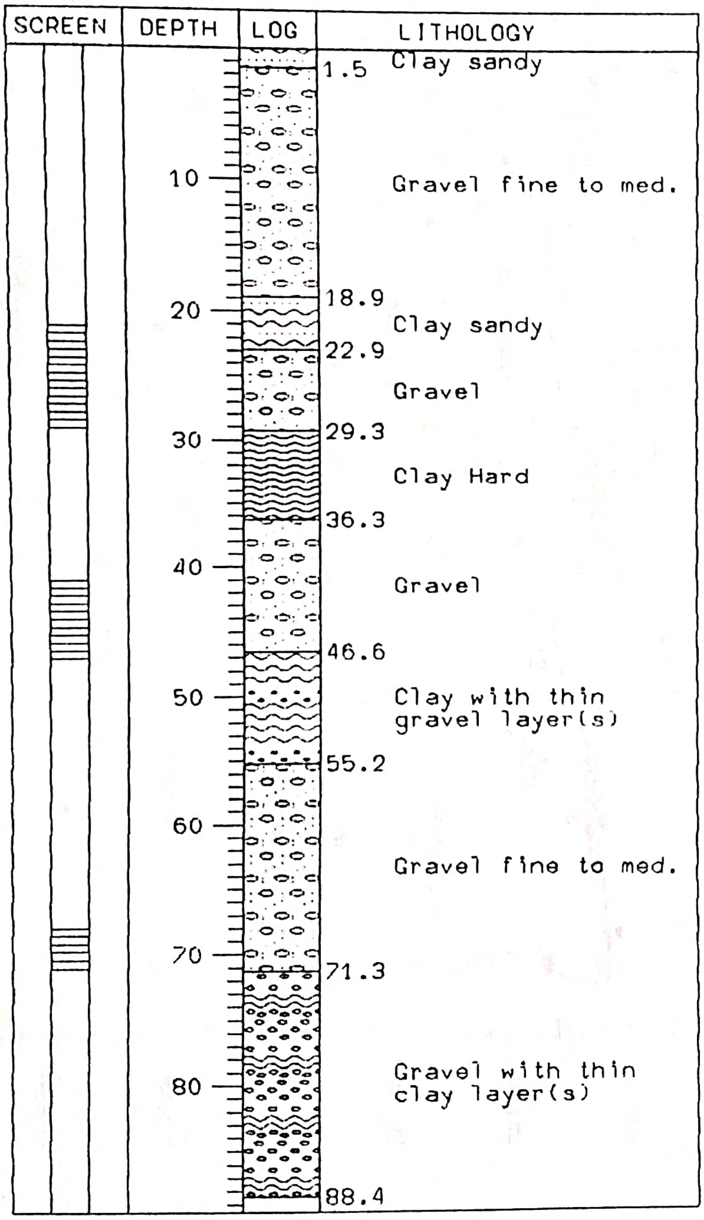
Well No. STW-21	Location: JALTHAL
Elevation: 84	X = 600200 Y = 2935600
Method of Drilling: MANUAL	
Drilling Dates : 14.1.90-19.1.90	
Total Depth : 18.60	
Comments : SCREEN TYPE: SLOTTED PIPE PUMP TEST ATTEMPTED BUT FAILED DUE TO LOW DISCHARGE	

WELL LOG



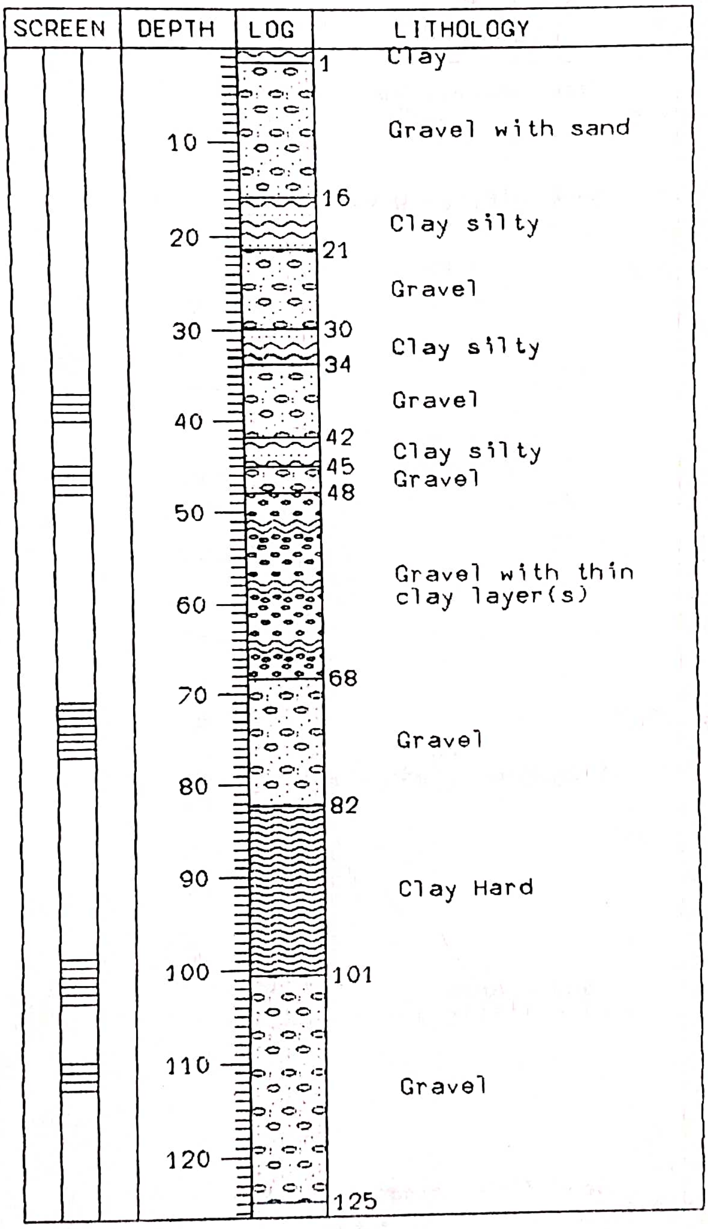
Well No. DTW 1	Location: H.T. GARDEN
Elevation: 126	X = 568200 Y = 2949800
Method of Drilling: RIG	
Drilling Dates : 16.3.83	
Total Depth : 88.40	
Comments : Screen Type: Slotted Pipe Screen Position:21.2 - 29.1,41.0 - 47.0, 67.9 - 71.0 m Drilled Under GWRDB Project	

WELL LOG



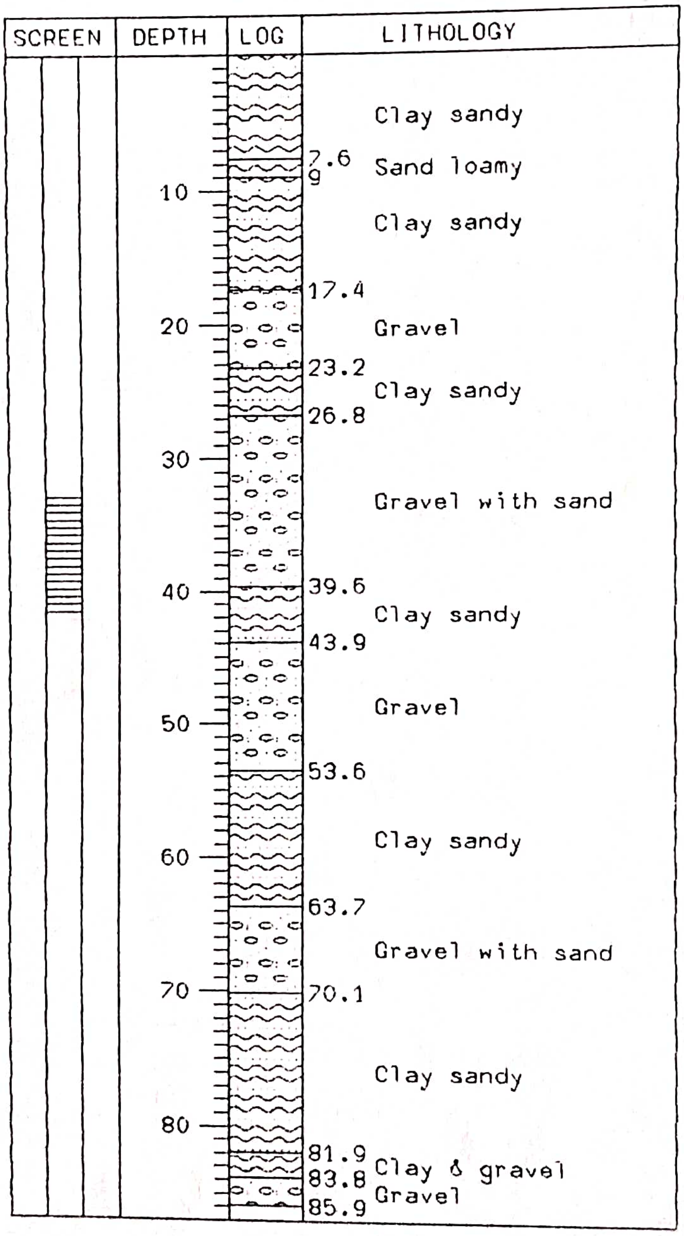
Well No. DTW 2	Location: CHARALI
Elevation: 130	X = 604200 Y = 2948200
Method of Drilling: RIG	
Drilling Dates : 23.6.83 - 16.7.83	
Total Depth : 124.90	
Comments : Screen Type: Slotted Pipe Screen Position:37.0 - 40.0,44.8 - 47.9, 70.6 - 76.7,98.5 - 103.3 109.7 - 112.7 m Drilled Under GWRDP Project	

W E L L   L O G



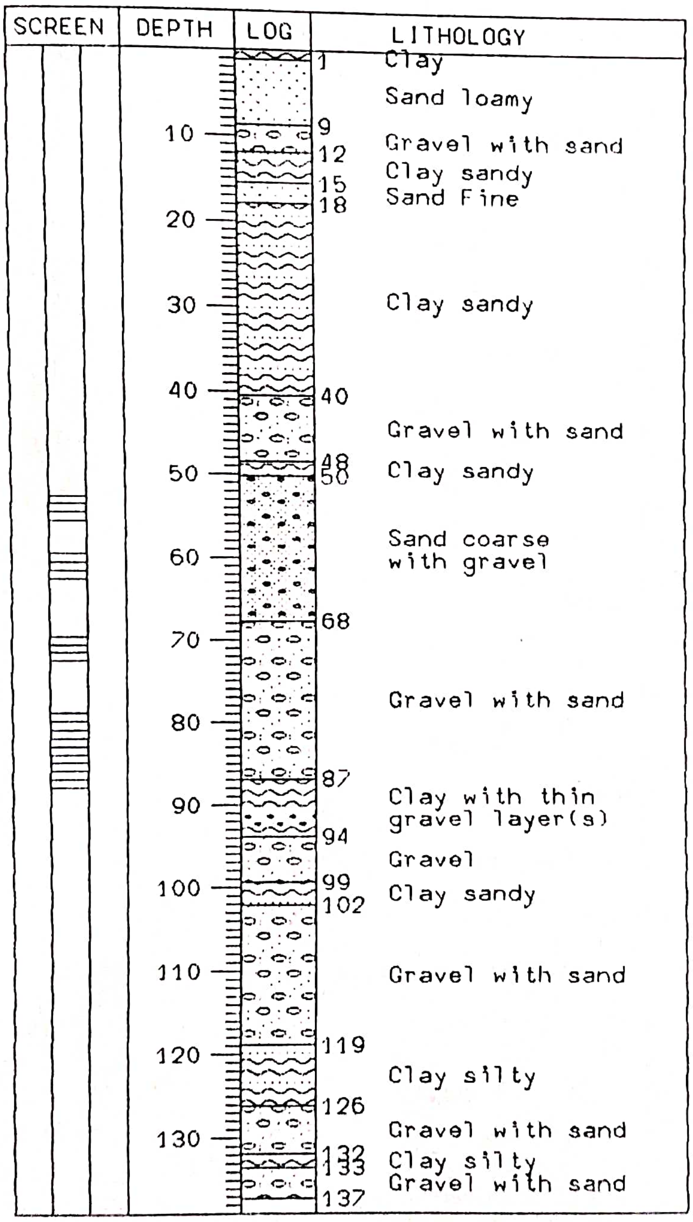
Well No. DTW 3	Location: KANKAI
Elevation: 120	X = 585900 Y = 2949500
Method of Drilling: RIG	
Drilling Dates : 1.12.1983 - 22.12.1983	
Total Depth : 85.90	
Comments : Screen Type: Slotted Pipe Screen Position: 32.8 - 51.5 m Drilled under GWRDB Project	

W E L L L O G



Well No. DTW 4	Location: BHALGAON	
Elevation: 100	X = 575700	Y = 2941300
Method of Drilling: RIG		
Drilling Dates : 28.12.1983 - 10.1.1984		
Total Depth : 137.20		
Comments : Screen Type: Slotted Pipe Screen Position:52.7 - 55.7,59.7 - 62.6, 69.7 - 72.5,78.9 - 87.8m Drilled Under GWRDB Project		

WELL LOG



Well No. DTW 5	Location: GWALDUBBA
Elevation: 85	X = 572800 Y = 2933900
Method of Drilling: RIG	
Drilling Dates : 13.1.1984 - 3.2.1984	
Total Depth : 137.20	
Comments : Screen Type: Slotted Pipe Screen Position:101.7-104.6,111.7-118.1 120.6-123.6 m Drilled under GWRDB Project	

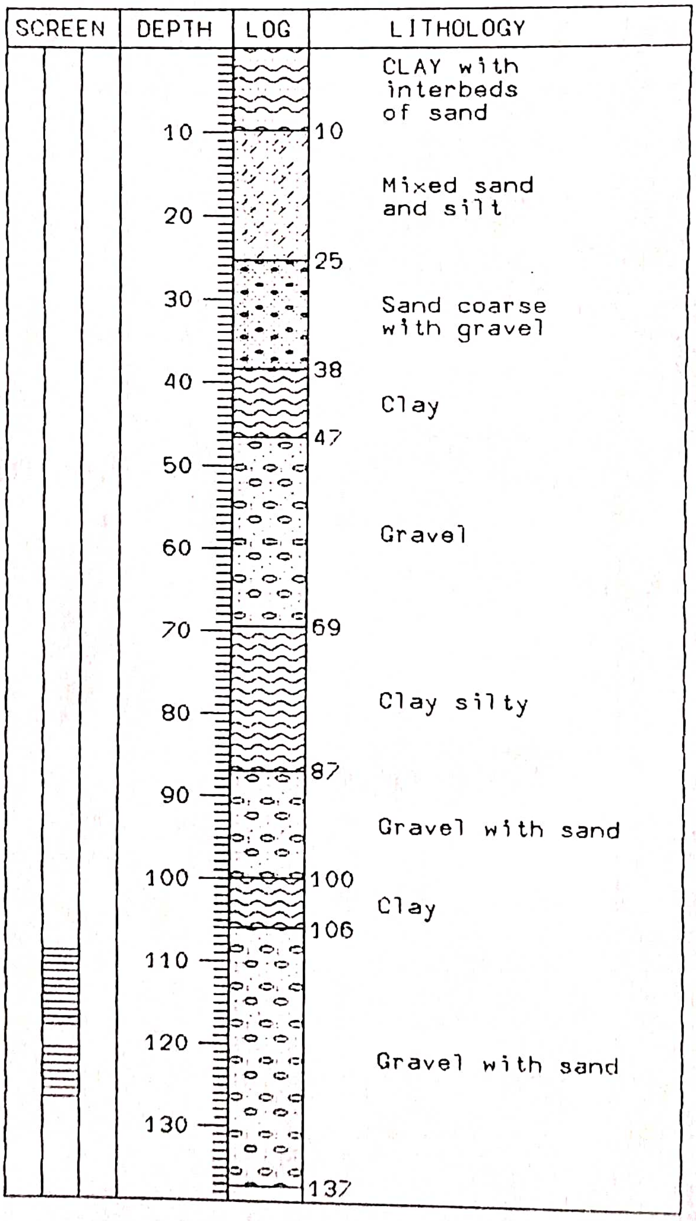
W E L L   L O G

DEPTH (layer base)	LITHOLOGY
9	Clay sandy
16	Gravel with sand
30	Clay
36	Gravel with sand
42	Clay Hard
56	Gravel with sand
65	Gravel with thin clay layer(s)
82	Clay Hard
90	Gravel with sand
97	Clay sandy
108	Gravel with sand
116	Clay with thin gravel layer(s)
127	Gravel with sand
134	Clay with thin gravel layer(s)
137	Gravel with sand

Well No. DTW 6	Location: BHAWANIPUR
Elevation: 71	X = 573000 Y = 2926700
Method of Drilling: RIG	
Drilling Dates : 1.3.1984	
Total Depth : 137.20	

Comments : Screen Type: Slotted Pipe
Screen Position: 108.8 - 118.0 m
120.8 - 126.8 m
Drilled under GWRDB Project

W E L L L O G



Well No. DTW 7	Location: PRAKASHPUR
Elevation: 105	X = 607900 Y = 2942200
Method of Drilling: RIG	
Drilling Dates : 25.12.1983 - 4.1.1984	
Total Depth : 148.40	
Comments : Screen Type: Slotted Pipe Screen Position: 66.1 - 69.2 m 73.2 - 82.3 m 91.3 - 97.2 m Drilled Under GWRDB Project	

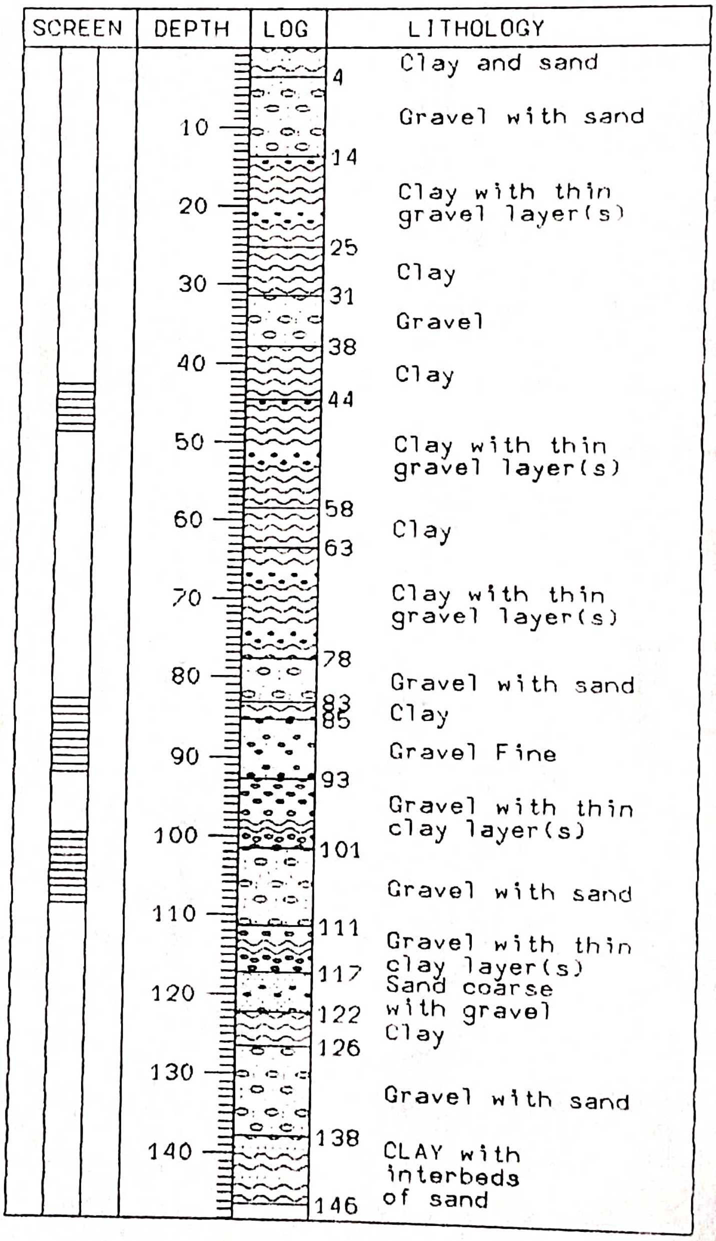
WELL LOG

DEPTH	LITHOLOGY
0 – 3	Clay
3 – 10	Sand coarse with gravel
10 – 12	Clay
12 – 33	Sand coarse with gravel
33 – 35	Clay Hard
35 – 53	Gravel
53 – 57	Clay
57 – 63	Sand coarse with gravel
63 – 78	Clay
78 – 89	Sand coarse with gravel
89 – 96	Clay with thin gravel layer(s)
96 – 135	CLAY with interbeds of sand
135 – 139	Sand coarse with gravel
139 – 148	Clay

Well No. DTW 8	Location: MAHESHPUR
Elevation: 84	X = 607700 Y = 2934600
Method of Drilling: RIG	
Drilling Dates : 10.3.1986 - 1.4.1986	
Total Depth : 146.30	

Comments : Screen Type: Slotted Pipe
Screen Position: 42.7 - 48.8 m
83.9 - 92.1 m
99.7 - 108.8 m
Drilled Under GWRDB Project

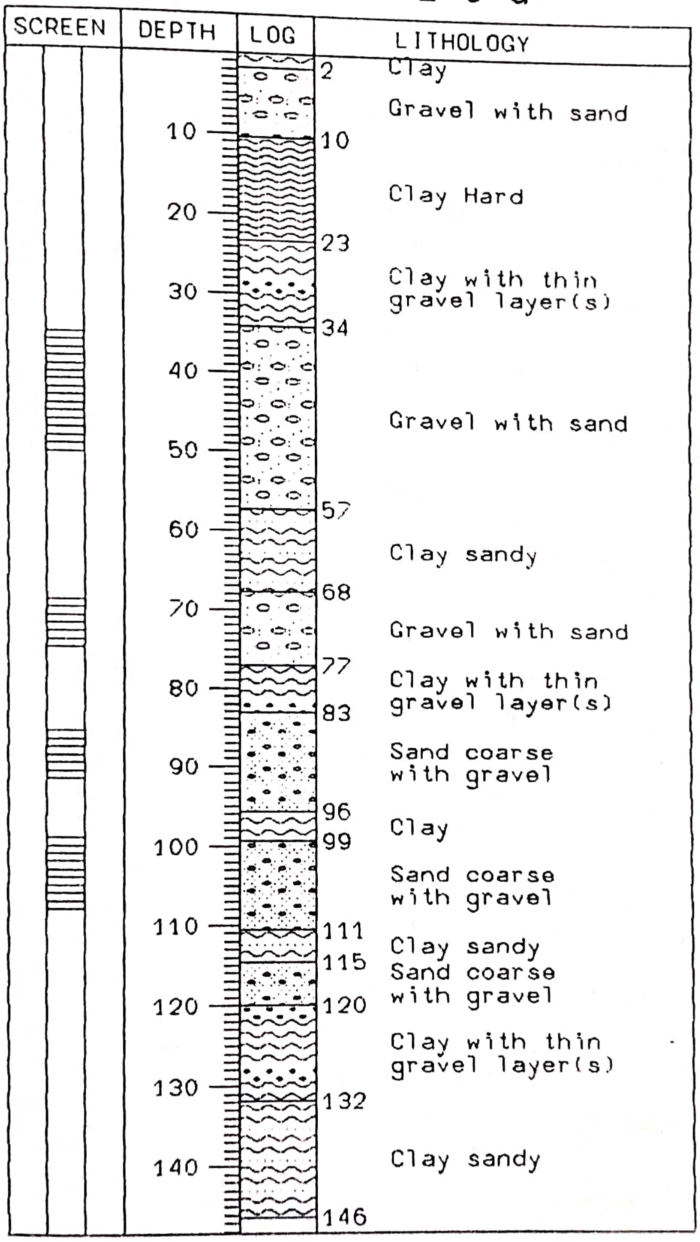
WELL LOG



GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

Well No. DTW 9	Location: GOLDHAP
Elevation: 95	X = 599400 Y = 2938900
Method of Drilling: RIG	
Drilling Dates : 23.2.86 - 7.3.86	
Total Depth : 146.30	
Comments : Screen Type: Slotted Pipe Screen Position: 35.2-50.3, 68.8-74.8, 85.5-91.5, 98.8-107.9 m Drilled under GWRDB Project	

W E L L L O G



Well No. DTW 10	Location: GHAILADUBBA
Elevation: 103	X = 591500 Y = 2943400
Method of Drilling: RIG	
Drilling Dates : 4.4.86 - 23.4.86	
Total Depth : 144.80	
Comments : Screen Type:Slotted Pipe Screen Position: 36.4-45.5, 60.6-66.6, 97.0-106.0 m Drilled under GWRDP Project	

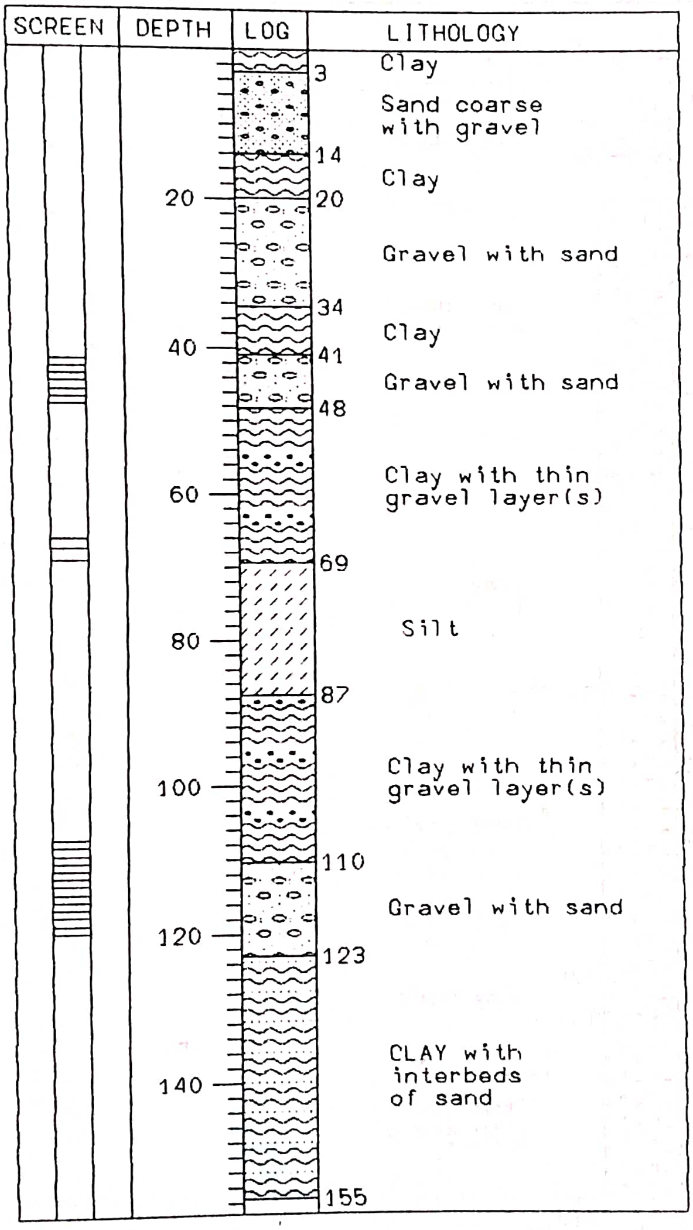
W E L L L O G

DEPTH	LITHOLOGY
0-4	Clay sandy
4-14	Gravel with sand
14-31	Clay with thin gravel layer(s)
31-50	Gravel with sand
50-65	Clay with thin gravel layer(s)
65-79	Gravel
79-85	Clay
85-95	Gravel with thin clay layer(s)
95-101	Clay sandy
101-119	Gravel with sand
119-145	Clay with thin gravel layer(s)

Well No. DTW 11	Location: PRITHIVINAGAR
Elevation: 81	X = 606000 Y = 2930500
Method of Drilling: RIG	
Drilling Dates : 30.1.1989 - 11.2.1989	
Total Depth : 155.50	

Comments : Screen Type: Slotted Pipe
Screen Position: 41.5 - 47.6 m
66.0 - 69.0 m
107.2 - 119.6 m
Drilled Under GWRDB Project

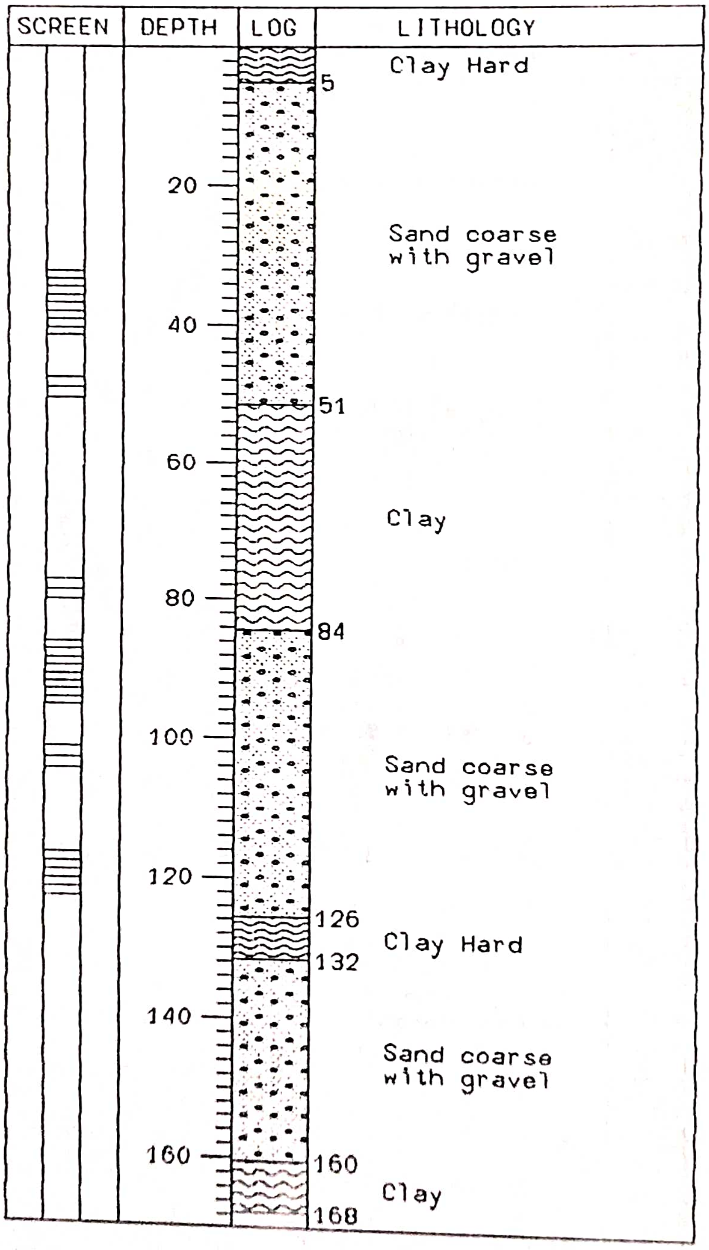
W E L L L O G



GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

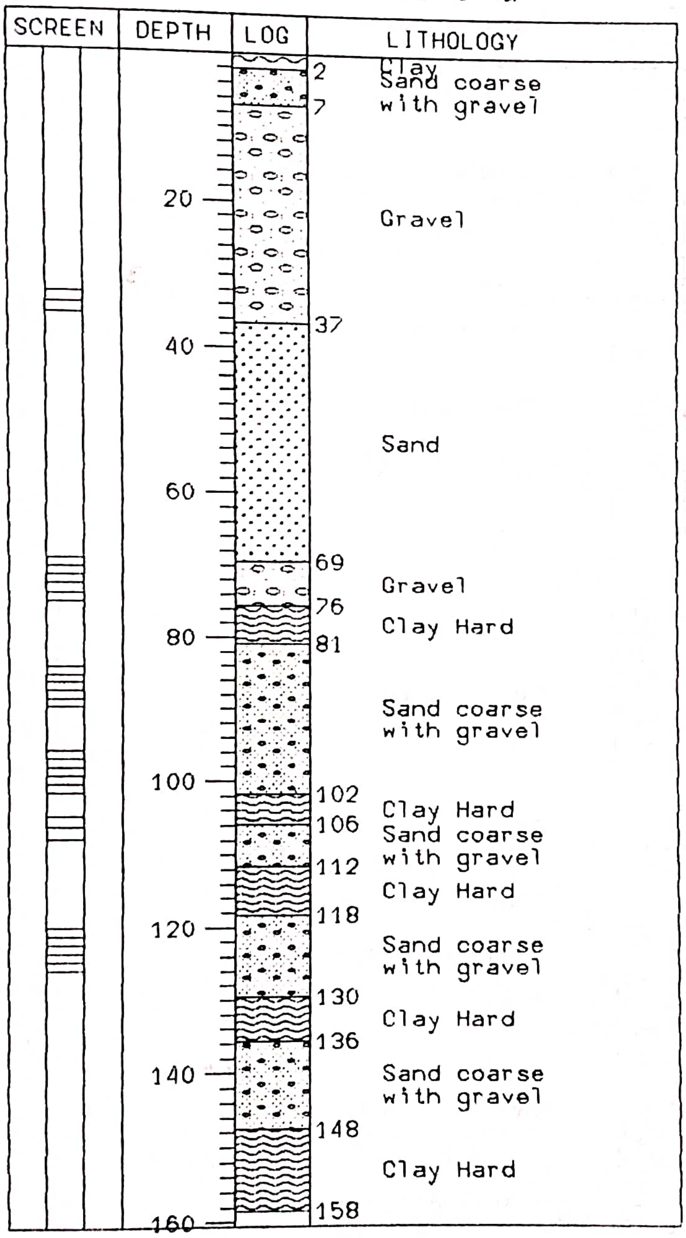
Well No. DTW 12	Location: RAJGADHAT
Elevation: 79	X = 593000 Y = 2932900
Method of Drilling: RIG	
Drilling Dates :	
Total Depth : 167.70	
Comments : Screen Type: Slotted Pipe Screen Position: 32.3-41.5, 47.6-50.6 77.4-80.1, 86.2-95.3 101.4-104.5, 116.7-122.8m Drilled under GWRDP Project	

WELL LOG



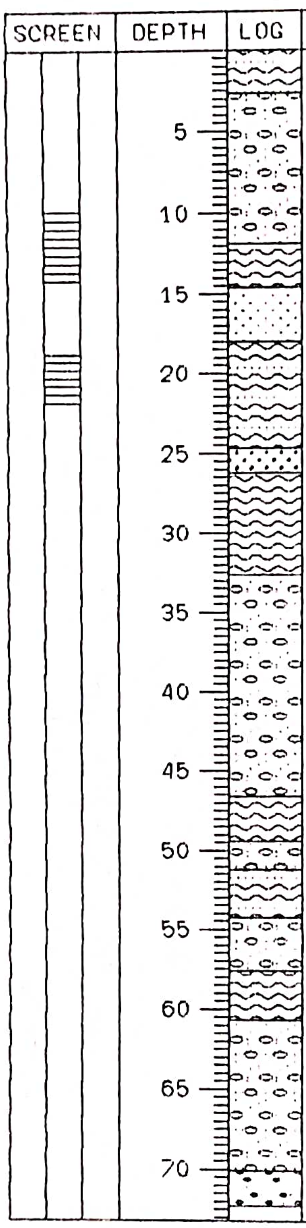
Well No. DTW 13	Location: JHAPA
Elevation: 75	X = 586100 Y = 2929900
Method of Drilling: RIG	
Drilling Dates : 16.4.1989 - 28.4.1989	
Total Depth : 158.50	
Comments : Screen Type: Slotted Type Screen Position:32.6-35.5,69.0-75.0 84.1-89.7,95.8-101.7 104.7-107.7,119.9-125.7m Drilled Under Drinking Water Project	

WELL LOG



Well No. DTW 14	Location: DAMAK
Elevation: 132	X = 569875 Y = 2950875
Method of Drilling: RIG	
Drilling Dates : 18.9.1981	
Total Depth : 72.30	
Comments : Screen Type: Slotted Pipe Screen Position: 10.0 - 14.2 m 18.8 - 21.9 m Drilled Under Drinking Water Project	

W E L L L O G



Depth to (m)	LITHOLOGY
2.7	Clay sandy
11.9	Sand with gravel pebble & cobble
14.6	Clay
18	Sand Fine
24.7	Clay sandy
26.2	Sand Coarse
32.6	Clay
46.6	Sand and pebble
49.4	Clay
51.2	Sand and pebble
54.3	Clay with sand
57.6	Sand and pebble
60.7	Clay
70.1	Sand and pebble
72.3	Gravel and sand

Well No. DTW 15	Location: SANISCHARE
Elevation: 162	X = 598375 Y = 2952750

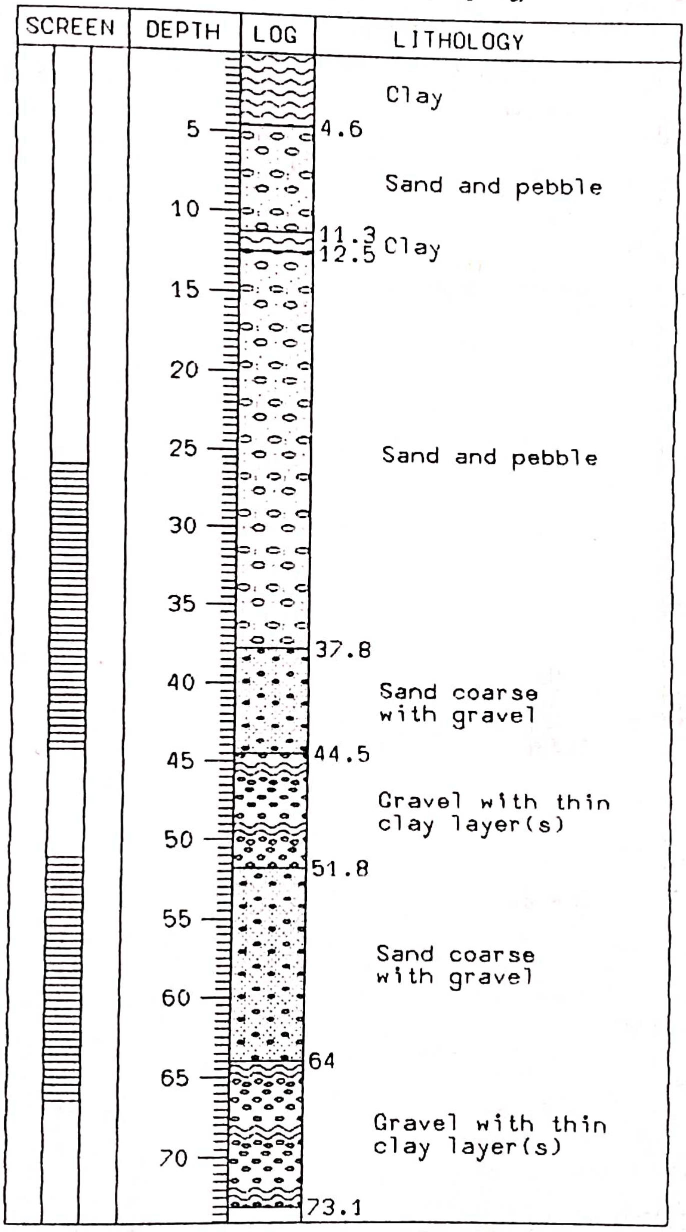
Method of Drilling: RIG

Drilling Dates : 29.10.1986 - 2.11.1986

Total Depth : 73.10

Comments : Screen Type: Slotted Pipe
Screen Position: 26.2 - 44.3 m
51.1 - 66.4 m
Drilled Under Drinking Water Project

W E L L   L O G

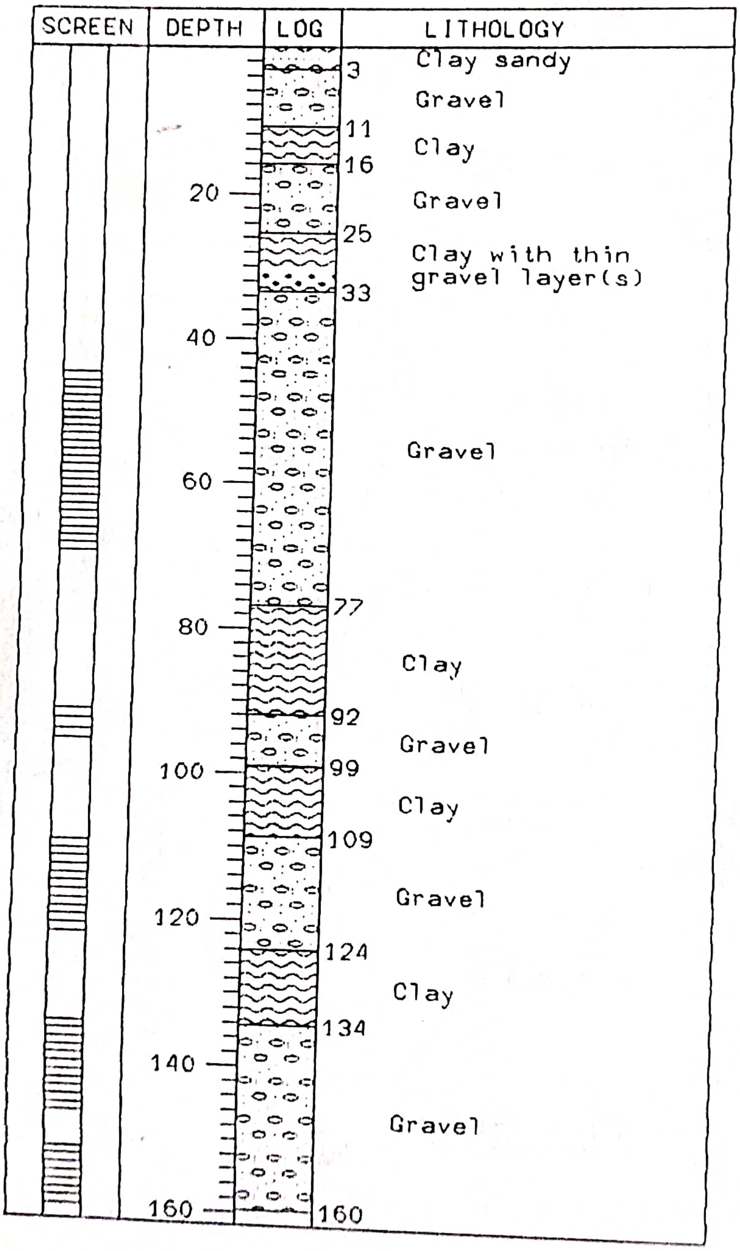


GWRDB - UN/DTCD NEP/86/025 JHAPA
GROUND WATER INVESTIGATIONS IN TERAI

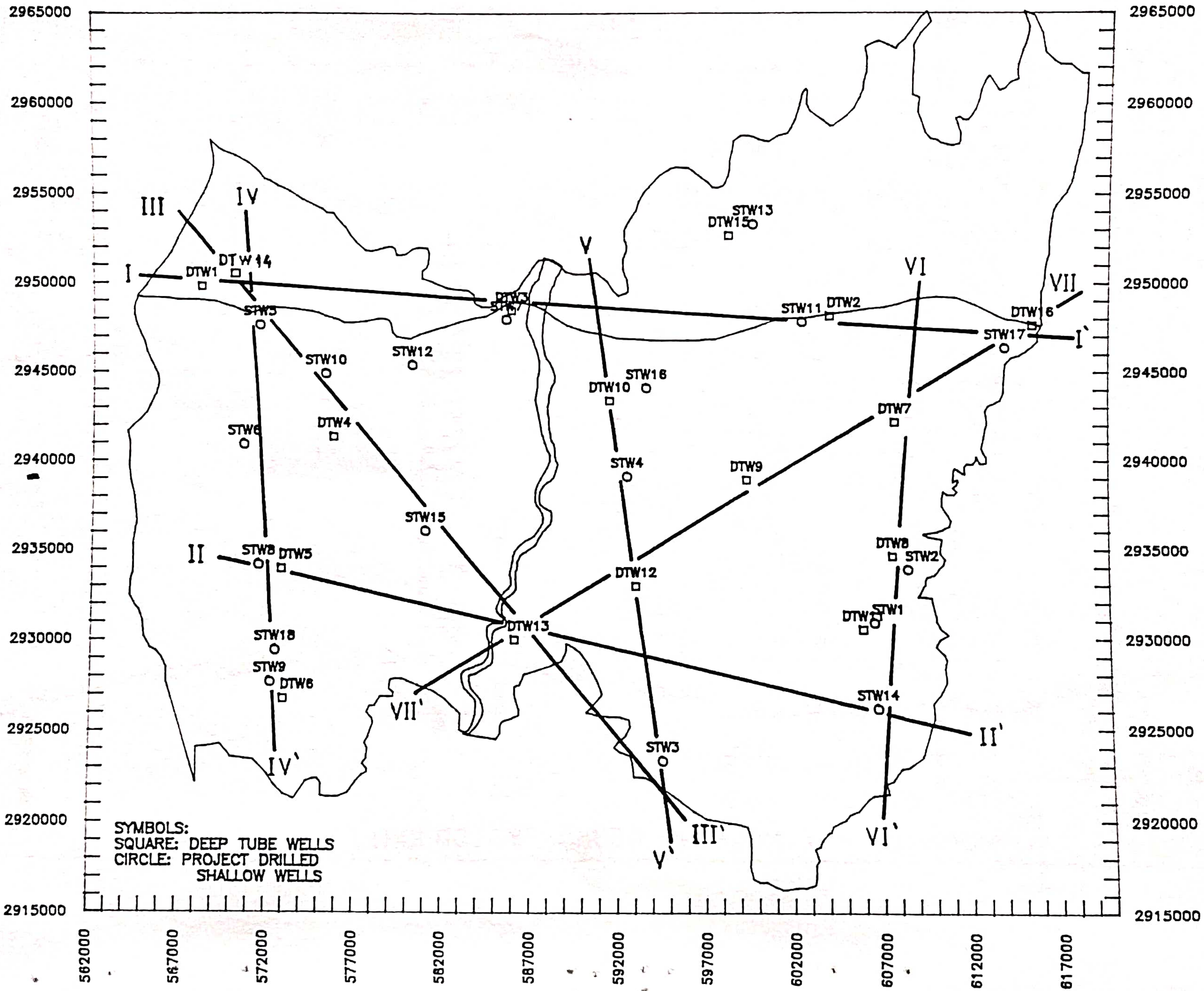
Well No. DTW 16	Location: KAKARBHITTA
Elevation: 120	X = 615688 Y = 2947625
Method of Drilling: RIG	
Drilling Dates :	
Total Depth : 159.70	

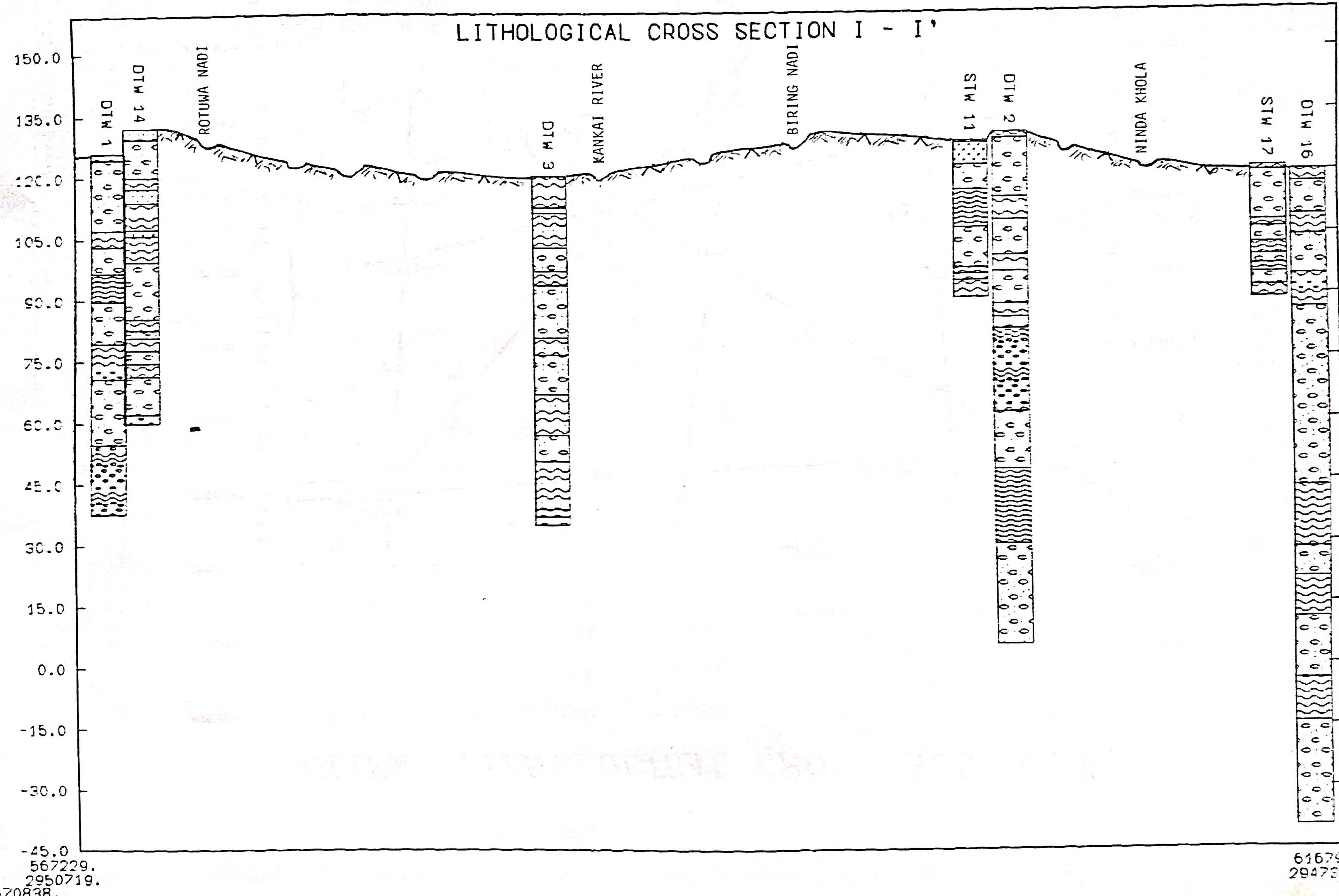
Comments : Screen Type: Slotted Pipe
Screen Position: 45.0-69.6,91.5-95.6
109.8-122.1,134.3-146.8
151.7-159.7 m
Drilled Under Drinking Water Project

WELL LOG

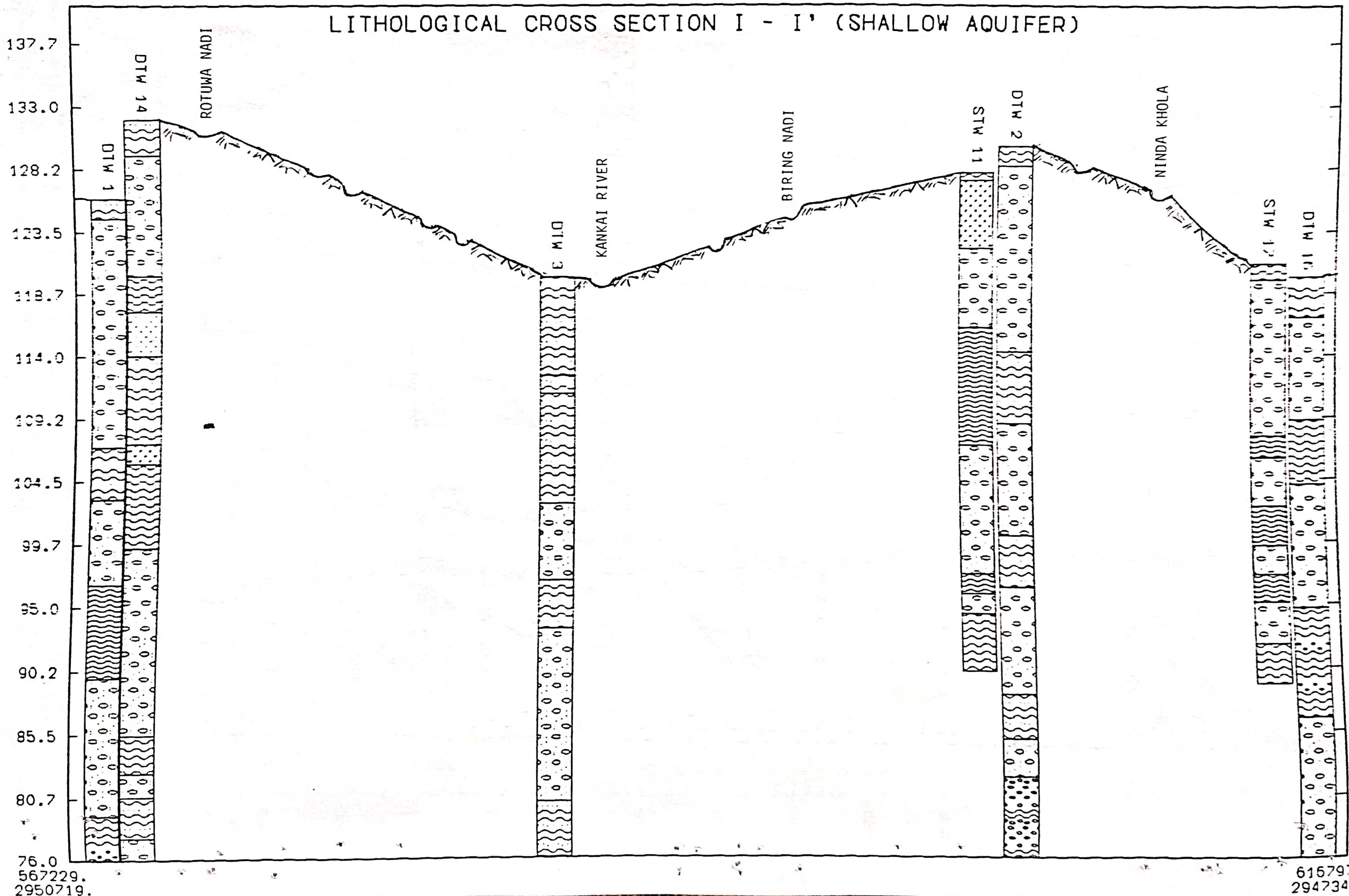


JHAPA LITHOLOGICAL CROSS SECTIONS



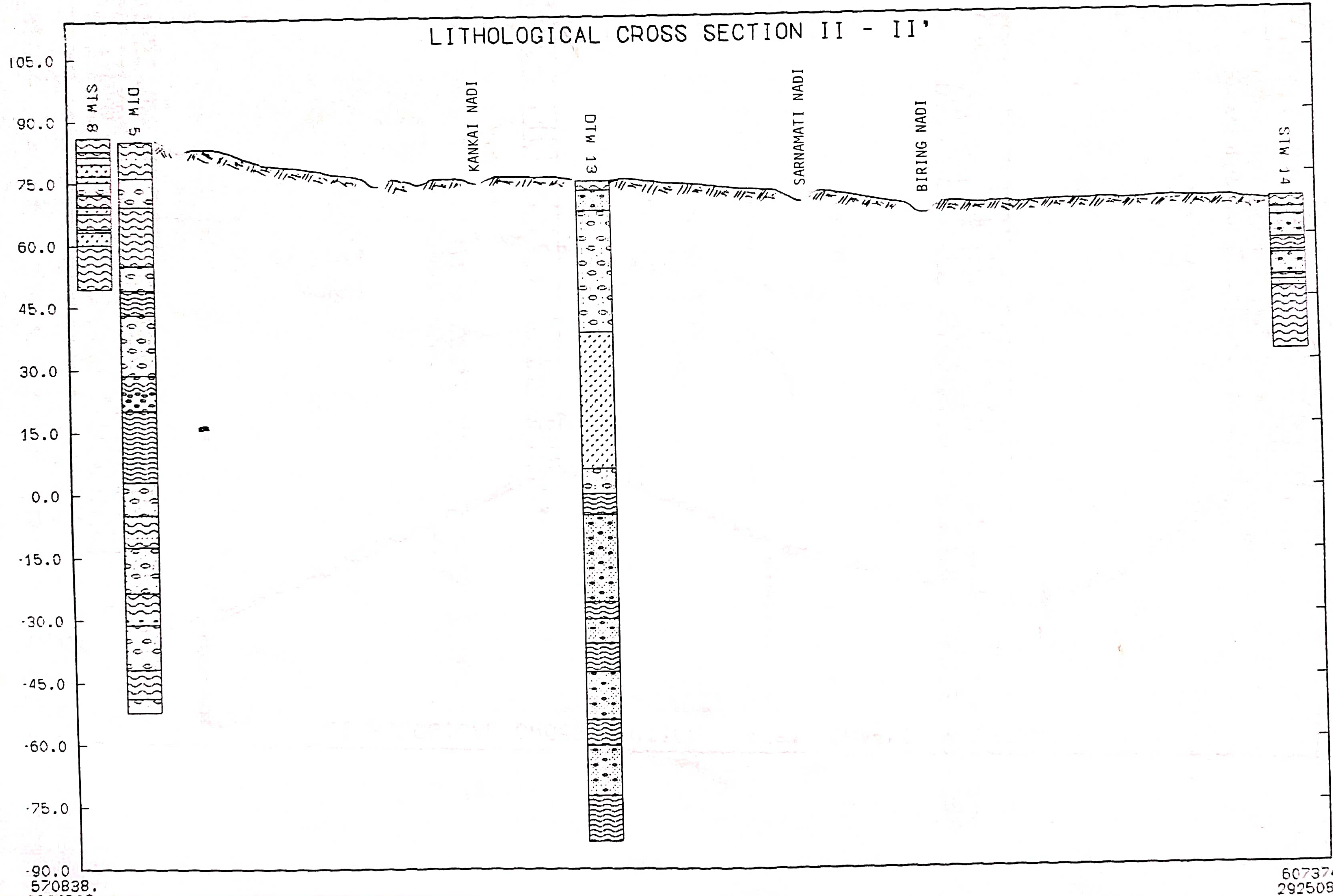

LITHOLOGICAL CROSS SECTION I - I'
DTW 1
DTW 14
ROTUWA NADI
DTW 3
KANKAI RIVER
BIRING NADI
STW 11
DTW 2
NINDA KHOLA
STW 17
DTW 16
150.0
135.0
105.0
75.0
30.0
15.0
0.0
-15.0
-30.0
-45.0
567229.
2950719.
570838.

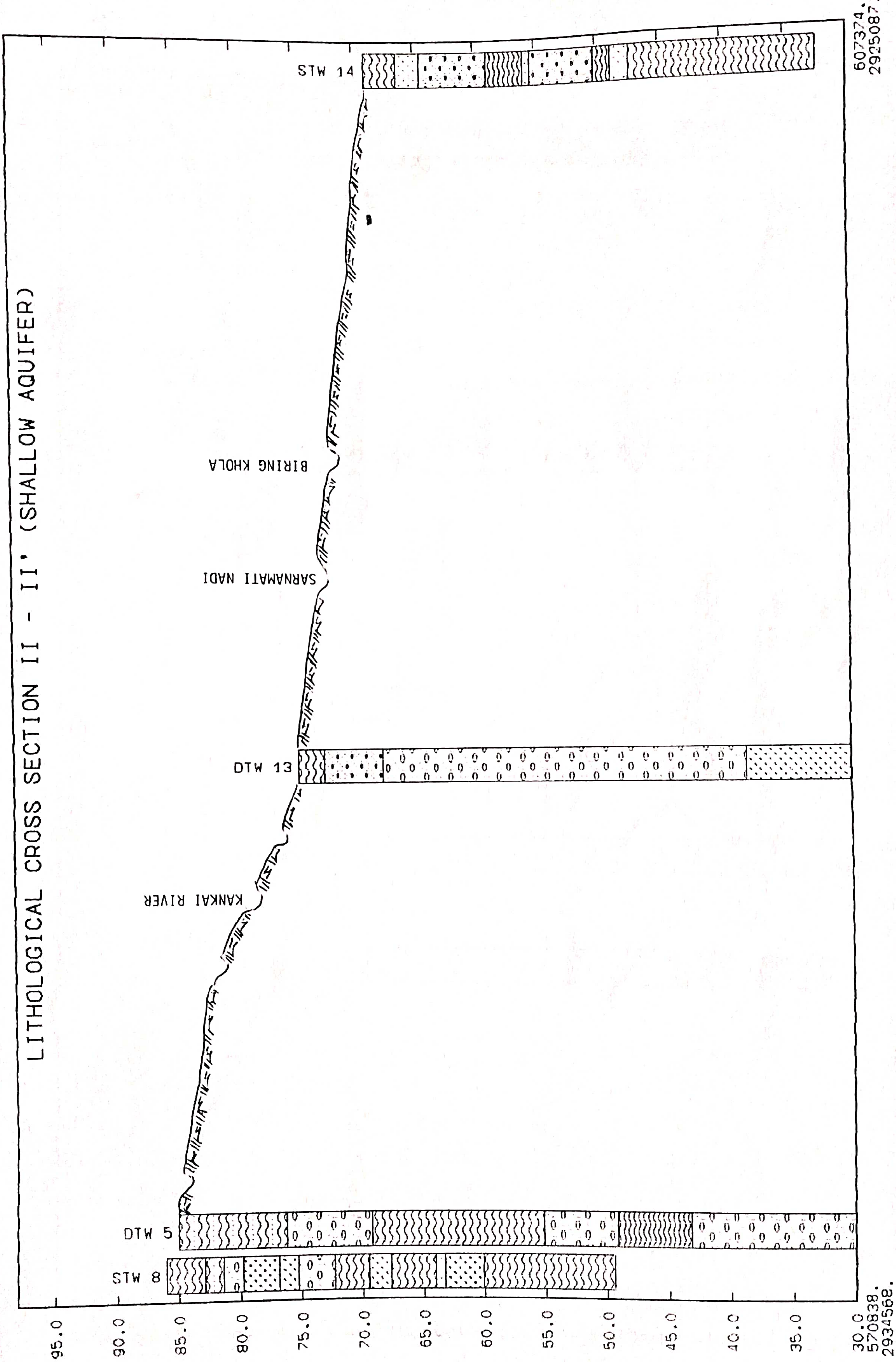
APPENDIX 4/2



LITHOLOGICAL CROSS SECTION I - I' (SHALLOW AQUIFER)
137.7
133.0
128.2
123.5
118.7
114.0
109.2
104.5
99.7
95.0
90.2
85.5
80.7
76.0
567229.
2950719.
616797.
2947347.
DTW 1
DTW 14
ROTUWA NADI
DTW 3
KANKAI RIVER
BIRING NADI
STW 11
DTW 2
NINDA KHOLA

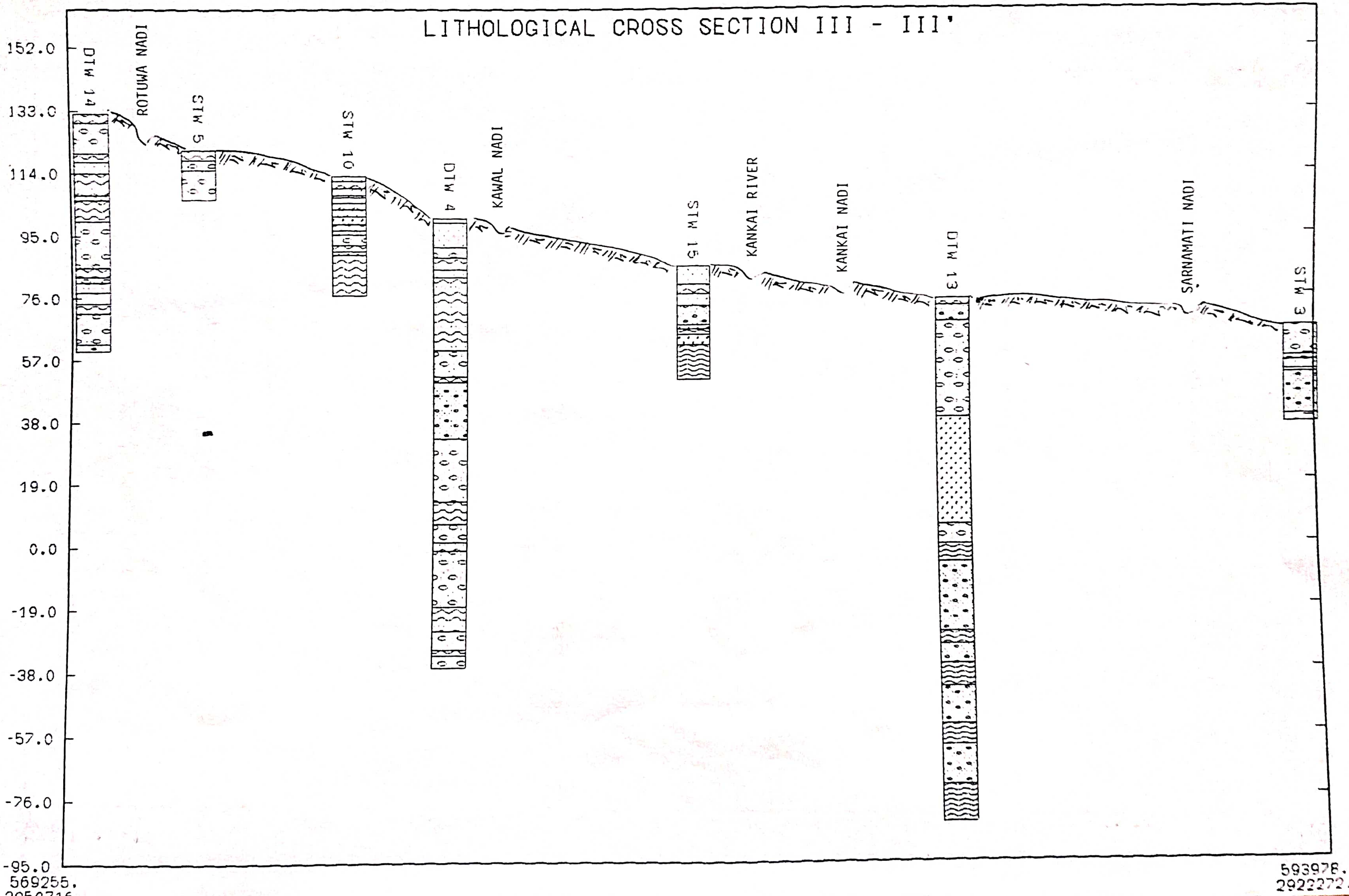
LITHOLOGICAL CROSS SECTION II - II'

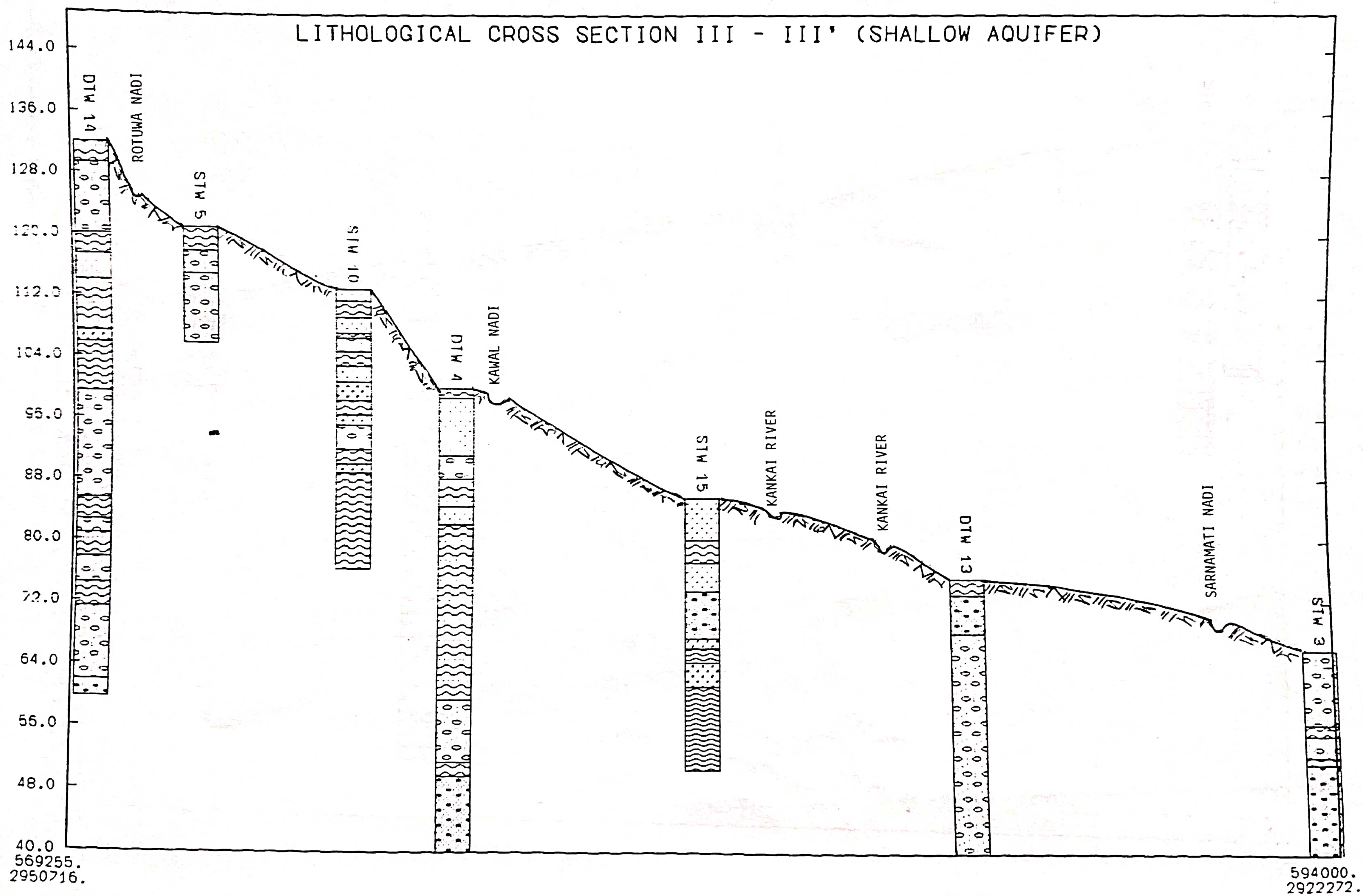


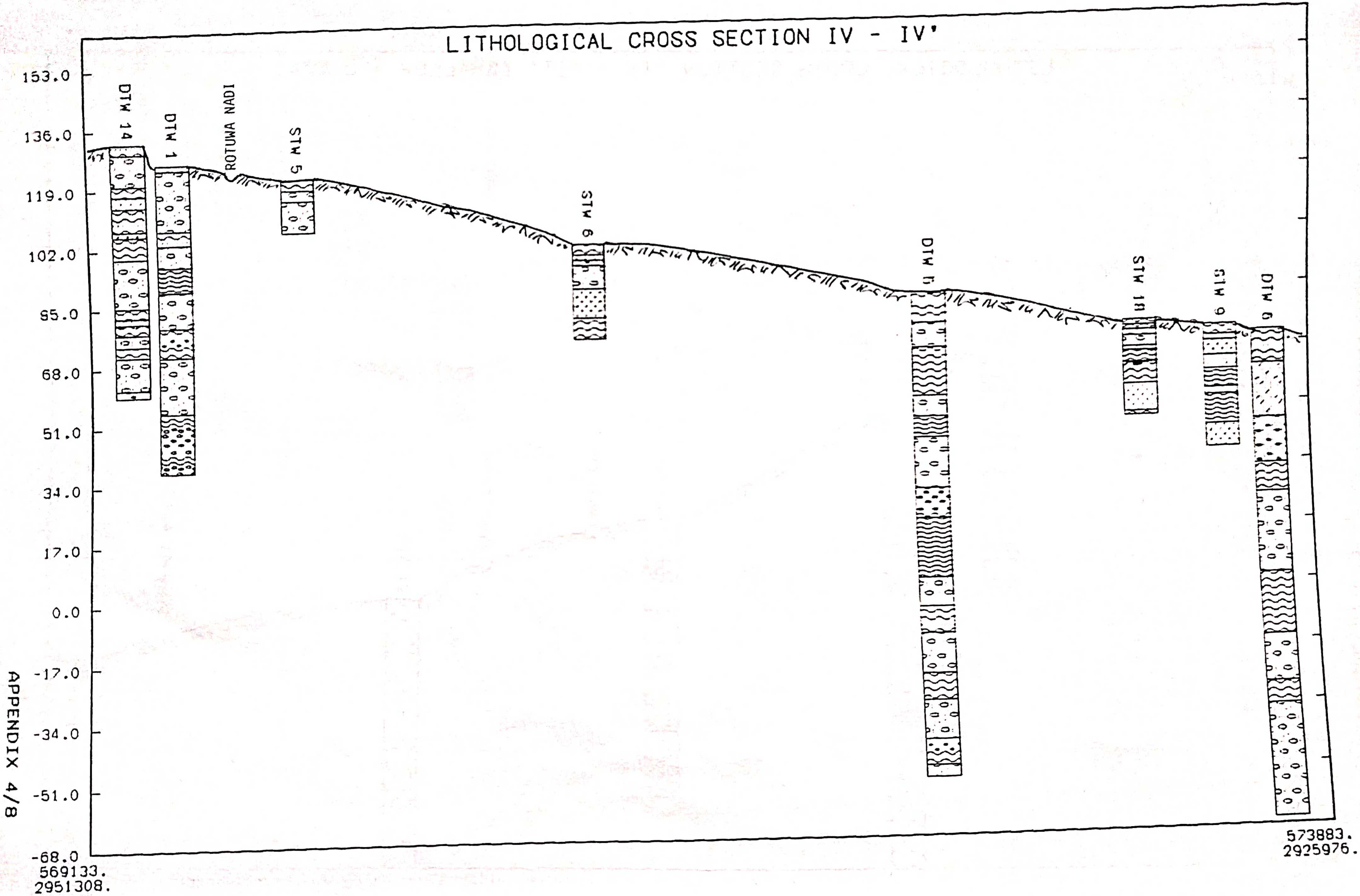


LITHOLOGICAL CROSS SECTION II - II' (SHALLOW AQUIFER)
STW 14
BIRING KHOLA
SARNAMATI NADI
DTW 13
KANKAI RIVER
DTW 5
STW 8
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
570838.
2934568.
607374.
2925087.

APPENDIX 4/5


LITHOLOGICAL CROSS SECTION III - III'
152.0
133.0
114.0
95.0
76.0
57.0
38.0
19.0
0.0
-19.0
-38.0
-57.0
-76.0
-95.0
DTW 14
ROTUWA NADI
STW 5
STW 10
DTW 4
KAWAL NADI
STW 15
KANKAI RIVER
KANKAI NADI
DTW 13
SARNAMATI NADI
STW 3
569255.
593978.
2922272.

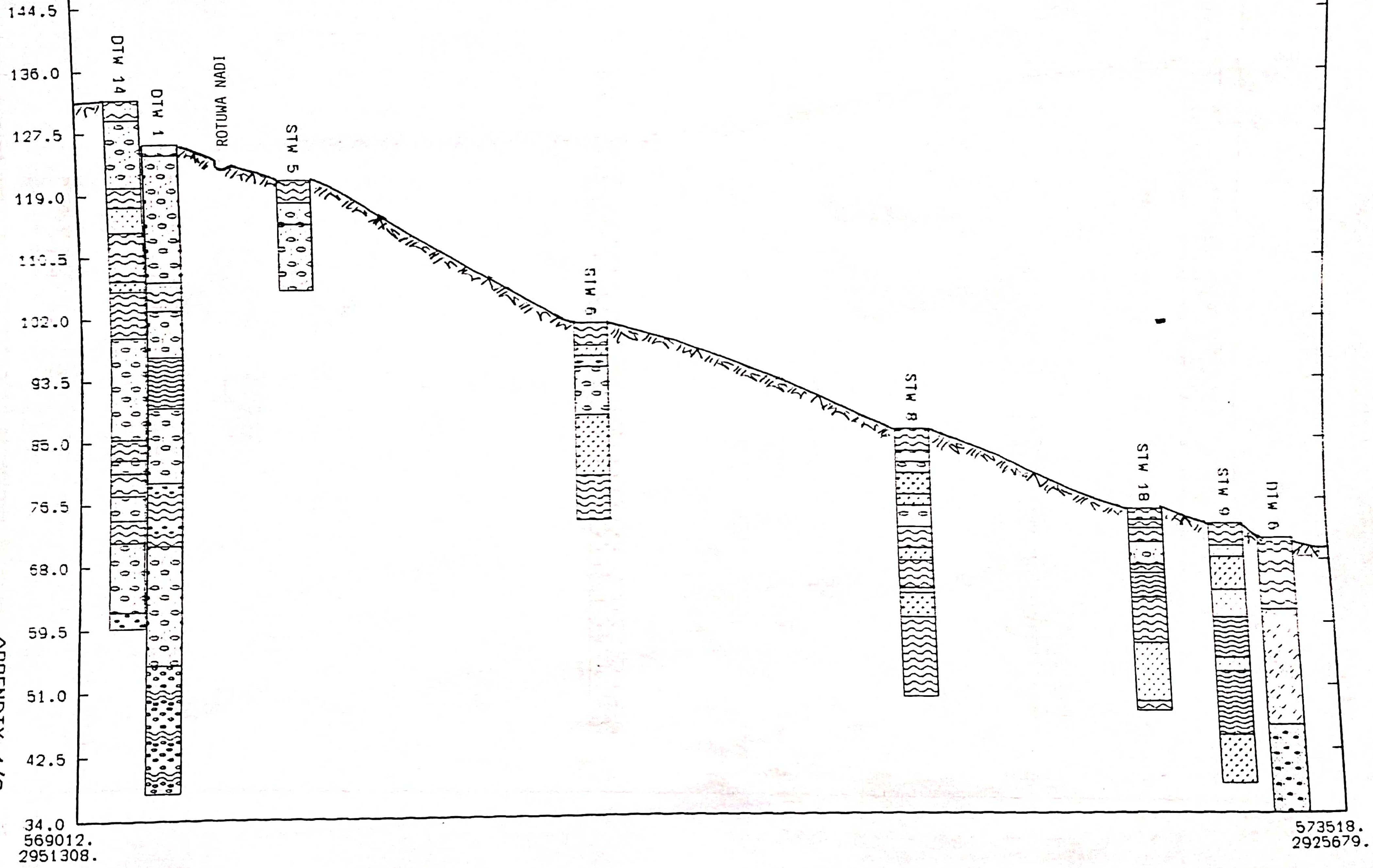

LITHOLOGICAL CROSS SECTION III - III' (SHALLOW AQUIFER)
144.0
136.0
128.0
120.0
112.0
104.0
96.0
88.0
80.0
72.0
64.0
56.0
48.0
40.0
569255.
2950716.
594000.
2922272.
DTW 14
ROTUWA NADI
STW 5
STW 10
DTW 4
KAWAL NADI
STW 15
KANKAI RIVER
KANKAI RIVER
DTW 13
SARNAMATI NADI
STW 3



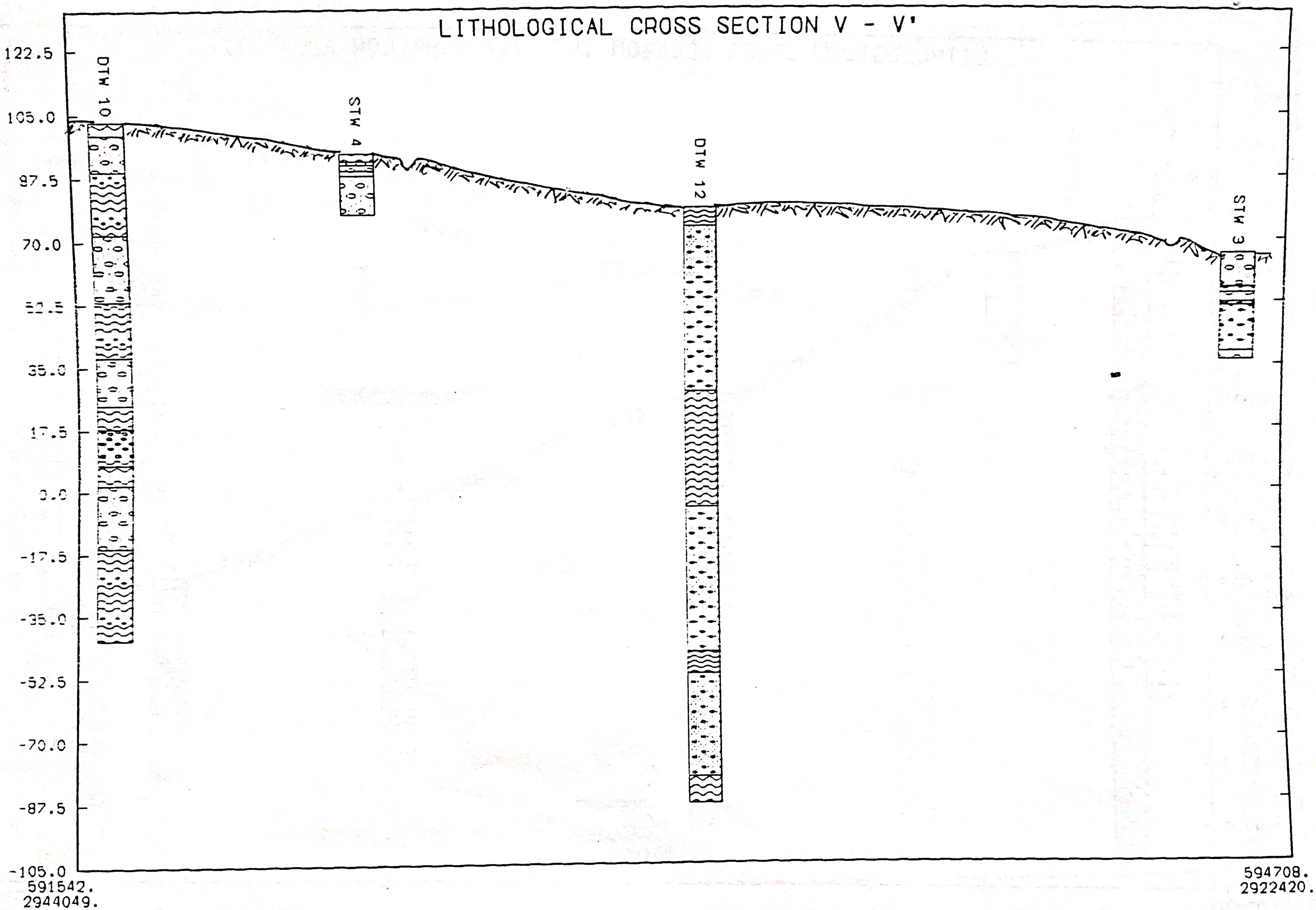
LITHOLOGICAL CROSS SECTION IV - IV'
153.0
136.0
119.0
102.0
85.0
68.0
51.0
34.0
17.0
0.0
-17.0
-34.0
-51.0
-68.0
569133.
2951308.
573883.
2925976.
DTW 14
DTW 1
ROTUWA NADI
STW 5
STW 6
DTW 5
STW 10
STW 9
DTW 6

APPENDIX 4/8

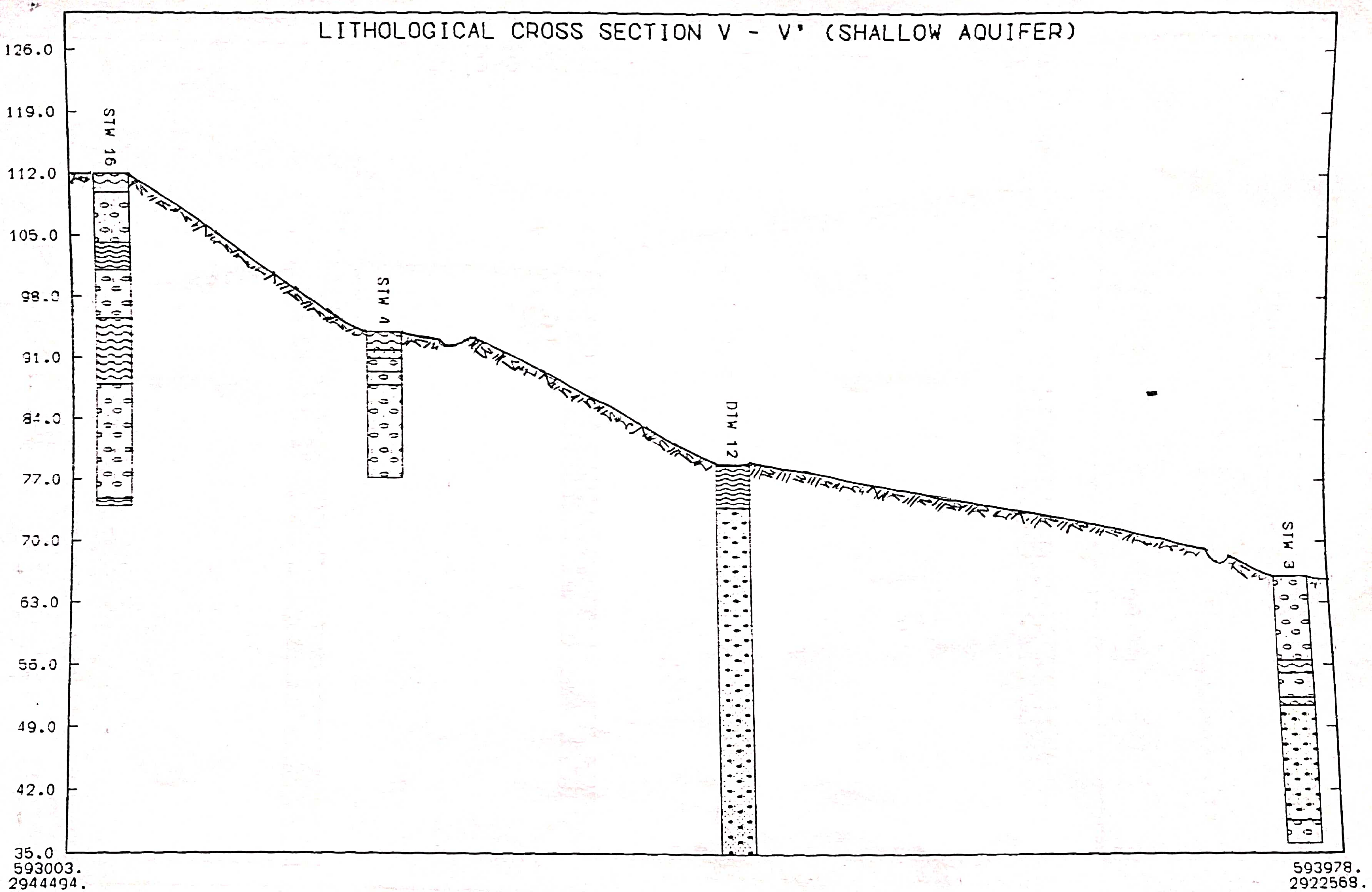
LITHOLOGICAL CROSS SECTION IV - IV' (SHALLOW AQUIFER)



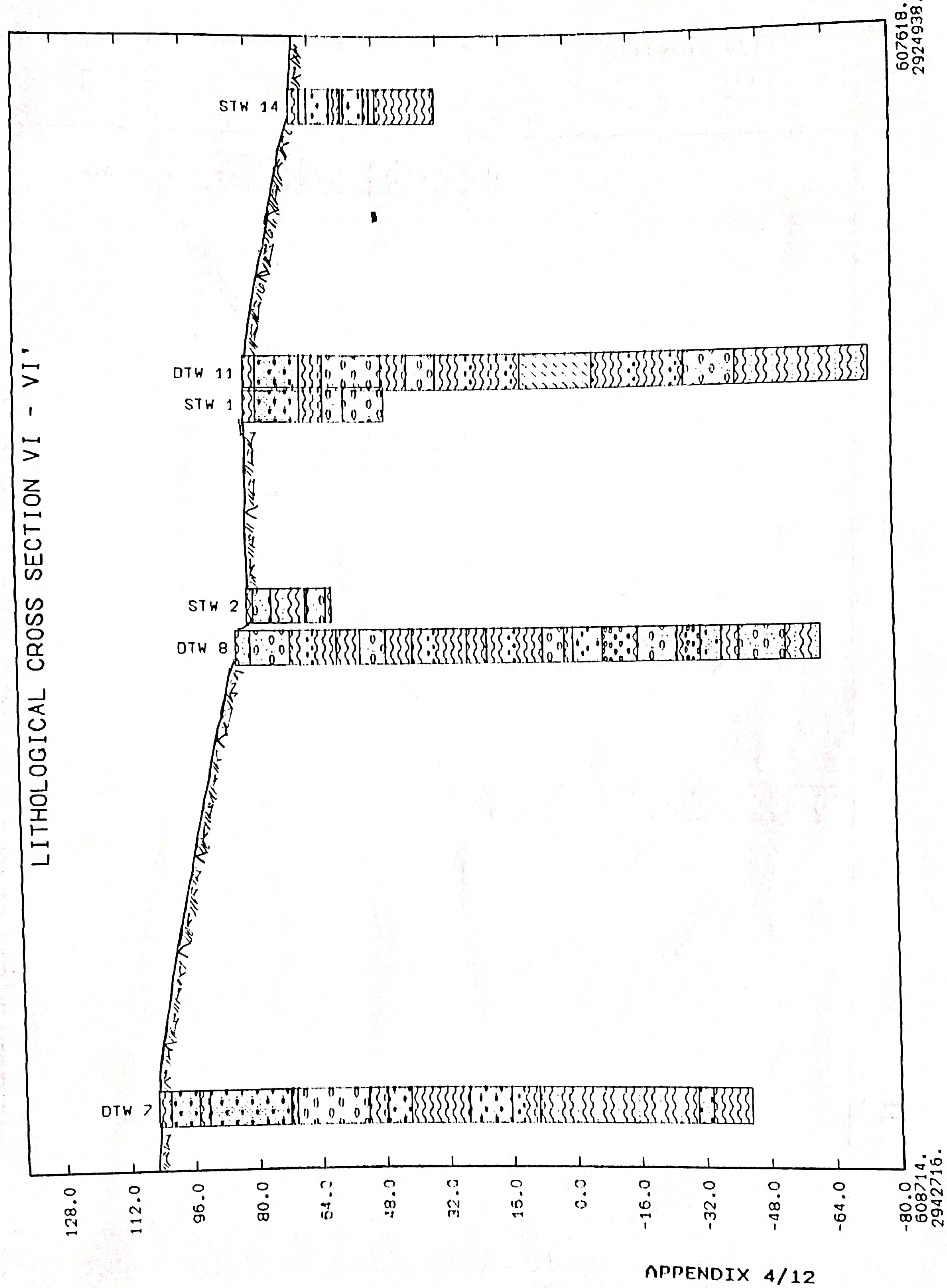
APPENDIX 4/9



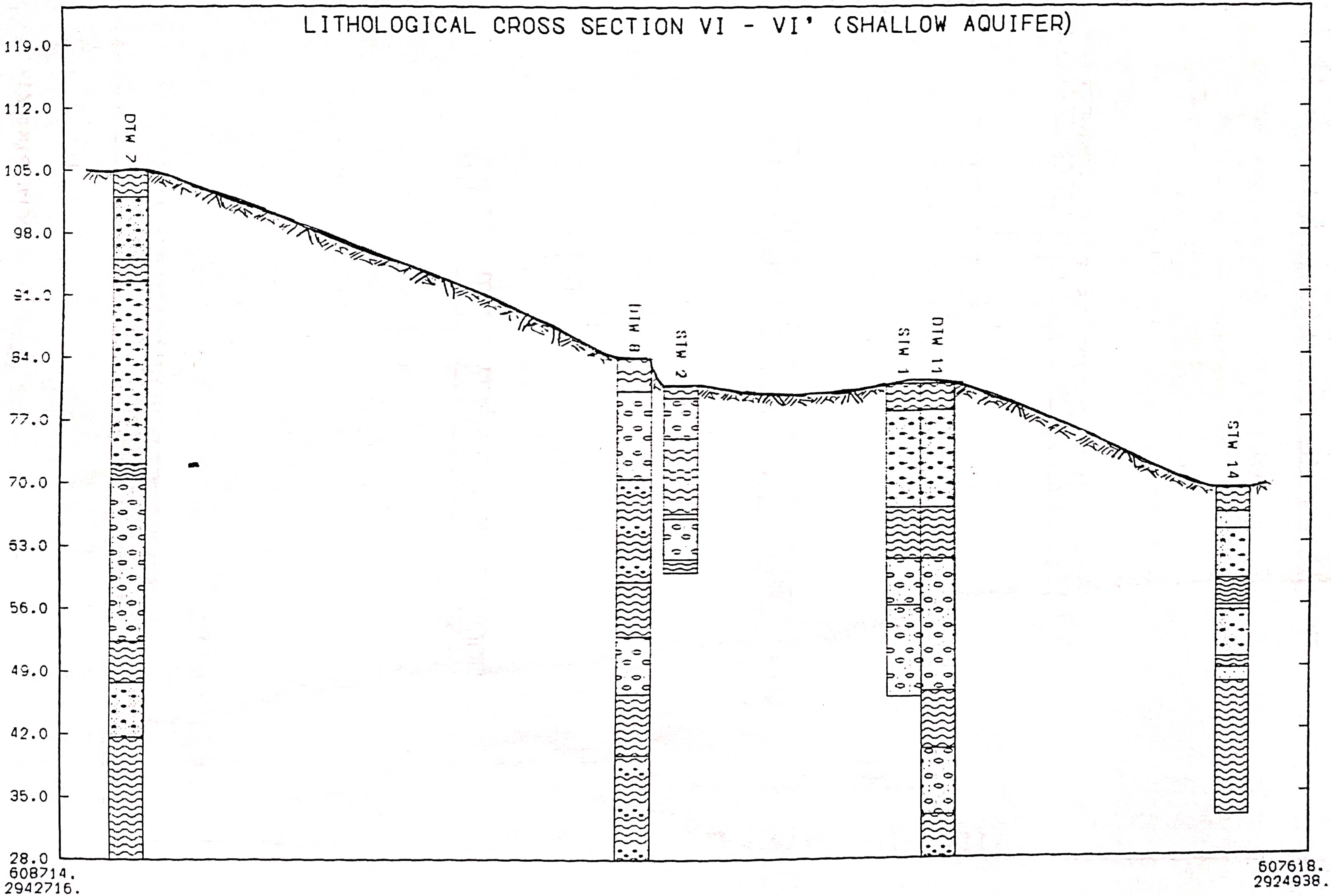
APPENDIX 4/10



APPENDIX 4/11

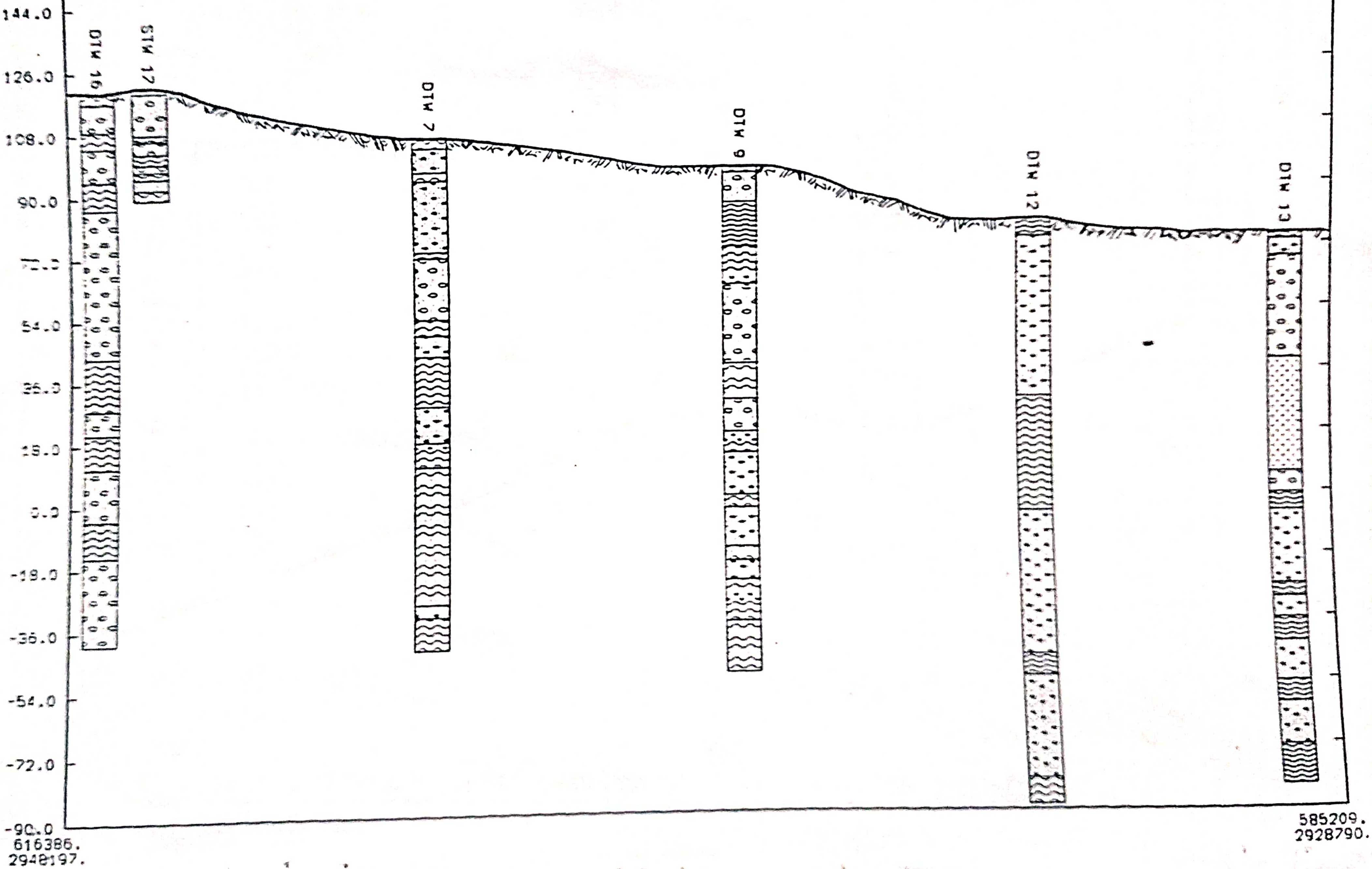


APPENDIX 4/12



APPENDIX 4/13

LITHOLOGICAL CROSS SECTION VII - VII'



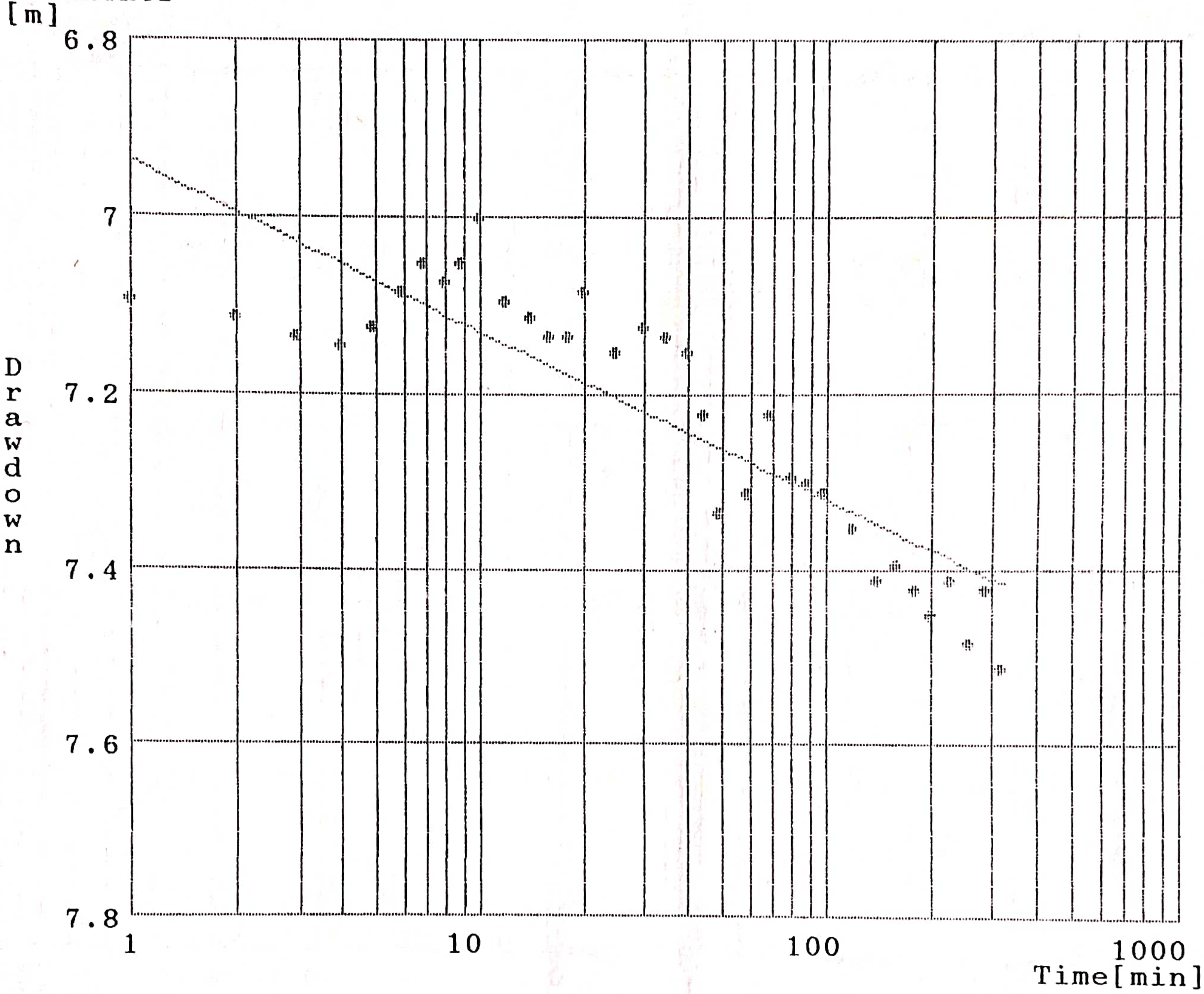
APPENDIX 4/14

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

Test : STW 2 MAHESHPUR

Constant Pumping Rate = 7.500 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

JACOB METHOD



Transmissivity = 621. [m2/day]

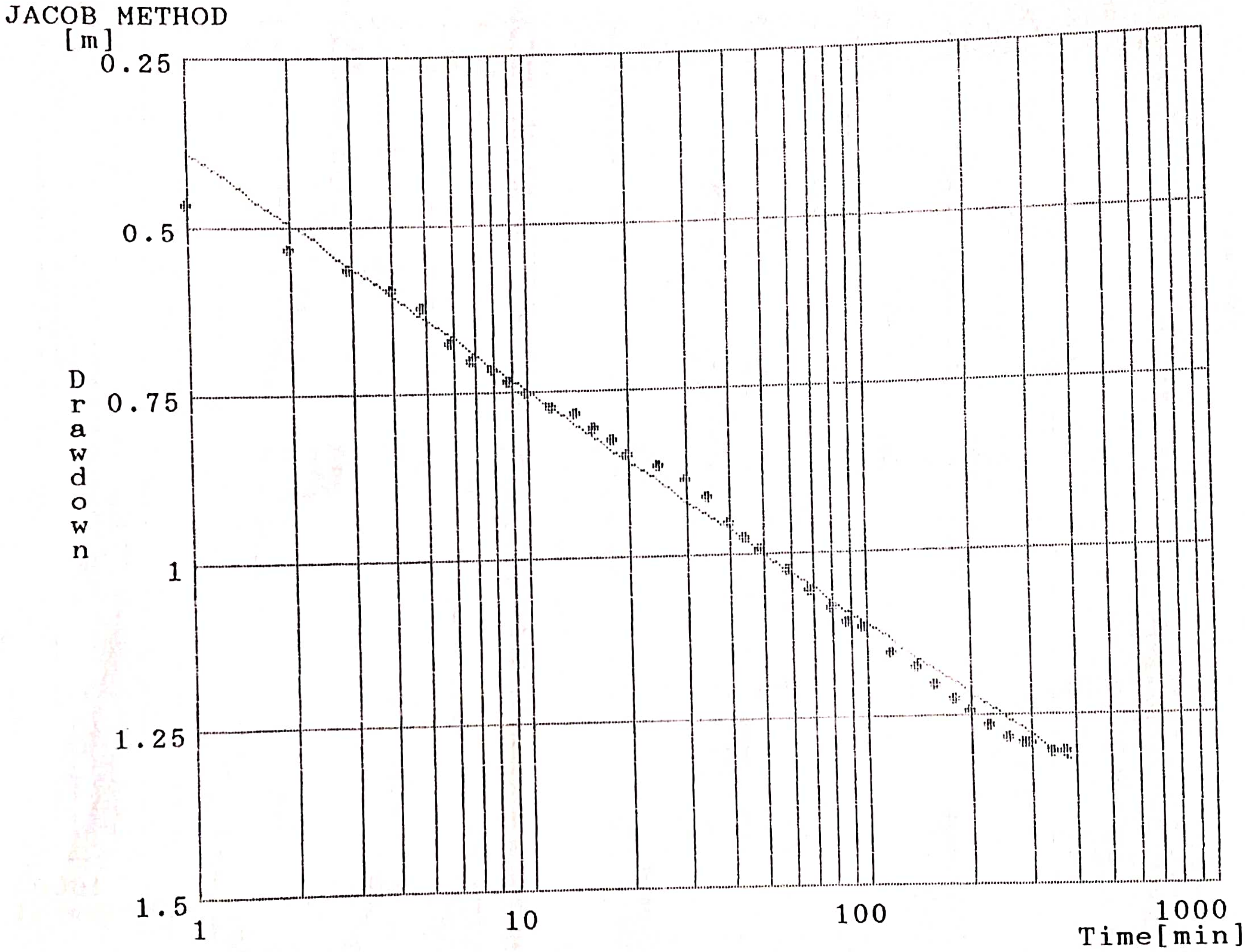
Standard Deviation = 0.0708 [m]
A0 = 0.693711E+01
A1 = 0.190891E+00
Number of Points = 35 of 35

APPENDIX 5/1A

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

Test : STW 2 MAHESHPUR (OBS)

Constant Pumping Rate = 7.500 [l/s]
Distance from Pumping Well = 11.75 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.22 [m]
Well Type = STANDARD



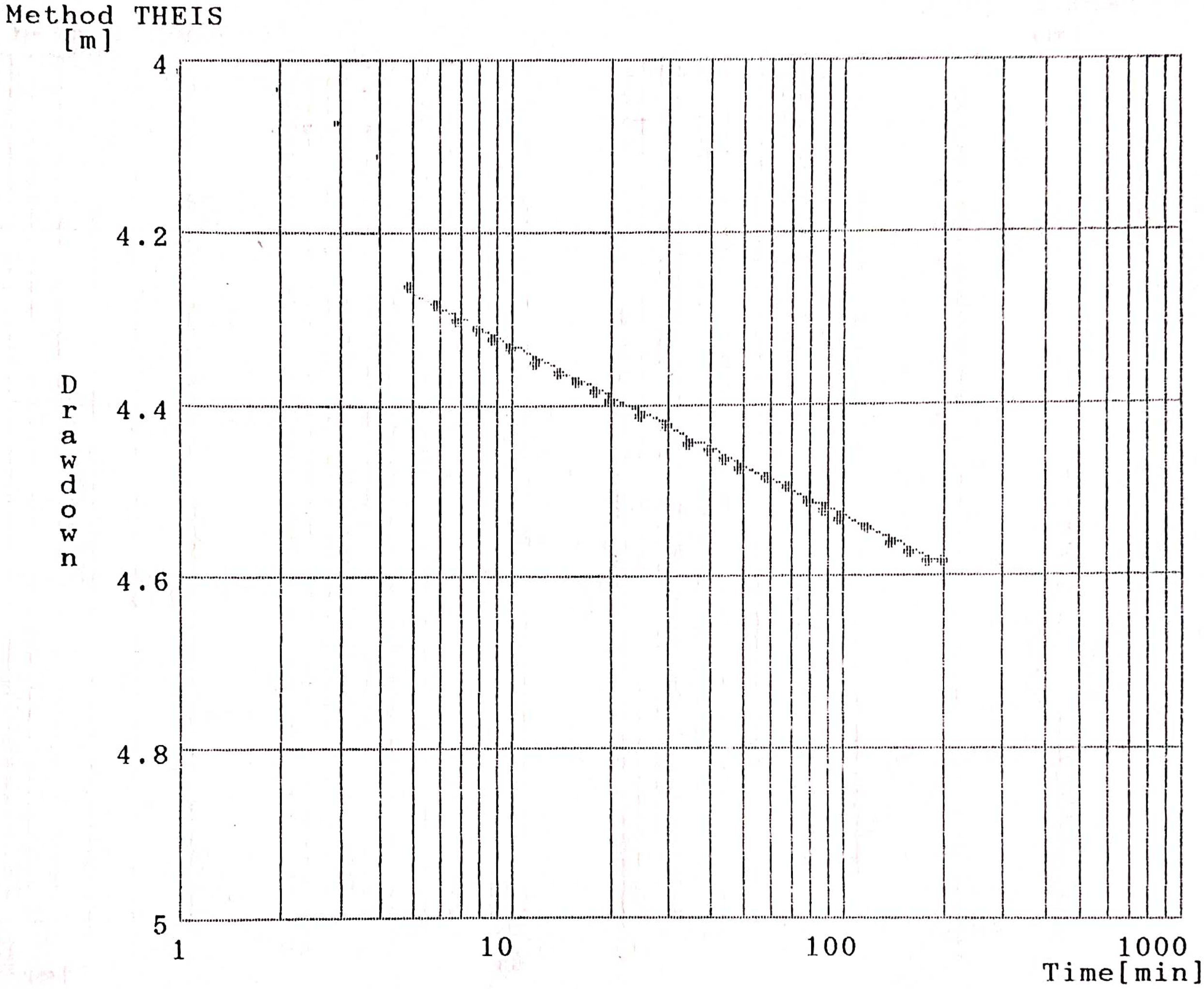
Transmissivity = 329. [m2/day]
Storage Coefficient = 0.31E-03
Standard Deviation = 0.0209 [m]
A0 = 0.387313E+00
A1 = 0.360320E+00
Number of Points = 37 of 37

APPENDIX 5/1B

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

Test : STW 4 PHULBARI

Constant Pumping Rate = 15.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.99 [m]
Well Type = STANDARD



Transmissivity = 1193. [m2/day]

Standard Deviation = 0.0035 [m]

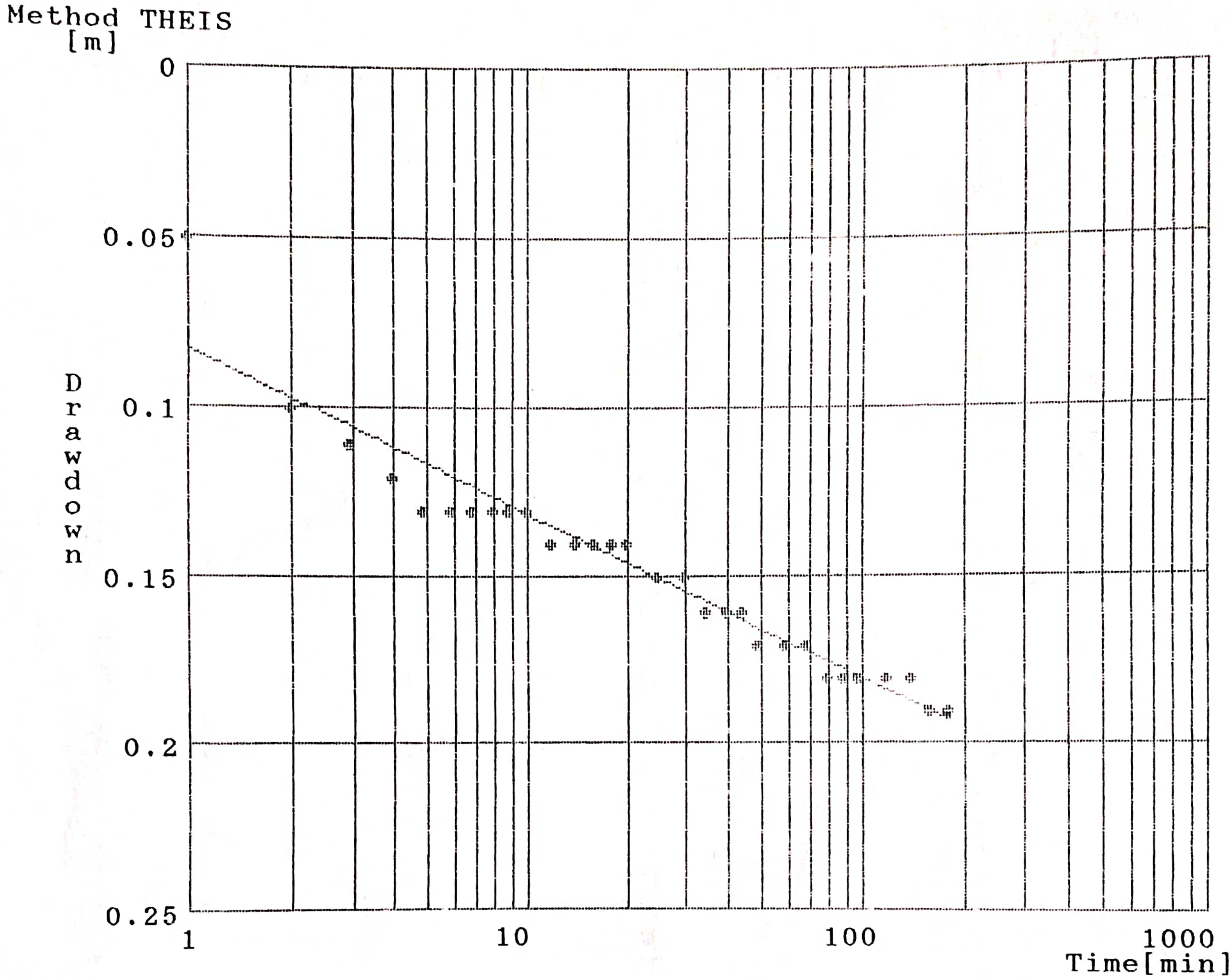
Number of Points = 27 of 31

APPENDIX 5/2A

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

Test : STW 4 PHULBARI (OBS)

Constant Pumping Rate = 15.000 [l/s]
Distance from Pumping Well = 9.30 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.54 [m]
Well Type = STANDARD



Transmissivity = 4833. [m2/day]
Storage Coefficient = 0.19E-02
Standard Deviation = 0.0076 [m]

Number of Points = 30 of 30

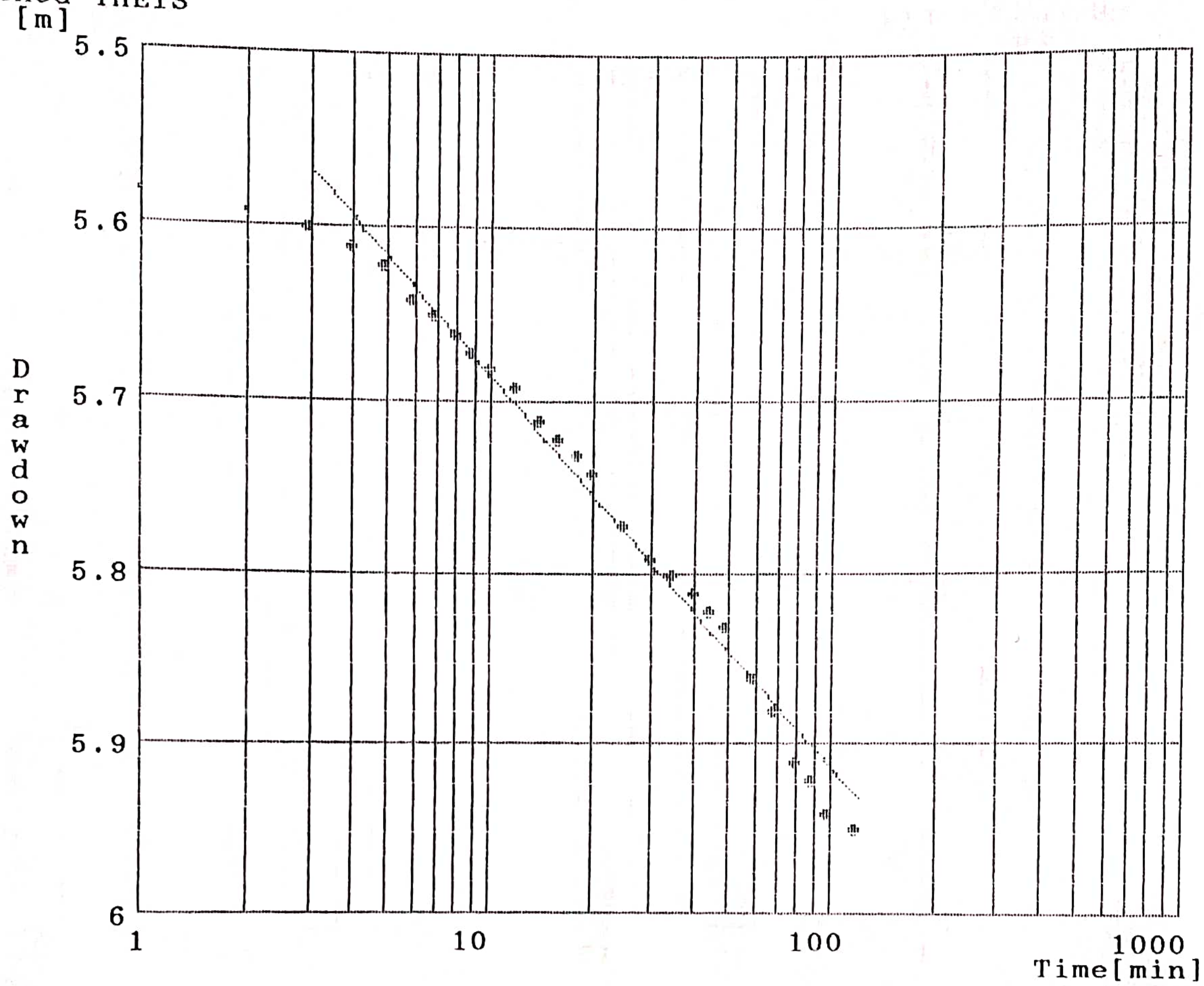
APPENDIX 5/2B

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

Test : STW 5 LAKHANPUR

Constant Pumping Rate = 8.700 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.03 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 601. [m2/day]

Standard Deviation = 0.0137 [m]

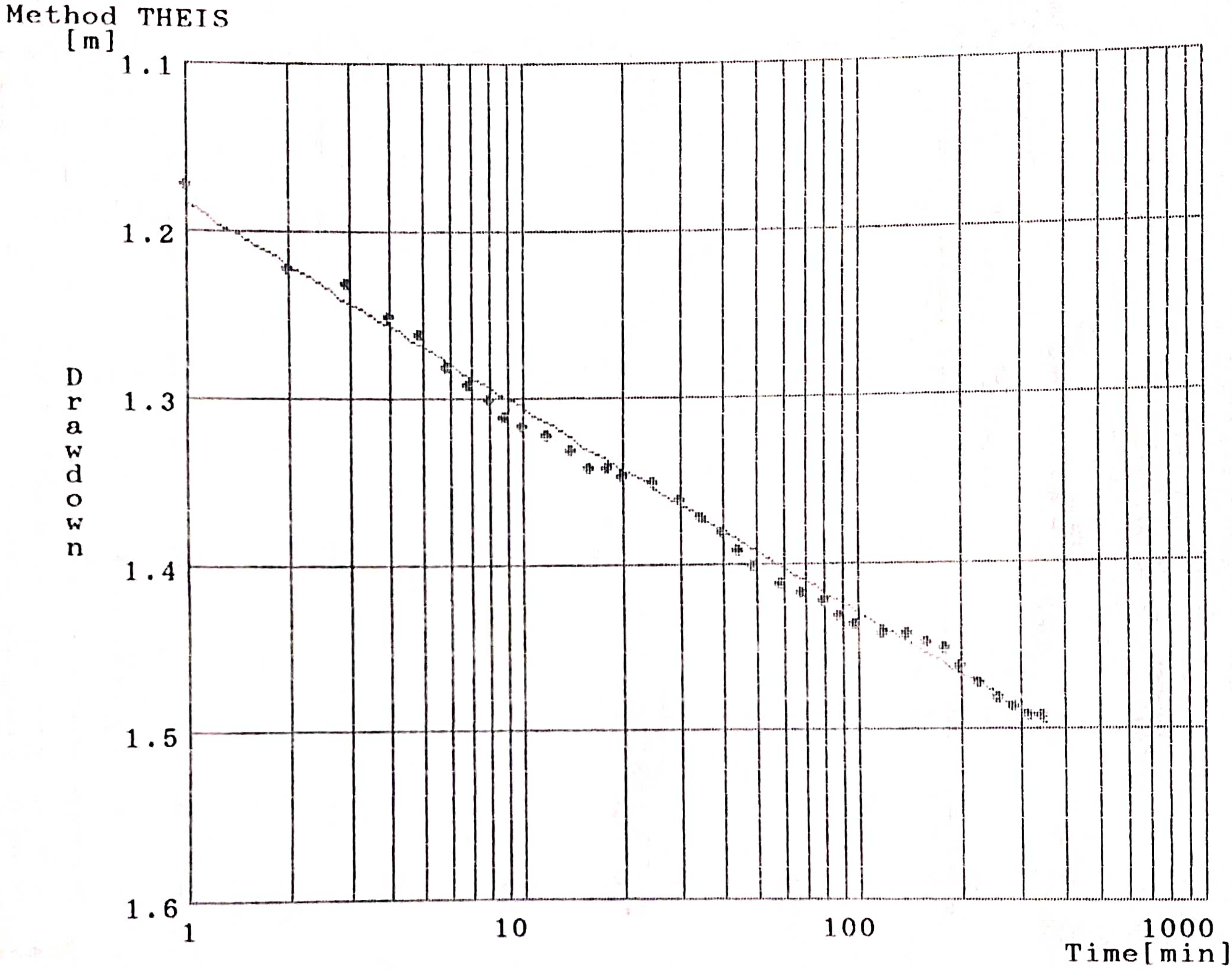
Number of Points = 25 of 27

APPENDIX 5/3

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

Test : STW 7 KANKAI

Constant Pumping Rate = 8.300 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -7.16 [m]
Well Type = STANDARD



Transmissivity = 1068. [m2/day]

Standard Deviation = 0.0063 [m]

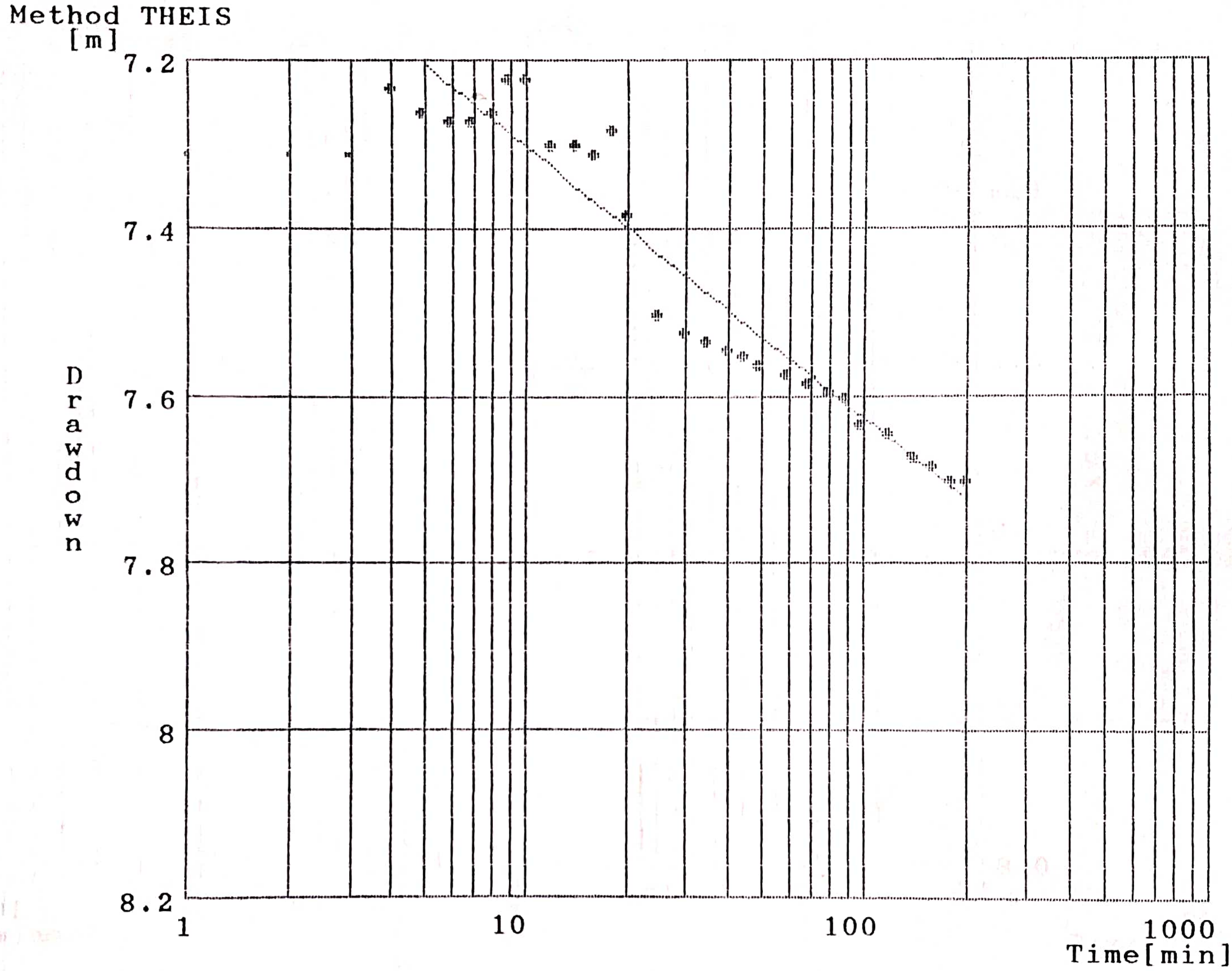
Number of Points = 36 of 36

APPENDIX 5/4

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

Test : STW 8 GWALDUBBA

Constant Pumping Rate = 6.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.40 [m]
Well Type = STANDARD



Transmissivity = 294. [m2/day]

Standard Deviation = 0.0441 [m]

Number of Points = 28 of 31

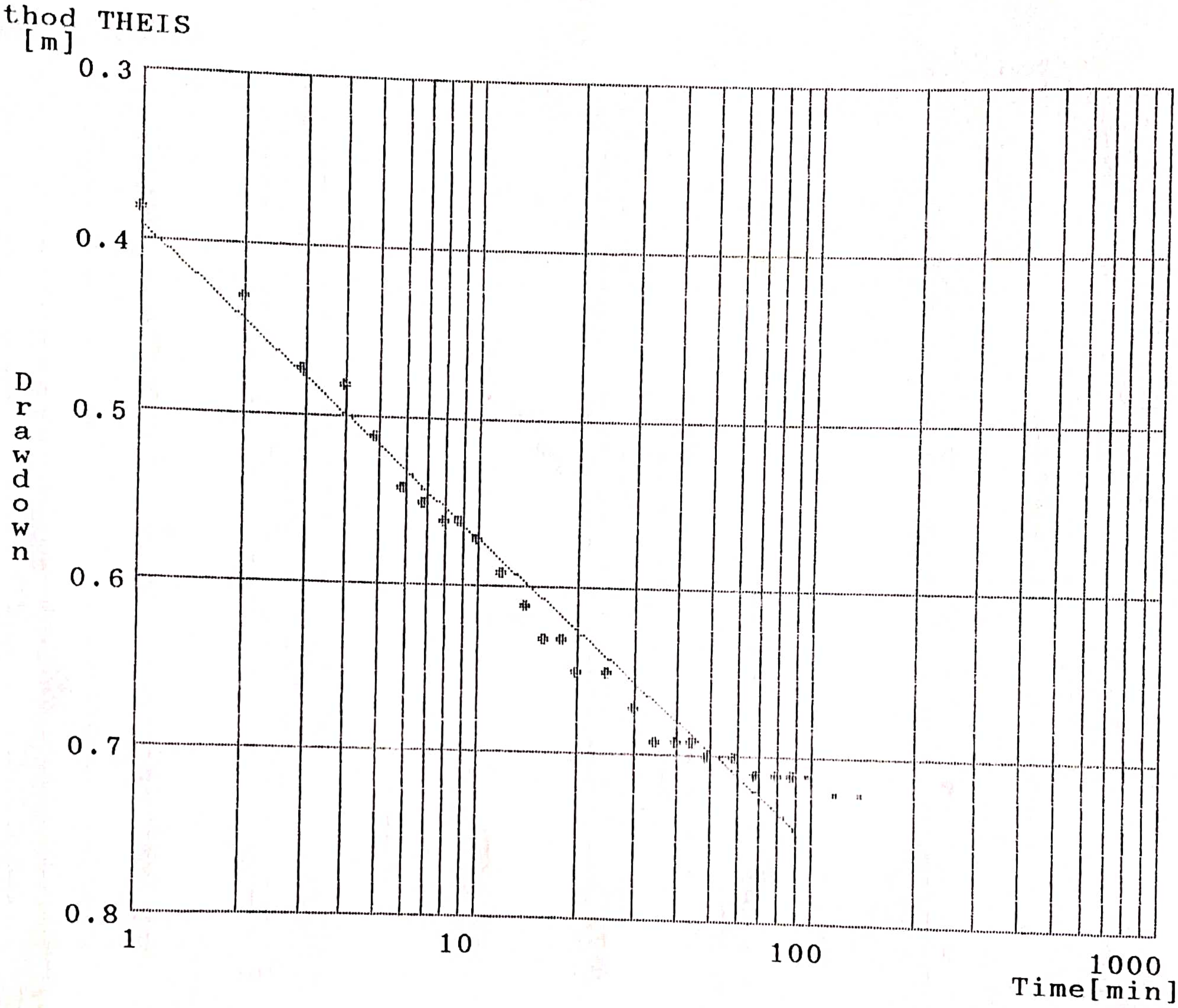
APPENDIX 5/5A

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

Test : STW 8 GWALDUBBA (OBS)

Constant Pumping Rate = 6.000 [l/s]
Distance from Pumping Well = 7.90 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.07 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 525. [m2/day]
Storage Coefficient = 0.91E-04
Standard Deviation = 0.0144 [m]

Number of Points = 25 of 28

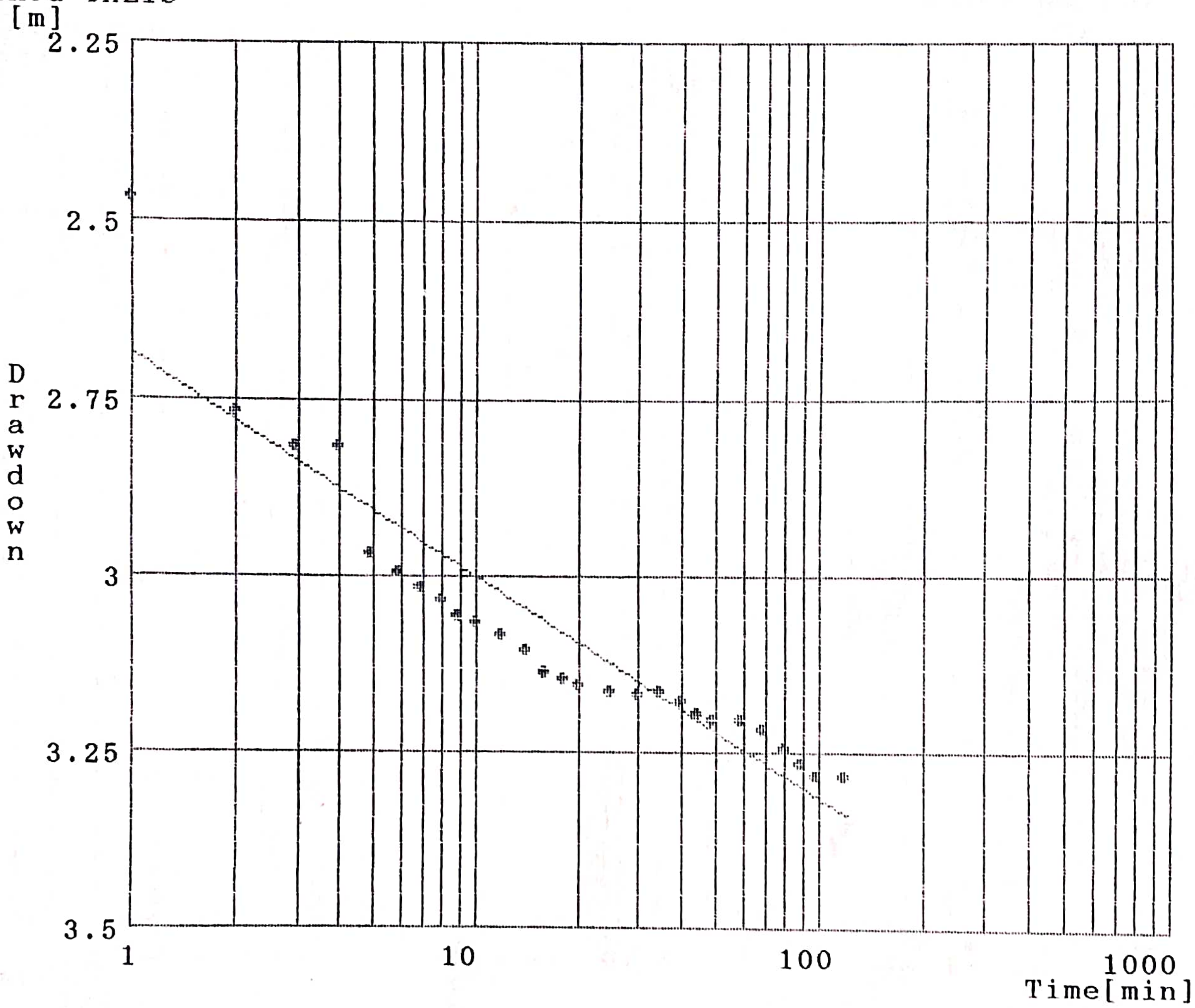
APPENDIX 5/5B

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

Test : STW 11 BUTTABARI

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 = -4.70 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 1005. [m2/day]

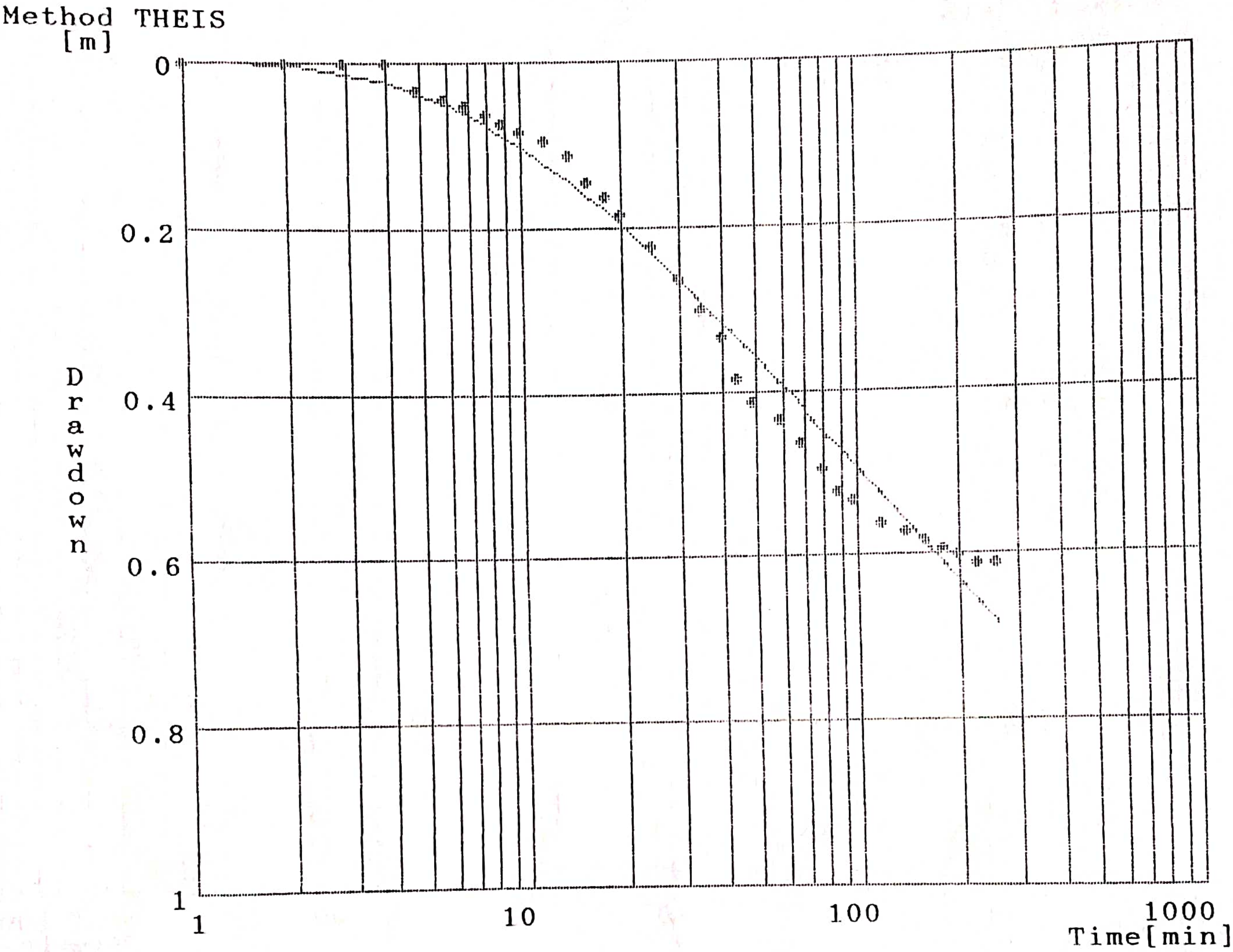
Standard Deviation = 0.0639 [m]

Number of Points = 27 of 27

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

Test : STW 11 BUTTABARI (OBS)

Constant Pumping Rate = 20.000 [l/s]
Distance from Pumping Well = 24.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.27 [m]
Well Type = STANDARD



Transmissivity = 654. [m2/day]
Storage Coefficient = 0.18E-01
Standard Deviation = 0.0302 [m]

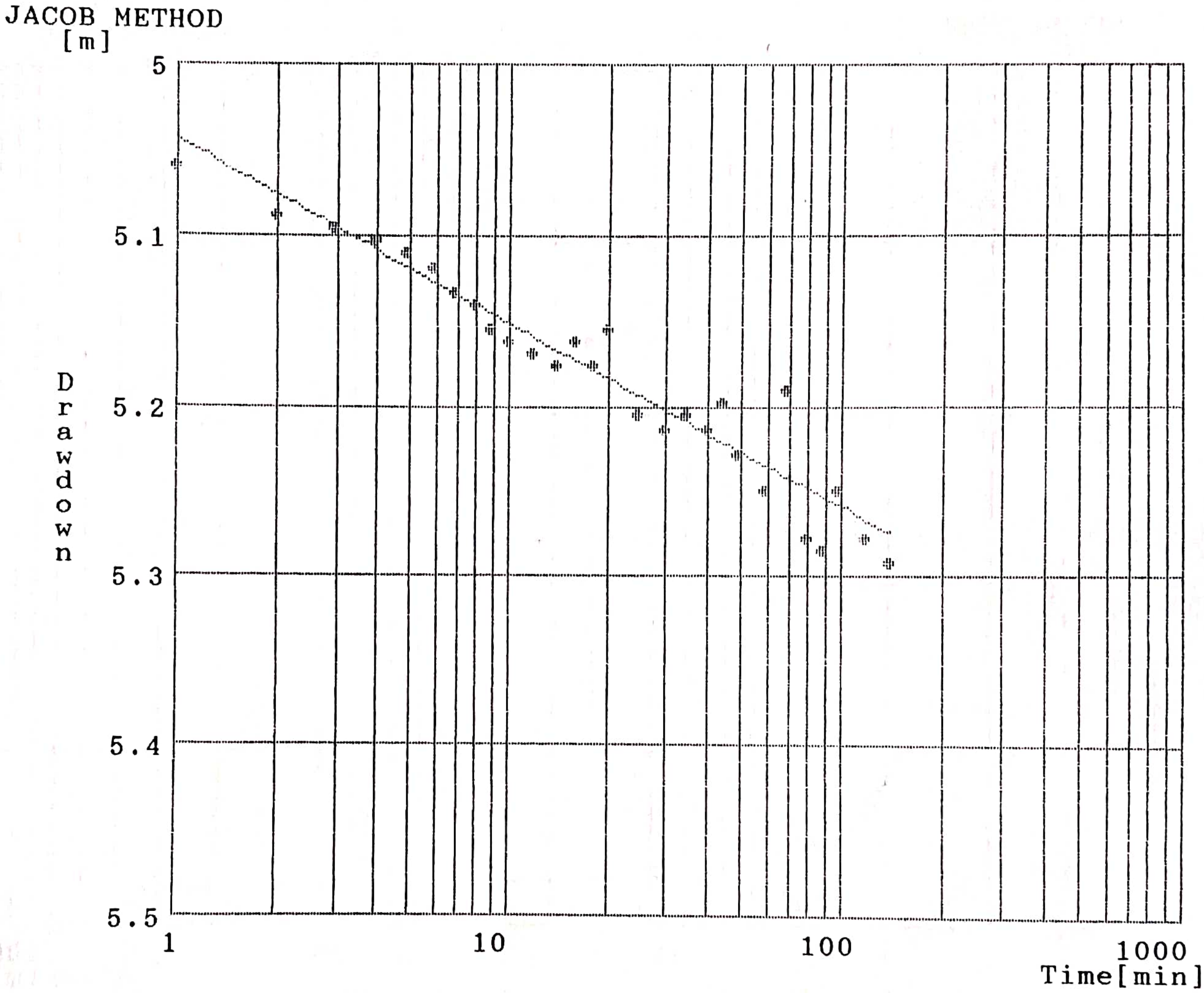
Number of Points = 33 of 33

APPENDIX 5/6B

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

Test : STW 12 SATASHI

Constant Pumping Rate = 4.000 [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 = -2.41 [m]
Well Type = STANDARD



Transmissivity = 588. [m2/day]

Standard Deviation = 0.0168 [m]
A0 = 0.504310E+01
A1 = 0.107472E+00
Number of Points = 28 of 28

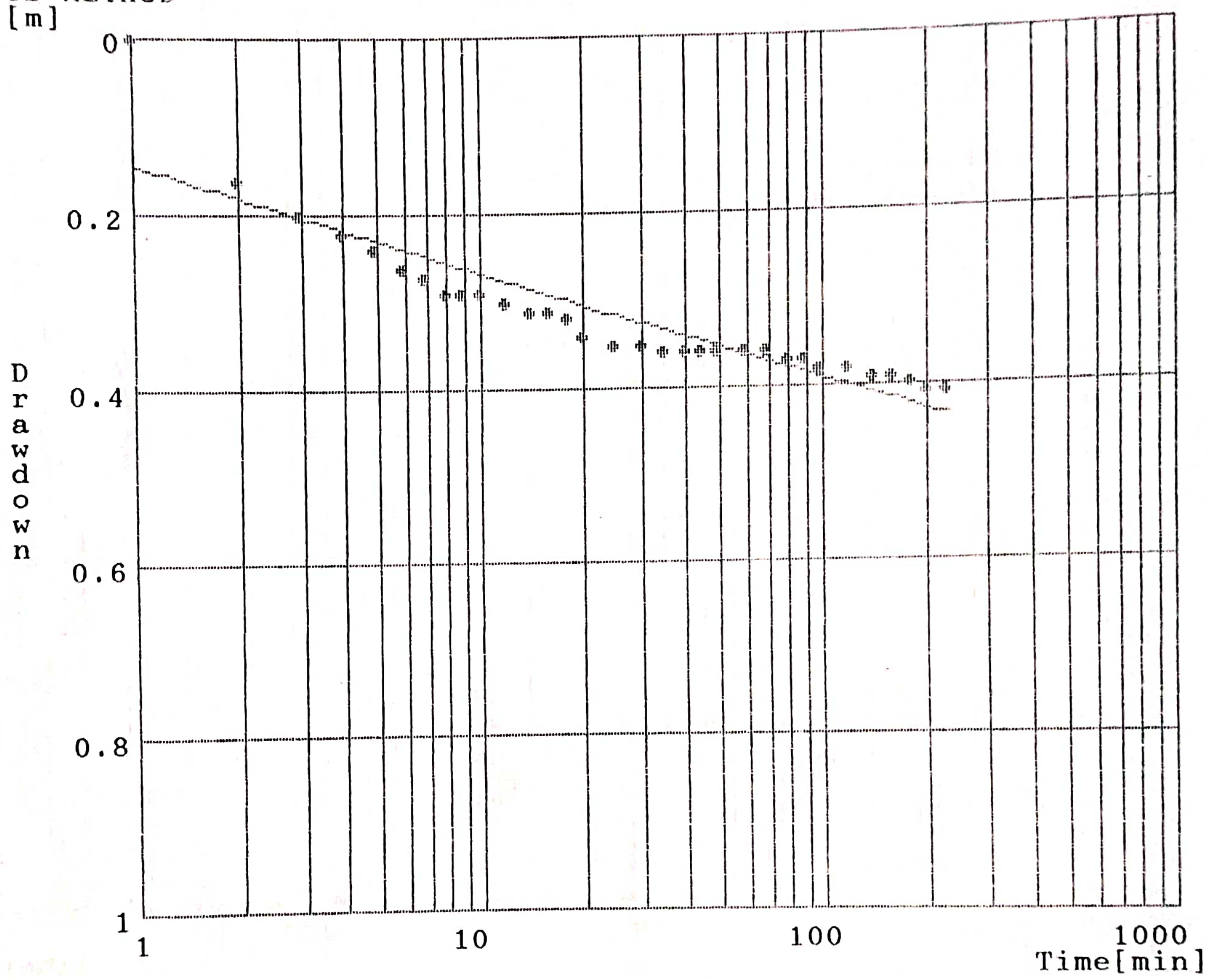
APPENDIX 5/7A

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

Test : STW 12 SATASHI (OBS)

Constant Pumping Rate = 4.000 [l/s]
Distance from Pumping Well = 5.10 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 22.00 [m]
Type of Input Data = LEVEL
Static Water Level = -0.91 [m]
Well Type = STANDARD

JACOB METHOD



Transmissivity = 515. [m2/day]
Storage Coefficient = 0.21E-02
Standard Deviation = 0.0325 [m]
A0 = 0.143220E+00
A1 = 0.122881E+00
Number of Points = 32 of 32

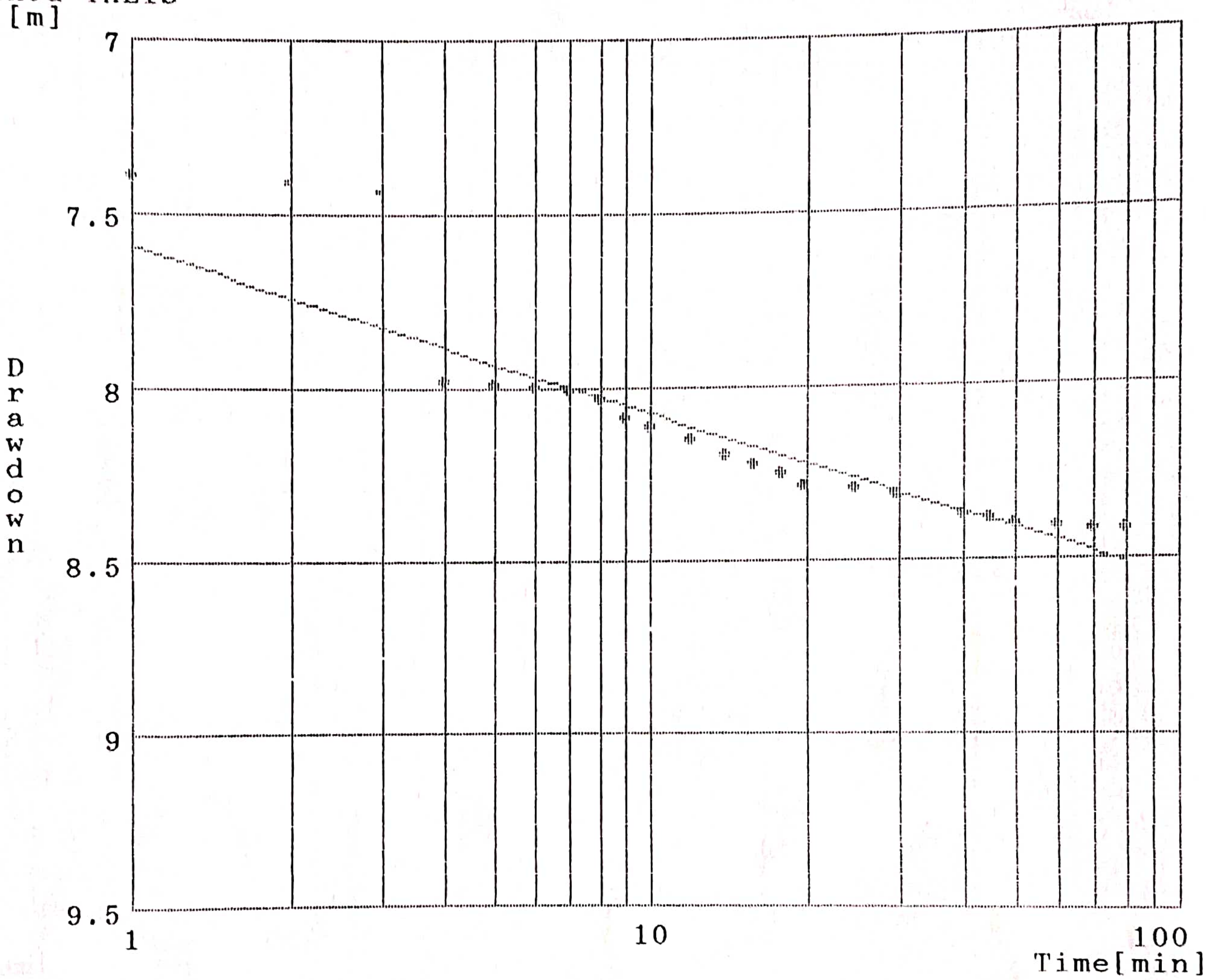
APPENDIX 5/7B

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

Test : STW 14 SANGAMBASTI

Constant Pumping Rate = 5.400 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -0.88 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 178. [m2/day]

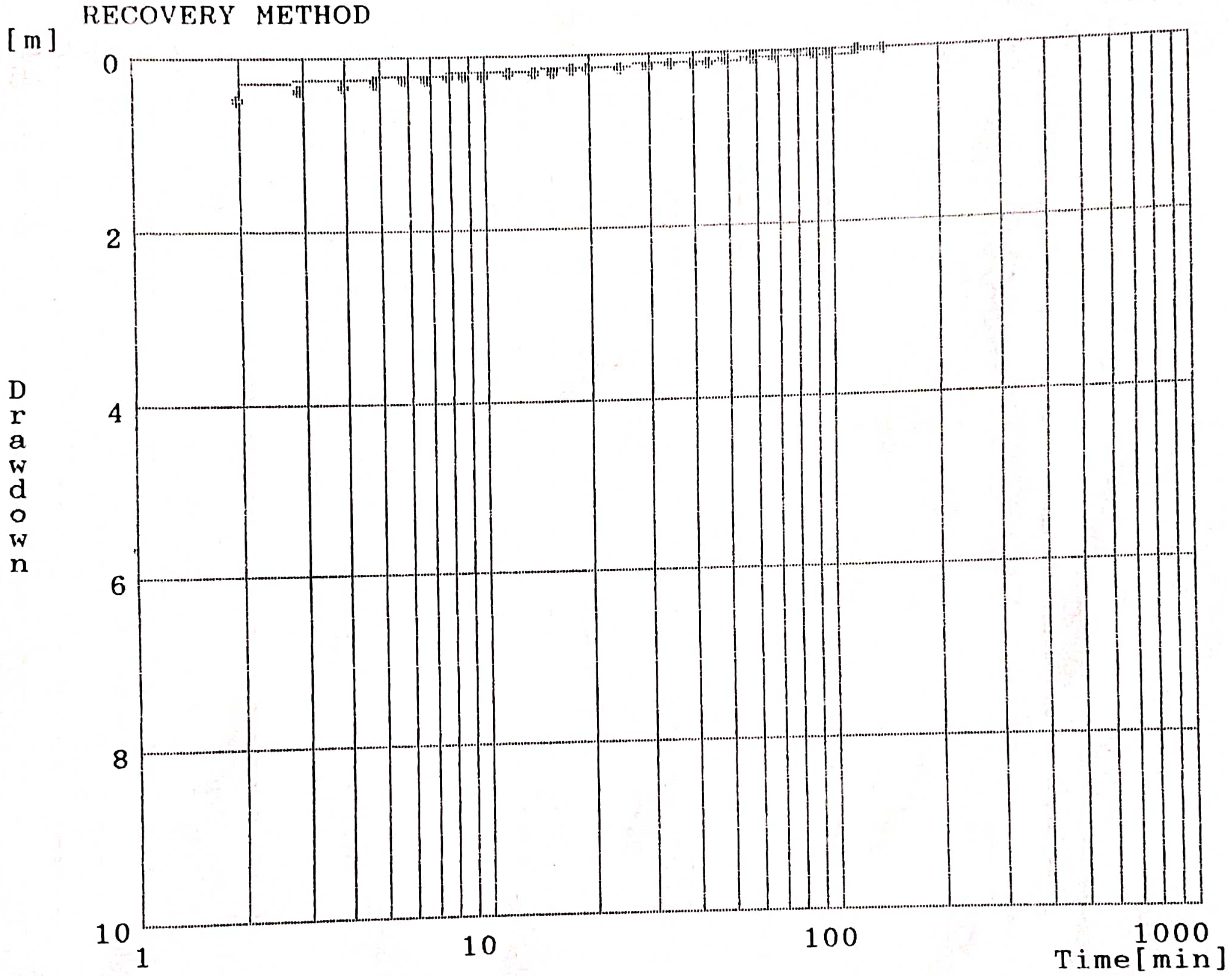
Standard Deviation = 0.0630 [m]

Number of Points = 21 of 23

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

Test : STW 15 PANCHGACHHI (REC)

Constant Pumping Rate = 8.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.23 [m]
Well Type = STANDARD



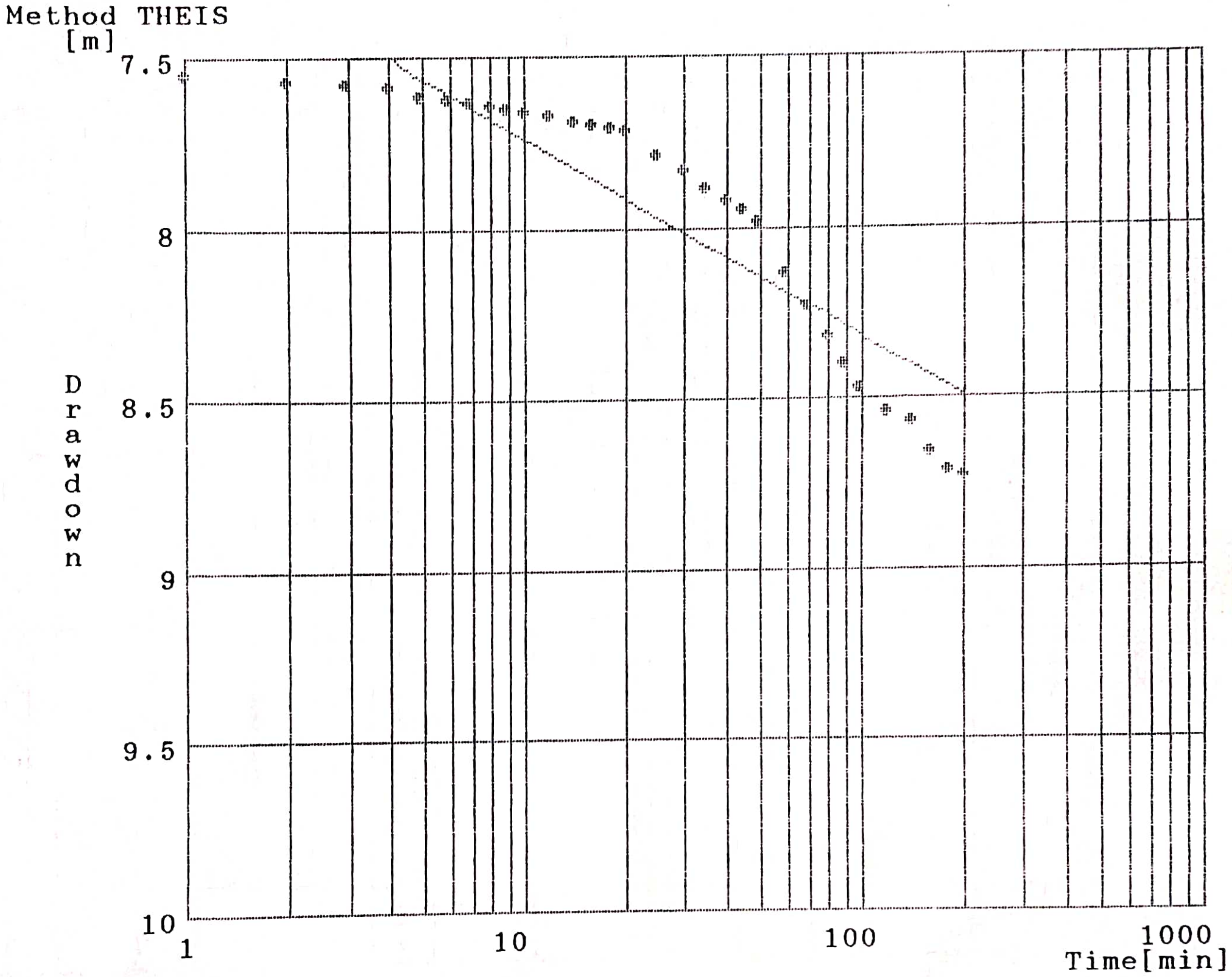
Transmissivity = 811. [m2/day]

Standard Deviation = 0.0423 [m]
A0 = 0.759027E+01
A1 = 0.481008E+00
Number of Points = 27 of 28

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

Test : STW 16 GHAILADUBBA

Constant Pumping Rate = 10.300 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -0.43 [m]
Well Type = STANDARD



Transmissivity = 280. [m2/day]

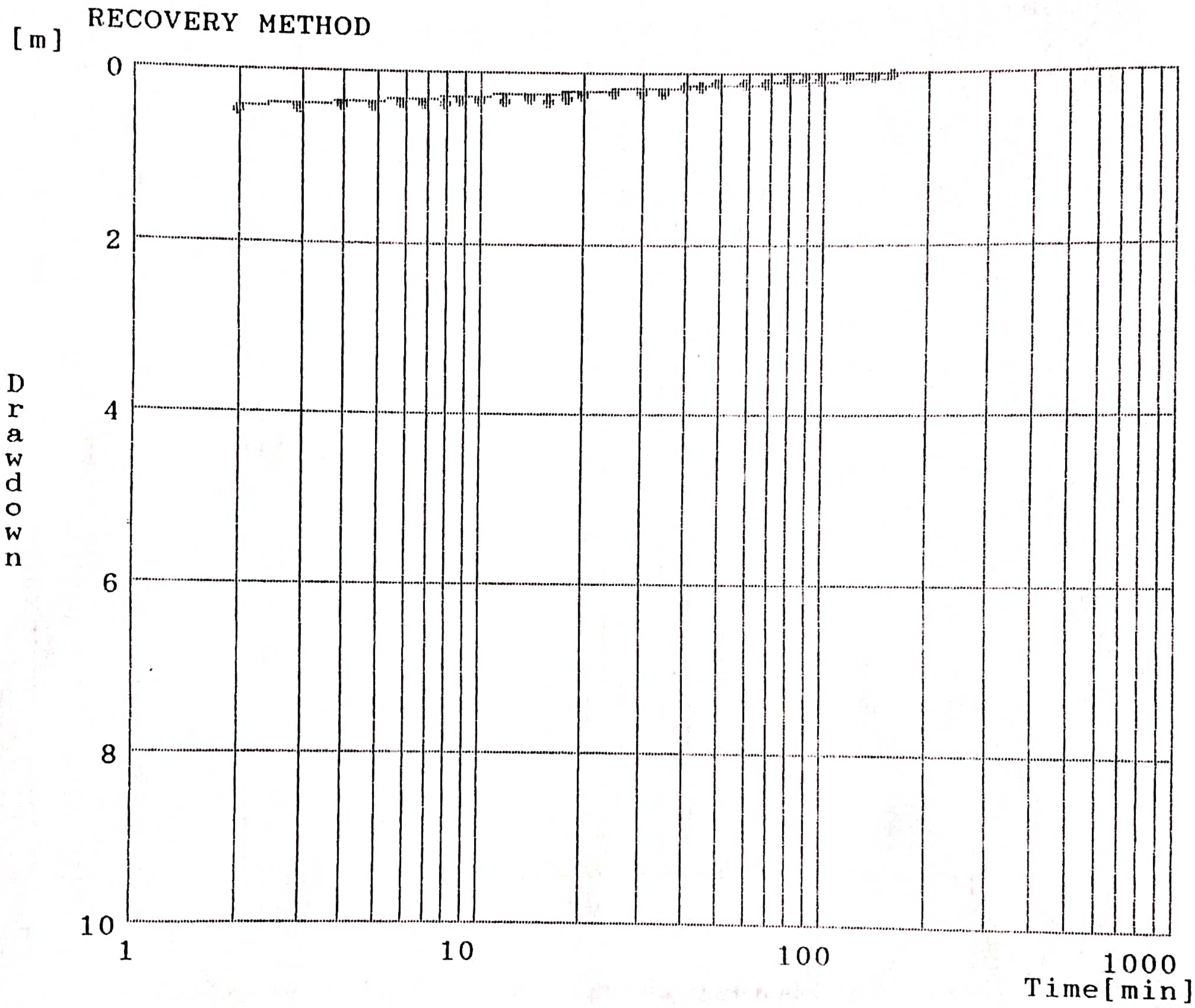
Standard Deviation = 0.1647 [m]

Number of Points = 31 of 31

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

Test : STW 17 SATIGATTA (REC)

Constant Pumping Rate = 3.000 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 20.00 [m]
Type of Input Data = LEVEL
Static Water Level = -2.26 [m]
Well Type = STANDARD



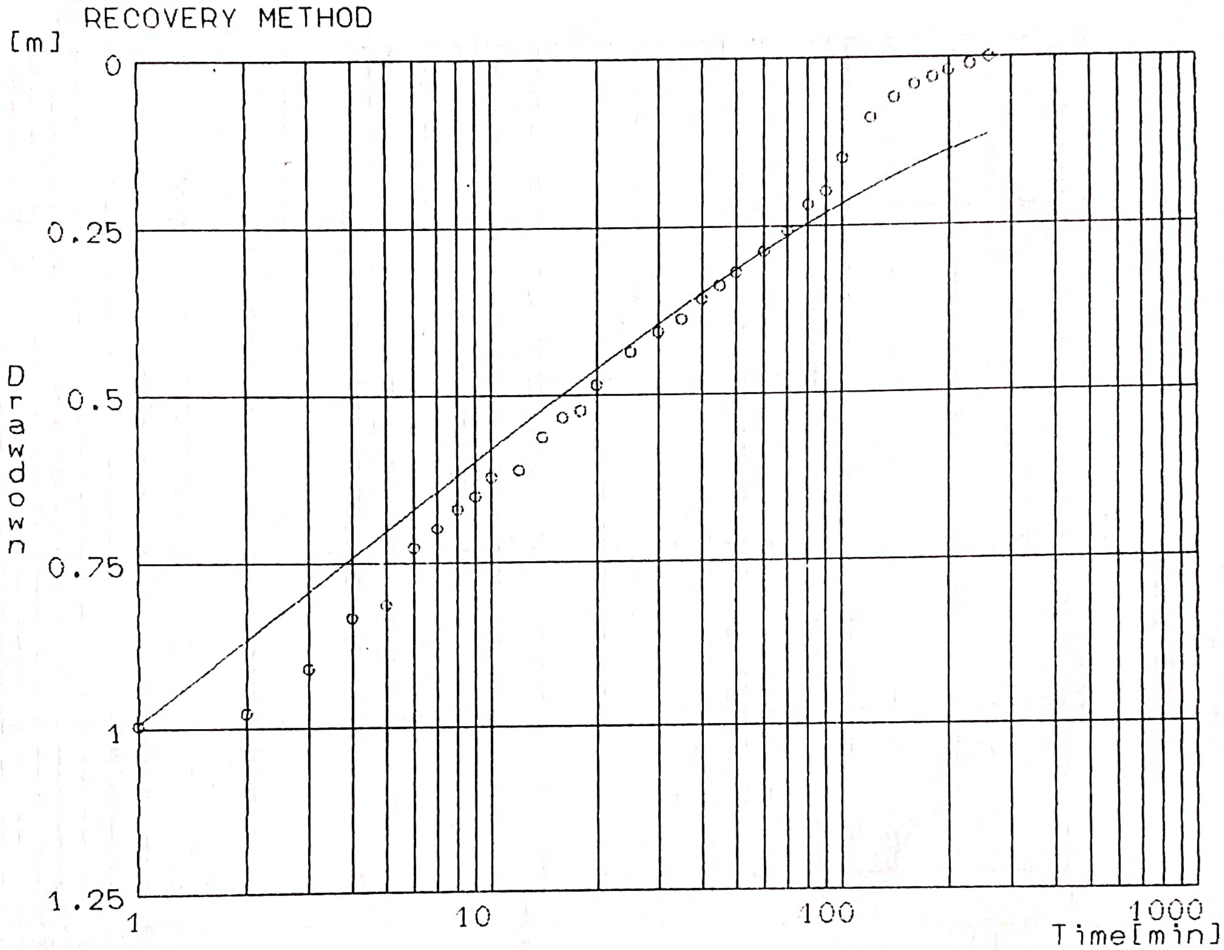
Transmissivity = 211. [m2/day]

Standard Deviation = 0.0402 [m]
A0 = 0.714862E+01
A1 = 0.583291E+00
Number of Points = 28 of 29

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

Test : GOLDHAP-4 RECOVERY

Constant Pumping Rate = 12.000 [L/SEC]
Distance from Pumping Well = 0.10 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 22.00 [m]
Type of Input Data = DRAWDOWN
Well Type = STANDARD



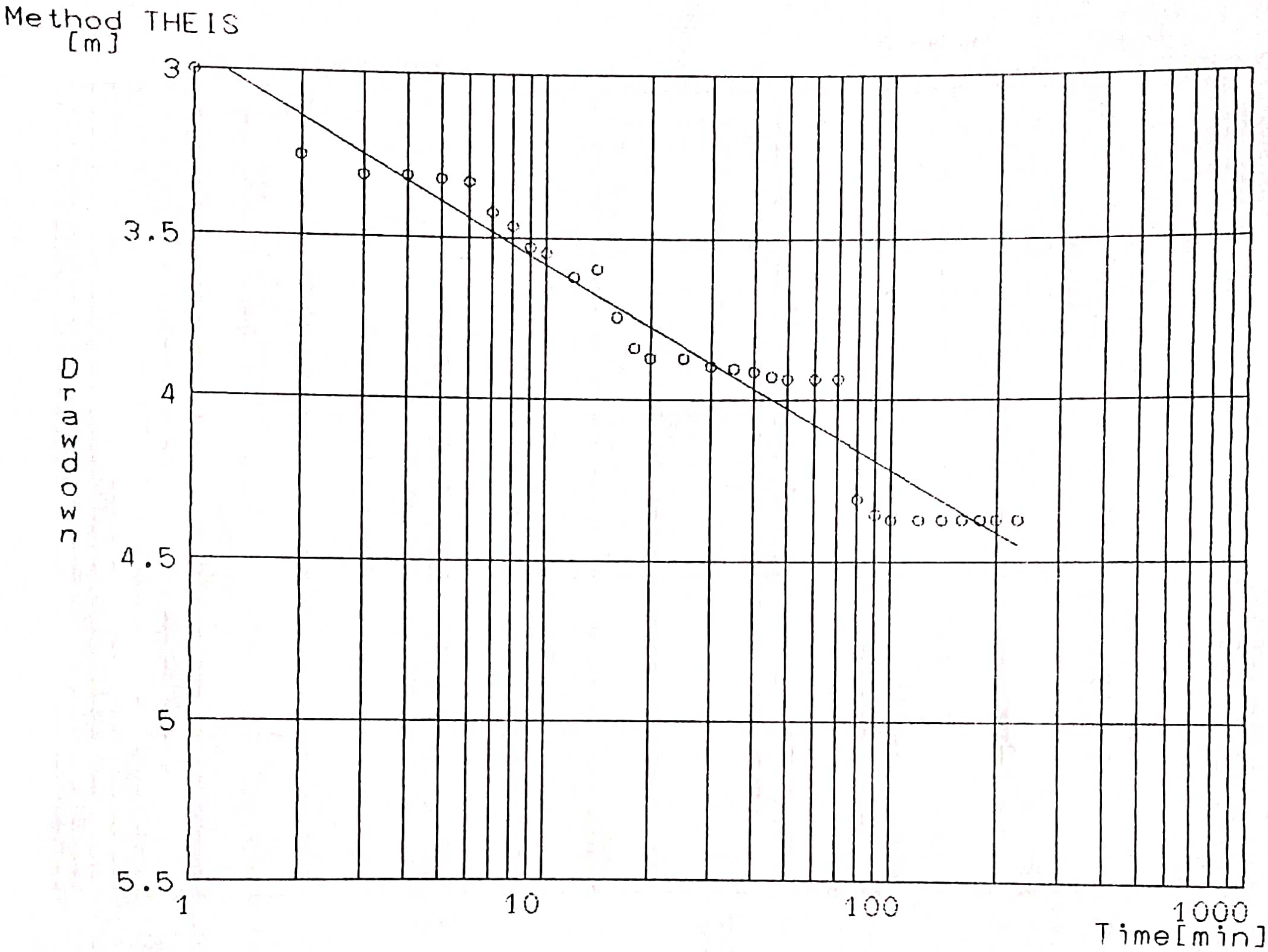
Transmissivity = 451. [m2/day]

Standard Deviation = 0.0722 [m]
A0 = 0.294388E+01
A1 = 0.637661E+00
Number of Points = 33 of 33

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

Test : GOLDHAP-4

Constant Pumping Rate = 12.000 [L/SEC]
Distance from Pumping Well = 0.10 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 22.00 [m]
Type of Input Data = DRAWDOWN
Well Type = STANDARD



Transmissivity = 298. [m2/day]

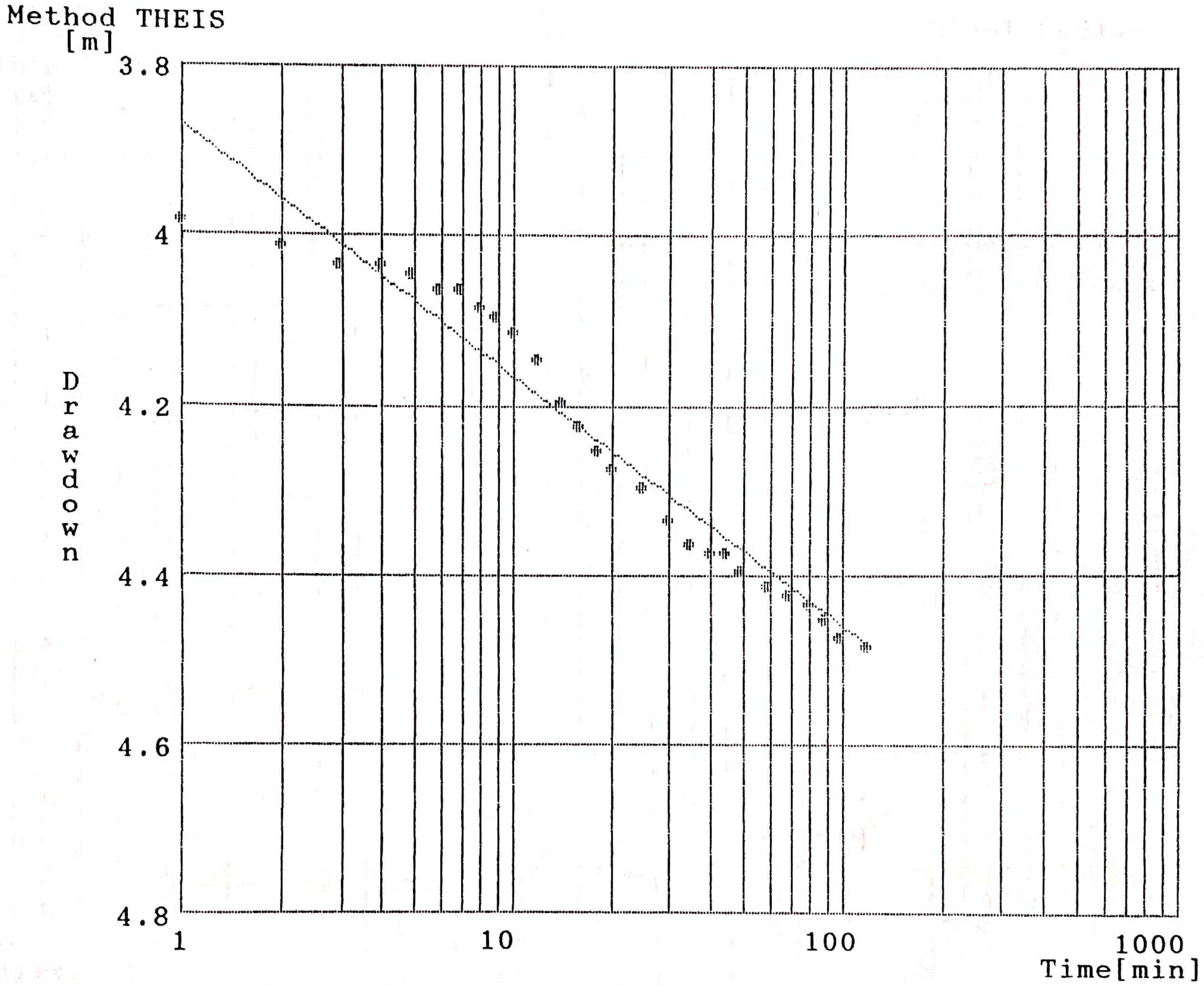
Standard Deviation = 0.0866 [m]

Number of Points = 32 of 32

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

Test : PRW 1 DASHARATPUR

Constant Pumping Rate = 9.790 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.55 [m]
Well Type = STANDARD



Transmissivity = 527. [m2/day]

Standard Deviation = 0.0376 [m]

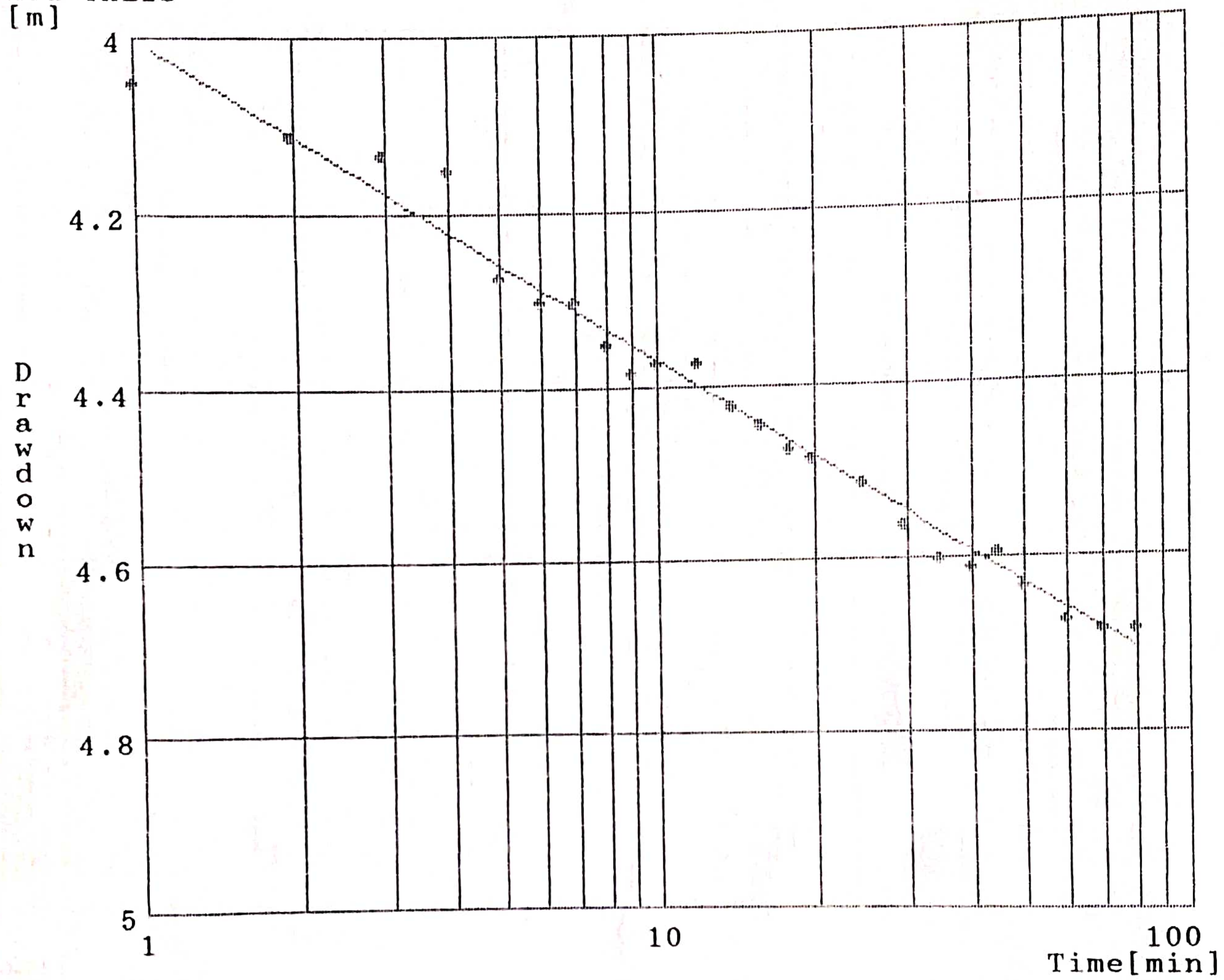
Number of Points = 27 of 27

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

Test : PRW 2 PATHARIYA

Constant Pumping Rate = 10.600 [l/s]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -1.37 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 453. [m2/day]

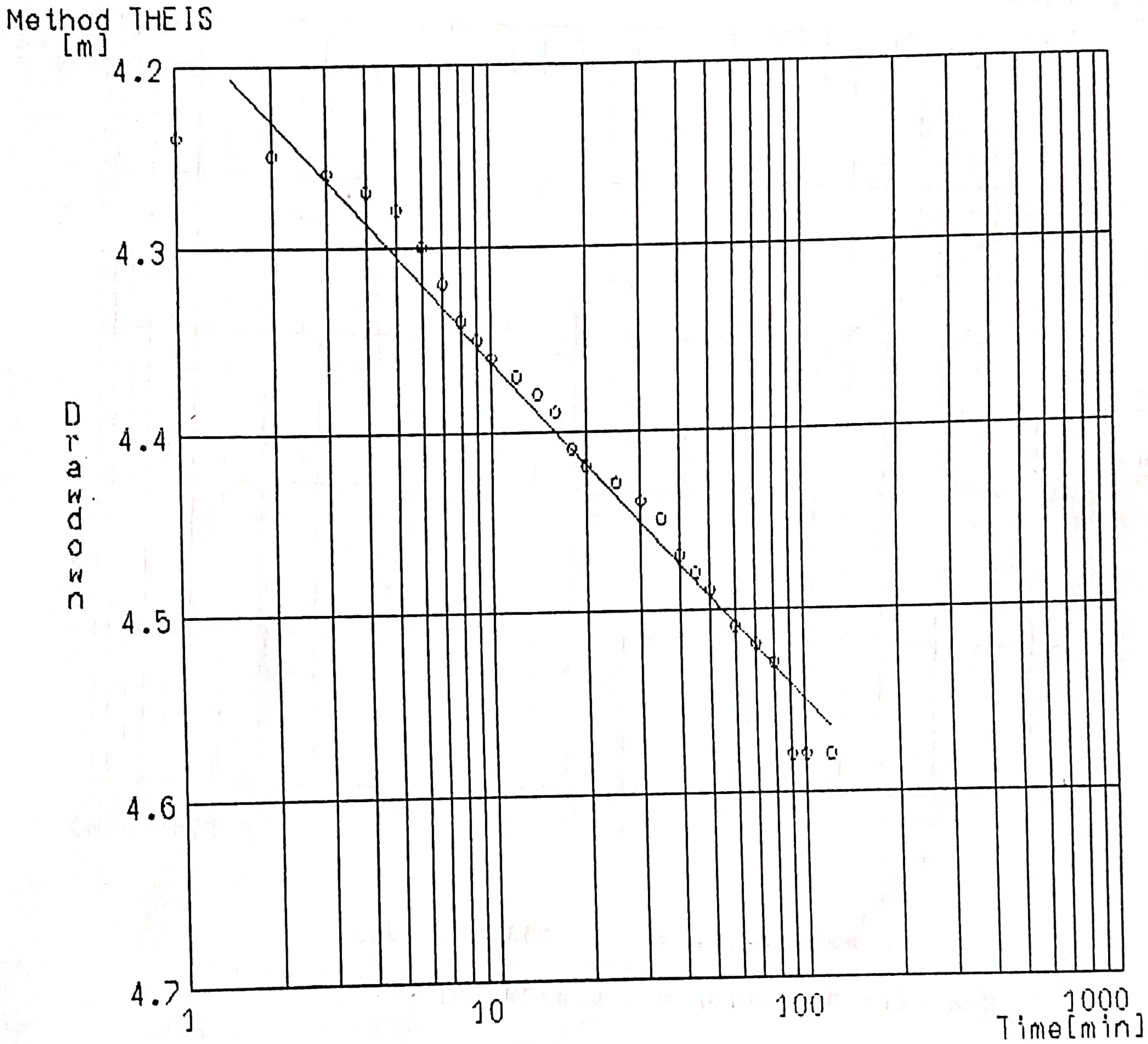
Standard Deviation = 0.0249 [m]

Number of Points = 24 of 24

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

Test : TOPGACHHI-3

Constant Pumping Rate = 4.500 [L/SEC]
Distance from Pumping Well = 0.05 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD



Transmissivity = 380. [m2/day]

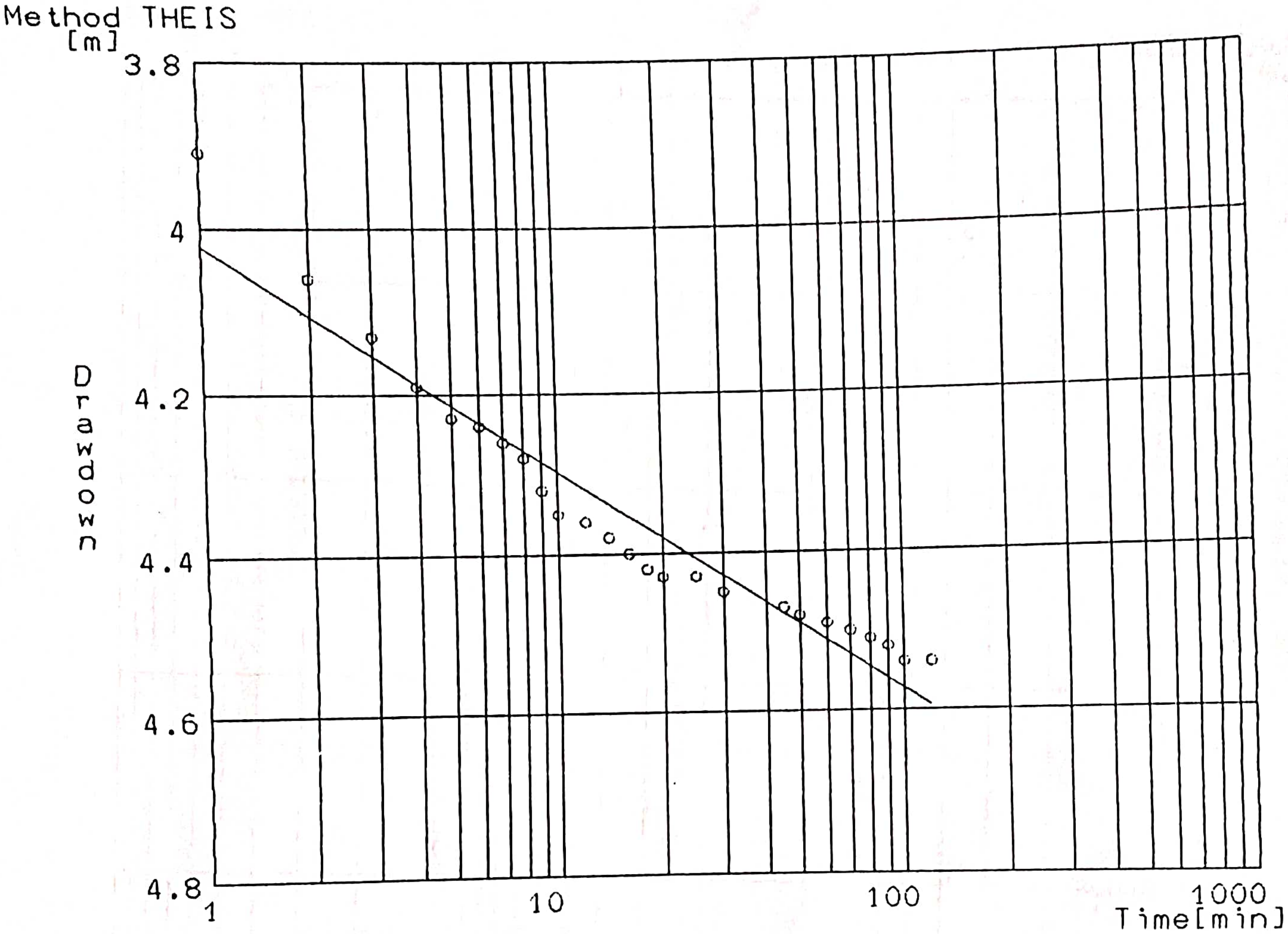
Standard Deviation = 0.0189 [m]

Number of Points = 27 of 27

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

Test : DHARAMPUR

Constant Pumping Rate = 8.400 [L/SEC]
Distance from Pumping Well = 0.10 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.11 [m]
Well Type = STANDARD



Transmissivity = 483. [m2/day]

Standard Deviation = 0.0399 [m]

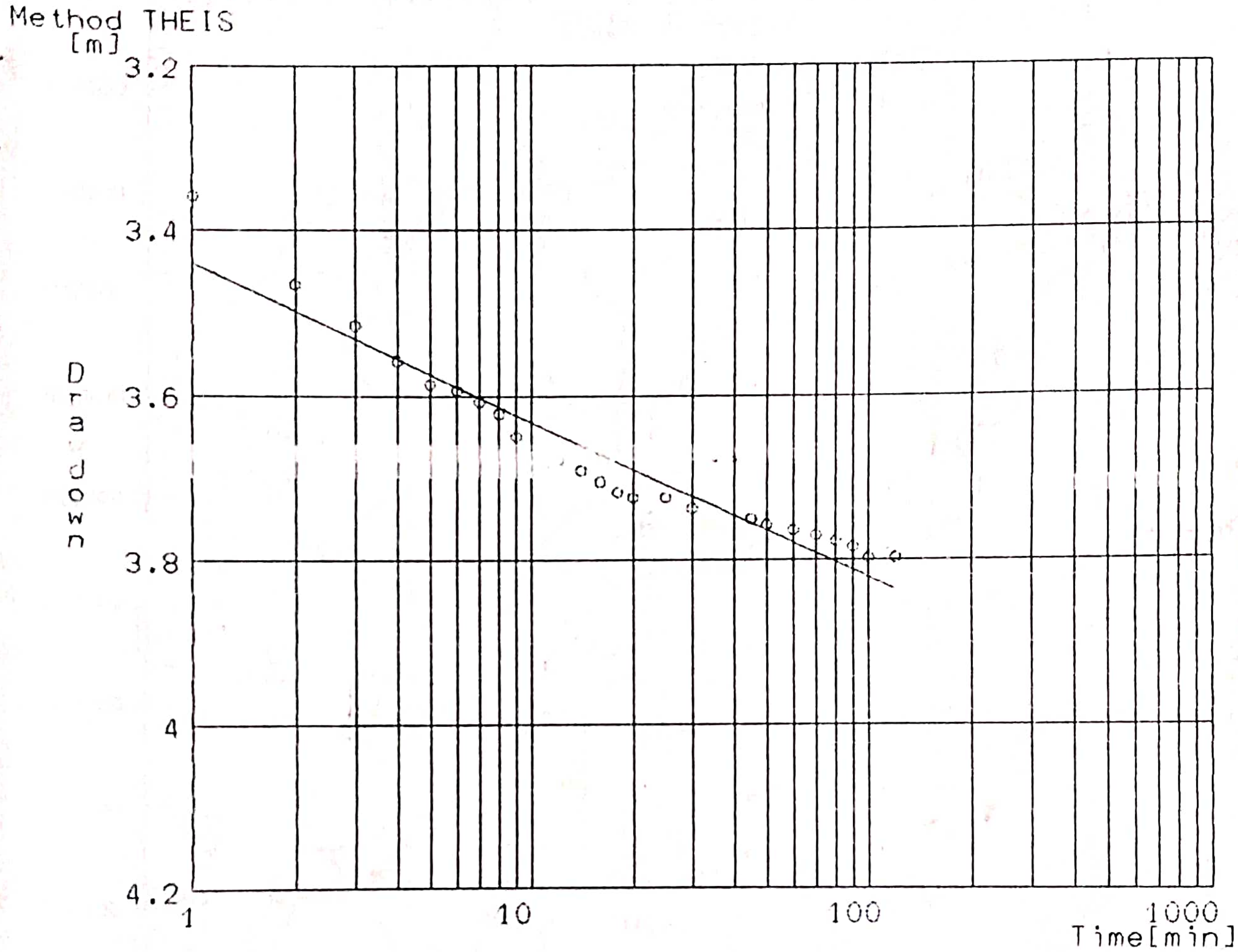
Number of Points = 25 of 25

APPENDIX 5/16A

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

Test : DHARAMPUR

Constant Pumping Rate = 8.400 [L/SEC]
Distance from Pumping Well = 0.10 [m]
Type of Aquifer = UNCONFINED
Initial Saturated Thickness = 13.89 [m]
Type of Input Data = LEVEL
Static Water Level = -4.11 [m]
Well Type = STANDARD



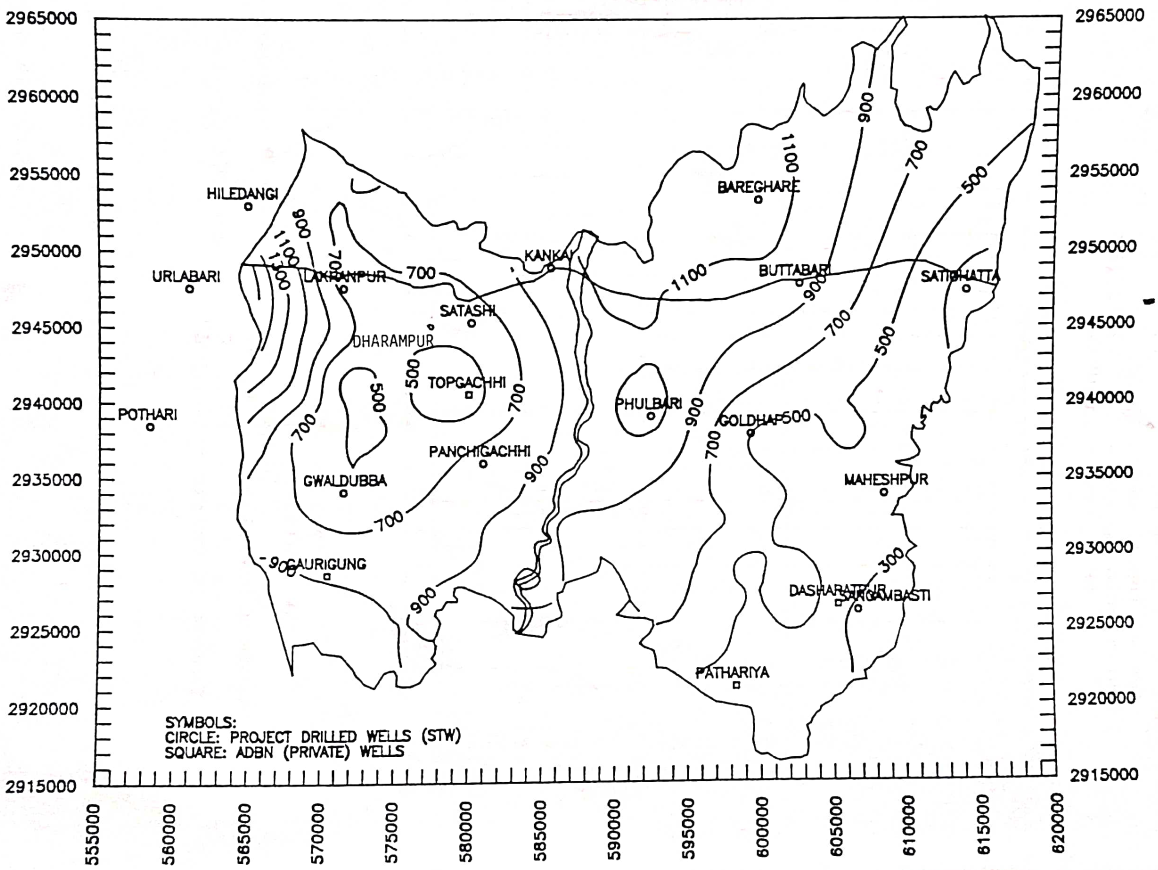
Transmissivity = 699. [m2/day]

Standard Deviation = 0.0285 [m]

Number of Points = 25 of 27

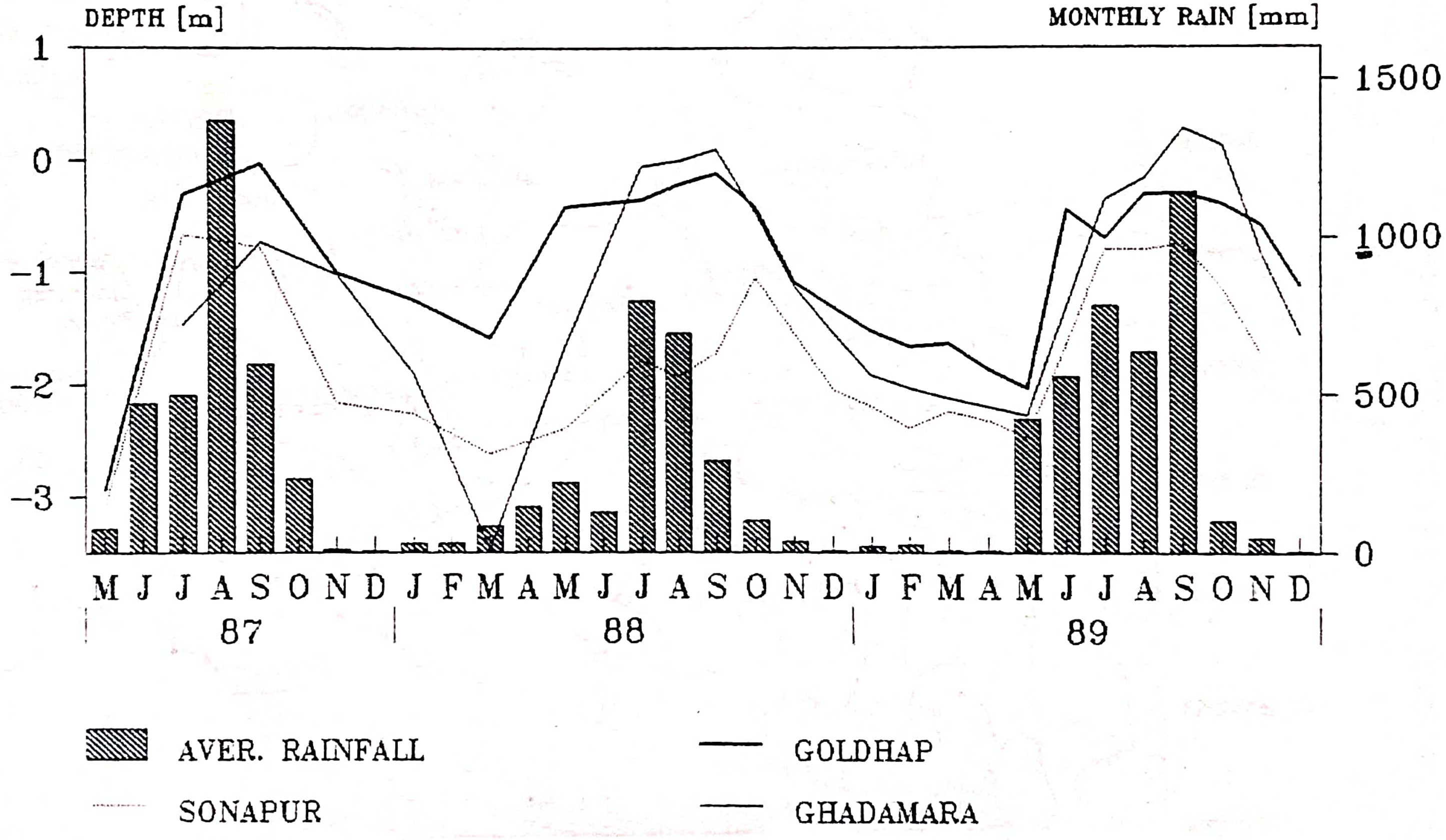
APPENDIX 5/16B

JHAPA TRANSMISSIVITY MAP (M2/DAY)



APPENDIX 6

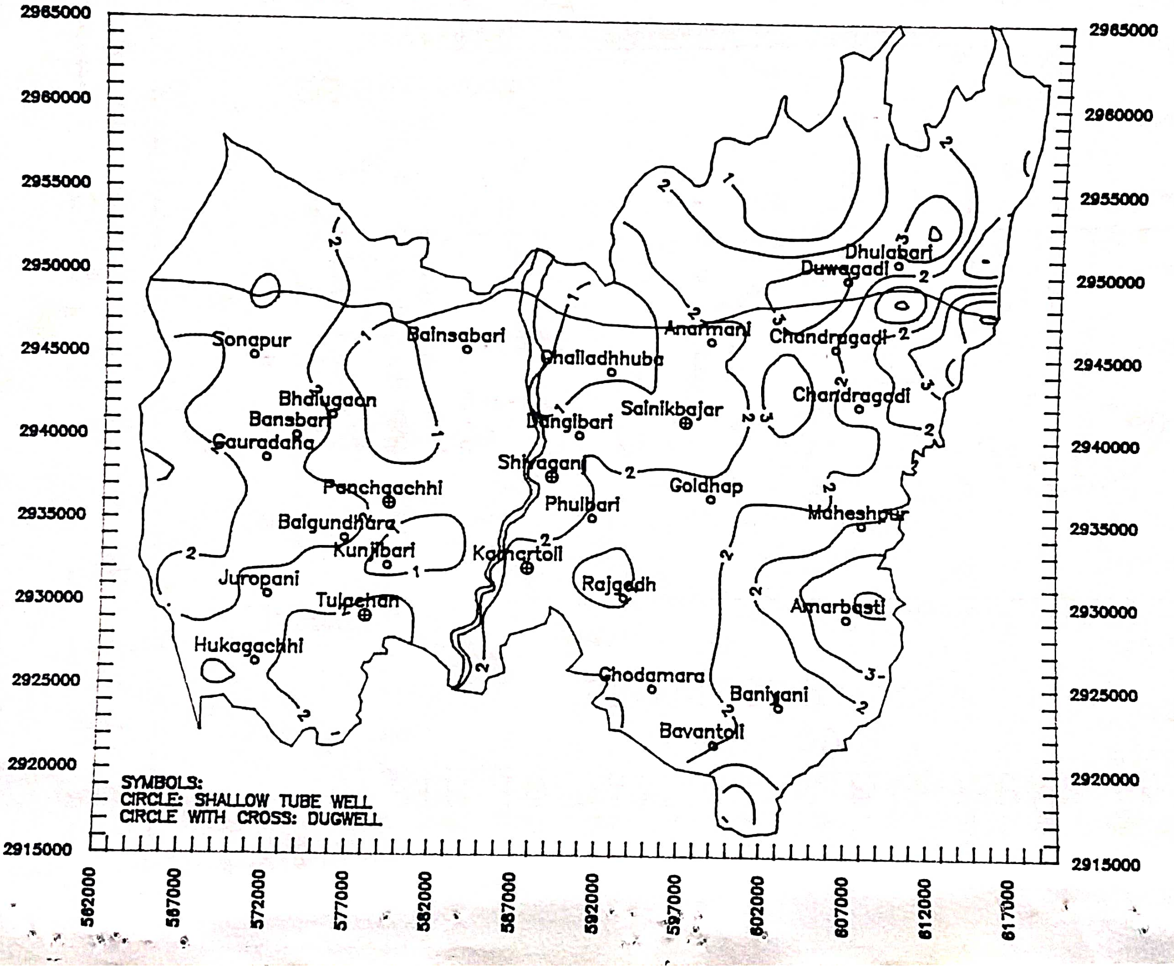
DEPTH TO WATER TABLE & RAINFALL
1987 – 89
DISTRICT JHAPA



RAINGAUGE STATION: KANKAI

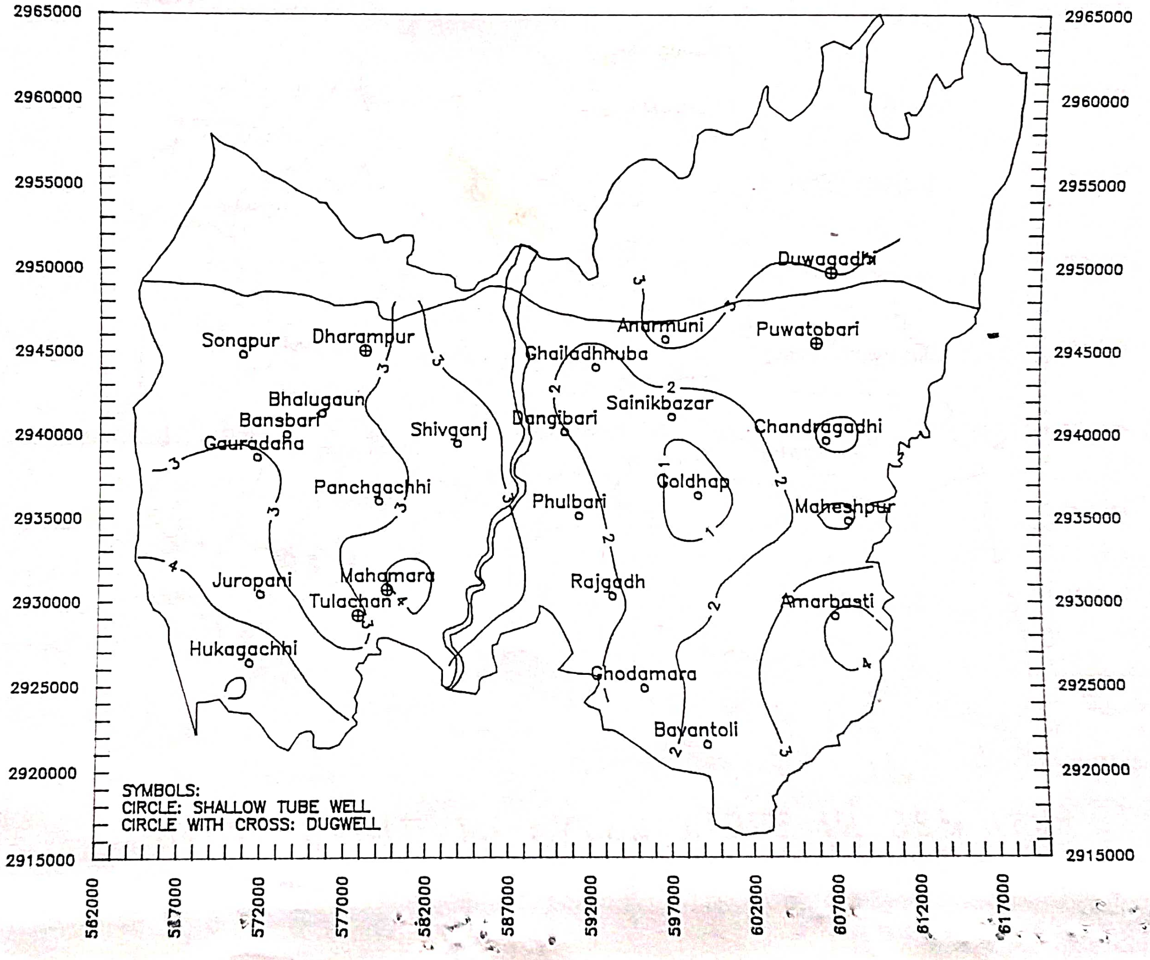
APPENDIX 7

JHAPA RISE OF WATER TABLE IN MAY - SEPTEMBER 1987



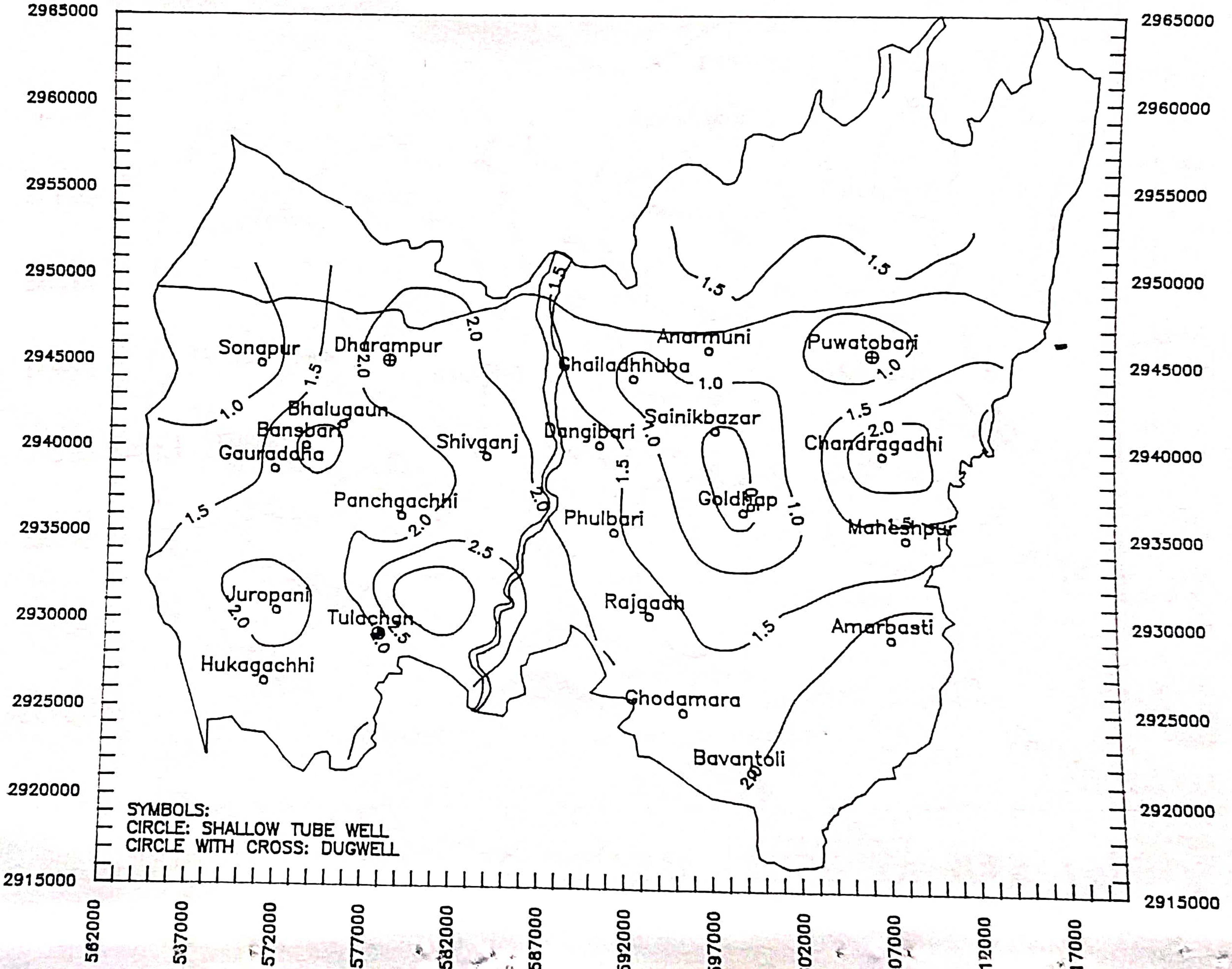
APPENDIX 8/1

JHAPA DEPTH TO WATER TABLE IN MAY 1988

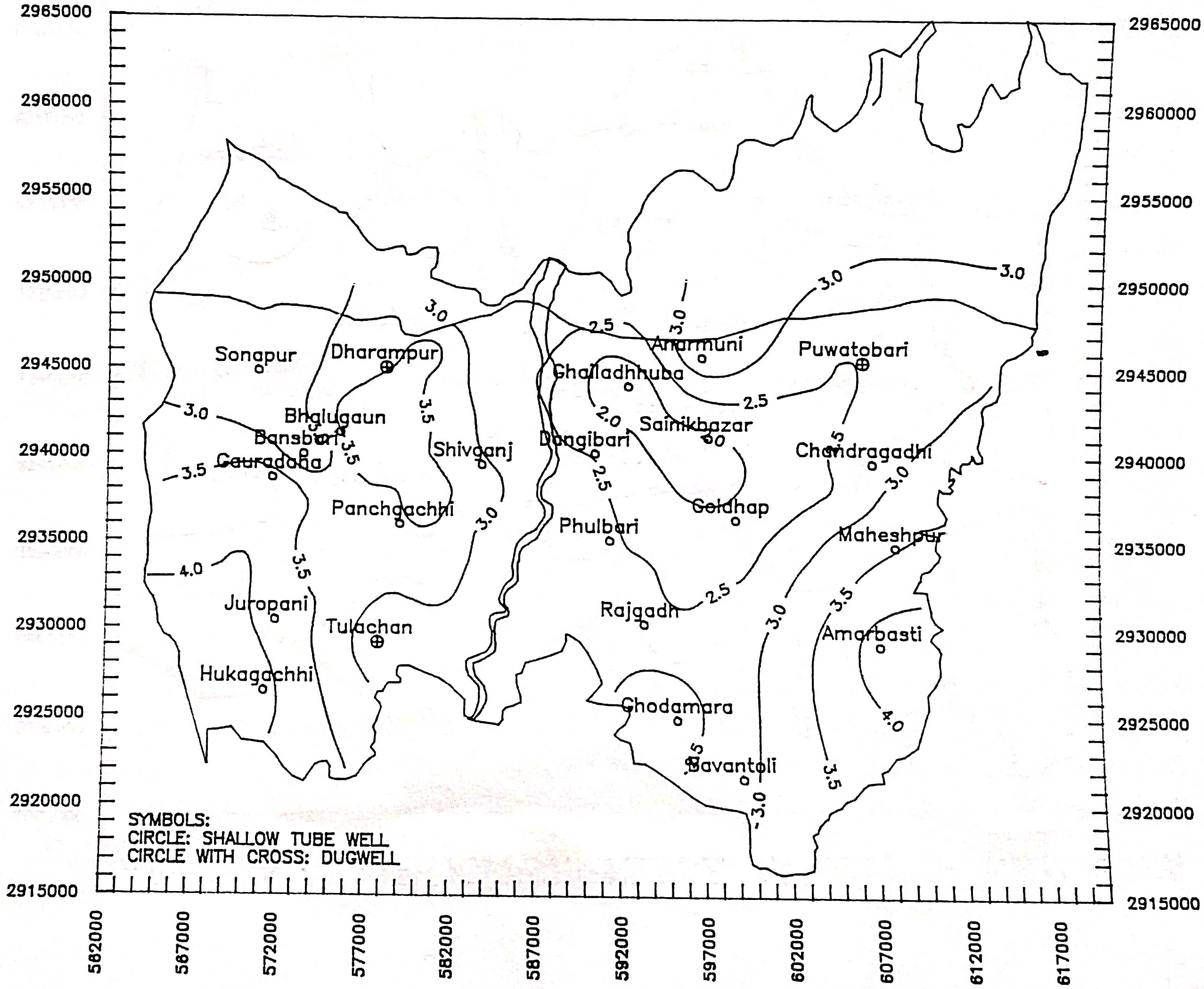


APPENDIX 8/2

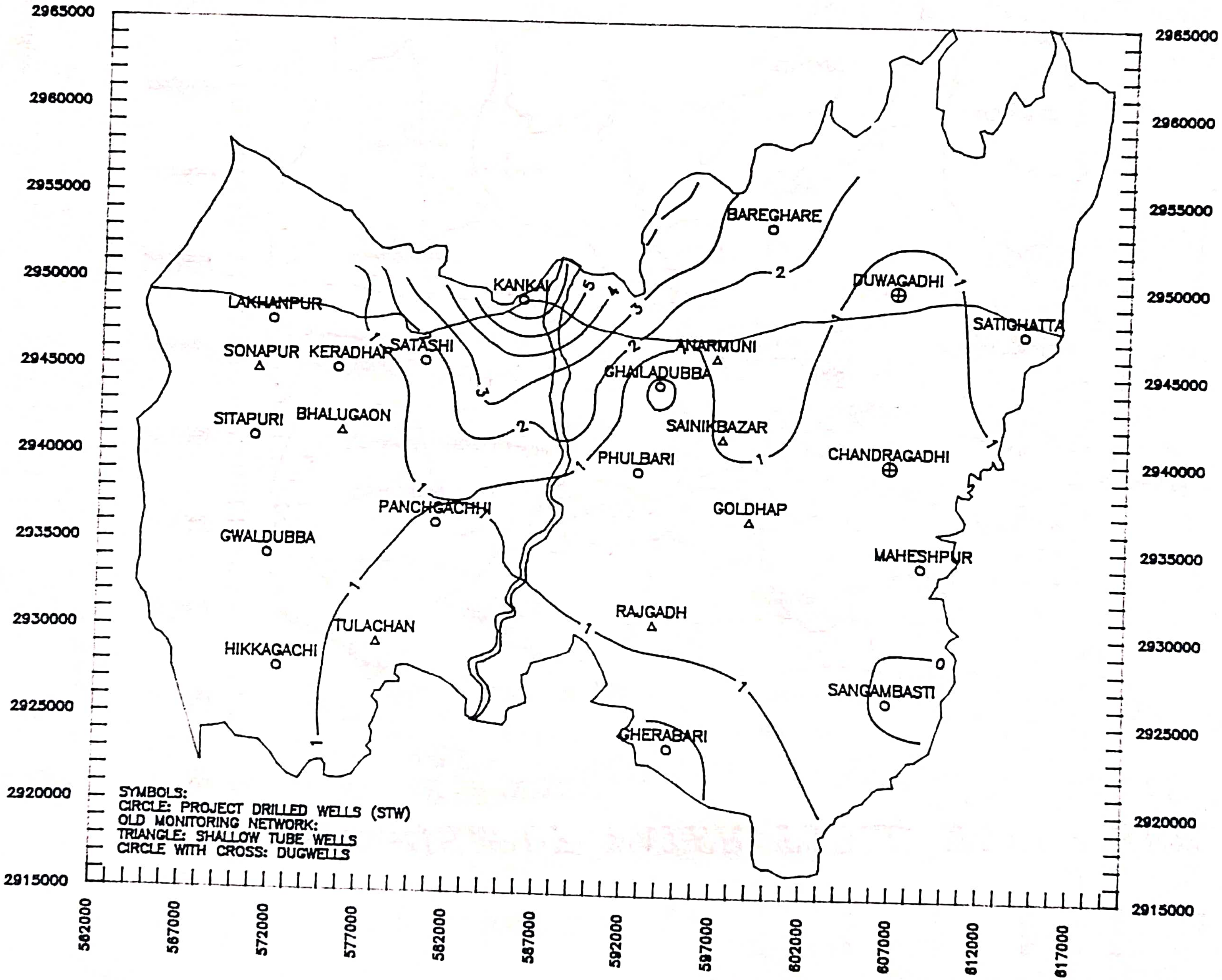
JHAPA RISE OF WATER TABLE IN MAY - SEP 1988



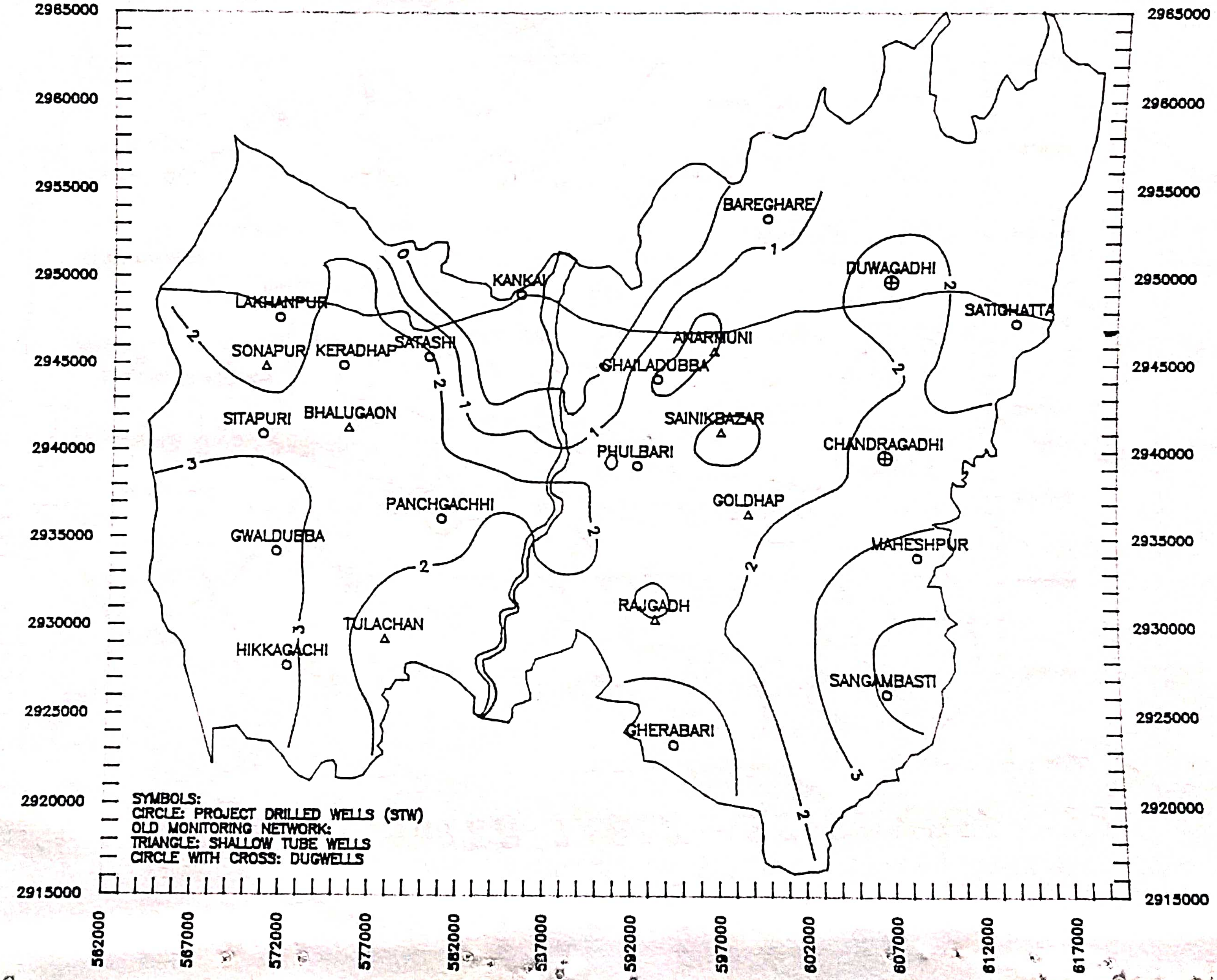
JHAPA DEPTH TO WATER TABLE IN MAY 1989



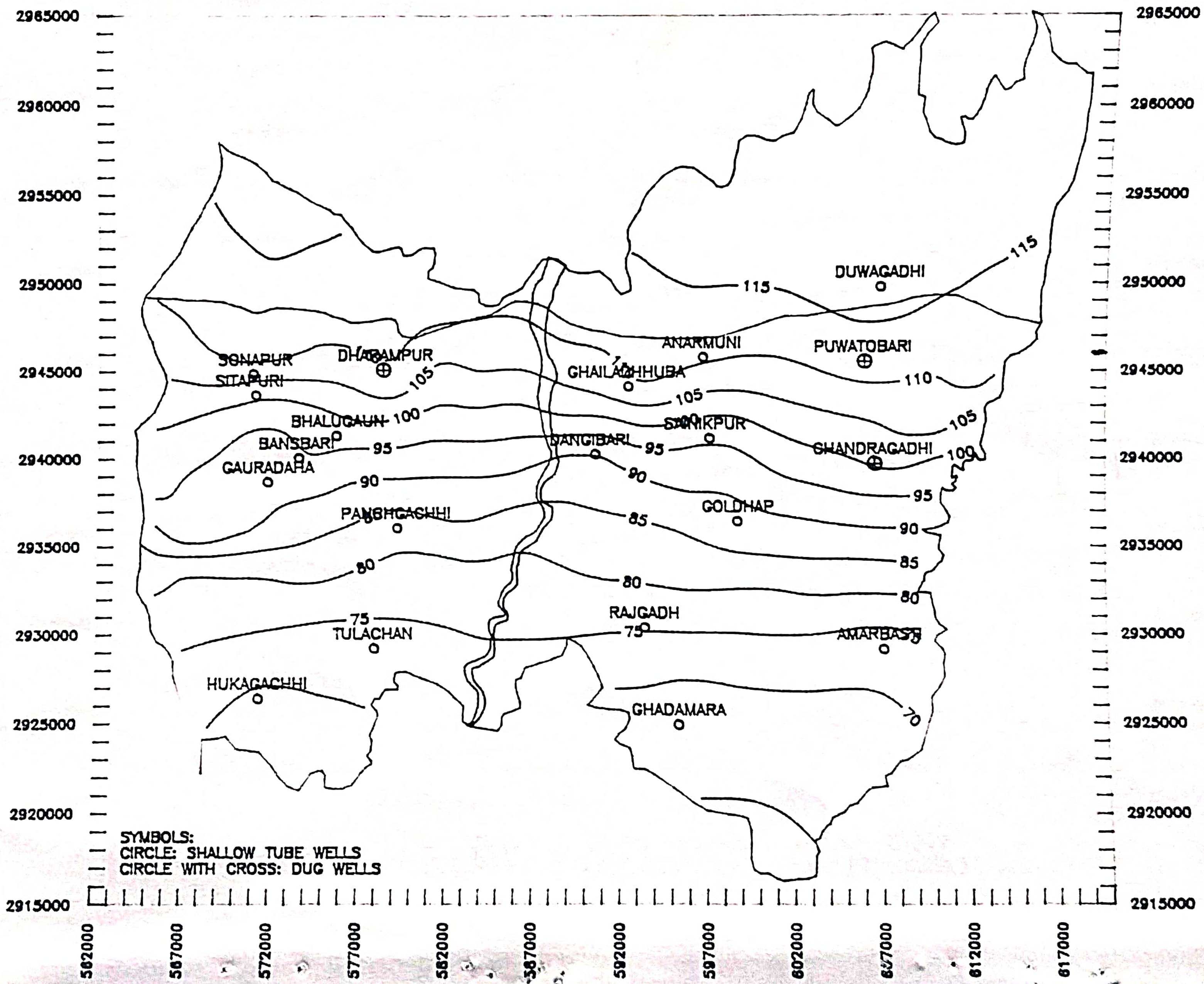
JHAPA DEPTH TO WATER TABLE SEPTEMBER 1989



JHAPA RISE OF WATER TABLE MAY - SEP 1989

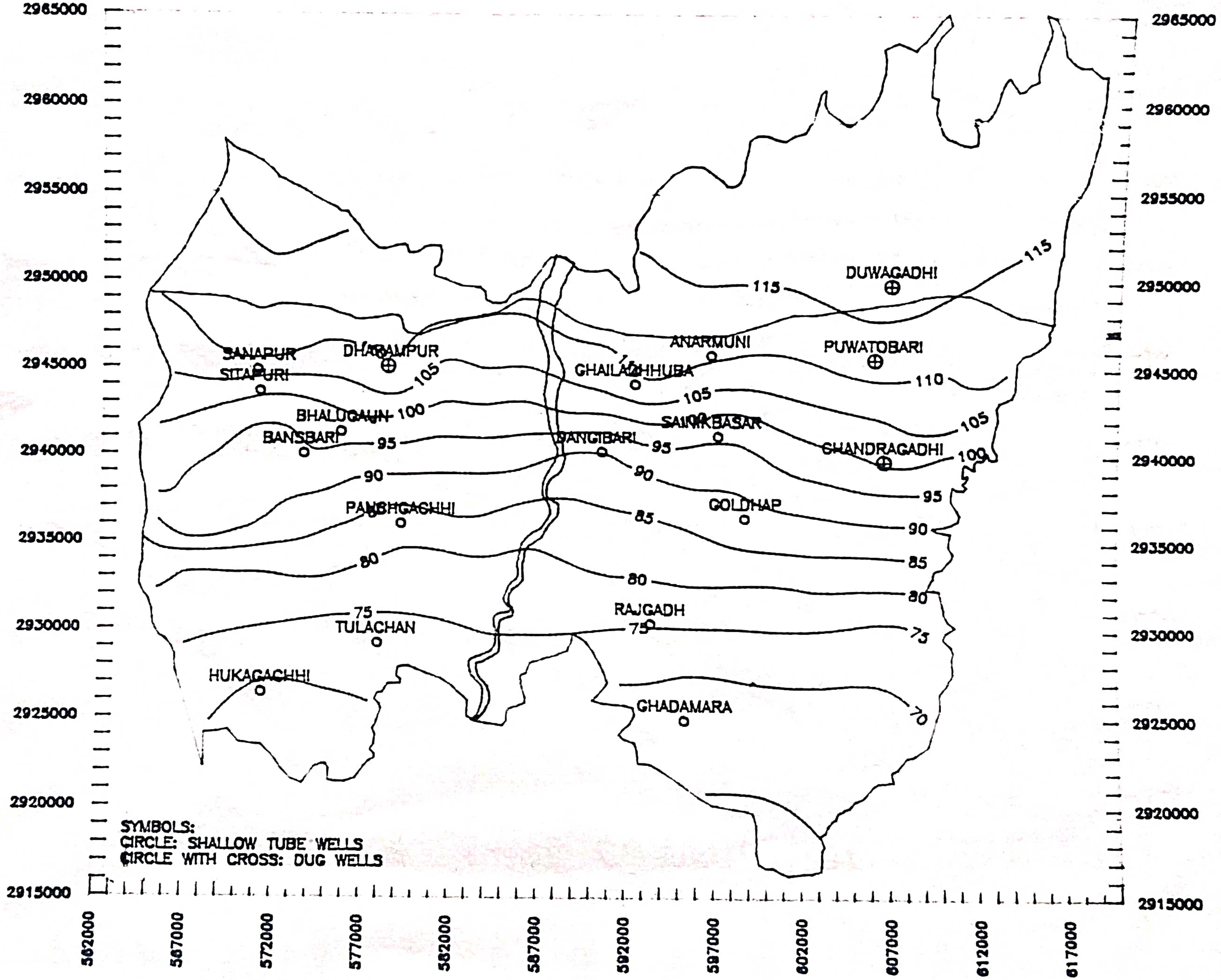


JHAPA WATER LEVEL CONTOUR MAP MAY 1989



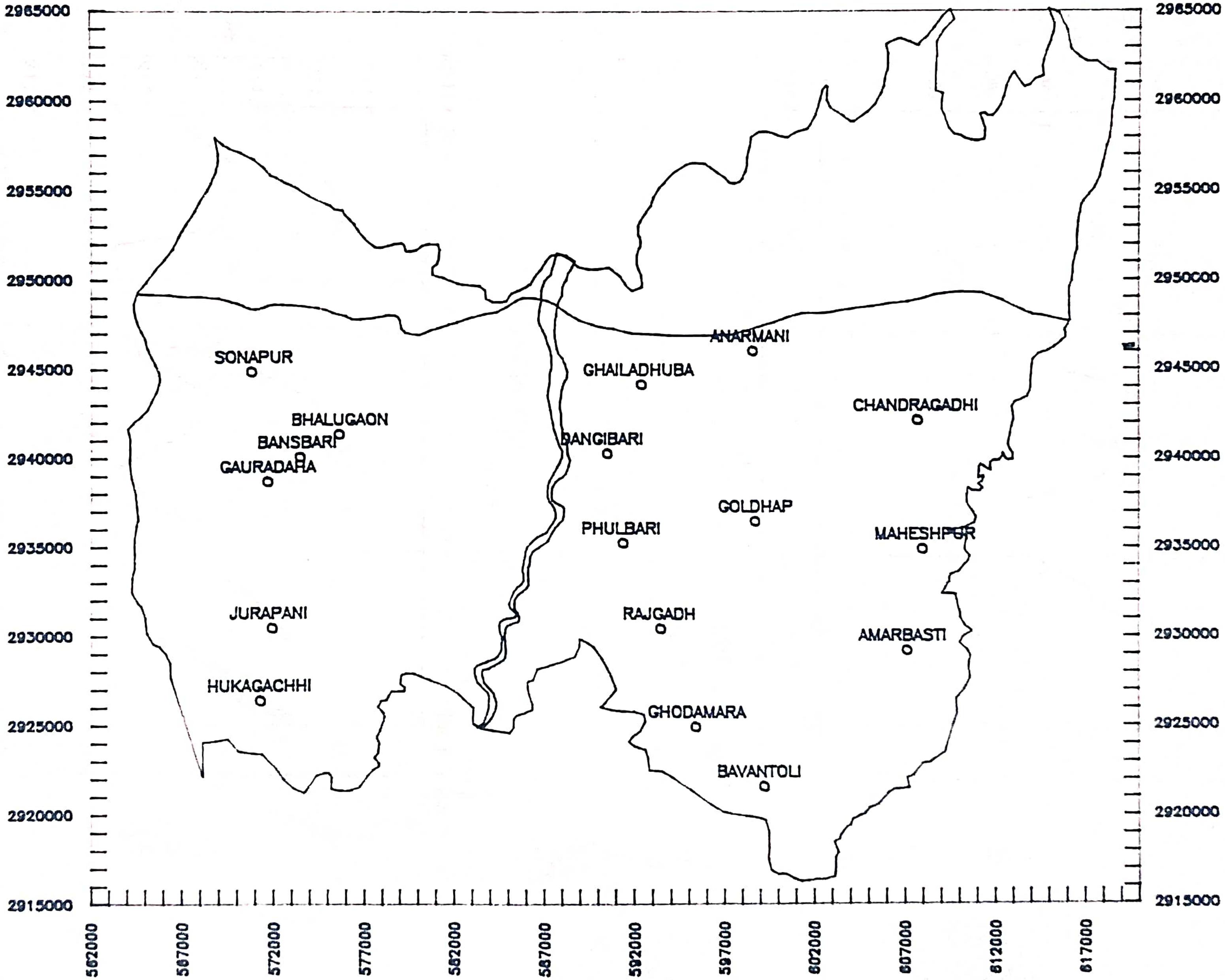
APPENDIX 8/8

JHAPA WATER LEVEL CONTOUR MAP SEPTEMBER 1989



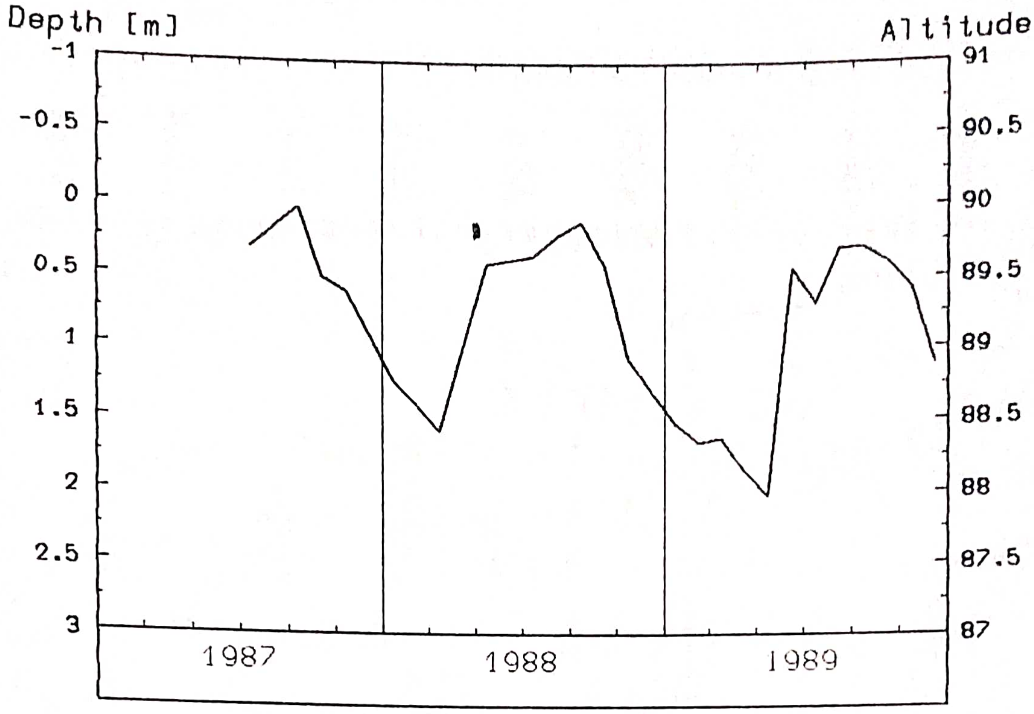
APPENDIX 8/9

JHAPA LOCATION OF HYDROGRAPHS



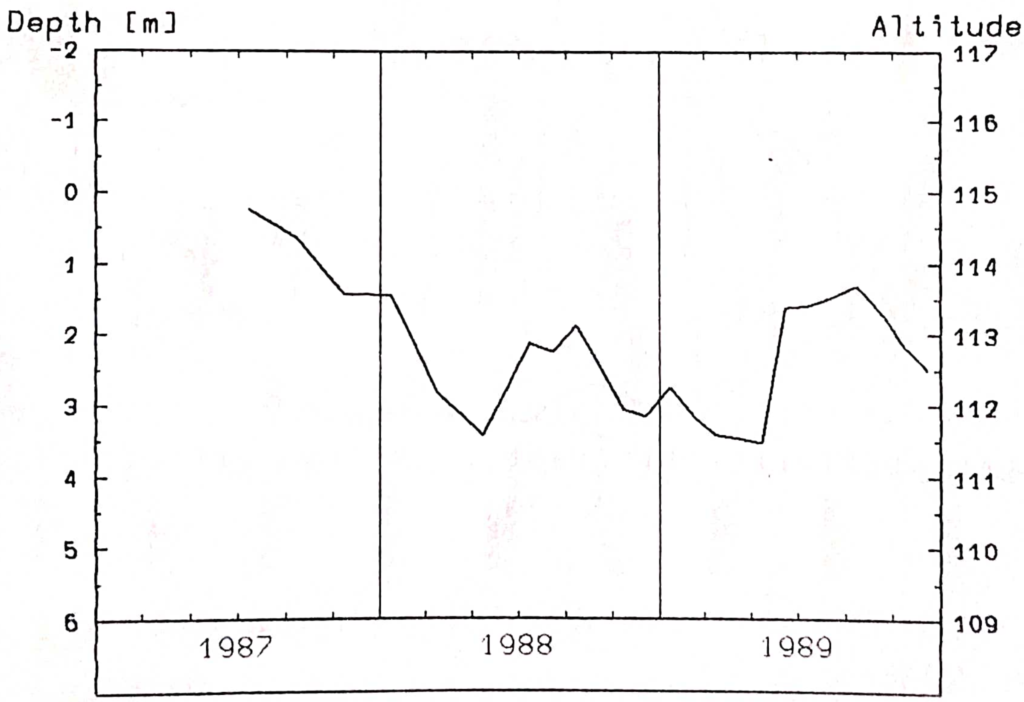
APPENDIX 9

GOLDHAP



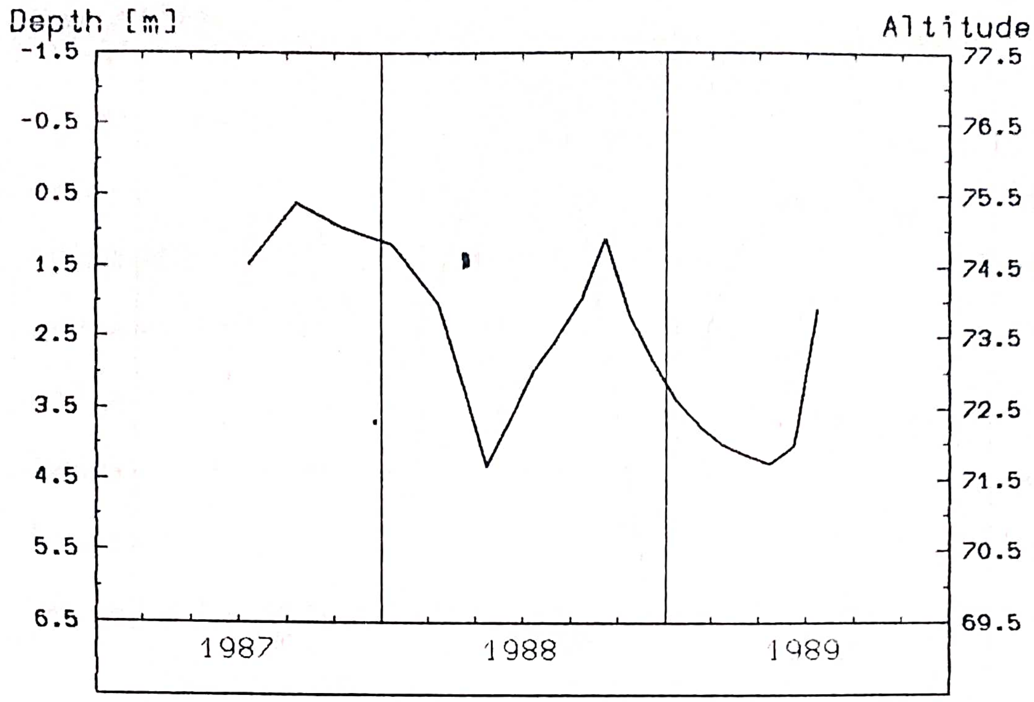
May 1, 1987 -- Dec 31, 1989

ANARMANI



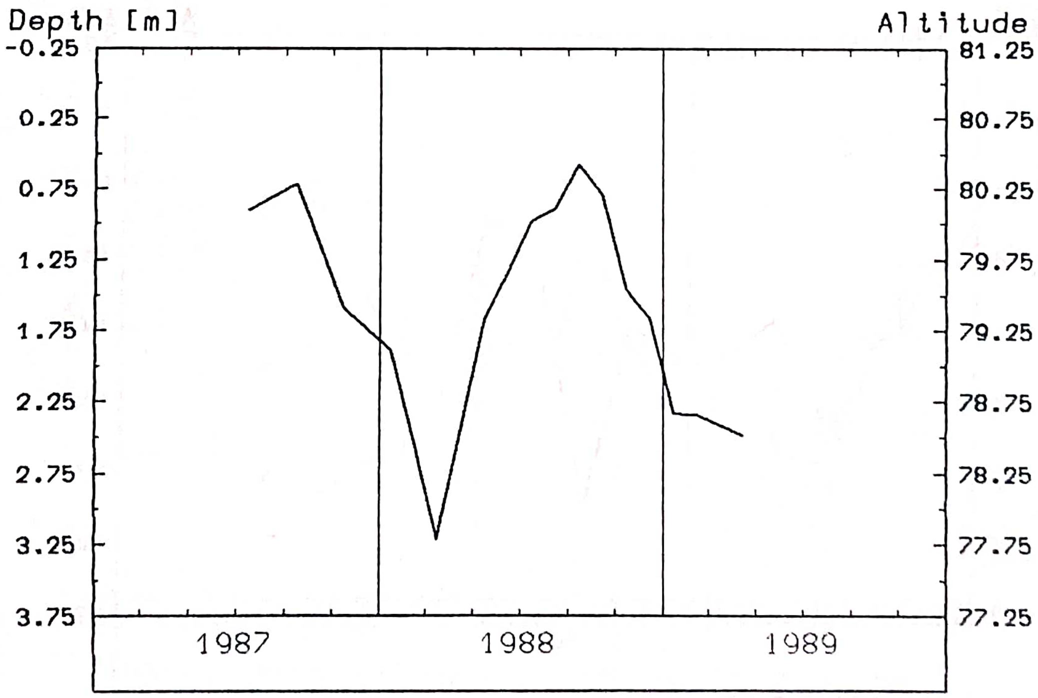
May 1, 1987 -- Dec 31, 1989

AMARBASTI



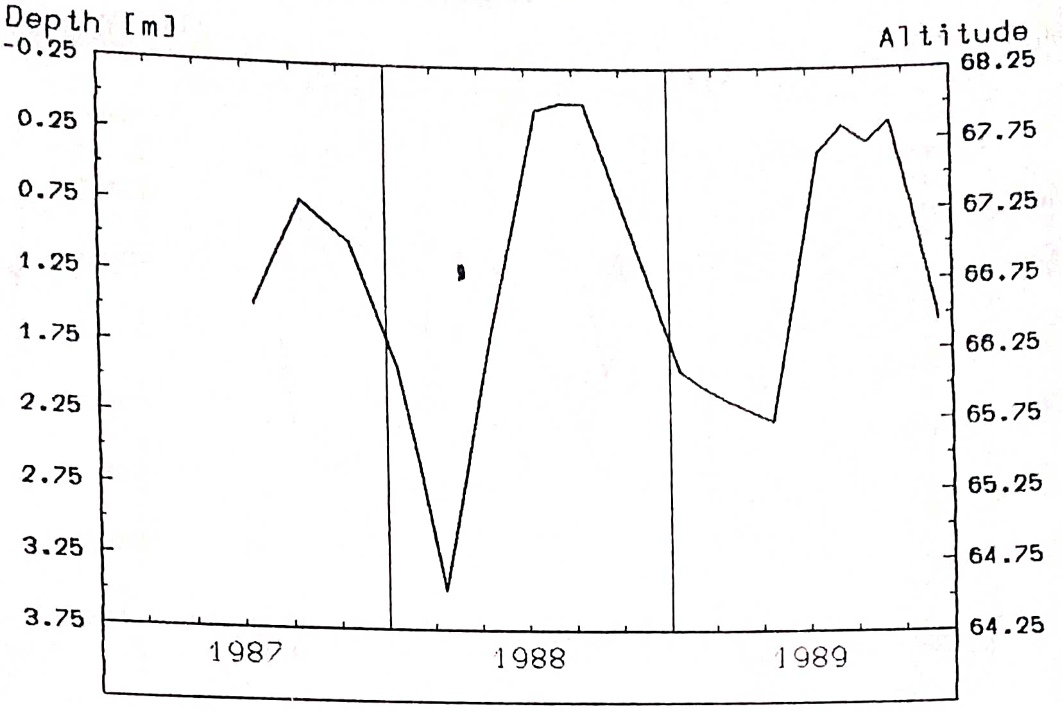
May 1, 1987 -- Dec 31, 1989

MAHESHPUR



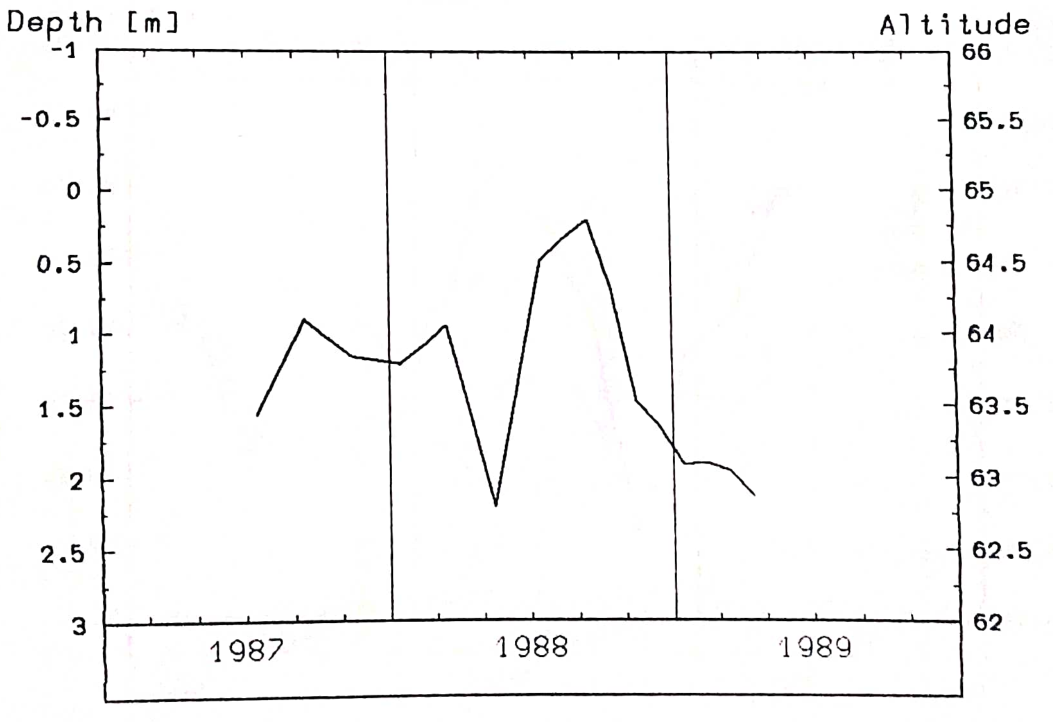
May 1, 1987 -- Dec 31, 1989

GHODMARA



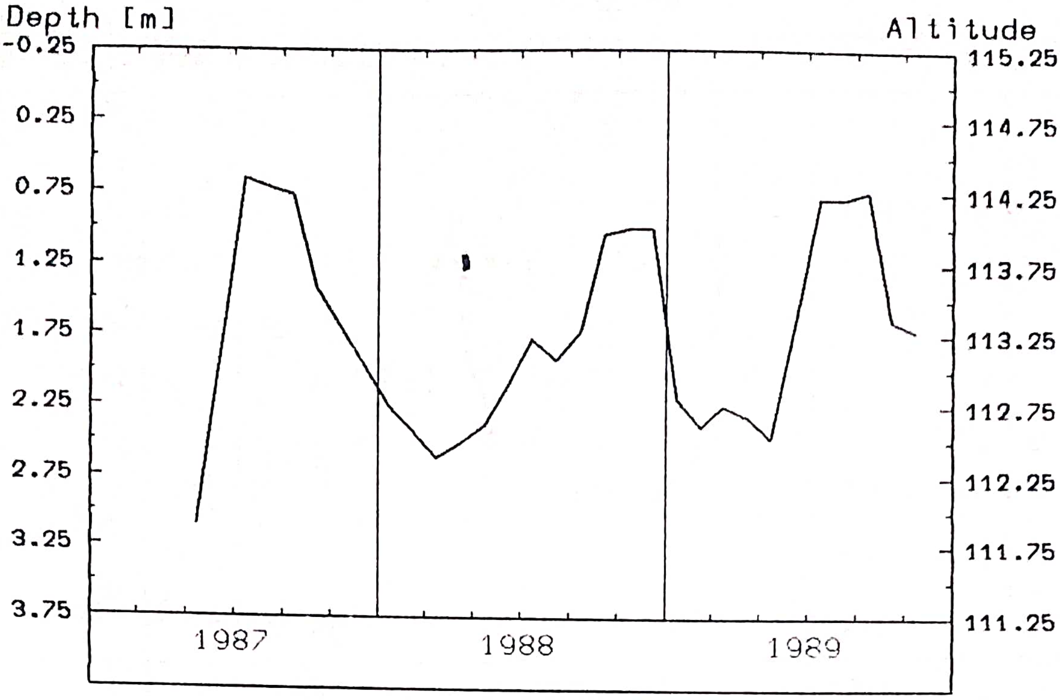
May 1, 1987 -- Dec 31, 1989

BAVANTOLI



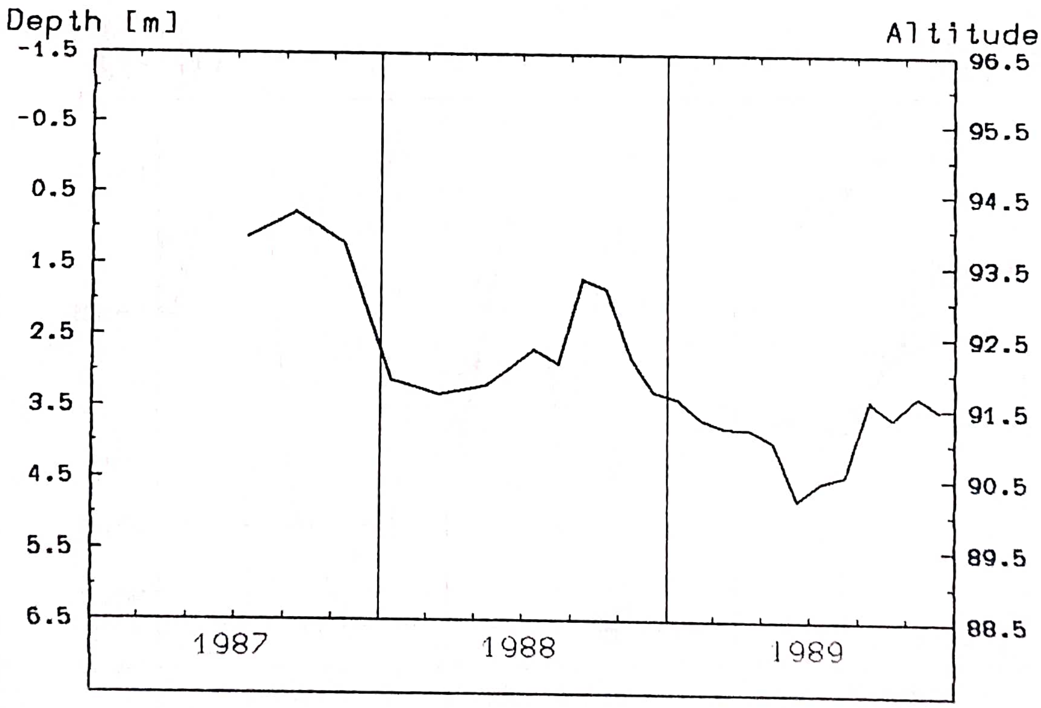
May 1, 1987 -- Dec 31, 1989

SONAPUR



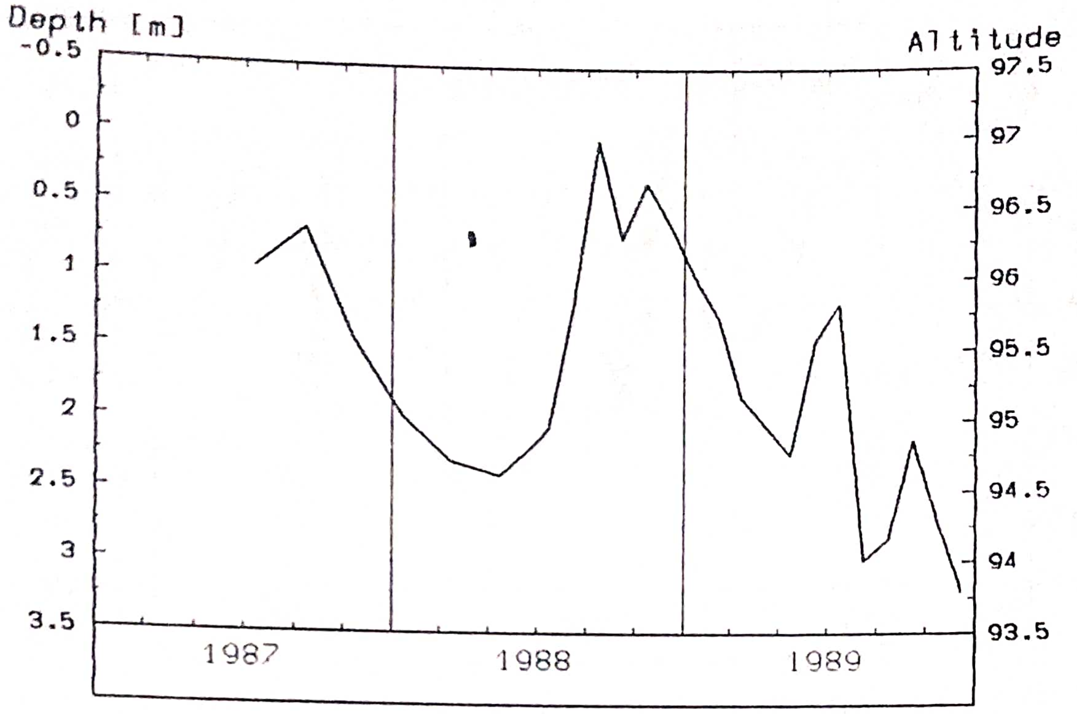
May 1, 1987 -- Dec 31, 1989

GAURADAHA



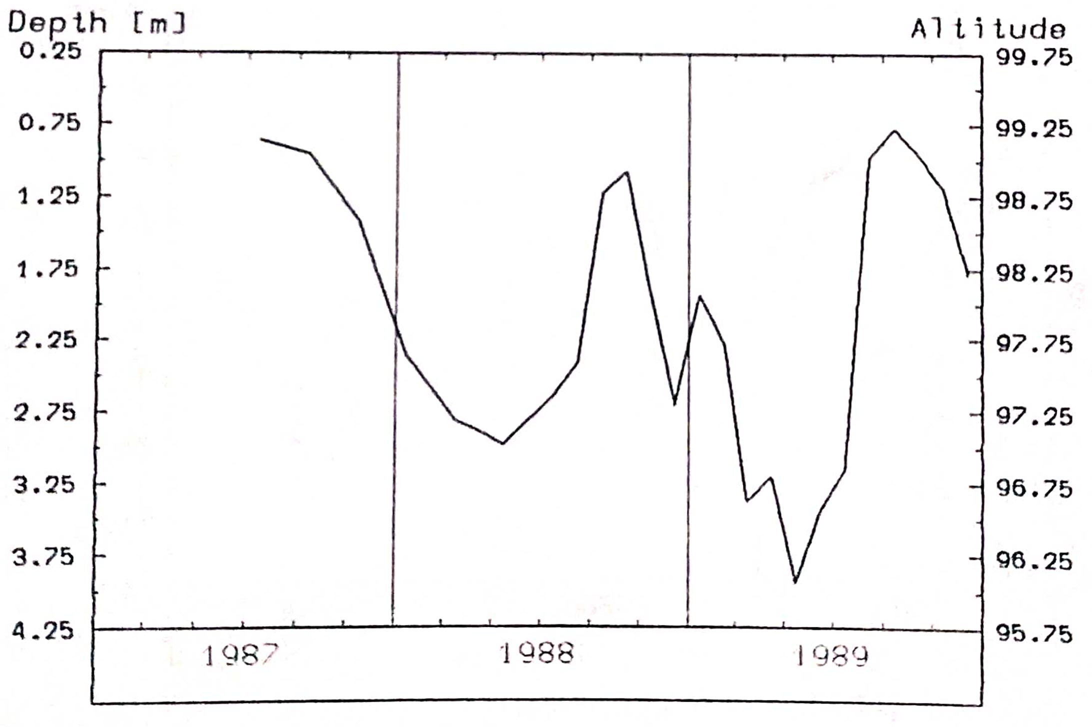
May 1, 1987 -- Dec 31, 1989

BANSBARI



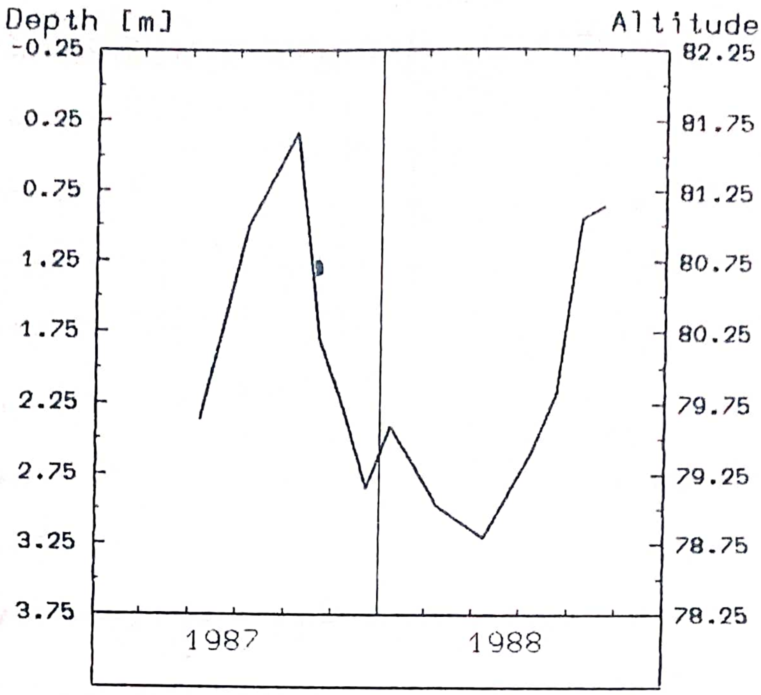
May 1, 1987 -- Dec 31, 1989

BHALUGAON



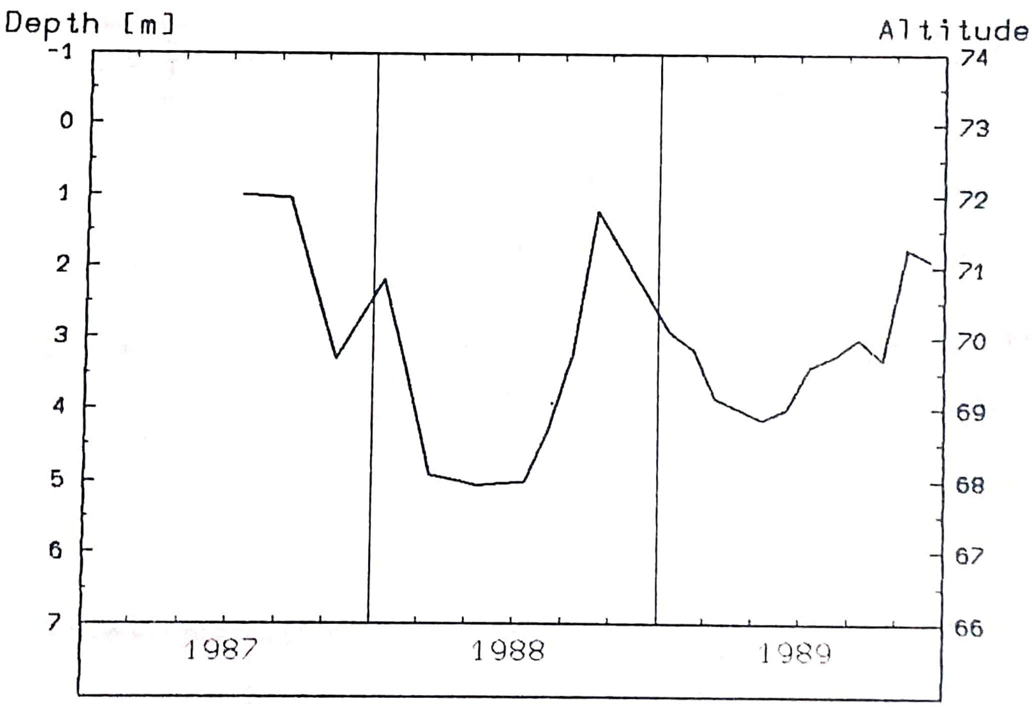
May 1, 1987 -- Dec 31, 1989

JURAPANI



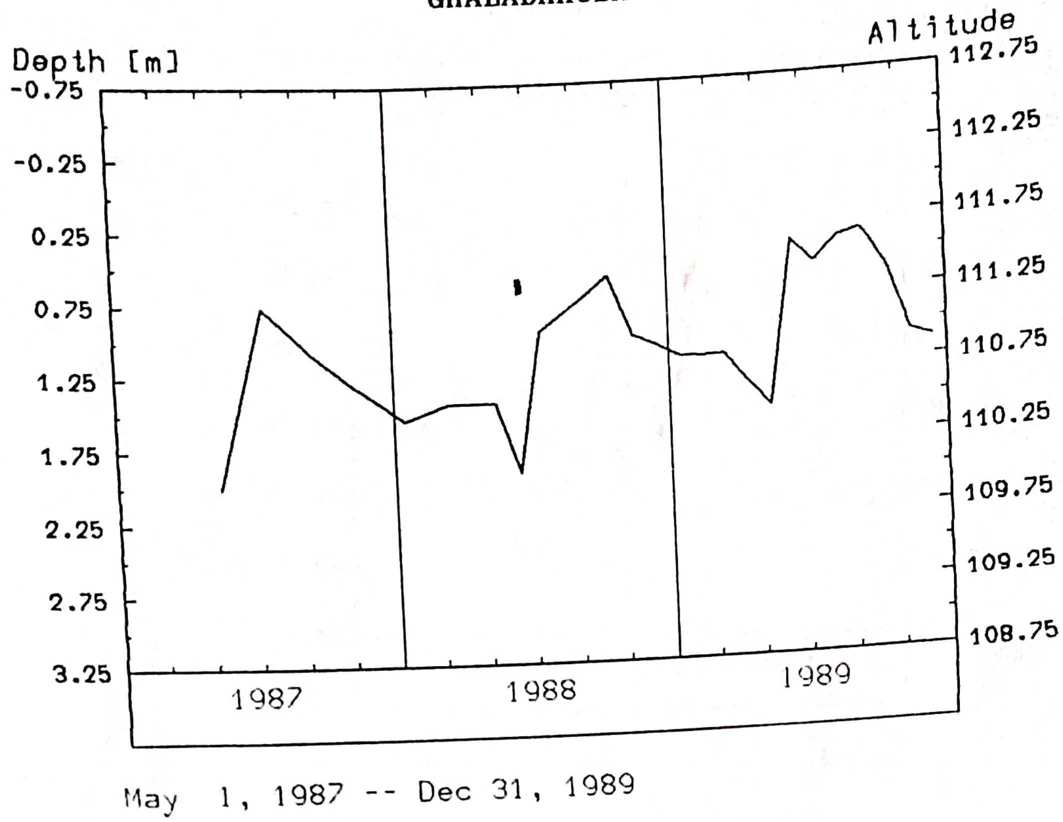
May 1, 1987 -- Dec 31, 1988

HUKAGACHHI

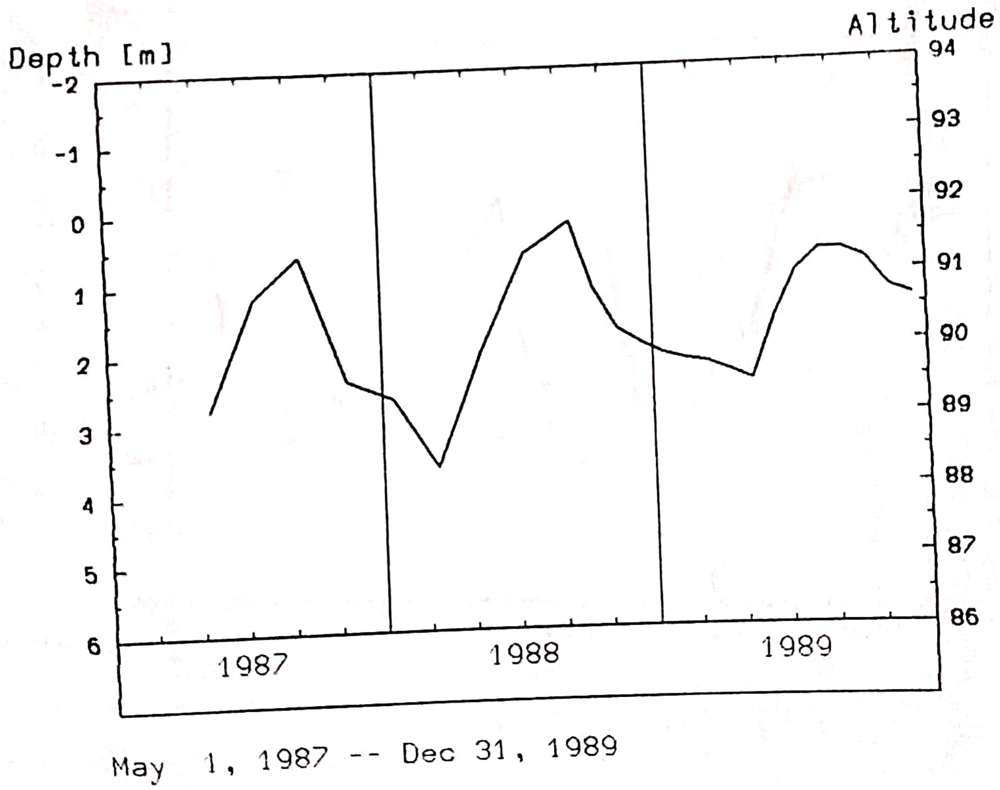


May 1, 1987 -- Dec 31, 1989

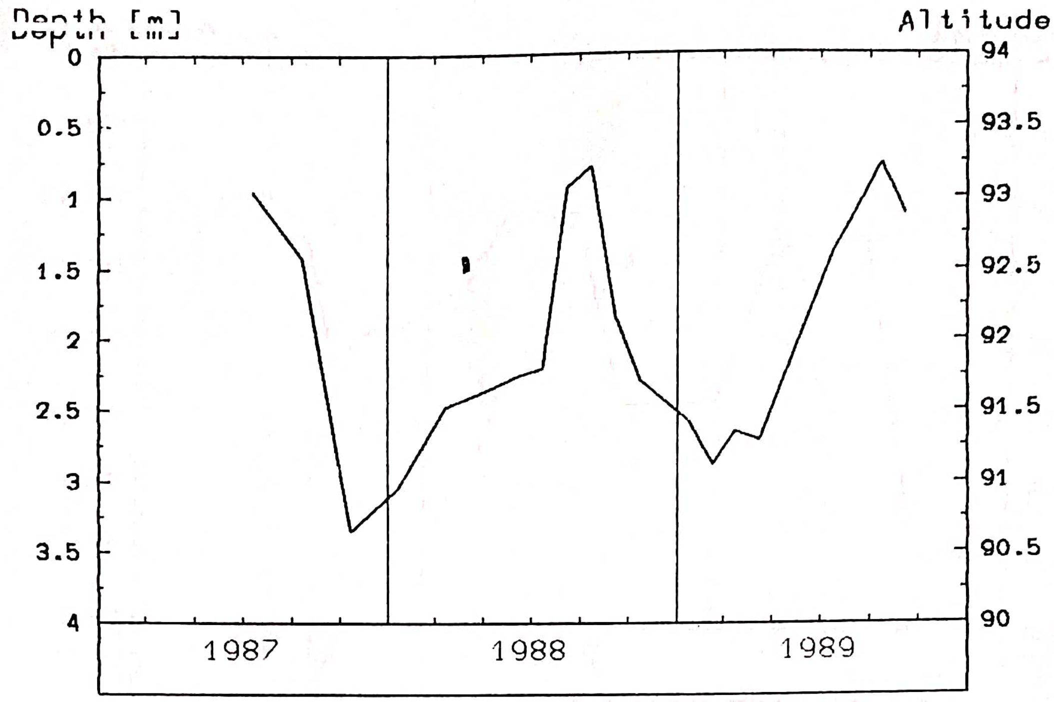
GHALADHHUBA



DANGIBARI

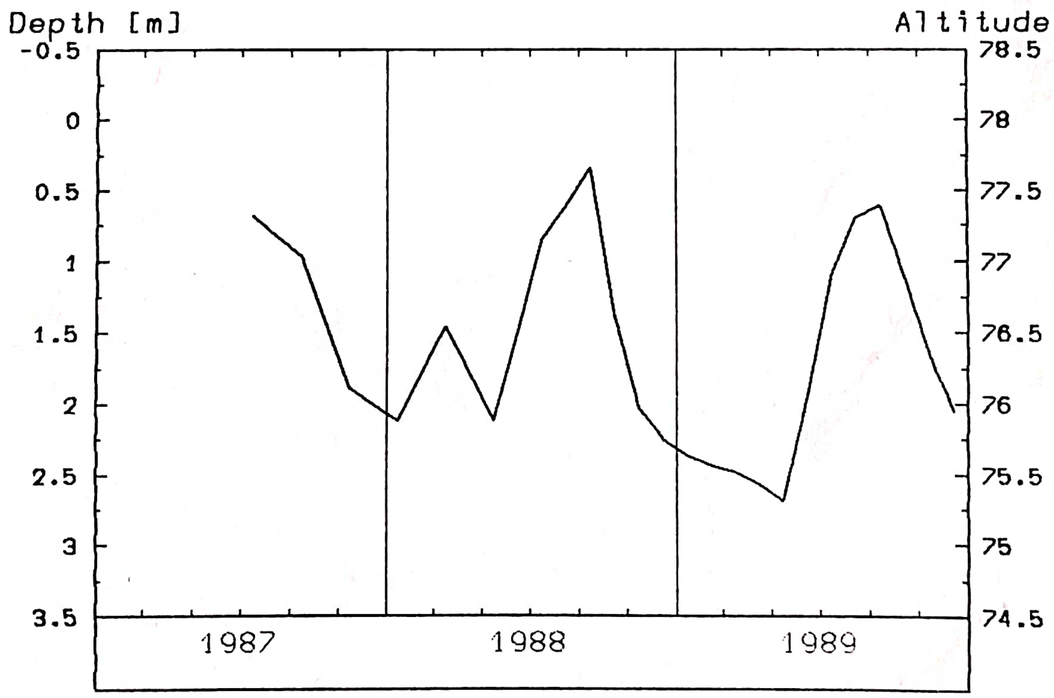


PHULBARI



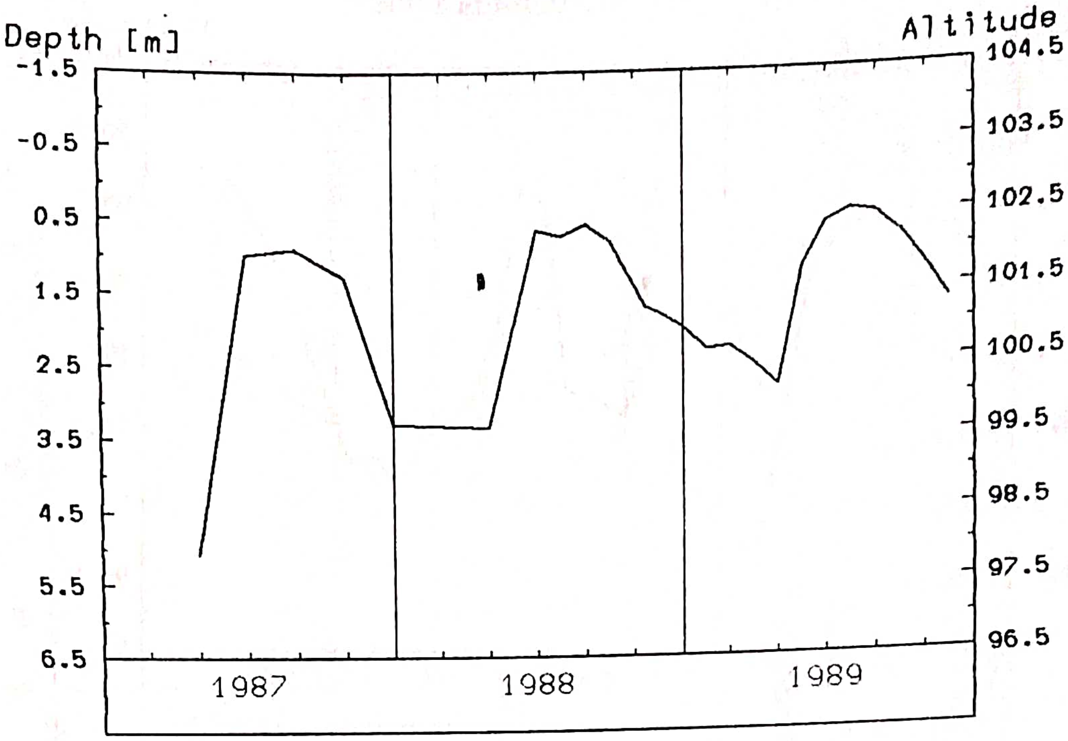
May 1, 1987 -- Dec 31, 1989

RAJGADH



May 1, 1987 -- Dec 31, 1989

CHANDRAGADHI



May 1, 1987 -- Dec 31, 1989