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SHALLOW GROUND WATER INVESTIGATIONS IN TERAI

BHAIRAWA-LUMBINI MATHEMATICAL MODEL

1st PROGRESS REPORT

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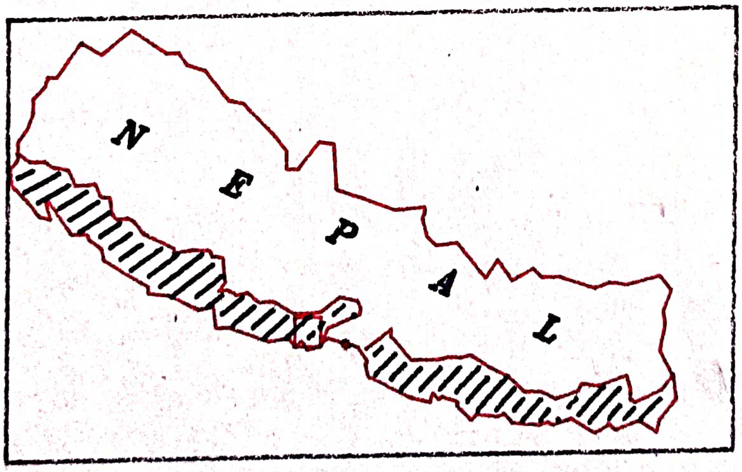

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NEP/86/025 - SHALLOW GROUND WATER INVESTIGATIONS IN TERAI

MATHEMATICAL MODEL
OF BHAIRAWA-LUMBINI GROUND WATER SYSTEM
1st PROGRESS REPORT

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The work reported herein is an outcome of training in mathematical modelling of ground water systems offered by Chief Consultant to project staff. In preparing this report he was assisted by A.Kanzler, Associate Expert in the project. Raw data were collected by M.B.Kunwar, project staff and hydrogeologist in Bhairawa-Lumbini ground water project. He will be mostly responsible for collecting additional data, preparing them for computer processing and as input to the model. Attending the modelling "course" were Messrs. S.R.Uprety, J.L.Shrestha, M.B.Kunwar, P.Karki, all project staff members.

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NEP/86/025 - SHALLOW GROUND WATER INVESTIGATIONS IN TERAI

MATHEMATICAL MODEL
OF BHAIRAWA-LUMBINI DEEP GROUND WATER SYSTEM

1st PROGRESS REPORT

A model is only as good as the data used to make it. Model does not answer questions. It raises new questions and demands that they be answered first. Model is not the goal per se; the real value of a model is the research and hydrogeological thinking that may produce a good model. (Author)

1. INTRODUCTION

The Bhairawa-Lumbini ground water irrigation project (BLGWP) is the largest "deep well" ground water development project in Nepal. It is located in one of the most promising "ground water environments", yet, it may serve as a reference for other similar districts of the Terai.

The irrigation project was based on the results of some 99 test wells drilled by the U.S. Geological Survey (USGS) and Ground Water Resources Development Board (GWRDB) prior to 1974, and 21 project test wells drilled in 1974/75. The deepest test well, Semari 6/6, with the depth of 457 m, did not reach the bottom of the Gangetic sediments.

The feasibility study findings of TAHAL (Ground Water Consultants from Israel) in January 1976 (Stage I) suggested that 60 million cubic meters (MCM) can be pumped annually from the confined aquifer of the Gangetic sediments, enough for 7,500 ha if the demand is 8,000 m³/ha. The following system of wells was suggested: each well and its own irrigation network shall be one individual service unit for about 50-70 ha net irrigation. There will be a total of about 250 wells; the tube wells would have maximum design capacity of 200 m³/hr (55 l/sec).

The feasibility study findings of TAHAL in January 1979 (Stage II) modified the previous estimate, suggesting that about 130 MCM of ground water could be utilized from deep layers in a larger area.

The design that followed included 7,680 ha in Stage I, and 1,850 ha in Stage II. The individual pumping capacity of each deep tube well was much higher than anticipated in 1976. An average well was designed to pump over 100 l/sec (360 m³/hr) and to distribute the water to about 120 ha each.

By the year 1986, the project completed wells of Stage I, surface distribution and irrigation network for Stage I, and all wells for Stage II (without surface network).

The following table (Table 1) is a summary of wells in Stages I and II, command areas and other related parameters which may amplify the size and importance of this ground water irrigation system.

TABLE 1.

STAGE I DTW´s	Perm. Flowing	Nonflowing	Seasonally Flowing	Total
1. Total installed	24	24	17	65
2. Total operating in July ´86	23	24	16	63
3. Total command area in ha	2872	2879	1930	7680
4. Total irrigation July 1986	2358	2586	1623	6667
5. Pump Q range (l/s) at end of dry season	max 153	min 69	average 111	
	1983/84	1984/85	1985/86	
6. Total DTW in operation	63	63	63	
7. Total pumping time (hrs)	78,475	100,375	100,375	
8. Total volume pumped (MCM)	31.4	40.2	40.2	
9. Total free flow (MCM)	25.3	22.5	19.7	
STAGE II DTW´s	**Perm. Flowing**	**Nonflowing**	**Seasonally Flowing**	**Total**
1. Total drilled by July 1986	15	1		16
2. Total free flow (MCM)	4.9			
3. Net command area (ha)	1743	107		1850
4. Pump Q range (l/s) at end of dry season	max 111	min 56	average 84	

In addition to Stage II, currently under evaluation and assessment is the extension of the present irrigation system to the east, south and west (Stage III).

It is obvious that such a large ground water development system needs to be interpreted by an adequate mathematical model. Modelling is today a routine job undertaken for much smaller system than is the Bhairawa-Lumbini ground water irrigation project, provided that sufficient data are available for model construction.

As a part of the United Nations project activities (NEP/86/025 - Shallow Ground Water in the Terai), the training in modelling to GWRDB staff is foreseen. Ground water system of the BLGWP is a composite of both shallow and deep components. The recharge to the system, and actually all water that is or will be pumped at the project site, comes through Bhabar zone near and around Butwal. The source of recharge is rainfall and some surface flow which infiltrate through the very permeable surface layer into the shallow aquifer from where the water flows laterally down the gradient toward deeper zones of the project area.

2. MODEL SETUP

2.1. Model Size and Network

Although the Stage I project area is not larger than 8 km by 20 km, i.e. about 160 km^2, the area involved in ground water flow is much larger. In confined aquifers pressure disturbances propagate at a rather high speed. The classical cone of depression may reach many tens of kilometers under heavy ground water withdrawal conditions. The minimum size of the modelled area for this early development of the model appears to be 45 km in the west-east direction by 40 km in the north-south direction (Fig. 1). The only natural boundary of the ground water system is the northern line, coinciding with the Siwalik hills - flat Terai plain boundary. Other three boundaries of the model are artificial. This is to say that if there would be in the future any ground water development near or outside these boundaries, the impact of such development (say, in Nawalparasi, India) shall be spread to the project area as well. To diminish the influence of boundaries, the model had to be made large enough to keep the pumping zones away from the boundaries. Yet, it appeared obvious that the present model, although occupying 1800 km^2 area, will need to be extended in eastern direction in order to accommodate an eventual ground water withdrawal in the future from Stage III.

The model´s coordinate system is expressed in rows (J) and columns (I). In the model there are 45 columns and 40 rows. This is an equidistant model, with equal spacing between model cells in I (column) and J (row) direction. This spacing is equal to 1000 m. Thus one cell represents an area of 1 km^2.

2.2. Modelled Processes and Aquifer Parameters

The deep aquifer of the Bhairawa-Lumbini project is recharged at its outcrop area which is some 10 km to the north, at the foothill of the Siwalik hills, near and around Butwal. The recharge area is the fan deposit known as Bhabar zone. From earlier reports (Tillson, 1985) the Bhabar zone covers in Rupandehi district about 100 km^2. It is a very permeable zone, composed of gravel with pebbles, some coarse sand and minor amount of finer clastics. Water that infiltrates in the Bhabar zone flows down the gradient toward deeper parts in the south. The flow is controlled by transmissivity of the deep aquifer. It is assumed that outside the Bhabar zone there is no interchange of water between ground surface and shallow aquifer on one side and deep aquifer on the other side. "Deep" in the context of the Bhairawa-Lumbini ground water system is the aquifer between 80 and 180 m of depth. Thus the processes of importance in this ground water system are (1) recharge in the outcrop area (Bhabar zone), (2) natural flow through the aquifer according to distribution of transmissivities and flow gradient, (3) boundary conditions at the southern edge of the model (toward India).

2.2.1. Recharge to Deep Aquifer

Duba (1982) calculated the recharge to shallow aquifers. For the Lumbini zone, to which belongs Rupandehi district, he calculated that out of an average annual rainfall of some 2490 mm (Butwal) about 43.7% infiltrate into subsurface recharging both shallow and deep aquifers. Thus the infiltrated surface water (both rain and surface runoff) may be as high as 1089 mm annually. If the same percentage prevails in the whole 100 km^2 of the Bhabar in Rupandehi, the total infiltrated volume could be as high as 109 MCM. Yet, again, this assessment is more or less subjective and extrapolated for the whole zone. One portion of this recharge reaches and stays in the shallow aquifer, and another, probably greater, flows through the deeper aquifer creating in most part of the Bhairawa-Lumbini proper a piezometric pressure above ground surface. This gives rise to flowing wells.

2.2.2. Transmissivity of Bhairawa-Lumbini Deep Aquifer

Although many pumping tests had been conducted in the project area, there was a conflict in interpretation among hydrogeologists evaluating such pumping tests. Early interpretations indicated extremely high transmissivity values reaching in some extremes 50,000 m^2/day. Such high values, from an aquifer with maximum permeable thickness of some 60 to 70 meters (gravel and sand), was very difficult to justify. Hydraulic conductivities of over 1000 m/day are hardly known in loose clastic rocks, including gravels, and if these were true the system would be unique. Reevaluation of pumping tests was in order. The results are presented in Appendix 1 at the back of this report.

It is clear that the transmissivity values are very high. However, the highest value from some 33 pumping tests that were evaluated by modern and dedicated computer software were of order of magnitude 27,000 m^2/day. (This alone is one of the highest values for transmissivities in loose materials ever recorded.) The summary of transmissivities is shown at the beginning of Appendix 1. The computer-produced map of transmissivities for the project area is shown in Fig. 2. Our interpretation of such high transmissivities is the following. Some wells in the Bhairawa-Lumbini project area "hit" some fossil river beds, filled with gravel and buried under the present cover. Same as today, large rivers were carrying plenty of coarse material from the Himalayas and were depositing it at the exit from gorges. In the geological past the land surface of the Terai was at much lower elevation then at present. A minute interpretation of the transmissivity distribution in the project area might even indicate the direction of these buried or "paleo" channels.

However, in the model area there are many other wells in which pumping tests have also produced some values of transmissivities. An overall map of transmissivity distribution was produced by the computer (interpolation and extrapolation) and is shown in Fig. 3. (Unfortunately, in early calibration runs, it was discovered that very low transmissivities - less than 2000 m^2/day - were probably a result of improperly developed wells and/or incorrect pumping test interpretation. Thus one has to question some of early values.)

It is of interest to note that pumping tests in most of wells follow the pattern which is characteristic for non-leaky aquifers, indicating that there is no hydraulic connection between shallow and deep layers (except in the recharge zone). This, plus flowing wells, plus no reflection of deep pumping tests on heads in shallow aquifer, points at the fact that ground water flows from north (Bhabar) to south (India) without any interchange with surface or shallow water in the project area. So, the processes such as evaporation from water table, interconnection with river water and like, are of no importance in the project area.

2.2.3. Storage Coefficient

In some deep wells, during pumping of one well levels were also observed in a nearby deep well. These observation wells were used to calculate the storage coefficient of deep aquifer. The values calculated by the computer are presented in Table 2 here below.

TABLE 2.

Well No.	Model Coordinates	Storage Coefficient
W/27	20,10	0.00055
W/4 Stage II	13,19	0.0046
W/28	29,16	0.0011
W/29	31,15	0.00034
W/14	24,13	0.0014
W/18	25,17	0.00046
W/20	24,14	0.0001
W/19	23,13	0.00036
W/36	19,11	0.00013
W/46	21,12	0.00018
W/45	21,15	0.0013
W/22	22,12	0.00013
W/47	20,13	0.0003
W/62	20,15	0.0023

The values of the storage coefficient of order of magnitude 0.001 and larger indicate an aquifer which is not under extremely high pressure so that elastic release of water from storage is not that high as in real confined aquifers characterized with the storage coefficient of order 0.00001 and smaller. (This may be obvious considering that "deep" aquifer of the BLGWP is only relatively deep - within 200 m from the surface.)

2.2.4. Model Boundaries

As mentioned before the only natural boundary of the model is its northern boundary, towards Siwalik hills. This is considered to be a physical termination of the aquifer. (The hypotheses of subsurface flow from below the Siwalik hills belongs to the domain of ground water illusions.)

The western (column 1) and eastern (column 45) boundaries are represented in the model as boundaries across which there is no flow. The model automatically treats the area outside of the model as zero transmissivity area, so the western and eastern boundaries coincide with one of streamlines (lines of flow direction, steepest gradient). Such a treatment may be correct under conditions of no or very little pumping from ground water system. It may not be correct if and when a hypothetic future extension of abstraction is simulated. (It was already mentioned that to forecast the impact of abstraction in Stage III and Stage II wells, the model will have to be extended west and eastward.)

The south boundary is treated as a constant head boundary, at least in this preliminary model testing. This is to say that the natural outflow to aquifer extension in India is taken care of by assigning constant water-head elevations which would act as "rivers" intercepting ground water flow. The "constant heads" are taken from maps of water levels that are used for model calibration and verification.

2.2.5. Phases of Modelling

Each ground water mathematical model must have at least two phases: (1) steady-state model calibration, and (2) unsteady-state model calibration. The third phase, which has most appeal to water planners and managers, the prognosis of system behavior under different (designed and tested) scenarios, may or may not be done. It depends on the success of model calibration. If a model is able to duplicate the system´s behavior in the past, it should be able to forecast the future as well.

The steady-state calibration is necessary to produce good initial map of water levels (although in confined aquifer the correct expression would be heads or piezometric surface, "levels" shall be used for convenience with understanding that the term implies a level in a well casing and/or pressure head in aquifer). Levels must be in equilibrium (recharge-flow-discharge) so that any non-steady state deviation from the balanced state produces changes in wanted direction. E.g., levels should decline in dry season or rise in wet. They will not do so unless the map of initial levels is perfectly balanced in the antecedent period.

For this model the steady-state configuration of levels in October 1983 was selected as the starting point of calibration. In climatic conditions such as in Terai, either minimum levels (May-June) or maximum levels (September-October) could be selected to start the modelling.

The real verification of model parameters are in so-called unsteady-state calibration (verification), which, in this case, shall extend from October 1983 through present days (May 1988).

The final stage of modelling is the use of the model, once properly calibrated and trusted, to forecast the future. This future may be in a form of providing answers to impacts of present continued exploitation, of inclusion of other zones into pumping, of interference between several zones (not forgetting that Indian side may also contemplate their own deep ground water production on large scale).

3. STEADY-STATE CALIBRATION

3.1. General

The work on the Bhairawa-Lumbini model did not go too far. At the moment we are calibrating the model under steady-state conditions in October 1983. The basis for the calibration is the map of water levels obtained from project observation wells and other wells all over the model area. This map is reproduced as Fig. 4. The map is the product of a computer contouring software which interpolates and extrapolates random values. Wells used to construct the map are also shown in Fig. 4.

The principle of modelling is simple. It may be sketched as a black box below.

```
!----------------------!                   !-------------------!
! DATA INPUT:          !                   !    OUTPUT:        !
! Recharge             !    !-----------!  !                   !
! Transmissivity       !    ! COMPUTER  !  ! MAP OF LEVELS     !
! Storage Coefficient  ! +  !  PROGRAM  ! =! WATER BALANCE     !
! Pumping              !    !-----------!  ! HYDROGRAPHS       !
! Boundaries           !                   !                   !
!----------------------!                   !-------------------!
```

Data create a model, program processes all data and produces output. Computer output is compared with maps, balance and hydrographs recorded (observed) in nature. If they do not fit input data are modified and process is repeated. Each of computer runs is called a calibration run. Finally after many calibration runs, of which each should lead to final solution although some may fail, the process of calibration is over and parameters and simulated processes are believed to correctly represent the system.

The more available data collected in nature, the more difficult it will be to calibrate a model. Yet, the model shall be much better if data are available. In the case of the Bhairawa-Lumbini model, we have a very long period of water-level observations, which resulted with minimum and maximum level maps (May/October) in the period from 1976 through present. Likewise, we have many hydrographs collected in project observation wells in biweekly intervals since 1976. Pumping tests produced many transmissivity and storage coefficient values. Rainfall data are collected in Butwal and elsewhere.

Pumping from project wells is recorded and/or estimated. At first glance it appears that data are abundant and that to construct an adequate model would be a straightforward procedure. A closer inspection of available data will refute such a conclusion.

3.2. October 1983 Water Levels

Evidently, well points used to produce the map of water levels in October 1983 (Fig.4) are not uniformly and optimally spread over the model area. Mostly observation wells from the project area proper are available, plus some occasional wells from old USGS/GWRDB drilling program. Although this map should be used to match the model output map against, it also should be questioned prior to approving or disapproving model output map in the same time interval. Two zones on the map are zones of computer-extrapolated levels.

The northwestern corner displays a very flat plateau of levels between 115 and 120 m absolute elevation. If this were true, it would imply an extremely high transmissivity (very low gradient of ground water flow) which is not the case. Most likely is that the contours 135, 130, 125, 120 extend to the west more or less parallel to the boundary of the Terai. Also the steep gradient in the central north part (10 km west of Butwal) would have indicated either a very low transmissivity or extremely large ground water flow. The second possibility is excluded since this would mean that most of recharge flows not into the Bhairawa-Lumbini project area but westward. So, the conclusion is that additional water level data are necessary to improve the water-level distribution in north-western corner. A search through old files, archives and reports may shed some light. Alternatively, any October levels (prior to or after 1983) may also greatly help. It is of help to know that the ground water system prior to 1983 was "virgin", without any pronounced ground water abstraction, and that fluctuations of water level were of seasonal character very much alike in one year as well as in another.

The southeastern corner is even worse. This is the portion of the model in India. If such levels were true than the aquifer in India would have extremely high transmissivity, much higher than in the project area. (It is a unanimous belief that deep aquifer becomes less permeable, more silty and clayey, going southward.) We do have some information on depth to water in deep wells on the Indian side of the model. However, our attempts to produce a topographic map with correct land surface elevation failed so far.

Before this map of initial water levels (October 1983) is corrected, any further work on modelling will be hopeless.

3.3. Transmissivities

From the map of transmissivity (Fig. 3) it is obvious that data are lacking in the whole southeastern part of the model. They are missing in north-western corner and in north-eastern part. Data from Stage II wells should be reevaluated and used for reconstruction of this map. Drilling of wells in Stage III, which will start this year, will greatly help to improve the data base.

(The northern part of the model, around Butwal, is excluded from modelling, being declared an area with T=0. This is the Siwalik portion of the model in which loose sand-and-gravel aquifer of the Terai disappears.)

The transmissivity data input into the model in the steady-state calibration run is shown in Fig. 6. (It is shown together with the output - map of levels in October 1983 as produced by the model.)

3.4. Recharge

To input recharge into the model in the Bhabar zone one needs first to know the amounts of rainfall in Butwal. As shown in Fig. 5, rainfall in Butwal is extremely high, over 2400 mm annually for a 10-year period. (It is almost twice that much of rainfall at Bhairawa.) Almost 90% of rain falls in the period from June through October, with July receiving as much as 700 mm. Since the modelling procedure assumes a percentage of monthly rainfall as an infiltration rate into the aquifer, it is evidently not the same percentage in the case of uniformly distributed rain over a month compared to heavy rains of several hundred millimeters in several days. In the first case the capacity of unsaturated soil is such that it can accept the infiltration. In the latter case, the recharge is rejected because the infiltration would be above the soil infiltration capacity. Obviously one need also daily amounts of rainfall in the case of monthly extremes. (Contrary to what one would expect, we were not able to obtain monthly rainfall data for the year 1983/84 and onwards.)

The model will, among other, show whether the Duba´s (1982) estimate of Bhabar recharge to aquifers in Bhairawa-Lumbini area is correct. However, lithology of Bhabar zone must be reinterpreted to make a demarcation of the Bhabar and recharge zone.

The recharge in the steady-state calibration run is shown in Fig. 7. This is a coded display covering an area of recharge of about 71 km^2 (71 cells). (This is not "far" from Duba´s 100 km^2 for the whole Lumbini zone.) Accepting percentage categories as shown in Fig. 7, and an average monthly rainfall of 350 mm in the period preceding October 1983, implying that in the rainy season of 1983 about 2100 mm of rain fell (see Fig. 5), the total recharge from rainfall (and associated surface runoff infiltration) amounts to about 204,768 m^3/day or 2370 l/s under the steady-state conditions.

3.5. Pumping

Pumping rates, volumes and distributions should be one of unquestionable input parameters. This is a human activity and as such should be recorded. This is the case in this project, as shown in Table 1. Yet, there are some doubts as to free flow from uncontrolled and unused wells.

For steady-state calibration, it was accepted that in the period from May through October 1983 the pumping was minimum, at about 3680 m^3/day (43 l/s). This is a small fraction of recharge and outflow across the row 40. In unsteady-state calibration of the model, from October 1983 till present days, the pumping shall be one of the most critical parameters, although still much below the maximum development potential.

3.6. Model-Produced Map of Levels in October 1983

The map of levels as produced by the model for October 1983 as shown in Fig. 6 is the outcome of at least 8 calibration runs. Since we have not accepted the levels in southeastern corner as shown in Fig. 4, but have lowered the south boundary´s constant head to 85 m (west) and 91 m (east), that corner cannot be compared. Water levels in the project area are still several meters too high in the model compared to the nature. Further calibration runs are needed to produce a better match. However, this can be done only after a better "original" map, or map to be matched, is produced.

4. UNSTEADY-STATE CALIBRATION /VERIFICATION

First to clarify the difference between terms "calibration" and "verification". Calibration is an early process in modelling in which the model is for the first time calibrated (fitted) with a selected set of parameters. These parameters are further verified by selecting an advanced period (later water levels). If model matches that period as well, without modifying parameters, than parameters are verified.

The period from October 1983 through May 1988 shall be discretized in equal intervals each of 30 days duration. The whole unsteady-state calibration period shall be divided into 55 equal-size intervals (time steps).

What was for the steady-state calibration the initial map of water levels (October 1983), for unsteady-state calibration shall be hydrographs at selected points strategically distributed over the model area. Model must match water level fluctuations in as many cells as available. In that process the following parameters shall be modified: transmissivity, storage coefficient, recharge distribution and volumes, boundary conditions. Pumping, which normally should be 100% unquestionable, may also need to be modified on the ground of not knowing free flow from wells. Also several maps may be produced by the model at the beginning or end of monsoon seasons and compared with similar maps from observations in the field. As an example of comparison between model output and field measurements, Fig. 8 shows model produced hydrographs at cells 24,12 and 29,16 and field-produced hydrograph in wells W/13 and W/65. This was the demonstration unsteady-state calibration run which did not pretend to be as good as future runs should be. Yet, even in this early stage, the decline of levels in cell 24,12 is about the same as in the well W/13 (in spite of initial levels being shifted for about 2.5 m). It is not the same in cell 29,16 when compared to W/65.

5. CURRENT RESULTS

The initial computer runs indicated the following: (a) water level map as shown in Fig. 3 cannot be matched (this map must be improved and modified); (b) the map produced by the model for October 1983 (Fig. 6) is not the final product of steady-state calibration but it is reasonably close to actual water levels; (c) the transmissivities are very high indeed in the project area (from 5000 to over 25,000 m^2/day); (d) the recharge in wet season (June-October 1983) could be about 204,750 m^3/day, or about 37 MCM in the six-month period; (e) outflow of ground water southwards, to India, may amount to about 2185 l/sec (188,784 m^3/day).

The model assumed 350 mm of rain as an average in months that preceded October 1983. Thus the rain input over 71 km^2 may be about 25 MCM in one month (in the period June-October). The recharge of some 204,750 m^3/day, which is equivalent to about 6.1 MCM per month, is only 25% of rain input. The recharge is probably on conservative side.

6. COMPUTER PROGRAM

The project staff working on the model of Bhairawa-Lumbini ground water project should be primarily concerned with data collection, data evaluation, selection, input into the computer, and by evaluation of output produced by the model. This "data input" - "evaluation of output", and decisions to be made for improvement of the model response is the most important part of the modelling exercise. The computer program, written by this author and based on well-known Prickett´s (1972) solution of finite difference equations, was tested over and over again, and should not be a concern of the user. Moreover, the program was rewritten specifically for the use in this UN project, it became menu-driven and transparent to the user. To get an appreciation of the interaction between the user and the program, most of menus that are normally displayed on the screen are reproduced in Appendix 2. The program code itself is saved in project computers and ready for the continued work on modelling when additional data become available. (This is programmed for August 1988, with November 1988 as the target date for an advanced calibration stage and first testing of future development schemes.)

To run the model one needs an IBM-compatible computer (running MS-DOS operating system) with a minimum memory of some 400 KB. To prepare maps as shown in Figs. 2,3,4,6, one needs graphical display, a contouring program, eventually a plotter (not mandatory). Same maps could be prepared with a graphics printer (almost any modern printer can do the job).

7. RECOMMENDATIONS AND CONCLUSIONS

(1) The model is set up, ready for further improvements and testing. The size is considerable, but it will need to be enlarged to permit the testing of development in Stage III wells. Transmissivities and storage coefficients are input according to pumping test results in the project area.

(2) Most of information comes from the project area proper. The rest of area is covered by extrapolation. This must be changed and additional data collected. Of critical importance for the steady-state calibration (and consequently for the whole process of modelling) is to collect the following data:

- Water levels in October 1983 (or any October) in north-western corner and south-eastern part; prerequisite for this is a topographic map with ground surface elevations. This will help to improve the initial map of water levels which is the starting point for the whole modelling.

- Lithological data of wells in the recharge zone. This will help to better demarcate the Bhabar zone from the rest of aquifer, or the zone in which there is direct recharge from the surface.

- Rainfall amounts (by months and days in extreme months) for the period October 1983 till present. The Butwal rain gauge is representative for the recharge zone.

- Pumping test data in Stage II wells need to be reevaluated. The computer program should be used for it. Likewise any other pumping test data outside of the proper Bhairawa-Lumbini project area may help in improving the map of transmissivity distribution.

- Pumping rates, volumes, hours of pumping and free flow, for each month in the period October 1983 till present. The model inputs these data on a cell by cell basis for each time step. A table which converts real well coordinates into model I,J coordinates is prepared in Fig. 9.

- Considering a possible extension of the model toward east (Stage III) and west (Stage II, phase II), one should collect data on water levels, pumping, transmissivity, storage coefficient, etc.

(3) Model can be realistically updated and calibrated in the period between August and November this year, provided that data mentioned in (2) above are collected.

(4) The results of the model, no matter how preliminary, should be used by the Stage III Feasibility Study team to process different design scenarios of future ground water development. Only the model can objectively integrate all processes and parameters all over the ground water system and produce results which are much better than classical ground water balance evaluation based on average values.

References

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2. Duba, D., 1982. Groundwater Resources in the Terai of Nepal. Report No. 4/2/181282/1/4

3. Prickett, T.A. and C.C.Lonnquist., 1972. Selected Digital Computer Techniques for Groundwater Resource Evaluation. Illinois Water Survey Circular 81.

Kathmandu
11 May 1988

FIGURE 1

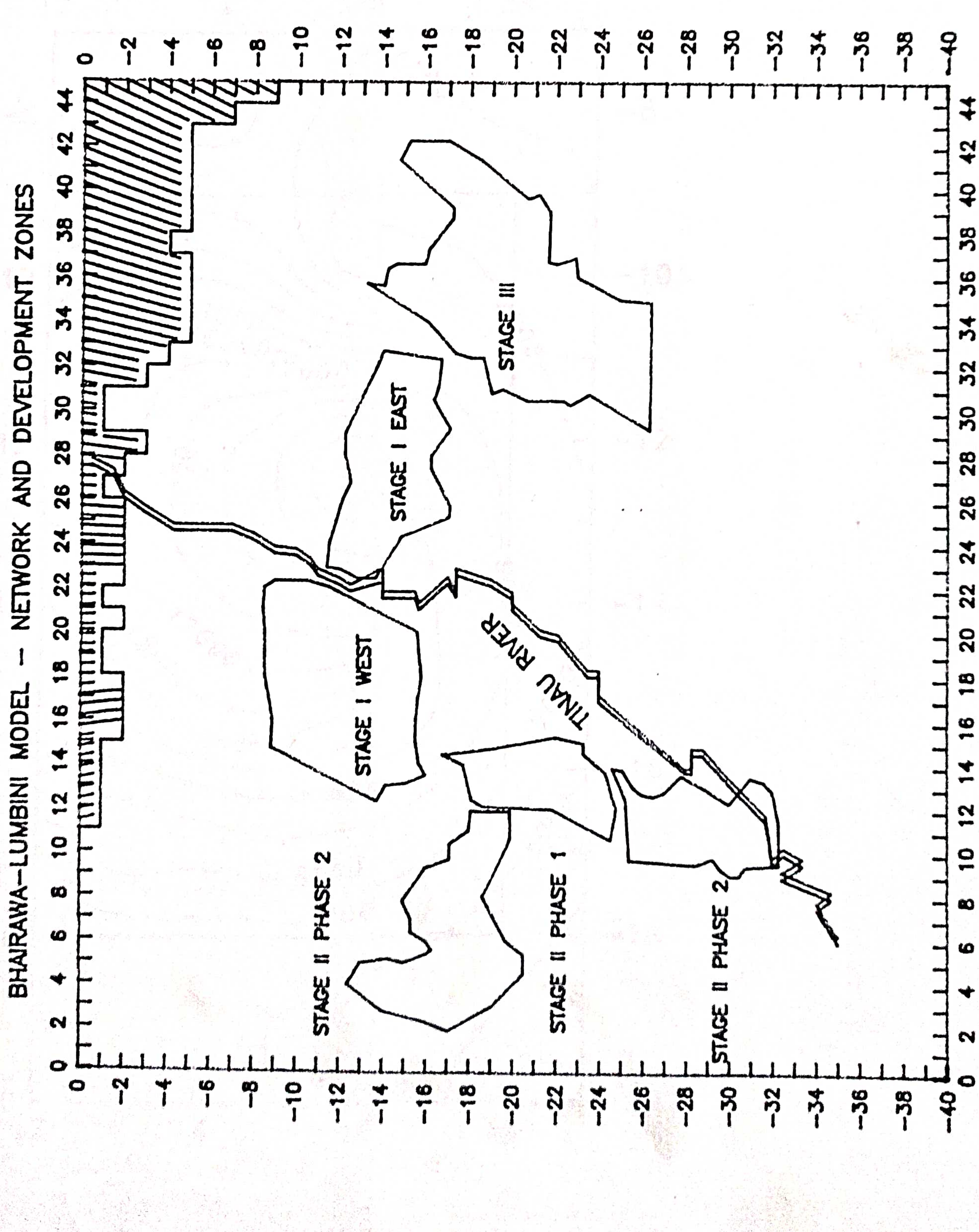
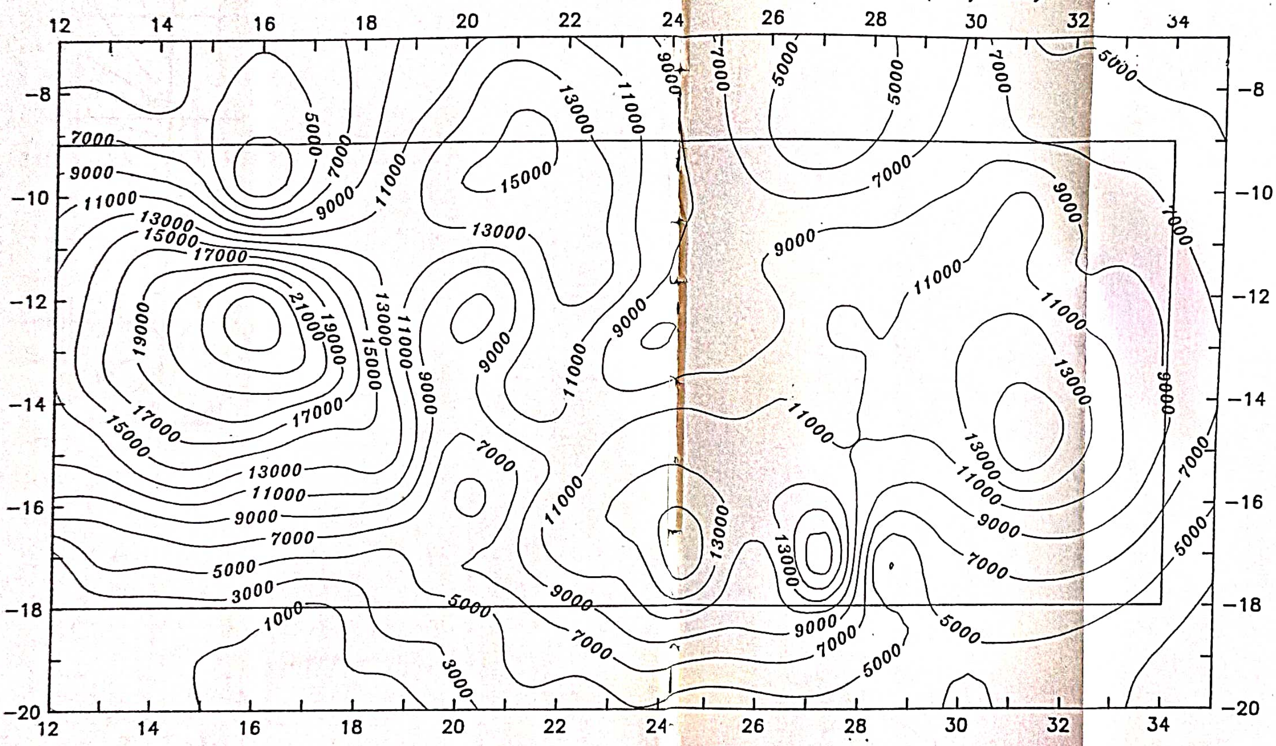

BHAIRAWA–LUMBINI MODEL — NETWORK AND DEVELOPMENT ZONES
STAGE I WEST
STAGE I EAST
STAGE III
TINAU RIVER
STAGE II PHASE 2
STAGE II PHASE 1
STAGE II PHASE 2

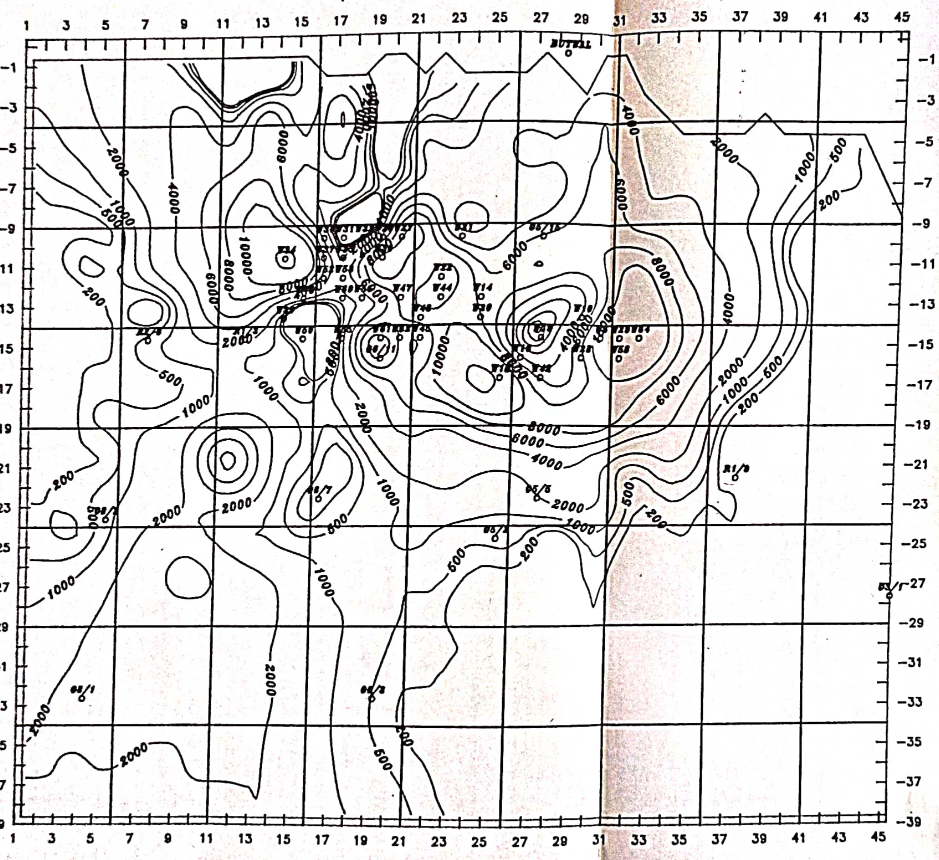
FIGURE 2

BHAIRAWA-LUMBINI MODEL - TRANSMISSIVITIES (M2/DAY)



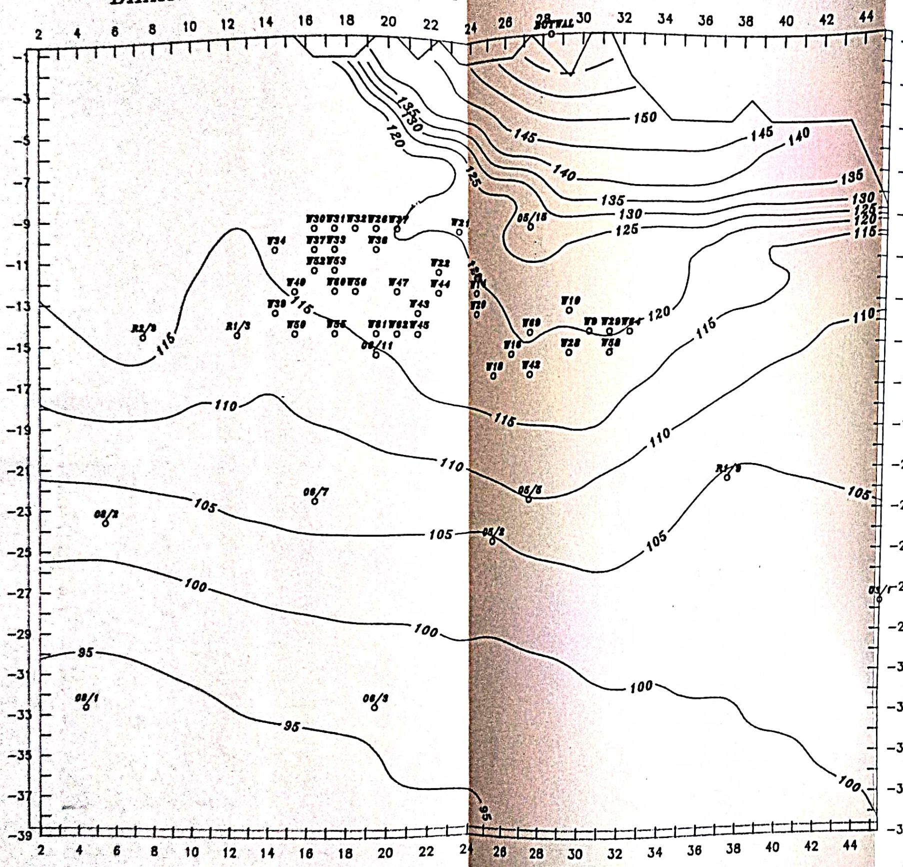
BHAIRAWA–LUMBINI MODEL – TRANSMISSIVITY FROM PUMPING TESTS

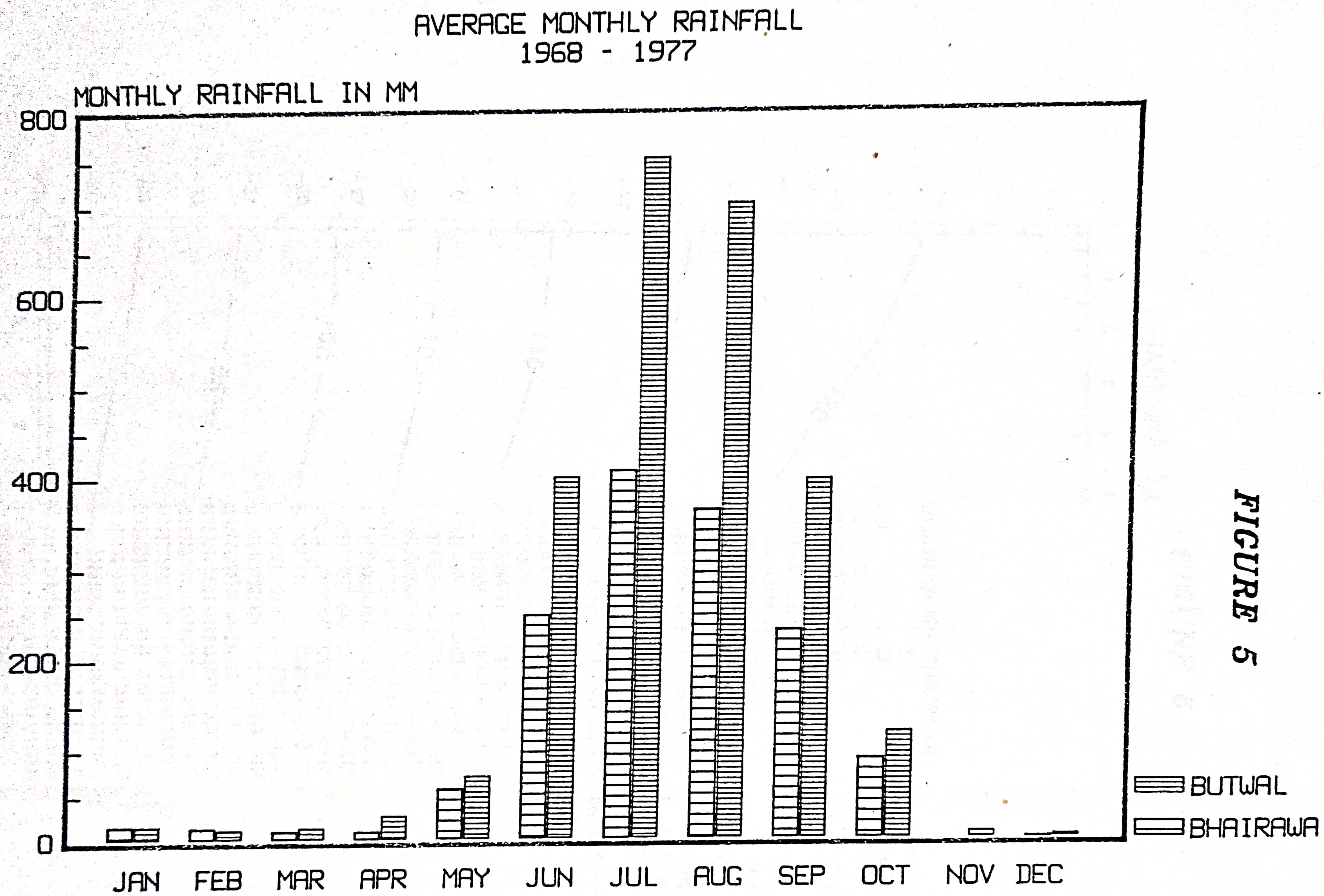
FIGURE 3



BHAIRAWA-LUMBINI MODEL - LEVELS IN OCTOBER 1983

FIGURE 4

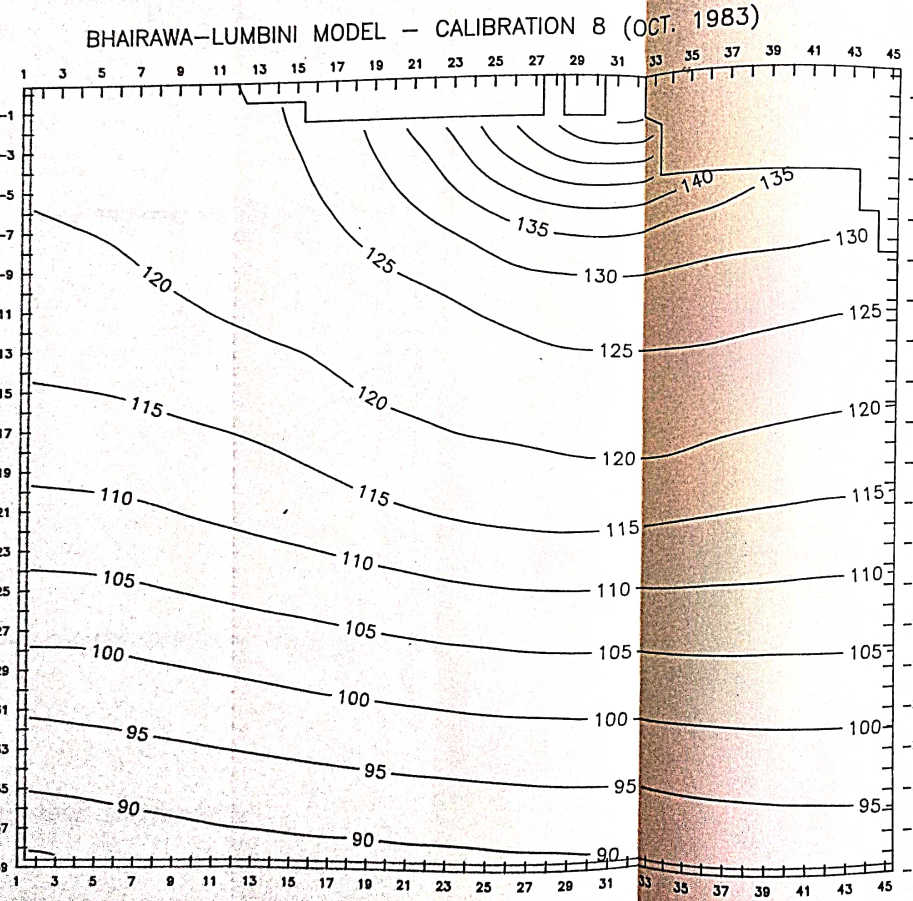




AVERAGE MONTHLY RAINFALL
1968 - 1977
MONTHLY RAINFALL IN MM
800
600
400
200
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
BUTWAL
BHAIRAWA

FIGURE 5

FIGURE 6



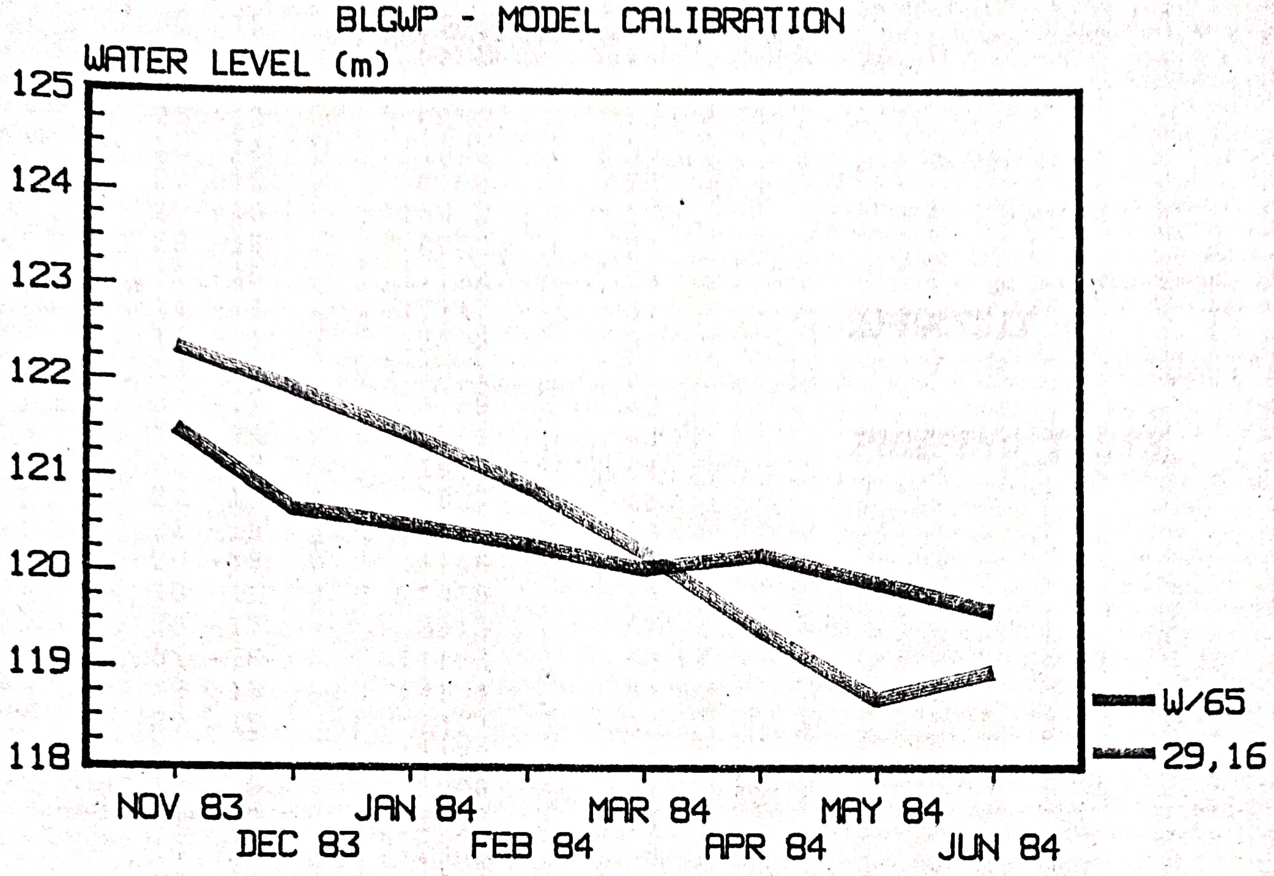

```
     123456789012345678901234567890123456789012345
   1 33333333333               2  22                1  MODEL.TR INPUT FILE
   2 333333333334444           2  22                2  TRANSMISSIVITIES
   3 33333455555665564333333222222222               3      (M2/DAY)
   4 2233344555566554433333332222222                4  0 - OUTSIDE OF AQUIFER
   5 22333445555666565333333222222222               5  1 - T = 1000 M2/DAY
   6 2233333556666656544444222223333333333222222  6  2 - T = 2000
   7 2222234556676555544444444443333333332222222  7  3 - T = 3000
   8 22222234567886533225544444443333333322222222 8  4 - T = 3000
   9 22222235667887621257654355566666555222222222 9  5 - T = 4000
  10 22222234567888554378876556666666655222222222210  6 - T = 6000
  11 222222345678987655788766566667787655444444443 11  7 - T = 8000
  12 222222234677756567889876666678876654444444443 12  8 - T =10000
  13 222222223666655555678987655567888765444444433 13  9 - T =15000
  14 2222222235555555676788755556889876544444444414
  15 2222222222555555597788755557898876544444444415  CALIBRATION RUN #8
  16 2222222222555555666788885567898876544444444416  (LAST - 5/5/88)
  17 2222222222255555556789988767888765444444444417
  18 2222222444555555556788888777777654444444444418
  19 2222222444555555555667887777776544444444444419
  20 2222223346555555555555556676665544444444444420
  21 2222223346676444444444555555553334444444444421
  22 2222223346653333333333333344344444444444444422
  23 2222223333333333333333333333333444444444444423
  24 2222233333333333333333333333333334444444444424
  25 2222233333333333333333333333333333334444444425
  26 2222233333333333333333333333333333333334444426
  27 2222333333433333333333333333333333333334444427
  28 2223333333443333333333333333333333333333333328
  29 2223333333443333333333333333333333333333333329
  30 2233333333443333333333333333333333333333333330
  31 2233333333443333333333333333333333333333333331
  32 2333333333443333333333333333333333333333333332
  33 3333333333443333333333333333333333333333333333
  34 3333333333443333333333333333333333333333333334
  35 3333333333443333333333333333333333333333333335
  36 3333333333333333333333333333333333333333333336
  37 3333333333333333333333333333333333333333333337
  38 3333333333333333333333333333333333333333333338
  39 3333333333333333333333333333333333333333333339
  40 3333333333333333333333333333333333333333333340
     123456789012345678901234567890123456789012345
```

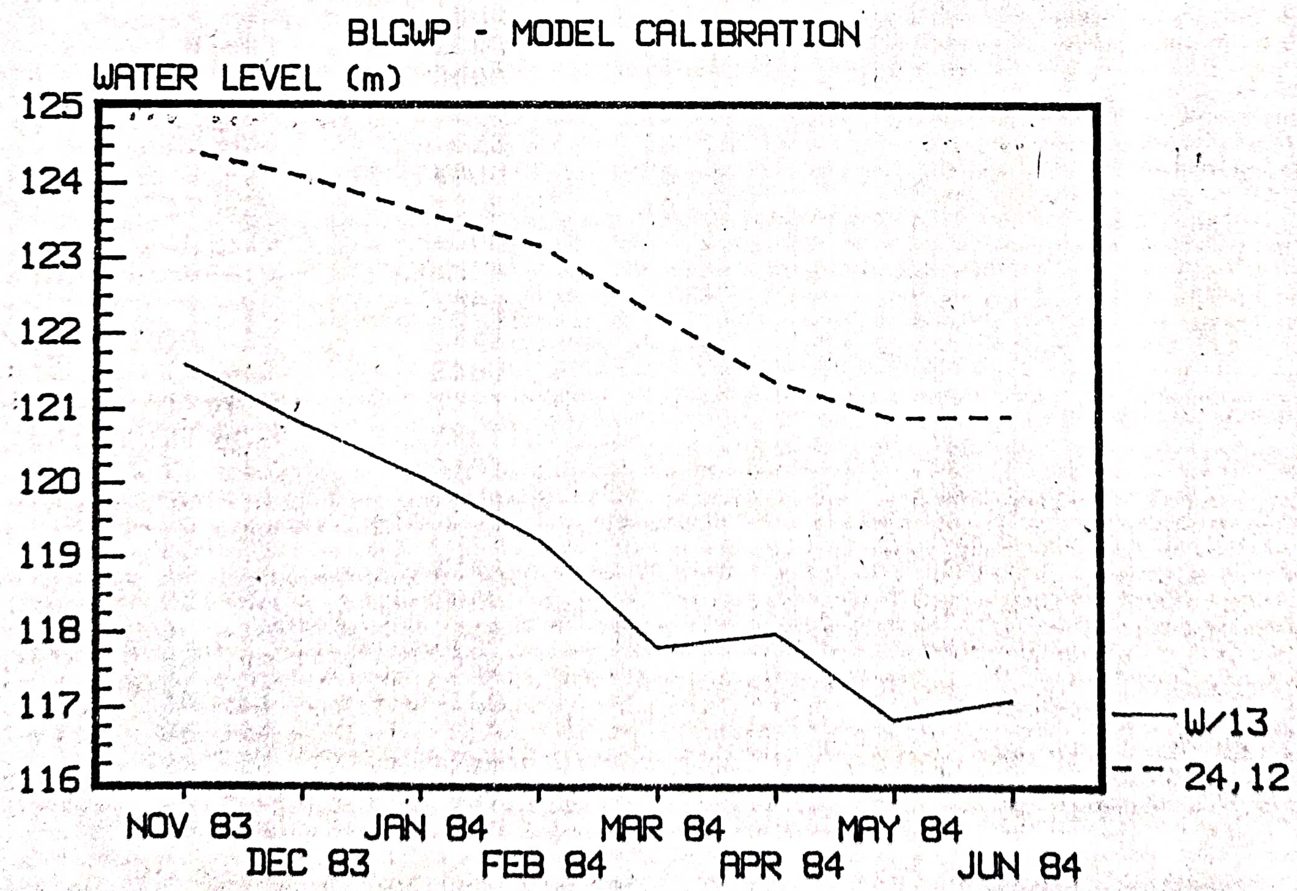
FIGURE 7.

```
    123456789012345678901234567890123456789012345
 1                             7  66                21   MODEL.REC INPUT FILE
 2              111            5  55                 2   RECHARGE DISTRIBUTION
 3               114444455567777 775                 3
 4                        5777777777                 4   0 - I = 0%
 5                         6666666666                5   1 - I = 5%
 6                          5555555555553333333      6   2 - I = 10%
 7                                        33333      7   3 - I = 15%
 8                                                   8   4 - I = 20%
 9                                                   9   5 - I = 25%
10                                                  10   6 - I = 30%
11                                                  11   7 - I = 35%
12                                                  12   8 - I = 40%
13                                                  13   9 - I = 45%
14                                                  14
15                                                  15
16              TOTAL RECHARGE: 204,768 M3/DAY      16
17                                 (2370 L/SEC)     17
18                                                  18
19                                                  19
20                                                  20
21                                                  21
22                                                  22
23                                                  23
24                                                  24
25                                                  25
26                                                  26
27                                                  27
28                                                  28
29                                                  29
30                                                  30
31                                                  31
32                                                  32
33                                                  33
34                                                  34
35                                                  35
36                                                  36
37                                                  37
38                                                  38
39                                                  39
40                                                  40
    123456789012345678901234567890123456789012345
```

RECHARGE DISTRIBUTION

FIGURE 8.


BLGWP - MODEL CALIBRATION
WATER LEVEL (m)
125
124
123
122
121
120
119
118
NOV 83
DEC 83
JAN 84
FEB 84
MAR 84
APR 84
MAY 84
JUN 84
W/65
29,16


BLGWP - MODEL CALIBRATION
WATER LEVEL (m)
125
124
123
122
121
120
119
118
117
116
NOV 83
DEC 83
JAN 84
FEB 84
MAR 84
APR 84
MAY 84
JUN 84
W/13
24,12

I	J	TRANSMISSIVITY (M2/DAY)	WELL No.
30	-15	11508	9
24	-13	5893	14
25	-17	18525	18
23	-13	6489	19
24	-14	11000	20
22	-12	16559	22
20	-10	15929	27
29	-16	8000	28
31	-15	17722	29
14	-11	17147	34
18	-11	12533	35
19	-11	12021	36
27	-17	26739	42
21	-14	13921	43
22	-13	11669	44
21	-15	7620	45
21	-12	6000	46
20	-13	6146	47
16	-12	27488	52
28	-17	3918	57
31	-16	11166	58
19	-15	14151	61
20	-15	2427	62
32	-15	14183	64
13	-19	2000	4
11	-23	3243	14
10	-20	2300	6
12	-20	3088	8
11	-21	10000	7
10	-22	2548	9
14	-22	1000	3
9	-23	2000	12
10	-23	3000	11
9	-24	600	10
10	-24	623	16
9	-25	4000	5
11	-25	1205	13
10	-26	4500	
6	-10	312	
4	-25	224	
16	-10	748	
26	- 3	2369	
27	- 6	5361	
27	- 9	2867	
27	-11	10161	
39	-11	374	
17	-18	374	
26	-17	2244	
25	-20	2942	
36	-18	748	
36	-22	262	
36	-27	150	
26	-24	623	
23	-24	1247	
14	-25	997	
20	-34	150	

APPENDIX 1

PUMPING TESTS

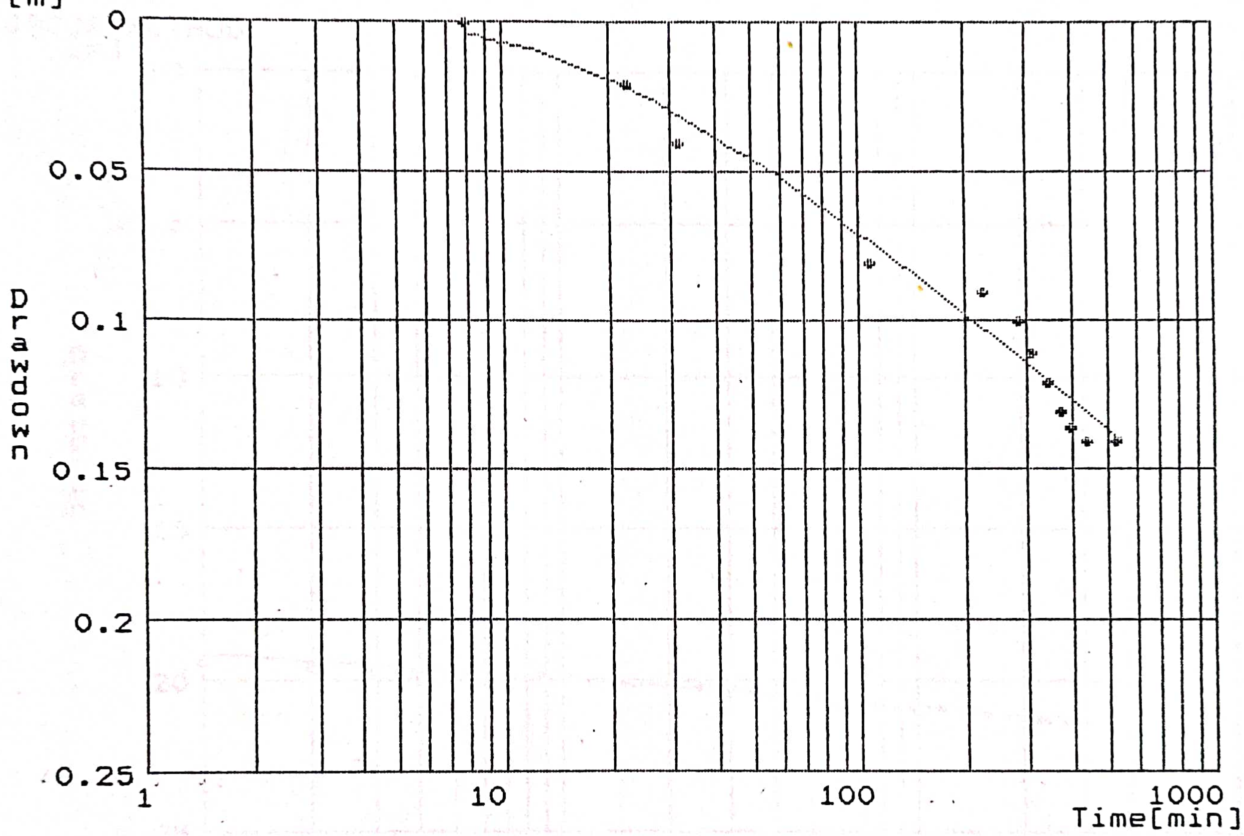
APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/1-PUMPED WELL W/27-OBS.WELL

Constant Pumping Rate = 360.000 [M3/HR]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

Method THEIS



Transmissivity = 15929. [m2/day]
Storage Coefficient = 0.00054706
Standard Deviation = 0.0077 [m]

Number of Points = 12 of 12

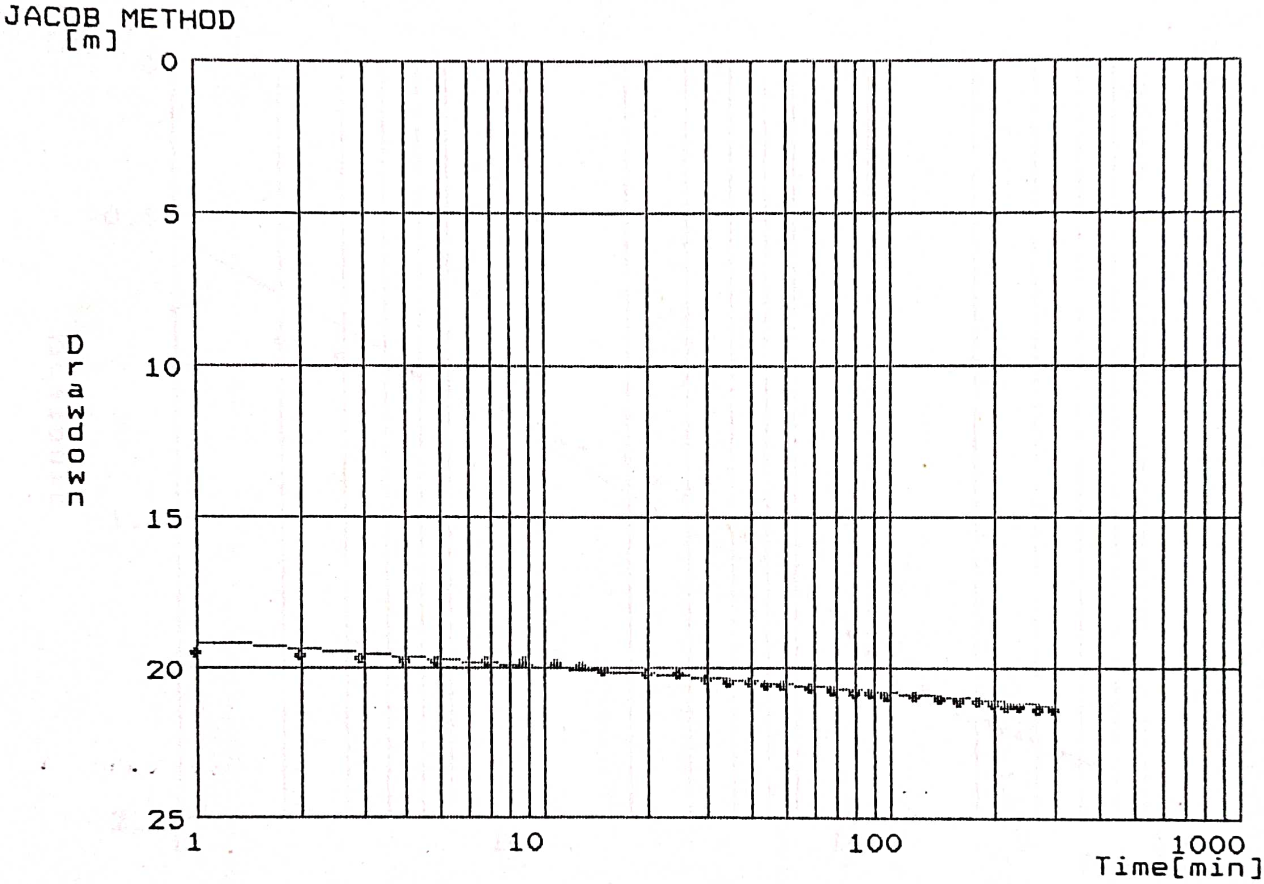
APPENDIX 1 - PUMPING TESTS

II

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : TW-4 PUMPED WELL (BHAIRAWA-LUMBINI)

Constant Pumping Rate = 8232.0 [m3/day]
Distance from Observation Well = 0.25 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 7.75 [m]
Well Type = STANDARD

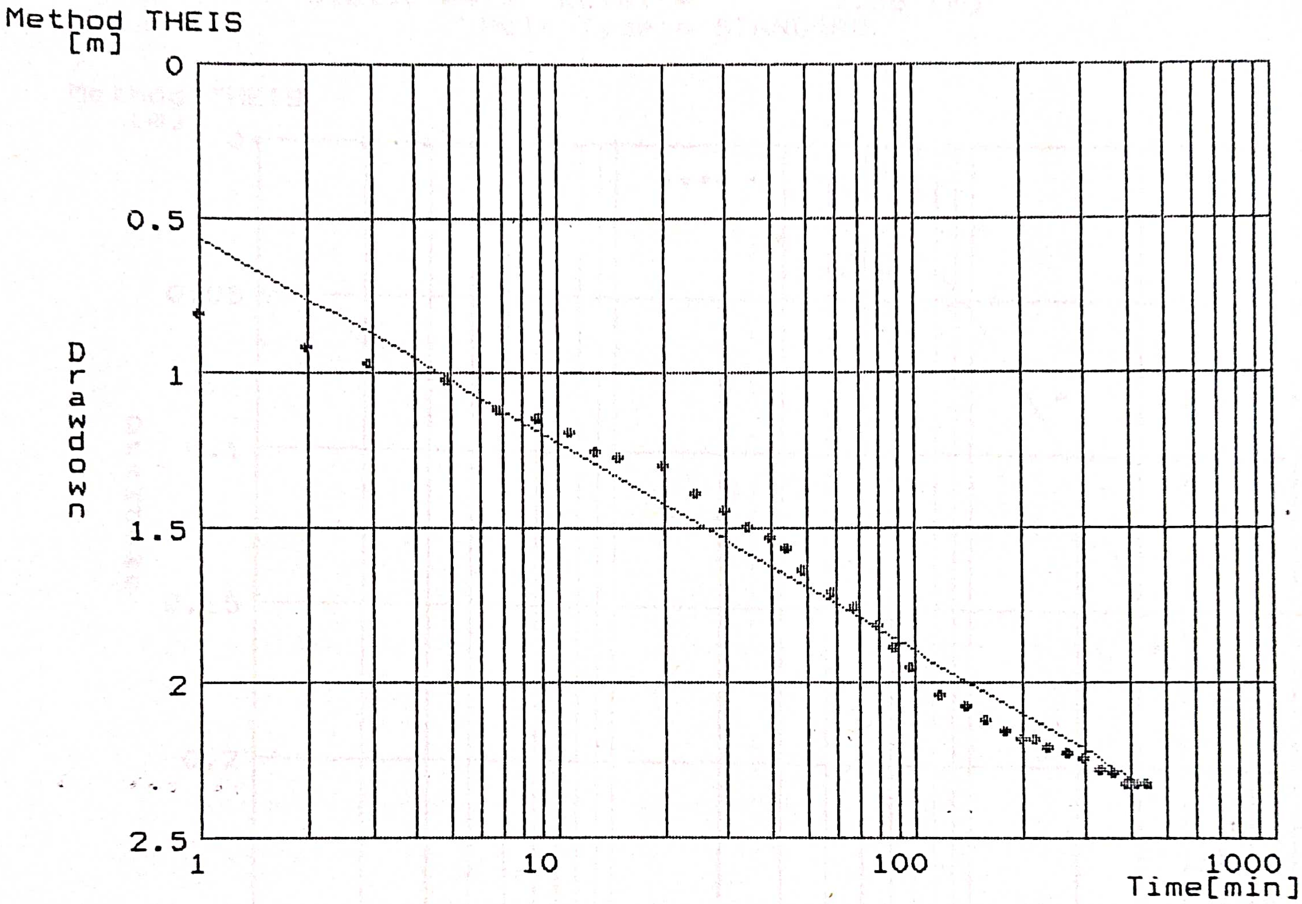


Transmissivity = 1779. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.1091 [m]
A0 = 0.191119E+02
A1 = 0.846585E+00
Number of Points = 31 of 31

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/4 PUMPED WELL - W/4 OBS. WELL

Constant Pumping Rate = 8232.0 [m3/day]
Distance from Observation Well = 11.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 6.25 [m]
Well Type = STANDARD



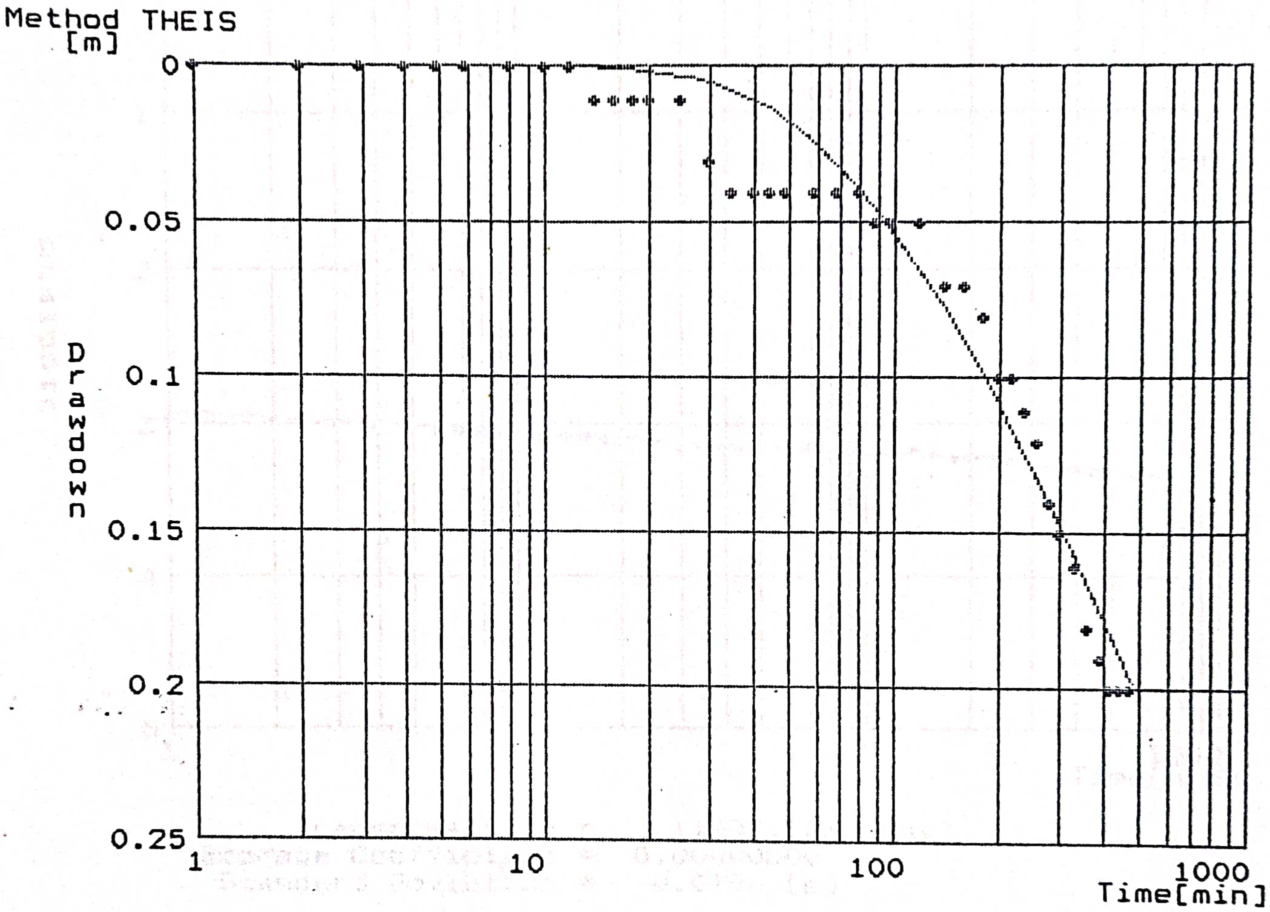
Transmissivity = 2228. [m2/day]
Storage Coefficient = 0.00456357
Standard Deviation = 0.0796 [m]

Number of Points = 35 of 35

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/4 - PUMPED WELL - W/28 OBS. WELL

Constant Pumping Rate = 415.000 [m3/hr]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 2.28 [m]
Well Type = STANDARD



Transmissivity = 6352. [m2/day]
Storage Coefficient = 0.00110523
Standard Deviation = 0.0132 [m]

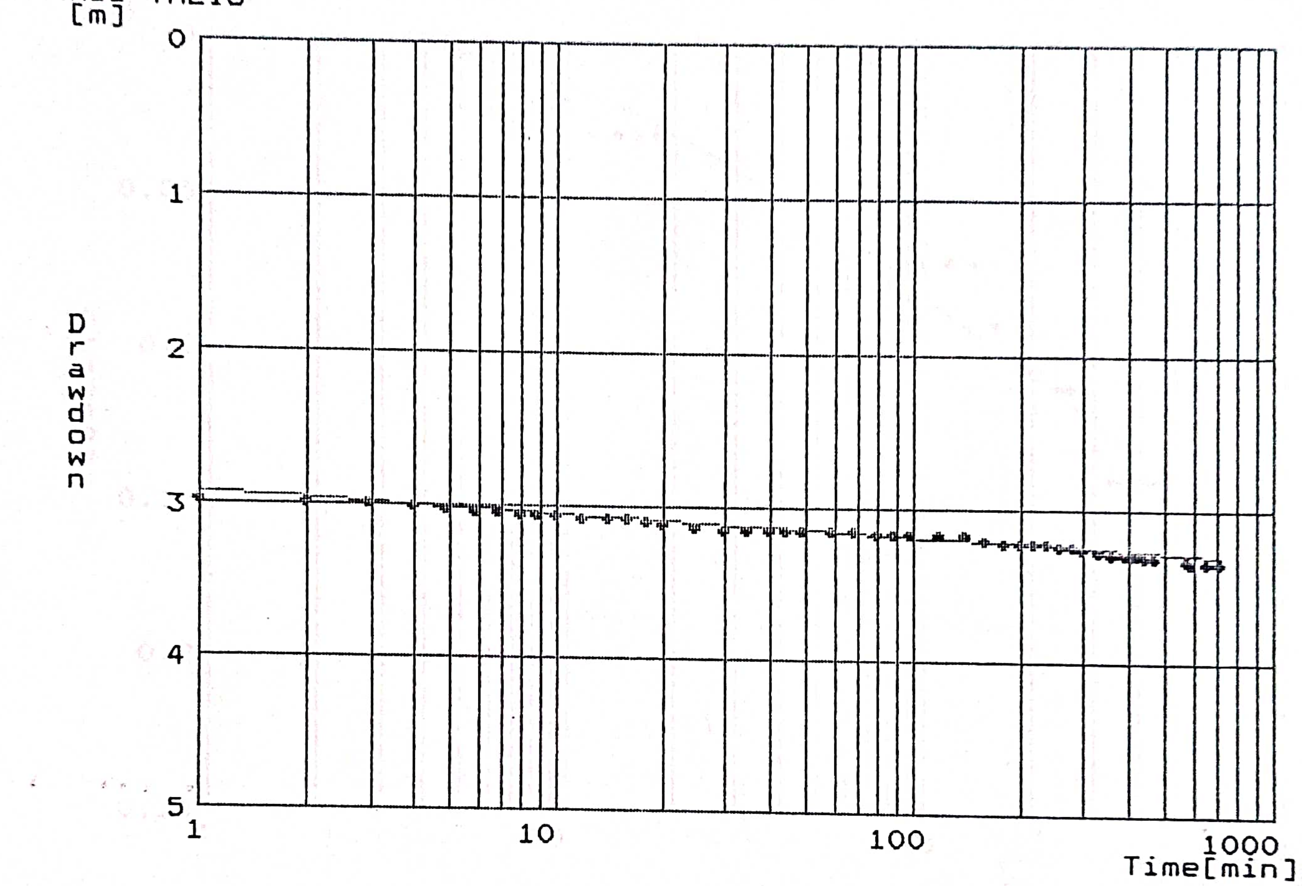
Number of Points = 40 of 40

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/9 - PUMPED WELL MURIYARI

Constant Pumping Rate = 350.000 [m3/hr]
Distance from Observation Well = 0.17 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 0.83 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 11508. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0196 [m]

Number of Points = 46 of 46

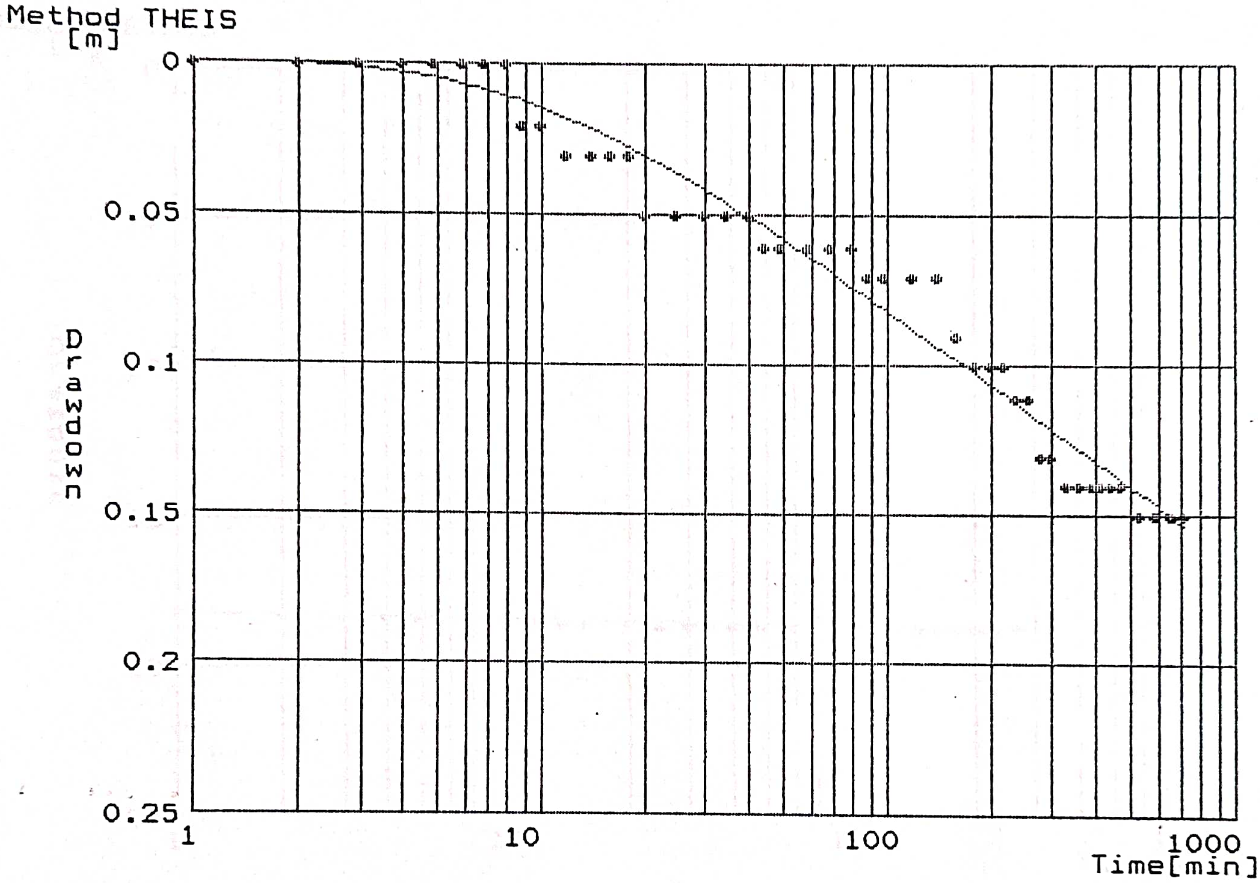
APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/9 - PUMPED WELL - W/29 OBS. WELL

Constant Pumping Rate = 350.000 [m3/hr]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 1.70 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 17722. [m2/day]
Storage Coefficient = 0.00033854
Standard Deviation = 0.0090 [m]

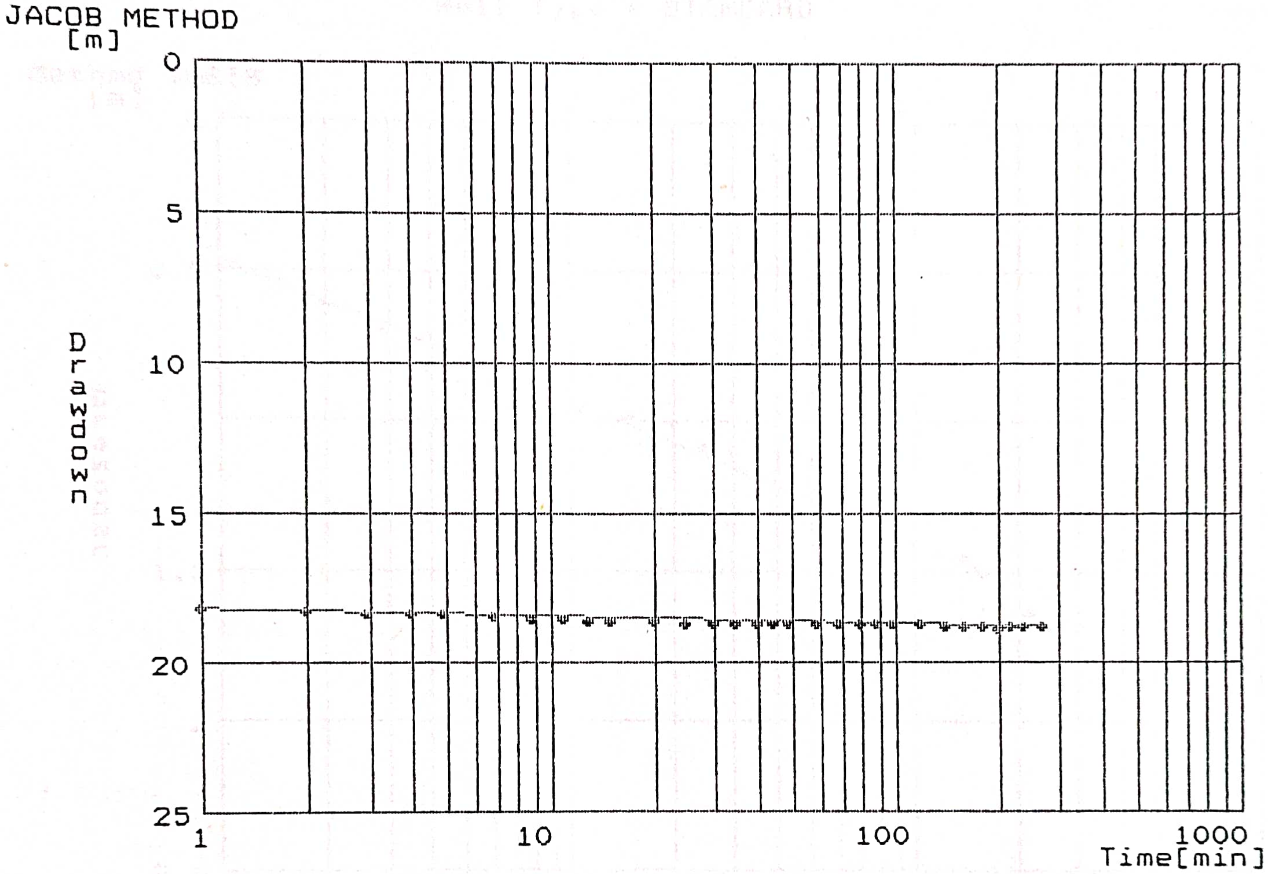
Number of Points = 46 of 46

APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W-14 PUMPED WELL

Constant Pumping Rate = 8424.0 [m3/day]
Distance from Observation Well = 0.25 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 6.30 [m]
Well Type = STANDARD



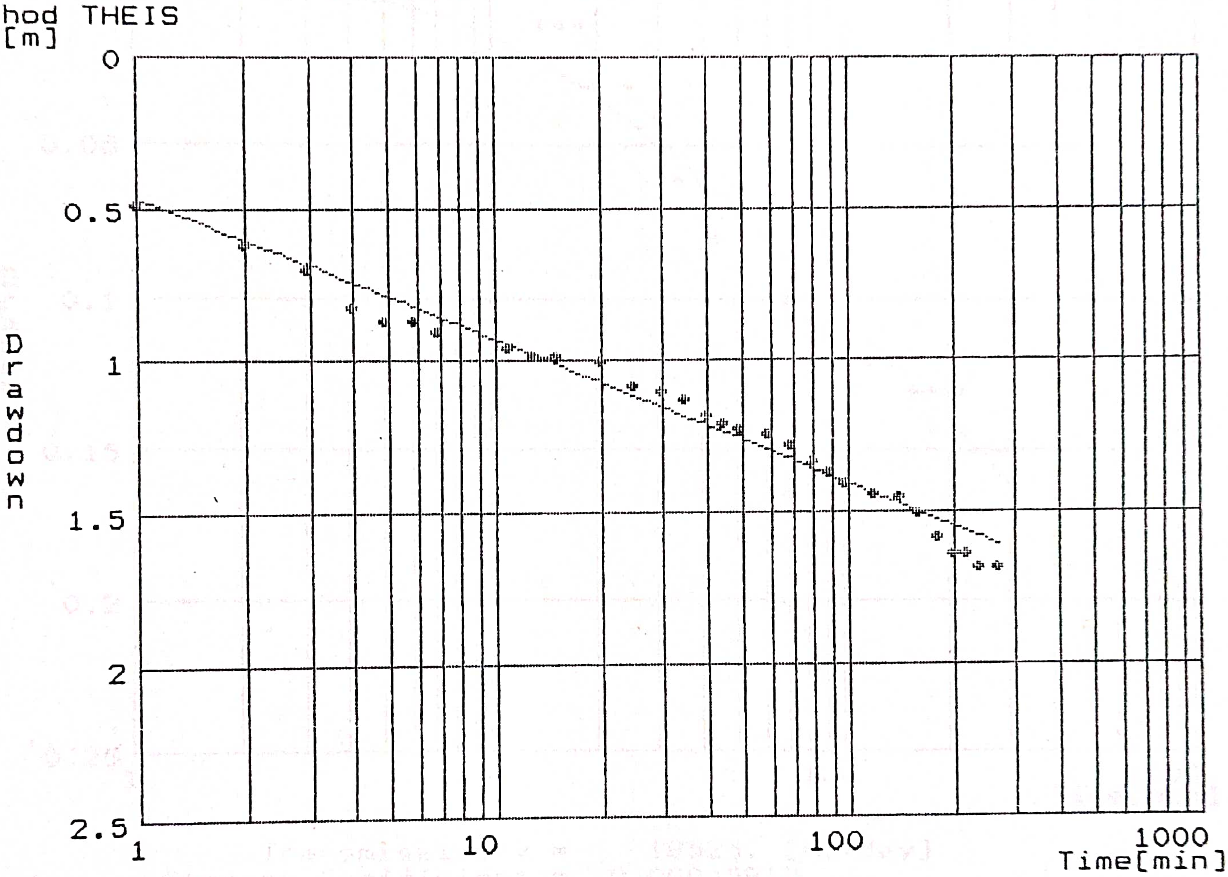
Transmissivity = 5893. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0434 [m]
A0 = 0.181466E+02
A1 = 0.261576E+00
Number of Points = 30 of 30

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/[illegible]-II PUMPED WELL - W/14-I OBS.WELL

Constant Pumping Rate = 8424.0 [m3/day]
Distance from Observation Well = 20.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 7.00 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 3243. [m2/day]
Storage Coefficient = 0.00142332
Standard Deviation = 0.0486 [m]

Number of Points = 30 of 30

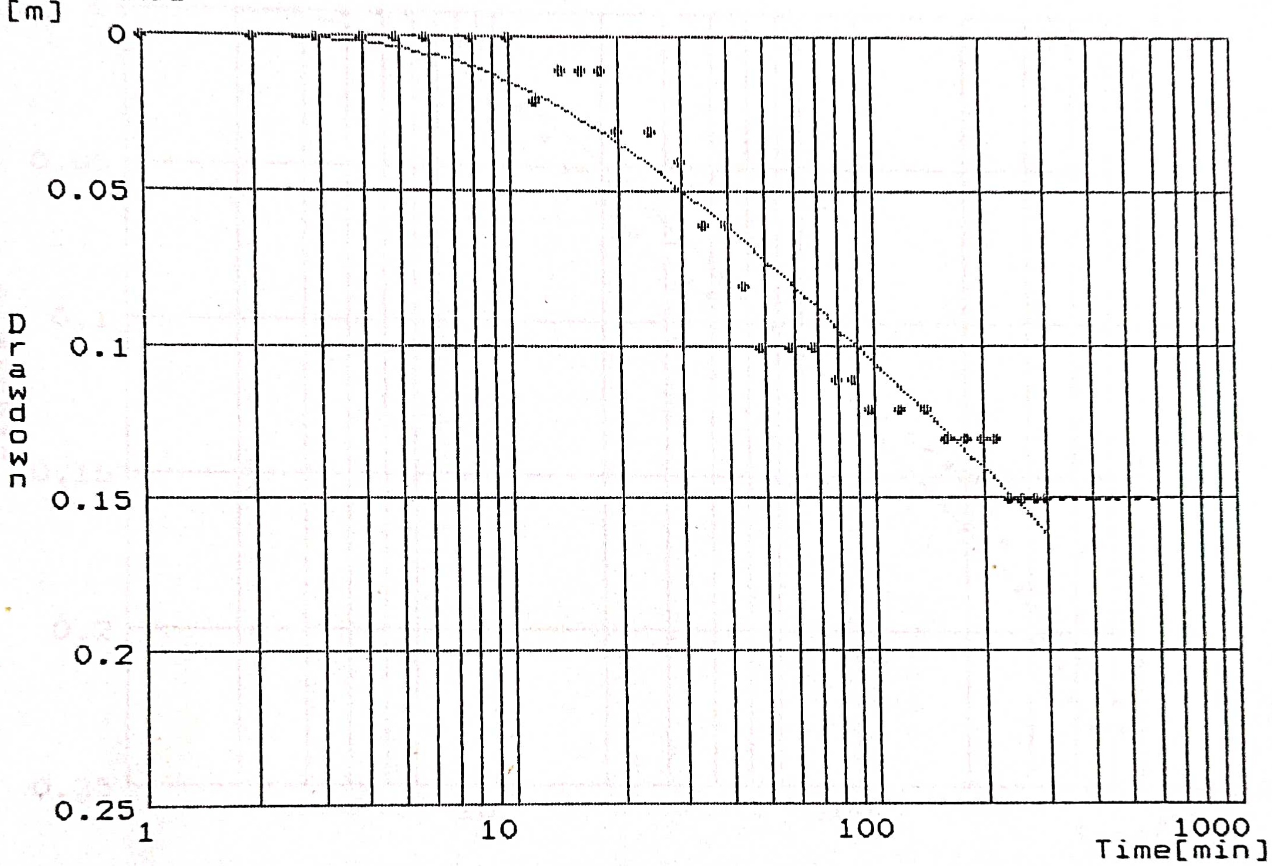
APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/16 - PUMPED WELL - W/18 OBS. WELL

Constant Pumping Rate = 528.000 [m3/hr]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 1.85 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 18525. [m2/day]
Storage Coefficient = 0.00045812
Standard Deviation = 0.0111 [m]

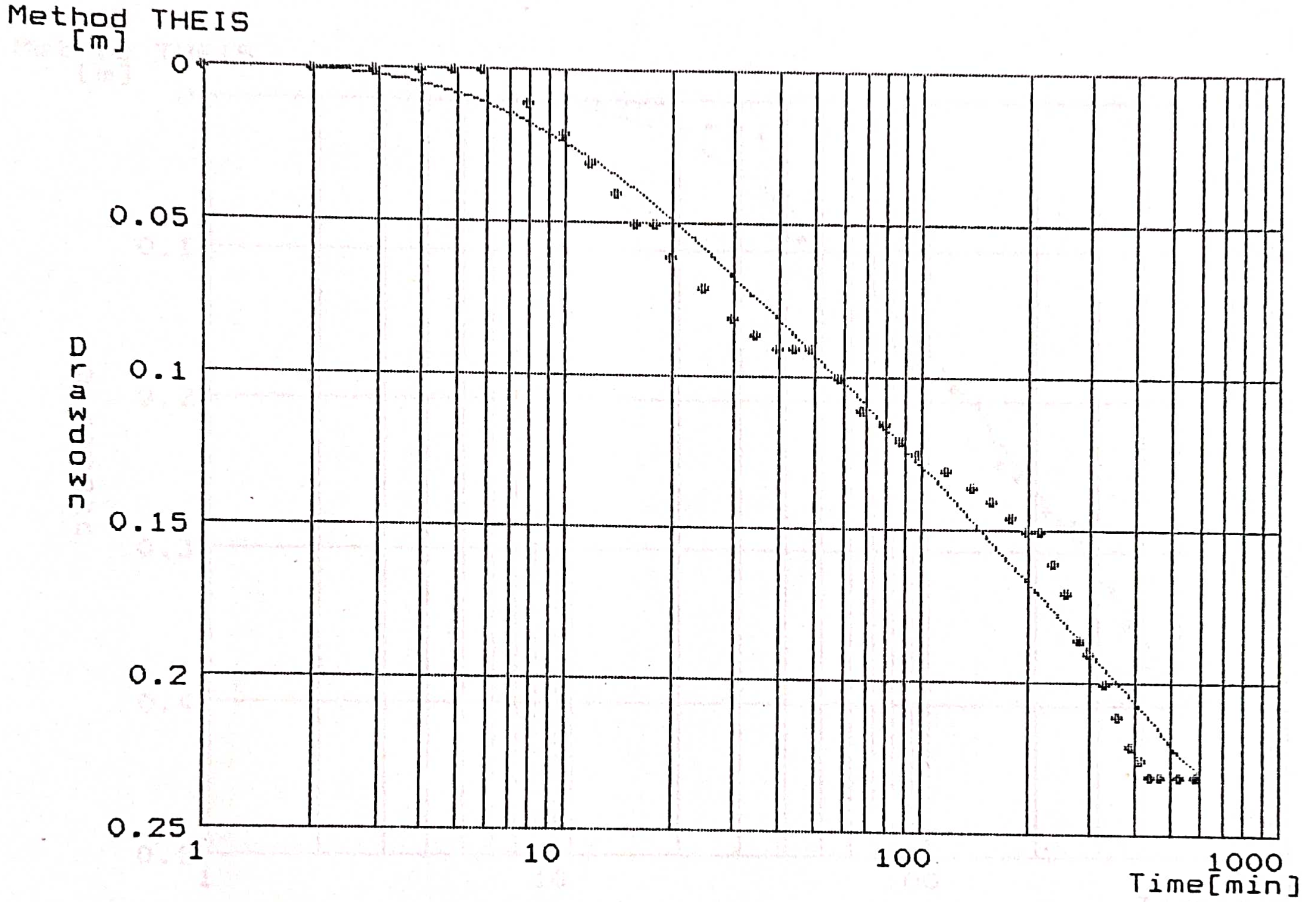
Number of Points = 35 of 43

Project : NEP/86/025
Organization : GROUND WATER RESOURCED DEV. BOARD

Test : W/17 KHARIYA - OBS.WELL W/20 TIKULIGARH

Constant Pumping Rate = 320.000 [m3/hr]
Distance from Observation Well = 1400.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

Method THEIS



Transmissivity = 10525. [m2/day]
Storage Coefficient = 0.00009731
Standard Deviation = 0.0099 [m]

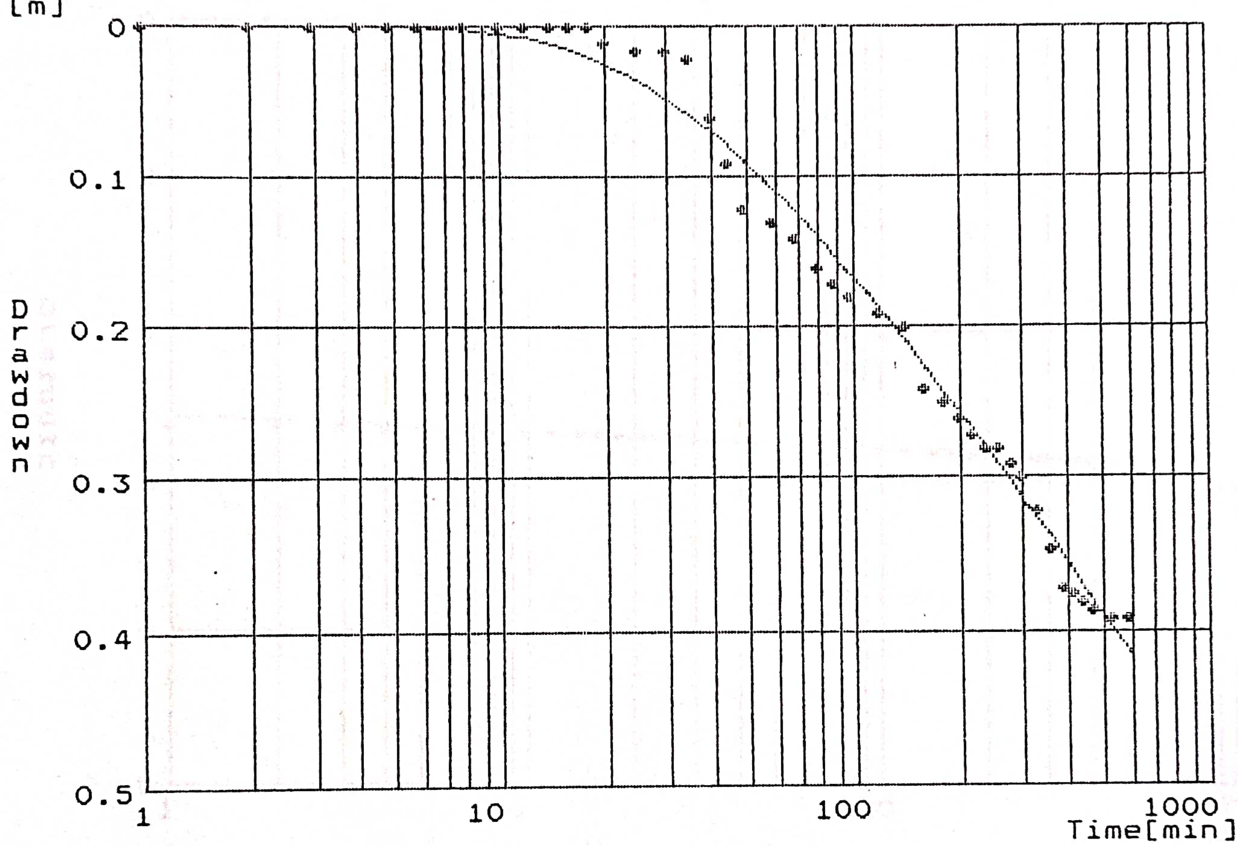
Number of Points = 42 of 42

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/20 - TIKULIGARH - OBS.WELL W/19 SEMARI

Constant Pumping Rate = 525.000 [m3/hr]
Distance from Observation Well = 1100.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.55 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 6489. [m2/day]
Storage Coefficient = 0.00035650
Standard Deviation = 0.0146 [m]

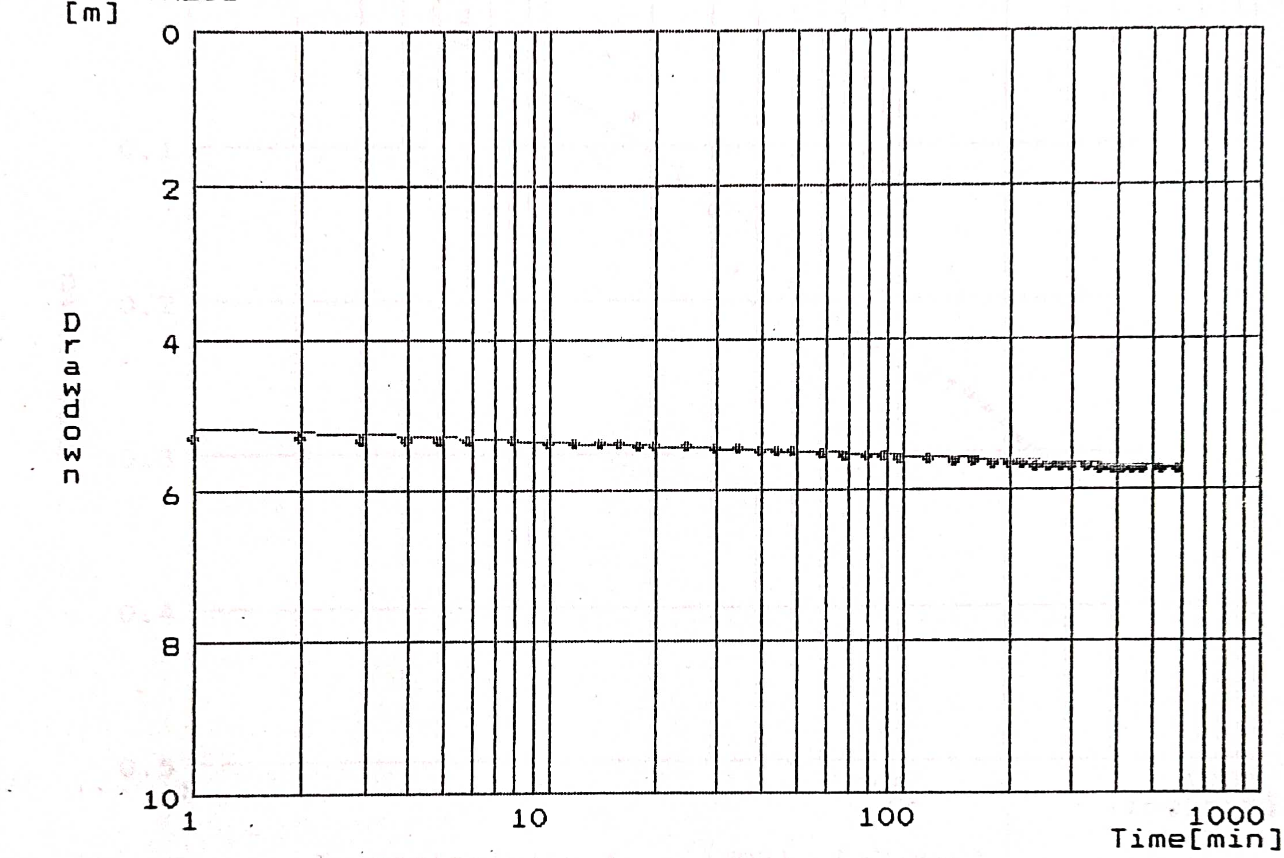
Number of Points = 42 of 42

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/20 - TIKULIGARH - Pumped well

Constant Pumping Rate = 525.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -2.98 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 11772. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0324 [m]

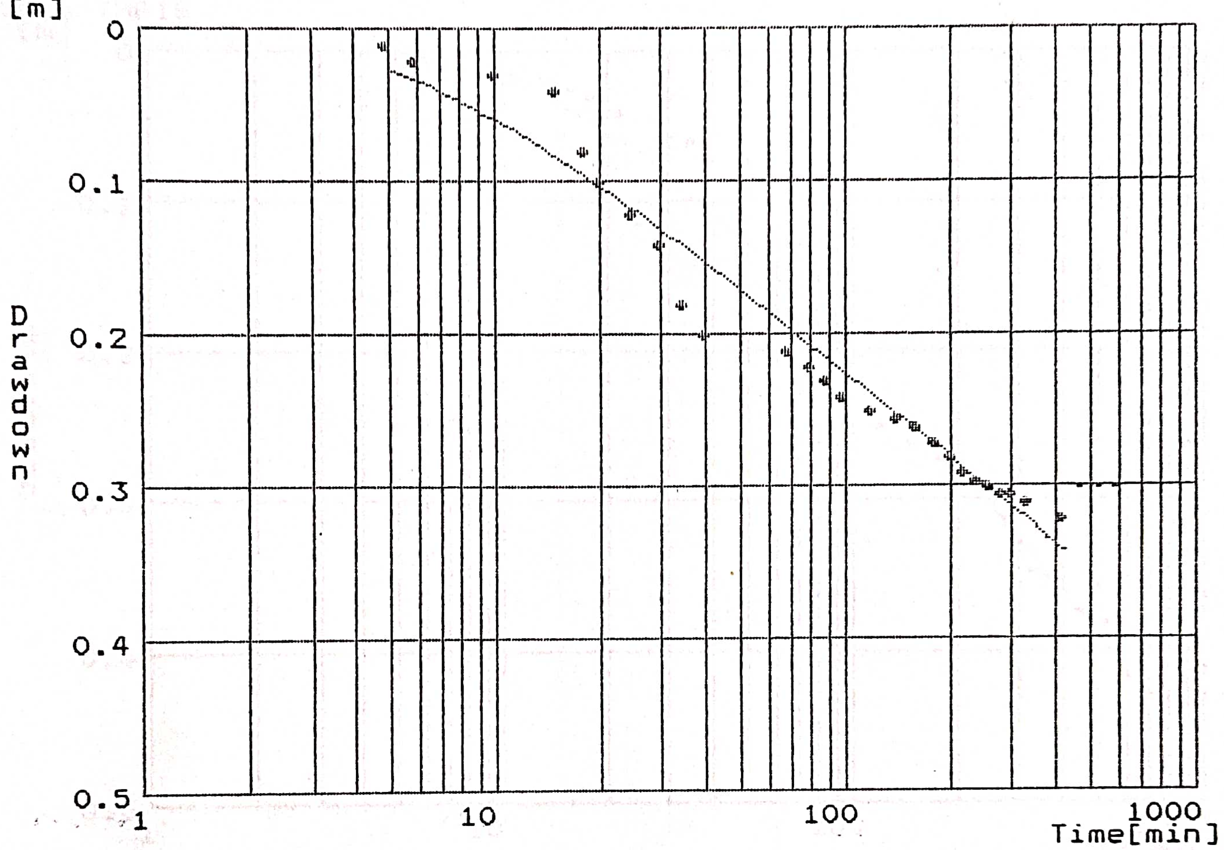
Number of Points = 42 of 42

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/24 - PUMPED WELL - W/36 OBS. WELL

Constant Pumping Rate = 525.000 [M3/HR]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

Method THEIS



Transmissivity = 12021. [m2/day]
Storage Coefficient = 0.00013079
Standard Deviation = 0.0184 [m]

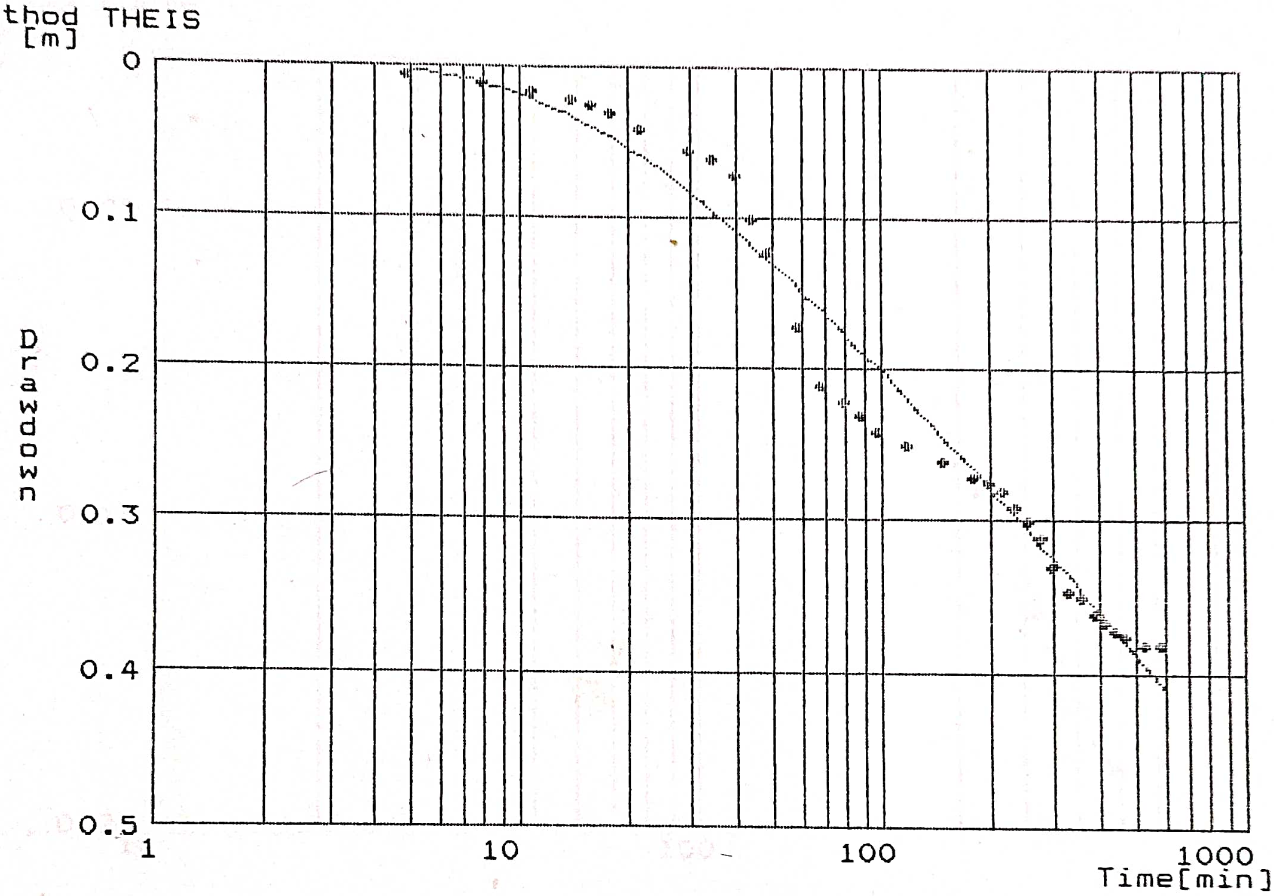
Number of Points = 26 of 29

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/25 - PUMPED WELL - W/46 OBS. WELL

Constant Pumping Rate = 350.000 [M3/HR]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

Method THEIS



Transmissivity = 5460. [m2/day]
Storage Coefficient = 0.00018586
Standard Deviation = 0.0215 [m]

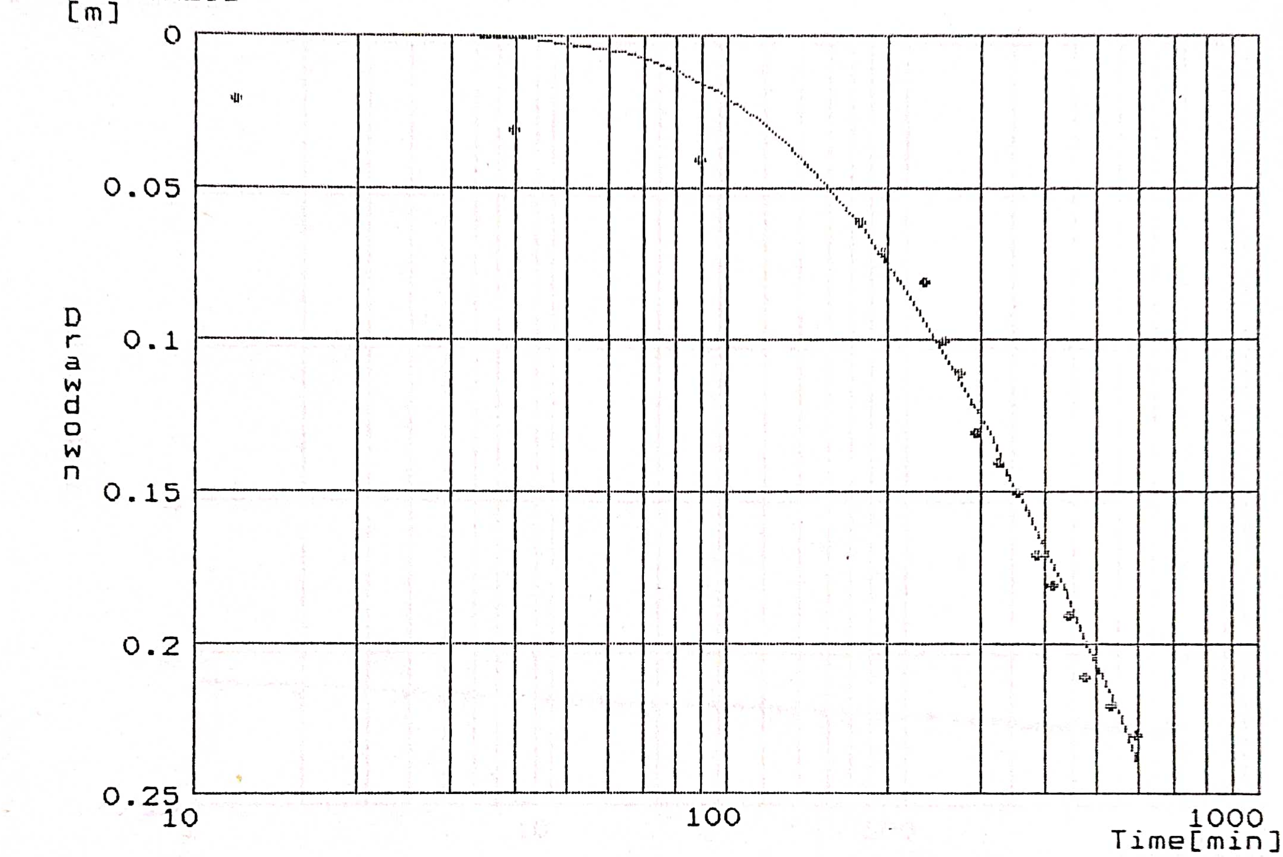
Number of Points = 34 of 34

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/28 - PUMPED WELL - W/57 OBS. WELL

Constant Pumping Rate = 500.000 [M3/HR]
Distance from Observation Well = 500.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = DRAWDOWN
Well Type = STANDARD

Method THEIS



Transmissivity = 3918. [m2/day]
Storage Coefficient = 0.00708590
Standard Deviation = 0.0120 [m]

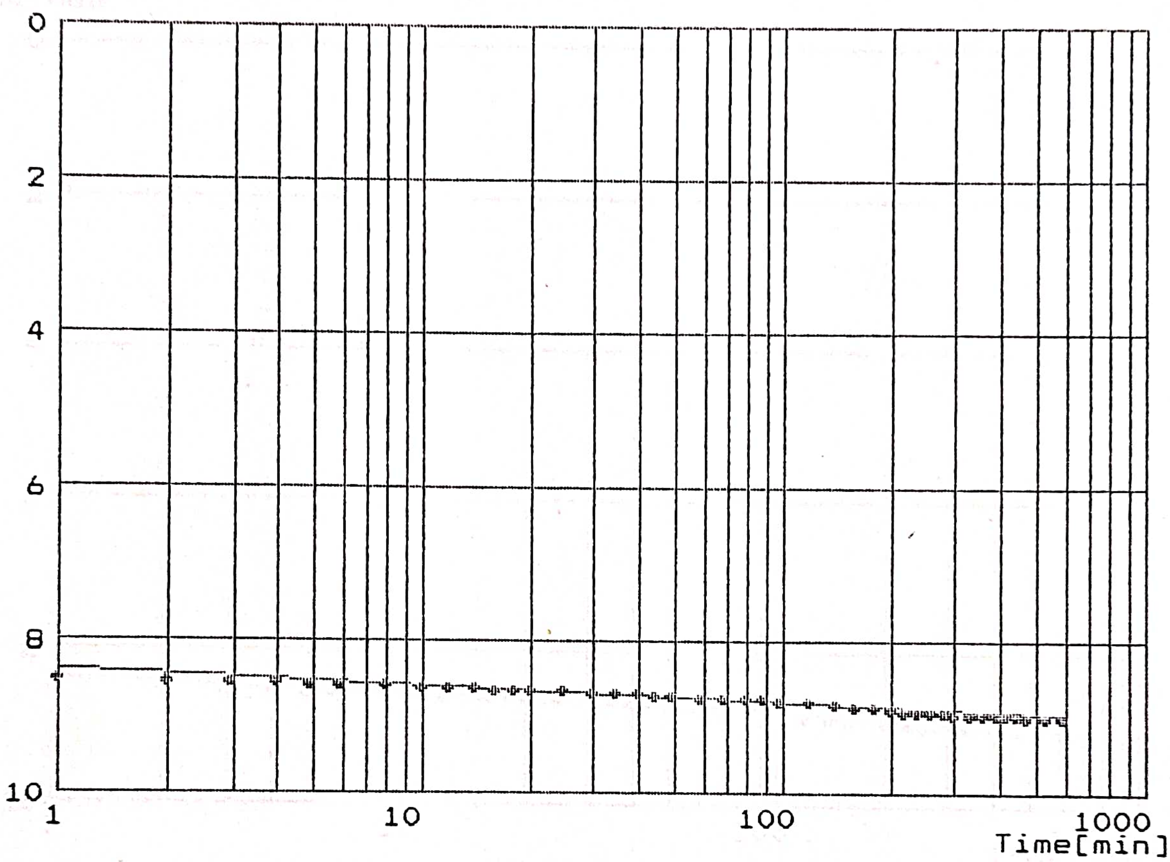
Number of Points = 17 of 17

Project : NEF/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/28 - PUMPED WELL BIHULI (II TEST)

Constant Pumping Rate = 500.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 2.28 [m]
Well Type = STANDARD

JACOB METHOD

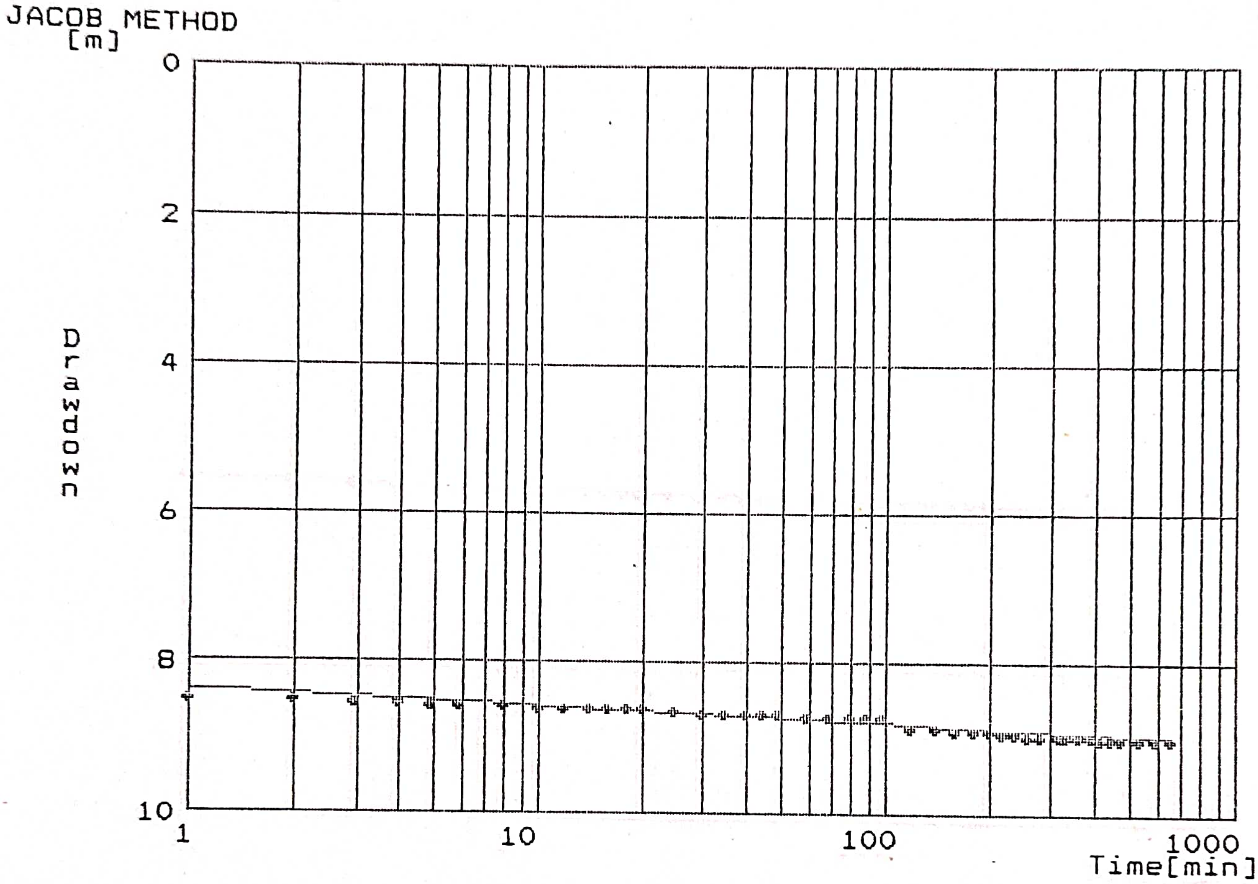


Transmissivity = 10568. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0350 [m]
A0 = 0.838282E+01
A1 = 0.207794E+00
Number of Points = 42 of 42

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/28 - PUMPED WELL BIHULI

Constant Pumping Rate = 500.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 2.28 [m]
Well Type = STANDARD



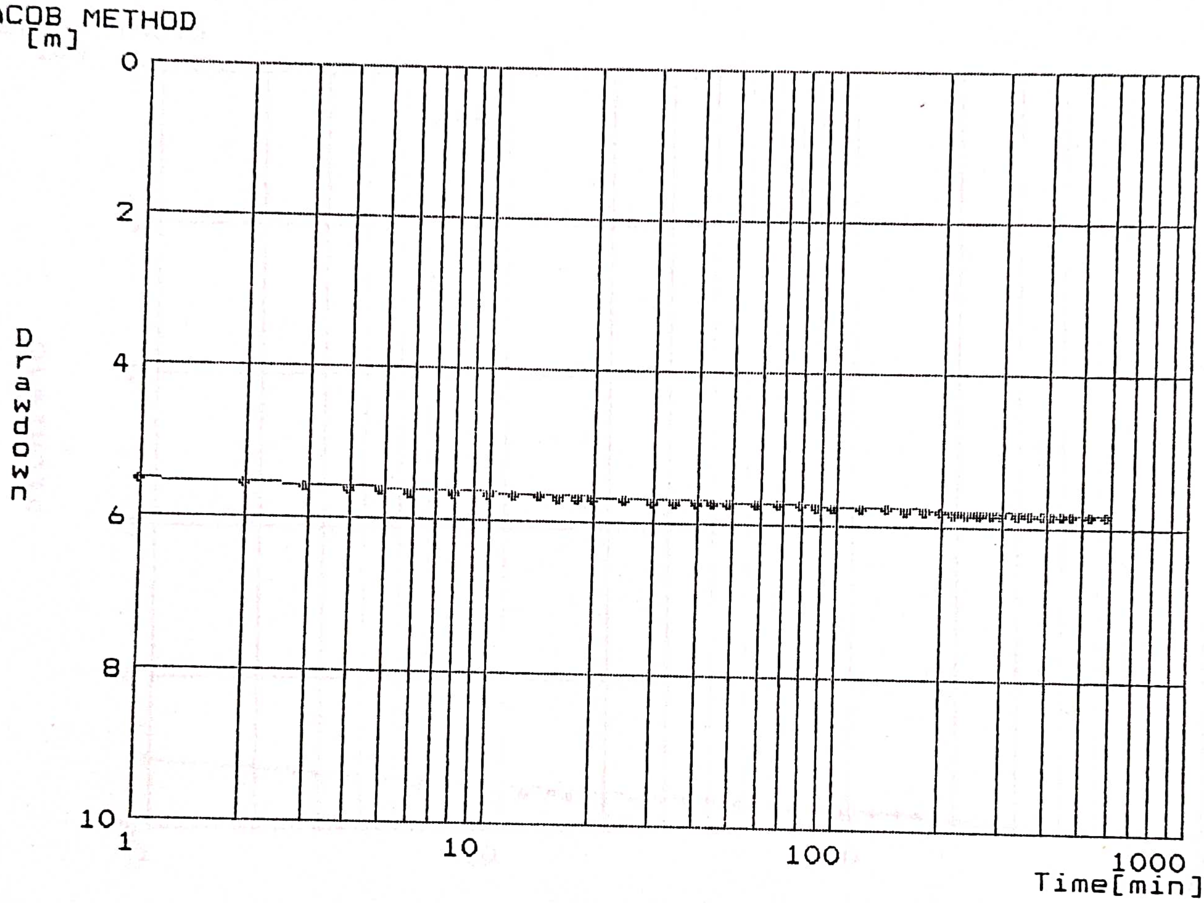
Transmissivity = 10058. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0483 [m]
A0 = 0.836488E+01
A1 = 0.218324E+00
Number of Points = 43 of 43

Project : NEP/86/025
Organization : GROUND WATER RESOURCED DEV. BOARD

Test : [illegible]34 PUMPED WELL S.GURAULIYA BHAIRAWA

Constant Pumping Rate = 450.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 4.08 [m]
Well Type = STANDARD

JACOB METHOD

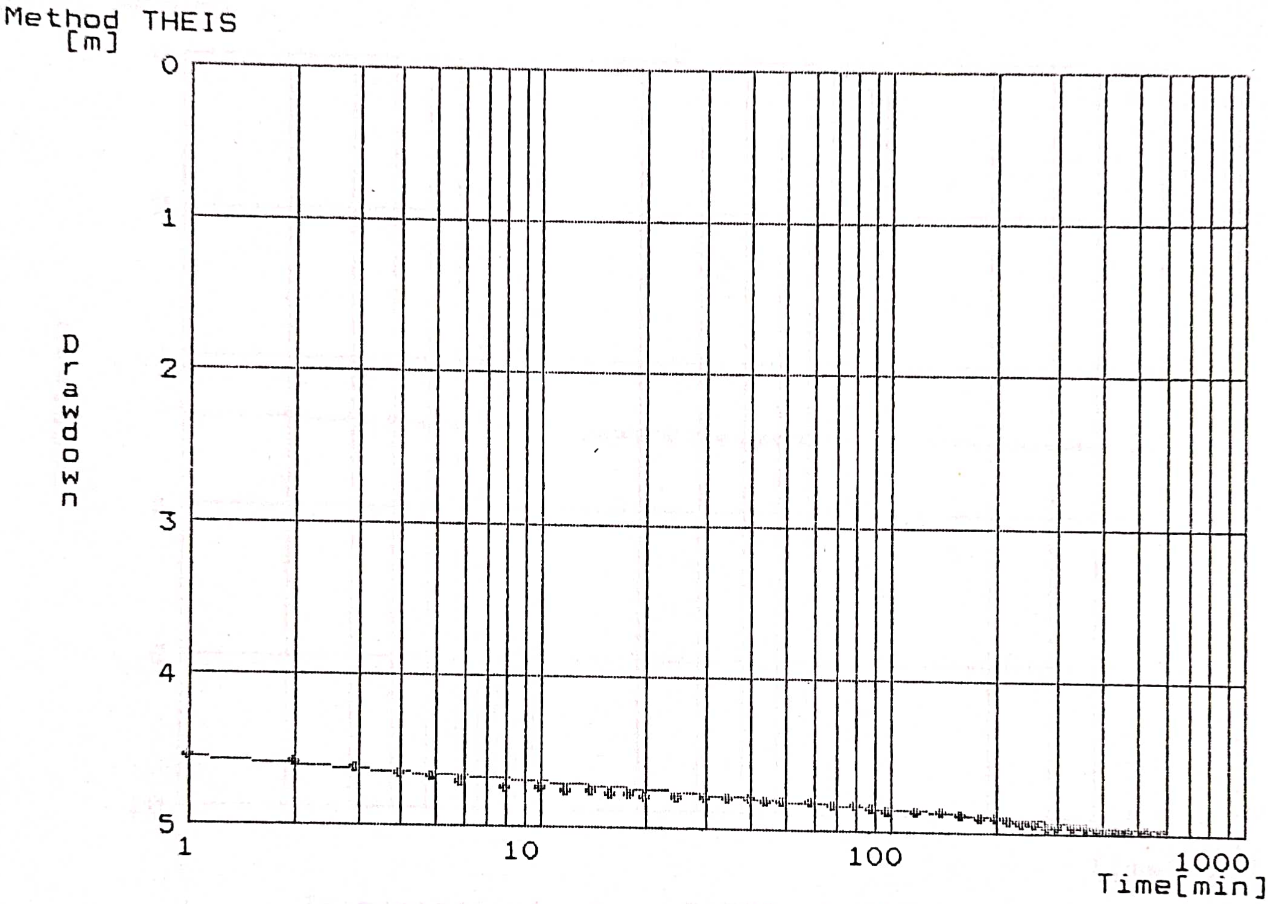


Transmissivity = 17147. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0102 [m]
A0 = 0.550692E+01
A1 = 0.115263E+00
Number of Points = 42 of 42

Project : ¨¯P/86/025
Organization : OUND WATER RESOURCES DEV. BOARD

Test : 35 W.SITALPAT - PUMPED WELL

Constant Pumping Rate = 430.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 0.61 [m]
Well Type = STANDARD



Transmissivity = 12533. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0185 [m]

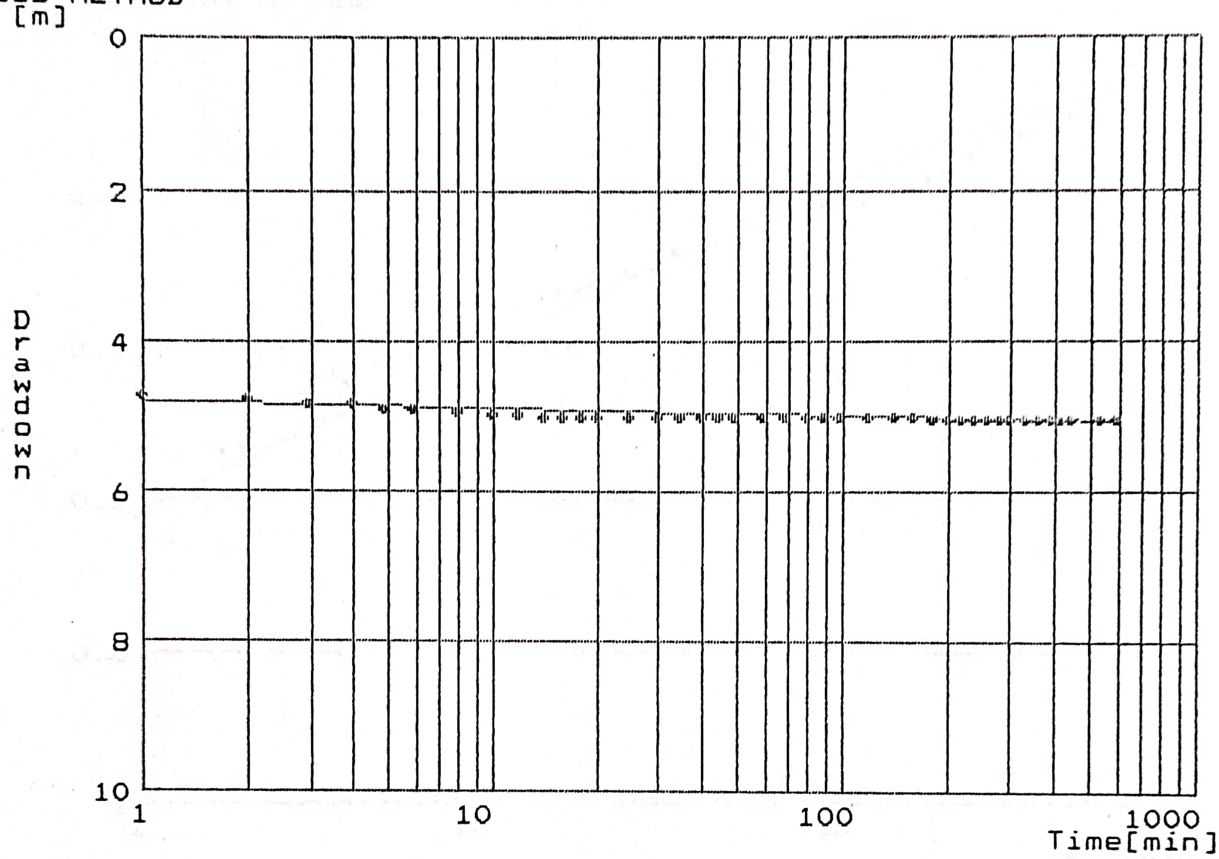
Number of Points = 42 of 42

Project : ??/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/42 - PUMPED WELL KOTIHAWA

Constant Pumping Rate = 560.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 1.10 [m]
Well Type = STANDARD

JACOB METHOD

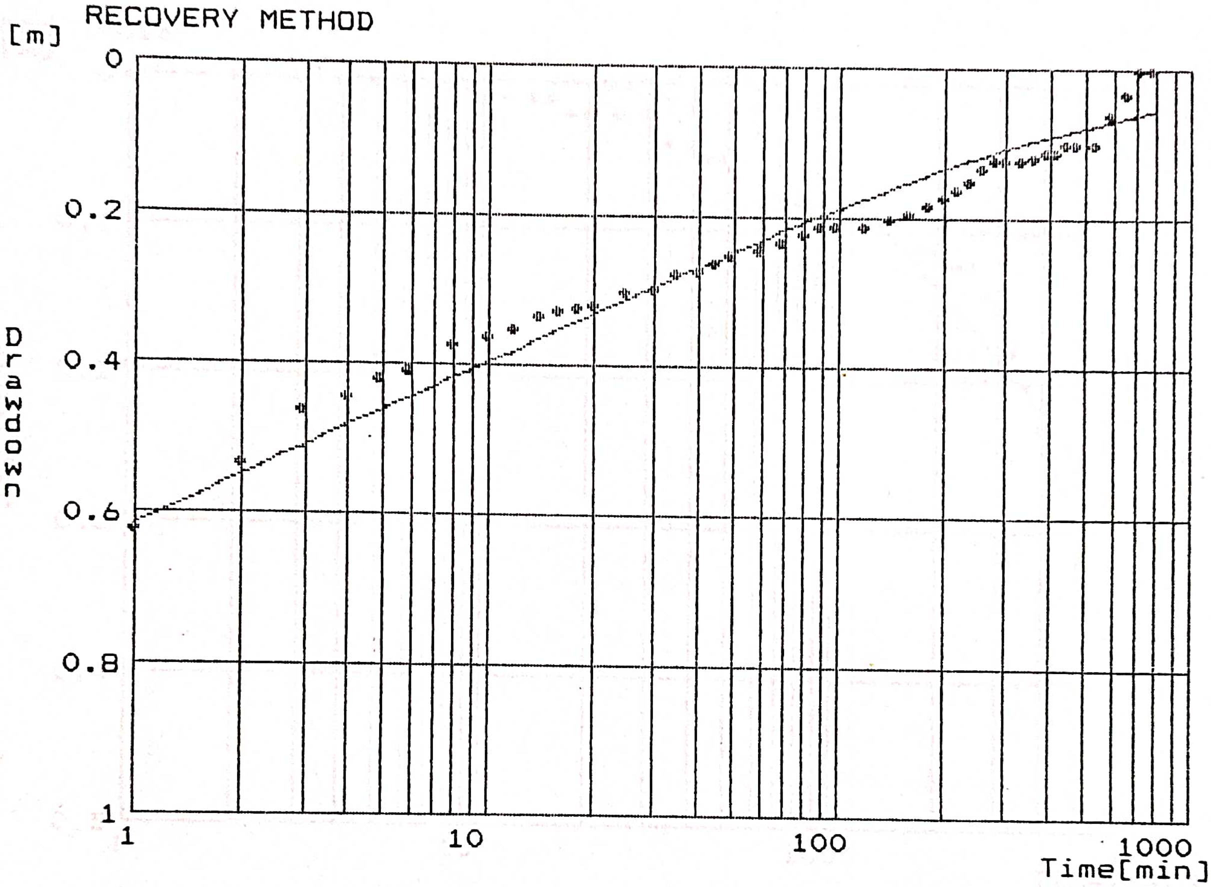


Transmissivity = 26739. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0369 [m]
A0 = 0.480695E+01
A1 = 0.919816E-01
Number of Points = 41 of 41

Project , TR/06/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/43 - AMUWA - RECOVERY

Constant Pumping Rate =	600.000 [m3/hr]
Distance from Observation Well =	0.20 [m]
Type of Aquifer =	CONFINED
Type of Input Data =	LEVEL
Static Water Level =	-0.84 [m]
Well Type =	STANDARD



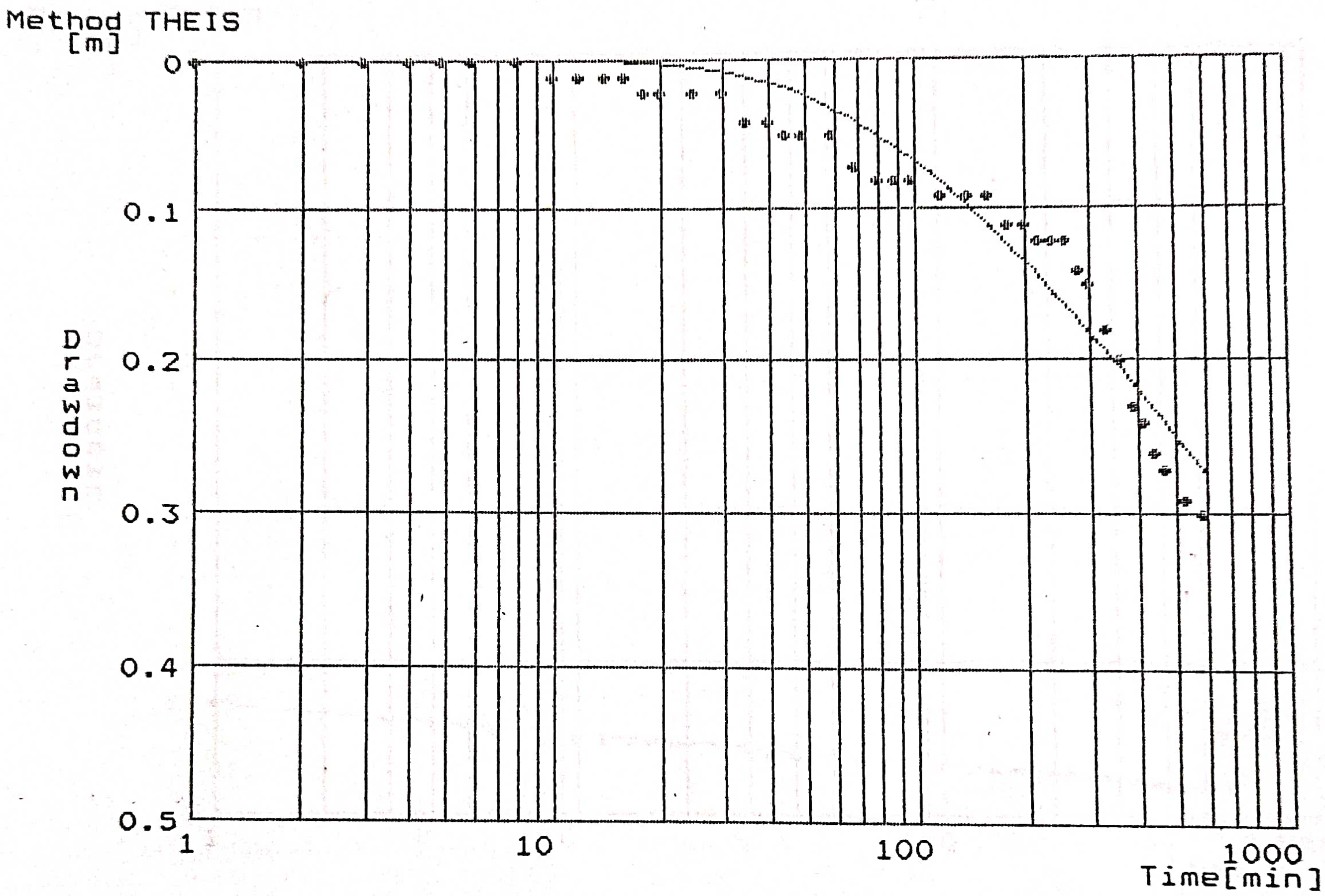
Transmissivity =	11929. [m2/day]
Storage Coefficient =	0.00000000
Standard Deviation =	0.0286 [m]
A0 =	0.515596E+01
A1 =	0.195913E+00
Number of Points =	45 of 45

APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/43 - PUMPED WELL - W/45 OBS. WELL

Constant Pumping Rate = 600.000 [m3/hr]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 1.40 [m]
Well Type = STANDARD



Transmissivity = 7620. [m2/day]
Storage Coefficient = 0.00127746
Standard Deviation = 0.0211 [m]

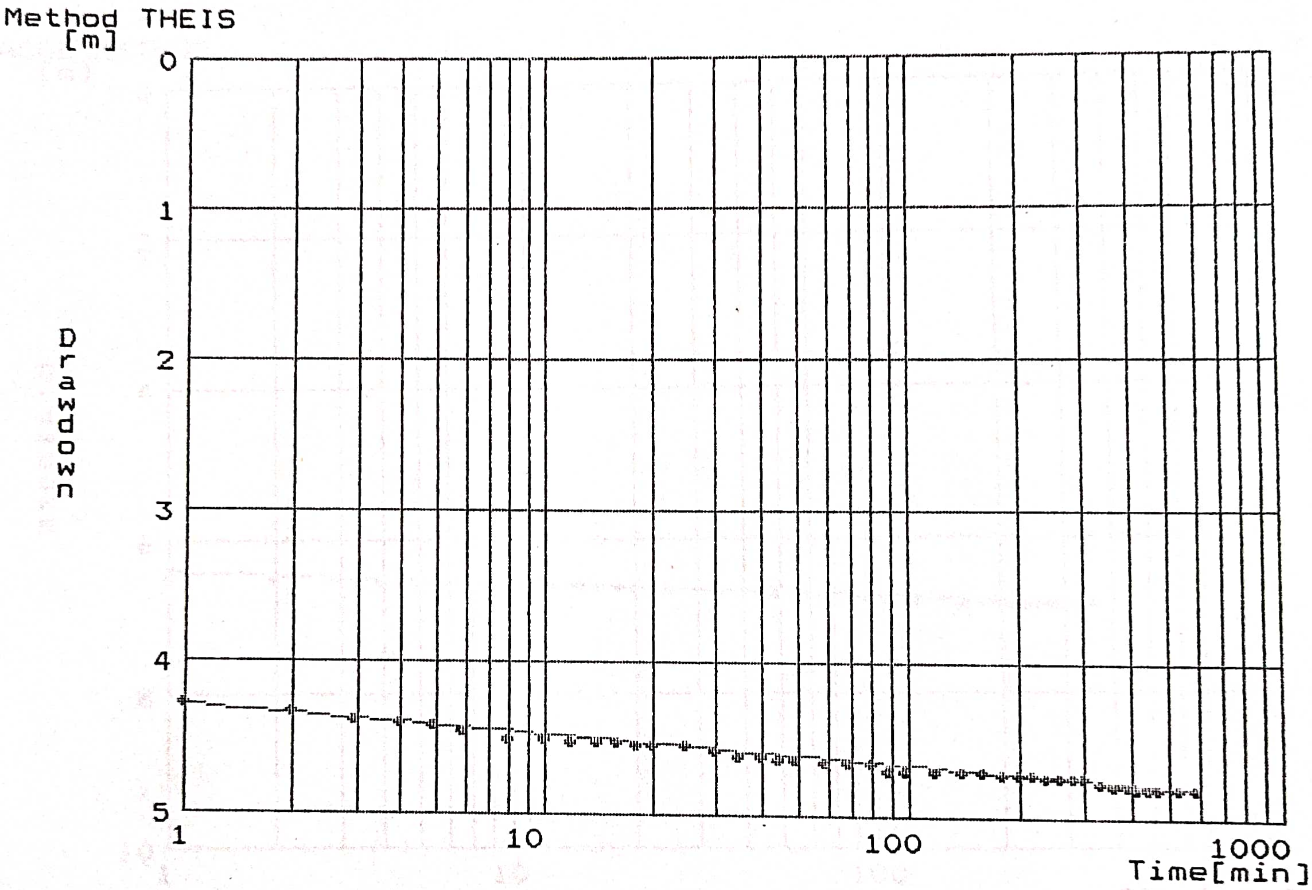
Number of Points = 42 of 42

APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/43 - PUMPED WELL AMUWA

Constant Pumping Rate = 600.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -0.84 [m]
Well Type = STANDARD



Transmissivity = 13921. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0154 [m]

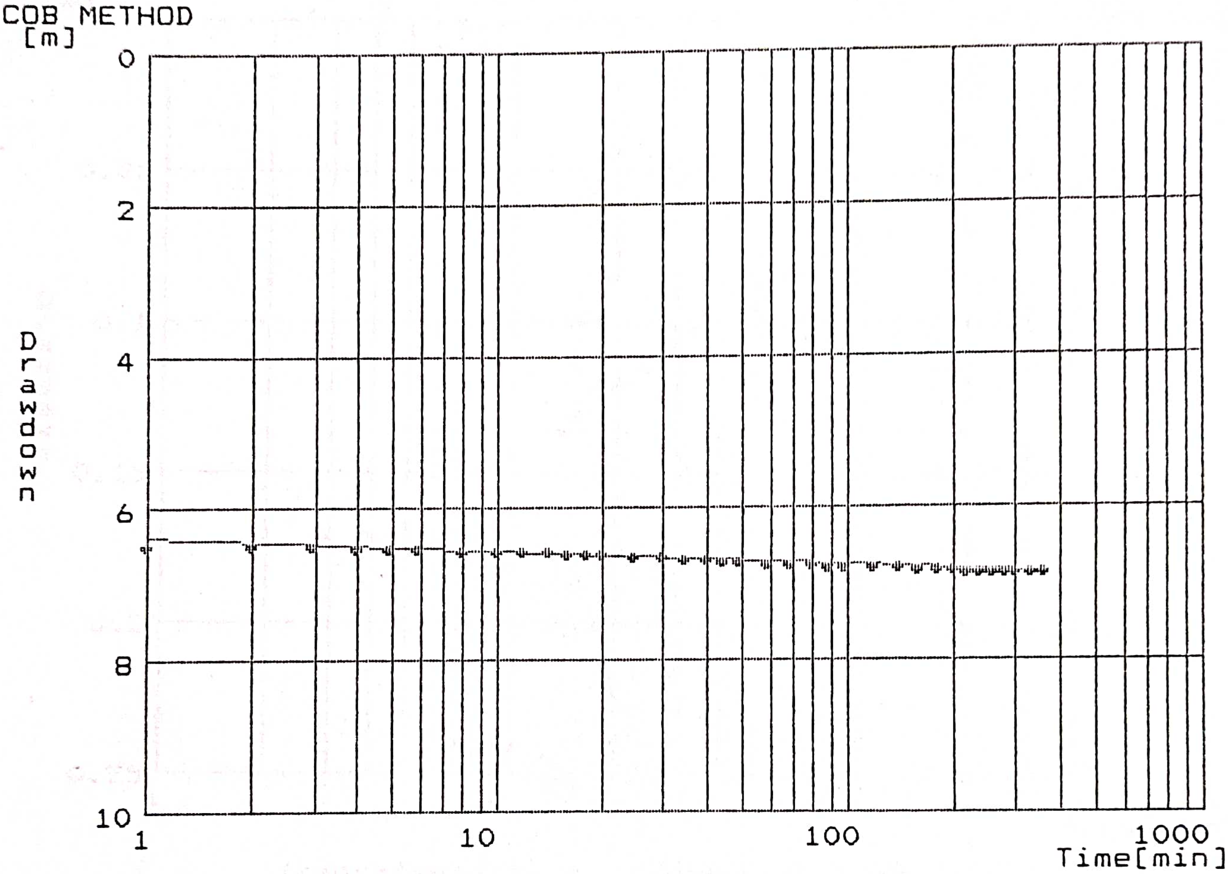
Number of Points = 42 of 42

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/44 W.SEKHUWANI Pumped well

Constant Pumping Rate = 470.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 1.72 [m]
Well Type = STANDARD

JACOB METHOD

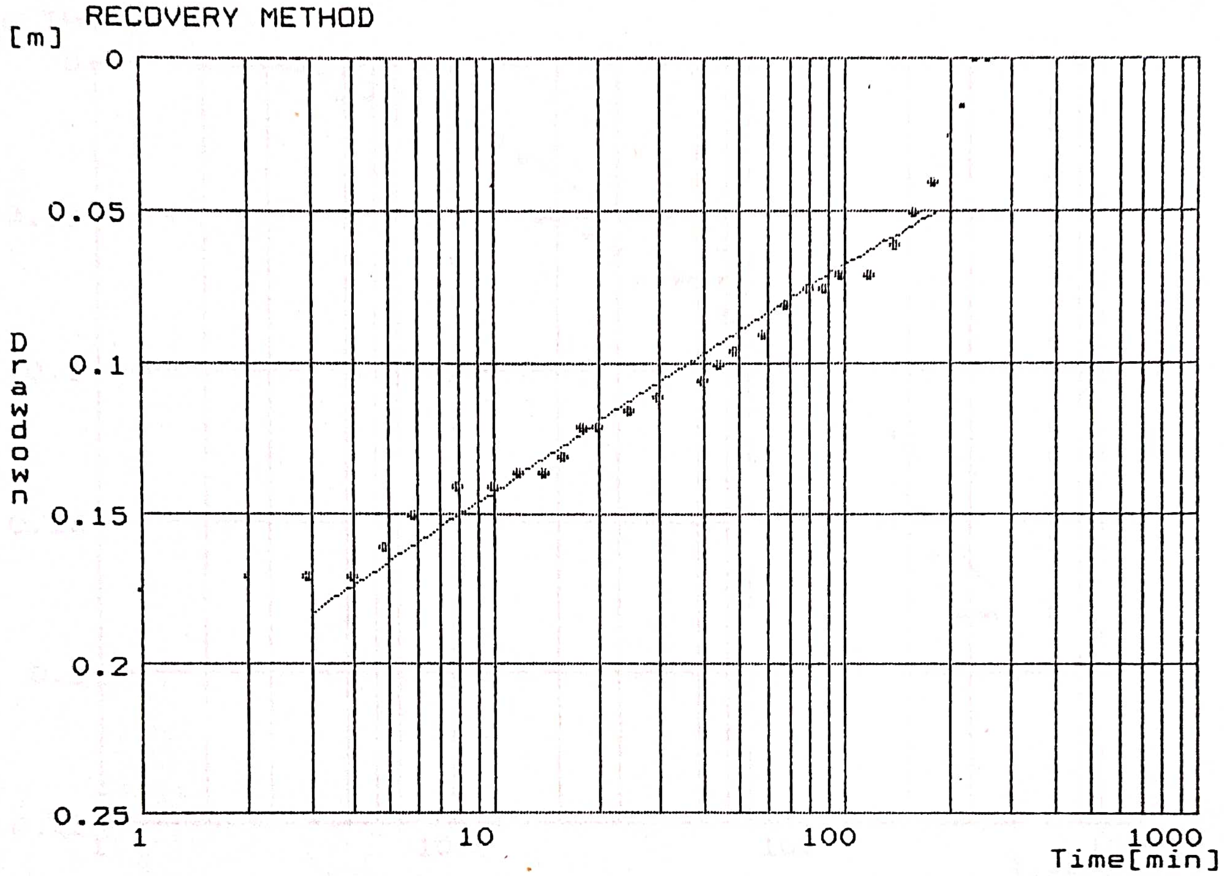


Transmissivity = 11669. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0227 [m]
A0 = 0.639955E+01
A1 = 0.176899E+00
Number of Points = 36 of 36

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/44 - PUMPED WELL - W/22 RECOVER

Constant Pumping Rate = 470.000 [m3/hr]
Distance from Observation Well = 1700.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.73 [m]
Well Type = STANDARD



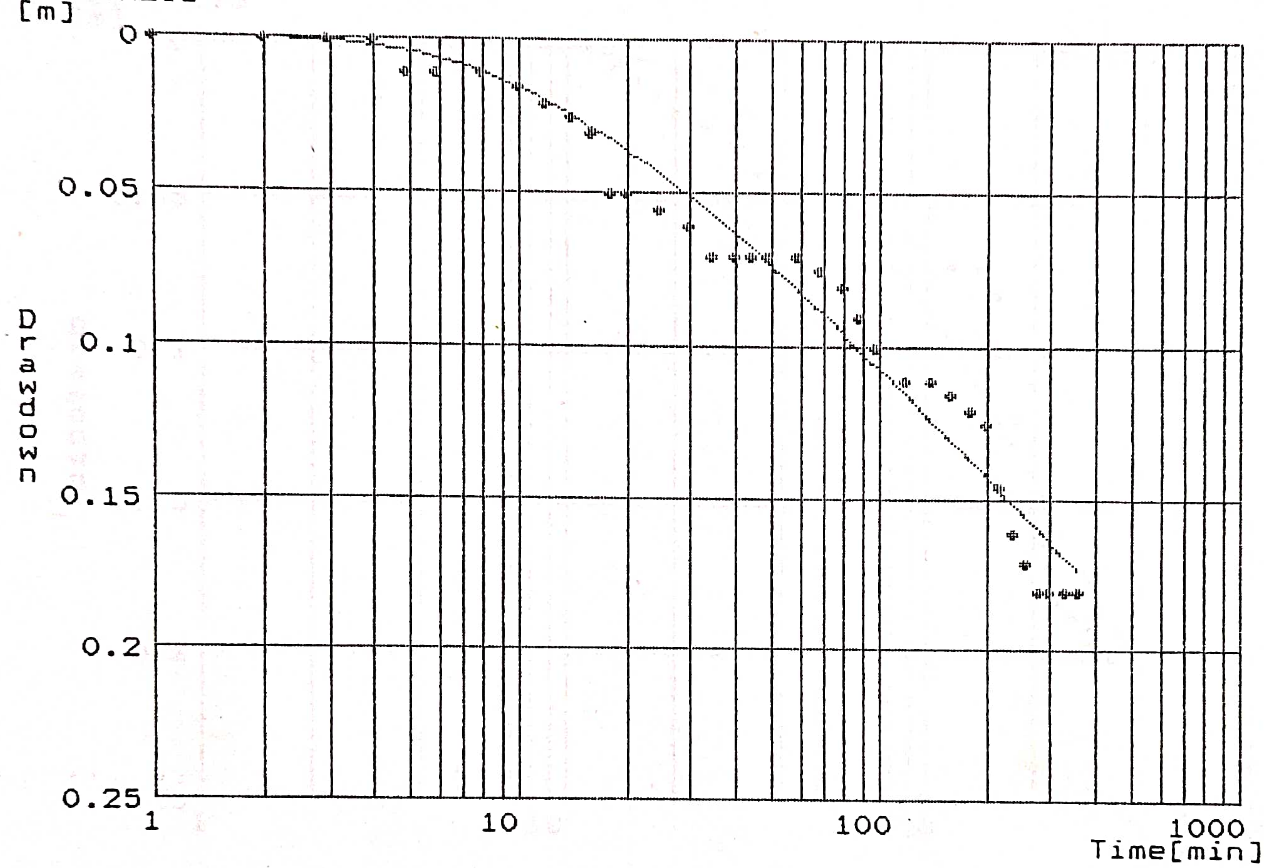
Transmissivity = 25861. [m2/day]
Storage Coefficient = 0.00004706
Standard Deviation = 0.0062 [m]
A0 = 0.208792E+00
A1 = -0.732484E-01
Number of Points = 25 of 31

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : 4 - PUMPED WELL - W/22 OBS.WELL

Constant Pumping Rate = 470.000 [m3/hr]
Distance from Observation Well = 1700.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -4.73 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 16559. [m2/day]
Storage Coefficient = 0.00013493
Standard Deviation = 0.0105 [m]

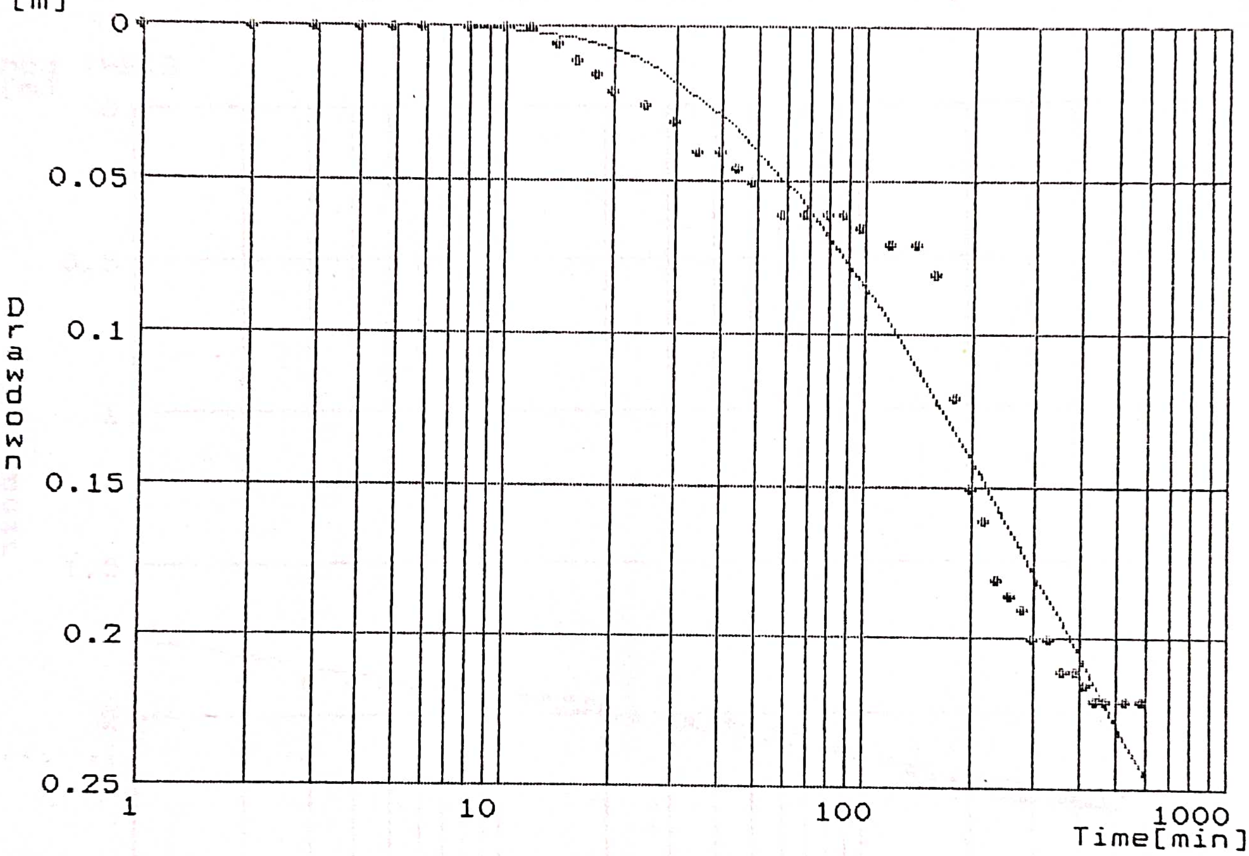
Number of Points = 36 of 36

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/46 - PUMPED WELL - W/47 OBS.WELL

Constant Pumping Rate = 340.000 [m3/hr]
Distance from Observation Well = 1400.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.14 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 6146. [m2/day]
Storage Coefficient = 0.00030450
Standard Deviation = 0.0151 [m]

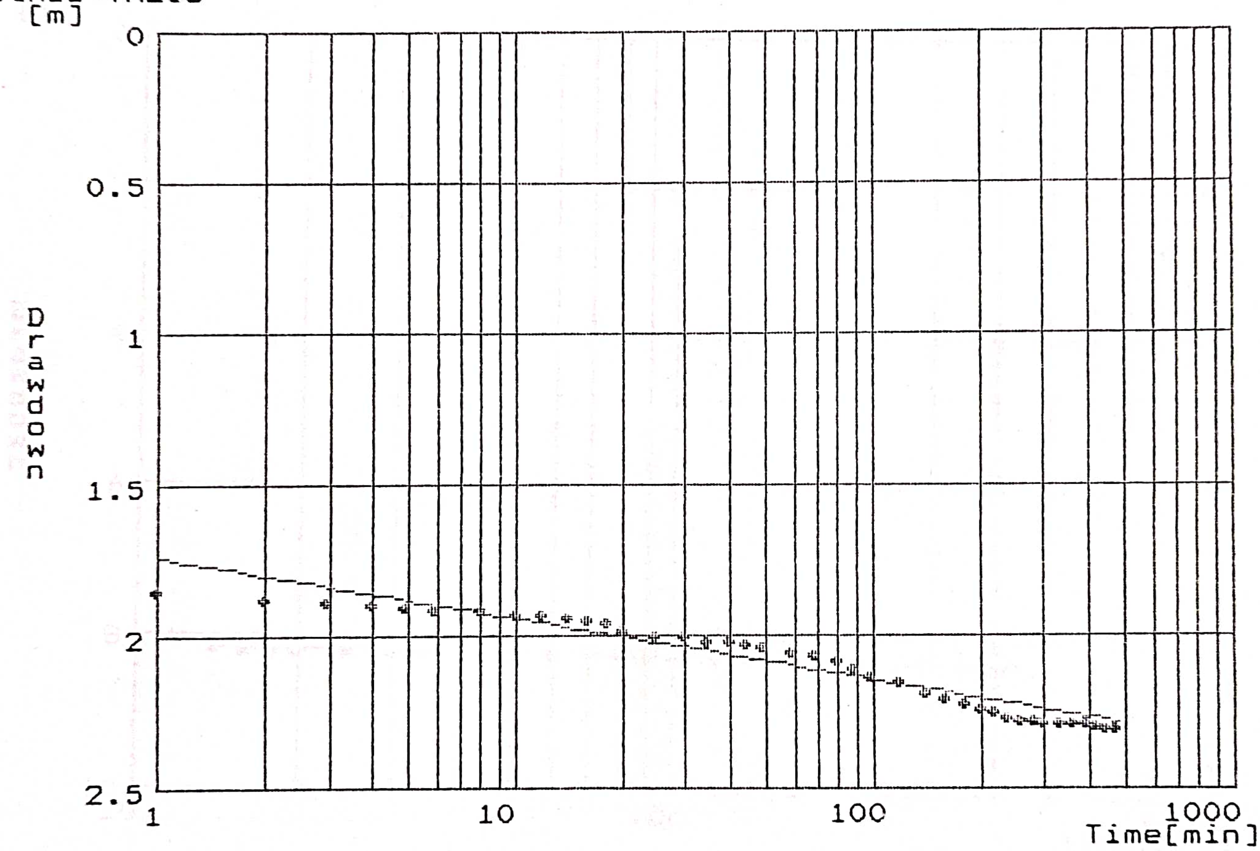
Number of Points = 42 of 42

Project : [illegible]P/86/025
Organization : [illegible]OUND WATER RESOURCES DEV. BOARD

Test : W/[illegible] - SARJUGANJ - Pumped well

Constant Pumping Rate = 340.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -5.25 [m]
Well Type = STANDARD

Method THEIS



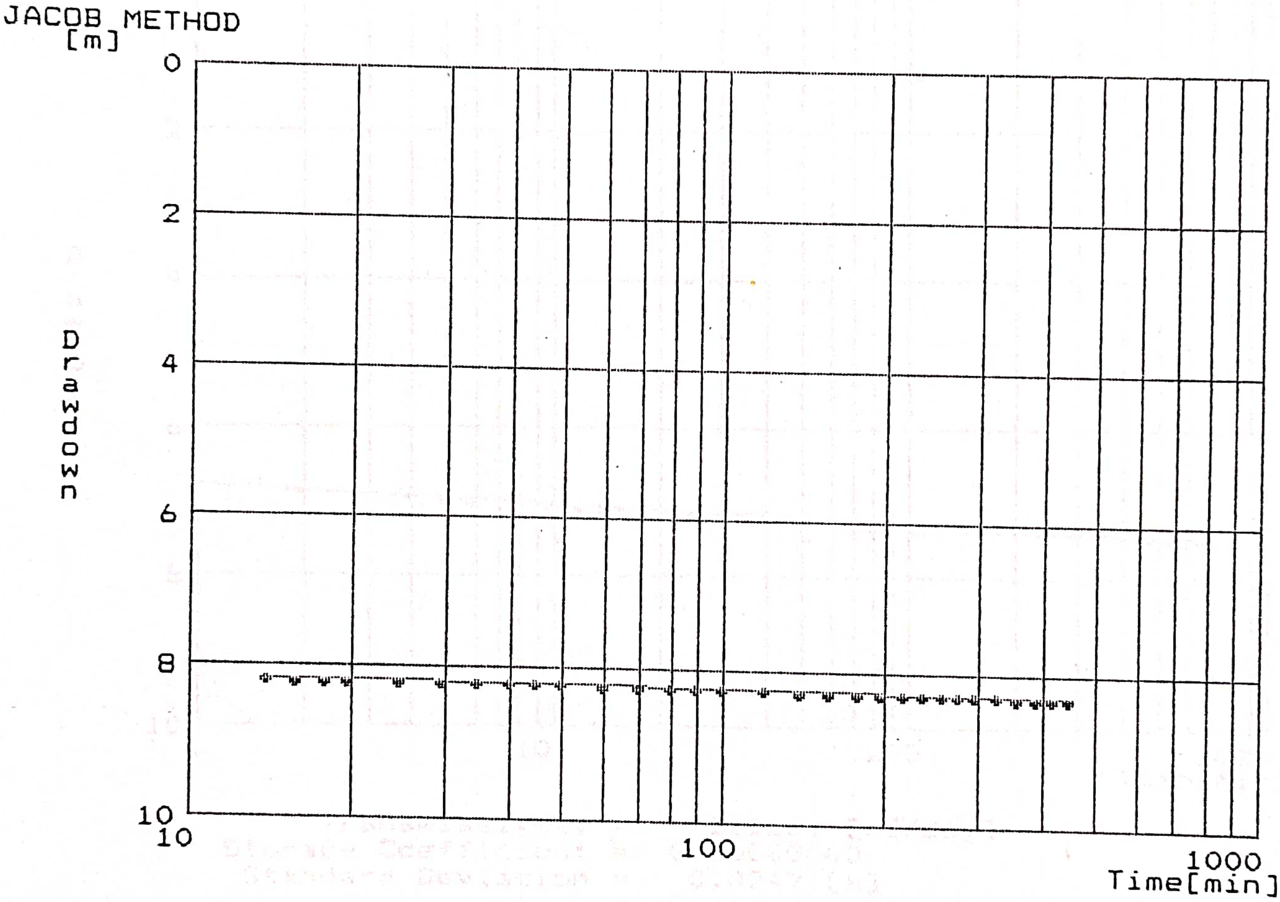
Transmissivity = 7325. [m2/day]
Storage Coefficient = 0.00000089
Standard Deviation = 0.0387 [m]

Number of Points = 40 of 40

Project : NEP/86/025
Organization : GROUND WATER RESOURCED DEV. BOARD

Test : W/52 - SEMARI

Constant Pumping Rate = 525.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 4.08 [m]
Well Type = STANDARD



Transmissivity = 27488. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0049 [m]
A0 = 0.807526E+01
A1 = 0.838849E-01
Number of Points = 30 of 30

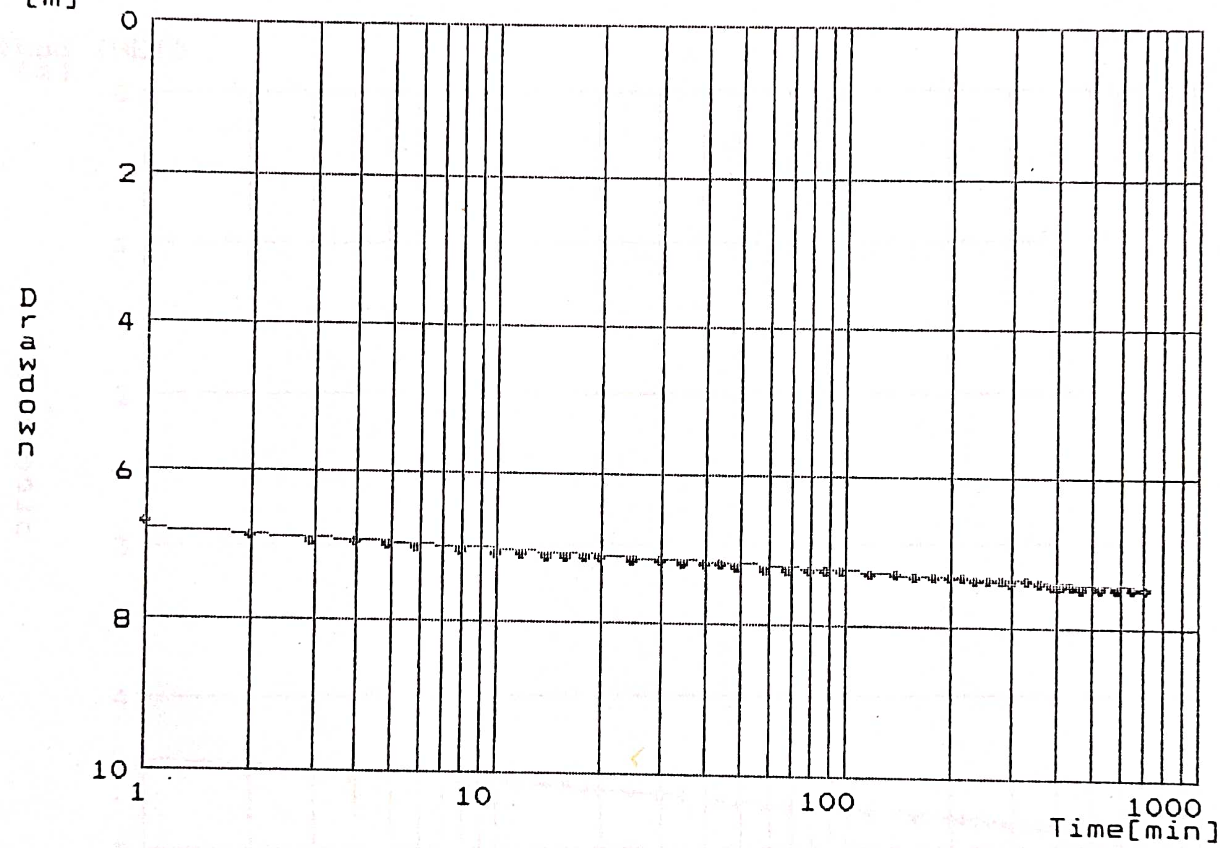
APPENDIX 1- PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/58 - PUMPED WELL BHARWALIYA

Constant Pumping Rate = 600.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 2.00 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 11166. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0242 [m]

Number of Points = 44 of 44

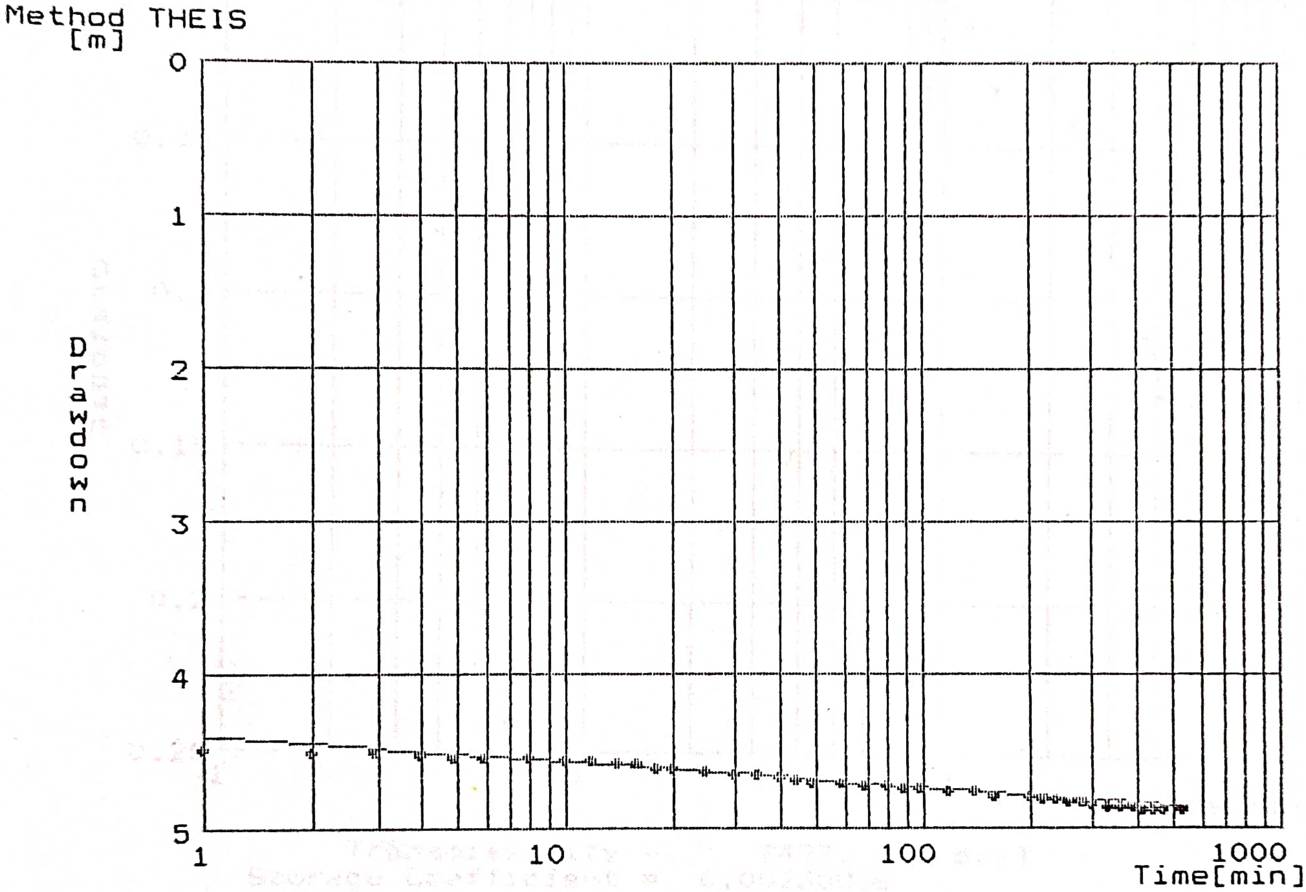
APPENDIX 1- PUMPING TESTS

Project : N?P/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : 61 - PUMPED WELL BADAULI

Constant Pumping Rate = 540.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 4.08 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 14151. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0208 [m]

Number of Points = 40 of 40

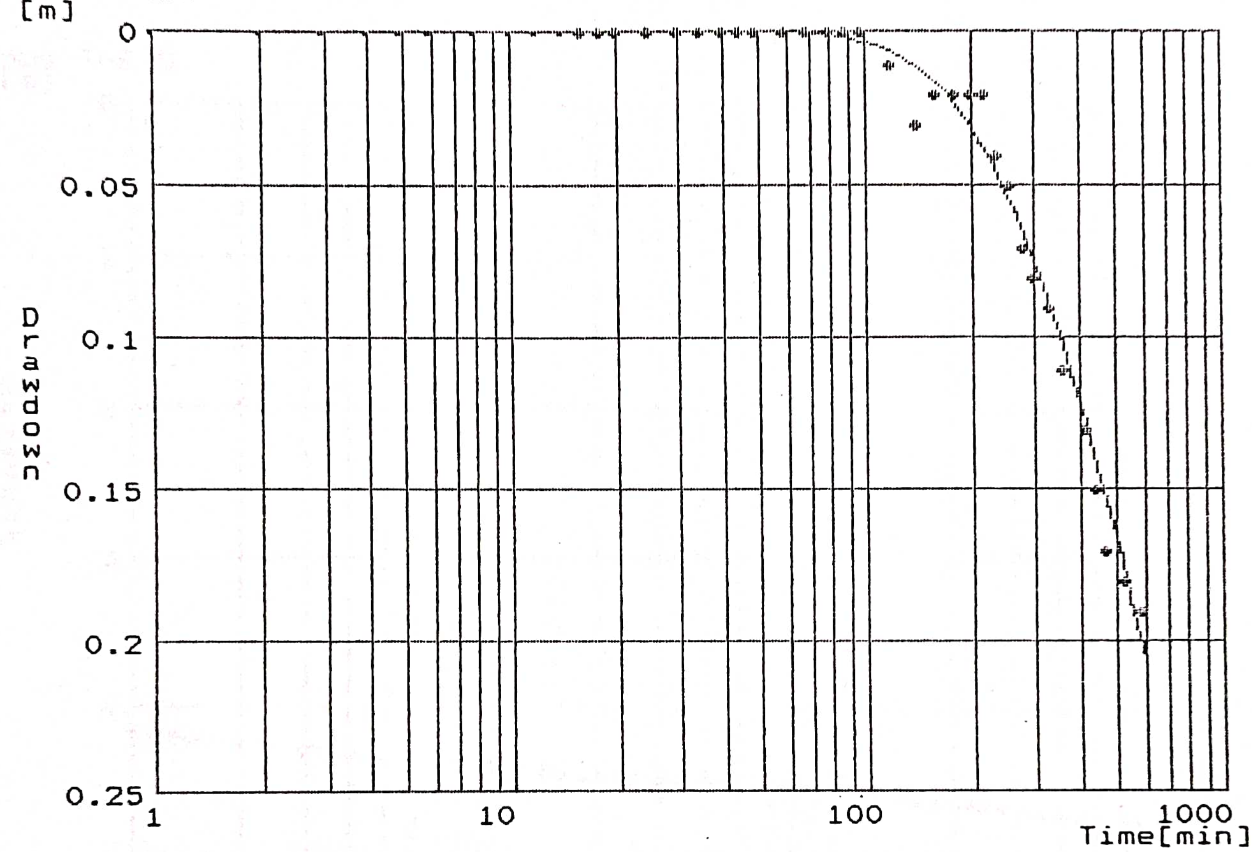
APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/61 - PUMPED WELL - W/62 OBS. WELL

Constant Pumping Rate = 540.000 [m3/hr]
Distance from Observation Well = 1000.00 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 2.91 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 2427. [m2/day]
Storage Coefficient = 0.00230038
Standard Deviation = 0.0073 [m]

Number of Points = 31 of 41

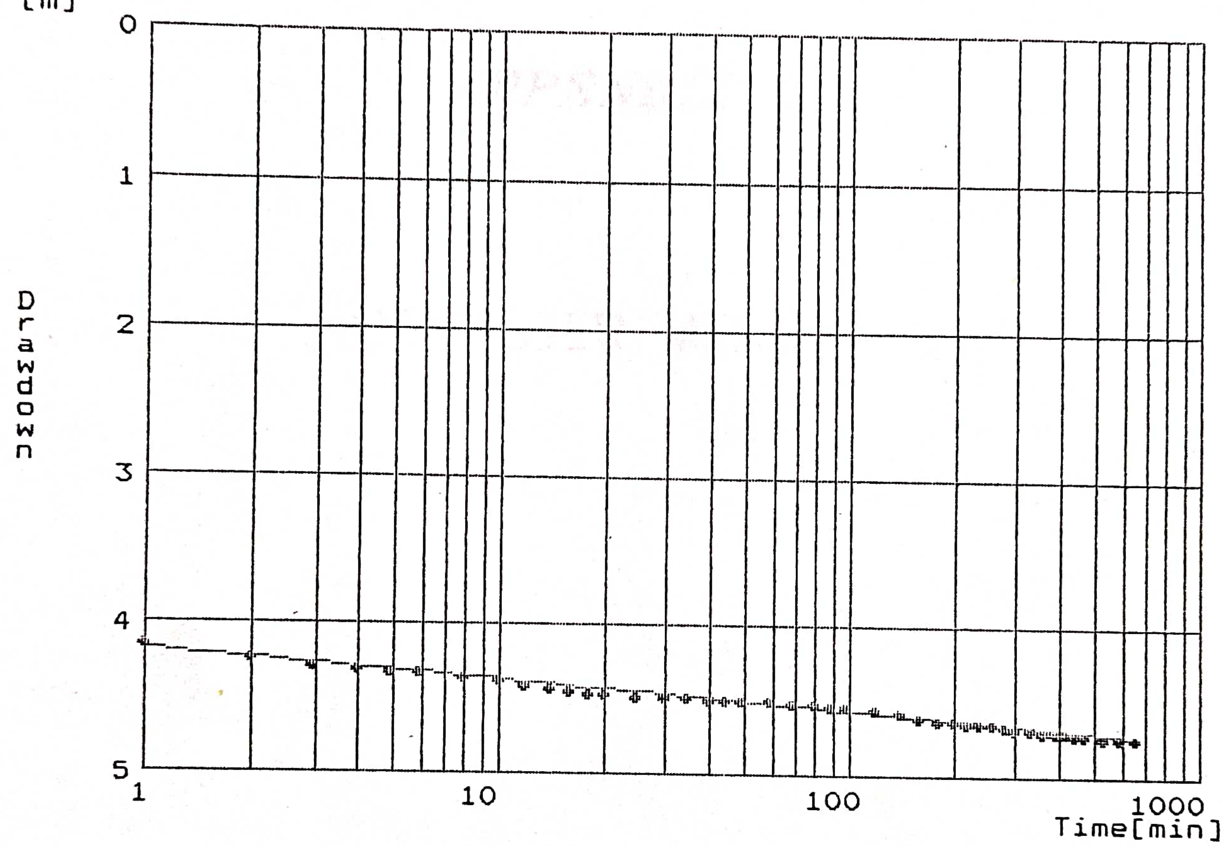
APPENDIX 1 - PUMPING TESTS

Project : NEP/86/025
Organization : GROUND WATER RESOURCES DEV. BOARD

Test : W/64 - PUMPED WELL BYURATALA

Constant Pumping Rate = 630.000 [m3/hr]
Distance from Observation Well = 0.20 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = 1.17 [m]
Well Type = STANDARD

Method THEIS



Transmissivity = 14183. [m2/day]
Storage Coefficient = 0.00000000
Standard Deviation = 0.0176 [m]

Number of Points = 43 of 43

APPENDIX 2

COMPUTER MENUS

```
**************************************************
*  GW5 - GROUND WATER MODEL No.1                 *
*                                                *
*                 UNITED NATIONS                 *
*  DEPARTMENT OF TECHNICAL CO-OPERATION          *
*                FOR DEVELOPMENT                 *
*                                                *
*     MAIN MENU                                  *
*                                                *
*  1. START NEW MODEL                            *
*  2. PREPARE AND/OR EDIT INPUT DATA FILES       *
*  3. RUN MODEL WITH NEW SET OF DATA             *
*  4. WRITE INPUT ("TRANS","STORAGE","WELLS",    *
*       "RECHARGE","BOUNDARY","TOTALQ","LEVEL")  *
*  5. WRITE OUTPUT ("MAP","BALANCE","GRAPH",     *
*                   "LEVEL.DAT")                 *
*  6. SHOW DATA FILES (INPUT or OUTPUT)          *
*                                                *
*  9. EXIT TO DOS                                *
*               Programmed by: Dr. J.Karanjac    *
*     April 1988                Dr. D.Braticevic *
**************************************************
  SELECT NUMBER:
```

```
******************************************************
*                                                    *
* This subroutine prompts for general modelling data *
*   model name, project, organization                *
*   number of columns, rows, size of cells           *
*   max. number of iterations, error criterion       *
*   time interval (steady/unsteady), number of steps,*
*   cells in which graphs are wanted, scale of graph.*
*                                                    *
*   You have two options:                            *
*                                                    *
*   (1) To input/edit data from keyboard             *
*   (2) To read already prepared data from file      *
*       MODEL.DAT                                    *
*                                                    *
*    If you select the option 1, new data will       *
*    be written to data file MODEL.DAT overwriting   *
*    an eventually existing data file.               *
*                                                    *
*    For the first time running a new model, you     *
*    must select the option 1.                       *
******************************************************
OPTION [1/2]:
```

```
------------------------------------------------------------------------------
GW5. Ground water software for UN. Modelling Program No.1.  APRIL 1988
------------------------------------------------------------------------------
    INPUT GENERAL PARAMETERS: (CHECK WHETHER CORRECT)

     MODEL IDENT.   :
     PROJECT        :
     ORGANIZATION   :
   NUMBER OF COLUMNS:  45
     NUMBER OF ROWS :  40
   SIZE OF TIME STEP:   0.3000E+02
NUMBER OF TIME STEPS:   8
              ERROR:   5.000
MAXIMUM ITERATIONS  :  25
LENGTH OF EACH CELL :   1000.0


  NUMBER OF GRAPH CELLS:    3
            GRAPH SCALE:    0.30 M
        25 14
        29 16
        24 12
Execution suspended :  PRESS <RETURN> TO CONTINUE!
```

```
------------------------------------------------------------------------------
GW5. Ground water software for UN. Modelling Program No.1.  APRIL 1988
------------------------------------------------------------------------------

          **************************************************
          *                                                *
          *   1. Create/Edit/Read Boundary Data File       *
          *   2. Create/Edit/Read Transmissivity File      *
          *   3. Create/Edit/Read Storage Coefficient File *
          *   4. Create/Edit/Read Recharge Data File       *
          *   5. Create/Edit/Read Initial Water Level File *
          *                                                *
          *   9. Return to Main Menu                       *
          **************************************************
           SELECT NUMBER:
```

```
*************************************************
* This program creates/edits and reads boundary  *
* file. First it reads flags (0,1,9) to locate   *
* constant-head and/or constant-flow boundary    *
* cells. Second part prompts for actual values of *
* constant heads and/or constant flow (inflow or  *
* outflow).  If constant head values are to be    *
* read from MODEL.LEV file there is no need to    *
* change these values. Constant-flow values must  *
* be input from second part of this program!      *
*************************************************

*************************************************
*  CONSTANT-HEAD or CONSTANT-FLOW BOUNDARY FILE   *
*                                                 *
* 1. Create New Boundary Data File from keyboard  *
* 2. Edit Existing Boundary File from keyboard    *
* 3. Read Existing Boundary File  (MODEL.BRY)     *
* 4. No Constant-Head or Constant-Flow Boundaries *
* 5. Exit to Main Edit Menu                       *
*************************************************
     Which Number:
```

GW5. Ground water software for UN. Modelling Program No.1. APRIL 1988

MODEL.BRY FILE IS O.K.

```
*************************************************
*      REMINDER:   CONSTANT HEAD    FLAG=1        *
*                  CONSTANT FLOW    FLAG=9        *
*      OPTIONS:                                   *
*                                                 *
* 1. Constant-head values shall be input from     *
*    keyboard following the program prompt        *
* 2. Constant-flow values shall be input from     *
*    keyboard following the program prompt        *
*                                                 *
* 9. Return to Main Edit Menu                     *
*                                                 *
*************************************************
     Which Number:
```

```
-----------------------------------------------------------------------
GW5. Ground water software for UN. Modelling Program No.1.  APRIL 1988
-----------------------------------------------------------------------

                    ***********************************************
                    *       TRANSMISSIVITY DATA FILE              *
                    *                                             *
                    * 1. Create New Transmissivity File from keyboard *
                    * 2. Edit Existing Transmiss. File from keyboard  *
                    * 3. Read Existing Transmissivity File (MODEL.TR) *
                    * 4. There is no separate input data file.   *
                    *     (Transmissivity values are constant)    *
                    *                                             *
                    * 5. Exit to Main Edit Menu                   *
                    ***********************************************
                         Which Number:
```

```
-----------------------------------------------------------------------
GW5. Ground water software for UN. Modelling Program No.1.  APRIL 1988
-----------------------------------------------------------------------

                    ***********************************************
                    *           WATER LEVEL DATA FILE             *
                    *                                             *
                    * 1. Create New Initial Level File from keyboard *
                    * 2. Edit Existing Level File from keyboard   *
                    * 3. Read Existing Level File (MODEL.LEV)     *
                    * 4. There is no separate input data file.    *
                    *     (Water levels start from a constant value) *
                    *                                             *
                    * 5. Exit to Main Edit Menu                   *
                    ***********************************************
                         Which Number:
```

```
**************************************************
*        WHICH FILES DO YOU WANT TO WRITE?       *
*                                                *
*  1. TRANSMISSIVITY         FILE "TRANS"        *
*  2. STORAGE COEFFICIENTS   FILE "STORAGE"      *
*  3. RECHARGE FROM RAINFALL FILE "RECHARGE"     *
*  4. BOUNDARIES             FILE "BOUNDARY"     *
*  5. WATER LEVELS           FILE "LEVEL"        *
*                                                *
*  9. RETURN TO MAIN MENU                        *
*                                                *
**************************************************
  SELECT NUMBER:
```

GW5. Ground water software for UN. Modelling Program No.1. APRIL 1988

```
*****************************************************
*    SELECT OUTPUT DATA FILES:                      *
*                                                   *
*    1. MAP OF WATER LEVELS AT END OF RUN   "MAP"   *
*    2. WATER BALANCE FOR EACH TIME STEP  "BALANCE" *
*    3. WATER LEVEL GRAPHS AT SELECTED CELLS        *
*         "GRAPH1" (in "graphical form")            *
*    4. WATER LEVEL GRAPHS AT SELECTED CELLS        *
*         "GRAPH2" (in numbers - as input to other  *
*          graphical programs (e.g. Graph-in-Box)   *
*    5. MAP IN CONTOUR-PROGRAM FORM  "LEVEL.GRD"    *
*****************************************************

 1. MAP OF WATER LEVELS    [Y/N]: Y
 2. WATER BALANCE          [Y/N]: Y
 3. GRAPHS in "graph form" [Y/N]: Y
 4. GRAPHS as numbers      [Y/N]: Y
 5. MAP FOR CONTOURING     [Y/N]: Y
```