His Majesty's Government of Nepal Project

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

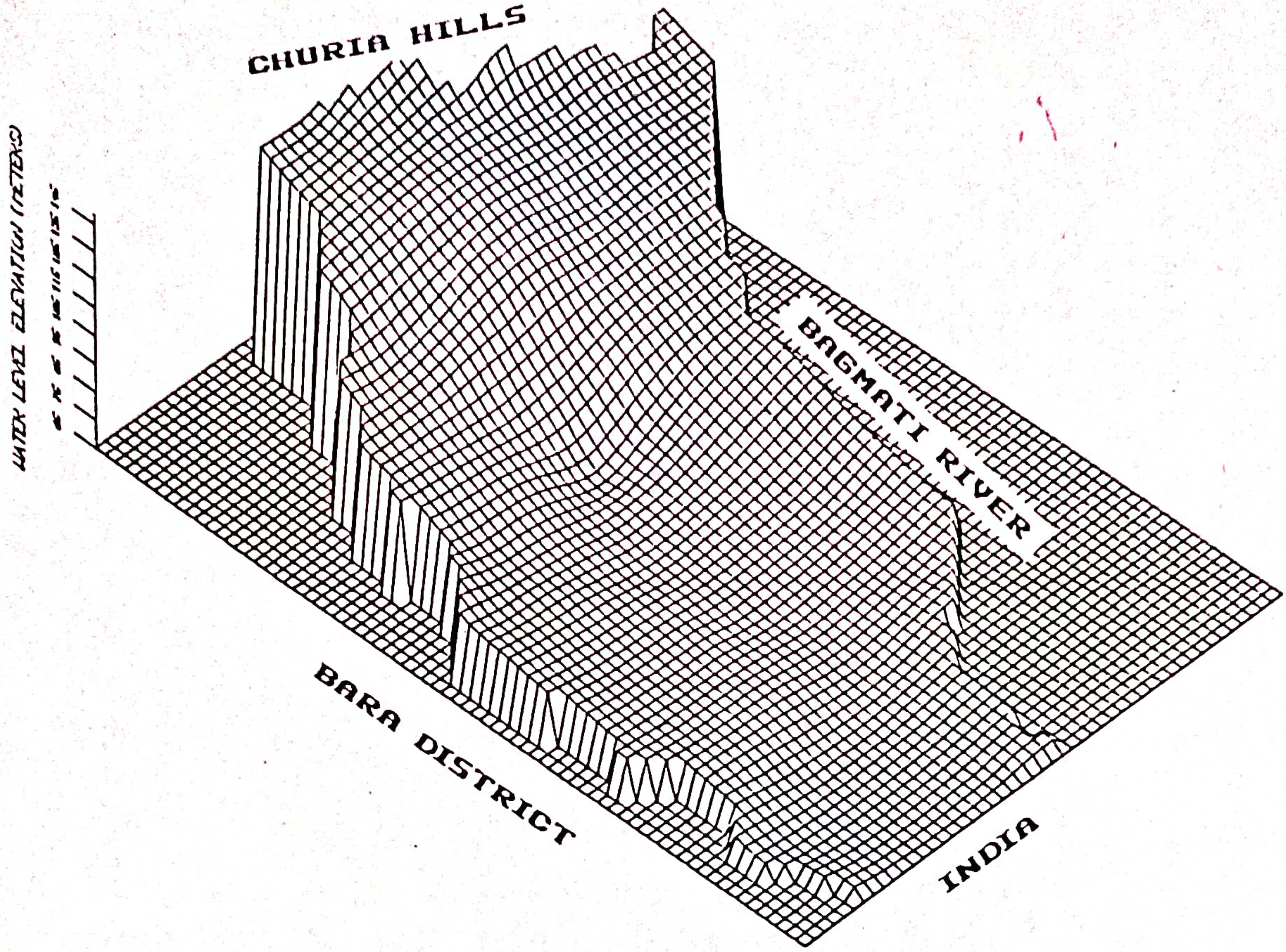
5th

MISSION REPORT
(October 21 - December 12, 1988)

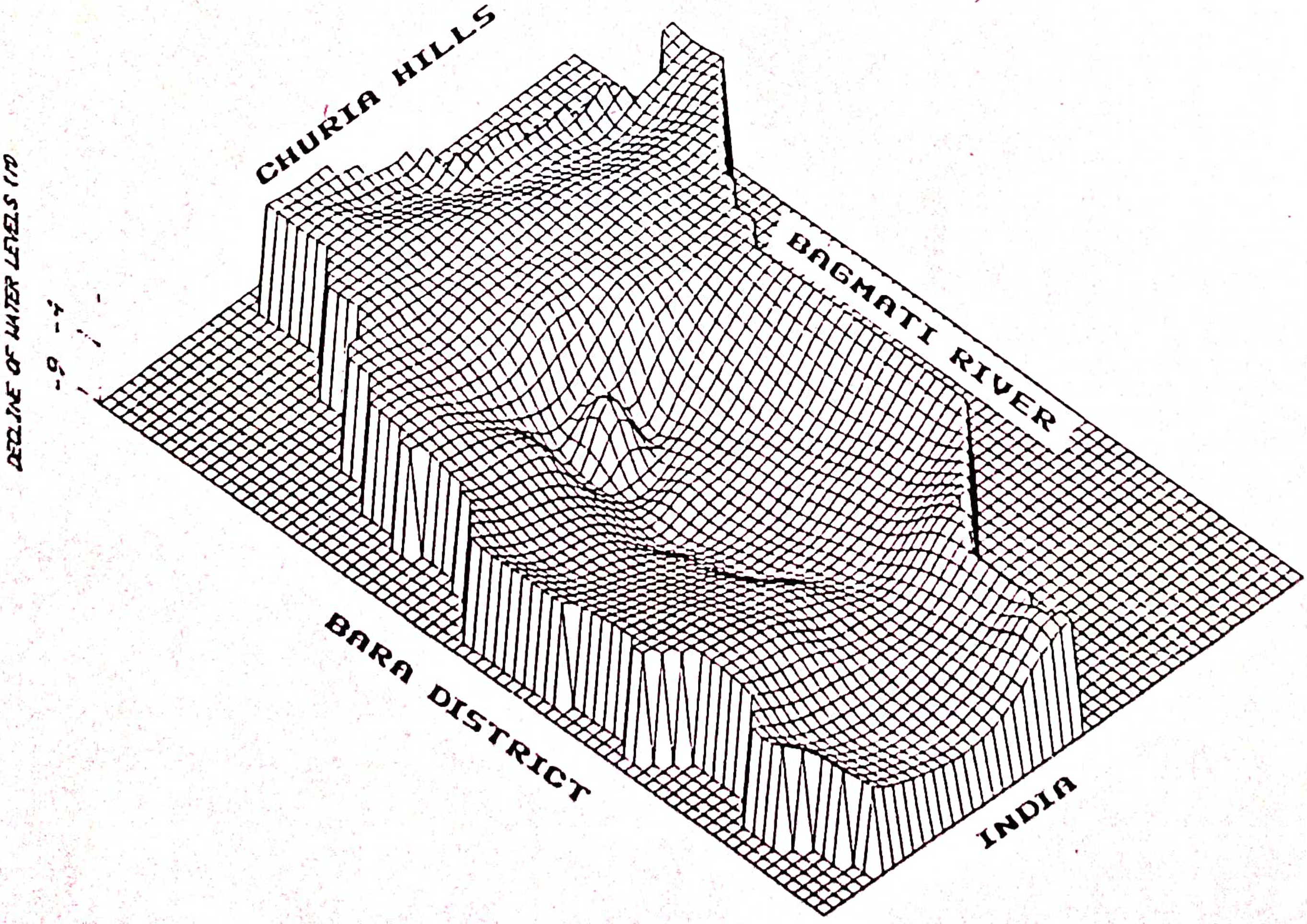
Author: Dr. J.Karanjac, Chief Consultant - Hydrogeologist

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

KATHMANDU, NEPAL
12 December 1988



RAUTAHAT MODEL - WATER LEVEL CONTOURS AFTER 4-YEAR OF PUMPING



RAUTAHAT MODEL - DECLINE OF WATER LEVELS AFTER 4-YEAR OF PUMPING

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APPENDICES

ACKNOWLEDGMENT

Most of appendices presented in this report were prepared by A.Kanzler, Associate Expert, for Technical Report No. 3 and for Tripartite Project Review. The software used for modelling the shallow ground water system of the Rautahat District is a proprietary software of the United Nations Department of Technical Co-operation for Development, which is the Executing Agency in this project.

1. INTRODUCTION

1.1. Project Objectives and Terms of References

The project "Shallow Ground Water Investigations in the Terai" is executed by the United Nations Department of Technical Co-operation for Development (UN/DTCD), and the counterpart agency in Nepal is Ground Water Resources Development Board (GWRDB) of the Ministry of Water Resources (Department of Irrigation).

The project's immediate objectives are to generate technical information on the occurrence and potential of shallow ground water resources in the Terai, and to enhance the capacity of GWRDB with respect to ground water exploration, assessment, development, interpretation of results, and advanced computer processing of collected data. The project started in June 1987. Its expected termination date, at the beginning of the project, was the end of 1990. (At the Tripartite Project Review held on 5 December 1988, it was agreed to extend the project through the end of 1991.)

The project is expected to produce the following outputs: (a) computerized data base with about 2000 selected shallow tube wells; (b) 200 project-drilled exploration-observation-test wells (total drilled metrage about 8000 m); (c) 400 pumping tests in shallow tube wells; (d) 400 observation wells hydrographs; (e) water level maps (depth to water, absolute water level elevation maps); (f) reports on availability and development potentials of shallow ground water resources; (g) report on drilling methods; (h) infiltration test reports and evaluation. Indication of optimal number of wells in each district of the Terai, the spacing of wells, construction, depth of exploitation, and rates of pumping, are among the most useful outputs for planning of shallow ground water development.

The immediate importance of the project is in the following. Agricultural Development Bank of Nepal (ADBN) is contemplating the financing on a loan basis the construction of several ten thousands shallow tube wells in the next decade. The immediate plan is to construct 9000 shallow tube wells (STW) in the next three-year period. The final ADBN's target is to install about 74,000 STW in the Terai by the year 2000. Yet, there is no sound technical basis which could assist in the decision making, planning and actual development of ground water resources. This UNDP-assisted project is to provide the missing information on the occurrence, availability, balance, development potentials, etc. of shallow ground water all over the Terai.

1.2. Terms of Reference for This Mission

This mission is a continuation of the previous missions of the Chief Consultant in the project. The routine work includes (a) supervision of past and current activities of the project staff (local GWRDB staff and UNDP Associate Expert), (b) guidance and assistance to the project staff, (c) technical reporting, (d) mathematical modelling. In this mission the terms of reference specifically called for (1) writing and assisting in writing of two technical reports from the Rautahat District, (2) making one mathematical model (Rautahat District), (3) preparing and attending the first Tripartite Project Review, (4) preparing, in conjunction with the National Project Director, the Work Plan for the second drilling season (December 1988 - June 1989).

1.3. *Previous Missions*

The first mission of the same consultant was implemented between 9 June and 6 July 1987. It was the initial mission which was used for getting acquainted with the project and staff and in formulation of the first year Work Plan.

The second mission was implemented between 3 and 29 November 1987. Its main activities were as follows:

(a) Preparation of the drilling program in four districts (Rautahat, Nawalparasi, Kapilvastu, Dang-Deukhuri).

(b) Processing of available information on shallow ground water in four districts (Rautahat, Nawalparasi, Kapilvastu, Dang-Deukhuri).

(c) Training of GWRDB staff in computer work.

The third mission was realized between 19 January and 10 February 1988. The highlights of the mission were as follows:

(a) Field visit to Nawalparasi, Rupandehi, Kapilvastu, and Dang districts.

(b) Briefing newly-arrived associate expert, preparing office and field work for the remainder of pre-monsoon season.

(c) Processing depth-to-water data in Jhapa, Rupandehi and Mahottari districts as examples of the computer-processing software.

(d) Processing newly conducted pumping test data from the Bhairawa-Lumbini ground water irrigation project.

The fourth mission was executed between 20 April and 31 May 1988. The consultant's activities during the six-week period were the following:

(a) Interpretation of information collected in the field.

(b) Running a short mathematical model course for the project staff (one week) with the actual example of the model of Bhairawa-Lumbini ground water irrigation system.

(c) Writing Technical Report No. 1 (Progress Report on the Bhairawa-Lumbini Mathematical Model).

(d) Preparation, jointly with other project staff, of Technical Report No. 2 titled "Shallow Ground Water Table Fluctuations in 1987 in the Terai".

(e) Setting up plotter and newly arrived digitizer (along with adapting software for the digitizer).

(f) Training project staff in using the digitizer and plotter.

1.4. This Mission Timing, Activities, Outputs

This mission started on 21 October 1988 and was carried until 12 December 1988, with a four-day break (20-24 November 1988) during which the consultant attended a desk review of a UN/DTCD project in India.

The major activities during this mission were as follows:

(a) Assisting Associate Expert, Mr. A.Kanzler, in preparing Technical Report No. 3: Rautahat District, Basic Documentation and Preliminary Interpretation.

(b) Constructing mathematical model of the shallow ground water system of the whole Rautahat District, calibrating the model and processing one hypothetical future intensive ground water development scheme.

(c) Writing Technical Report No. 4: Rautahat District, Mathematical Model of Shallow Ground Water System.

(d) Assisting Associate Expert in preparing Tripartite Project Review.

(e) Attending the TPR on 5 December 1988.

(f) Preparing, in conjunction with other project staff, the work plan for the second year of the drilling activities.

1.5. Planning for Next Mission and Its Terms of Reference

The next mission of this consultant is planned for the period between 15 February and 15 March 1989. The main activities shall be the following:

(a) Evaluating, improving and completing technical reports 5 and 6 on basic documentation and preliminary interpretation in districts Dang and Nawalparasi. These reports shall be prepared, mainly, by the local project staff under the guidance of Associate Expert A.Kanzler.

(b) Assisting Associate Expert A.Kanzler in constructing the mathematical model of the shallow ground water system in Nawalparasi district, and project hydrogeologist Shrestha in constructing the mathematical model of the shallow ground water system in Dang valley. These reports shall have numbers 7 and 8.

(c) Evaluating field work progress (drilling, monitoring water levels, pumping tests) in all districts in which project activities shall be carried out.

2. EVALUATION OF WORK IN 1987/88

2.1. General

The drilling and pumping test activities in 1987/88 were carried out in four districts: Dang, Kapilvastu, Nawalparasi, and Rautahat (Appendix 1). The execution of drilling works is shown in Appendices 2 and 3. The target for drilling was 77 shallow wells with a total drilled metrage of some 2,990 meters. The total of 87 wells have been drilled, out of which 11 wells were abandoned for various reasons (insufficient thickness of permeable layers, problems with lowering casing-and-screen string, problems in penetrating through coarse near-the-surface material).

The drilling metrage was very close to the planned one, although more than 400 m of drilled metrage was in abandoned wells.

If the drilling was sufficiently successful, the pumping tests trailed very much behind the programmed number. Out of 112 wells designated for testing, only 58 pumping tests have been made. The explanation for this is in the following:

(a) Inadequate pumping equipment, leaky pumps and pipes.

(b) Improperly developed wells (notably in Nawalparasi District) in which there was very little ground water inflow into the well.

(c) Lack of interest and understanding of persons in charge of the objectives of pumping tests in this project (Kapilvastu district).

(d) Too deep water table for available pumping equipment (Nawalparasi East).

The achievements in each of districts are shown graphically in Appendices 4 through 9. The drilled metrage in each of districts is presented in Appendix 10. The drilling target was exceeded in districts Kapilvastu, Rautahat and in Dang valley of the Dang district. The absolute failure of the drilling program was in Nawalparasi East. The drilling was below expected in Nawalparasi West. Pumping tests expectations have not been fulfilled in Kapilvastu and in both parts of Nawalparasi. Slightly below expectations pumping test program was also in Dang and Deukhuri. Only in Rautahat District the pumping test program was slightly above the plan.

All taken together, the best work had been done in Rautahat district, followed by the work in Dang and Deukhuri. The drilling was satisfactory in Kapilvastu district in which the pumping program failed completely. The worst accomplishment comes from Nawalparasi district.

2.2. Tripartite Project Review

The project's tripartite review, the first in this project, was held in Kathmandu on 5 December 1988. It was attended by:

Messrs. M.D.Karki, General Director of Department of Irrigation; Y.L.Vaidya, Member and Secretary of GWRDB - on behalf of the Government;

Messrs. P.Subba, Senior Program Officer; J.Gerstle, Program Adviser- on behalf of the UNDP;

Messrs. U.Golani, Technical Adviser of UN/DTCD Water Resources Branch; J.Karanjac, Chief Adviser, and A.Kanzler, Associate Expert - on behalf of the executing agency UN/DTCD.

The TPR concluded the following:

(a) GWRDB activities and project outputs were in line with the expectations in spite of some problems with drilling, development of wells, pumping test equipment, measuring instruments and practices.

(b) The program of work formulated by the GWRDB for the second year of the project is very optimistic and much above the program-document-required activities. (The project document specifies that 200 "project" wells shall be drilled in the 3-year period. The 2nd year work plan foresees the drilling of about 240 STW.) Some of deficiencies noted in the first year shall be removed. Pumping test equipment, instruments, and practices shall be improved.

(c) Levelling of newly drilled project wells, plus some other shallow and deep wells, shall be given in subcontract to a local company. Considering the time schedule of evaluating the shallow ground water development potential in districts by means of mathematical models, it was accepted as important to assign a portion of levelling work to the subcontractor at an early date so to obtain absolute elevations of about 80 well points in the districts Dang, Nawalparasi and Kapilvastu within two to three months.

(d) Following the request of the government, it was decided to recommend the expansion of project objectives (and consequently of activities, outputs, and budget) to include the establishment of a data base for deep tube wells in the Terai, and to transfer a certain portion of the data into such a base. A consultant in data base operations shall be recruited for a total of 6 man months in the third and fourth year of the project.

(e) It was also accepted to increase the number of man months for Chief Consultant, from 12 to 18, and to extend the project life span from three to four years, i.e. through the end of 1991, to make possible the reporting on and evaluation of shallow ground water resources of all districts in the Terai by means of mathematical models.

3. TECHNICAL REPORTS

3.1. Rautahat District - Basic Documentation and Preliminary Interpretation - Technical Report No. 3

The objective of that report, which was released in November 1988, was to present technical information on the occurrence of shallow ground water in Rautahat District. The report was configured as a basic documentation (on drilling, lithology, pumping tests, rainfall, water levels) and a preliminary interpretation (contour maps in May and September 1988, transmissivities, etc.). The main points of the report are reproduced here below.

The drilling program was completed according to the expectations. The number of holes drilled was higher than programmed, but six wells were abandoned for no reason except for the misunderstanding of the project objectives. Out of twenty five wells, eighteen wells were successfully completed and turned into observation wells. The average depth of completed wells was 23.7 m. Out of 25 drilled wells, 14 wells were constructed by a drilling rig using bentonite mud, and 11 wells by indigenous (manual) methods of drilling. The locations of newly drilled wells and wells in which pumping tests have been run are shown in Appendix 11. Lithology of each of 25 newly drilled wells was presented in graphical form as demonstrated by one example in Appendix 12.

None of manually constructed wells failed but their depth of penetration was much below that of rig-drilled wells. In addition, eight out of eleven "manual" wells were terminated in a permeable layer. Evidently local drillers could not penetrate through coarse sand with gravel in spite of shallow depth of drilling.

For a future ground water development program it is clear that to the north of the King Mahendra highway the prospects for shallow ground water development shall be slim for at least two reasons: (1) drilling problems due to gravel content and occasional individual cobble and pebble, (2) deep water table which demands expensive pumps, larger well diameter, higher water lift, and consequently involves higher costs.

In addition to lithology of shallow aquifers, which became known from drilling operations, pumping tests provided most of knowledge on aquifer parameters. Although we may not be absolutely satisfied with the results of pumping tests, they did produce the values of transmissivity, and, in few cases, storage coefficient. The quality of testing must be improved, as well as the accuracy of equipment used in testing.

Both lithology and transmissivity data indicate that northern and eastern portion of the district are more favourable for shallow ground water development than the western portion. An earlier speculation that the aquifer material becomes finer from north to south may not be quite correct, especially for the upper 30 meters. On the contrary, the wells at the south, around Gaur, and in the southeastern corner along the Bagmati River, have shown quite a high content of sand and gravel. One of lithological cross sections from the report is reproduced here in Appendix 13 (V-V').

Some wells have confirmed high transmissivity of shallow aquifer. The highest values were obtained from the north. In most of wells in that area the transmissivities are higher than 1000 m²/day. The average transmissivity in the whole district is about 700 m²/day, and the average permeable thickness is 11.4 m. It appears that an average hydraulic conductivity (permeability) is about 60 m/day. One of typical interpretations of pumping tests in Rautahat district is reproduced in Appendix 14. The pump testing program in Rautahat district should be continued. There are many wells that lend themselves to testing. Most of hand-pump equipped wells (drilled by ADBN and Japan Red Cross Society in recent years) could be easily tested.

Rautahat district is well covered with water-level monitoring network. At this moment all successful "project" wells (18) are included into the observation. The map of observation well locations is shown in Appendix 15. The water-level behavior is directly correlated with rainfall. In 1987, the average rise of water table in the period from May through September was about 2.7 m (from -3.8 m to -1.1 m). In 1988, the rise was more moderate, about 1.8 m (from -3.0 to -1.2 m). It is interesting to note that in the month of September in a great portion of Rautahat District the water table is very close to the land surface. This may be beneficial for paddy crops but may lead to water logging and salinity problems for other crops. The maps of depth to water table in May and September 1988, the rise of water table in the monsoon season of 1988, and contour maps of water levels in May and September 1988, are shown in Appendix 16.

Assessment of shallow aquifer water balance was not attempted in this report. A parallel study was run by the project in which a mathematical model was constructed and tested. The model provided answers to the following: (a) recharge from rainfall in the Bhabar zone and elsewhere, (b) the connection with the Bagmati River, (c) the importance and magnitude of the evaporation process, (d) the correct order of magnitude of hydrogeological parameters, (e) the volume of outflow across the district boundary into India.

For a better understanding of the relationship between the Bagmati River and shallow aquifer the following program of investigations was recommended:

(a) Drilling of 5 observation wells at the banks of the river (20 m far, or in dry river bed which is normally not flooded; 20 m deep; equipped with an automatic water level recorder).

(b) Continuous monitoring of water table in the above observation wells in the period from May through September in any one-year period.

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

(d) Correlation of water table in near-the-river observation wells with the river level height, and calculation of the base flow at upstream and downstream stations in the dry season.

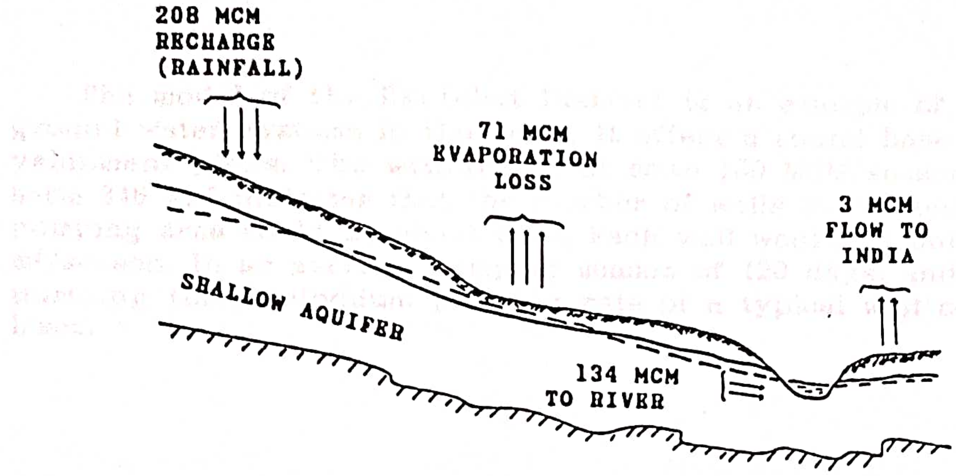
3.2. *Rautahat District - Mathematical Model of Shallow Ground Water System*

The objective of this report, which was released in early December 1988, was to evaluate the whole shallow ground water system of the Rautahat District, to arrive at a global water balance of the whole district and to indicate a maximum development potential for future intensive ground water exploitation. In the process, all components of the system have been verified. The model also checked and verified the conclusions of the companion report (Technical Report No. 3, see 3.1.).

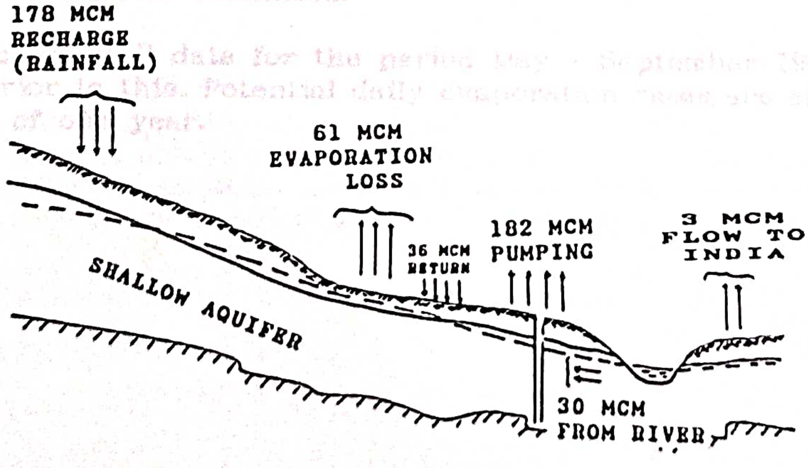
The following are the excerpts from the Executive Summary of the report.

The modelling work reported in Technical Report No. 4 confirmed the following typical one-year water balance. The recharge from rainfall, mostly in the near-the-hill area, including some subsurface inflow from streams cutting through the Churia Range, amounts to about 208 MCM (million cubic meters) per year. Considering the size of the model of about 1,008 km², the average infiltration percentage of a typical annual rainfall of 1500 mm is about 14%. Out of this, in "virgin" (non-development) conditions, 71 MCM is lost through the evaporation process (from the shallow water table), about 3 MCM flow out into India, and the remaining 134 MCM flows into the Bagmati River contributing to the river base flow. The distribution of water in a typical one year period is sketched here below.

From this distribution one may easily conclude where are the sources of additional shallow ground water development in the future. The evaporation loss can be reduced, although not eliminated, by lowering the water levels to a depth that will prevent or diminish the losses. The outflow into the Bagmati River can be reduced by pumping from shallow wells located along a stretch parallel to the river bank. It is a favourable coincidence that along the right bank of the Bagmati River the shallow aquifer is the most promising, having good thickness and almost the best transmissivity in the whole district.



After successful calibration and verification of the model on the basis of the past ground water record (water levels in many observation wells in one year period), one hypothetical future development scheme was tested. The scenario of development included an area of 346 km² as shown in Appendix 17, from which about 182 MCM of ground water were pumped on a six-month per year basis. Twenty percent of this volume was returned into the subsurface in the form of return irrigation. The simulation continued for four years and the results were as follows. The volume tested is probably slightly above the maximum development potential of the district. The drawdown was in most of the area less than 6 m, and was approaching a steady or balanced state. In some cells, near the King Mahendra highway, the drawdown is excessive, unbalanced and depletes the aquifer. A comparative sketch of the evolution of the cone of depression (drawdown) after the second, third, and fourth year of pumping, is shown in Appendix 18. With minor modifications of the pumping distribution, with a shift toward south and south-center, the shallow ground water system of the Rautahat District can sustain the total withdrawal of about 160 MCM in a year. In the tested scheme of development, the excessive pumping was offset by the contribution of the Bagmati River water in a form of an induced recharge. The balance in the fourth year was the following. The recharge from all sources, including the return irrigation flow, is 216 MCM/year. The withdrawal from the shallow aquifer is 182 MCM/year. The evaporation loss is about 61 MCM/year. It is reduced compared to the "virgin" conditions, but not appreciably. The "deficit" of withdrawal compared to the recharge of some 31 MCM/year comes from the Bagmati River. The system is still not quite balanced after the fourth year of pumping, so that the maximum contribution from the Bagmati River may be reached after several more years. The sketch of the water balance in this hypothetical scheme is shown below.



The model of the Rautahat District is an example of modelling shallow ground water systems in the Terai. It offers a sound base for the ADBN development plans. The withdrawal of some 160 MCM/season from an area of some 346 km^2 indicates that the number of wells to be constructed over the pumping area could be about 5300. Each well would be pumping some 30,000 m^3/season. In an average pumping season of 120 days, and 8 hours per day pumping time, individual pumping rate of a typical well could be about 8.6 l/sec.

3.3. Dang District – Basic Documentation and Mathematical Model

Drilling activities in the Dang valley of Dang District are completed. There was a parallel program of deep aquifer exploration by deep tube wells (DTW) run by GWRDB teams as a part of routine exploration activities, and shallow aquifer exploration by ten "project" shallow tube wells (STW) out of which two were abandoned. A report on deep aquifer exploration shall be soon completed and released by the field staff of GWRDB (not as an activity of the project NEP/86/025). However, the reporting on shallow aquifer lithology, aquifer characteristics, water level evolution in 1987/88, and correlation with rainfall, shall be the task of the project team, notably Mr. J.L. Shrestha, with assistance of the field hydrogeologist Mr. P.G.Tater and Associate Expert Mr. A.Kanzler.

Utilizing basic documentation contained in the report on shallow aquifer exploration program, a mathematical model shall be constructed. The sketch of the model network is shown in Appendix 19. The area of the model shall be 1166 km^2, the size of each model cell 1000 m by 1000 m, or 1 km^2. The total number of columns shall be 22 and of rows 53.

The model demands the following data:

(a) Land surface elevation of all newly drilled "project" wells, and some other strategically located points (DTW, other shallow tube wells) to be used for the construction of water level contour maps in May and September 1988, respectively, and land surface elevation information for each cell in the model. The same information shall be used for producing maps of elevation of the top and bottom of shallow aquifer.

(b) Pumping tests results, with respect to transmissivity and storage coefficient. Calculation of hydraulic conductivity from transmissivities and saturated aquifer thickness.

(c) Rainfall data for the period May – September 1988, and at least one year prior to this. Potential daily evaporation rates are also required for the period of one year.

(d) Information on the Rapti River in the dry and flood period of 1988. Lithological cross-sections perpendicular to the river course to indicate the connection between the shallow aquifer and the river.

(e) Information on eventual pumping in the past from shallow aquifer.

The report including the basic documentation and the model should be completed by the end of March 1989.

3.4. Nawalparasi District – Basic Documentation and Mathematical Model

The drilling work in the Nawalparasi District (west) is completed although not quite as expected and programmed. The number of wells is 17 and each is successful and turned into an observation well. Some wells were poorly developed and inadequately constructed (0.5 mm screen slots), and pumping tests could not produce any water in spite of good lithology. However, in the district the Japan Red Cross Society and its subcontractor Nissaku Co., Ltd. drilled many shallow tube wells for the Nepal Drinking Water Supply Scheme. The sketched location of the wells is shown in Appendix 20.

The report that will include and compile all basic lithological data from all available wells must also produce lithological cross sections from which the top and bottom of shallow aquifer shall be interpreted and "taken". The target date for completing the basic documentation report in the Nawalparasi District is the beginning of February 1989. On its basis the model shall be constructed covering the whole area of the western portion of the Nawalparasi District.

The size of the model shall be 20 columns by 41 rows, and each cell shall be 1000 m by 1000 m, i.e. 1 km^2 large. The input data to construct the model are the same as explained in section 3.3. for the Dang valley model. The Narayani River makes the eastern boundary of the model, while the long northern boundary of the Churia hills is a natural termination of the shallow aquifer. Other two boundaries shall be artificial. The sketch of the network of the Nawalparasi model is shown in Appendix 21. The tentative target date for the completion of both reports is end of March 1989.

3.5. Other Reports

The drilling and aquifer testing activities have been completed in Kapilvastu district (21 successful STW and 13 pumping tests) and in Deukhuri valley of the Dang District (6 drilled wells, 9 pumping tests). For both areas all drilling data should be processed, driller's and lithological logs prepared, lithological cross-sections made utilizing all available lithological information from sources other than "project" wells. Pumping tests should be reinterpreted and appended to respective reports. Rainfall data from nearby stations should be also included into "Basic Documentation". If available, any data on stream flow and/or river stage should be presented. The target dates for the reports with basic documentation and some preliminary interpretation is end of March 1989. This work should be done by the GWRDB-project staff with assistance of Chief Consultant and Associate Expert.

4. WORK PLAN FOR 1988/89 DRILLING SEASON

4.1. General

The map of proposed drilling activities in 1988/89 (starting in November 1988, terminating in June 1989) is appended to this report as Appendix 22. According to the GWRDB drilling program, the UNDP/DTCD/GWRDB project activities shall be carried out in 5 districts: (from west to east) Bardiya, Banke, Sunsari, Morang, Jhapa. In the western two districts, the total number of STWs shall be 20 wells in each district. In the eastern three districts, there shall be 14 STWs in each. The total of "project" wells programmed for the second drilling season is 82.

In addition to "project" wells, GWRDB plans to drill shallow exploration wells in 6 more districts: Kanchanpur (20), Kailali (20), Rupandehi (20), Mahottari (20), Siraha (25), and Saptari (25). The total number of wells in these 6 districts shall be 130.

The overall total of shallow wells to be used for the definition of lithology, pumping tests, and monitoring water levels is planned as 212 (see Appendix 23). This is a very ambitious plan which requires an excellent organization, logistical support, and, overall, timely and qualified supervision. Considering such a large program, both in scope and in surface coverage, it will be difficult to maintain a full control over field activities from the UN project with presently available staff. The staff shall be entrusted with the reporting task (Nawalparasi, Dang, Kapilvastu, Deukhuri), modelling work (Dang, Nawalparasi), routine processing of field-collected data (water levels, drilling logs, pumping tests), etc. In the same time each of project geologists and hydrogeologists should spent most of the drilling-season time in the field supervising the field work.

The levelling of land surface (elevation) in all newly drilled wells, plus in some strategic points (DTWs, other STWs), shall start probably in January 1989. The priority shall be given to the Nawalparasi District (west) and Dang valley of the Dang District. In each of the two there should be about 25-30 points levelled and the results produced in one month time (by the beginning of February). The levelling accuracy and areal distribution of levelled points is more important in the Dang district than elsewhere considering a substantial difference in elevations between distant points.

At the Tripartite Review of the Project it was agreed to assign a subcontract for levelling of the first batch of some 80 to 100 points to a local surveying contractor. In the same time, the Department of Irrigation surveying services should initiate a levelling program in other districts with their own equipment and staff. Most if not all wells, both shallow and deep, that will be entered into the data base (2000 STWs plus an unknown number of DTWs) should eventually have their elevations known through the levelling.

4.2. Jhapa District

The area of Jhapa district is about 1400 km², out of which reportedly suitable for irrigation is about 1121 km². The number of potential shallow wells, as suggested by Tillson in 1985 is 5269.

GWRDB has not drilled shallow tube wells in Jhapa. However, there are more than 1200 ADBN-drilled STWs, but only somewhat more than 200 are located on the map. There are 12 deep tube wells drilled recently by GWRDB. Although the original GWRDB proposal suggests the drilling of 14 STWs for this project (see Appendix 23), provided funds are available, the number of selected locations for the drilling is 23. Pumping tests shall be conducted in all 23 new STWs, plus in selected 5 existing wells financed by ADBN. The officer-in-charge for the drilling and testing of shallow tube wells shall be Mr. P.Karki.

Earlier hydrogeological studies of the Jhapa district reported that deep and shallow aquifers are not separate entities and that percentage of aquifer material is fairly constant down any vertical section. The reported aquifer percentages average 56% down to 46 m and 59% below. Jhapa is classified as suitable district for STWs, except in the northern fringe where water levels may be too deep.

4.3. Morang District

The size of the Morang District is 1450 km², out of which suitable for irrigation is about 1063 km². Tillson in 1985 suggested the maximum potential number of shallow wells 5342.

GWRDB has already drilled 11 STWs (about the year 1985), and some 21 DTWs in 1986. For all these wells the lithology is known. Likewise, our maps show some 150 STWs financed by ADBN. The original GWRDB proposal (Appendix 23) suggests 14 new wells to be drilled for this project, while the planning of drilling activities in the Morang district has increased this number to 18. Pumping tests shall be conducted in all 18 new wells plus in 7 existing wells.

Previous reports indicate that the STW construction potential is generally good but variable, with shallow aquifers averaging 46% of the section down to 46 m. The northern Bhabar fringe is probably excludable due to deep water levels. There is a minor central flowing artesian zone, which is not considered to be of great importance.

The officer-in-charge for the Morang District shall be Mr. P.Karki.

4.4. *Sunsari District*

The size of the Sunsari District is about 1240 km², out of which about 1026 km² are suitable for irrigation. The Tillson report (1985) suggests a very large number of potential shallow tube wells, 7080. This is because the Sunsari district is totally dominated by the present and Recent course of the Sapta Koshi and its piedmont fan. The aquifer percentages and permeabilities are high. So-called deep and shallow aquifers cannot be easily separated. Aquifer percentages are generally in the 70 to 80% range with permeabilities in the range of several hundreds of meters per day.

The number of ADBN-financed shallow tube wells is more than 500. GWRDB drilled some 14 deep tube wells about the year 1985. The revised proposal for drilling STWs in the Sunsari district is 15 (one more than shown in Appendix 23). Pumping tests shall be carried out in each newly drilled well plus in 6 existing wells. The officer-in-charge in the Sunsari district is P.Karki.

4.5. *Banke District*

The size of the Banke District is only 800 km², out of which some 544 km² are suitable for irrigation. The number of STWs, according to Tillson, is 2802. One fourth of the Banke Terai is interpreted as a zone with good prospects for deep aquifer development. This area is located in the south eastern corner of the district. The whole Banke Terai, with minor exceptions, can be considered good for shallow well development.

Existing shallow tube wells in the north-western corner produce from 7 to 35 l/sec, and the static water level is mostly between 4 and 6 meters below the land surface. The number of existing STWs is between 450 and 500. The discharge of STWs near the Rapti River and Indian border is 25-37 l/sec.

The GWRDB proposal calls for the drilling of 20 STWs (see Appendix 23). The number of pumping tests shall be 30, including 10 existing STWs plus 20 to-be-drilled STWs.

There is an ongoing shallow wells drilling program carried out by the Japan Red Cross Society for the Nepal Drinking Water Supply Scheme. There are over 200 hand tube wells (HTWs) with diameter 1.5".

The officer-in-charge of the STWs construction and testing program in the Bara District shall be Mr. P.S.Tater.

4.6. Bardiya District

The size of the Bardiya district is 1350 km², out of which about 1037 km² are suitable for irrigation. The number of maximum STWs according to Tillson is 5449. About two thirds of the Bardiya Terai are considered as having good ground water development potentials. The area of good development covers most of the western and smaller areas in northern and southern parts of the district. Both shallow and deep aquifers can be developed. The percentage of water bearing layers in the upper 46 m is from 27 to 83. All test holes show very high permeability values, from 90 to 204 m/day. Drilling difficulties are anticipated along the banks of the Karnali River due to large cobbles and boulders. The rest of the area seems to have good potential for shallow tube wells.

The GWRDB proposal for drilling suggests 20 STWs to be drilled. There are about 150 ADBN-financed STWs located on our maps. Pumping tests shall be carried out in all 20 newly drilled wells, plus in some 10 additional, existing wells. The officer-in-charge of the well construction and testing shall be Mr. P.S.Tater.

4.7. Saptari District

The size of the Saptari District is 1030 km², out of which about 747 km² are reported as suitable for irrigation. Tillson (1985) suggested 3921 STWs as the maximum potential for the district.

Saptari district has relatively few deep exploration holes. However, there is a western/southwestern slice of the district which has clearly been affected by the Sapta Koshi fan. Here the aquifer is generally excellent and there is no clear separation into discrete shallow and deep aquifers. Both DTWs and STWs should be perfectly feasible in this section, with drilling problems restrictions on the latter due to cobbles. Water level drops to considerable depths in the district's piedmont fringe, being unsuitable for STWs. There is also a zone in the west, against the southern border, where STW success rates have been low in the past. The number of ADBN-financed STWs which are located on our maps is 1140.

The GWRDB proposal suggests the drilling of 25 shallow tube wells. They are located on a uniform grid, of 8 km (west-east) by 5 km (north-south). About 50 to 60% of all wells shall be drilled by manual (indigenous) methods. The officer-in-charge is Mr. S.P.Khan.

4.8. Siraha District

The size of the Siraha District is about 930 km², out of which about 713 km² are classified as suitable for irrigation. The maximum number of STWs according to Tillson (1985) is 3351.

The Kamala River, in spite of being trans-Churia, seems to have developed almost no Bhabar material in Siraha and certainly not a fan. In a northern zone, the water table in STWs is unsuitable (40 m below ground level in places). In a southern zone the shallow aquifer is highly variable locally and STWs may be impractical.

There are about 1055 shallow wells financed by the ADBN which are located on our maps. There are also some 11 deep tube wells drilled by GWRDB. The GWRDB proposal suggests the construction of 25 STWs to the depth between 40 and 50 m. The locations for new wells are on a uniform grid of 8 km (west-east) by 5 km (north-south). About 50% of these shall be constructed by manual methods of drilling. The officer-in-charge is Mr. S.P.Khan.

4.9. Mahottari District

The size of the Mahottari District is about 1090 km², out of which some 632 km² are suitable for irrigation. Tillson reported the maximum number of STWs 2970. Mahottari District has a considerable amount of data points spread throughout it, plus the shallow tube wells interpretation of JADP (Janakpur Agricultural Development Project). The "good" STW zone coincides fairly well with that of JADP, being limited to the north by water table depths. The extreme north is of limited use because of excessive depths to water table.

The GWRDB proposal suggests 20 STWs (see Appendix 23) but the funds appear to be available for some 25 shallow wells, which are located on a uniform grid of 5 km by 5 km. The depth of drilling in the south shall be between 45 and 50 m, and in the north 25 to 30 m.

The officer-in-charge for the construction and testing of wells is A.N.Mandal.

4.10. Rupandehi District

The size of the Rupandehi District is 1140 km², out of which some 810 km² are suitable for irrigation. Tillson suggested some 3807 as the maximum development number. In the district, there is a large deep well irrigation project, the Bhairawa-Lumbini project, which, recently, also paid some attention to monitoring the shallow aquifer. Information on dug wells, piezometers (both shallow and deep), and former USAID program, is available and already stored in computers.

The GWRDB proposal calls for the construction of additional 31 STWs, which is an increase over the original proposal of some 20 wells (Appendix 23). However, the locations selected for these new 31 wells are shown without any consideration given to the existing information. The grid is uniform, 7 km by 5 km, which is absolutely unacceptable.

Out of 31 STWs, the proposal splits the drilling into 20 wells by manual methods, and 11 wells by rig. However, the drilling program in Rupandehi district does not seem realistic for the year 1988/89, since only one rig has first to complete the drilling of some 15 deep tube wells, which will probably consume the entire length of the dry season.

4.11. Kailali District

The size of the Kailali District is 1970 km^2 (the largest district in the Terai), out of which 1271 km^2 are reported as being suitable for irrigation. Tillson reports the maximum number of STWs 6386. Good ground water development potentials for both shallow and deep tube wells are found in eastern part of the district and in a small area in the northwestern corner. Drilling difficulties will be encountered along the bank of the Karnali River. Aquifer percentages vary from 38 to 95 within the shallow zone (down to 46 m). Permeabilities are high, between 163 and 319 m/day. The rest of the district appears to have good potential for shallow wells and marginal for deep wells.

The original GWRDB proposal suggests the construction of 20 shallow wells. It is amended and increased to construct 24 STWs. There are at least 351 shallow wells in the district, as shown on our maps.

The officer-in-charge in the Kailali district shall be Mr. Gairhe.

4.12. Kanchanpur District

The size of the Kanchanpur District is 1450 km^2, and the area suitable for irrigation is about 842 km^2. Tillson (1985) suggested the maximum number of shallow wells 4272. About one fifth of the district has good both deep and shallow aquifers due to extensive occurrence of fan deposits of the Mahakali River. In the southern part of the district there is another zone of good development potentials (high aquifer percentages and high permeabilities). Excluding the southeastern part of the district in which both shallow and deep aquifer development potentials are at best marginal, the rest of the district is considered good for shallow aquifer and marginal for deep aquifer development.

In the district there are at least 301 STWs drilled by the GWRDB, plus some deep tube wells. The original proposal of 20 STWs by the GWRDB is reduced to 16 wells, out of which 8 shall be constructed by "tokuwa" or driven method, and 8 by "boggi" or sinking/sludge method, or eventually, by rig.

The officer-in-charge in the Kanchanpur district shall be Mr. Gairhe.

5. CONCLUSIONS & RECOMMENDATIONS

The first-year program of shallow wells drilling, pumping tests, and monitoring water levels in the selected network of observation wells has had good and weak points. Among good points one may include the following: (1) the number of drilled wells is absolutely satisfactory, (2) the drilling metrage is acceptable and as planned, (3) the water levels are monitored in regular intervals, (4) four technical reports have been prepared and submitted to the UNDP, Government, and executing agency, (5) computer training is provided to the GWRDB staff. Weak points are the following: (1) the drilling could have been better, with less abandoned wells, (2) well development and screen characteristics could have been improved by using less bentonite, completing wells immediately after the drilling, and using more appropriate screens (slot opening of 1.5 mm instead 0.5 mm); (3) field supervision should have been much better, more frequent; (4) pumping tests should have been more in number, with better equipment (pumps, measuring instruments); (5) depths to water table in observation network could have been more reliable, information obtained on time and submitted to the project's office in Kathmandu in more regular intervals.

Overall, one should be satisfied with the activities of the GWRDB, processing of information by the project staff, both international and local, and by reporting outputs.

The program for the second year is very ambitious, optimistic, and, if implemented, shall provide a wealth of information. To improve the mode of operation, all project staff should spend much more time in the field in the period from December 1988 through June 1989. The computer processing and reporting time shall be from June through November 1989. By that time, according to the latest project revision, there will be two more computers in the project which will permit all information collected in the drilling season to be processed and reported. The total number of shallow exploration/testing/observation wells is 242 which is a 15% increase over the originally programmed 212. The amended program is shown in Appendix 24. The total drilling metrage, according to this revised drilling program, is shown in Appendix 25. The total metrage amounts to about 9,680 m. Individual well's depth is in general on average 40 m.

The pumping tests program is shown in Appendix 26. A total of 309 pumping tests should be run. This is a difficult task to accomplish, considering that in the first year only 58 tests have been made, which was much below the programmed target of 112 tests.

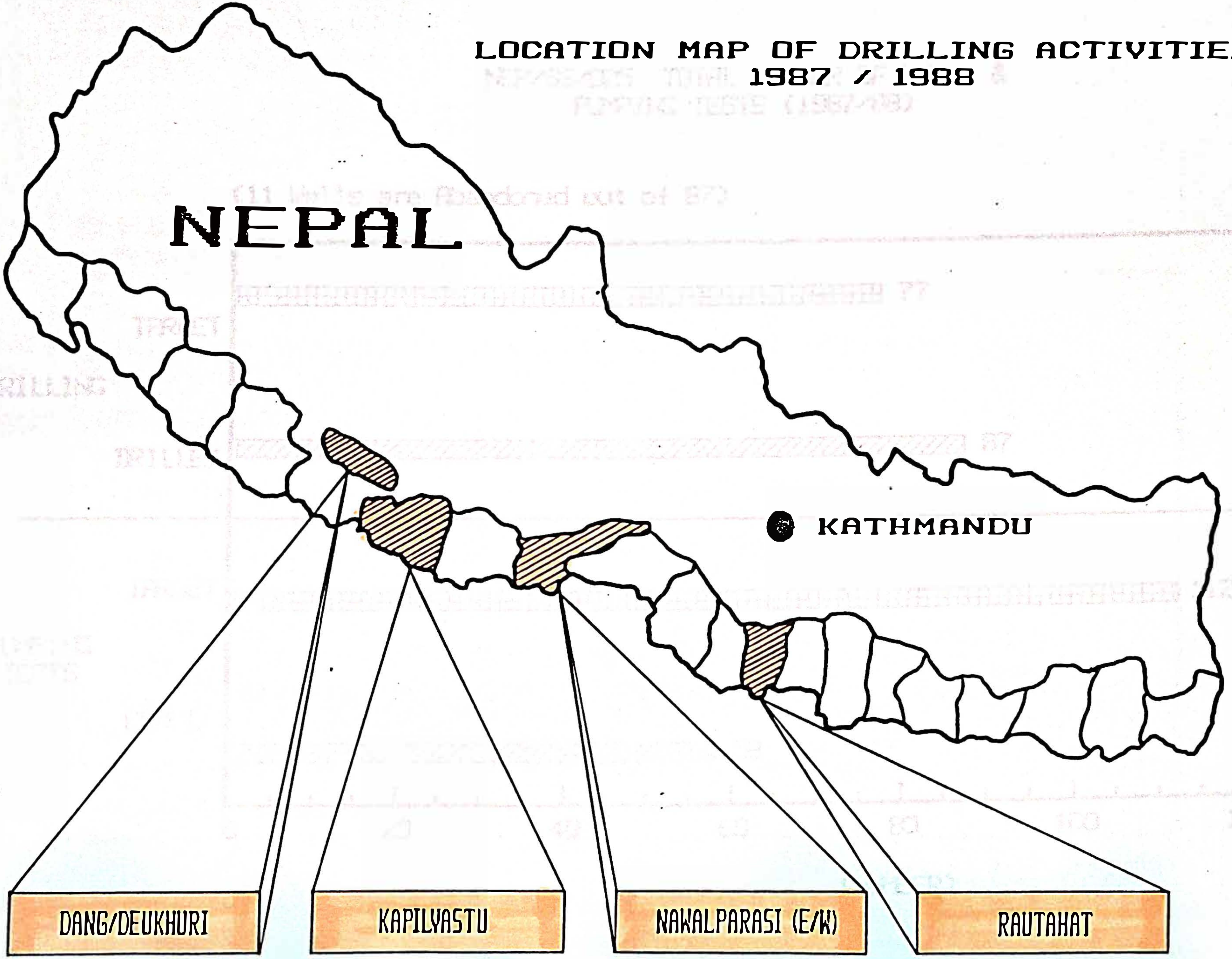
The staff assigned to the project in the Kathmandu office is not a sufficient guarantee that (1) field activities shall be properly and authoritatively followed, supervised and modified if and when needed, (2) all available information on shallow wells in the Terai shall be compiled and utilized in the preparation of "Basic documentation" reports. The GWRDB will have to assign to the project a better motivated staff, or increase the involvement of their leading field staff in the UNDP project.

The Tripartite Project Review decided to add one objective to the project - that of establishing a deep well data base. The motion is acceptable since, in reality, there is not so much difference between deep and shallow aquifers. The distinction is mostly based on economical reasons. However, the addition of deep aquifers to the originally planned shallow ground water project, adds a new dimension, and expands the project to cover all ground water resources in the Terai. As a consequence, all major project components are expanded, such as activities, international staff (one additional consultant, specialist for ground water data base; 4 more months for chief consultant), equipment (two additional computers, some software, spare parts), fellowships and study tours, etc. The life span of the project is also lengthened for one year. This is not so much to account for expanded activities, but to realistically program the time needed for ambitious reporting, and, especially, mathematical modelling.

Kathmandu, 11 December 1988

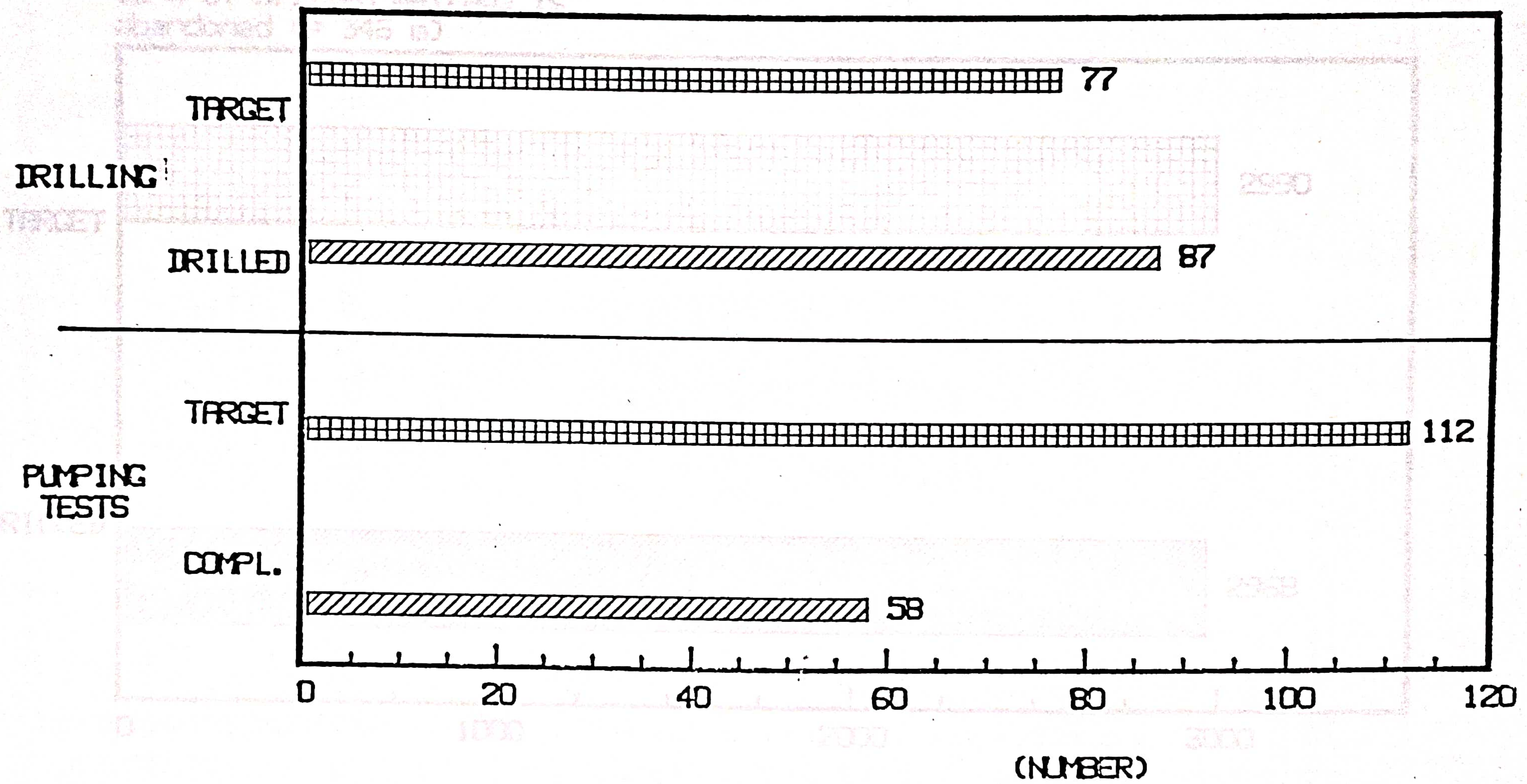
APPENDIX 1

LOCATION MAP OF DRILLING ACTIVITIES 1987 / 1988



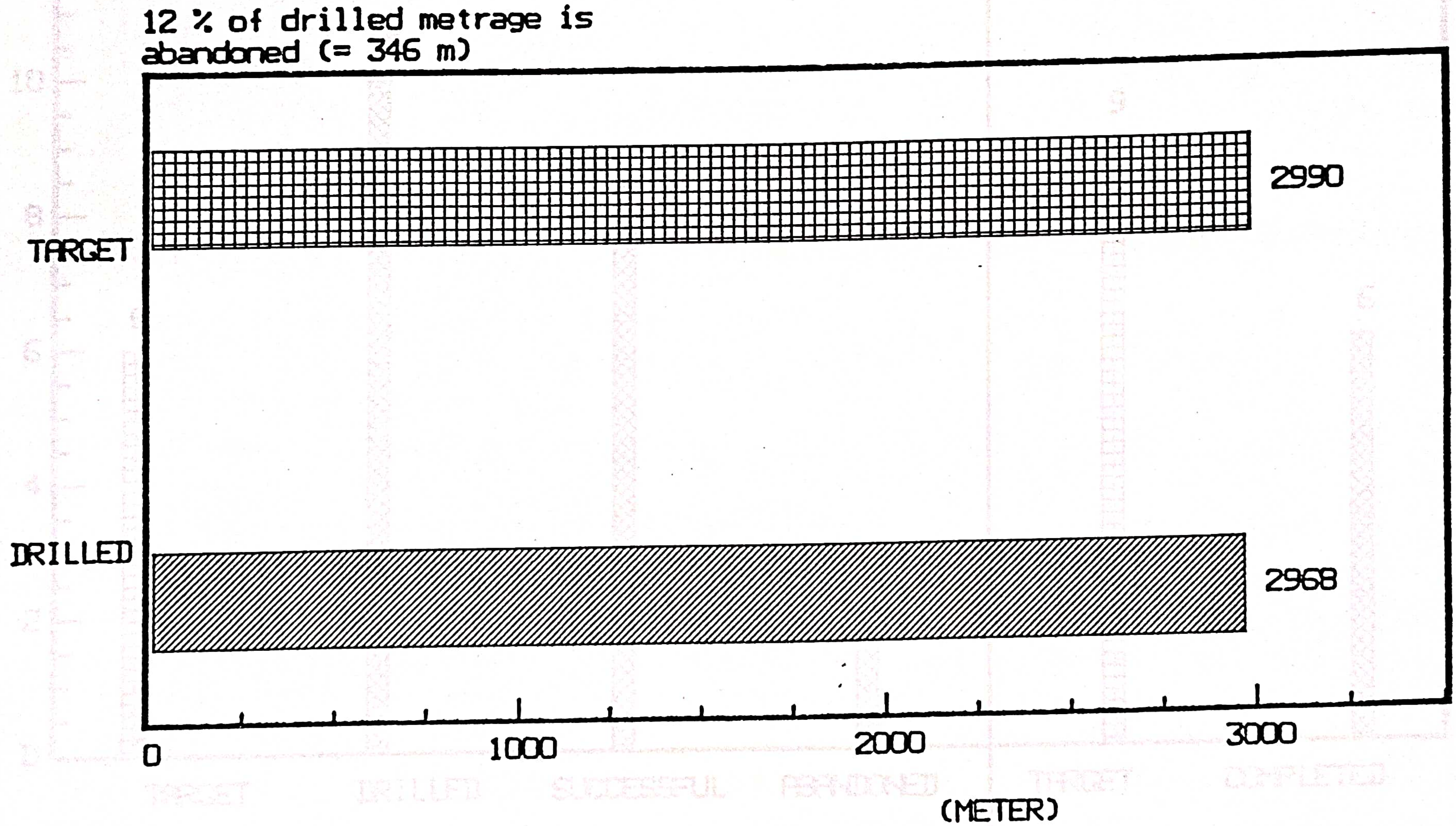
NEP/86/025 TOTAL NUMBER OF WELLS & PUMPING TESTS (1987/88)

(11 Wells are Abandoned out of 87)



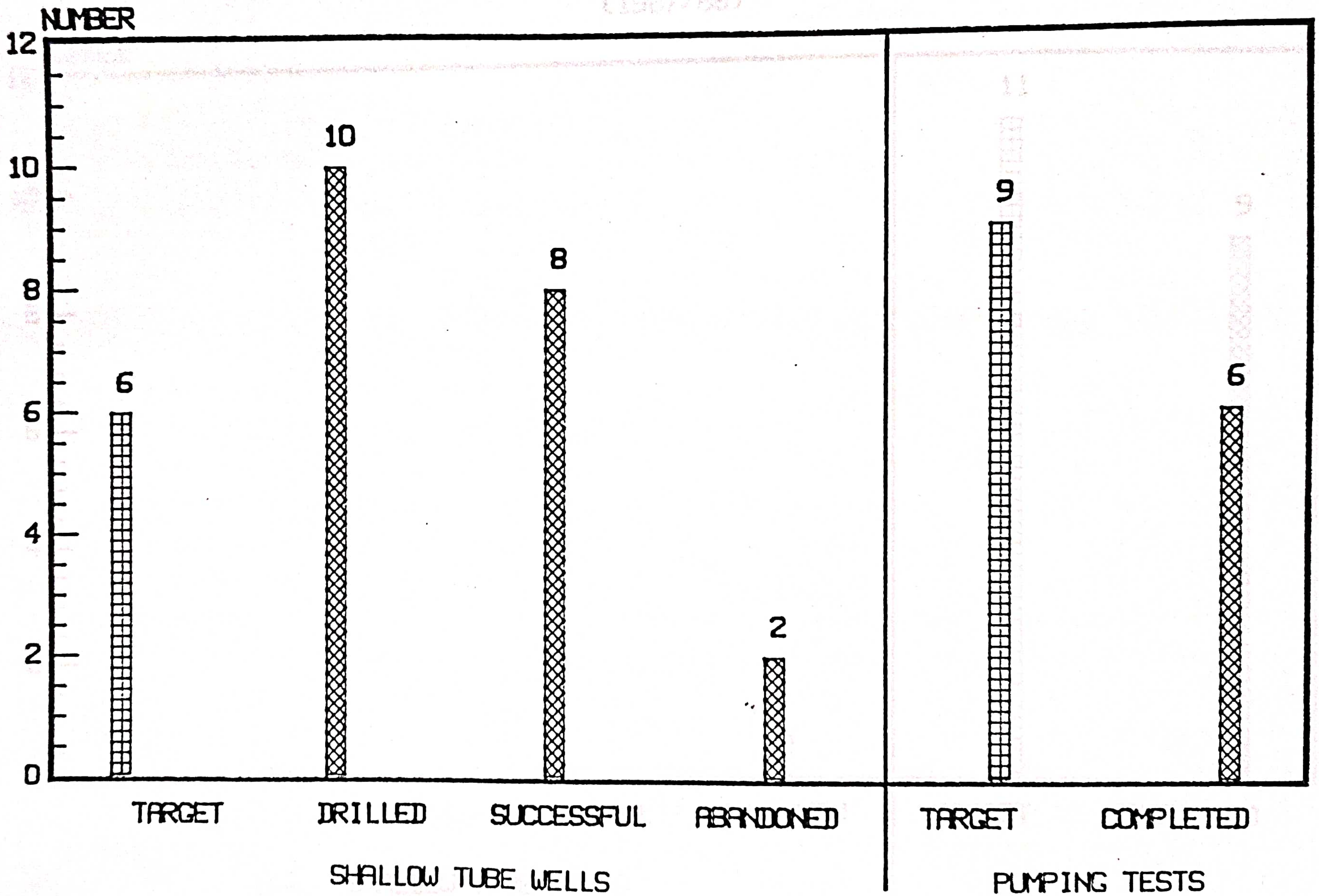
APPENDIX 2

NEP/86/025 TOTAL DRILLING METRAGE IN 1987/88



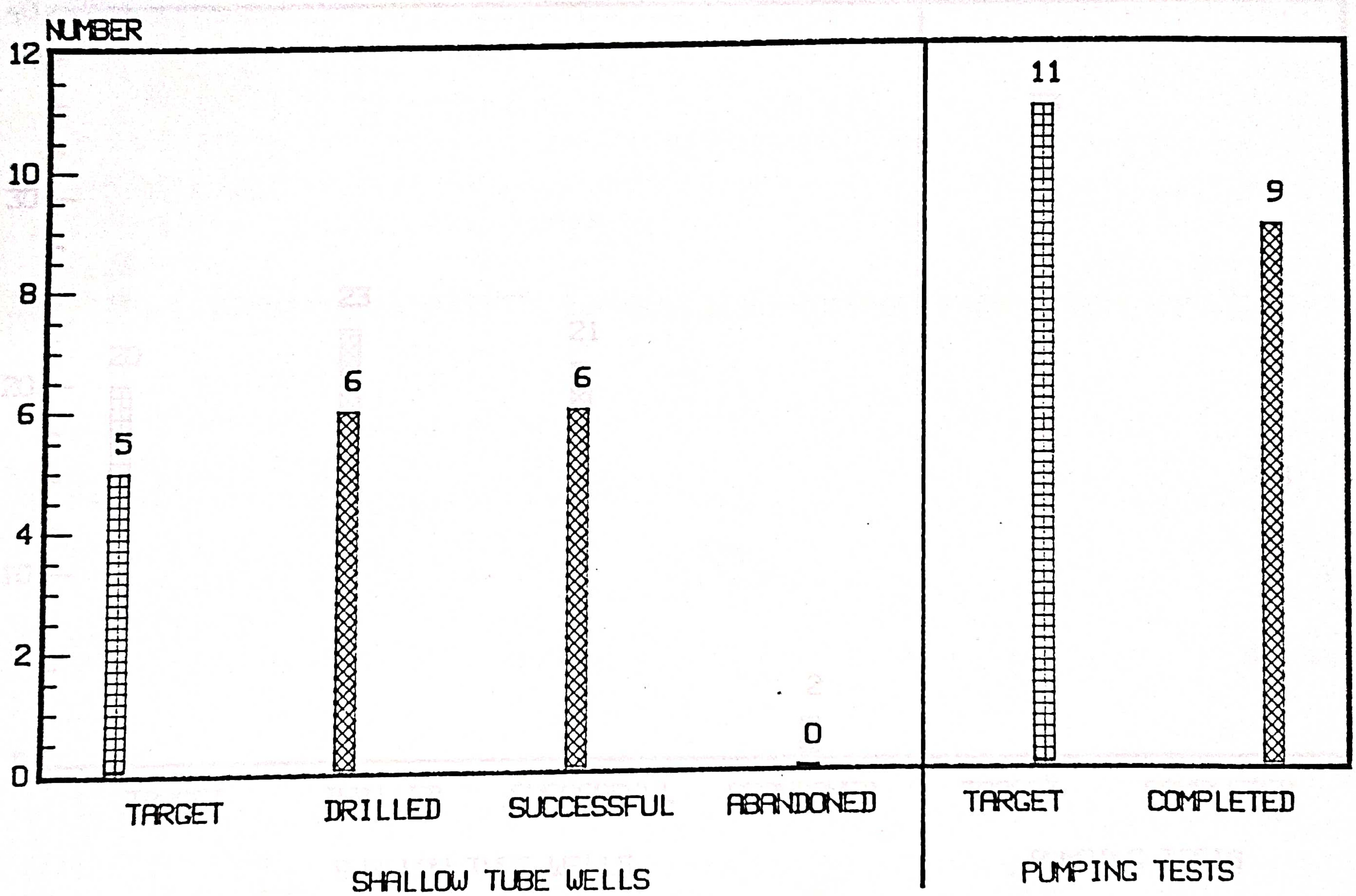
APPENDIX 3

NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN DANG VALLEY (1987/88)

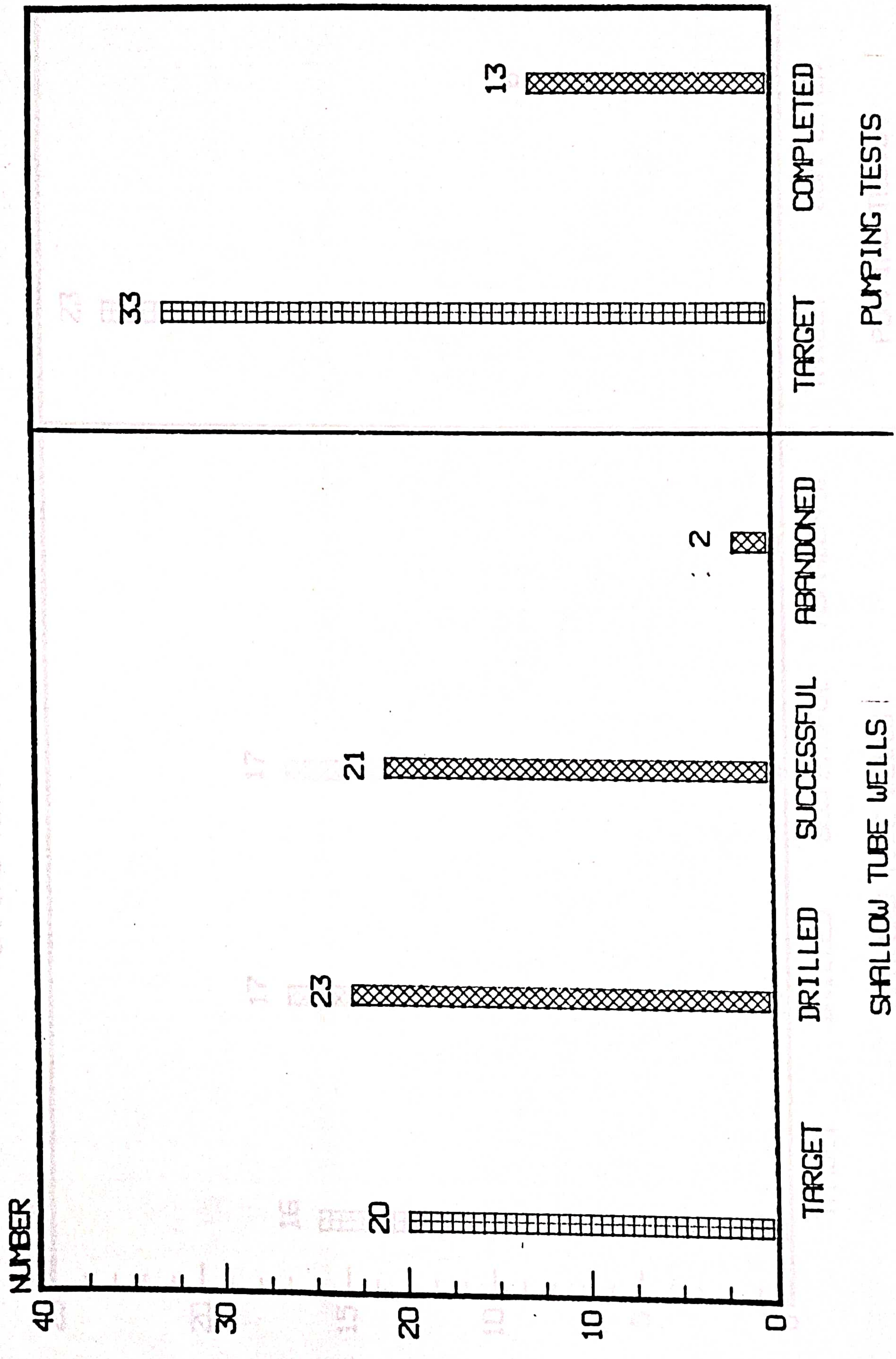


APPENDIX 4

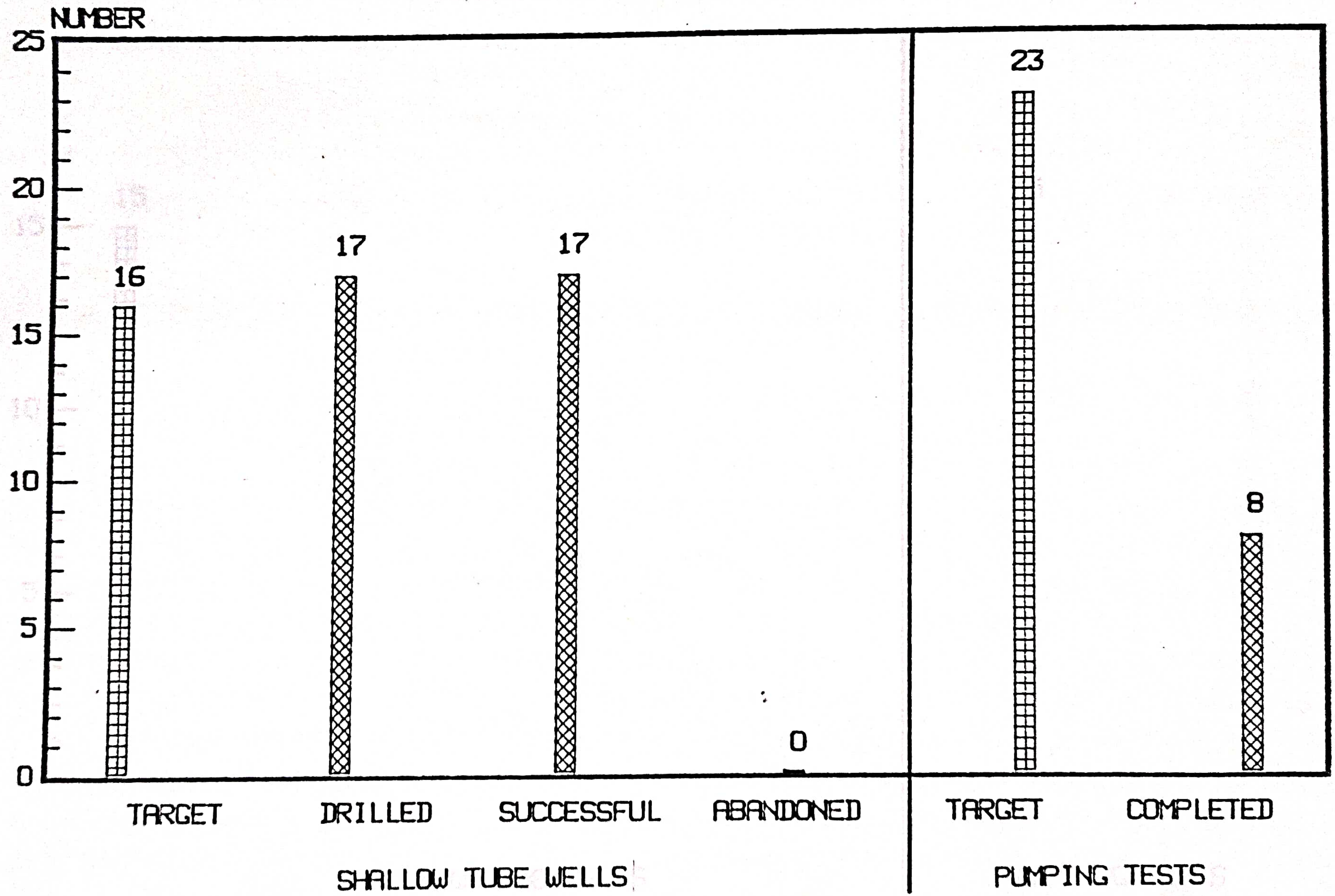
NEP/86/025 NUMBER OF WELLS & PUMPING TESTS IN DEUKHURI VALLEY (1987/88)



NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN KAPILVASTU (1987/88)

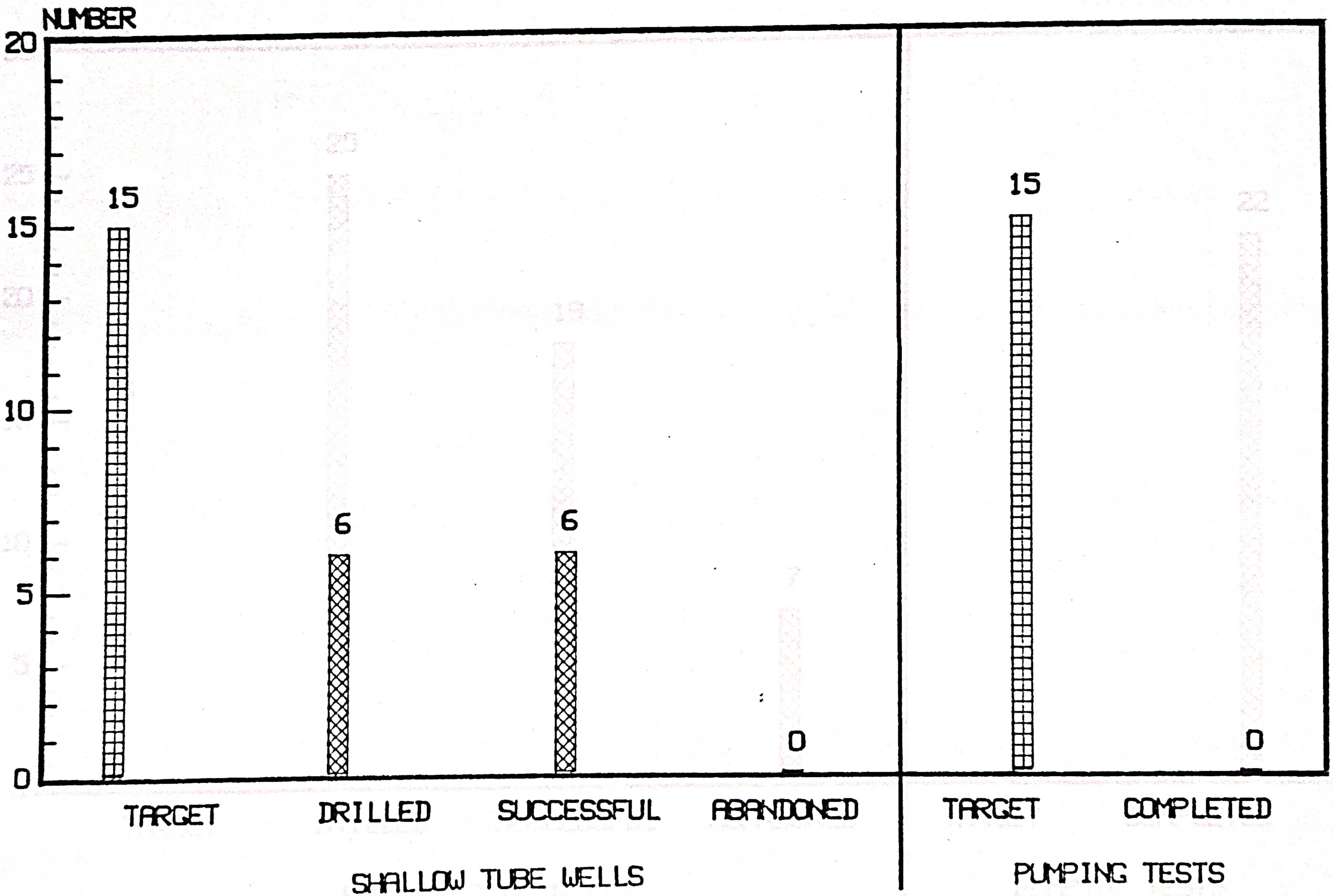


NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN NAWALPARASI-W (1987/88)



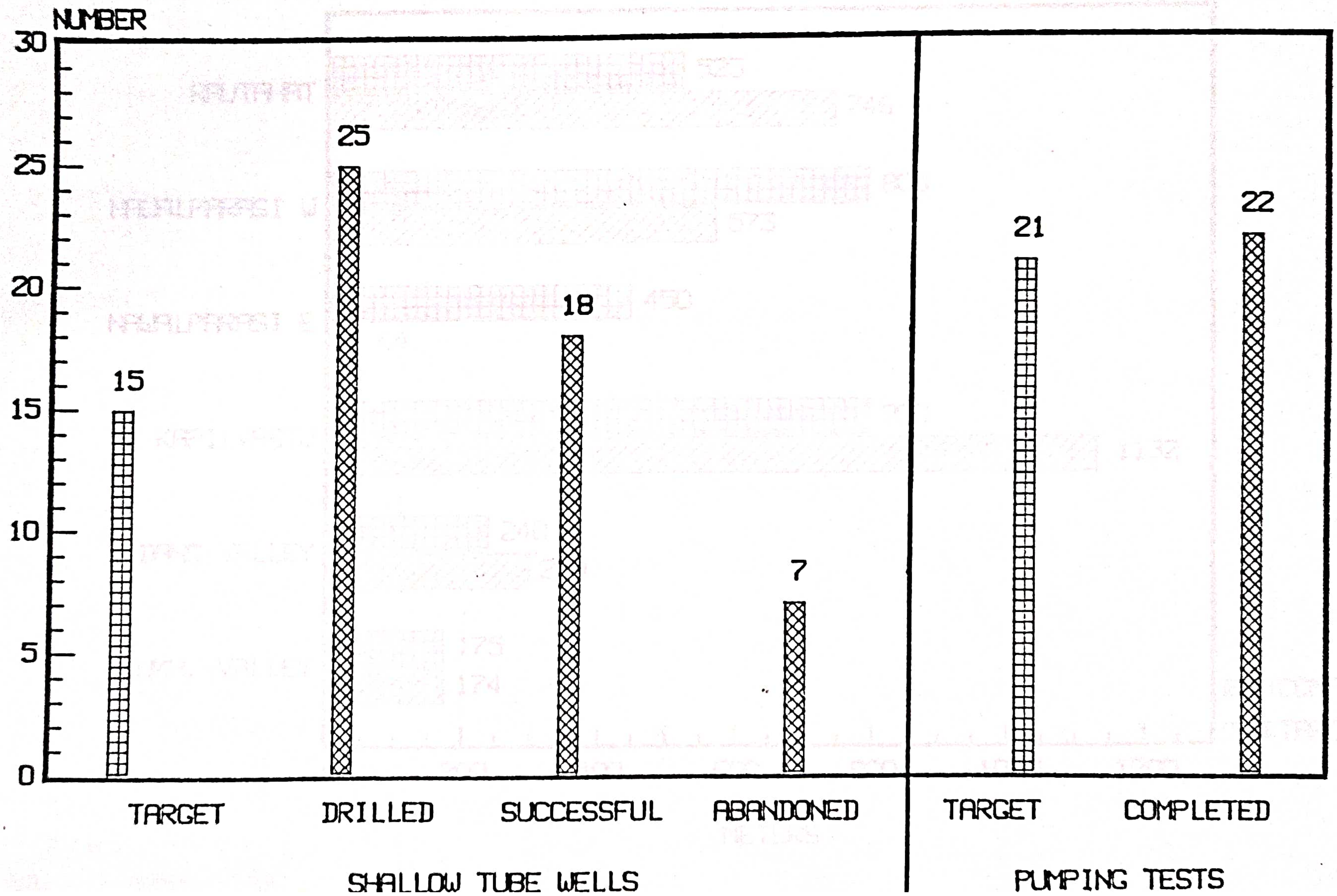
APPENDIX 7

NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN NAWALPARASI-E (1987/88)



APPENDIX 8

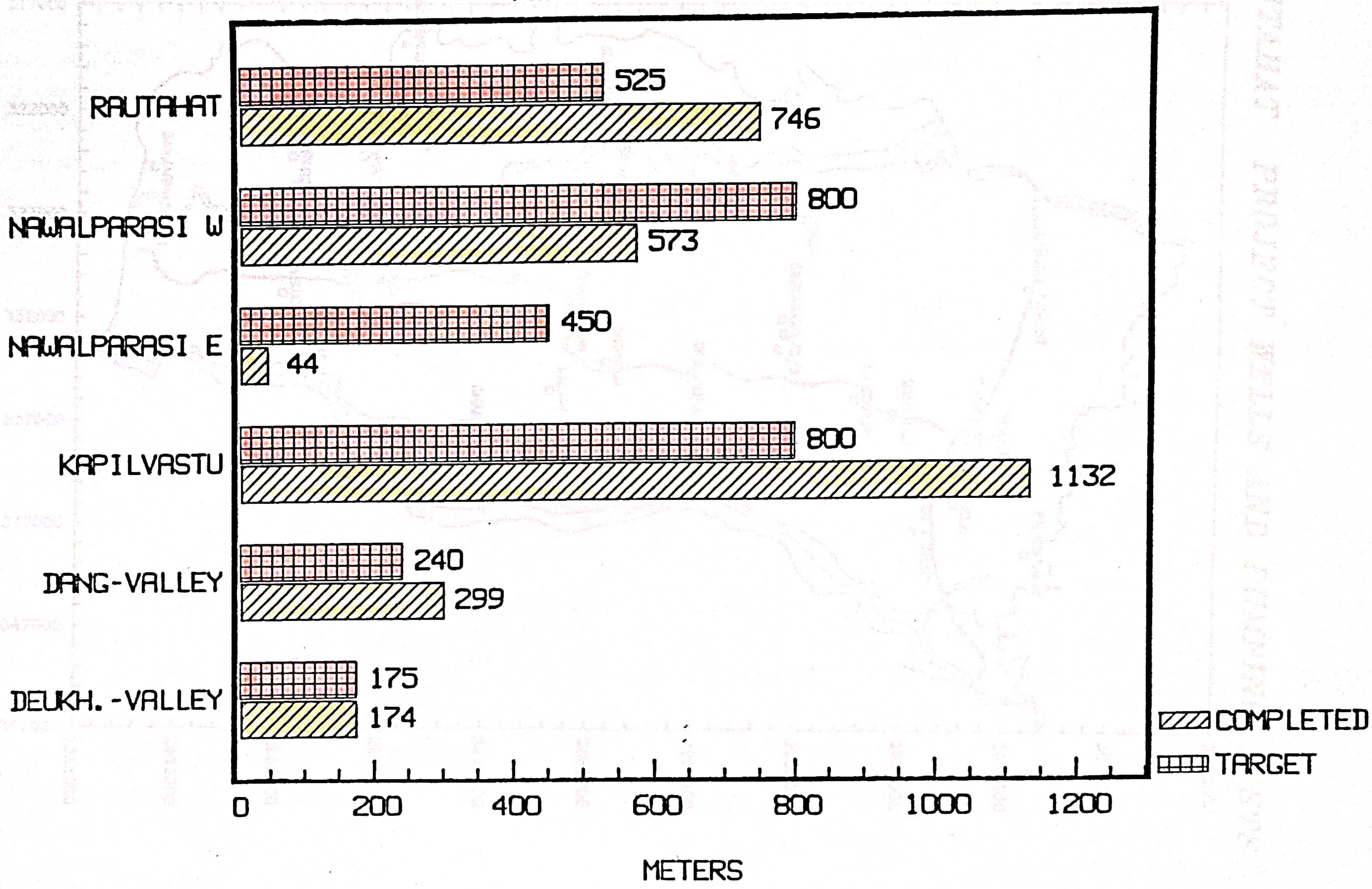
NEP/86/025 NUMBER OF WELLS &
PUMPING TESTS IN RAUTAHAT (1987/88)



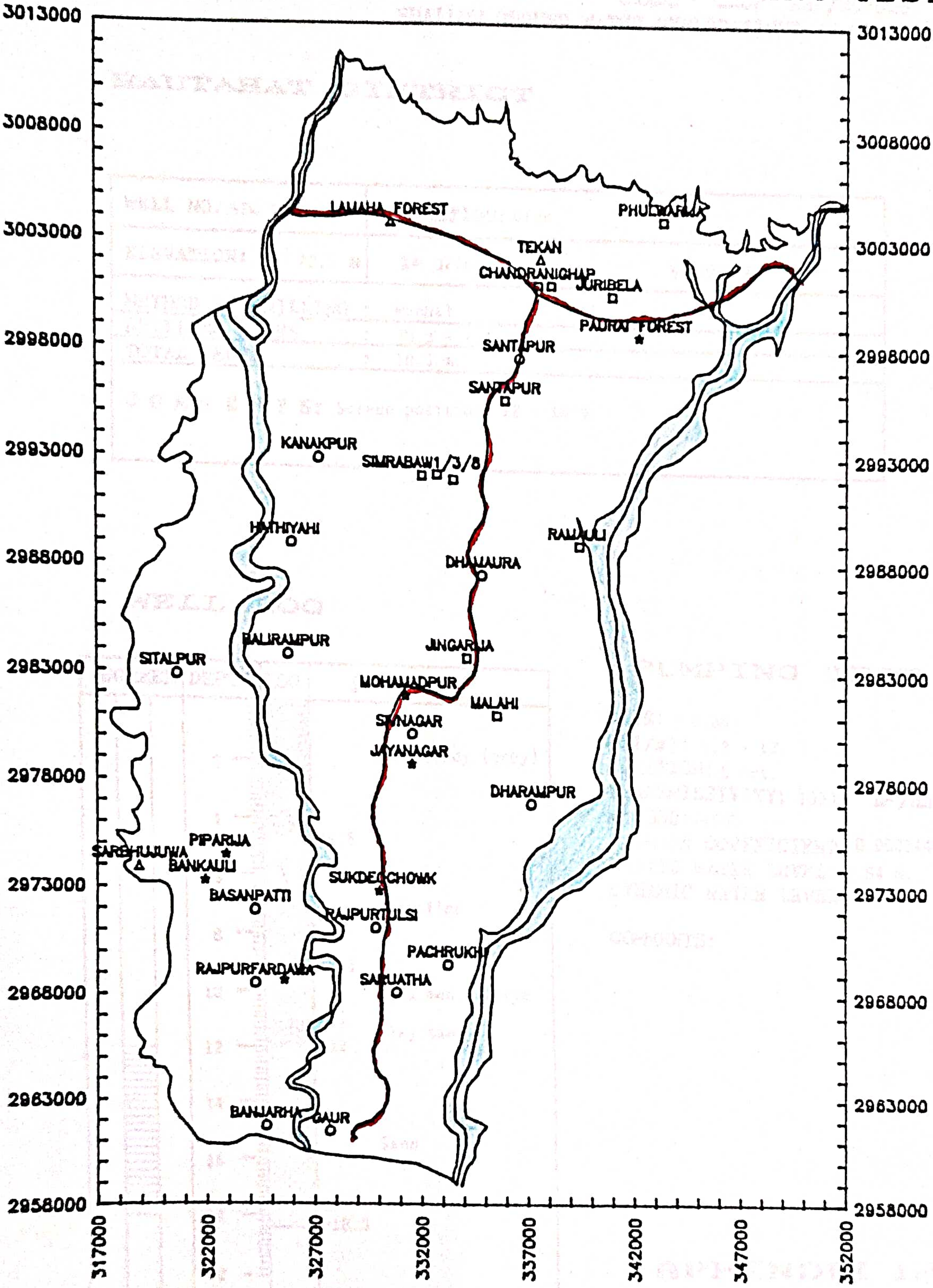
APPENDIX 9

APPENDIX 10

NEP/86/025 DRILLING METRAGE
PER DISTRICT (1987/88)



RAUTAHAT PROJECT WELLS AND PUMPING TESTS



SYMBOLS:

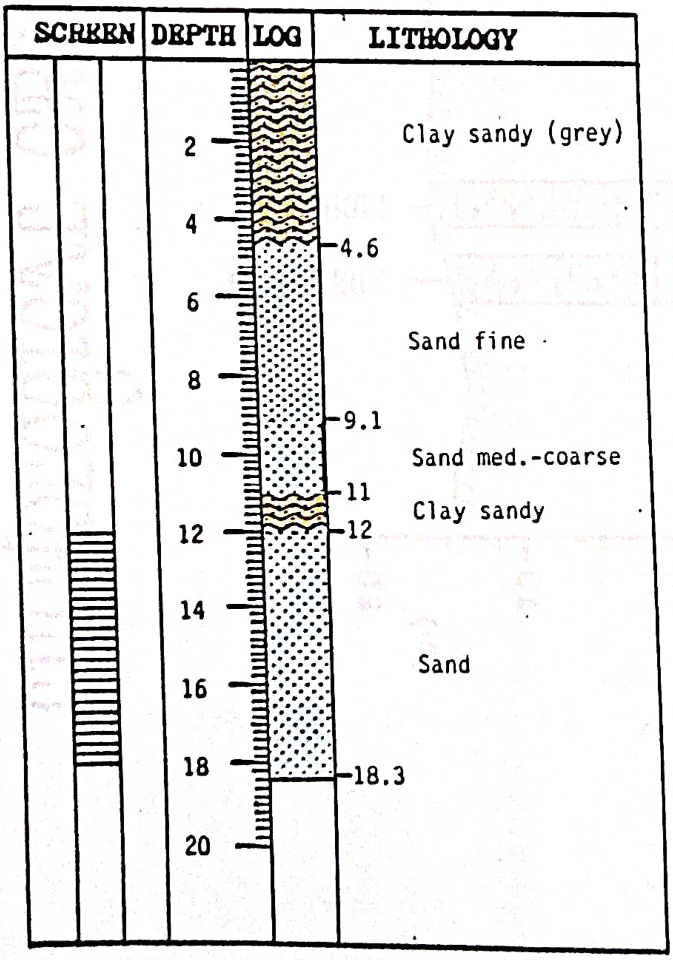
CIRCLE: STW PROJECT-DRILLED, COMPLETED, PUMPING TEST
STAR: STW PROJECT-DRILLED, ABANDONED
TRIANGLE: STW PROJECT-DRILLED, NO PUMPING TEST
SQUARE: OTHER STW (ADBN, MAH.GR.PROJ.)WITH PUMPING TEST

APPENDIX 11

RAUTAHAT DISTRICT

WELL NO. STW 10	LOCATION: Gaur	
ELEVATION: 72.5 m	X= 327687	Y= 296148
METHOD OF DRILLING : Manual		
DRILLING DATES : 30.3 - 1.4.88		
TOTAL DEPTH : 18.3 m.		
COMMENTS: Screen position: 12 - 18 m.		

WELL LOG



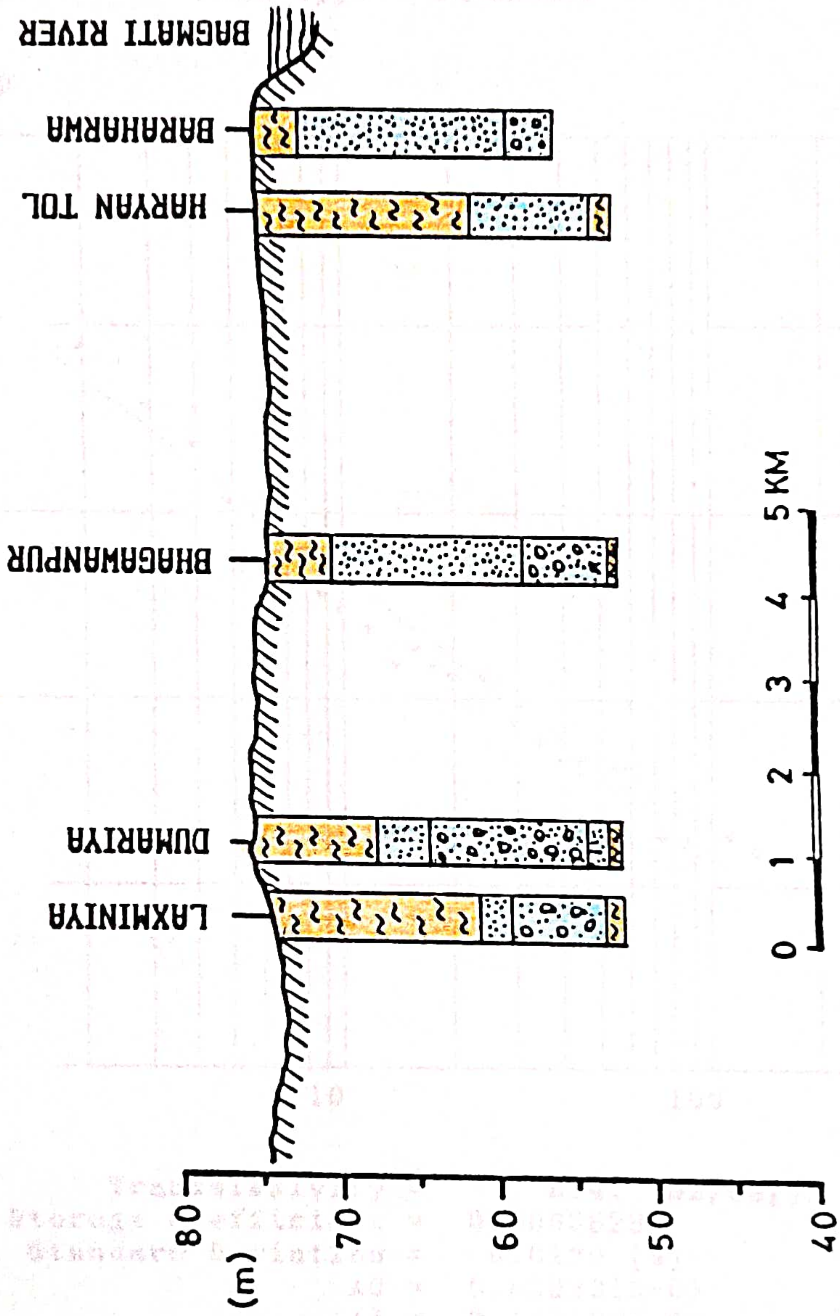
PUMPING TEST

DATE: 2.6.88
Q(l/s): 9.2 - 12
DURATION: 5 hrs.
TRANSMISSIVITY: 1000 m^2/day
METHOD: Jacob
STORAGE COEFFICIENT: 0.0003440
STATIC WATER LEVEL: 2.84 m.
DYNAMIC WATER LEVEL: 8.85 m.

COMMENTS:

APPENDIX 12

LITHOLOGICAL CROSS SECTION V – V'

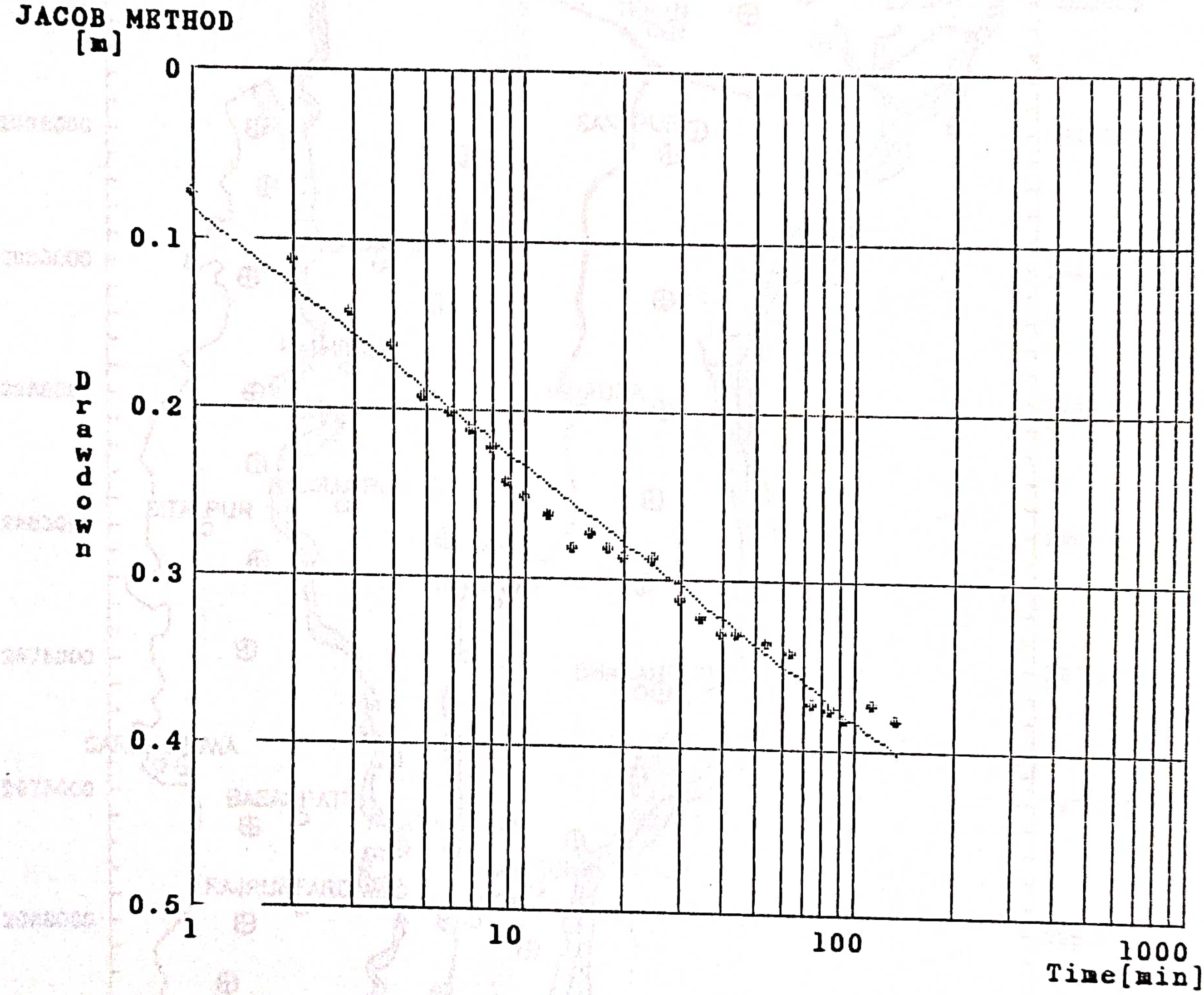


APPENDIX 13

Project : NEP/86/025 (RAUTAHAT DISTR.)
Organization : UNDP/GWRDB

Test : STW 13 RATPURFARDAWA (OBS.WELL)

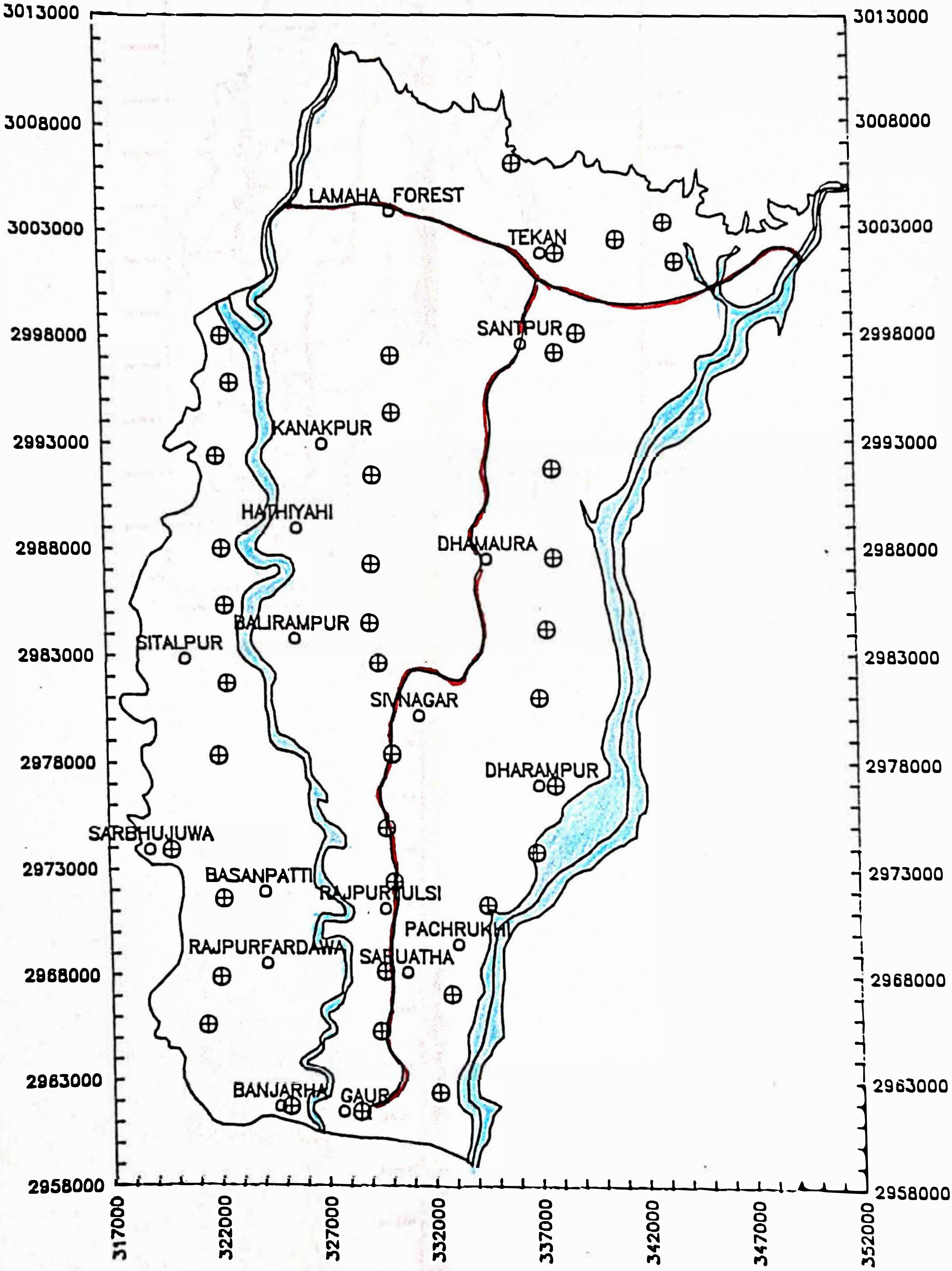
Constant Pumping Rate = 6.000 [l/s]
Distance from Observation Well = 27.60 [m]
Type of Aquifer = CONFINED
Type of Input Data = LEVEL
Static Water Level = -3.81 [m]
Well Type = STANDARD



Transmissivity = 634. [m2/day]
Storage Coefficient = 0.00036288
Standard Deviation = 0.0120 [m]
A0 = 0.830331E-01
A1 = 0.149589E+00
Number of Points = 27 of 27

APPENDIX 14

RAUTAHAT LOCATION MAP FOR MONITORING NETWORK



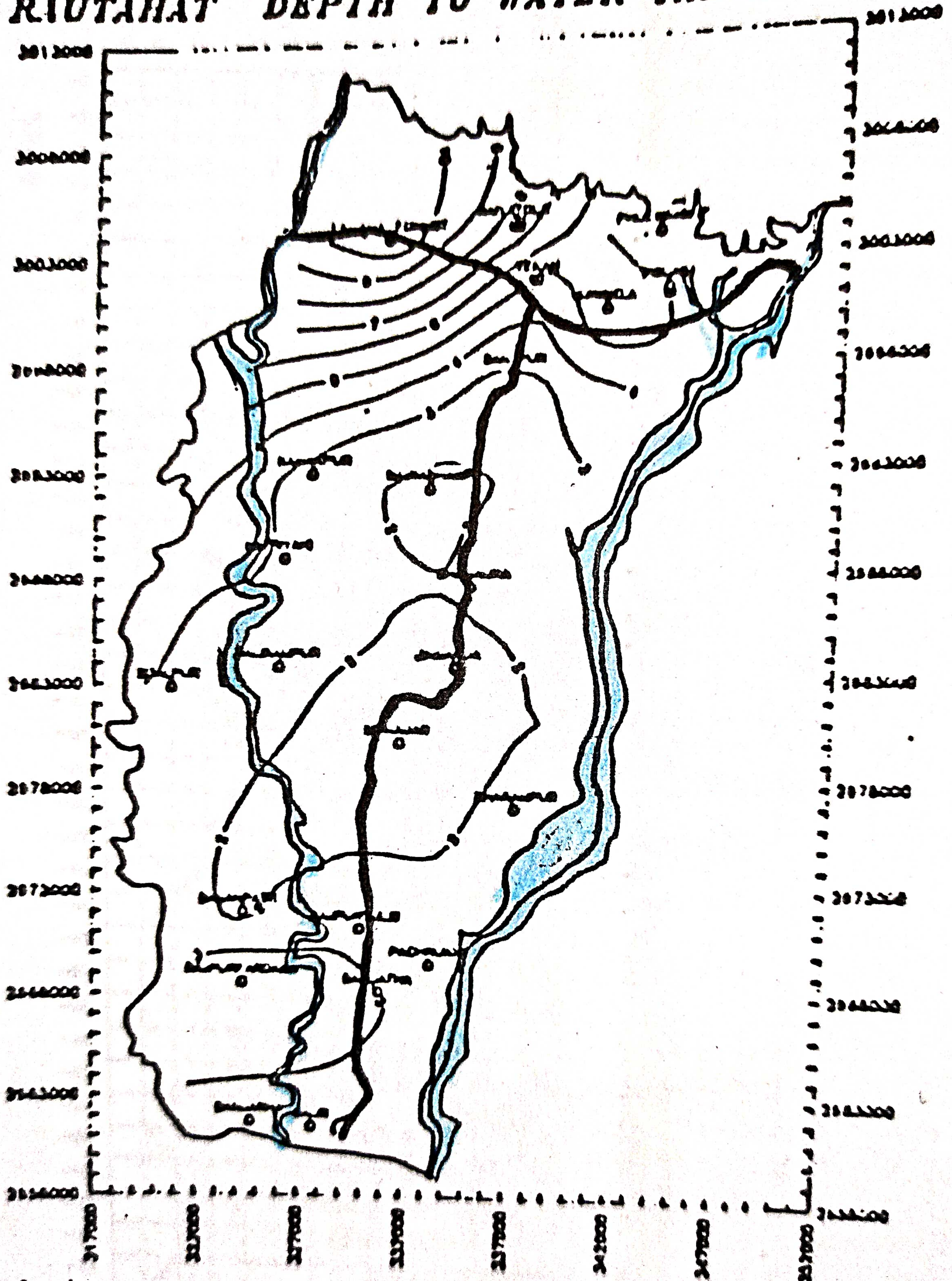
Symbols:

Circle with Cross: First Monitoring Network, Dugwell (May '87)

Circle: Actual Monitoring Network (Project drilled STW)

APPENDIX 15

RAUTAHAT DEPTH TO WATER TABLE MAY 1988

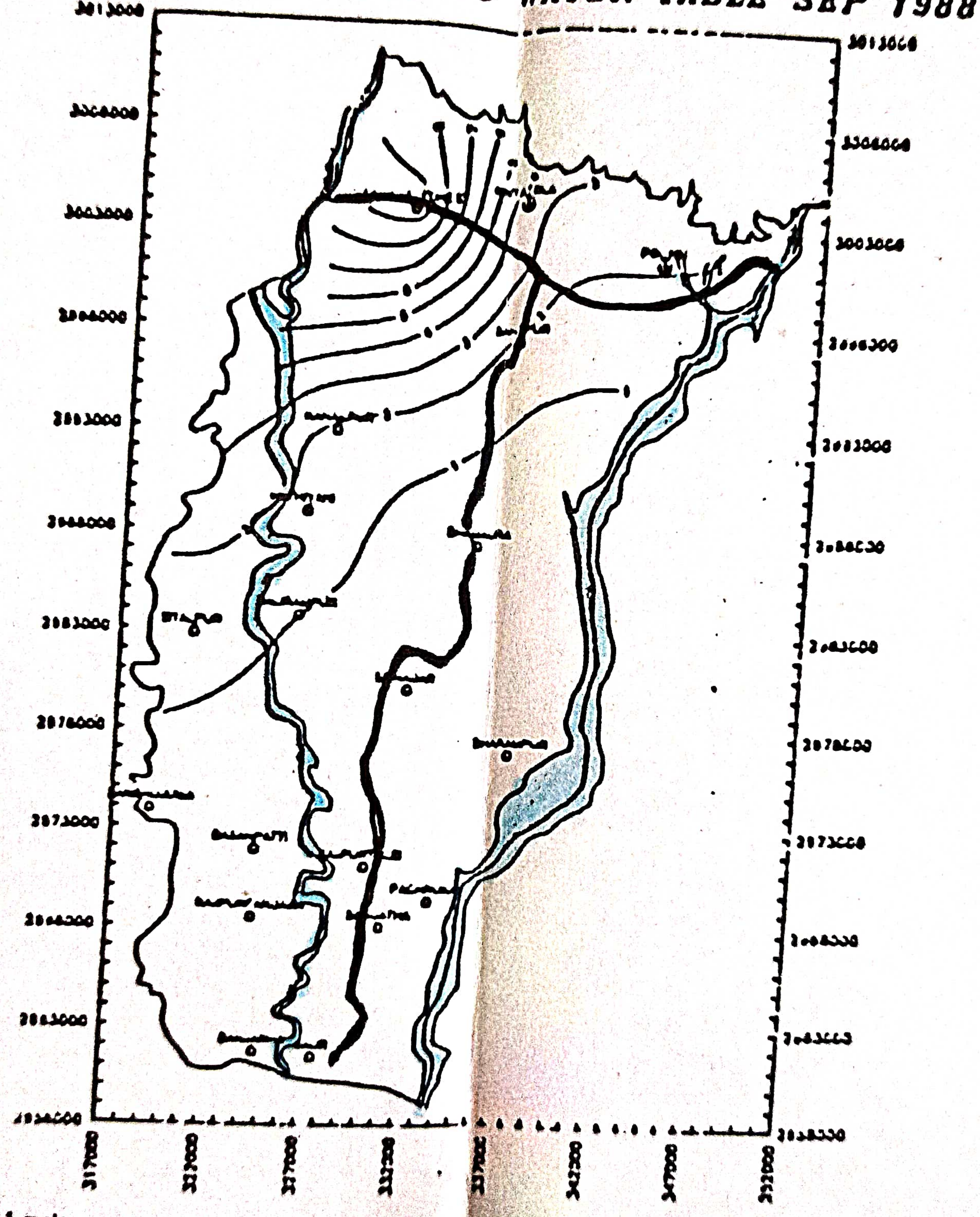


Symbols:

Circle with Cross: Dugwells

Circle: Shallow Tube wells

RAUTAHAT DEPTH TO WATER TABLE SEP 1988

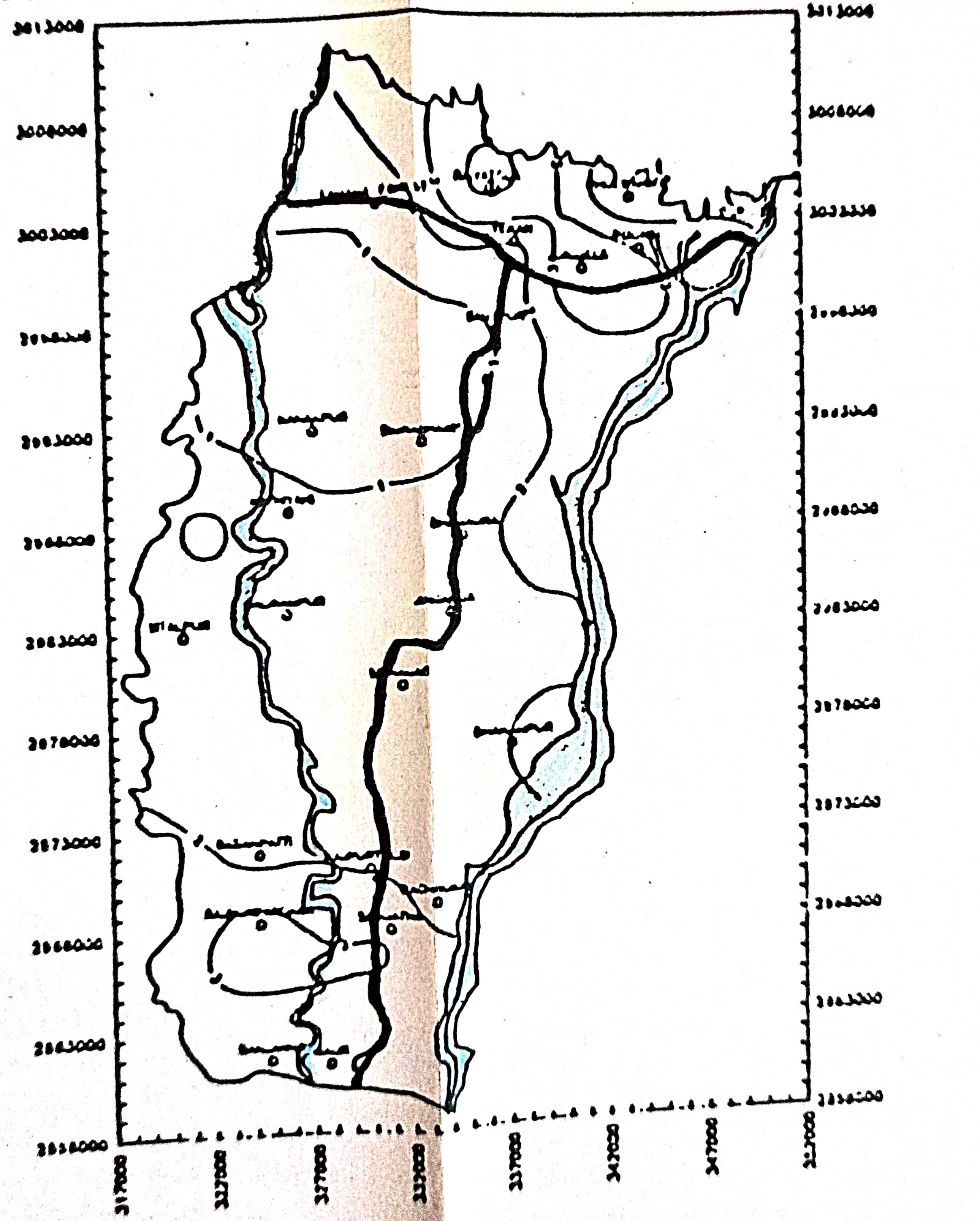


Symbols:

Circle with Cross: Dugwells

Circle: Shallow Tube wells

RAUTAHAT RISE OF WATER TABLE MAY – SEP 1988

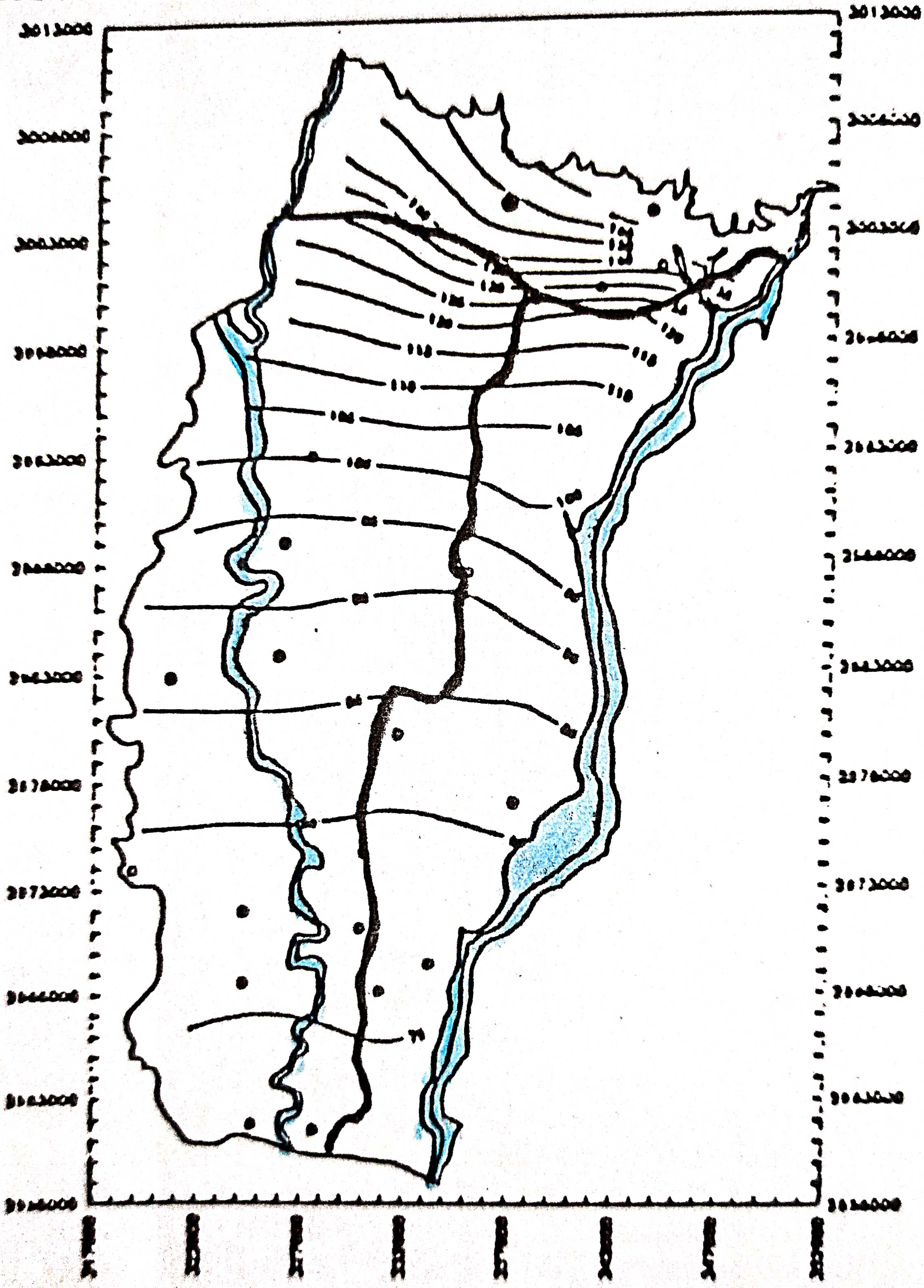


Symbols:

Circle with Cross: Dugwells

Circle: Shallow Tube wells

RAUTAHAT WATER LEVEL CONTOUR MAP SEP 1988

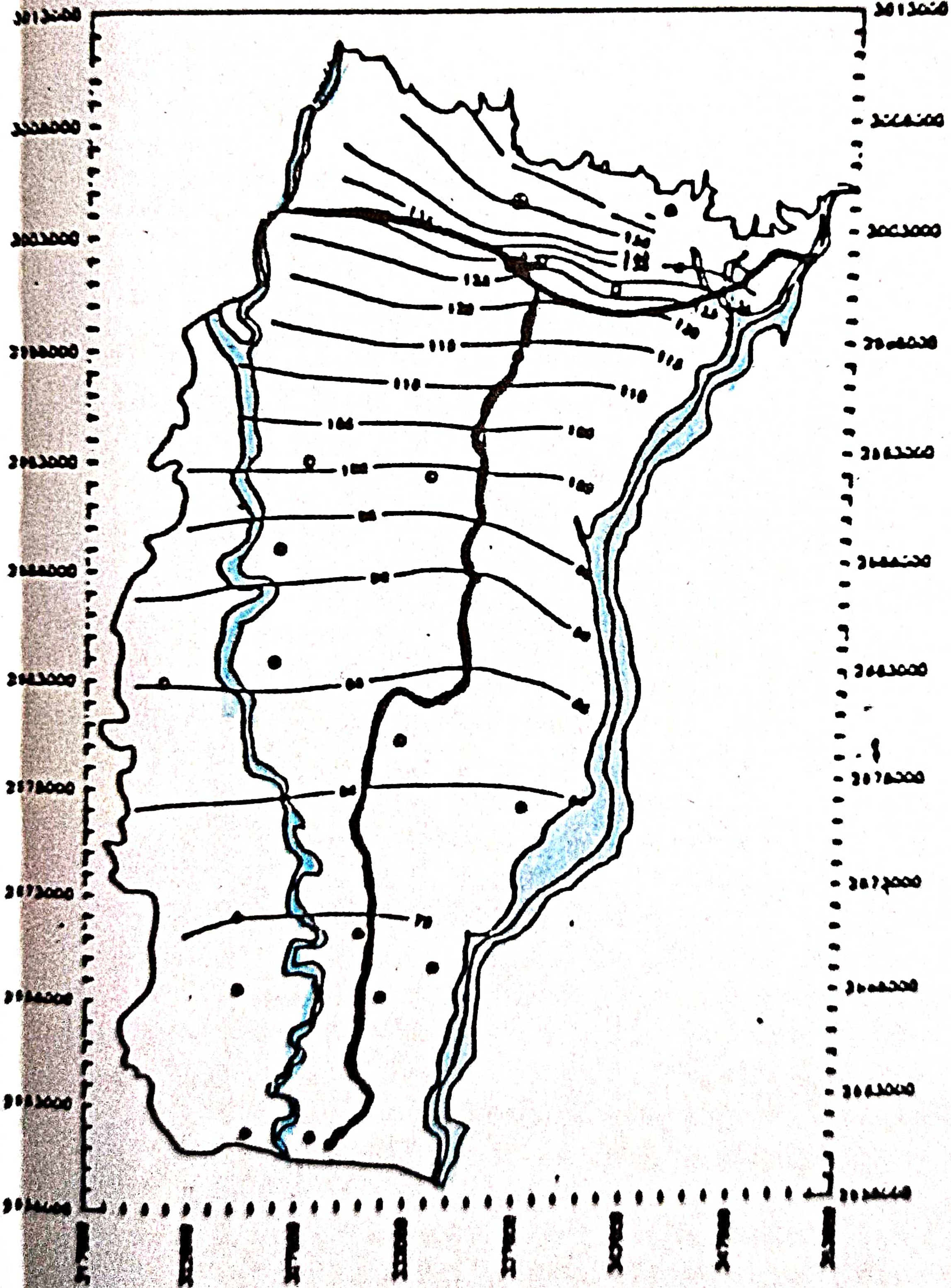


Symbols

Circle with Cross: Dugwells

Circles: Shallow tube wells

RAUTAHAT. WATER LEVEL CONTOUR MAP MAY 1988

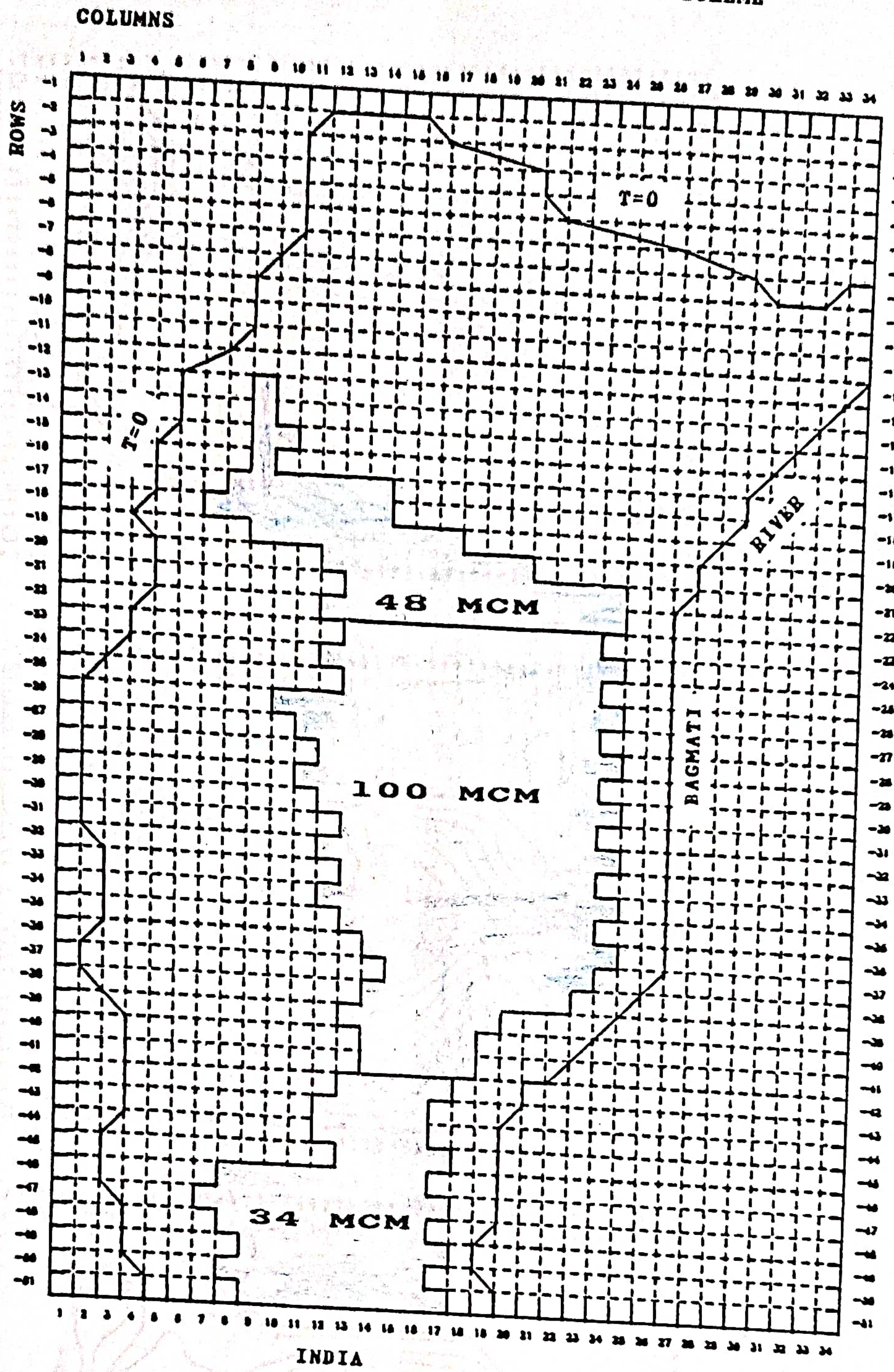


Symbols:

Circle with Cross, Dugwells

Circles: Shallow Tube wells

RAUTAHAT MODEL - FUTURE DEVELOPMENT SCHEME

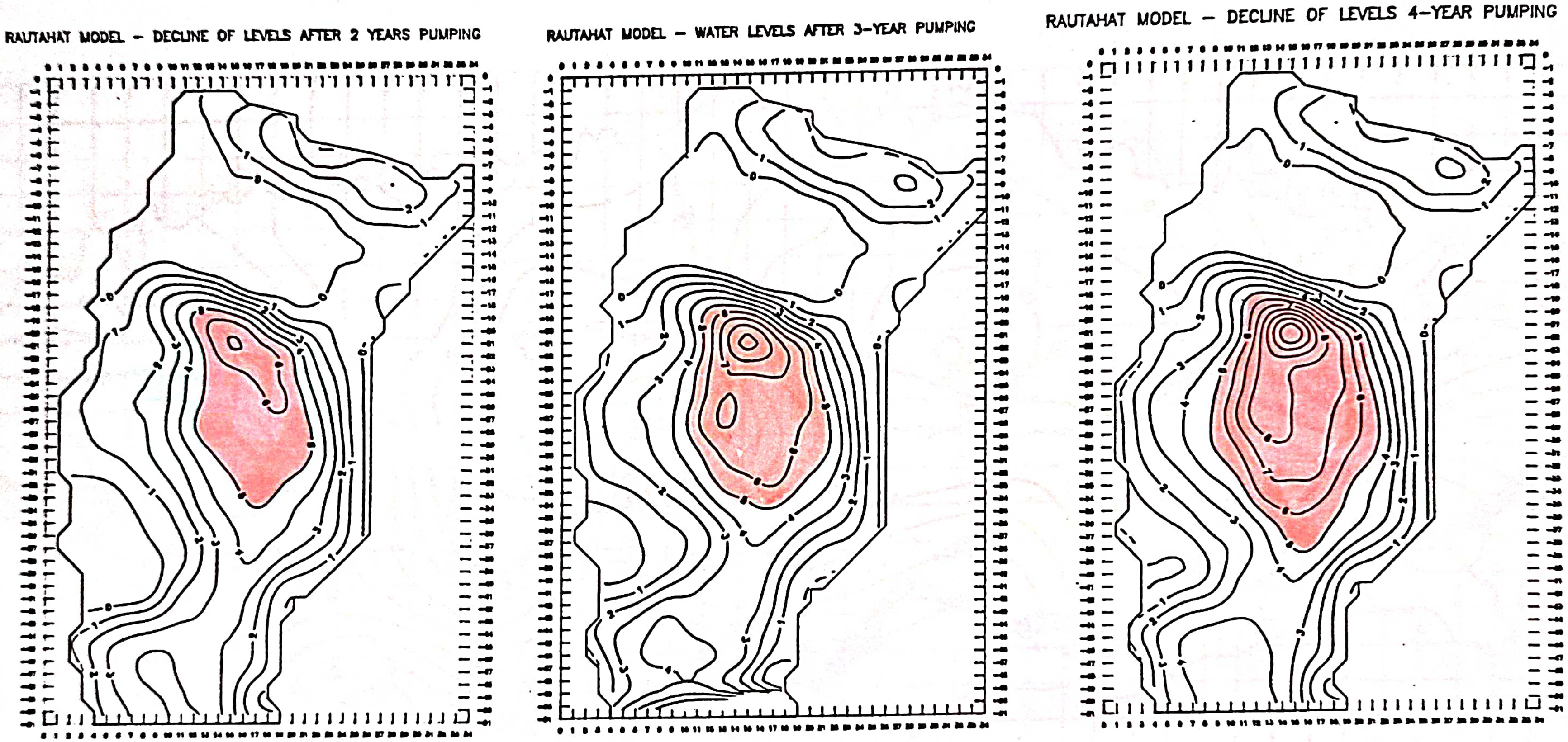


APPENDIX 17

SHALLOW GROUND WATER DEVELOPMENT

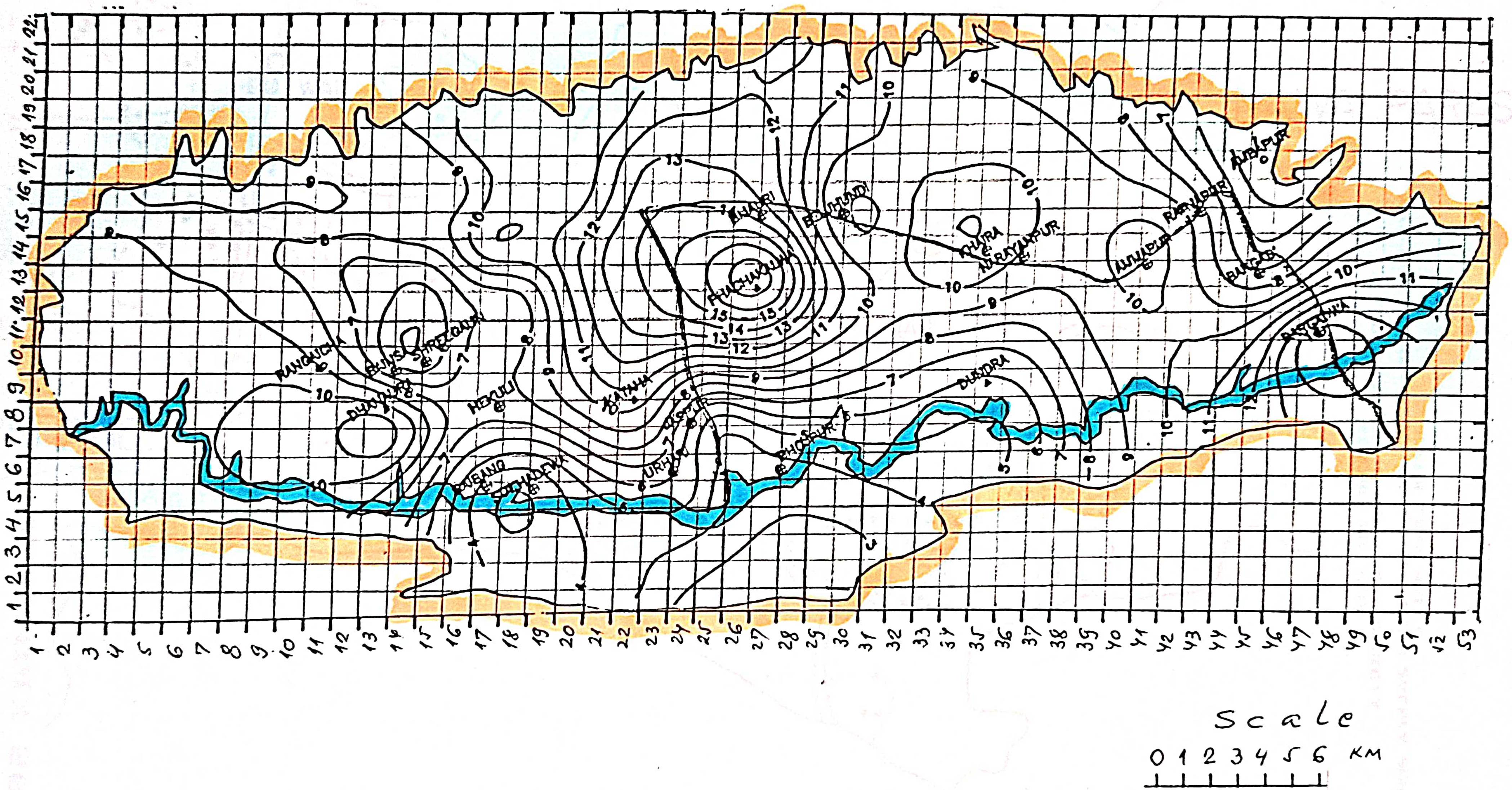
FORECAST OF DECLINE OF LEVELS

2 Years **3 Years** **4 Years**



APPENDIX 18

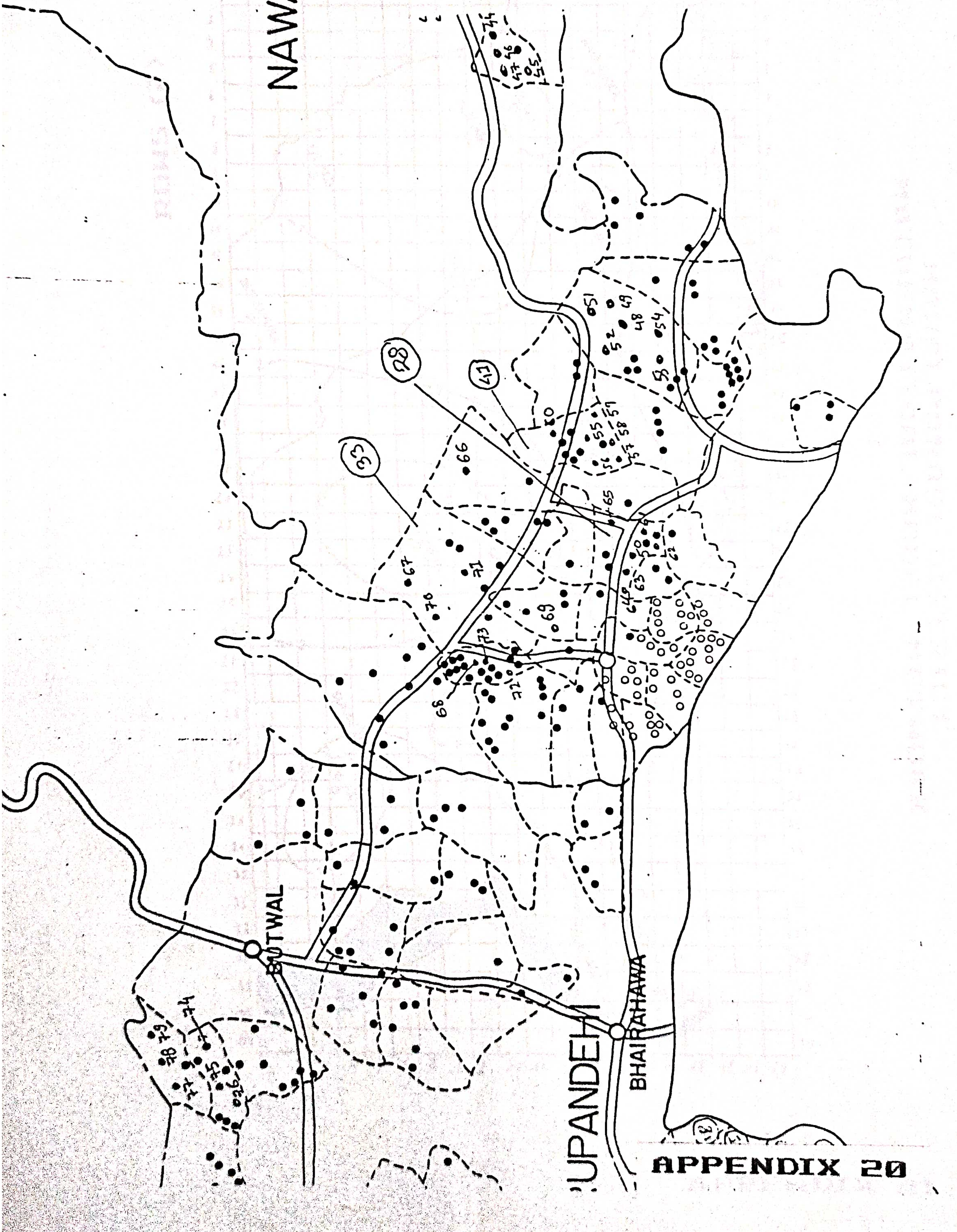
DANG DISTRICT
MATHEMATICAL MODEL NETWORK



APPENDIX 19

SHALLOW TUBE WELLS
DRILLED WITHIN NEPAL DRINKING WATER SUPPLY SCHEME

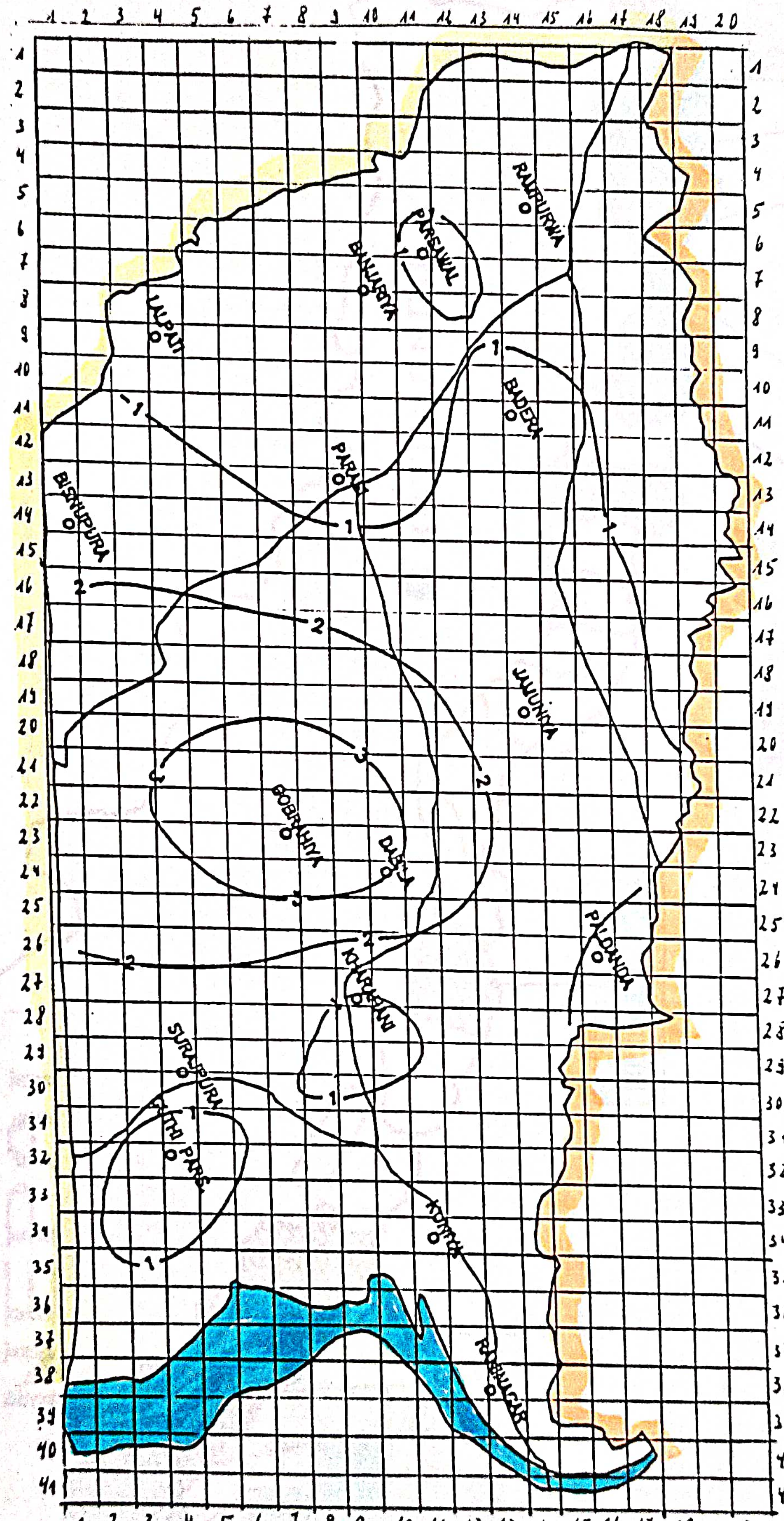
by JAPANESE RED CROSS SOCIETY
NISSAKU CO., LTD.



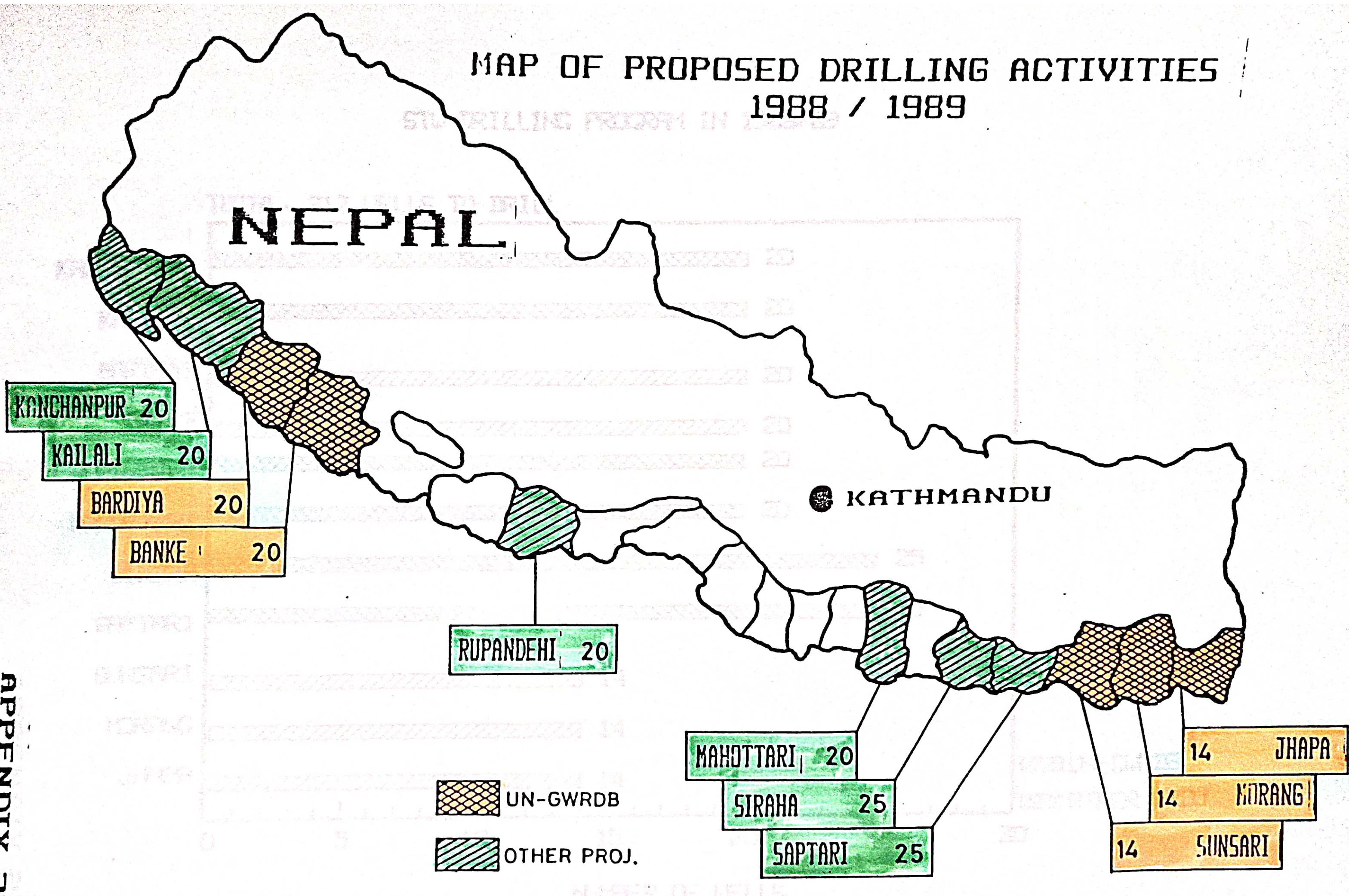
APPENDIX 20

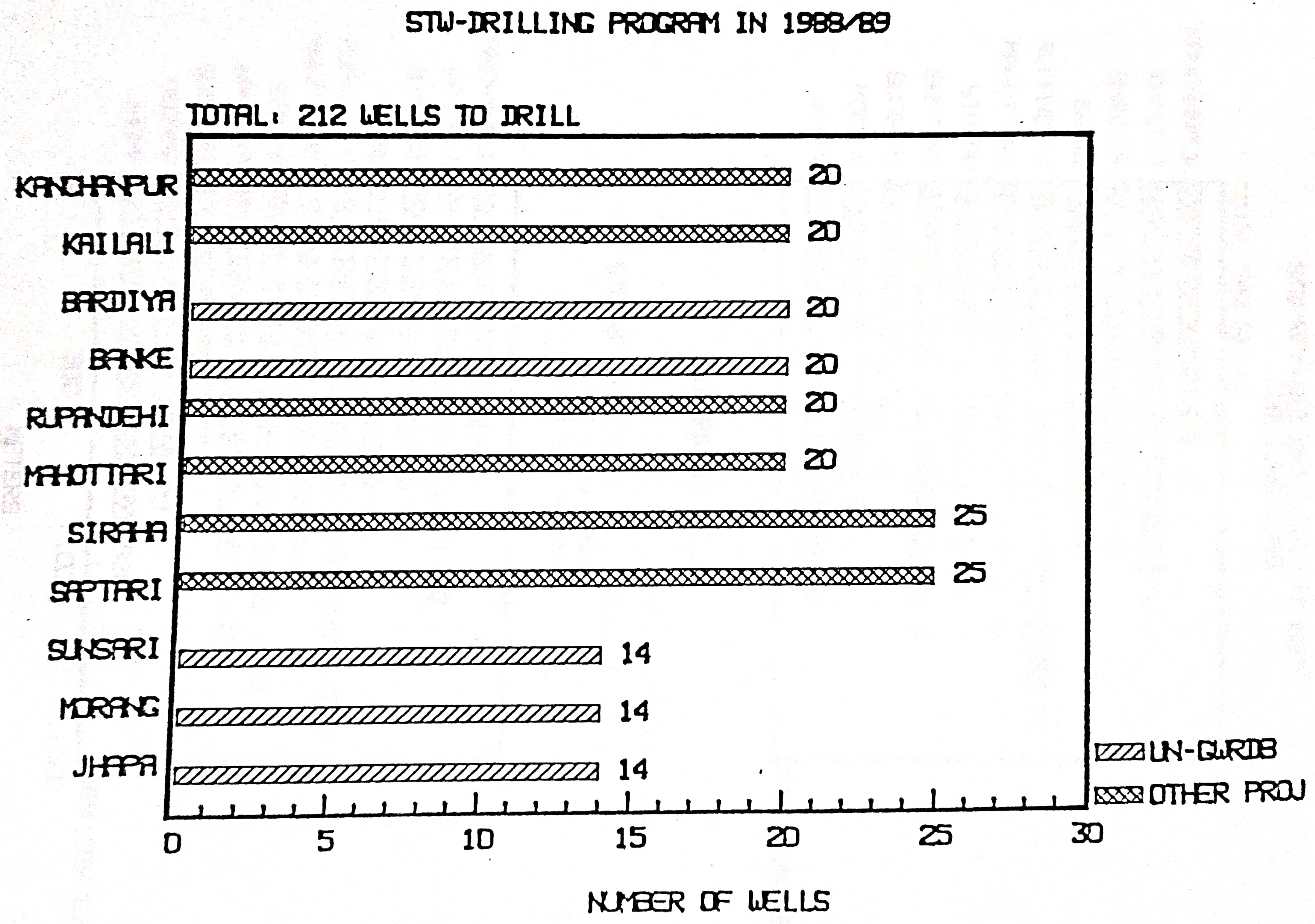
COLUMNS (I)

ROWS (J)

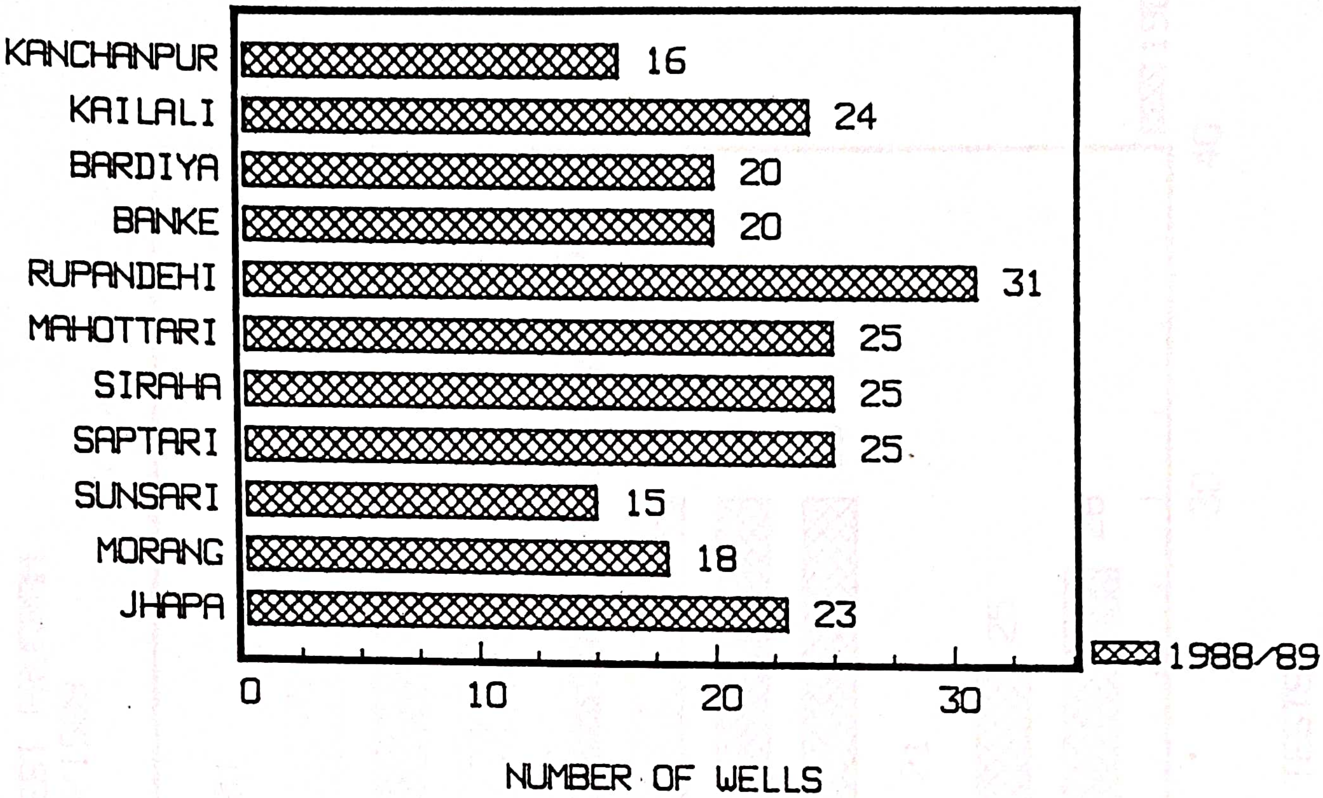


NAWALPARASI DISTRICT
MATHEMATICAL MODEL NETWORK


MAP OF PROPOSED DRILLING ACTIVITIES
1988 / 1989
NEPAL
KATHMANDU
KANCHANPUR 20
KAILALI 20
BARDIYA 20
BANKE 20
RUPANDEHI 20
MAHOTTARI 20
SIRAHA 25
SAPTARI 25
14 JHAPA
14 MORANG
14 SUNSARI
UN-GWRDB
OTHER PROJ.

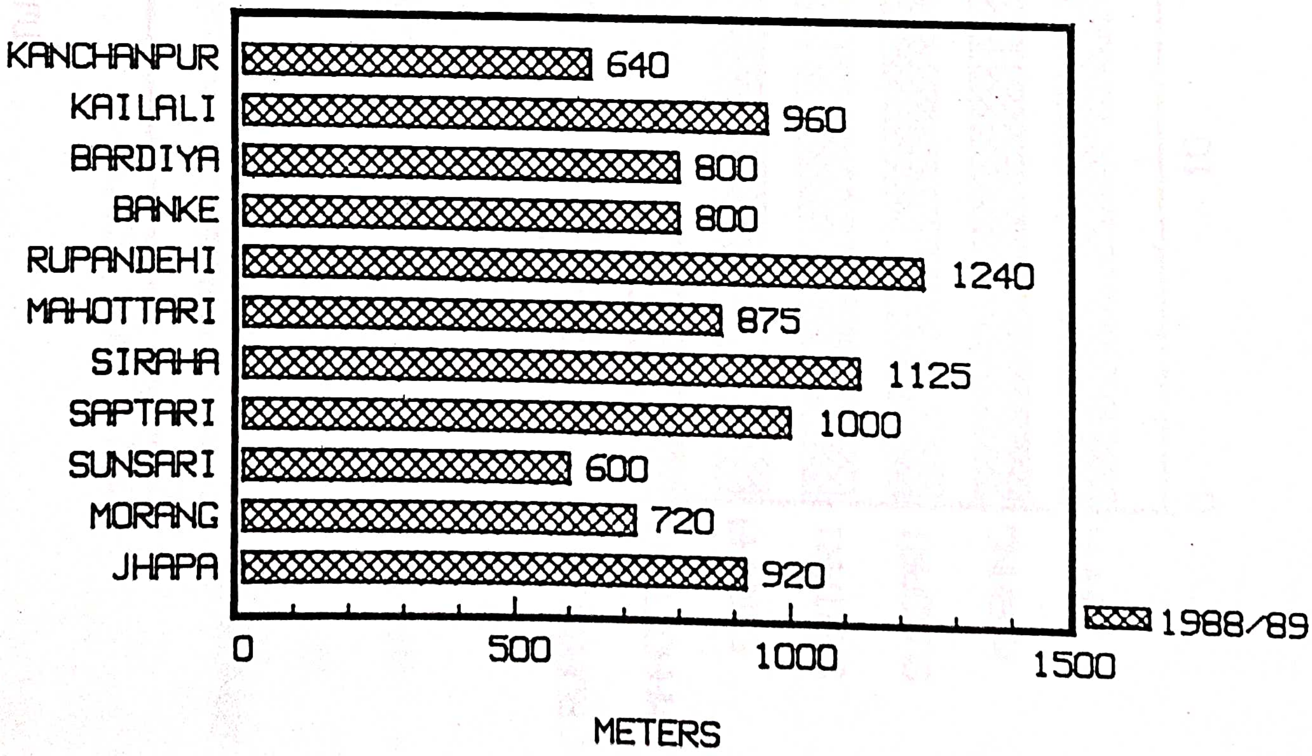

STW-DRILLING PROGRAM IN 1988/89
TOTAL: 212 WELLS TO DRILL
KANCHANPUR 20
KAILALI 20
BARDIYA 20
BANKE 20
RUPANDEHI 20
MAHOTTARI 20
SIRAHA 25
SAPTARI 25
SUNSARI 14
MORANG 14
JHAPA 14
0
5
10
15
20
25
30
NUMBER OF WELLS
UN-GWRDB
OTHER PROJ

STW-REVISED DRILLING PROGRAM
FOR 1988/1989
TOTAL 242 WELLS



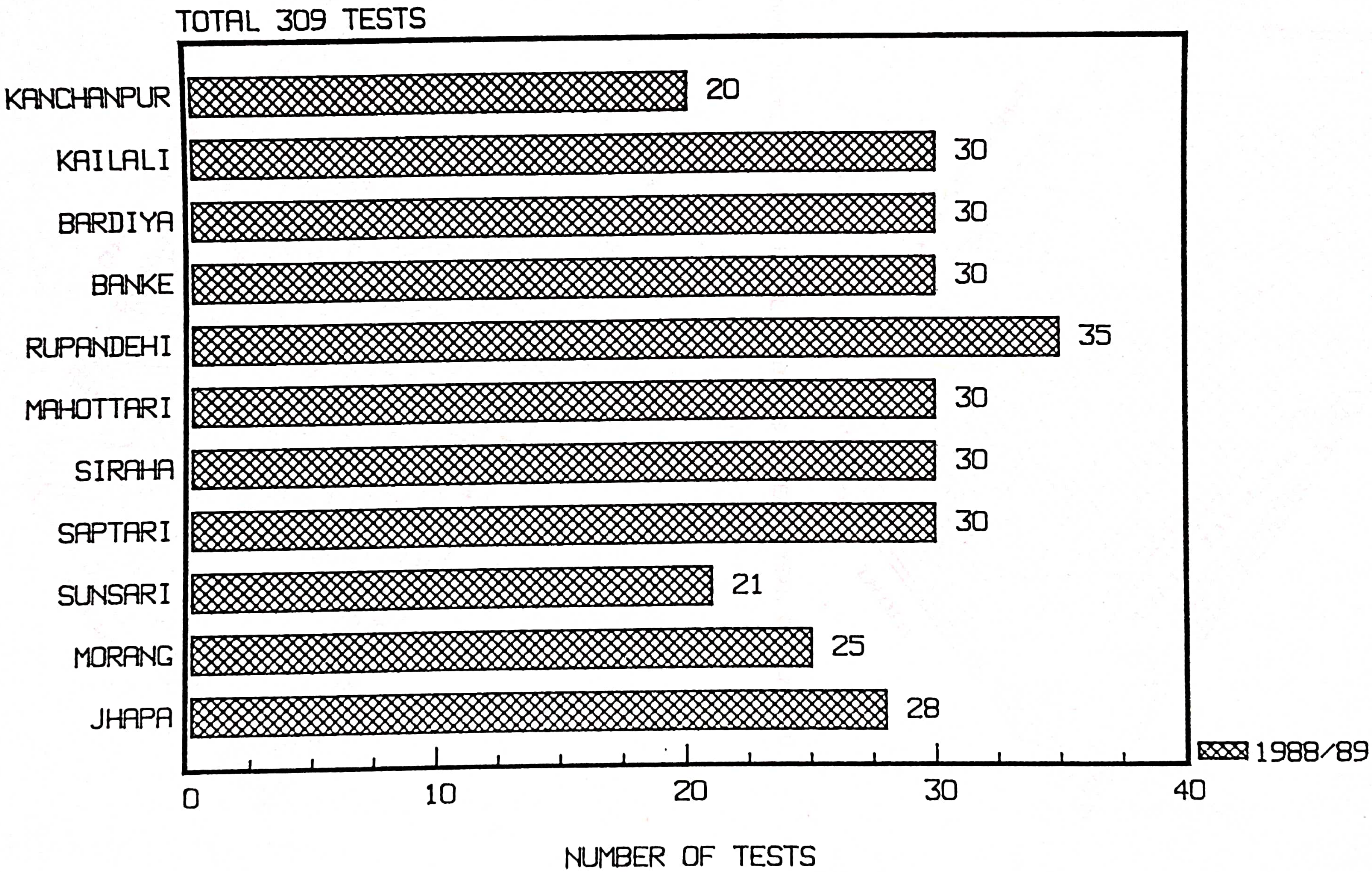
APPENDIX 24

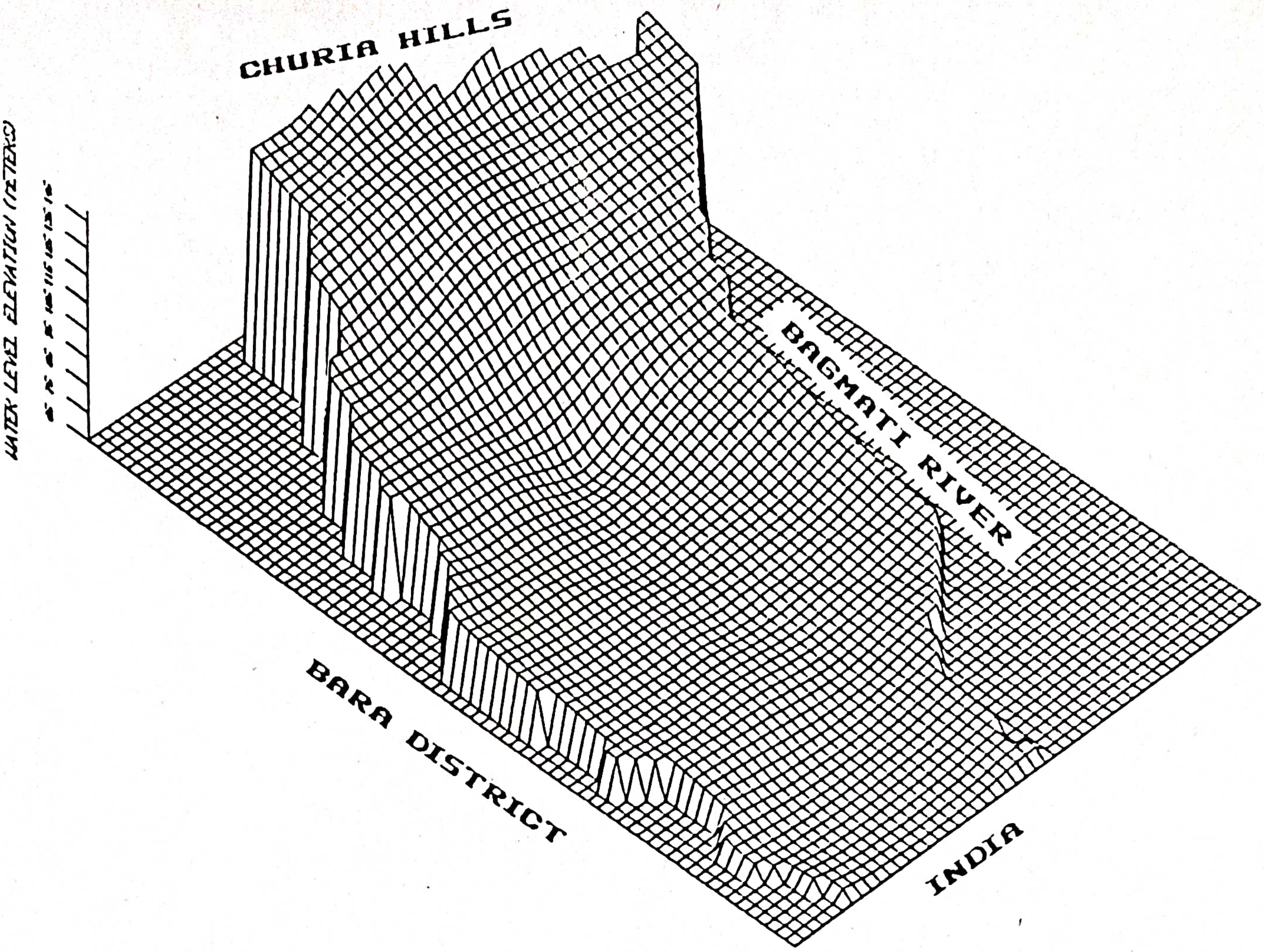
STW-REVISED DRILLING PROGRAM
FOR 1988/1989
DRILLING METRAGE



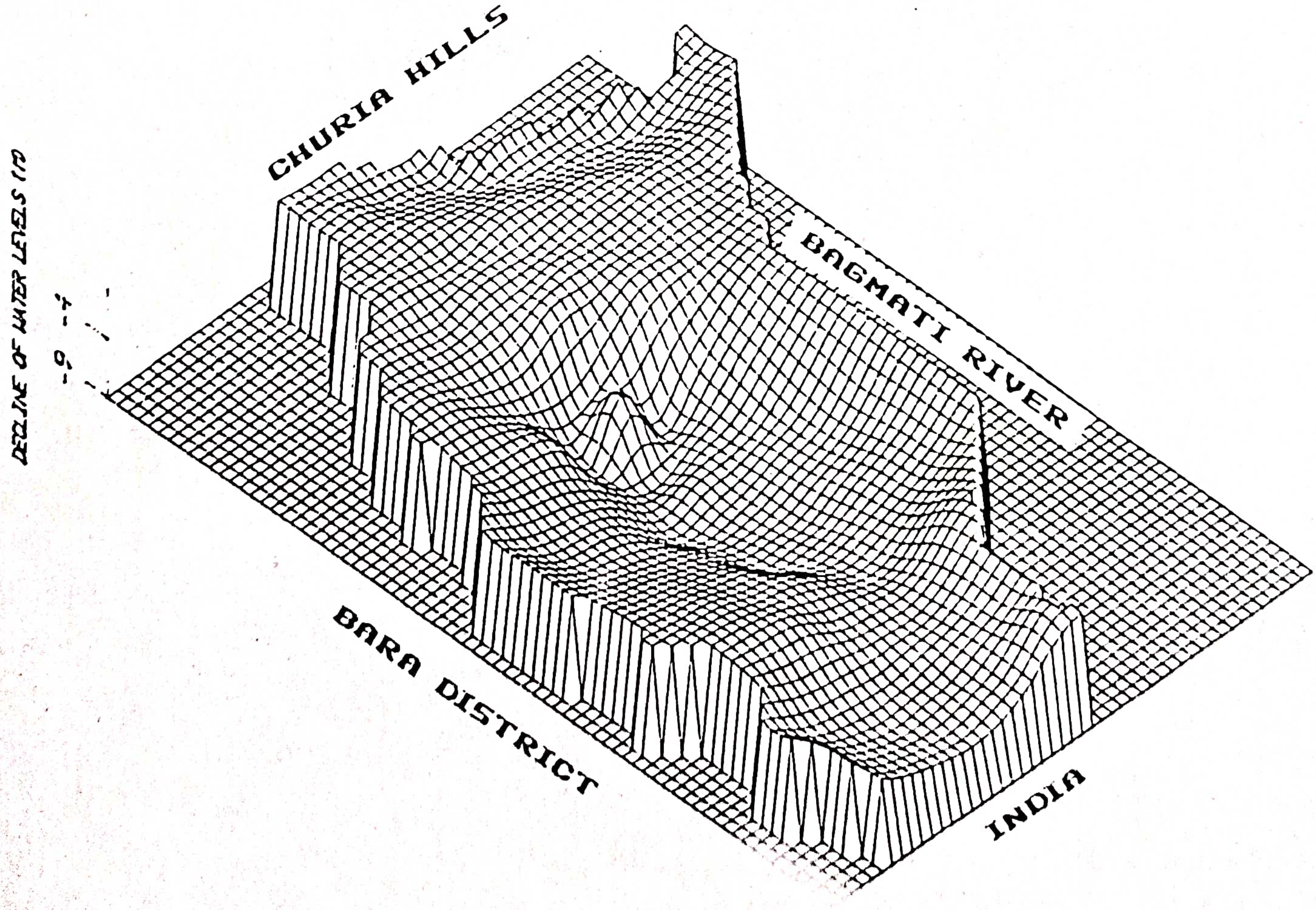
APPENDIX 25

STW-PUMPING TEST PROGRAM
FOR 1988/1989





RAUTAHAT MODEL - WATER LEVEL CONTOURS AFTER 4-YEAR OF PUMPING



RAUTAHAT MODEL - DECLINE OF WA... ...TER 4-YEAR OF PUMPING