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GROUNDWATER MODELING IN GHATAPRABHA SUB BASIN OF KRISHNA RIVER BASIN

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ABSTRACT

A two layered finite difference model has been generated for groundwater.flow analysis of Ghataprabha sub basin of Krishna river basin. The conceptual model has been calibrated for steady state condition and validated for both steady state and transient condition through USGS, 3D-Finite Difference Code, MODFLOW. Various applications were tried out on the calibrated model, like River-Drain Influencing the aquifer, Reasons for water logging and drying out of wells and Well design strategies. This Model is useful for Groundwater Development activity in Ghataprabha sub-basin in Krishna River basin.

1.0 INTRODUCTION

Today mathematical models are used in all branches of science and engineering. In hydrogeology, by contrast, we are dealing with systems that were designed by nature. These natural systems are nearly always highly complex in their composition and arrangement of the component materials. We can test these systems and materials by drilling holes, testing cores, analyzing water samples, measuring water levels, and applying geophysical techniques. Even then it is merely a small window of information, a limited picture of the real world that extends beneath our feet.

Therefore groundwater flow in general, itself is a complex phenomena and as such its complexities increases many more times when the flow is in fractured media. Heterogeneties are present in such a large scale that it is hardly possible to define the actual velocity vectors in the study domain. Its variation specially and also temporally may not have been always successfully handled by the computers specifically due to large memory requirements. Elsewhere pathways are not always the important aspect of proposed problem to resolve, but its sole objective may more arguably be confined to look in to the response of the generated system, having mathematical resemblance with the overall behavior of the actual physical domain. What we need is a realistic sense of what a model can do and what it can not do.

Almost all the river basins and sub-basins of peninsular India, have been facing groundwater development problems of various nature and degree. Ghatprabha sub-basin of Krishna river basin, no more an exception, has in recent times thrown many cases of failure of open and dug wells at several places on one hand and on the other hand, thousands of hectares of land became waterlogged and lost its fertility value. In absence of proper scientific approach to find out the causes behind these types of problems individuals dealt it in patches and tried to remediate the local problems solely for their own interest, without bothering its side effects on or near by areas.

Most interesting and unique aspect about water resources development sector is the need for unified global approaches and when it comes to the term of groundwater nothing can be restricted but our limitations out of technical skills and accessories available to individuals. Therefore, if for example, there are failures of wells in Hukkeri taluk and waterlogging in nearby area of Gokak taluk both from Belgaum district, in one simplified version it can simply and more correctly be argued as improper development of groundwater in the Ghataprabha sub-basin rather than some localized problems of Hukkeri and Gokak. This is just one simple example. Many more would come during the course of this study. Who can guide about all these proper development other than mathematical modeling.

Therefore in the present report a three dimensional two layered finite difference model has been generated for Ghatprabha sub-basin. Model has been calibrated and validated using USGS Modular three dimensional finite difference ground water flow model (MODFLOW). Various existing and proposed groundwater development scenarios have been simulated to recommend solution to groundwater problems at selected locations. The model can be useful in its present form or with possible future refinements, in addressing several groundwater issues of the region.

2.0 STUDY AREA

2.1 Sub-basin

River Krishna is the second largest river in Peninsular India, rises in the Mahadev range of the Western ghats near Mahabaleshwar at an altitude of about 1337 m above mean sea level about 64 Km from the Arabian sea. After traversing a distance of about 1400 Km, the river joins the Bay of Bengal in Andhra Pradesh. The principal tributaries of the river are the Ghataprabha, the Malaprabha, the Bhima, the Tungabhadra, the Musi, the Palleru and the Muneru.

The basin has been divided into 12 sub-basin. Ghataprabha sub-basin is one of them. Ghataprabha river is one of the southern tributaries of the Krishna in its upper reaches. The catchment of the sub-basin lies approximately between the northern latitudes 15° 45′ and 16° 25′ and eastern longitudes 74° 00′ and 75° 55′. The index map of the sub-basin is at Plate-1.

The river Ghataprabha rises from the western ghats in Maharashtra at an altitude of 884 m, flows eastward for 60 Km through the Sindhudurg and Kolhapur districts of Maharashtra, forms the border between Maharashtra and Karnataka for 8 Km and then enters Karnataka. In Karnataka, the river flows for 216 Km through Belgaum district past Bagalkot. After a run of 283 Km the river joins the Krishna on the right bank at Kudli sangam at an elevation of 500 m, about 16 km from Almati.

Its principal tributaries are the Tamraparni, the Hiranyakeshi and the Markandeya. Tamraparni rising in Maharashtra flows in Maharashtra for 26 km and after a run of another 26 km in Karnataka joins the Ghataprabha. Hiranyakeshi rising at Amboli village in Sindhudurg district of Maharashtra flows in and Karnataka for 6 km and after a run of 19 km in Karnataka, joins the Ghataprabha on the left bank. Markandeya rising in Maharashtra flows in Maharashtra for 8 km and after a run of 66 km in Karnataka, joins the Ghataprabha on the right bank.

Total catchment area of the sub-basin is 8829 sq.km., out of which 77.2% lies in Karnataka and rest falls under Maharashtra. In Karnataka and Maharashtra parts of two districts in each, namely Belgaum, Bijapur and Kolhapur, Sindhudurg respectively lies in the sub-basin. Most of the sub-basin area is flat to gently undulating except for isolated hillocks and valleys. Ground level contours are depicted in Plate-2.

The climate of the sub-basin is marked by a hot summer and a mild winter. The monsoon sets early in June and continues to the end of October. The winter is from November to mid-February and the summer is from mid-February to end of May. April is generally the hottest month with mean daily maximum and minimum temperatures of 35.7 C and 19.5 C. December is generally the coldest month with the mean daily maximum and minimum temperatures being 29.3 C and 13.9 C respectively.

The sub-basin experiences only the south-west monsoon and the period is from 1st June to 31st October. It is seen that major portion of the south-west monsoon rainfall occurs in the months of June to September, July being the rainiest month. The rainfall during the month of October is the lowest. The relative humidity is high during the south west monsoon and low during the non-monsoon period. In summer the weather is dry and the humidity is low.

2.2 Land Use

Land use particulars of Ghataprabha sub-basin with respect to geographical area of the sub-basin are listed below. This is for the year 1980-81 as taken out from NWDA report for technical study no.17, Year 1991.

Net Area Sown	63.7 %
Forest	12.6 %
Current Fallows	8.7 %
Non Agricultural Use	4.0 %
Barren Land	3.9 %
Curlturable Waste	2.7 %
Permanent Pastures and other Grazing Land	2.3 %
Other Fallows	1.8 %
Land under miscellaneous crops and trees	0.3 %

2.3 Soils and Cropping Pattern

Coarse shallow black soils are occupying areas in north and north-west parts of the districts of Belgaum and Kolhapur in the sub-basin. these soils are shallow at depths less than 23 cm. These soils are well drained and have moderate permeability. The dominant clay mineral is montmorillonitic. The crops grown under rainfed conditions are Jowar, Bajra, Millet and Pulses. However, the yields of crops are poor owing to shallow rooting depths and scanty rainfall.

Medium black soils usually occur in the Deccan trap, schist, lime-stone and shale regions of the Karnataka State, occupying areas in parts of Belgaum, Hukkeri, Bailhongal, Mudhol and Bilagi taluks. The medium black soils are also found to some extent on the peninsular gneiss areas. These soils are moderately deep to deep (23-90cm).The texture on the surface horizon is usually clayey. These are moderately well drained with low permeability. The crops grown in theses soils under rainfed conditions are Jowar, wheat, millets , cotton , safflower, tobacco, groundnut, ginger, linseed, chillies, tur, gram and other pulses.

Deep black soils occur on very gently sloping to nearly level or flat topography in the low lands of Deccan trap and limestone regions, in parts of Hukkeri, Gokak, Ramdurg, Mudhol and Bagalkot taluks. These soils are very deep (more than 90 cm). The texture is usually clayey throughout the profile. At places, on surface, locally loam to silty clay texture is also common. The crops grown under rainfed and irrigated conditions are same as for the medium black soils given earlier.

Mixed red and black soils usually occur on gently undulating plain or complex geological material comprising gneisses dharwar schistose and sedimentary rock formations and occupy areas in parts of Ramdurg and Bailhongal taluks in the sub-basin. the red sand black soils are found in association with each other in this area. The red soils are comparatively of coarser texture and have moderate drainage and slow permeability. The crops grown under rainfed conditions are jowar, cotton, groundnut, chillies, wheat and pulses. The crops grown under irrigation are cotton, pulses, paddy, sugarcane maize, wheat and tobacco.

Lateritic soils are found on undulating, rolling plain to gently sloping topography of the peninsular gneisses regions occupying areas in parts of Kolhapur district coming under the dry agro-climatic region. These soils are deep to very deep, These soils are well drained to excessively drained with moderate to moderately rapid permeability. The depth of these soil in sub-basin varies from 15 cm to 100 cm. The crops grown in these soils under rainfed conditions fare jowar, groundnut, pulses, safflower, linseed and other millets. Under irrigation the crops grown are paddy, sugarcane, chillies, wheat, turmeric and vegetables.

All these soil types are shown in Plate 3.

2.4 Geology

The geological formations met within the sub-basin are i) Deccan trap of tertiary age, ii) Sedimentary formations known as "Kaladagi group" comprising lime stone, shale and quartzites, iii) Schistose, gneiss and other crystalline rocks and iv)Laterite rocks. Areal distribution of all these rock types are depicted in Plate.4. and details of these geological settings have been discussed elsewhere in the form of technical reports(GSDA,1972 & CGWB,1997). Borelogs and lithologs at various locations summarises to 5 zones. They are Soil cover, Weather, Partially weathered, Fractured and sound rock . Water yielding properties of these rock types are summeried below as table 1.

Table. 1. Water yielding properties of various Rock types in Ghataprabha sub basin.

(After DANIDA,1995 and CGWB,1997)

Rock Type	General Features	Water Yielding Properties Radhakrishna & Pathak	CGWB
River alluvium	Mostly composed of gravel, sand and silt	Dug well yields could be expected around 400 cum/day very much limited.	Development Potential very much limited
Laterites	Weathered product with cavities	Dug well yields may vary from 20 to 180 cum/day	Dug well yield ranges from 25 to 300 cum/day
Sandstone and quartzite of Kaladgi Group	Hard and compact	Poor aquifers	Dug well yield ranges from 25 to 150 cum/day where as bore well yields are less than 1.0 lps to 7.6 lps
Schists and phylites of Dharwar Super Group	Highly folded, weathered to form clay material	Dug well yield varies 30 to 200 cum/day where as bore well yields are of the order of 30 cum/day	Dug well yield ranges from 20 150 cum/day whereas bore well yielded 0.4 lps
Deccan Trap	Horizontal lava flows, columnar joints, vesicular and amygdaloidal structures	Well yield varies from0.5 to 200 cum/day. Red bole between two flows are good aquifers	Dug well yield ranges from 20 to 250 cum/day whereas bore well yields less than 1.0 lps to 7.6 lps
Granites and gneiss's	Coarse grained, occasionally transversed by joints	Dug well yield is of the order of 50 to 250 cum/day and bore well ;yield varies from 50 to 480 cum/day	Dug well yield ranges from 20 to 150 cum/day whereas bore well yielded 0.4 lps

Transmissivity and Storage Coefficients of these Hard Rocks as suggested by NABARD study are abstracted below in table 2.

Table 2. Flow Properties of Hard Rocks.

Rock Type	Transmissivity in Sq. m/day	Storage Coefficient
Greywake	17.6-467.7	0.0046-0.0062
Basalt	90.9-545.7	0.0019-0.0057
Limestone	131.8-227.9	0.039
Granitic Gneiss	164.1-180.7	$7.8x10^{-7}$-$2.3x10^{-3}$
Charnockite	98.3-135.4	$2.1x10^{-4}$-$6.0x10^{-3}$
Granite	535.1	$7.8x10^{-7}$

(Source : DANIDA report, 1995)

NABARD study also computed the spacing of wells in various formations on Radius of influence and Recharge approaches. It is concluded that for a pumping rate of 100 cum/day a spacing of about 475 m and for a pumping rate of 50 cum/day, a spacing of 250 m is necessary in all the geological formation like Granites, Basalts, Gniesses and Charnochites which occupy major tracts of Karnataka. NIH(1995) analysed the pumping and recovery test data, conducted in Hukkeri, by Kumarswamy's method. Rock mass permeability values were found out and were ranging from 0.08 m/hr to 0.346 m/hr.

CGWB(1997) has broadly classified the subsurface geology in two types of aquifers, viz. 1) the top weathered zone which extends down to 30.0m. and forms the shallow or the phreatic aquifers tapped mostly by dug wells and dug cum bores, shallow bore wells and filter point wells and 2) the fractured aquifer which lie below the shallow zone and extend down to 80 m. and beyond, the maximum drilled depth being 200m. Accordingly Permeability values in shallow aquifer zone varies from less than 1 m/day to 5 m/day, and Transmissivity of second aquifer zone varies from a few sq.m/day to more than 100 sq.m/day.

2.5 Groundwater Quantity

Various hydrogeological studies have been carried out by the Central Groundwater Board and the State Groundwater Departments in the sub-basin part by part. The studies reveal that in all gneisses, quartizites and alluvial deposits, groundwater occurs in the sub-basin under phreatic to semi-confined conditions. Total groundwater potential as estimated by NWDA comes out to be 975 MCM against an average draft of 174 MCM estimated on the basis of CGWB publication of Maharashtra(1985) and CGWB publication of Karnataka(1983). The occurrences and movements of groundwater in these rocks are controlled by the nature and extent of weathering and the presence of joints and fractures in them. The groundwater development in the sub-basin is from open wells and dug-cum borewells.

Under the International Development Associations Programme for Maharashtra credit project the Groundwater Survey and Development Agency, was entrusted with work of carrying out groundwater assessment for the entire state of Maharashtra on watershedwise. Accordingly total annual groundwater recharge from the watersheds falling under the Ghataprabha sub-basin in Maharashtra state comes out to be 165 MCM as against the estimated draft of 28.42 MCM in the year 1972-73.

Central Ground Water Board has also carried out the yearly ground water assessment for the Ghataprabha canal command area in the parts of Belgaum and Bijapur district in Karnataka for the period of 1988-89 to 1992-93. Net recharge comes out to be 1533.59, 1123.946, 1077.181, 1084.459, 1122.797 MCM for the year 1988-89, 1989-90, 1990-91, 1991-92 and 1992-93 as against the draft values of 333.584, 340.089, 346..96, 353.942 and 361.015 respectively. These includes individual stations namely; Gokak, Hukkeri, Chikodi, Raibag, Jamkhandi, Mudhol, Bilgi, Bagalkot, Belgaum, Badami, Athani, Bailahongal, Saundatti, Ramdurg and Hungund.

2.6 Groundwater Flow

Overall ground water flow in the sub-basin follows the ground level profile, except some local disturbances due to geological, geophysical variations in the weathered and fractured mass and changes in the water levels of surface water bodies. Plate 5.(a&b), 6.(a&b) and 7.(a&b) shows the water table contours for pre and post monsoon water tables of the year 1976-77, 1986-87, 1996-97. Which shows that water table gradients vary areally with a maximum value of 2 m/km in the upper reaches and with a minimum value of 0.5 m/km in the lower reaches of the basin after Hukkeri.

Seasonal fluctuations in subsurface water levels are mainly affected by the respective seasonal precipitation. In command areas it is being added by the seepage from canals and Irrigation return flows. To sense these fluctuations analysis of monthly water level data has been carried out in selected locations. Results of the analyses are depicted in Table. 3.

Table 3. Ground Water Level Fluctuation in Ghataprabha Sub basin(all in meters).

Location	District	State	Period	GWL Fluctuation		
				Max	Min	Average
Karve	Kolhapur	Maharashtra	1974-1995	8.20 (1984)	1.73 (1976)	5.35
Nesri	Kolhapur	Maharashtra	1989-1995	3.00 (1992)	0.55 (1994)	1.64

Location	District	State	Period	GWL Fluctuation		
				Max	Min	Average
Kalavikatti	Kolhapur	Maharashtra	1976-1995	11.08 (1988)	1.06 (1976)	6.29
Sambra	Belgaum	Karnataka	1977-1996	14.15 (1988)	3.95 (1987)	9.96
Hukkeri	Belgaum	Karnataka	1987-1996	10.72 (1987)	1.17 (1980)	4.62
Chikkandi	Belgaum	Karnataka	1972-1996	7.95 (1991)	0.90 (1972)	3.59
Bailhongal	Belgaum	Karnataka	1973-1996	10.93 (1975)	0.65 (1985)	3.53
Muragod	Belgaum	Karnataka	1973-1996	6.30 (1996)	0.96 (1977)	2.92
Lokapur	Bijapur	Karnataka	1973-1996	6.05 (1994)	0.70 (1984)	2.41
Bilgi	Bijapur	Karnataka	1973-1996	7.99 (1980)	0.95 (1992)	3.30
Bagalkot	Bijapur	Karnataka	1973-1995	23.00 (1993)	1.00 (1985)	5.05
Guledgudda	Bijapur	Karnataka	1973-1996	6.30 (1984)	0.73 (1977)	2.77

2.7 Water Demand

By and large complete regional economy of the sub-basin depend upon the available water resources. Various types of water usages are; Domestic, Forest, Agriculture and animal husbandry, Power, Minerals and Industries. This demand is fulfilled by Surface and subsurface resources except some places like Hukkeri where groundwater is being utilised for meeting almost all the purposes.

3.0 PROBLEM DEFINITION

On the basis of whatever have been discussed in previous sections, it is proposed to generate a three dimensional finite difference grid covering entire Ghataprabha sub-basin of Krishna river basin. This conceptual model would be calibrated and validated using 3D-USGS source code MODFLOW for following conditions.

(i) Calibration in Steady state condition with River and Drain blocks active.

(ii) Validation in Steady state condition with Constant Head Surface Water body blocks.

(iii) Validation for a transient condition.

This model would possibly be defining various hydrological scenarios like

1. The influence of fluctuating water levels in the Ghataprabha river and its tributaries.
2. Reasons for the failure of wells and waterlogging problem at selected locations.
3. Well design application.

4.0 SITE CONCEPTUALISATION

4.1 Conceptual Realisation

This section describes the conceptual model of the groundwater system at the Ghataprabha sub-basin site independent of density gradients on flow. A conceptual model was postulated based upon the available information to understand the physical processes to be simulated by the numerical model. Relevant information indicate that there are 5 hydrostratiographic layers which forms mainly three zones for the groundwater development possibilities i.e., shallow, medium and deep aquifer zones. At the site , the general direction of groundwater flow is west to east in the study domain . The generalised subsurface geology existing beneath the site and approximate depths of the units are:

. zone 1	0-5 mt	Soil cover
. zone 2	5-20 mt	Weathered zone
. zone 3	20-35 mt	Partially weathered zone
. zone 4	35-80 mt	Jointed and fractured zone
. zone 5	below 80 mt	Sound rock

Lateral continuity of these hydrostratigraphic layer varies throughout the flow domain and as such its layer thickness also maintains some positive values always. Contour profile for the bottom of all these zones are generated on the basis of available borelogs and lithologs data for the bottom level values at the c.g. of 10,000 grid blocks through Krigging model 'GEOPACK'. These are plotted through 'SURFER' and shown in plate 8.0 to 8.5 . Some cross-sections are enmarked in Plate 9. (a to e). Mostly Dug wells are used for tapping water from shallow aquifer zones whereas borewells penetrate the medium to deep aquifers. Therefore instead of incorporating four individual layers only two layers have been conceptualised merging zone 1 & 2 in first layer and zone 3 & 4 in layer 2. Zone 5 would act as the bottom boundary for the conceptual model.

4.2 Study Grid

Spatial Domain

Groundwater flow for the sub-basin was investigated by subdividing the spatial domain into 20,000 finite difference grid blocks as shown in plate 10. The discretization consists of 100 grid blocks in both the direction . Length of each grid block is 2.095 km in x-direction and

1.116 km. in y-direction. The stratiographic units are represented by two layers , merging soil cover and weathered zone in first layer and partially weathered, jointed and fractured in second layer respectively from the top. Therefore the top of the spatial domain represents the ground surface while the bottom boundary of the domain is set at bottom levels of the jointed and fractured zone. Spatial extents of rivers, tanks, canals and drains would be accommodated through River package, Drain package and Head boundary packages available in MODFLOW. The thickness and elevation of the 20,000 finite difference grid blocks are individually adjusted in order to match the geological layering at the site.

Areal recharge to the flow system is spatially variable. Contributing factor to this spatial variability is flow system heterogeneity which is guided by the soil types in layer 1 and geological classification in layer 2. In all heterogeneity would be put into the conceptual model through these 6 classified zones. First layer behaves within unconfined water table condition, where as layer type is uncertain in second layer and would be tested for three possible layer types in MODFLOW while calibration. These are:

I. Confined aquifer with Transmissivity & Storage coefficient of the layer is constant for entire simulation.
II. Confined/unconfined aquifer with Transmissivity constant. Storage coefficient may alternate between confined and unconfined values. Vertical leakage from above is limited if the layer desaturates.
III. Confined/unconfined aquifer with transmissivity of layer varies. It is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient may alternate between confined and unconfined values. Vertical leakage from above is limited if the aquifer desaturates.

Whichever type results in a best similar fashion to that of the actual flow domain, that type would be implemented for further simulations. Stratiographic relationship with ground water table indicates the influence of river and drainage pattern on the groundwater flow. Ground water storage is governed by the factors such as recharge and well abstraction.

Temporal Consideration

Conceptualised model is proposed to be calibrated and validated for steady state pre-monsoon water table condition in the year 1982-83. Aquifer parameters would be finalised based on various runs manually. Model would be again validated for transient run for one selected season in year 1982-83. Number of stress period is 6 , each representing 30 days, starting from pre-monsoon water table condition.

Boundary Conditions

Conceptual model is bounded by inactive cells all around in both the layers to indicate the basin boundaries showing no sub-surface inflow or outflow from this basin to other adjacent basins or sub -basins. Out of 10,000 blocks, 6551 cells are zero cell in each of the layers. This would provide us ample opportunities to ascertain the basin boundaries hydrologically in future in case of any misconcept in the present model.

River Network

Following Rivers are considered in the conceptual model.

(1) Ghataprabha
(2) Markandya
(3) Bellary halla
(4) Hiranyakeshi

Physical characteristics of these rivers are delivered to the model by two parameters i.e.; River Bottom elevation and Conductance. Conductance values are estimated by actual stream width, length of the cell, hydraulic conductivity of the bed material and thickness of the transmitting layers. These rivers are expected to interact with the aquifer system depending upon the stages in the river and water table in the aquifer.

Drain & Canal Network

Following drainage systems are taken in to the consideration.

(1) Hire Halla
(2) Tamrapani
(3) Gadhar nadi
(4) Hira Halla

Again physical characteristics are fed in the same manner as in the case of river package. All the canal systems existing in the study area are lined and as such not considered in the model.

Water Bodies

Water spread areas are entered in the conceptual model through constant head boundary condition. Following two water bodies are considered in the model.

(1) Rakaskop tank
(2) Hidkal Reservoir
(3) Dupdhal Weir
(4) Daddi water body
(5) Bijapur water body

There are few more tanks existing in the ghataprabha sub-basin but those are mainly in black cotton soil overburden, therefore not considered here due to low water infiltrating capacity of the soil.

Model Properties

Hydraulic Conductivity

Flow property of the conceptual model has been devided in six zones in two layers. Soil classification in first layer and geology in second layer is the basis for that. These zones are shown in Plate 11. and 12. Initial HYDRAULIC CONDUCTIVITY values considered are as shown in Table 4.

Table 4. Initial Hydraulic Conductivity values.

Property No.	Layer No.	Layer Type	Kx(m/sec)	Ky(m/sec)	Kz(m/sec)
1	1	Deep Black Cotton Soil	1.000e-11	1.000e-11	1.000e-12
2	2	Basalt	4.000e-7	4.000e-7	4.000e-8
3	2	Schist and Gneiss	2.150e-6	2.150e-6	2.150e-7
4	1	Medium Black Soil	1.000e-9	1.000e-9	5.000e-10
5	1	Coarse Black Soil	1.000e-7	1.000e-7	1.000e-8
6	2	Limestone & sandstone	4.250e-6	4.250e-6	4.250e-7

(Source: Domenico & Schwartz, CGWB, DANIDA)

Storage Property

Storage Properties are again classified in five zones in first layer according to the soil classification as shown in Plate 13., whereas it is kept same in all the blocks in second layer. Storage property data base is stipulated below. in Table. 5.

Table. 5. Storage properties considered in the conceptual model.

Property No.	Layer No.	Layer Type	Storage co-efficient(1/m)	Specific Yield	Porosity
1	1	Deep Black Cotton Soil	0.01	0.05	0.35
2	2	Rock formation	1.00e-6	0.14	0.35
3	1	Medium Black Soil	0.001	0.10	0.35
4	1	Mixed Red& Black Soil	0.001	0.10	0.35
5	1	Coarse Black Soil	0.001	0.20	0.40
6	1	Lateritic soil	0.001	0.12	0.30

(Source: Domenico & Schwartz, CGWB, DANIDA)

Rainfall Recharge Blocks

Areal variation of groundwater recharge in the transient simulation has been accorded as per the theissen polygon generated on the basis of 11 rainguage stations in and arround the study basin shown in plate 14. Area covered under each location is enumerated below. Annual

Recharge values are adjusted to have good match between the observed and estimated water level contours for the year 1982-83. Initial recharge values considered for simulation is 15% of the annual rainfall and are also depicted below in Table 6.

Table. 6. Recharge values for transient run.

S. No.	Station Name	State	Area covered in Sq.Kms	Annual Rain-fall 1982-83	Initial Recharge
1	Chandgad	Maharashtra	948.89	2814 mm	422 mm
2	Gadinglaz	Maharashtra	781.78	644 mm	97 mm
3	Belgaum	Karnataka	976.60	877 mm	131 mm
4	Bailahongal	Karnataka	417.34	382 mm	57 mm
5	Chikodi	Karnataka	252.76	365 mm	55 mm
6	Gokak	Karnataka	1542.57	353 mm	53 mm
7	Hukkeri	Karnataka	644.08	391 mm	59 mm
8	Ramdurg	Karnataka	532.38	457 mm	68 mm
9	Bagalkot	Karnataka	644.07	456 mm	68 mm
10	Bilgi	Karnataka	424.90	395 mm	59 mm
11	Mudhol	Karnataka	1231.87	334 mm	50 mm

5.0 RUN AND RESULTS

5.1.0 Calibration:

A manual calibration procedure has been followed. The hydraulic conductivity values are adjusted until a reasonable comparison is obtained between the observed and calculated water levels in both the layers. Results of calibration is a hydrostatic condition achieved through maintaining water levels at various river blocks for June 1982. The calibrated base case hydraulic conductivities are presented below in Table 7.

Table. 7. Calibrated Hydraulic Conductivities.

Property No.	Layer No.	Layer Type	Kx(m/sec)	Ky(m/sec)	Kz(m/sec)
1	1	Deep Black Cotton Soil	2.350e-10	2.350e-10	2.350e-11
2	2	Basalt	3.100e-9	3.100e-9	3.100e-10
3	2	Schist and Gneiss	7.000e-7	7.000e-7	7.000e-7
4	1	Medium Black Soil	5.500e-10	5.500e-10	5.000e-11
5	1	Coarse Black Soil	1.000e-8	1.000e-8	1.000e-9
6	2	Limestone & sandstone	3.000e-8	3.000e-8	3.000e-9

Initial heads are considered at the maximum top level of the conceptual model. Bottom layer has been allocated all the three types of water table conditions and Type 3 was found giving most convincing solution. It shows that the bottom layer behaves like semiconfined aquifer. All these calibrated water heads are shown as water table contours in plate 14 and 15 for each layer . Velocity vectors for this calibration are again depicted in Plate 16 and 17. To achieve steady state water table condition recharge property has been adjusted to have following Mass balance results in Cum .

In

Storage = 0.00
Constant Head = 0.00
Drains = 0.00
Recharge = 65.431
River Leakage = 0.0036
Total In = 65.434

Out

Storage = 0.00
Constant Head = 0.00
Drain = 13.127
Recharge = 0.00
River Leakage = 53.115
Total Out = 66.242
In - Out = - 0.80802
Percent Discrepancy = -1.23

Plate 18 and 19 depicts steady state water table conditions for layer 1 and 2.

5.2.0 Validation :

The calibrated model parameters were tested for the same temporal model with different boundary conditions. Constant head were assigned for surface water bodies at Daddi, Rakaskop, Hidkal dam site, Gokak and Bagalkot. Steady state validated results for the same is depicted in plate 20 and 21. Mass balance results of the validated is shown below.

In	Out
Storage = 0.00	Storage = 0.00
Constant Head = 0.00	Constant Head = 19.404
Drains = 0.00	Drain = 0.00
Recharge = 19.574	Recharge = 0.00
River Leakage = 0.00	River Leakage = 19.404
Total In = 19.574	Total Out = 19.404
	In - Out = 0.16944
	Percent Discrepancy = 0.87

The calibrated model has been validated for transient condition also for one season i.e 1982-83. Monthly water level contours after first stress period are shown in Plate 22 and 23. Initial conditions are as per the pre monsoon Krigged water levels estimated on the basis of water levels in Dugwells and borewells for layer 1 and 2 respectively. Rainfall recharge has been allocated as per the thiessen polygon for stations namely, Chandgad Gadinglaj, Belgaum, Bailahongal, Chickodi, Gokak, Hukkeri, Ramdurg, Bagalkot, Bilgi, Mudhol. Mass balance results for achieving water table conditions after first monthly stress period are listed below.

In	Out
Storage = 54712.00	Storage = 26126000.00
Constant Head = 0.00	Constant Head = 0.00
Drains = 0.00	Drain = 39.297
Recharge = 26092000.00	Recharge = 0.00
River Leakage = 2.2542	River Leakage = 162.74
Total In = 26146000.00	Total Out = 26126000.00
	In - Out = 20000.00

5.3.0 Simulation of a leaky Bore hole :

These simulations are carried out locally by generating a local grid of 16 X 16 with dimension of 251 m X 279 m near Hukkeri shown in Plate 24. Base case has been developed on the basis of pre monsoon 1982 run for the local grid and calibrated parameters. Various well locations with different pumping rates have been tried out to see the effect of well spacing and well production. Results of these hypothetical scenarios are depicted in Plate 25(a) to 25(f).

6.0 DISCUSSIONS

Results of the MODFLOW application to Ghataprabha sub-basin of Krishna River basin have been discussed topicwise below to justify the problem definition of this report and hence to achieve the objectives.

(1) Calibration

Objective behind calibration of the model was to find out the model parameters with minimum number of assumptions. Model geometry is well defined only assumption was made, is about considering no flow boundaries throughout the basin boundary during conceptualization. It was just a matter of starting with something and subsequently finding it, well justified . Calibrating the model with solely river and drain blocks interacting with the aquifer provided more opportunity to attain steady state condition in one hand and on the other hand we could have better geometry for our model run. This implications perhaps eased out certain degree of restrictions imposed on the conceptual model by putting no flow boundary conditions all along the basin boundary. More-over practically chances of interaction of river and drain with aquifer is widespread as compared to the influence of stagnant water bodies. Initial conditions were the hydrostatic pressures out of a water head up to top most point in the mesh. To start with , recharge component was not considered due to its more uncertain behavior but once the simulations were arrived to have good match of estimated water table patterns to that of the observed pattern generated from the data of 1976-77, 1986-87 and 1996-97, mass balance error was adjusted to minimum with appropriate recharge values to attain the steady state condition. Point of interest here is that because the total quantity of water coming out of the model in rivers and drains was surplus we could adjust it with recharge component and hence again nullifies the restrictions out of imposition of no flow boundary all along the basin boundary. Hence two sets of results are included in the report from calibration. One is the simulated water heads, which are the results of the calibrated model parameters, but certainly not falling under the steady state condition in terms of mass balance results because of the imposition of no flow boundary. Subsequently Steady state water tables are also drawn which are the water levels resulted out of the run, after adjusting the mass balance with recharge component. Now again this steady state water tables are the conceptual Hydrostatic condition and should not be confused with the observed conditions prevailing in the aquifer domain as no aquifer system can be under static condition whatsoever isolated it is from the human exploitation. Parametric and statistical calibrations have been overlooked due to the fact that any number of residual error was not just sufficient to yield a satisfactory closeness between the observed and estimated head values in such an large and complex domain.

(2) Validation

Generally validation in steady state condition does mean to run the model with calibrated parameters for some other history period and observe the closeness of the results with the observed values. In the present study we are not much concern about the exact head values but matching its trend in the study domain. Therefore instead we preferred to validate the same steady state model for some other boundary condition that for which it has been calibrated. Therefore while validation all river and drain nodes used for calibration, have been omitted and instead very few constant heads have been allocated based upon the data of some surface water bodies at Daddi, Rakaskop, Hidkal, Gokak and Bagalkot. Results of the validation run shows almost same trend except some area in Mudhol taluk of Bijapur district, where uncertainties got involved due to influence of drainage pattern out of very sharp and frequent bends in the Ghataprabha river. This again stimulates the significance of River-Aquifer and Drain-Aquifer interaction in the sub-basin.

Once the model was calibrated and validated in steady state condition and it was found that rivers and drains are governing the groundwater flow in the study domain, the same model was processed for one transient condition in 1982-83 season. Calibrated model parameters were used and initial conditions were generated for both the layer independently from Dug and Bore well water levels. Krigged water tables for premonsoon condition were estimated on all the 10,000 blocks in each layer through Geo-static model GEOPACK. Estimated recharge values have been allocated zonewise. No separated well production has been allowed for this base case simulation. The model yielded very good results in its first run itself.

This calibrated and validated model would be useful for the solving various groundwater development problems. Effect of water levels in Ghataprabha river has got enormous emphasis on the groundwater condition specifically prior to Gokak. This can be seen through velocity vectors generated for Transient state condition. Generally aquifer on the right bank of the river discharges water to the river and in turn aquifer on the left receives water. Now if water level in the river goes low, more water would be drained off from the aquifer on the right bank and left bank aquifers would have very little addition of ground water flow. There vector direction may also change as we find between steady state condition and transient condition.

Second type of problem which could be defined, are the problems of water logging and drying out of wells. In the present model area we look at two locations, in near vicinity of each other , Hukkeri is experiencing number of failure of wells, and on the other hand Gokak is experiencing water logging problems out of excess water. All the results of the simulations, whether they are in steady state or transient condition, shows the possibility of these problems. In fact model results emphasis on the interconnection between water logging in Gokak with dry out of well in most of the neighboring places. Some artificial protection measures have to be instituted very soon, so that at least Groundwater flow towards Gokak from all other neighboring locations be curtailed to some extent. Again flow in the Ghataprabha river plays a key role behind the stagnation of water table near Gokak.

Most important aspect of any groundwater development model should be its possible use for hydrological design of wells. Wells are the local issues and as such to look into this aspect and a sample local grid has been generated in Hukkeri and well design parameters like Pumping Rate. Screen length and spacing between the wells have been tested. Results are not conclusive but certainly encourages use of mathematical models for well design aspects. Only matter of concern is to transfer the model from macroscopic level to microscopic or local level.

7.0 CONCLUSION AND RECOMMENDATIONS

No mathematical modeling is conclusive unless the model becomes prototype, which is absolutely unfair to expect for. In the present world of numerous multidisciplinary uncertainties involved in the field of groundwater flow and balance analysis, use of numerical model is the best capable solution. Altogether it can view and suggest integral solution to various number and types of groundwater development problems. Only aspect is to se that what a model can do and what it cannot. In the present report, Three Dimensional Finite Difference Groundwater Flow model has been generated to look into following main issues.

I. Interaction between Ghataprabha river and the conceptualised Ghataprabha basin aquifer.
II. Hydrological analysis of the water logging problems and Failure of Wells inside Ghataprabha sub-basin.
III. Hydrological design of wells.

Generated mesh would allow trails for many other options for boundary conditions all along the Ghataprabha sub-basin boundary. The boundary condition used here is the surface water Hydrological boundary which ultimately worked well . However there may be interaction between Krishna sub-basin and Malaprabha sub-basin with Ghataprabha sub-basin, all under Krishna River Basin, but it has to be assessed in terms of the extent of interaction between these sub-basins.

The calibrated parameters have been validated for steady state as well as transient condition for only one season of 1982-83. It would have nice if more simulations would have carried out and included in this report, but due to a time frame in mind same have been reserved for future before putting the model for field use. Though the Steady state condition results are only a conceptualised condition and may not exist at any time step but it has enormous importance as an hydrostatic condition while designing water development activities. There is all the scope available for making the mesh more finer while using it for addressing local issues. The more accurate the geometry and drainage patterns is, more accurate the model results would be on our desk. Therefore it is recommended to incorporate more and more bore logs and litho logs, as and when available, to have more and more certain Geometry of the aquifer system. Setting up of some more river gauging stations in Ghataprabha River and it its tributaries may also add enormous degree of certainty to the model results. Finally, it is to be recommended that similar model studies may be initiated for more certain development activities in various hydrological basins of peninsular India.

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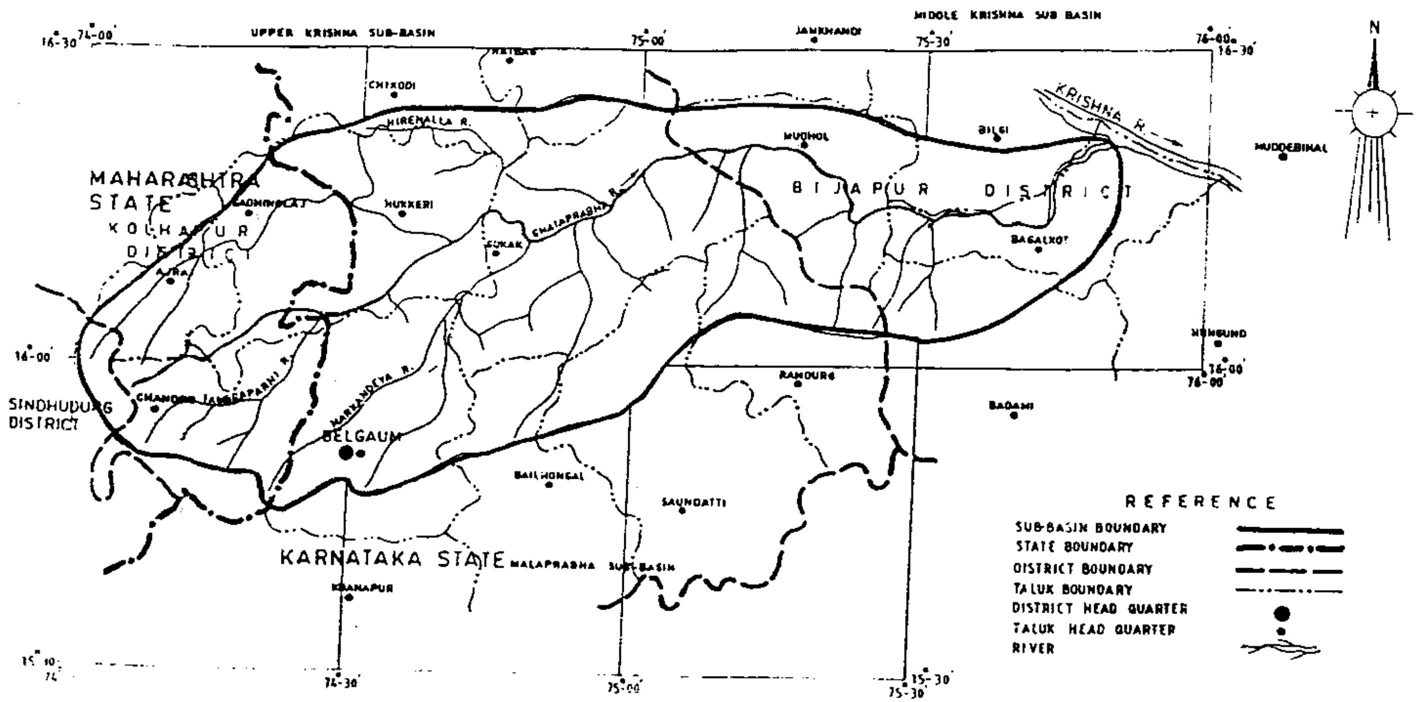

PLATE 1. ADMINISTRATIVE MAP OF GHATAPRABHA SUB BASIN.

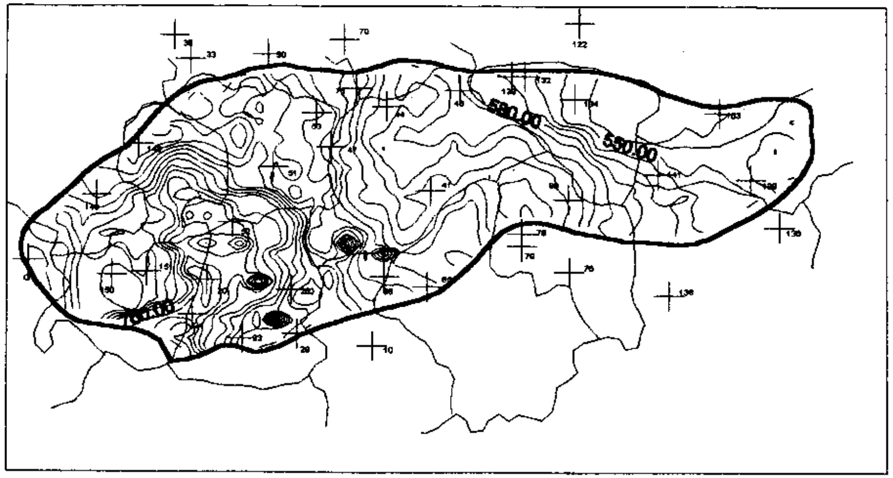

Plate 2.0 : Krigged Ground Level Contours

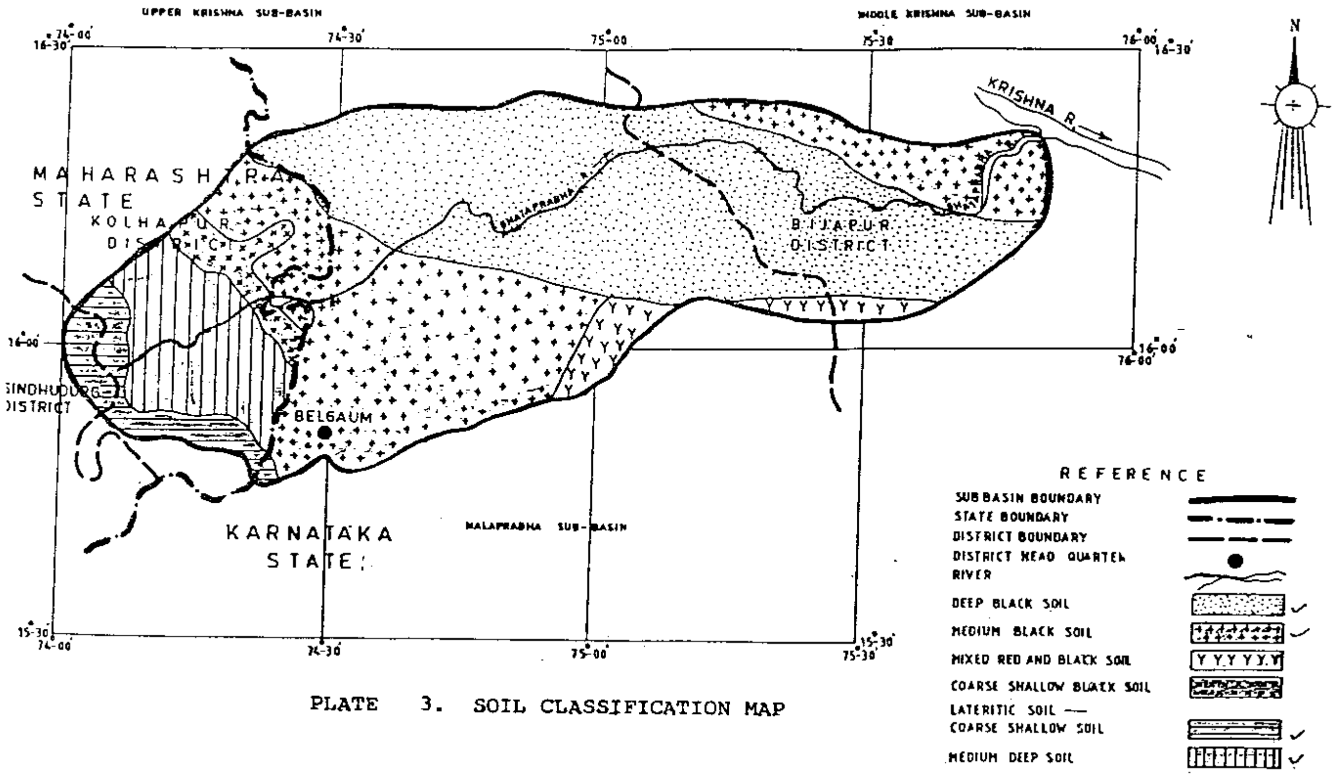

PLATE 3. SOIL CLASSIFICATION MAP

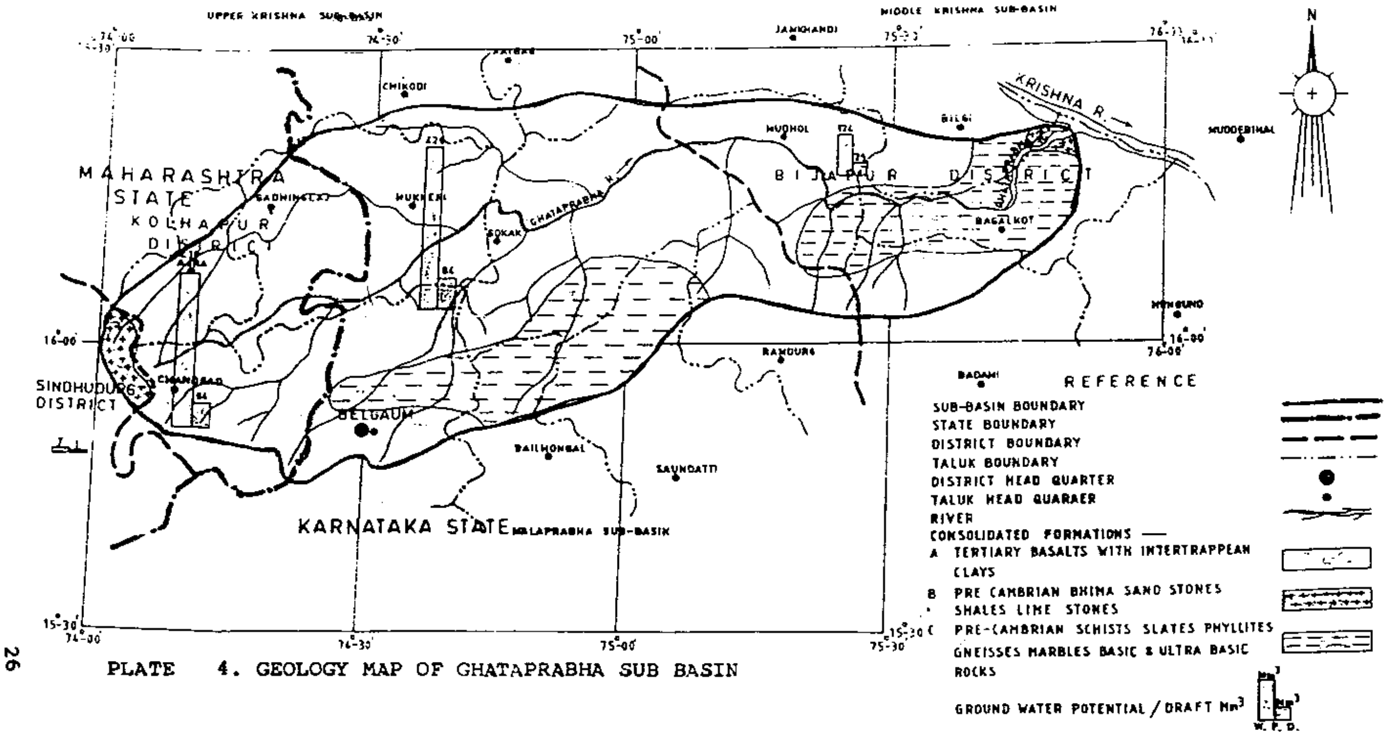

PLATE 4. GEOLOGY MAP OF GHATAPRABHA SUB BASIN

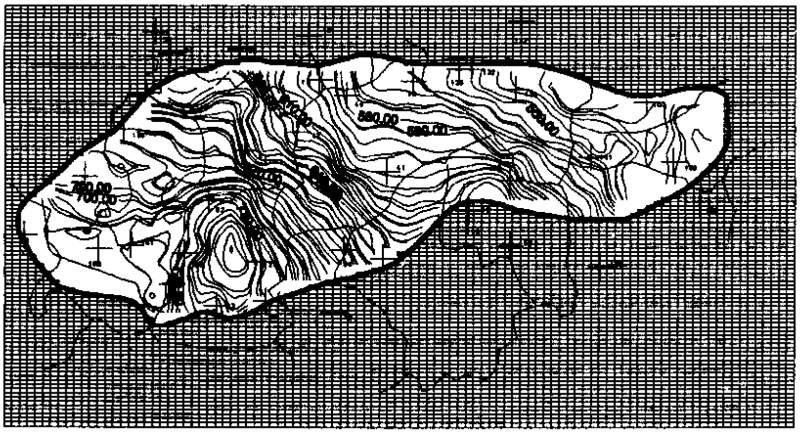

PLATE 5(A). PRE-MONSOON GROUND WATER LEVEL TREND IN FIRST LAYER.

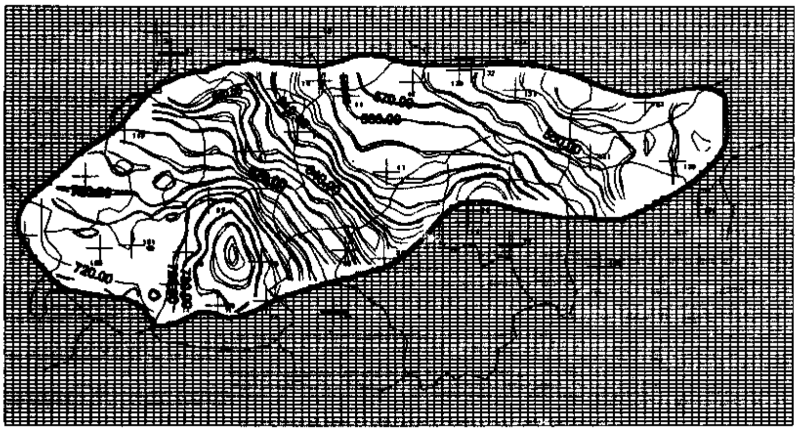

PLATE 5(B). POST MONSOON GROUND WATER LEVEL TREND IN FIRST LAYER.

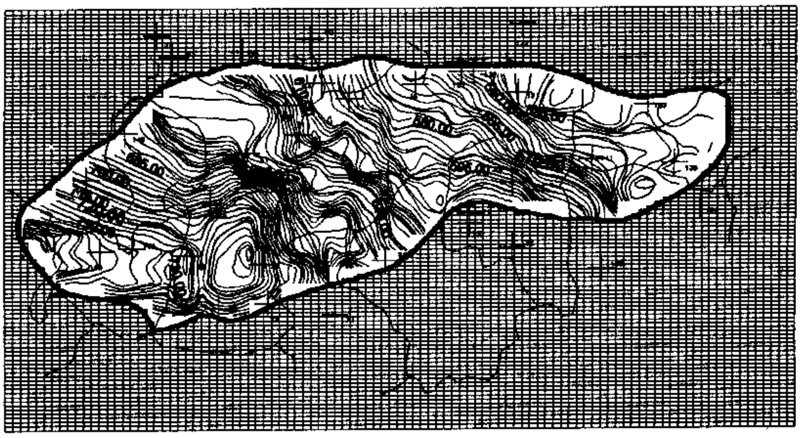

PLATE 6(A). PRE-MONSOON GROUND WATER LEVEL TREND IN SECOND LAYER.

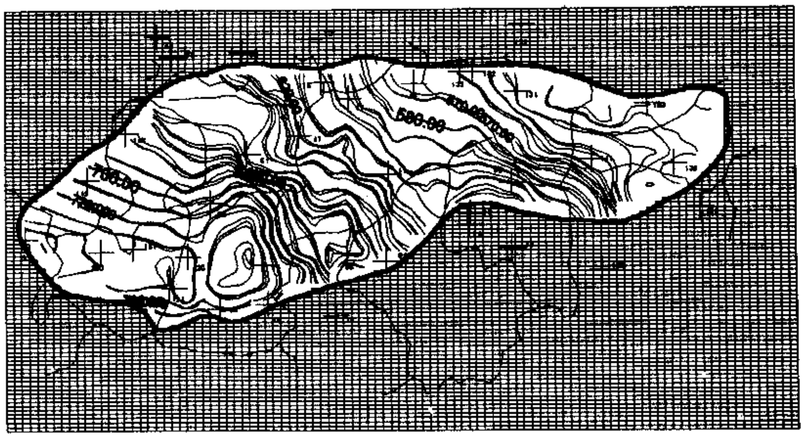

PLATE 6(B). POST-MONSOON GROUND WATER LEVEL TREND IN SECOND LAYER.

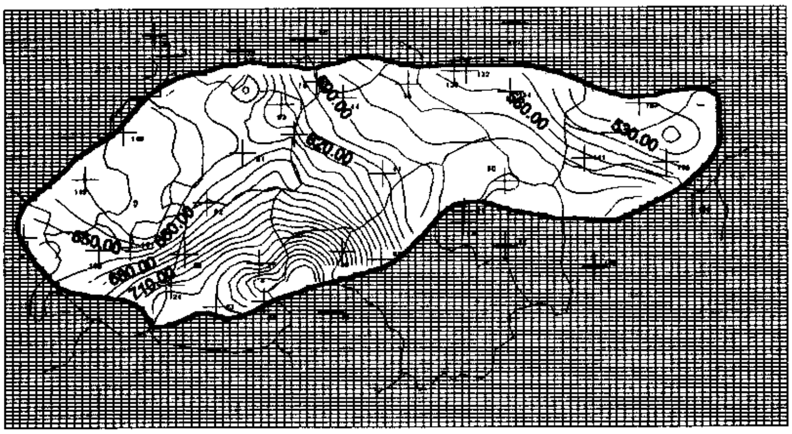

PLATE 7(A). PRE-MONSOON GROUND WATER LEVEL CONTOURS FOR THE SEASON 1982-83 IN FIRST LAYER.

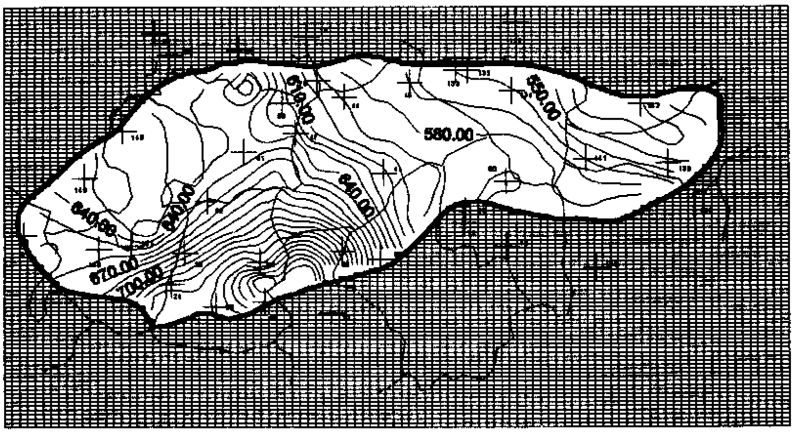

PLATE 7(B). POST-MONSOON GROUND WATER LEVEL CONTOURS FOR THE SEASON 1982-83 IN FIRST LAYER.

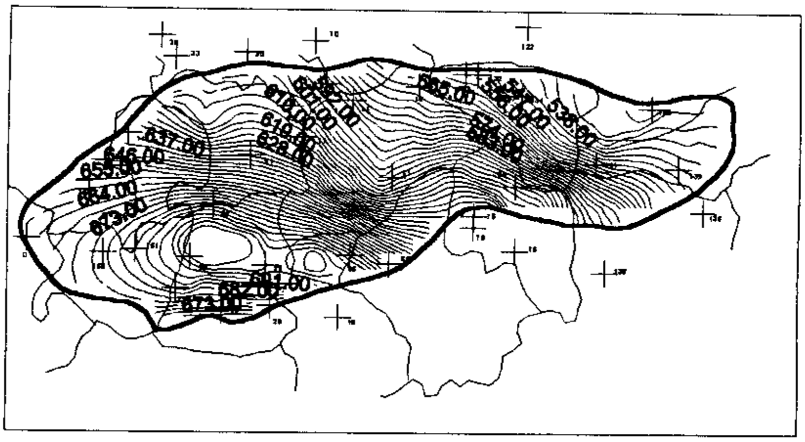

PLATE 7(C). PRE-MONSOON GROUND WATER LEVEL CONTOURS FOR THE SEASON 1982-83 IN SECOND LAYER.

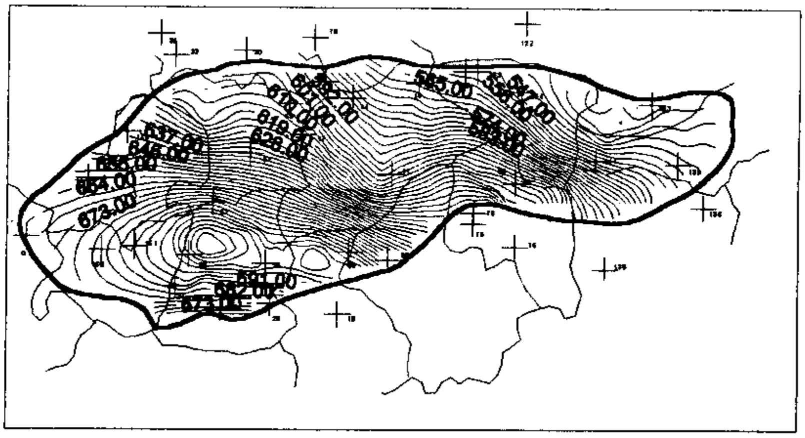

PLATE 7(D). POST-MONSOON GROUND WATER LEVEL CONTOURS FOR THE SEASON 1982-83 IN SECOND LAYER.

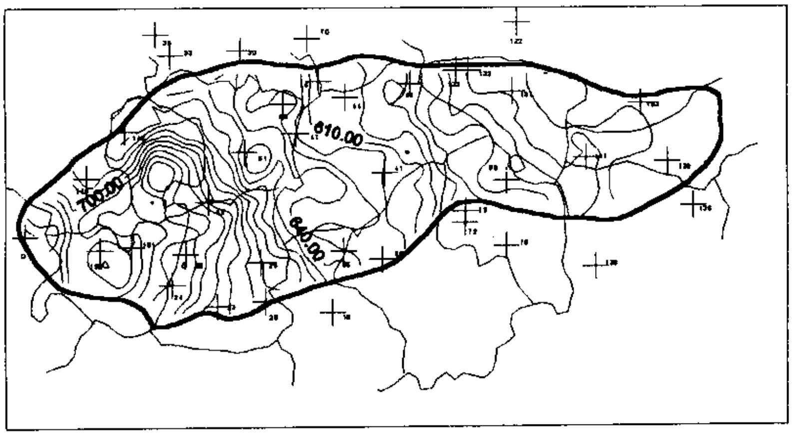

PLATE 8(A). KRIGGED SOIL BOTTOM LEVEL.

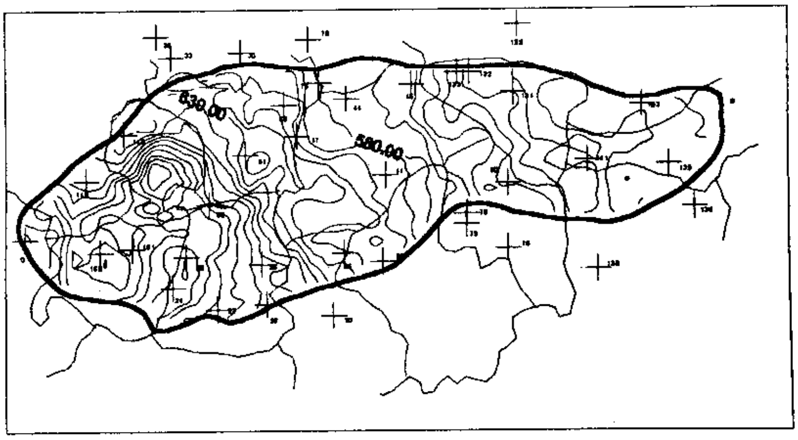

PLATE 8(B). KRIGGED WEATHERED BOTTOM LEVEL.

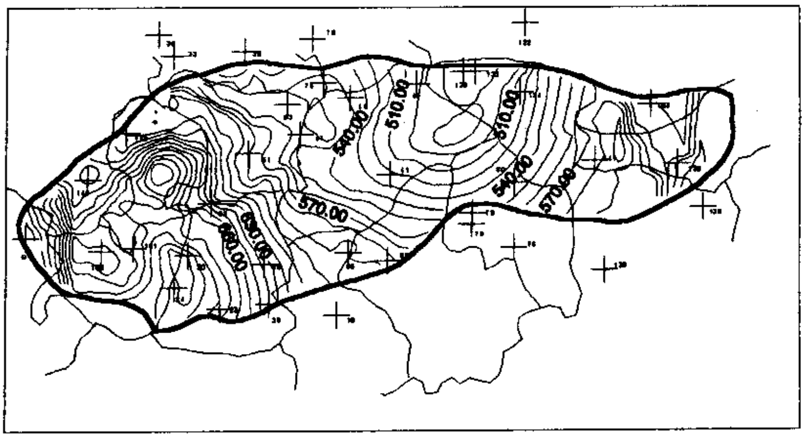

PLATE 8(C). KRIGGED PARTIALLY WEATHERED BOTTOM LEVEL.

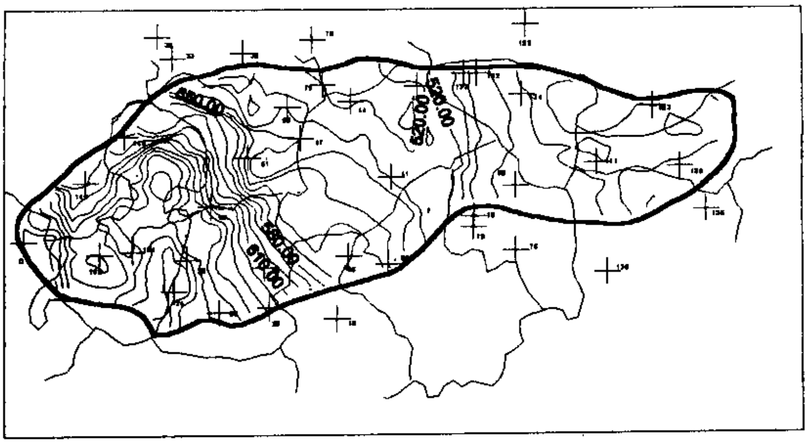

PLATE 8(D). KRIGGED FRACTURED BOTTOM LEVEL.

PLATE 9(A). CROSS SECTIONAL VIEW AT COLUMN 150.

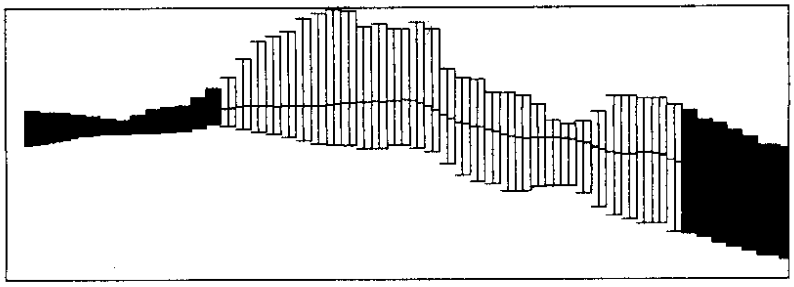

PLATE 9(B). CROSS SECTIONAL VIEW AT COLUMN 60.

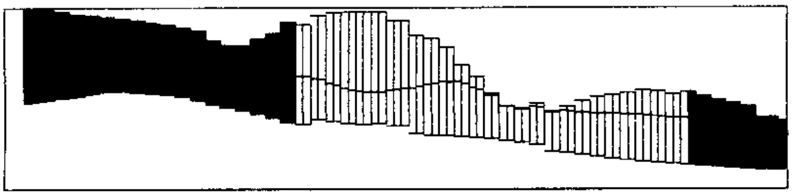

PLATE 9(C). CROSS SECTIONAL VIEW AT COLUMN 90.

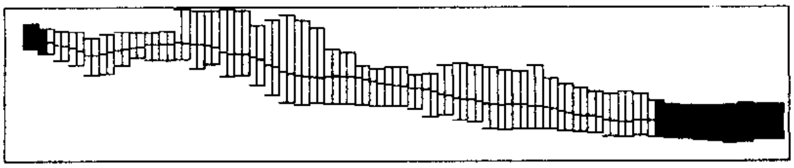

PLATE 9(D). CROSS SECTIONAL VIEW AT ROW 60.

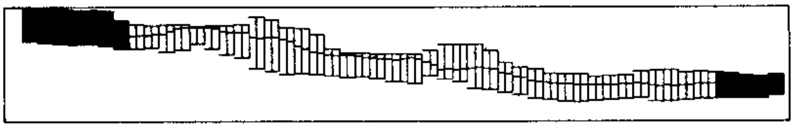

PLATE 9(E). CROSS SECTIONAL VIEW AT ROW 80.

x = 2.095 km.
y = 1.116 km.
No. of layers = 2.

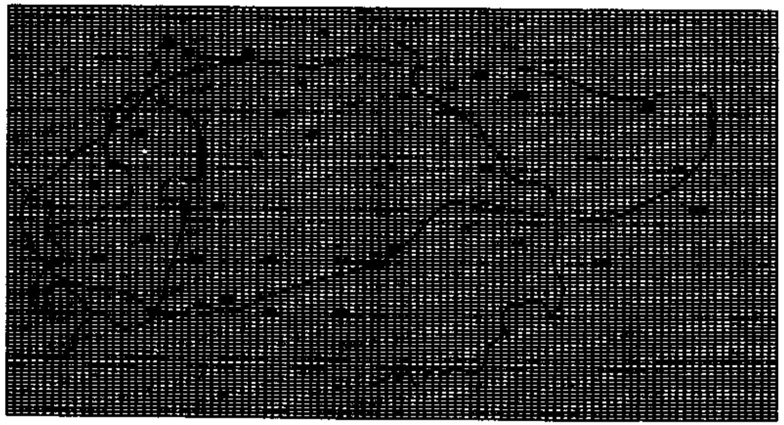

PLATE 10. FINITE DIFFERENCE GRID.

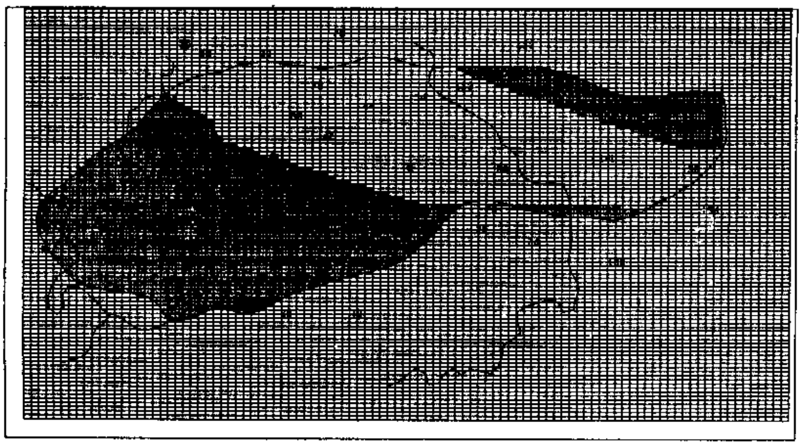

PLATE 11. HYDRAULIC CONDUCTIVITY ZONES IN LAYER FIRST.

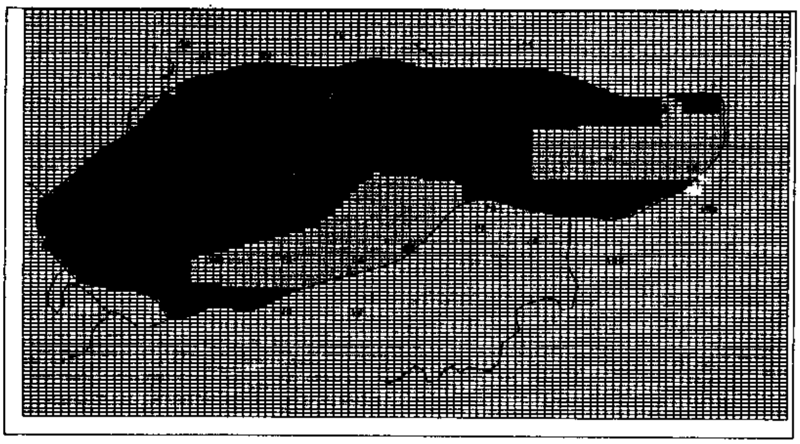

PLATE 12. HYDRAULIC CONDUCTIVITY ZONES IN LAYER SECOND.

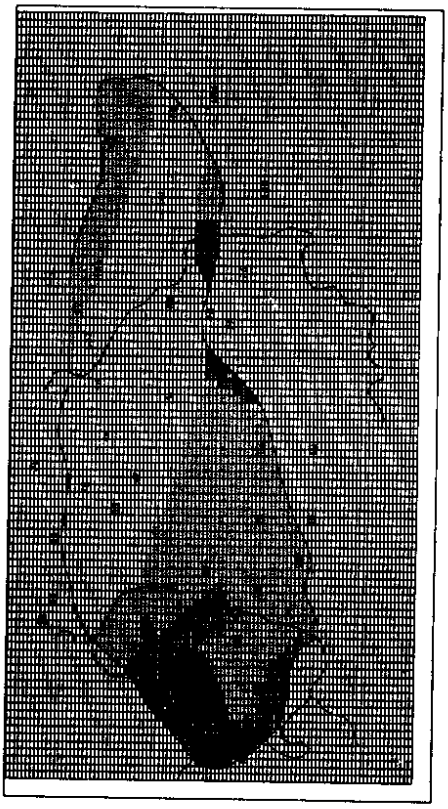

PLATE 13. STORAGE CO-EFFICIENTS ZONE IN LAYER FIRST.

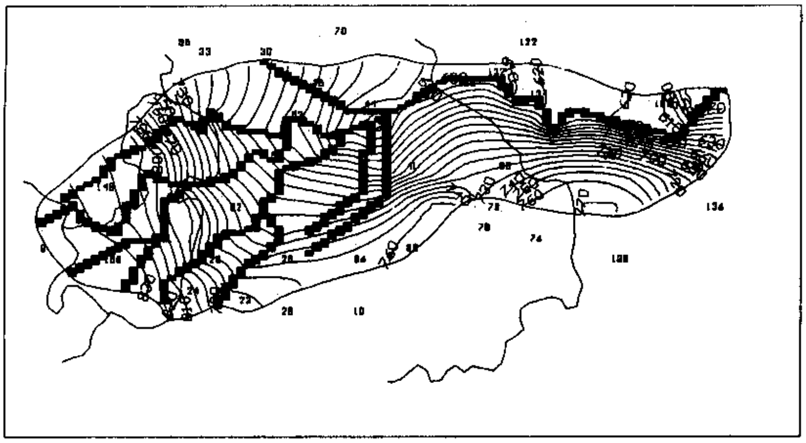

PLATE 14. CALIBRATED WATER LEVEL CONTOURS IN LAYER FIRST.

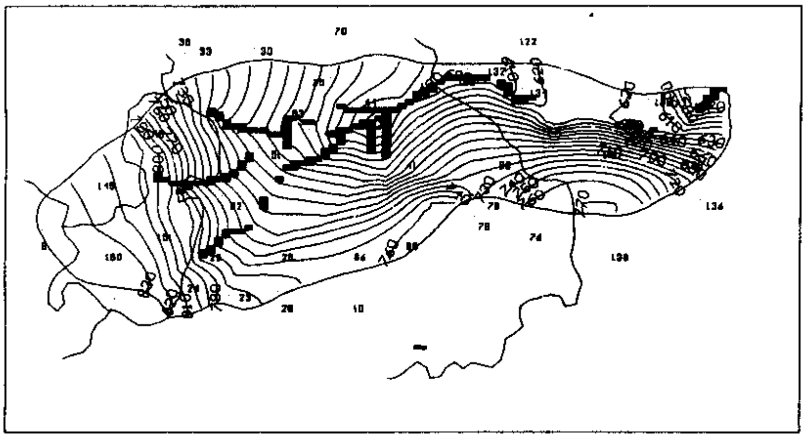

PLATE 15. CALIBRATED WATER LEVEL CONTOURS IN LAYER SECOND.

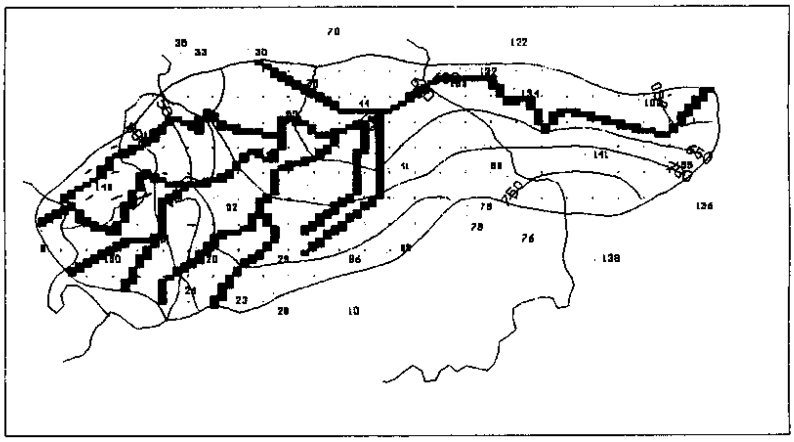

PLATE 16. VELOCITY VECTORS FOR CALIBRATED MODEL IN LAYER 1.

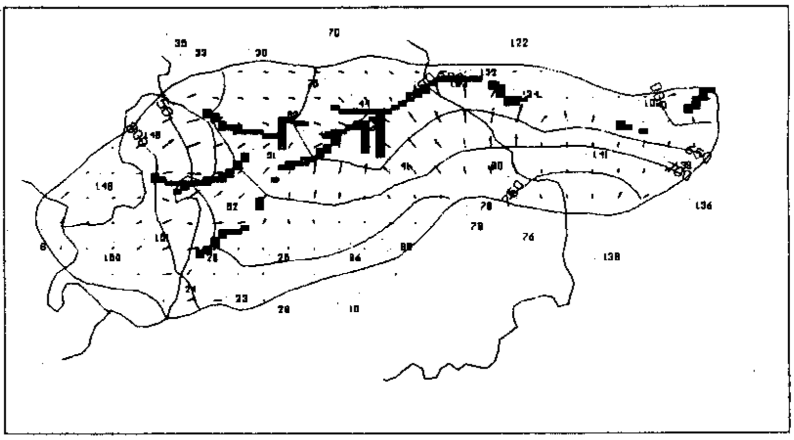

PLATE 17. VELOCITY VECTORS FOR CALIBRATED MODEL IN LAYER 2.

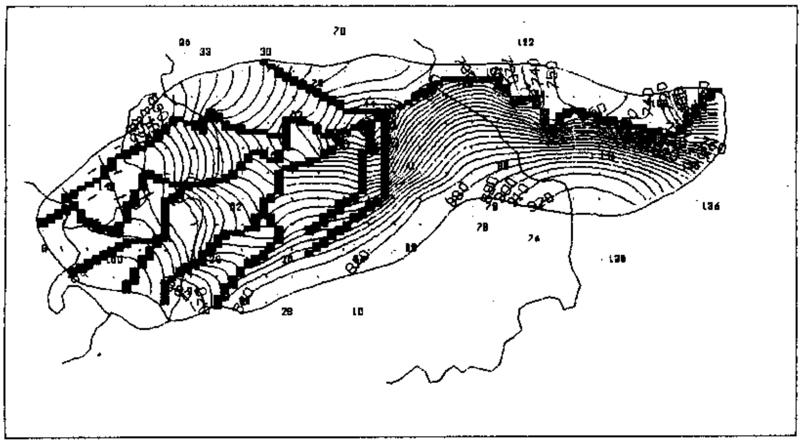

PLATE 18. STEADY STATE WATER TABLE CONDITION IN LAYER 1.

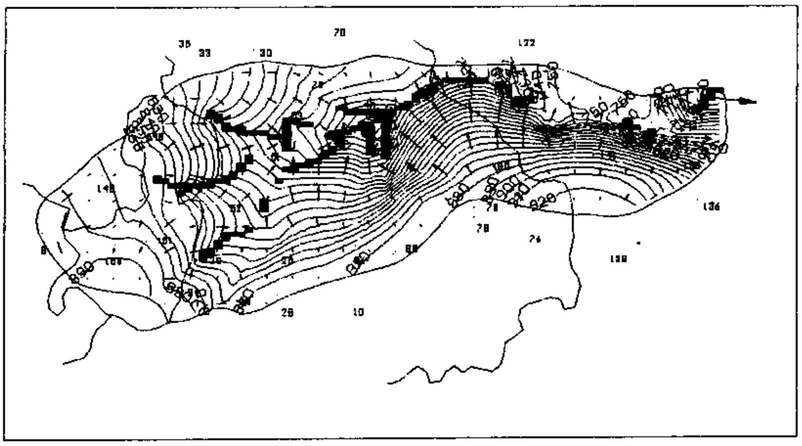

PLATE 19. STEADY STATE WATER TABLE CONDITION IN LAYER 2.

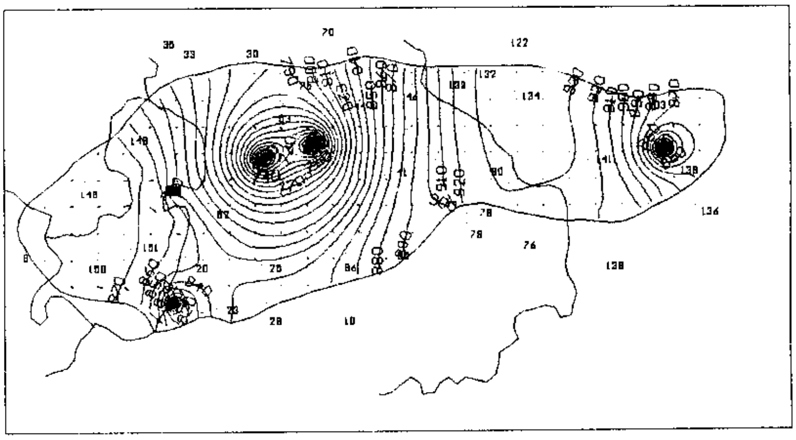

PLATE 20. VALIDATED STEADY STATE WATER TABLE CONDITION IN LAYER 1.

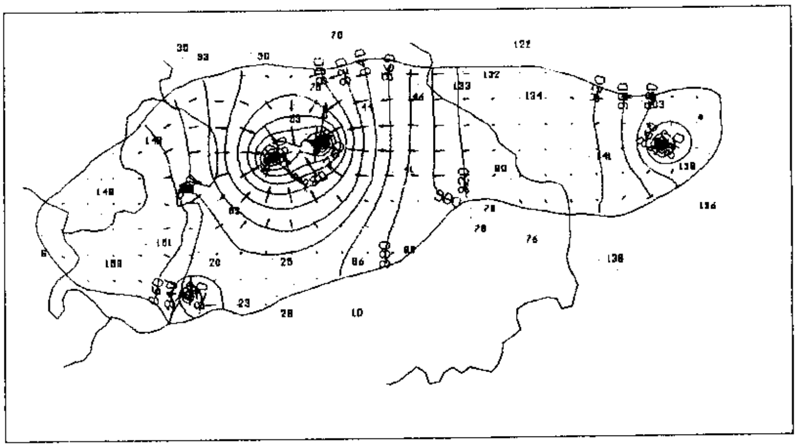

PLATE 21 VALIDATED STEADY STATE WATER TABLE CONDITION IN LAYER 2.

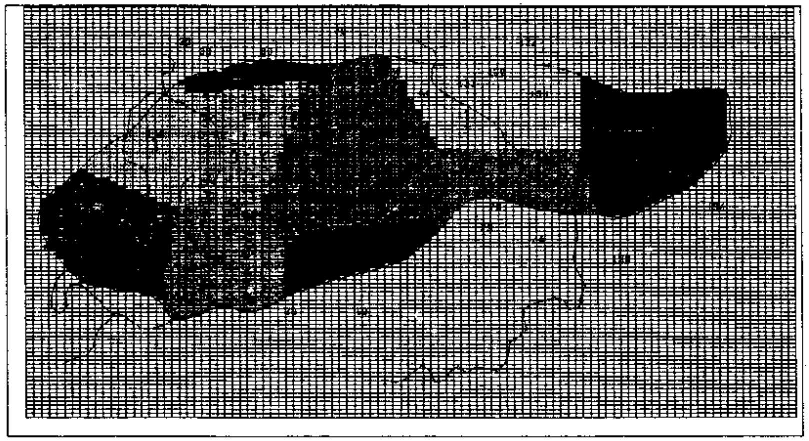

PLATE 22. RECHARGE DISTRIBUTION ZONES ON LAYER 1.

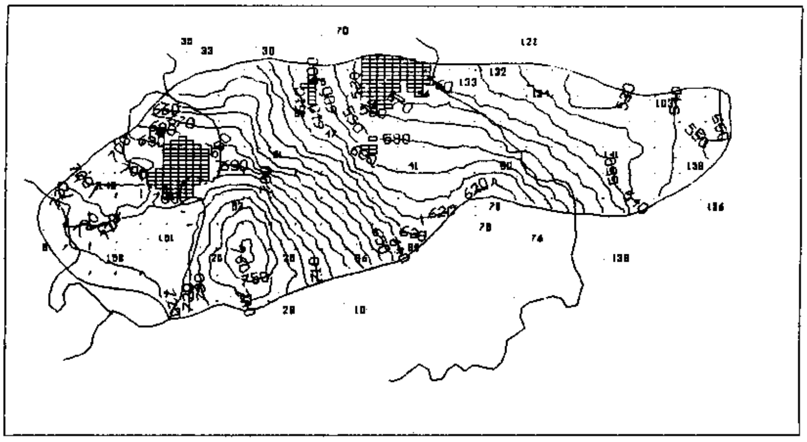

PLATE 23. VALIDATED TRANSIENT WATER TABLE CONDITION FOR THE YEAR 1982-83 IN LAYER1.

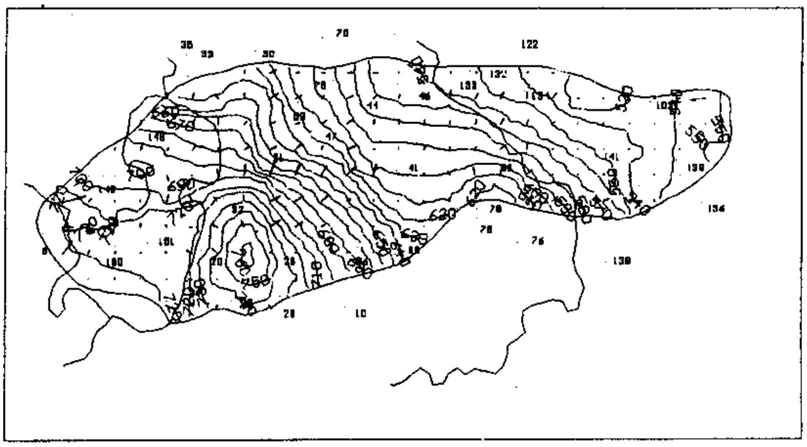

PLATE 24. VALIDATED TRANSIENT WATER TABLE CONDITION FOR THE YEAR 1982-83 LAYER 2.

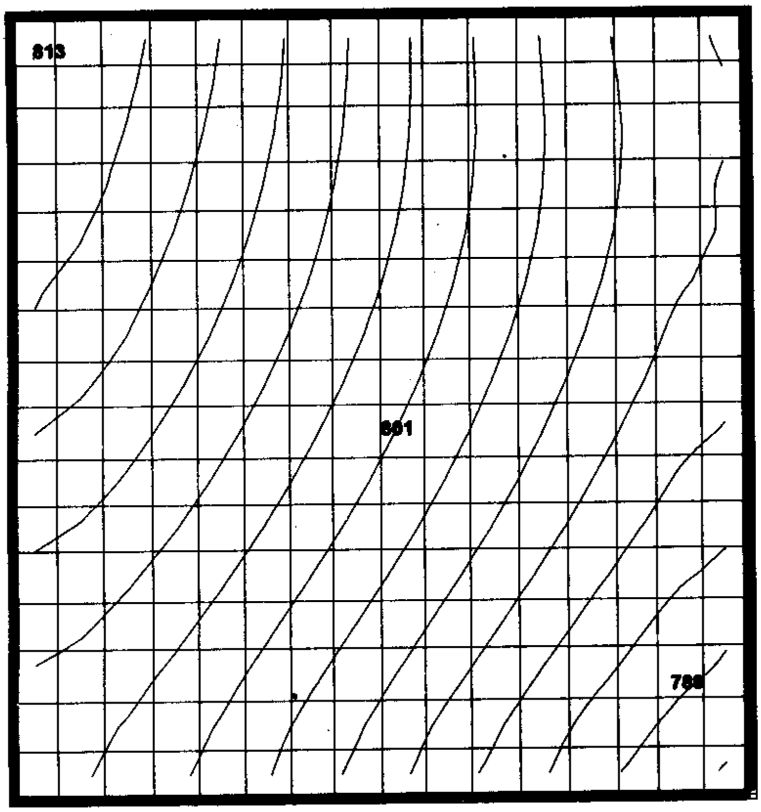

PLATE 25. BASE CASE FOR WELL DESIGN.

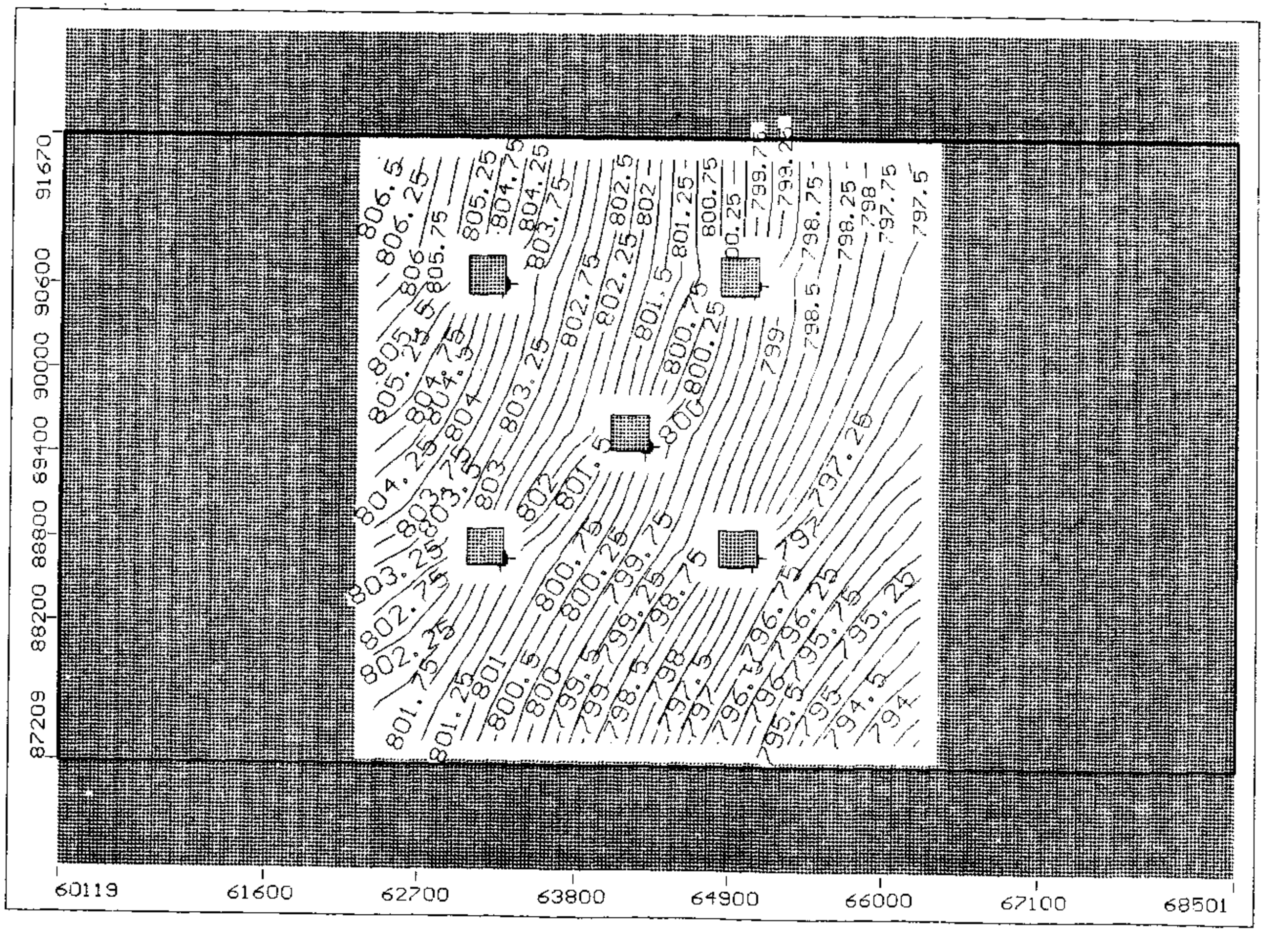

PLATE 26(a).WATER LEVEL CONTOURS WITH WELL PRODUCTION OF 10 CU. m/day

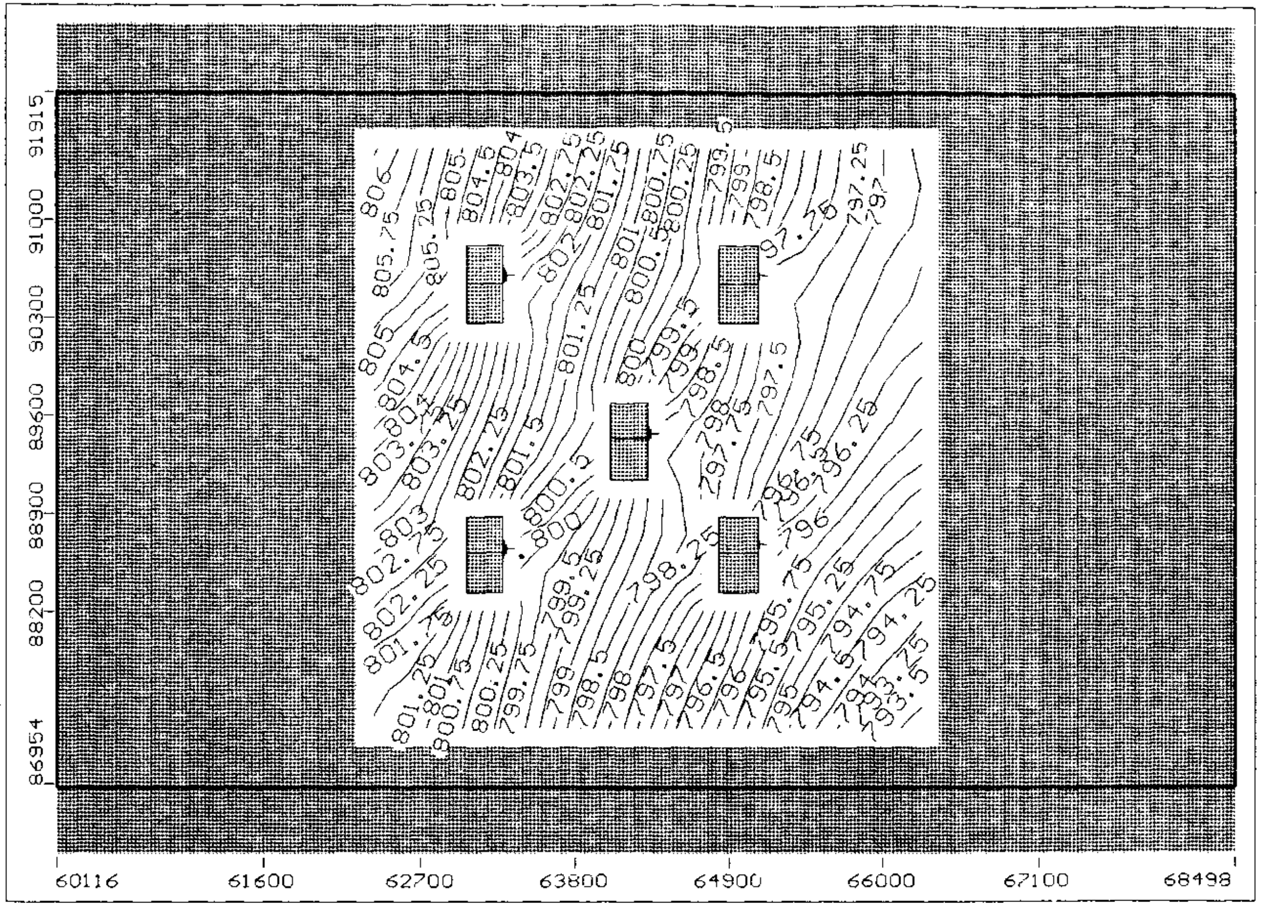

PLATE 26(b). WATER LEVEL CONTOURS WITH WELL PRODUCTION OF 100 cu. m/day.

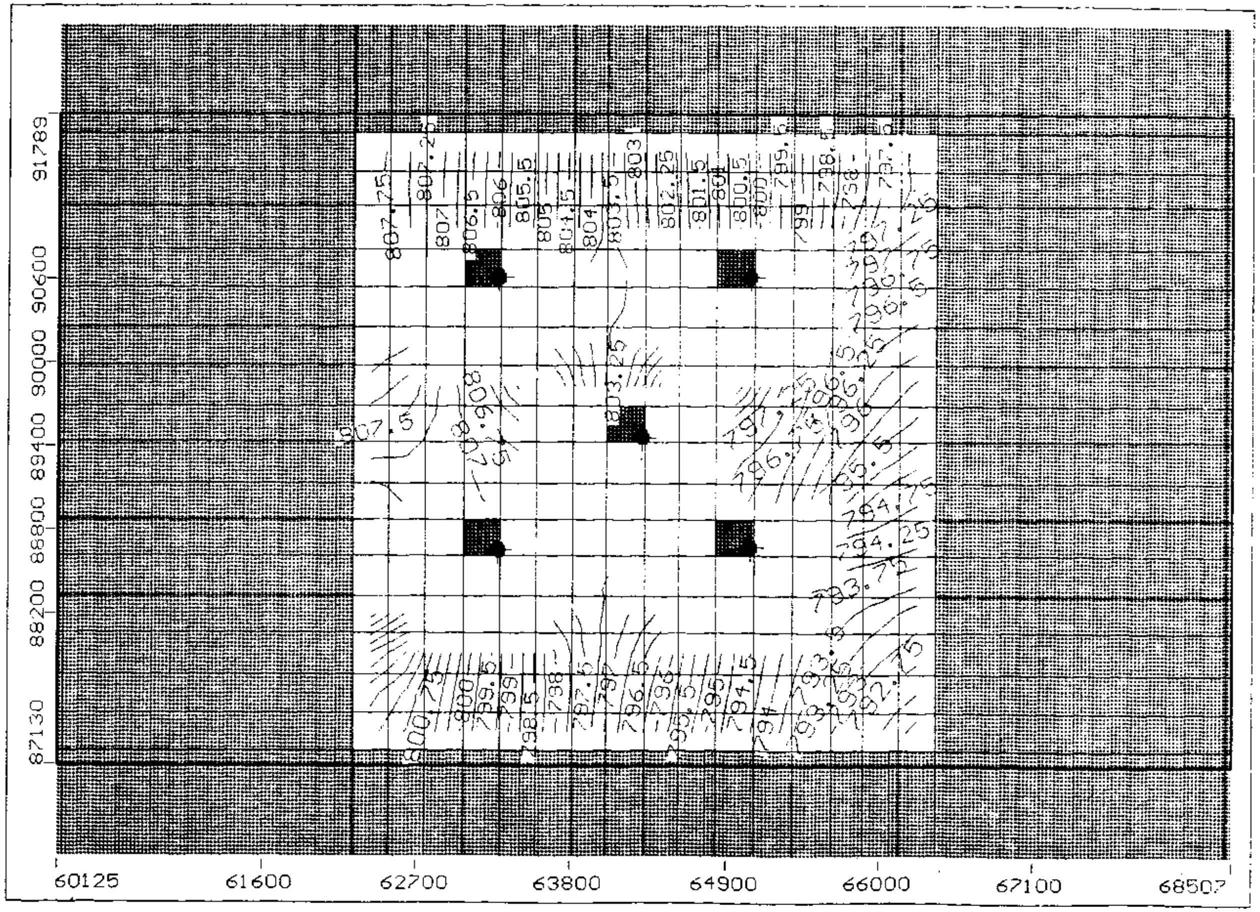

PLATE 26(c). WATER LEVEL CONTOURS WITH WELL PRODUCTION OF 500 cu. m/day.

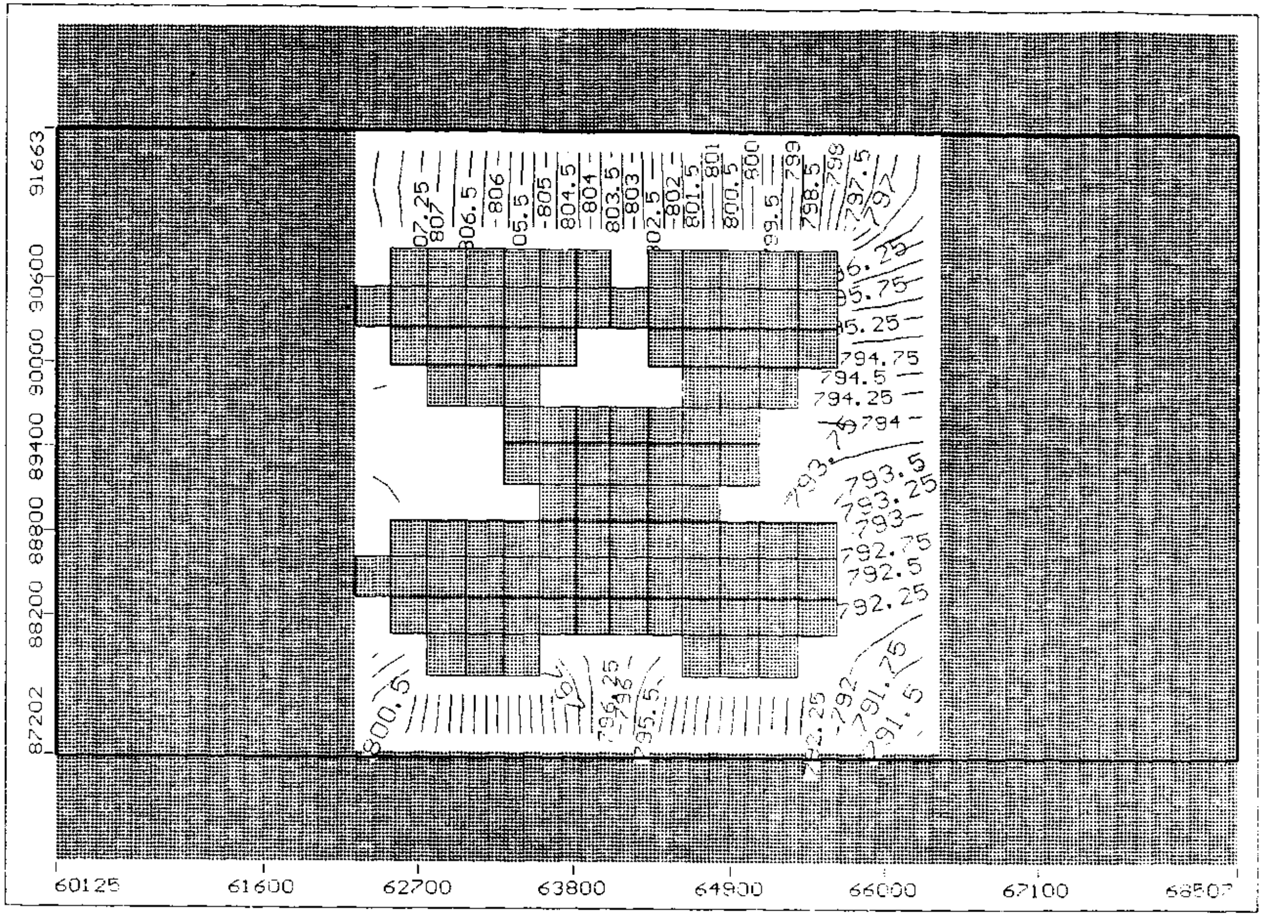

PLATE 26(d). WATER LEVEL CONTOURS WITH WELL PRODUCTION OF 1000 cu.m/day.

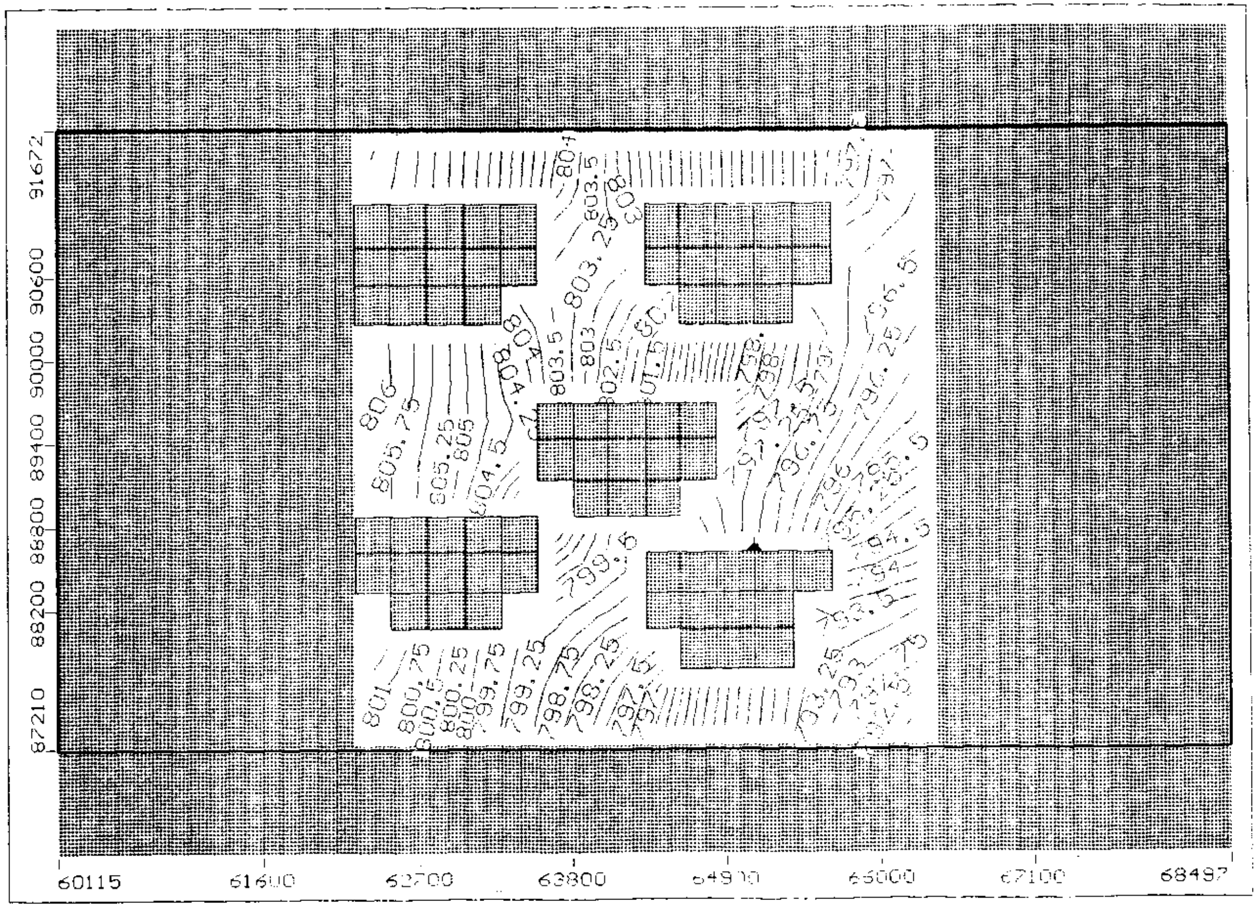

PLATE 26(e). WATER LEVEL CONTOURS WITH WELL PRODUCTION OF 500 cu. m/day and well spacing.

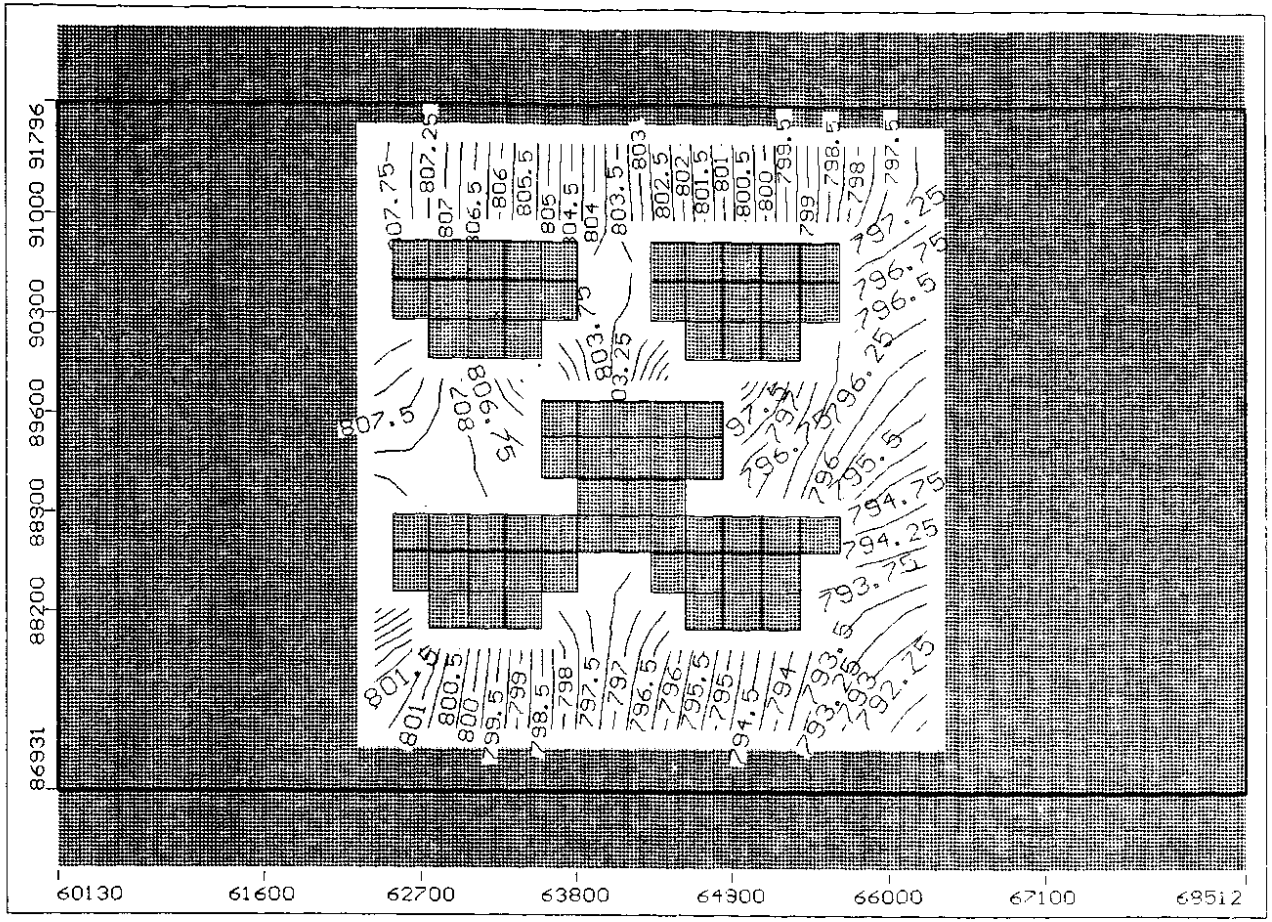

PLATE 26(f). WATER LEVEL CONTOURS WITH WELL PRODUCTION OF 500 cu. m/day half casing.

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