PROGNOSIS OF THE DEWATERING EFFECTS IN THE PLIOCENE AQUIFERS IN VELENJE COLLIERY USING MATHEMATICAL MODEL

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ABSTRACT

Hydrogeological problems have accompanied underground coal extraction activities in the Velenje colliery for a long time. The dewatering activities are most intensive in a Triassic dolomite aquifer under the seam and in Pliocene water bearing sands above the seam. During the forthcoming years the mining activities are moving towards the Preloge area in the northwestern part of the mine, where the isolating clay layer between the water bearing strata and the coal is not thick enough to ensure the required protection against mud-water inrushes. There are five line batteries of wells, consisting of 36 units for dewatering and prevention of rewatering, that are located around and above the coal seam.

For economical and technological reasons it would be convenient to abandon one of the line batteries, which is situated across the seam. The question appeared how such an action would affect the underground water pressure development. In order to find out the related difference in Pliocene water bearing sands, we tried to simulate the forthcoming occurrences with the mathematical model.

Finishing and moderating the model we faced a series of problems, as at unsteady state calculation as at the steady state too. Trying to moderate the model we reached all the possible limits:

- changes in height of the lower and upper limit of the aquifer
- changes in transmissivity of the aquifer
- low values of permeability coefficient
- the demand for great depressions (300 and more metre)

We found some successful solutions for the calculation and link problems.
The model gives the results with probability of 68% and within the 1.2 bar errors. The 95% probability is reached with 2.4 bar errors. For any different simulated variant it is possible to forecast the pressure development, abandoning the certain line battery. Such model is also a useful tool for design of new dewatering objects which are needed for reducing the pressure in the water bearing sands above the coal seam. This is the only way to increase, by safety criteria calculated, permitted excavation height.

INTRODUCTION

The Velenje Coal-mine is one of the largest and most modern equipped collieries in Europe. It is in the northeastern part of central Slovenia where the Šalek Valley represents a tectonic depression, filled with more than one thousand metres of Pliocene sediments. The sedimented materials represent the complete fill up sequence ranging from sub-aerial to lacustrine clastic sediments. The fluviatile sediments, transported from the northern and northwestern side sometimes interrupted this sequence. The coal seam is at average 60m thick (max. 160m) and deposited in the depths from 200m to 500m. Above the coal seam are Pliocene and quaternary roof sediments. These sediments consist of clay, mudstone and sand. They represent the so called multi layer aquifer, which is potentially risky for safe underground coal extraction.

Production of the Mine reaches four million tons per year, and the assured reserves amount approx. 300 million tons (at 600 million tons of geological reserves). Fig. 1 shows the sketch cross section of the basin.

The hydrogeological problems are accompanying the underground coal extraction activities in the Velenje colliery for a long time. Dewatering activities are most intensive in a Triassic dolomite aquifer under the seam and in a Pliocene water bearing sands above the seam. In the years between 1960 and 1974, some expansive dewatering activities of a certain part of the roof aquifers were finished and the coal below extracted.

In the future the mining activities will move towards the northwestern part of the mine. There the isolating clay layer between the water bearing strata and the coal is not thick enough to ensure the needed protection against the mud-water inrushes.

For the needs of dewatering of the Pliocene aquifers in the Velenje lignite mine there are five line batteries of wells. These consist of thirty-six units for dewatering and prevention of rewatering. The line batteries are around and above the coal seam: the central line battery (V-9o - VO-9), the northwestern line battery (BV-2 - BV-13), the northern line battery (BV-20), the line battery "depression" (V-11n - V-12z), the southern line battery (BV-22 - BV-31). The central line battery was finished as a testing line already in 1981 and the other ones until 1988.

The fig. 2 shows the Preloge mine field situation and the locations of the dewatering objects.

For economical and technological reasons, abandoning of the line battery across the seam would be convenient. The question appeared how such an action would affect the underground water pressure development above the mine field.

According to the data provided by the hydrogeological department of the mine, for the years 1994 and 1995, the central line battery is receiving at the time some 55-60 % of all the water from roof aquifers. This line battery is very well situated considering the borders of the sand layers that fade out towards south. Therefore, this line battery causes great pressure lowering in the northwestern part of the mine at the time.

The proposed action would definitely affect the water pressure distribution in the Pliocene aquifers (mostly in the northwestern and partially in the central part of the mine), therefore a detailed study of the possible consequences was considered important.

To find out the related difference in Pliocene water bearing sands, we tried to simulate the forthcoming occurrences with the mathematical model.

PREPARATION OF THE MODEL

For the modelling we applied the mathematical model MODFLOW (software package developed by U.S.G.S and constantly improving). The graphical interface was the VisualModflow developed by Waterloo Hydrogeologic, Canada. The program is the really three-dimensional one. The calculation part is based on the finite differences method.

The spatial position of the model

We defined the position of the model with local coordinates Ymin = 3500, Ymax. = 8000, Xmin = 7000, Xmax. = 9500. The model is not extending over the whole site where the Pliocene roof aquifers are appearing. However, it is limited on the northwestern and northern side by the recharging boundaries (general head boundaries). These enable the dynamic modifications of the water table in the calculation. Towards the east, south and southwest, the Pliocene aquifers fade out. Therefore, in these areas the aquifer limits are presented as physical boundaries of the model or as an inactive part of the model. Fig. 3. shows the shape of the model we used.

Knowledge and experience from past years modelling attempts determined the model limits. To achieve as good a result as possible, we constructed the grid of the model in such way that allowed at least three (even more where possible) empty elements between each dewatering object and its neighbour. After some corrections, the applied grid consisted of 164 X 107 elements in three layers on the Z coordinate. Thus, the model is built of 52644 elements.

We decided to choose the time limited modelling, so the model started to simulate the processes in aquifers from 1984 onwards. Until this year some local activities did happen (test pumping, well activations, damage reparations) but the data are too poor and the time of activity too limited to include them into the model.

Pliocene roof aquifers classification

In 1981 we divided the roof aquifers of the Velenje depression into Pliocene and Quaternary. We divided the Pliocene aquifers into three distinct packages. The aquifers directly above the seam and isolating layer - first water bearing sands (Pl_1), the aquifers placed 20-80 m above the coal seam (Pl_2) and upper Pliocene aquifers (Pl_3). More criteria were responsible for this division: water table level in a single aquifer, pumping reactions, water chemical analyses, geophysical properties. Fig. 1 shows the division of the roof aquifers.

The most interesting aquifers are the first water-bearing sands. The pressure of the underground water in these sands directly affects the safety of mining. On many locations these sands appear in a shape of limited lenses, without any direct connection to the surrounding sediments. This means that we can get relatively high primary pressure when we drill into the lens, but one active dewatering unit leads to a rapid fall of the pressure and water quantity. However, the dewatering wells are constructed in the way to capture the whole Pl_2 and somewhere even a part of Pl_3 complex too. These aquifers are thicker and give up to 90% of all the Pliocene roof water. Some wells are dewatering only the Pl_2 and Pl_3 aquifers and indirectly lower the pressure in the Pl_1.

The aquifers marked Pl_2 and partially Pl_3 are composed of several mudstone and sand sequences but hydrodynamically much more homogenous than the first water bearing sands. The whole dewatering liable water-bearing series is round 150 m's thick but the thickness of the water-bearing layers is minor while some impermeable or low permeability layers of clay, sandy clay, silt and mudstone are placed in-between. In spite of geological heterogeneity the water bearing series acts in a more homogenous way than the first water bearing sands above the coal.

Determination of the aquifer thickness

It is difficult to determine the aquifer thickness. The first problem is the heterogeneity of the whole aquifer series that consists of various separate layers with intermediate impermeable or low permeability layers, and not also the lateral connection. The second problem deals with the determination of the dewatering affected part of the series. In the well neighbourhood it is relatively simple but the determination becomes complicated in the areas away from the wells and relevant piezometry. The third problem is the areas where no data exist. In the case described last, we had to accept a compromise. We treated many aquifer thickness data in areas where they were available and then we widened them with means of extrapolation to the areas with very few or none data.

Defining the lower boundary of the aquifer was much easier, while the fist water bearing sands are frequently registered over the whole modelling area. We also extrapolated the boundary areas.

The aquifer thickness does not represent the whole layer package thickness. The term describes only one part of the series. Because of complicated geological structure, modelling each water bearing layer separately is impossible. Therefore, we decided to join the water bearing layers in one layer. The aquifer thickness is therefore a synthetic (joint) thickness used for later calculations.

Determination of the model limits

The model limits represent the borders of the active layers of the model and are on the eastern, southern and a southeastern side determined by the sand layer borders, where these sands fade out. Towards north and northwest, where no coal seam appears, the aquifers join in one, almost uniform and well-connected series with mostly equal water tables. This is the only real water source part and the direction from where the water comes. The water origin is in Quaternary aquifers or occasionally directly from precipitation.

The simulated northern and northwestern limit is a water source border. Fig. 3 shows its situation. The model allows use of the adaptive (general head boundaries), dynamic water table data instead of constant source level.

Determination of the hydrodynamic characteristics of the modelled layers

For each element of the model entering of its physical characteristics (expanse, thickness, spatial position) and hydrodynamical characteristics (permeability coefficient, specific yield (aquifer type under pressure) and effective porosity (for an opened aquifer) are obvious. The dewatering process carried out in Velenje coal-mine is changing the aquifers from closed ones into opened ones, so all three characteristics of the layers must be entered.

Determination of the permeability coefficient

For the complete series of the roof aquifers the values for the permeability coefficient were acquired through many pump tests performed on the dewatering wells. For the areas where no wells were drilled, we can use the piezometry pump test data, which are limited to one layer. Therefore, the mean permeability coefficient value $k = 2.5*10^{-6}$ m/sec was chosen. During the calibration of the model the values were modified due to the specific area from $3.8*10^{-8}$ to $2.5*10^{-6}$ m/sec.

Determination of the coefficient of storage

Only a few values for a coefficient of storage (specific yield) are given. Due to the model calibration results we decided to adopt one certain value $S_0 = 5*10^{-5}$ m^{-1} for the whole area.

Determination of the effective porosity

Because no data for effective porosity were achieved through past years, we had to use the adopted value $n_{ef} = 5\%$. According to the references this is the value for the dense silty sands. However in the zones where more silt is present one can expect some lower values too.

Determination of the primary water table level

Like physical characteristics of the modelled aquifers, the primary water table level for the whole area needs to be determined too. In case of working on steady state, the primary pressure values are not so very important (except the stability calculation). The primary pressure values are especially important for the case of non stationary state when we try to model the spatial time dependant pressure development. The water table of a certain point in time is a result of successive time development in this point. We chose the primary pressure distribution of the 1982. The effect of the pumping activity from the years 1960-1974 was relatively low and the tests in central line battery were still time limited and therefore the effects not so large.

CALIBRATION OF THE MODEL

The calibration of the model was very complicated, because the present state of the water table is a result of dewatering and mining activities through past years. Also the aquifers are laterally and vertically variable and connected.

In the first instance we assumed that the pressure distribution was the same as in 1982 when a piezometric level were stabilised and the effects of the central line battery are not evident yet.

Calibrations caused great troubleshooting because the model was not stable and the calculation was impossible. The slightest change of input parameters caused a final breakdown. Trying to moderate the model we reached all the possible limits and problems:

- changes in height of the lower and upper limit of the aquifer: the lower height is changing for up to 450m, the thickness however from zero to 120m.

- changes in transmissivity of the aquifer: these changes are linked with spatial changes of permeability coefficient and changes of the aquifer thickness. The model does not allow quick and big changes of transmissivity, but the thickness changes caused exactly that. So we finally had to adopt a uniform value as average aquifer thickness to reach the calculation stability. For the calculation we adopted the thickness of 60m that represents average aquifer thickness captured in the wells of certain line batteries.
- permeability coefficient values. In our case the permeability coefficient values are very low (k $2.5*10^{-6}$ m/s).
- the aquifer depressurisation at each well may exceed 30 bars.

Reaching the steady state calculation stability, we passed to the unsteady state.

We intended to do the calibration of the model with the unsteady state in such way that we assigned the pumped volumes (somewhere calculated pumped values) to particular wells. Then we tried to reach the water table levels as close to measured water table as possible. In spite of great efforts the chosen way of simulation is evidently practically impossible. All the time we could notice that the water table on a single well started to rise or fall under the lower aquifer limit.

Some possible reasons for this are as follows:

- the dewatering concept used in Velenje coal mine is such that ensures always the maximal possible volume from each dewatering unit (gravitational in the colliery). Because of slight errors in assumed layer characteristics it is practically impossible to achieve that with the model using assigned pumped volumes.

- the hydrodynamical characteristics of the layer are change locally therefore the general scheme cannot cover such differences. This means that a particular well can pump too little or too much so the water table level can fall under the critical value. In such case the model itself is unable to exclude single units, but from our experience with other models we know that this can cause great oscillation and unstable calculation.

- the available measured pumping volumes' data, especially from 1984 to 1988 were acquired in too large time periods, so there are not enough qualitative data.

After considerable testing we found out that the chosen way of modelling is not appropriate and we finally decided to adopt the method of given pressure distribution on pumping spots = dewatering wells. The applied method has some limitations considering the possibilities to exclude one object for a certain period or include single wells in different times. However, dividing the modelling procedure into many steps or periods during which the wells display constant pressures is possible.

The calibration of the model is more precise when we can use given pumping volumes, and calculate than the opposite performance. Often, we can recognize that some dewatering units from a group with assumed constant water table level, after some times start to simulate inflow instead of pumping or vice versa. This problem occurs mostly on the area where many dewatering units are close together or positioned in a straight line. We solved these problems relatively successfully by optimizing the density of the grid of the model to avoid negative pumping results and artificial preservation of water table level on single wells.

RESULTS OF THE DEWATERING SIMULATION WITH MATHEMATICAL MODEL UNTIL 2005

All the limitations forced us to model the dewatering process of a single well by assumed constant pressure respective to the outlet point. To manage the situation, we had to divide the simulation into many sub-models, or periods. The time from January 1984 to December 1995 has been divided into five periods; the results of the calculation were applied for the calibration of the model.
The calculated water table levels in Pliocene aquifers for 1995 are shown on Fig. 4.

Some different occurrences were simulated for many periods from 1995 on:

- all dewatering wells are active like before.
- the dewatering wells of the central line battery are progressively abandoned
- drilling and activation of substitute objects (one or two wells)

Single calculation variants were chosen according to excavation time-plan of the Preloge mine field and foreseen possible optimal dewatering activities.

Calculation for the period 1995 - 1998

Considering the excavation time-plan, no need appears to change the dewatering activities until 1988. In the pumping simulation, besides the central, the "depression" and the northwestern line battery, the southern line battery was included.

The results show no real influence of southern line battery on the central line battery but enormous influence in the neighbourhood where until now, no special dewatering effects were present. Dewatering simulation results for period 1995-1998 are shown on Fig. 5.

Calculation for the period 1998 - 2000

Based on the excavation term plan we can expect that the dewatering objects of the central line battery are going to be abandoned due to the face advance across the line battery drive. Therefore, some more variants were simulated for the period between 1998 and 2000. The drilling and activation of substitute units - the dewatering wells BV-23 and BV-24 was taken into account and the possibility to let some of central line's wells active too.

The Fig. 6 shows the water table differences during the period considering the optimized dewatering variants. The related negative difference means a rise of the water table level consequently of abandoning of some wells.

Calculation for the period 2000 - 2005

The period after 2000 is characterized by the total abandonment of the central line battery. Considering the drilling and activation of substitute objects, some different variants were simulated, with and without the substitute objects.

Fig. 7 shows the water table differences during the period 2000 - 2005 considering the optimized dewatering variants.

CONCLUSIONS

The model forecasts different simulated variants of the pressure distribution until 2005, considering the abandoning of the central line battery. At 68% probability the error of the forecast is ± 1.2 bars and at 95% ± 2.4 bar.

From the forecast using the optimal variant the pressure distribution in the major part of the northwestern area and in the area between central and depression line battery is evidently going to stay at the same level as it was in 1995, until 2005. However, only a narrow area above the abandoned line battery is expected to rise in pressure up to four bars.

The pressure differences 1995 - 2005, shown by the model are in the range of measured and forecasted errors.

The required additional dewatering activities depend on isolating clay layer thickness and planned excavation level height considering the adopted safety criteria calculation.

The model showed the importance of drilling the substitute wells (BV-23 and BV-24), which can, with planned, optimized abandoning of the central line battery ensure slower rise of the water table above the excavation area.

Although the model allows for the inclusion of further changes in dewatering, we think that to predict simulation beyond 2010 or 2020, would not be reasonable at the moment. Because in the first place the mine plan may alter and secondly the model will be improved by the collation of further hydrogeological data. It is our intention to install monitoring equipment also in the areas where we have no data for a throughout model verification.

SKETCH GEOLOGICAL CROSS SECTION NW - SE

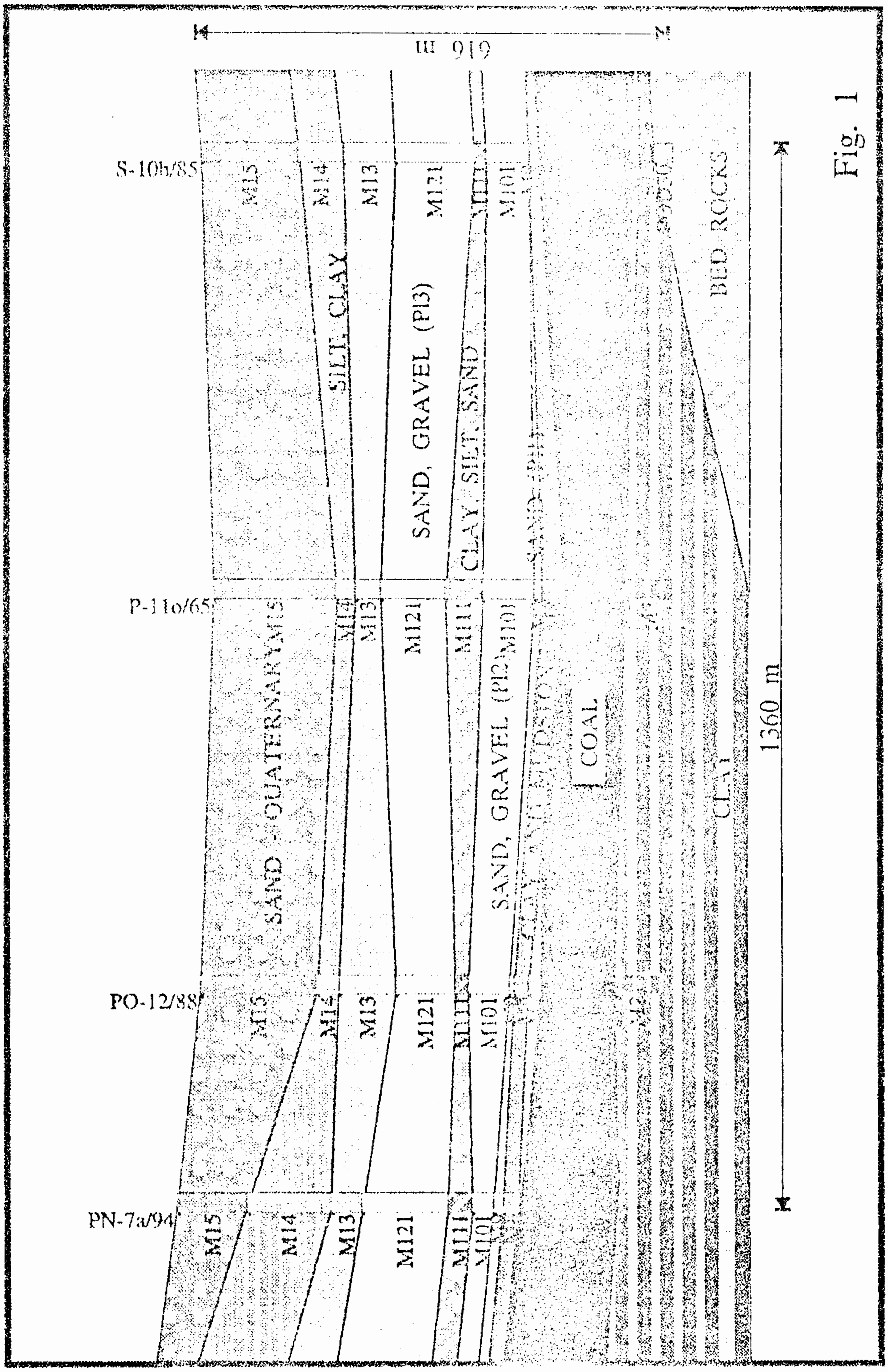

Fig. 1

LOCATIONS OF THE DEWATERING OBJECTS
AND THE MINE FIELD AREA IN THE FUTURE

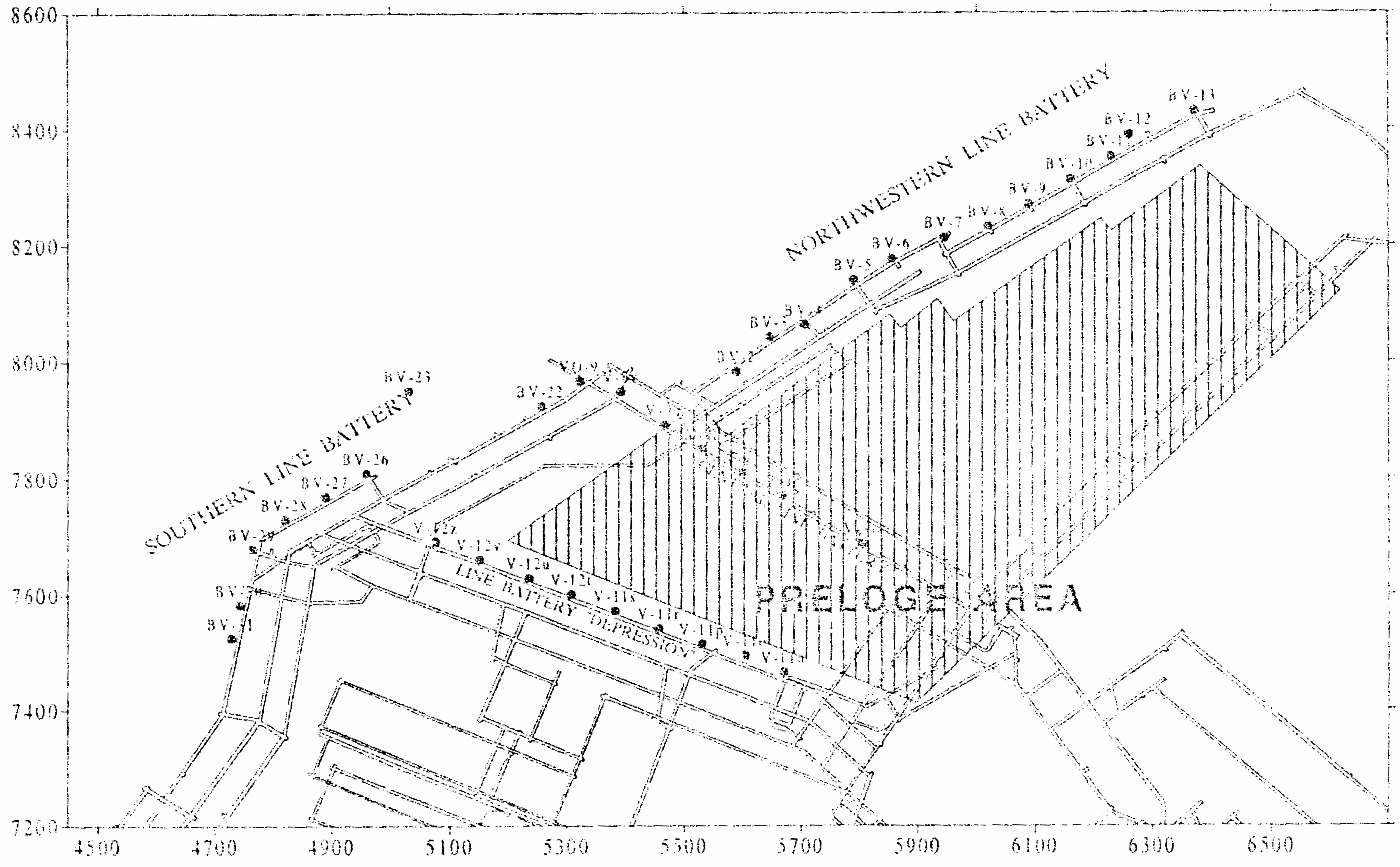

Fig. 2

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SPATIAL POSITION AND SHAPE OF THE MODEL

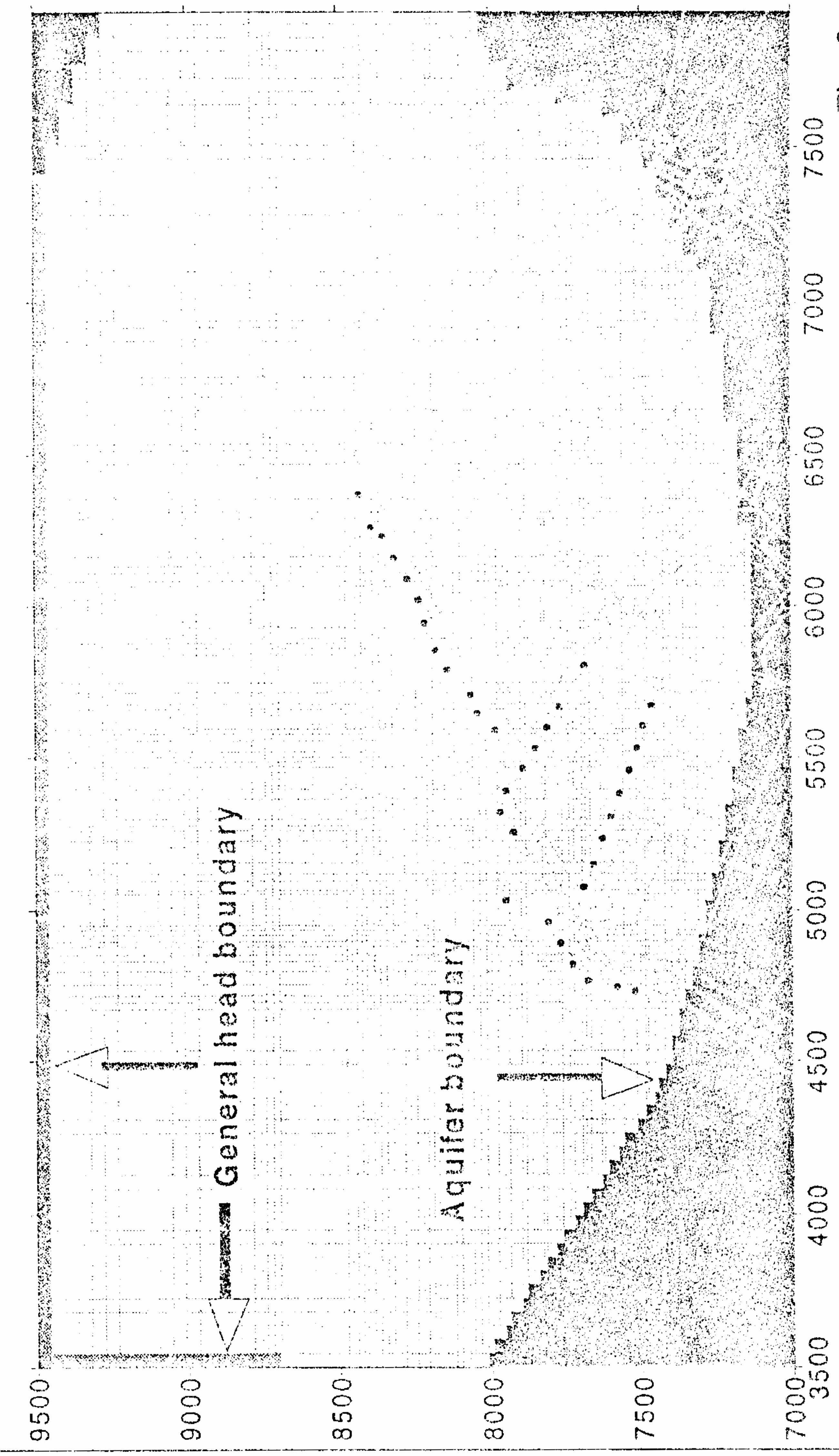


Fig. 3

CALCULATED WATER TABLE LEVELS
IN PLIOCENE AQUIFERS FOR 1995

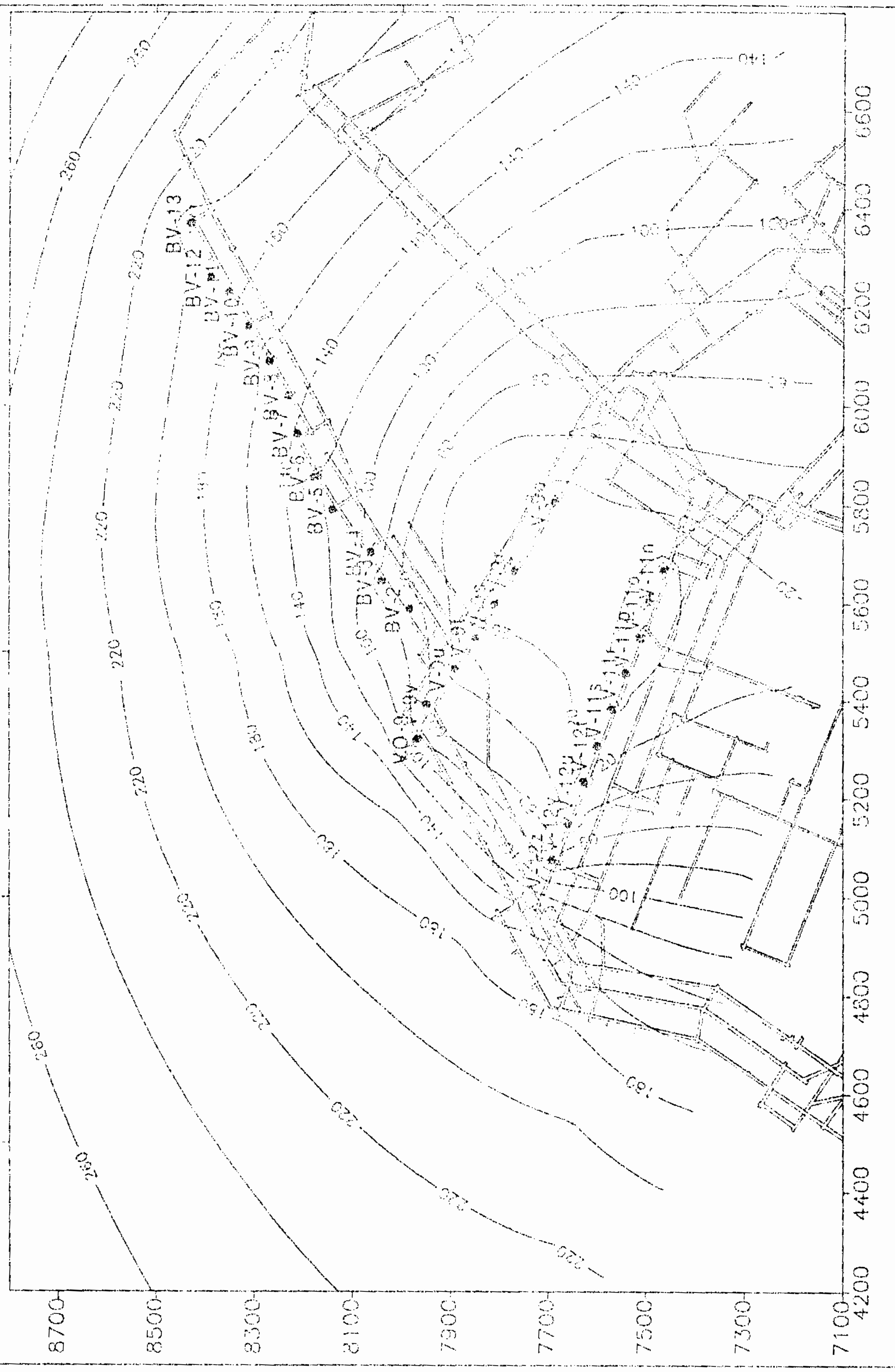
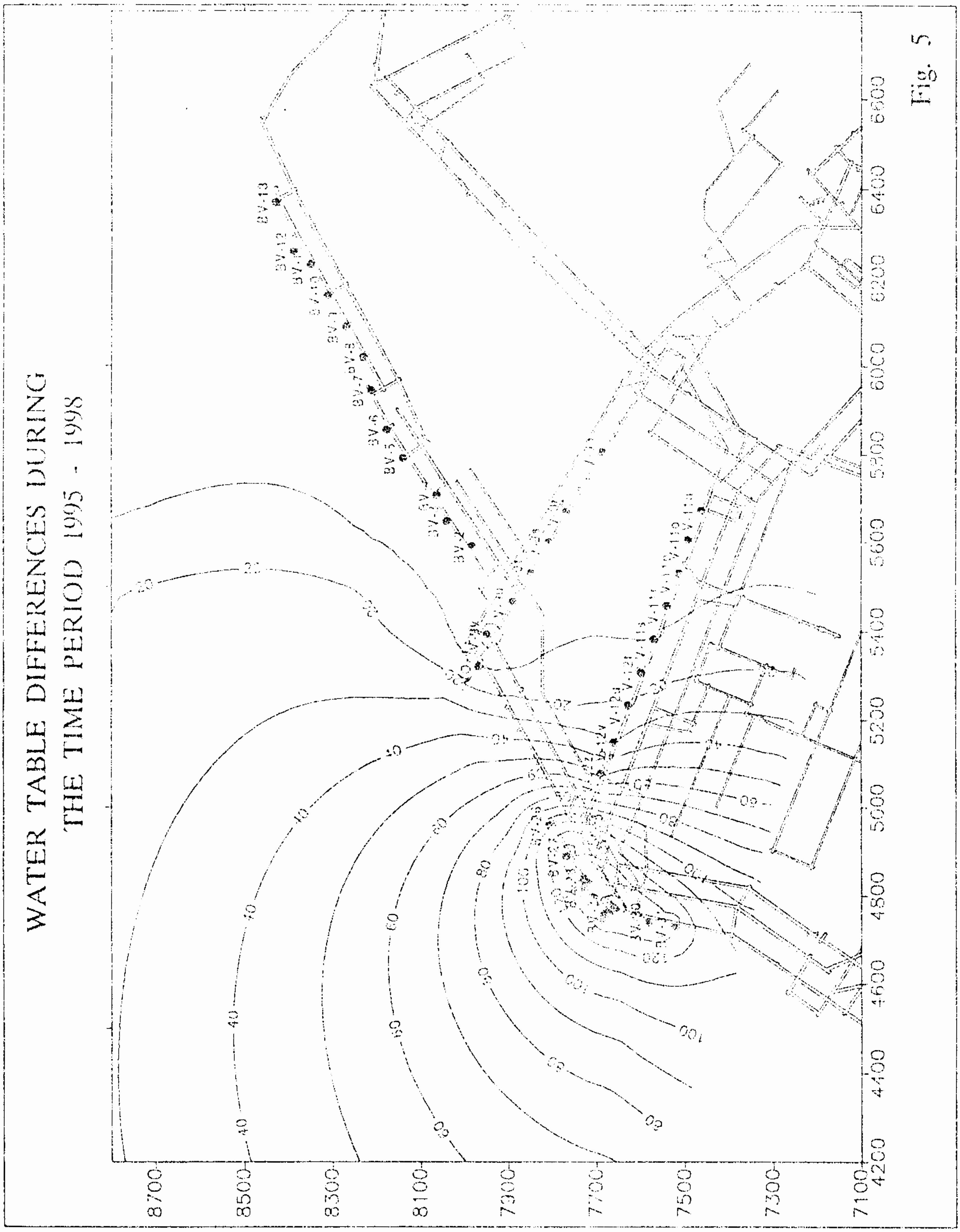
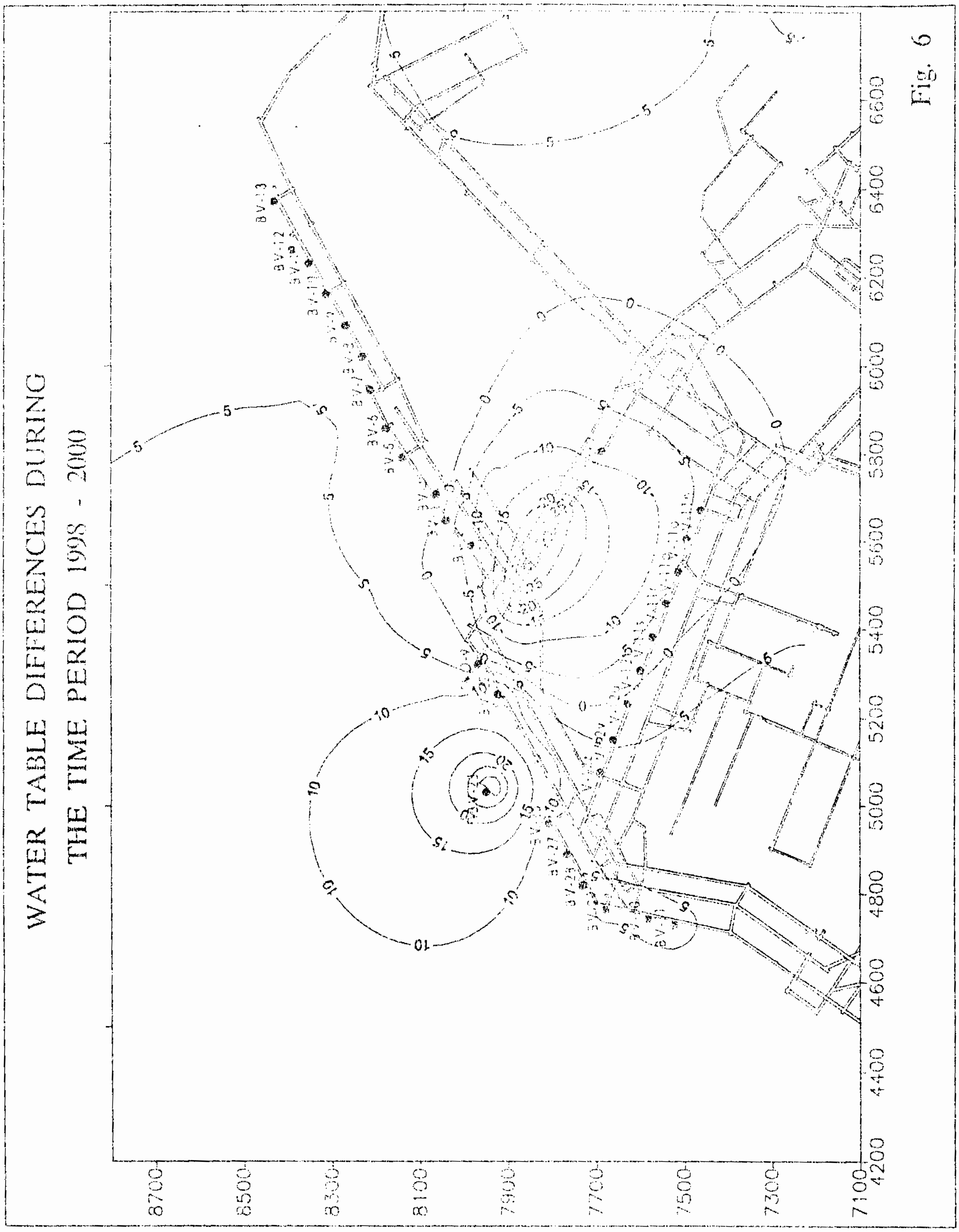


Fig. 4



WATER TABLE DIFFERENCES DURING THE TIME PERIOD 1995 - 1998

Fig. 5



WATER TABLE DIFFERENCES DURING THE TIME PERIOD 1998 - 2000

Fig. 6

WATER TABLE DIFFERENCES DURING THE TIME PERIOD 2000 - 2005

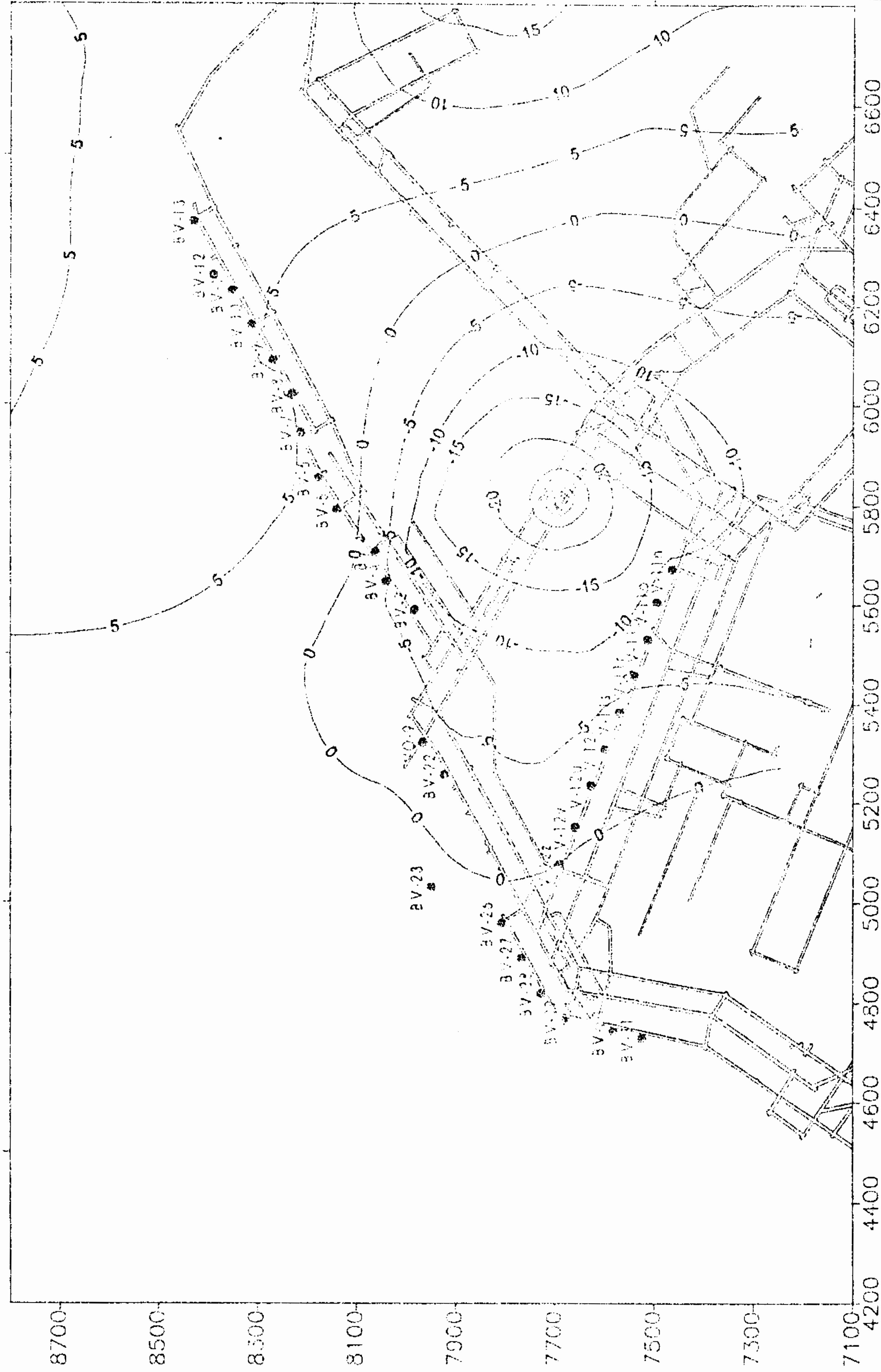


Fig. 7