APPLICATION OF A CONTINUOUSLY OPERATING MODEL FOR FORECASTING A REGIONAL GROUNDWATER FLOW SITUATION CAUSED BY OPEN-CAST MINE DEWATERING MEASURES

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ABSTRACT

The groundwater flow in the south-eastern part of the region Lusatia (Lausitz) is influenced especially by open-cast mine dewatering measures. For forecasting the expected groundwater conditions in this region a model-system was developed, that is capable of taking into account factors influencing the regional groundwater flow process. This model system, called a continuously operating model (COM), is operated parallel as to time, but discontinuocusly im comparison with the running original process.

The model was calibrated for the period from 1975 to 1980 by means of measurements of water levels and mine water pumpage. According to that, the future calculations was carried out for the period from 1980 to 2000. Here, the most important results are

1. future development of the groundwater table

2. future amount of mine water pumpage

3. forecast of the influence on the regional groundwater flow of the operation of the newly formed remaining pits used for water resources management or disposal of industrial wastes

4. forecast of the effects of mine drainage and use of pits on the operation of waterworks.

1. INTRODUCTION

All industrialized countries are facing the problem of a steadily increasing demand for water. Its solution leads to an ever more intensified utilization of the natural water resources. This general situation is particularly true for the GDR where already now the water resources are very intensively used. Groundwater is the major source for supplying water of a high quality to population, industry and agriculture.

To an ever increasing extent the groundwater resources are endangered both by accidental spillages of chemicals, oil, fuel, radioactive materials and by planned measures such as the use of chemical fertilizers in agriculture, the disposal of wastes, the underground storage of oil and natural gas etc. Moreover, the groundwater flow is strongly affected by several man-made impacts. Among them, the lowering of the groundwater table by open-cast mining is most important , also affecting the whole water balance of large regions.

Due to the long-term lowering of the water table in large areas cones of depression are formed that influence the operation of waterworks and the utilization of areas of agriculture and forestry as well as cause the drainage of ponds and rivers. Not only the lowering of the groundwater table but also its rise after closing down mines has to be taken into account. Then, often the negative effects of the open-cast mine dewatering for several water users are often compensated for. An effective management of the newly formed remaining pits has a particularly important influence on the controlling of the rise of the water table after having closed down mines.

There is no doubt that the controlling of man-made impacts on the groundwater resources require complex economic and social decisions taking into account the conflicting interests of several branches of the national economy. An important input into such decisions is sufficient information about the development of regional groundwater flow situations to be obtained by means of modelling.

2. GROUNDWATER RELATED PROBLEMS IN THE SOUTH-EASTERN PART OF THE LUSATIA REGION

Problems generally discussed in section 1 of this paper can be found especially in the south-eastern part of the Lusatia (Lausitz). This region of about 1,300 km^2 situated between the rivers Schwarze Elster and Neiße is one of the most important lignite centres of the GDR. About 25 % of the whole output of lignite of the GDR are produced here from open-cast mines.

Due to dewatering measures carried out in those open-cast mines, the groundwater flow is especially strongly influenced , because the water table depressions of many mines in a relatively small area superpose each other (see fig. 1). Additionally, this superposition of water table depressions is permanently changing in time and place due to the progress of the mines. Therefore, the difficult forecast of effects of lowering the water table on the operation of municipal and industrial waterworks and on mining dewatering well systems is additionally complicated in this region. On the other hand, necessary decisions about providing systems capable of compensating for the negative effects to be expected depend largely on the accuracy of such forecasts.

In other parts of the region in question the process of groundwater table lowering caused by open-cast mine dewatering measures is already superposed by the rise of the water table, resulting from closing down dewatering systems of exhausted mines as well as from the operation of newly formed remaining pits due to water-management or industrial utilization. Taking into account the development of the rise of the water level in the remaining pits and the planned final water levels, we have to calculate effects on the amount of water to be pumped in the mines operating in the immediate vicinity of the remaining pits. The extent of this influence cannot be known correctly from the beginning, but is expected to require a considerable financial expenditure.

For making decisions on possibly utilizable water discharges for flushing the remaining pits it is necessary to know the run-off balance of the rivers in this region for a long-term period. This run-off balance is decisively determined by the dewatering measures of the open-cast mines both by changing the catchment area of rivers and aquifers and by discharging the pumped water into rivers. At present, it is not possible to give detailed information about the development of the run-off balance of rivers under conditions of superposed water table depressions of the individual open-cast mines and the rising water table in the vicinity of the remaining pits discussed before. The explained problems that are closely interrelated are shown to necessitate comprehensive investigations about the development of the groundwater flow in this region, taking into consideration all influencing factors in order to derive concrete decisions for an optimum investment policy.

3. SELECTION AND ESTABLISHMENT OF A MODEL SYSTEM

Due to the complexity of effects influencing the groundwater flow system, the implementation of control measures derived from a single simulation of the groundwater flow process does not lead to satisfactory results in most cases. For the forecast of the groundwater development for longer periods a multiple modification of the influencing factors, caused by new technical and technological or economic characteristics as well as administrative decisions must be expected from the beginning. Consequently, the knowledge about the behaviour of the system needs to be continuously improved.

In order to be able to take into account the variability of the influencing factors, the method of the continuously operating models (COM) is presently used, which allows us to organize the processing according to cybernetical aspects. According to /1/, /2/ and /3/ a continuously working model is a model system for the monitoring and controlling of long-term industrial or economic processes (see also /4/ and /5/). It mainly consists of two parts - a specific data bank for information storing and a simulation model for information processing - that are coupled by an analoque or digital simulation method, which is suitable for practical data processing. The system of data collection, data processing and simulation includes the feedback of information used already during the simulation of the particular groundwater flow process or becoming effective during the implementation phase. In such a way, the simulation is guaranteed to be based on the latest data available at the time of the operating of the model system. By means of this model system the influence of feasible control measures can be simulated before their implementation in practice. The model system is operated parallel in time, but discontinuously with the running original process. The steps of its operation depend on the size importance of the model (see /4/ and /6/).

Such a continuously operating model was established for the South-East Lusatia region. Details about information storing and the simulation model are described in /7/ and /8/. For the simulation of the regional development of the groundwater flow a two-dimensional non-steady model was chosen - the HOREGO program. It is implemented at the electronic computer ES 1040 or ES 1055 resp. This program is based on a mathematical model of the non-steady horizontal-plane groundwater flow with non-linear parameters of permeability /9/. The discretization of the flow field is done by a grid of orthogonal finite elelemts. The number of finite elements is limited only by the CPU memory of the computer used for simulation. The single elements have to be arranged in such a way that a minimum number of elements leads to an optimal adaption of the model to the internal and external boundary-conditions. In figure 2 the grid used for the South-East Lusatia region is shown.

The following boundary-conditions were considered in the model system for simulating the period from 1975 to 2000

- development of all open-cast mine dewatering measures as to time and locations
- operation of all existing and newly formed remaining pits, used for water resources management or disposal of industrial wastes
- operation of all waterworks including their planned development
- operation of irrigation systems for agricultural purposes
- natural recharge of groundwater depending on the operation of mines, including their reclamation (this develepment was separately investigated before by means of a special program)
- infiltration/exfiltration of rivers and ponds

The model was tested and calibrated for the period from 1975 to 1980 after the installing of all boundary-conditions. Measurements of water levels in gauge wells and measurements of water pumpage in the individual open-cast mines were used for this purpose.

The calibration of the model system was carried out by means of the trial-and-error method. In this process these were changed mainly the transmissibility in single elements and the infiltration or exfiltration of rivers and ponds which is unknown in most cases from the beginning. The degree of the obtained correspondence between measured and calculated results of groundwater levels is shown in figure 2 as an example for 1976. The absolute size of deviation must be seen in connection with the amount of groundwater lowering at the single elements and with the relatively rough discretization of the field. The obtained correspondence for the mine water pumpage is shown in figure 4 also as an example for one of the mines.

4. RESULTS OF THE MODEL FORECASTS

In the following, the calibrated model was used for forecasting the regional groundwater flow process with regard to all influencing factors for the period from 1980 to 2000. Of course, the reliability of the model results is decreasing with increasing time horizons for predictions. Therefore one must aim at extending the period of calibration when the model system is oparating for later prediction phases.

4.1. DEVELOPMENT OF GROUNDWATER TABLE

The results of the forecasts of the development of the groundwater table in the region of interest were obtained in the form of water table maps for 1980, 1985, 1990, 1995 and 2000. Figure 3 shows an example for the year 2000.

When we know development of the regional groundwater table, it is possible to determine the influences on the dewatering plants of the single open-cast mines by each other and by remaining pits. Therefore the new information gained about the boundary-conditions as to time and location is precisely known for the calculation of these plants. Based on this, a more economical arrangement and equipment of the dewatering systems as well as an increased protection of the mines against water hazzards can be achieved. Furthermore the knowledge of the development of the regional groundwater table permits a more precise establishment of mining protection areas. The water table maps also provide information on the dates and extent of the limitations to be expected for the operation of the wells of the waterworks which are situated in the influenced area. Dependent on this, decisions can be made in time on the type and extent as well as the implementation time of possibly required replacements.

4.2. DEVELOPMENT OF THE OPEN-CAST MINE WATER PUMPAGE

As a further result of the investigations on the development of the groundwater flow is the South-East Lusatia region by means of the discribed model system the amount of mine water pumpage of the open-cast mines situated in the interesting area could be determined. In figure 4 an example is shown for one of these mines. We see clearly the difference between the development forecasted by the regional model system taking into consideration all factors influencing the groundwater flow (line 2) and the development, determined by a former calculation without such considerations (line 3). Line 1 shows the development of the amount of pumpage, as it was actually given out by the model. The difference to the development of line 2 appears to be the share of bottom water that is pumped out of the wells of the dewatering systems and that is impossible to be simulated by the simulation-program used at present (see /8/ and /9/.

The knowledge of the development of mine water pumpage enables the lignite factories to economically design treatment plants and discharge systems for mine water. It forms also a major tool for the water authorities which are responsible for balancing the discharge into the river network.

Based on this process, information on the available water discharge to be used for filling remaining pits can be provided. Provided that the results obtained are in good agreement with those achieved by the long-therm forecast of the regional groundwater flow, final decisions on the filling rules for remaining pits can be made. Otherwise a simulation run has to be repeated using the newest data available.

4.3. OPERATION OF REMAINING PITS

The simulation of the regional groundwater flow considering all influencing factors provides important information on the operation rules of remaining pits and their impacts on the surrounding territory or on dewatering systems of neighbouring open-cast mines.

Figure 5 shows two stages of the course of the filling process to be expected in a big remaining pit situated near the centre of the area in question (see fig. 1). We see that it is impossible to reach the planned upper or lower level of the water table necessary for a utilization for water management or recreation when only the natural rise of the groundwater table in the surrounding areas after closing down the mines contributes to the filling process (line 1). On the other hand, the lower level of the planned water table can be reached in 1998 and the upper level in 2001, provided that an additional amount of water of about 100 Mio m^3/year will be available (line 2).

Figure 6 shows the influence of the rise of the water table in the same remaining pit on the dewatering works of a neighbouring open-cast mine. The western well fields of the mine situated east of the remaining pit are planned to continue operation, in order to avoid water inflow into the dumps.

We can see that nearly 30 million cubic metres of water per year will have to be pumped additionally by these wells when the water table in the remaining pit will reach the level at 118 m NN. This cannot be accepted because of the large amounts of material and energy to be spent. Thus, a different solution must be found. Possible are variations in the mining technology, the changing the dewatering method, the establishing of other water tabel levels to be reached in this remaining pit etc. The newly created conditions form new boundary-conditions to be sonsidered in future simulation runs.

5. CONCLUSIONS

The described problems in the South-East Lusatia region cannot be solved by a single simulation of the regional groundwater flow process. Multiple modifications of the various influencing factors caused by new technical and technological as well as economic changes must be expected from the beginning. The problems to be investigated require a continuous access to a model system that represents the most topical state of the original system at any point of time. This requires both, the collection of new information on the system of the groundwater flow and the feedback of information obtained in the phase of implementing control measures. Consequently a continuously operating model has to be established.

According to this, it is obvious that the work on the continuously operating model South-East Lusatia cannot be considered as being finished. At present, this model system is already operating in its third working phase, but still a lot of new conditions caused by changing of conceptions of lignite exploitation have to be expected.

Besides this, the simulation results obtained so far have contributed very much to an improved decision-making process in the lignite mining industry, in water management and environmental planning as well as in municipal authorities. Because of these facts it is one of the main tasks of the research group for open-cast mine dewatering to hold this model system continuously in operation and to improve its capabilities.

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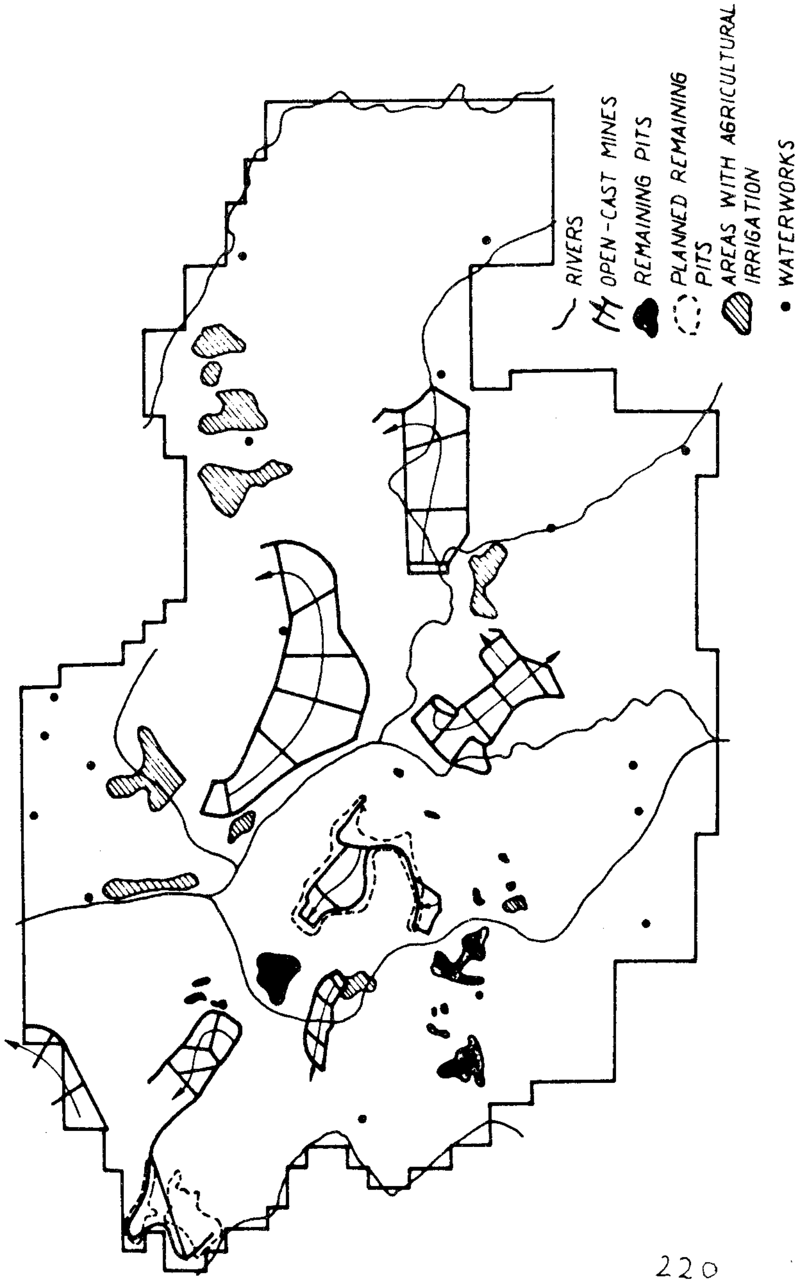
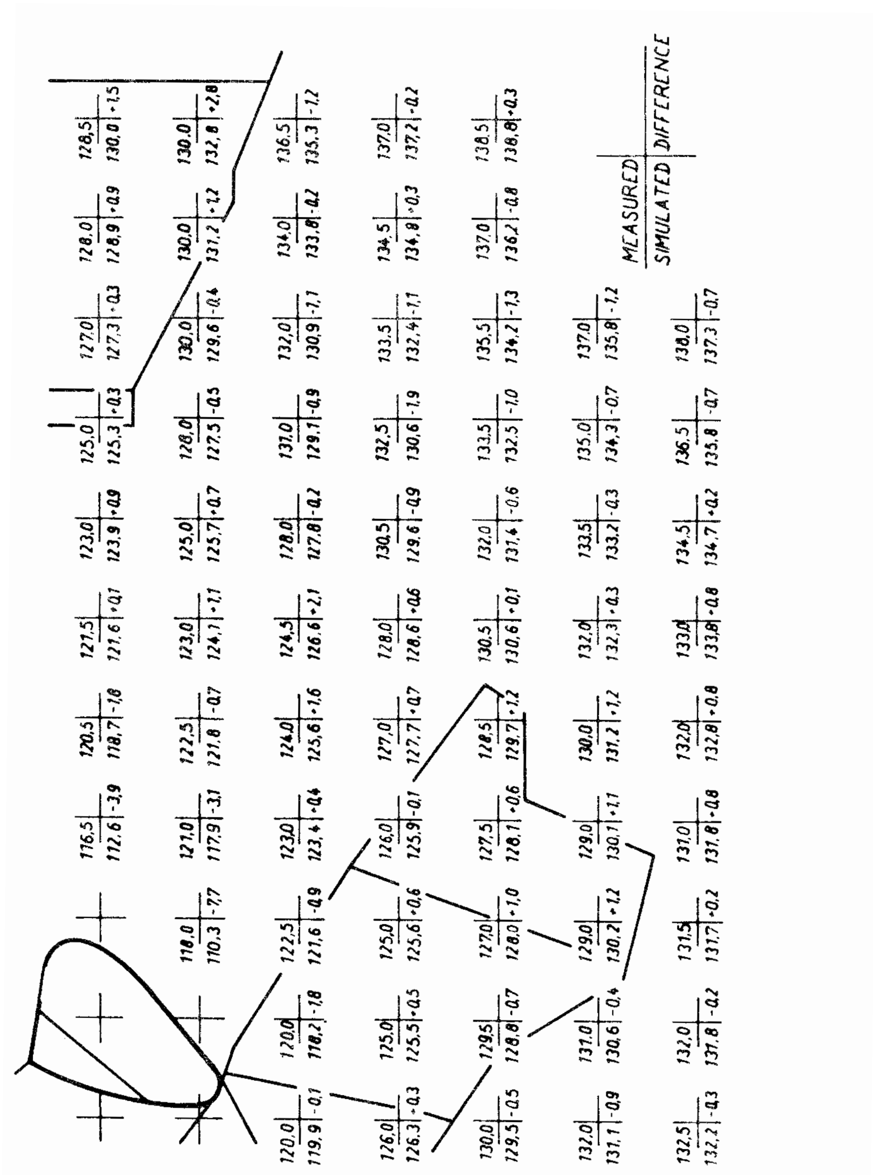
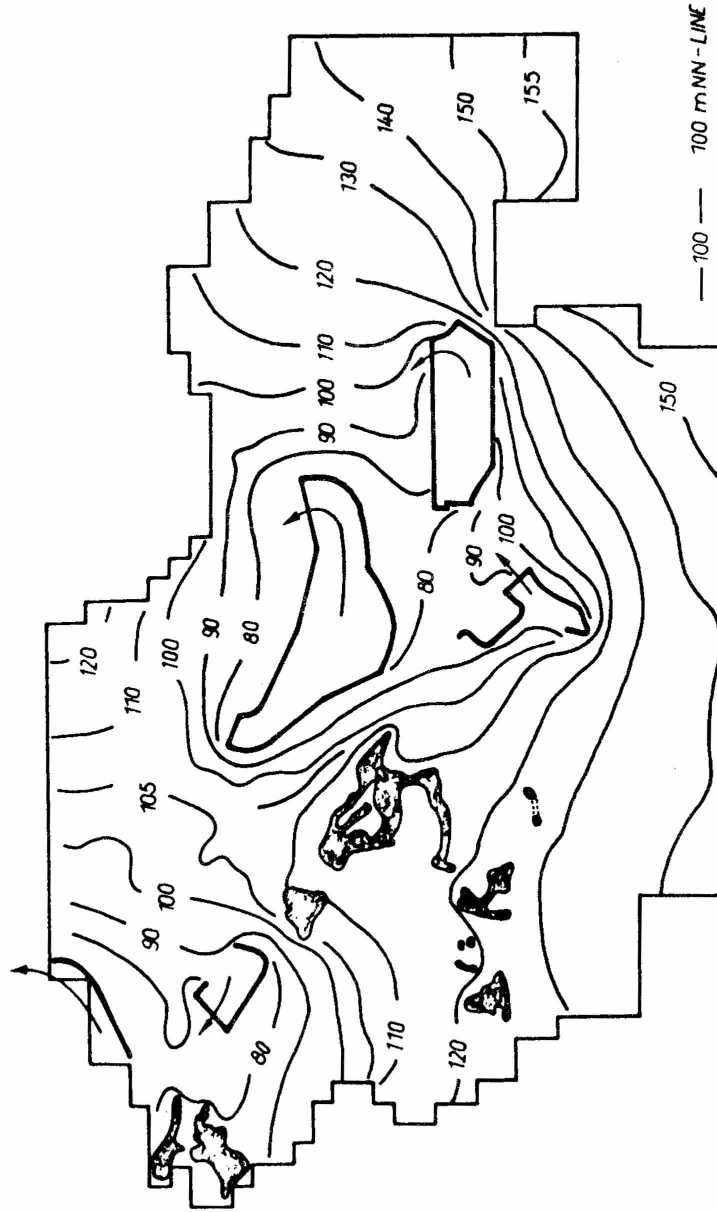
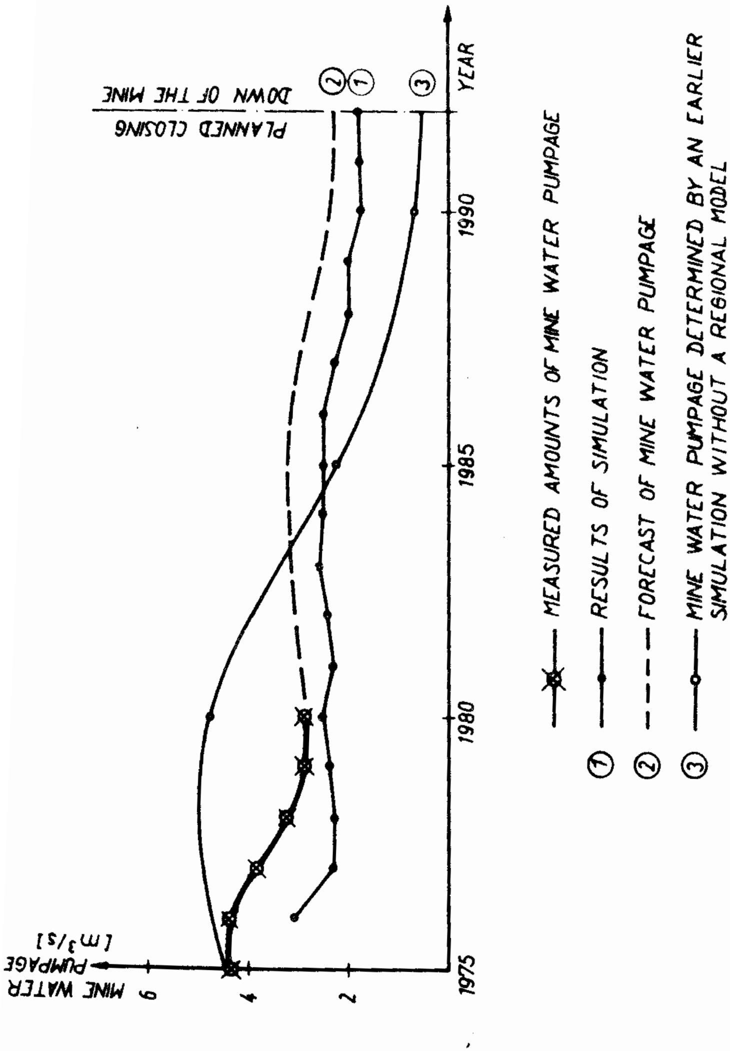
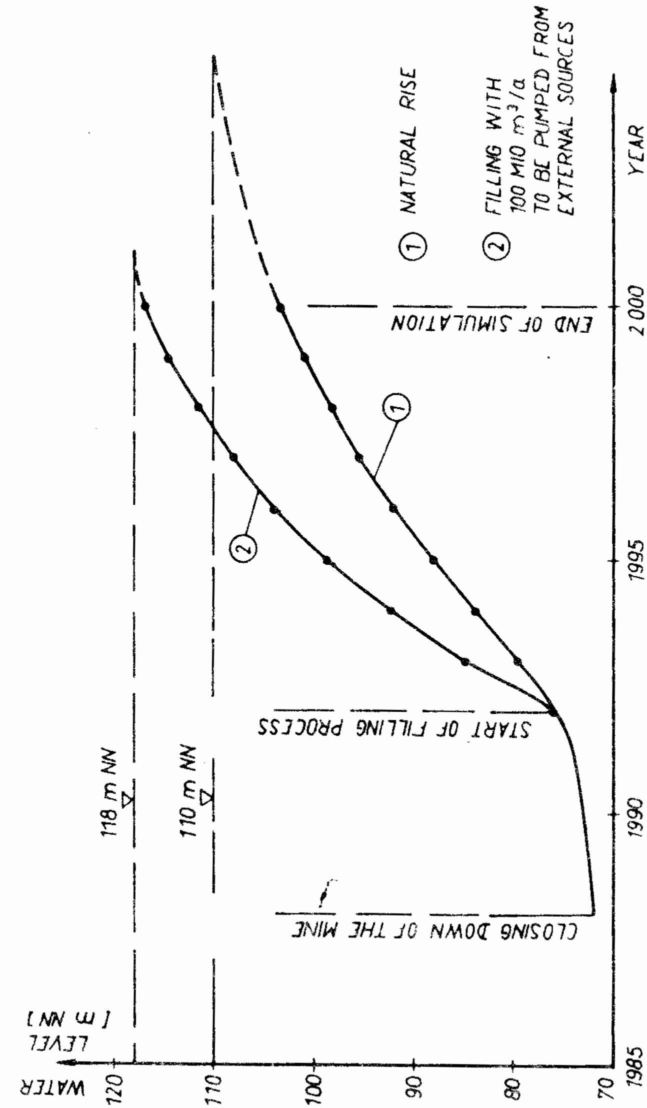
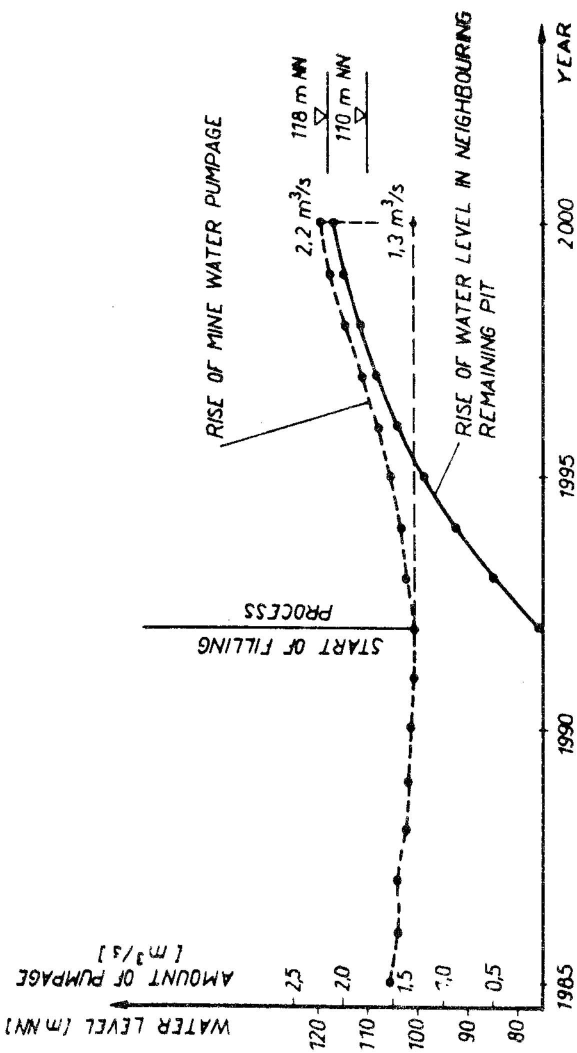

RIVERS
OPEN-CAST MINES
REMAINING PITS
PLANNED REMAINING PITS
AREAS WITH AGRICULTURAL IRRIGATION
WATERWORKS


MEASURED
SIMULATED
DIFFERENCE


—100— 100 mNN-LINE
155
150
140
130
120
110
100
90
80
105


MINE WATER PUMPAGE
[m³/s]
6
4
2
1975
1980
1985
1990
YEAR
PLANNED CLOSING DOWN OF THE MINE
① ② ③
MEASURED AMOUNTS OF MINE WATER PUMPAGE
① RESULTS OF SIMULATION
② FORECAST OF MINE WATER PUMPAGE
③ MINE WATER PUMPAGE DETERMINED BY AN EARLIER SIMULATION WITHOUT A REGIONAL MODEL


WATER LEVEL [m NN]
120
110
100
90
80
70
1985
1990
1995
2000
YEAR
118 m NN
110 m NN
CLOSING DOWN OF THE MINE
START OF FILLING PROCESS
END OF SIMULATION
1 NATURAL RISE
2 FILLING WITH 100 MIO m³/a TO BE PUMPED FROM EXTERNAL SOURCES


RISE OF MINE WATER PUMPAGE
2,2 m³/s
118 m NN
110 m NN
1,3 m³/s
RISE OF WATER LEVEL IN NEIGHBOURING REMAINING PIT
START OF FILLING PROCESS
AMOUNT OF PUMPAGE [m³/s]
WATER LEVEL [m NN]
2,5
2,0
1,5
1,0
0,5
120
110
100
90
80
1985
1990
1995
2000
YEAR