SIMULATION OF MASS AND HEAT TRANSFER IN A LARGE KARSTIC RESERVOIR FOR MINE WATER MANAGEMENT

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ABSTRACT

The regional simulation of Transdanubian Mountains /Hungary/ is presented in this paper using CCC-type numerical model developed by the Lawrence Berkeley Laboratory /California, USA/. The single-layer, three-dimension model covers an area of 11.ooo km² with about 6oo m³/min mass transport. The homogeneous, isotropic elements are specified with hydraulic and heat parameters according to the natural hydrogeological and stratigraphical conditions. The connection between mine water outputs and thermal springs are studied by the simulation of mass and heat transport. The phenomena of porous and karstified rocks were compared in order to take practical conclusions. The detailed mine water management model will be based on this simulation.

1. PRELIMINARIES

About 4o % of the coal production in Hungary comes from the region of the Trandanubian Mountains. The bedrocks of minable coal seams are fissured-carstified dolomite and limestone of mesosoic age. The bauxite deposits overlying the triassic reservoirs are exploited by two big companies. The mining activities being over the karstic water level at the beginning were extended downward, consequently the operations became water dangered. The yield of inrushes and water drainage constitutes presently a significant element of karstic water equilibrium. Other water works for municipal water supply are existing in the region. The natural and artificial water discharges exceed the dinamic water recharge. The relationship between mine dewatering and thermal springs - which are important for balneologic purposes - should have been investigated first from the viewpoint of mass and heat transport.

The simulation modelling was based on

- the Conduction Convection Compression type numericl model developed by Lawrence Berkeley Laboratory /California, USA/,

- the realistic hydraulic parameters distribution verified by the use of a mass transport model developed in our Institute were well-known.

As a result of these efforts a new model simulating the processes of the total reservoir, in particular the geothermal systems of Budapest and Héviz regions has been gained.

2. THE CCC MODEL

Modelling the natural phenomena by using the method of finite elements or finite differences requires high capacity computers. /Mangold, Lippmann 198o; Narasimhan, Goyal 1979; Tsang, Bodvarsson, Lippmann 198o. Tsang, Buseck et al.198o/. In these models the investigated area is divided into a great number of elements. The elements can be featured by changeable parameters, conditions according to requirements. The method of finite differences discretizes the saturated medium and formulates the governing equations. The sets of equations are solved by an iterative solution technique /Edward, 1972; Narasimhan and Witherspoon, 1976/. Details of the model are given by Lippman et al. /1977/ and Mangold et al. /1979/.

The CCC program was developed further to make it suitable for the solution of this special problem. The model was adapted for home computer facilities and completed with some modifications, for example:

- it was made suitable for modelling a system containing confined and unconfined reservoir parts,

- the measured water level data can be used as input,

- it is suitable to simulate the geothermal heating.

3. HYDROGEOLOGICAL MODEL

The approximation of the hydrogeological scheme as a uniform reservoir was clearly proved by the earlier reservoir simulation tests.

The structure of the network was constructed according to the tectonical, stratigraphical and rock characteristics of the region. The area of mass transport is supposed to be concentrated in the upper 3oo m zone of the karstified rocks. As a first approach an izotropic water conductance was supposed. 12 reservoir rock types of different permeability and porosity were defined.

The precipitation of the uncovered carstic rocks, the hydraulic communications with the Danube river and the neogene overlaying porous strata, the natural and artificial water discharges, the pore- and compression storage changes are taken into account as terms of the mass-balance equation.

4. HEAT MODEL

The aim of the regional simulation of the conductive and convective heat transport is to study the influence of the artificial water output - particularly for mining purposes - on the heat balance of system.

The main terms are considered as follows:

- The heat content of nodes is specified by their altitude. The value of heat capacities is based on the data of literature. Lacking in-situ measurements, the initial temperature depending on depth of nodes was determined by the extrapolation of the measured geothermal gradient and the theoretical distribution of "undisturbed temperature".

- In case of decreasing the actual node temperature down below the undisturbed theoretical geothermal temperature value the geothermal heating occurs.

- The heat content changes are modelled by conductive and convective heat transport. The precipitation nodes are characterized as heat resources with temperature of 11 °C and water output nodes are represented by their own actual temperature.

- The heat conductivity is based on data of literature, consequently the realistic modelling of the geothermal anomalies are approximate.

- Anisotropy and inhomogeneity are neglected generally, but some special nodes representing thermal springs are characterized by parameters equivalent to local inhomogeneity.

5. GEOMETRICAL STRUCTURE

The basis of the better approximation of the existing natural streamlines is to form the fitting network.

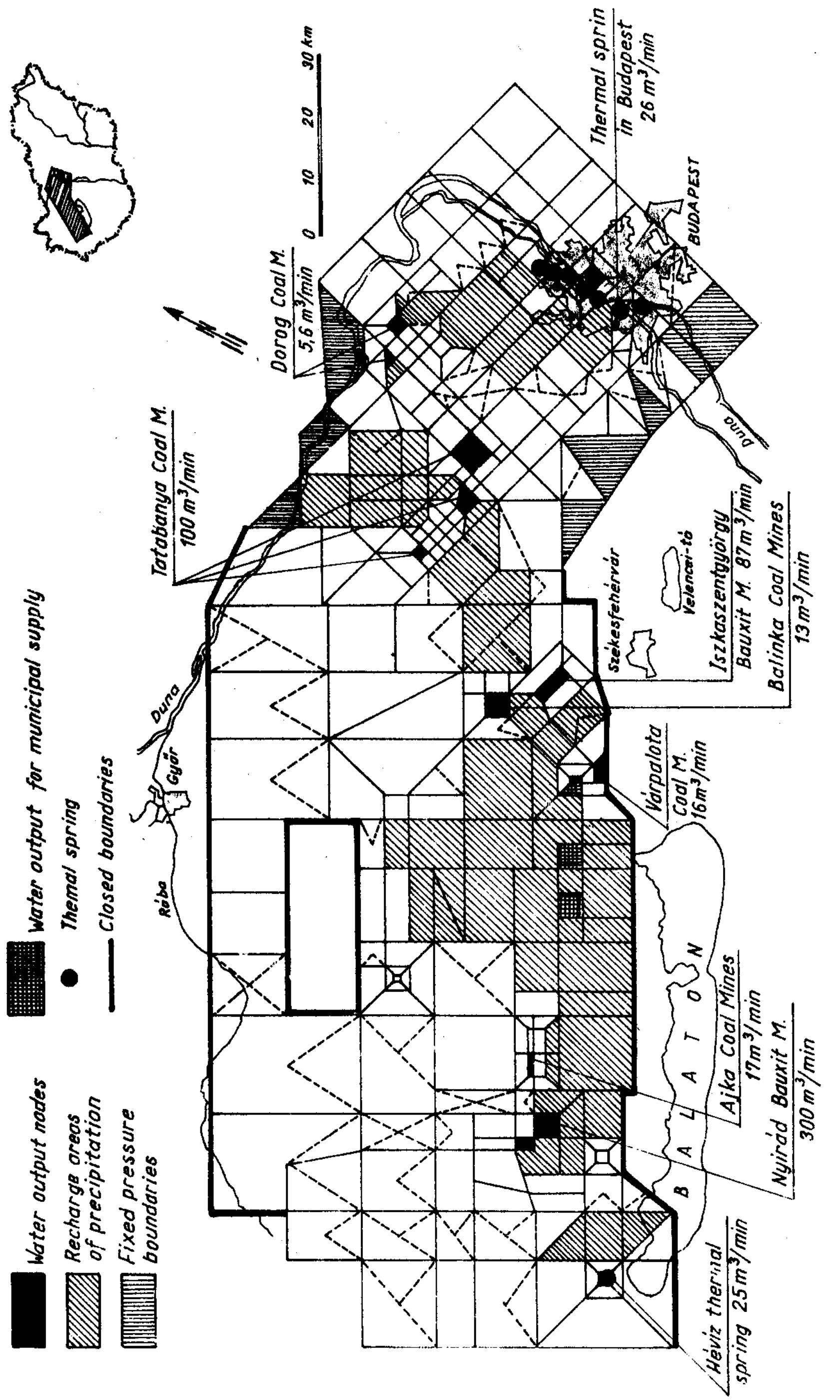
The main principals for the consideration were as follows:

- the proper location of water output nodes and more detailed grid for their surrounding areas /all possible details are available/,

- the best approach of the hydrogeological and hydraulic conditions,

- minimized number of nodes and interfaces because of limited home computer capabilities /triangular-shape "connection nodes"/,

About an area of 11.000 km² is covered by 495 nodes /including 150 "connection nodes" representing the main tectonic lines/. The configuration of the single-layer, three-dimensional modell is shown in Fig. 1. On account of a more detailed modelling of the important zones, the number of nodes will be extended during the next stage of modelling.



Configuration of the CCC simulation on Transdanubian Mountins
Figure No. 1

6. HYDRAULIC PARAMETERS

The main parameters determining the mass transport are the specific storage and conductivity of the rock-matrix and the initial water head of the system. The reliability of the modelling is based on fitting of the parameters and on the accuracy of their determination and specification. Because of the regional-type of the model the programmed 12 material types do not allow to vary the parameters on a large scale.

The applied porosity values ranging from o.ol to o.o3 were based on the experience of other simulation modelling of the same reservoir and on data of literature.

The pore volume and compressive volume are effected by the specific storage coefficient. Under confined conditions it takes $10^{-8} \div 10^{-7}$ depending on rock properties /porosity/. Under unconfined conditions this parameter is increased by an order of magnitude of 2 to 3.

The first approach of permeability values was given by using transmissibility values of the former reservoir simulation. The distortion because of the average thickness of the nodes was corrected occasionally.

The initial hydraulic pressure was specified by using the hydroisohypse-map based on data of piezometers in the region prepared and published yearly by the Water Management Institute of Hungary.

The water recharge of precipitation was calculated with different intensity for the various areas. These values were also provided by the former reservoir simulation fitted to the natural conditions.

7. HEAT PARAMETERS

The heat content of a node depends on its depth and the cooling effect of the mass transport. The reliability of the heat parameters are limited.

The initial temperature was calculated on the basis of the map of geothermal gradients.

The heat capacity of the rock-matrix is 9oo J/kg ^{o}C.
The conductivity ranges from 2.7 to 4.4 J/m sec ^{o}C.
The geothermical heating is modelled by using little mass flow rate /GI= 10^{-20} kg/sec/ that heats the node with

$$Q = GI \cdot c \cdot \Delta T \quad /Joule/sec/$$

where c is the proper heat capacity of the fluid suitable for modelling the actual geothermal heat flux, ΔT is the difference between the theoretical geothermal and actual temperature.

8. BOUNDARY CONDITIONS

In addition to the reliability of parameters the realistic modelling is basically effected by proper initial and boundary conditions.
The mesosoic zone of the reservoir directed SW-NE is surrounded by paleosoic impermeable rocks representing "closed boundaries". Fixed mass flux boundaries are modelled at the shorter edges.

The hydraulic connection with the Danube river and the upper neogene water bearing strata is represented by fixed pressure, changing temperature nodes.
The nodes of uncovered triassic rocks represent the precipitation as water recharge, and the artificial water discharges and natural springs are modelled as mass and heat sources with different intensity.

9. MODEL VERIFICATION

The simulation modelling of the total area of the Transdanubian Mountains was carried on in two steps.

Testing and verification of the western part required 4-5 quantum per running on a Honeywell computer type HWB 6o/6o. The mass flow crossing the interface of two parts of the model was determined by the finite difference model of the mass transport verified previously. /Szilágyi 1978/

The steps of verification were as follows:

a./ Verification of the mass transport:

- The determination of permeability on the basis of water level changing under quasi-static conditions. The difference of pressure did not exceed ± 1o m. /See Fig.2 /

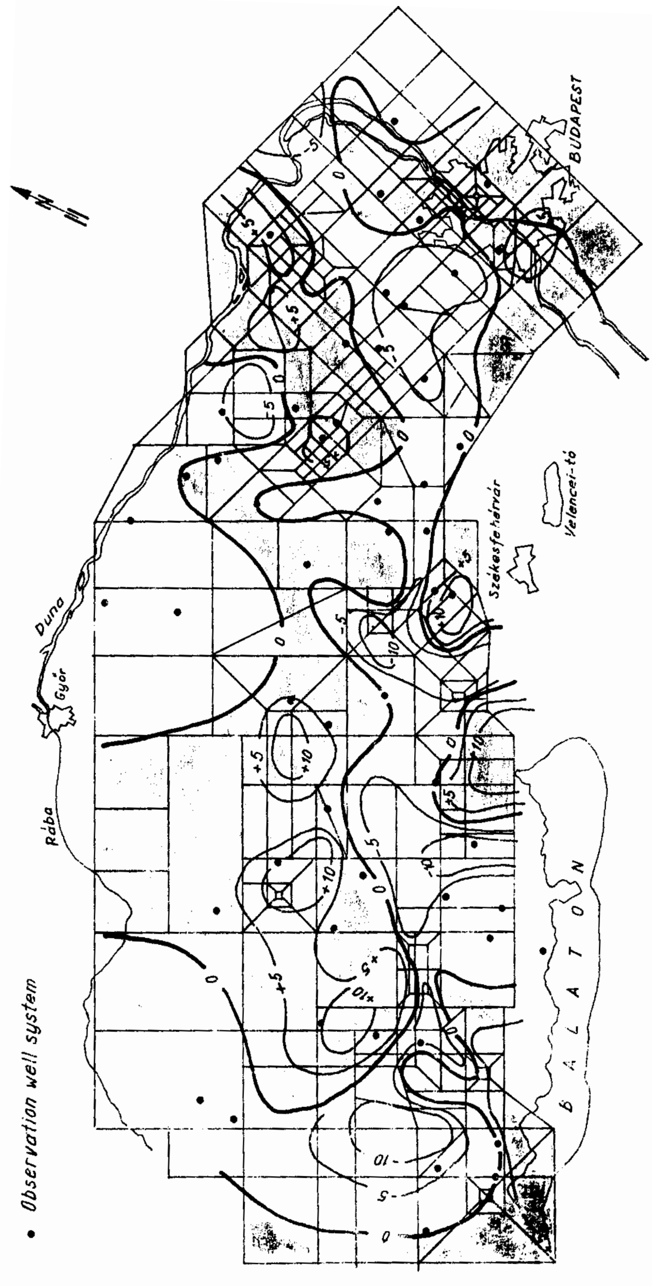
- The verification of storage parameters under dinamic state by comparing the water level changes to the measured or simulated data in another way. /See Fig. 3 /

b./ The verification of the heat transport on the basis of diagramms of temperature versus time.

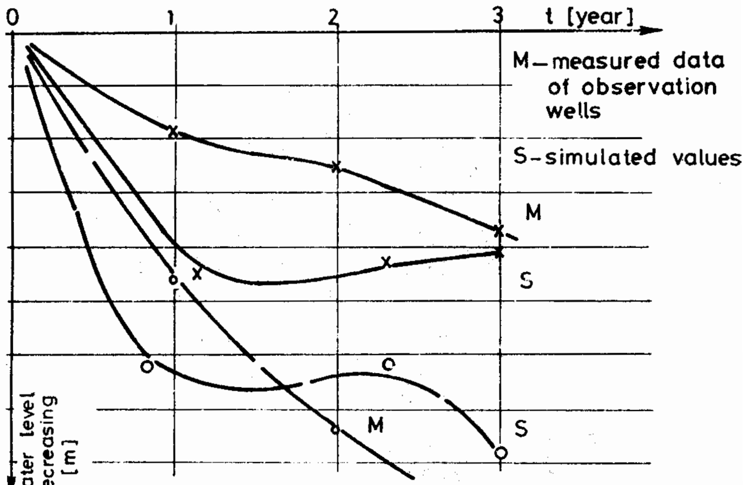
- A rough calibration was made by the alteration of the ratio of warm and cold mass flows.

- Fine verification was made by modifying the heat capacity in the nodes of water output and surroundings. /See Fig. 4/

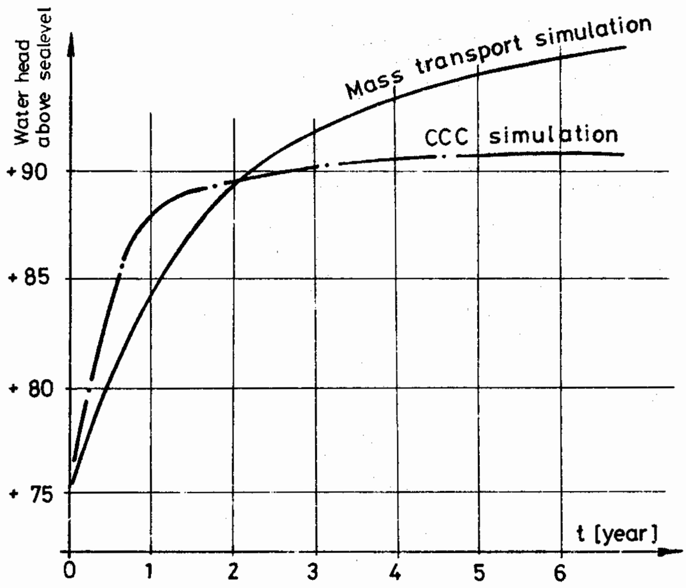
The available data were enough for the verification of the mass transport but not for the heat one. Since the heat transport is determined by convections, therefore the well-calibrated mass transport improves the accuracy in the heat process too.



Change of pressure during 5-year running
Figure No. 2

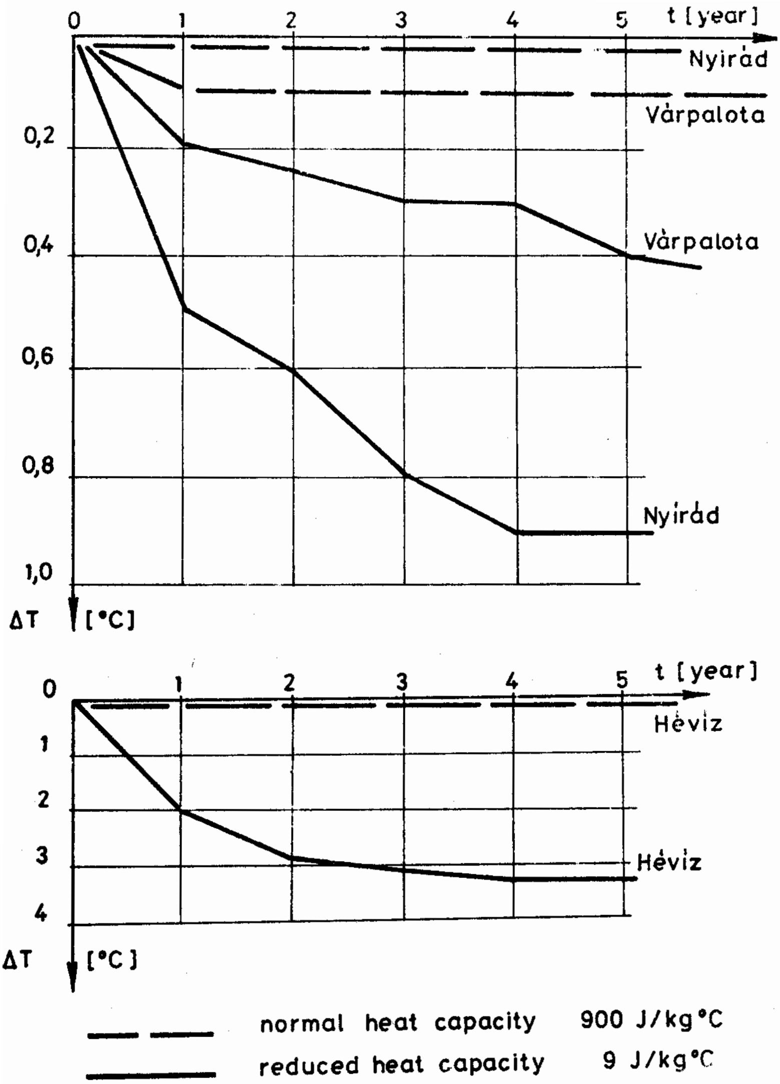


3.a. Dinamical fitting of selected regular nodes



3.b. Rebuilding of the Nyirád node with reduced water yield [120 m^3/min]

Figure 3.



Change of temperature at selected water ouput nodes

Figure 4.

10. RESULTS AND CONCLUSIONS

A quasi-fitted regional mass and heat transfer simulation model is available as a result of investigations presented. During the model the main geothermal features of the Transdanubian karstic reservoir appeared. These are as follows:

- The heat processes of the fissured-carstified rocks are determined by the static heat content.
- In spite of the hydraulic instability caused by an artificial water discharge there is no remarkable change in the large scale heat balance of the reservoir.
- Some concentrated water output of high quantity may influence the heat conditions of thermal spring areas locally.
- The difference between the calculated and adapted specific storage may point out the importance of the rubble rocks connected with the reservoir hydraulicly.
- Comparing the results of simulations of the porous reservoirs with karstified ones, two types of reservoirs can be recognized with regard to the heat phenomena. /Havasy et.al. 1982/

From porous reservoirs the static heat content of the rocks can be exploited /or decreased/ by water production showing that the heat capacity of the pore water is dominant. The static heat content of the rock matrix in fissured-karstified rock is slightly effected by mass transport.

The quasi-fitted regional model of the Transdanubian karstic massif will be developed for detailed modelling of the local phenomena. All of the terms on mass and heat balance are given both for each node and for the total investigated area at an arbitrary time. The past and precasted changes of terms can be calculated.

Even the home computer facilities allow to extend the number of nodes up to 600-1000. It means, that a proper modification of the network in a more detailed manner for the areas of the main thermal springs will provide phenomena to be forecasted/controlled.

In some special cases more detailed local models can be also inserted into this regional model. Using an iterative connection between the two models, the regional model will provide the boundary-conditions for the local model. This program will be realized in the near future.

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