Numerical model for water management at complicate underground workings

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Abstract: Numerical modeling of water flow has developed to a practical standard in surface water and groundwater operations. Modelling of water flow in underground mines requires a special approach due to large and interlinked cavities. The key to simulate such a process is the reduction of model-balance-cells to a minimum (large boxes), following the requirements of the flow field and disregarding the classic discretisation-scheme. Properties of boxes can be deter-mined from readily available mining documentation. By means of standard CAD applications and data processing an excellent multi-purpose data base is created.

The theory and simplifications of a box-model are described. The various types of hydraulic connection between boxes are reflected by the conductance (m^2/s) which can be calculated from measured flux and hydraulic heads.

The successfull application of box-models is quoted from two underground uranium mines where ecological requirements demand a sophisticated prognosis of the environmental impact of mine closures. For partial or complete flooding of larger underground mines box-models facilitate compilation of many hydrogeological data and provide an excellent planning tool for alternate scenarios of water management and mine closure.

1 OBJECTIVE

Operators at larger underground mines generally have at their disposal considerable data on up to date total mine drainage and costs associated with it. Individual components of water intake, usage and discharge are represented in more or less sophisticated graphical flow charts ("water trees") or flow sheets. Due to often long term mining history water handling changed and during operation mine water received somewhat lesser attention fostered by historic permits and grandfather clauses. New legal requirements and ecological considerations demand an adequate forecast on present and future impact of mine water on groundwater and surface water. At partial or complete mine closure answers need to be given to:

- What new flow regime will be established?
- How long will flooding take?
- Where will underground mine drainage come to surface at what quantity and quality?
- Are their any requirements for mine water catchment and treatment?
- What are the effects of alternative water management/mine closure concepts?

For appropriate answers the paper will indicate a numerical model approach tailored to conditions prevailing at larger and complicate underground workings.

2 GENERAL CONSIDERATIONS

Numerical models are in demand where pure assessment by experience or comparison with similar events does not suffice. Well accepted models do exist for water management problems, e.g. seepage, surface run-off, groundwater flow and contaminant transport. On the market, finite element and finite difference models are available for flow in porous and fractured media. However, numerical problems are involved at mine cavities and in simulating hydraulic "short cuts". Generally, a tremendous "ballast" of numerous nodal points is needed to approximate a complicate geometry. Albeit there are differences in methodology, numerical models for hydrogeological problems are very similar in their basic functions but can be very different in their degree of sophistication. The governing terms, described below, apply to all modelling approaches and so do the requirements to fill these terms with adequate data:

General Term	**Typical Situation at Underground Workings**
Storage (available water volume, floodable volume)	• long term mining with incomplete records of mine survey, but detailed records on total outcome of waste and coal or mineral • large rock volume, large area affected • different mining methods at different times (caving, room & pillar, backfilling) • effects on adjacent rock formations by blasting, collapsing of roofs • convergence of cavities and drifts
Flow (hydraulic connections between model units, permeabilities, transmis-sivities …)	• extensive connections between faces by drifts, adits, shafts (hydraulic short circuits) • partial blocking of mine water flow by underground dams, hydraulic backfilling • convergence/collapse of drifts, shafts, cavings, subsidence • hydraulic properties of geological formations, faults affected by mining activities
Source-Sink (recharge, losses …)	• influence of service water • cross flow via drainage ditches • possibility to control recharge assessment by pump and discharge records

In addition to the considerations above, boundary conditions need to be determined for any type of numerical model. Regarding water quality data the typical mining condition is that mixing of water of different origin occurs already underground. Often water quality is also affected by mine ventilation inducing oxidisation of otherwise stable minerals. In total, we will only achieve an approximate knowledge on components of mine site drainage quantity and quality. The available hydrogeological information from the mining activities relate mostly to a minefield (some square kilometres) or a level of an underground mine. Detailed data referring to a dense grid of data points would be the exception.

In considering the nature of larger underground mines we have to decide what kind of model structure is reasonable, what is functional?

3 APPROACH FOR A NUMERICAL MODEL (BOX-MODEL)

3.1 The Box

The necessary compromise between a detailed imaging of the complexity of a hydraulic situation and practical answers to a complex mine has to consider three aspects:

- simplifications can only be accepted to the extent that important anwers to the operation, flooding, and post flooding process remain correct (or the limitation to our prognosis remains known)
- the system has to be stable and clearly arranged so that acceptance by mine operators can be found and the capability of their staff be integrated
- the system must be capable for development when more data become available (e.g. adding more boxes or connecting to a ”classic” numerical model)

The first point is very closely connected with the question how large a balance unit should be to describe the flow field. For each balance unit a hydraulic potential is to be assigned. However,

- we have generally only hydraulic information for an entire mine field, but divided in several slices of mining activities.
- inside of a minefield at a special level we often have a hydraulic short-circuit.

The answer we got from field tests (i.e. measurements of the ongoing flooding process at the Ronneburg mine of Wismut) and studies of the hydraulic system is, that the pressure (or potential)-differences inside a mine field are close to zero in the horizontal direction. Hence, there is no reason to create a balance-unit (a box) smaller than such mine field. Additional boxes would not increase the information about the hydraulic system. On the other hand, in the vertical direction (inside of a column of a mine field) the consideration of several boxes is very important. Here, we are measuring a significant potential difference and therefore, the problem of contaminating an ecological system could result from ascending mine water.

Consequently, we arrive at fairly large balance cells or volumes, the so called boxes. A box is assigned all important information and components of the mine field in the hydrogeological sense: storage volume, recharge, discharge and also information on mine-water-quality: pH, Eh, temperature, concentrations, stored contaminants, typical minerals etc..

A box is not only a fictive balance unit, it is a picture of a real mine field and needs real geographic data: X-, Y – coordinates, bottom and top elevations of each box (Figure 1).

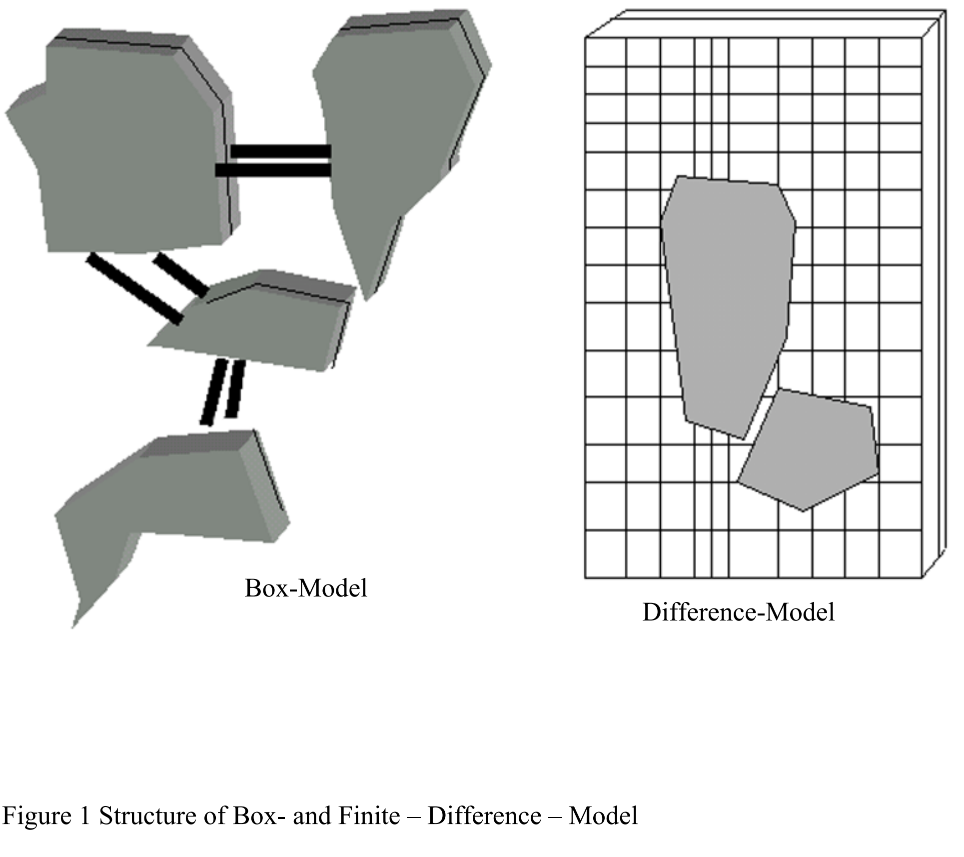

Figure 1 Structure of Box- and Finite – Difference – Model

With the support by a CAD system and a good software package a future development to additional boxes is easy and, if necessity arises to combine the box-model with ordinary groundwater flow in aquifers, a suitable solution has already been developed to handle the hydraulic problems by an interactive mode between the mine model (box-model) and a finite difference model (GEOMODEL) which has the same structure as MODFLOW.

The data base created will also be of value for further developments. This assurance, guaranteed by a closed theory and real world test at a complex mine, is important before starting investments to obtain further data.

3.2 The connection of boxes

The description of the flow process has to consider geological hydraulic connections like porous aquifers, in the same way as hydraulic short circuits (drifts, shafts), fractures etc.. The hydraulic connection between boxes must be a very general parameter, which can be calculated from the permeability or the transmissivity under consideration of the geometry of the special water bearing unit.

All detailed information can be combined to one complex-parameter. The Conductance is the functional key (complex) parameter for all hydraulic connections:

$$\mathbf{C = k_f \times A / s} \qquad \textbf{or}$$
$$\mathbf{C = T \times M / s} \qquad \textbf{or}$$
$$\mathbf{C = \text{directly from measurement}}$$

C	Conductance [m^2/s]
k_f	permeability [m/s]
s	distance between boxes ore relevant distance for the special resistance to flow [m]
A	rectangular area passed [m^2]
T	Transmissivity [m^2/s]

The calculation of C, directly by division of flux and potential difference between mine fields, is very practicable when one is unable to describe the detailed geometry of hydraulic connections.

This conceptual approach of boxes and connections is easily understood and can give reasonable answers to day-to-day questions, however, we need a new numerical discretisation scheme to solve this problem (Figure 1):

3.3 The free structurable box-model

The requirements mentioned before, result in a numerical structure of the flow equation which cannot that easily be solved as e.g. the "band matrixes" of the well known MODFLOW program. In order to sumulate flooding of mines an effective and fast implicit solution for this system was developed to solve the hydraulic problem. (Implicit here means: at each step of time all variables were considered at their values pertaining to the new actual time level). A very good mass-balance of the solution was proven.

Hydraulic connections (Conductance) between boxes (calibration by means of measured differences in water levels and fluxes) can very practically be measured during the initial stage of the flooding process. Usually partial or complete flooding of a mine requires a number of years, and there is the possibility of calibration or re-calibration under a ”stress-period” in order to improve the quality of the prognosis.

Which features are provided by such a type of numerical model:

- allow feasibility/impact analysis for alternate mine water operation/flooding schemes
- provide well based quick response, with allowance for adequate recalibration with increasing experience and level of knowledge
- approximation of mine water flow
- mixing of water quality between boxes
- consideration of non-steady components
- **and it brings order into the traditional flow chart: the reorganizable ”water tree” in the flooded and non-flooded (flow across drainage ditches in drifts, seepage water) mine section!!**

4 APPLICATION OF THE BOX-MODEL

The box-model has been applied to date at two European mines.

The Buhovo Mine (Bulgaria):
The uranium mine Buhovo (near Sofia) consists of 8 minefields, 17 levels (vertical distance more than 1,000 m). Due to the hydrogeological situation only 1/3 of the mine can be subjected to flooding, the balance will stay in the vadose zone all times. This means, oxidisation processes and therefore the leaching of uranium and sulphate will persist.

By means of a box-model tailored to this mine (Figure 2), forecasts were made for:

- time for flooding
- the contaminant load for the next years (”flushing” of the mine),
- the flux at the expected points of discharge and
- effect of technical solutions to prevent the outflow at critical points by blocking of drifts.

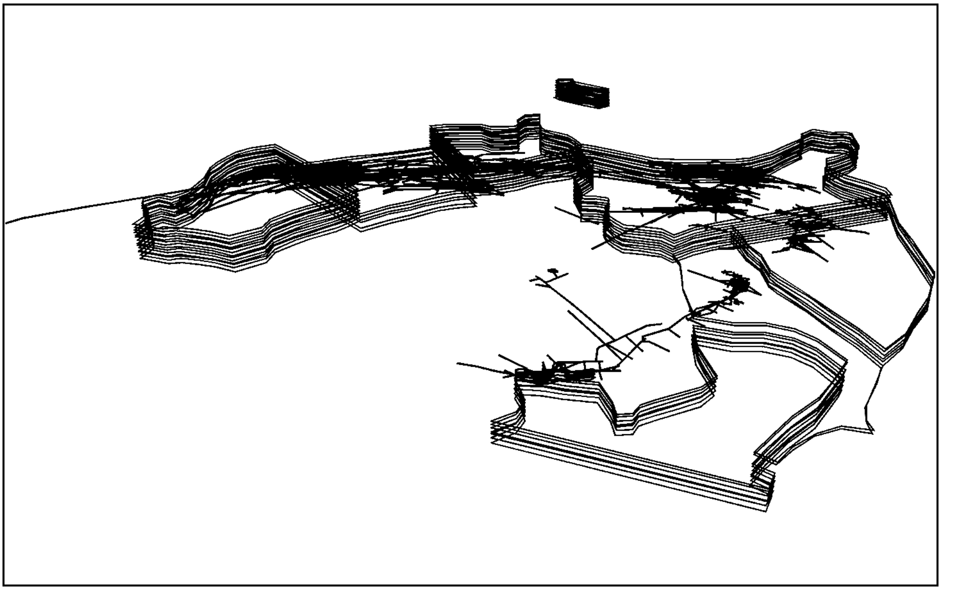

Figure 2 Box – Structure and drifts Buhowo Mine

The Ronneburg Mine (Germany):
At the Ronneburg Mine of Wismut pumping of groundwater for more than 40 years produced a cone of depression extending for more than 60 km^2. The entire mine consists of 21 minefields and the vertical distance of active mine workings differs from 400 to 800 m below ground.

In contrast to the Buhovo Mine, the Ronneburg Mine can be flooded almost completely. Therefore, the contaminant load will decrease during the first years after flushing.

Only with the help of the box-model the transient flooding-process could be calculated. The calculated time to flood this mine is almost 10 years.

5 CONCLUSIONS

The box-model specially tailored to the hydraulic conditions at underground mines provides a powerful tool for mine drainage operations and forecast of environmental impacts of mine flooding. Its degree of sophistication can easily be varied with the level of knowledge and experience, including ties into high resolution 3D numerical fate and transport models. Box-models are the appropriate answer to close the gap between highly demanding numerical models and available mine data averaging over large areas.

Model numeryczny dla zarządzania zasobami wodnymi w kopalniach o skomplikowanych systemach wyrobisk podziemnych

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Streszczenie: Modelowanie numeryczne przepływu wód stało się standardowym działaniem przy obliczeniach przepływu zarówno wód powierzchniowych jak i podziemnych. Modelowanie przepływu wód w kopalniach podziemnych wymaga specjalnego podejścia ze względu na występowanie dużych i połączonych pustek górniczych (wyrobiska). Kluczem do symulacji takiego procesu jest ograniczenie do minimum bilansowych komórek modelu (duże bloki obliczeniowe), zgodnie z wymaganiami pola przepływu i pominięciem klasycznego schematu dyskretyzacji. Właściwości bloków można ustalić (określić) na podstawie dostępnej dokumentacji kopalnianej. Poprzez przetworzenie uzyskanych danych i zastosowanie standardowej aplikacji CAD stworzono znakomitą, wielofunkcyjną bazę danych. Opisano teorię uproszczenia modelu blokowego. Różnorodne typy połączeń hydraulicznych między blokami są odzwierciedlone przez przewodność (m^2/s), która może być wyliczona na podstawie strumienia przepływu i wysokości hydraulicznych. Model blokowy zastosowano z sukcesem dla dwóch podziemnych kopalń uranu, gdzie z powodu wymagań ekologicznych konieczna była skomplikowana prognoza wpływu zamknięcia kopalń na środowisko. W przypadku częściowego lub całkowitego zalania większych kopalń podziemnych modele blokowe ułatwiają kompilację wielu danych hydrogeologicznych i zapewniają doskonałe narzędzie do planowania i zmian w zarządzaniu zasobami wodnymi.