SYSTEMS APPROACH FOR MINE WATER CONTROL

Kesserü, Zs.*; Bogárdi, I.*; Szidarovszky, F.**

ABSTRACT : Design and operation of mine water control warrants the use of systems analysis. Objectives of the system are defined (economic, life protection, environmental). A system model of economic mine water control is presented. Elements of the systems model are formulated : input, state variable, output, state transition function, output function. Due to stochastic natural environment, the systems model of mine water control has also stochastic elements. The model refers to Hungarian mining conditions but principles are common for any kind of mining under water hazard.

RESUME : La conception et la mise au point des modes de protection contre les eaux souterraines rendent possible d'utiliser des méthodes d'analyse de système. Les objectifs de l'emploi de ce système sont définis (rentabilité, protection de la vie et environnement). On présente un modèle de système économique pour la lutte contre les venues d'eau. Les éléments de ce dernier sont : entrées, variables d'état de transition et sorties. Par suite de l'environnement naturel de caractère stochastique, le modèle de système comporte également des éléments stochastiques. Mis au point pour les conditions minières hongroises, il est basé cependant sur des principes généraux valables dans n'importe quelle mine luttant contre les eaux.

RESUMEN : La concepción y puesta a punto de los métodos de protección contra la irrupción de aguas subterráneas, hacen posible el empleo de la técnica de análisis de sistemas. Se definen los objetivos del empleo de estos sistemas (economía, protección de la vida y medio ambiente). Se presenta un modelo económico para la lucha contra las irrupciones de agua en la mina. Los elementos de este sistema son : entradas, variables de estado, función de transición y salidas. Debido a la naturaleza estocástica del medio ambiente, el modelo tiene igualmente elementos estocásticos. El modelo, puesto a punto para minas húngaras, está basado en principios generales válidos en cualquier trabajo minero con problemas de agua.

* Mining Research Institute, Mikoviny u. 2-4. 1037 Budapest, Hungary.
** Department of Computer Sciences, University of Agriculture
Villányi ut 36. 1013 Budapest, Hungary.

1. INTRODUCTION

This paper analyses typical objectives /life-protection, economic, environmental/ of mine water control systems, reviews some Hungarian works on systems approach for mine water control and introduces a new mathematical model.

Dynamic programing /DP/ model can be used for an economic optimal design of mine water control system. Under Hungarian conditions the control of mine water is one of the key elements of the mining production and especially in the case of planned mines in the Transdanubian Mountains, near Budapest, it is of primary importance to develop mine water control systems appropriate from both economic and engineering aspects [KAPOLYI, 1977]. The fact is that due to the natural conditions a considerable part, 10-20 % of total production costs is related to water control in that region. Thus, the economics in mine water system may affect the economic feasibility of the overall mining activity. The task is aggravated by the fact that water hazard - similarly to other natural hazards - can be known in advance only with uncertainty; thus stochastic methods are required. In addition to the task of finding economic mine water control systems, environmental criteria should be also observed which are related in that region mostly the water budget of the regional karstic aquifer [SZILÁGYI et al., 1978].

A number of engineering methods for mine water control has been elaborated [SCHMIEDER et al., 1975] and recently a new control method, the so called "instantan" method has been developed which seems to be more effective than the previous ones [KAPOLYI, 1975].

This paper describes first the objectives of mine water control and gives examples on the application of systems analysis in that respect /Section 2/. Next, the typical problem of mine water control, pertinent to the Budapest region /Section 3/ is outlined. In this vein, the mine water hazard is characterized, and principles of its calculation are shown. Possible alternatives of control methods are summarized and water budget constraints due to environmental protection are discussed.

The core of this paper aims at the elaboration of the DP model /Section 4/. First, main assumptions are fixed, variables are defined and the objective function is formulated. State variable, the yield of mine water inrushes can be regarded as a random variable, thus a stochastic DP problem should be solved. Advantages of the DP formulation are evident in view of the computational saving as compared to optimum seeking with total enumeration.

In Section 5 numerical data and functions for the application of the model are provided. Numerical results on the optimal mine water control system will be given at the conference.

Section 6 summarizes conclusions reached and recommendations for further research with the ultimate goal that the model be applicable under similar mining conditions and model principles be useful to solve other kind of sequential development problems of mining /e.g. ventilation, gas protection, haulage/.

2. MINE WATER CONTROL

Mine water control constitutes a subsystem of the mining system and is connected, on the one hand, to other subsystems /haulage, ventilation, etc./ through common elements /e.g. cuts/,and,on the other hand, to the natural environment, through drainage wells, sealing holes, etc. Engineering definition of mine water control systems can be found in SCHMIEDER et al. [1975] . Mine water control induces changes in the interaction between rocks and water around mining spaces [KESSERÜ, 1978]. Mine water phenomena include water movements, as inrushes and movements of gas and rock, caused by mine water. Among these movements those induced by the mining activity are regarded as water hazard and those induced by control elements mean the effect of the control system.

2.1. Objectives of mine water control

Objectives of a mine water control system are related to life protection, economics and the environment.

The effectiveness of life protection can be measured by the risk of fatal accidents caused by mine water phenomena.

The economic objective calls for such a control which results in minimum water related costs and mining losses regarding the total life-time of the mine. In many cases the economic control means a constrained optimum, since e.g. an annual production rate is to be maintained.

The environmental objective refers to the smallest disturbance of the natural environment. The effectiveness of reaching this objective can rarely be expressed in monetary units but in natural units of water quality, quantity, land subsidence, etc.

2.2. Systems analysis of mine water control

Systems analysis seeks to answer the following main questions.

a./ What is the required or optimal degree of reaching different objectives?

b./ What is the system satisfying the above objectives?

Concerning life protection, investigations have been made to estimate the required magnitude of the risk of fatal accidents mentioned [SCHMIEDER et al., 1975]. As a result of these investigations Hungarian mining safety regulations prescribe system elements satisfying life protection objective. Among the three objectives life protection requirements are thus generally fixed, no trade-off with other objectives can be analysed, and as constraints can be included in a systems model.

An example of the economic analysis of mine water control system can be found in KESSERÜ and PRUZSINA [1970], who estimated an economic capacity for the conveyance system and the pumping station.

It has been demonstrated that the economic and environmental objectives are often in conflicts with each other [BOGÁRDI et al., 1978]. In this paper the environmental objective is considered as a constraint, namely the upper limit of maximum drained water. Since numerical value of this constraint can be changed the model shown in Section 4 is regarded as one phase of a multiobjective analysis.

Clearly, a mine water control system has a number of interrelated natural and manmade elements. Though the reliability of such a system is not easy to estimate, investigations have been made to determine system reliability, that is,1 - probability of failure, since this is a key figure of design and operation [SCHMIEDER et al., 1975].

In the next Section typical mine water control in the Budapest region is briefly described.

3. MINE WATER CONTROL IN THE BUDAPEST REGION

3.1. Water hazard

Coal and bauxite deposits are located under the karstic water level in a fractured rock aquifer. Water hazard may stem from either the upper layers or the bed rock material. Water inrushes would yield more or less sediment into the underground spaces. The amount of sediment can be estimated from inrush data /flowrate, volume/ and rock properties. Total yield of water inrushes into a given space depends on rock properties, piezometric pressure, and the magnitude of the space, which, in turn, is known from the mining plan.

Total yield of inrushes during a time period /stage/ can be taken as the sum of inrush events along the space corresponding to the stage considered. Subsequent inrush events are practically independent. Both the magnitude and number of inrush events can often be regarded with good approximation as random variables [SCHMIEDER et al., 1975]. As a result, stochastic methods are available to characterize water hazard [SCHMIEDER, 1976], and in this way probability density function /pdf/ of the total yield of inrush events per stage can be estimated. The method of estimation is based on geological analogy and/or the measured rock properties.

Direct statistical samples of inrushes for the planned mine cannot evidently be available. However, as mining operation starts and proceeds, more and more samples on water inrush events could be observed. Thus, pdf of inrush events and total yield can already be estimated with greater confidence for the following stages.

3.2. Control system

The mine water control system /Fig. 1/ consists of two main parts

a./ protection of production activity, e.g. faces by various methods, and

b./ water /and sediment/ conveyance and pumping equipments.

The economic analysis may cover both parts of the control system or either of them. This paper considers the first part, thus decision alternatives considered include fixed conveyance and pumping design /cuts, shafts, pumping station/. The common practice is accepted, that the conveyance and main pumping equipments are designed with due allowance to a high reliability prescribed in safety regulations and to other requirements /ventilation, haulage, etc./.

Control methods of mine water can be divided into two main groups [SCHMIEDER et al., 1975]:

a./ Preventive /active/ protection aims at the elimination, dedrease or postponement of water inrush occurrences by
- sealing with some artificial protective layer or with the use of natural protective layers;
- dewatering with shafts and wells out of the mining space to decrease piezometric head.

b./ Subsequent /passive/ protection covers
- the collection, conveyance, and pumping of water from mining spaces;
- the abandoning of, and the rescue from flooded spaces;
- the drainage of the flooded spaces.

In most of the cases the above methods are applied in a proper combination. A recently recommended combination is the instantan method by which water inrushes to be caused by the mining are brought about in advance in borings or cuts [KAPOLYI, 1975].

Thus, the decision model on mine water control design should be capable of selecting among the various alternatives including the combinations thereof.

In the case of the planned mines investigated we seek a proper combination of
- the instantan method,

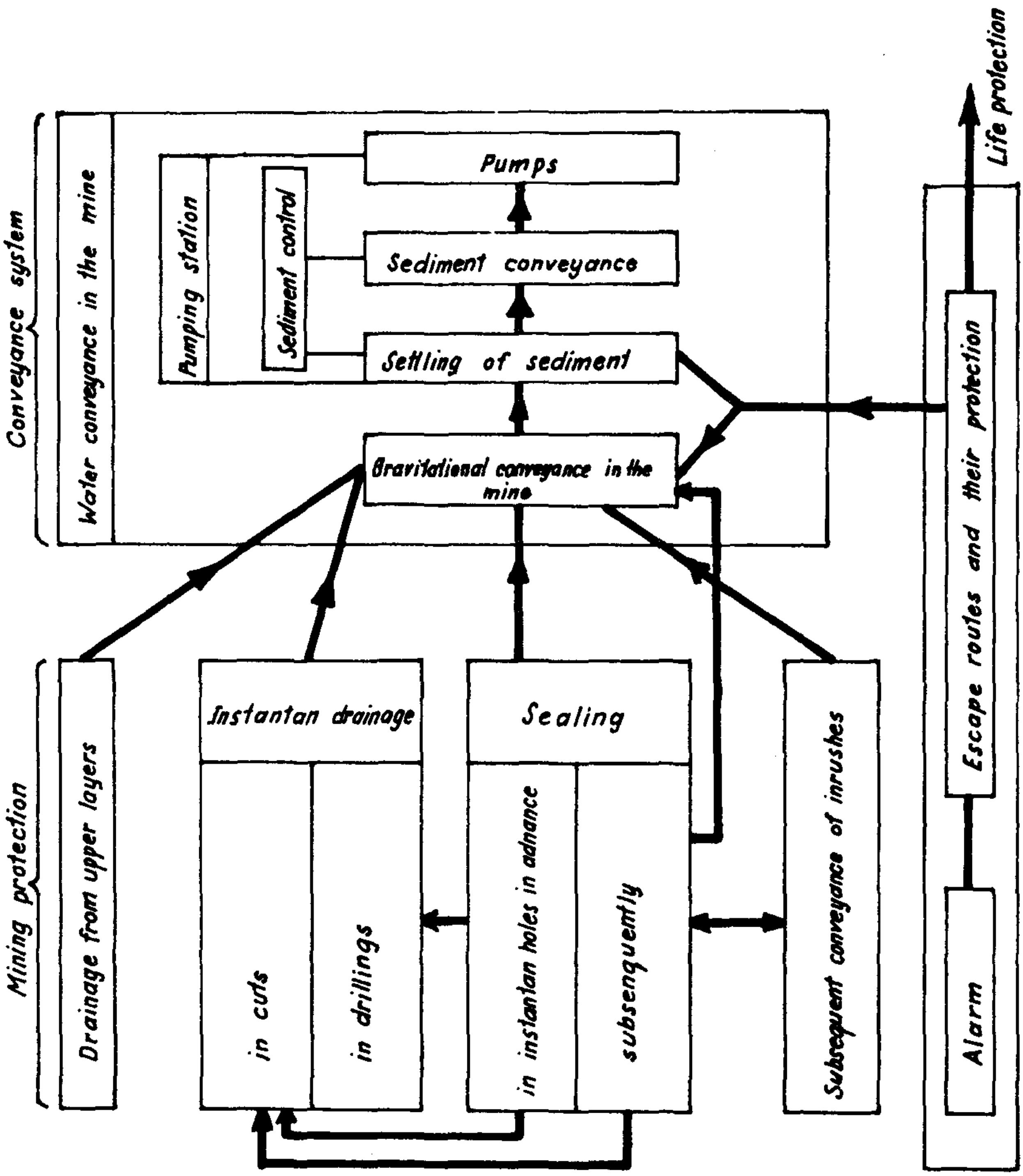
Conveyance system
Water conveyance in the mine
Pumping station
Sediment control
Pumps
Sediment conveyance
Settling of sediment
Gravitational conveyance in the mine
Life protection
Escape routes and their protection
Alarm
Mining protection
Drainage from upper layers
Instantan drainage
in cuts
in drillings
Sealing
in instantan holes in adnance
subsenquently
Subsequent conveyance of inrushes

Fig. 1

- dewatering,
- sealing /in advance and after inrushes/, and
- subsequent protection.

By the help of such a combination a reduction can be reached in:
a./ the total yield of inrushes /by sealing/,
b./ the ratio of yields in the production spaces to the total yield /in the holes of instantan and other preventive drainage methods/.

The realization and operation of mine water control measures requires considerable costs. If subsequent protection is applied more or less damages should be also reckoned with. These are related to less production, adverse working conditions, smaller efficiency of machine fleet and other loss factors [KESSERÜ, 1977]. Construction and operation costs as well as the losses occur in different stages during the lifetime of the mine. As a consequence, present value /discounted/ costs and losses should be calculated and compared.

The environmental objective refers in the region to the least disturbance of the regional karstic water budget. Namely it might be possible that such a high amount of mine water should be drained /economic optimum/, that cannot be tolerated due to environmental hazards /drying-out of waterworks, thermal baths, etc./.

4. DYNAMIC PROGRAMMING MODEL

DP model is developed in four steps. First the main assumptions are given /4.1./, and model variables and functions are defined /4.2./ as state variable, input, output, state transition function and output function. Next the goal function of the model is formulated /4.3./ and the way how DP algorithm can be used for the optimalization is shown /4.4/.

4.1. Assumptions

Decision model is based on the following three assumptions:

I. Mineral resources, desired annual production and, thus, the life-time T of the planned mine is given. Total life-time can be divided into characteristic stages $t = 1, 2, \ldots, i, \ldots, T$. Stages may be years; however, the periods between stages may be as desired and not necessarily constant.

II. On the basis of a mining sheduling plan, for each stage the area of underground spaces $F(t)$ is denoted which consists of the operating and abandoned faces in various blocks.

III. The pdf of the total yield of water inrushes per stage, $f\ [\Delta \underset{\sim}{Q}(t)]$ can be estimated.

Symbol refers to a random variable.

4.2. Definition of the variables and functions
Input $\tilde{Q}$ (t) for stage t is the total yield of water inrushes until this stage; a random variable.

State variable is the total yield of inrushes, $\Delta\tilde{Q}$ (t) during stage t.

Output $\tilde{Q}$ (t+1) for stage t is the total yield of inrushes after stage t, this output equals the input for stage (t+1). Output is thus determined by the input, state variable and decision set defined next. For each stage t we can decide on the method of water control, to be used over the area F(t). Possible set of decisions can be characterized by vector $\underline{d}$ (t); the components thereof consist of the specifications of possible water control methods outlined in the previous section, e.g. the total length of instantan borings, the number of sealings /groutings/, total amount of sealing material, all for stage t.

State transition function can be given thus as

$$\tilde{Q}\,(t+1) = g\left[\tilde{Q}(t),\ \Delta\tilde{Q}(t),\ \underline{d}(t)\right] \qquad (1)$$

where function g can be of any type, not necessary linear, given sometimes in a table form with discrete numerical values.

If density function $f[\Delta\tilde{Q}(t)]$ is given for each stage, starting from t = 0 we can calculate pdf of output $\tilde{Q}(1)$ for each possible decision in t = 1, then pdf of $\tilde{Q}(2)$ etc. It might happen that simulation is necessary to calculate these pdf in the case of complicated distributions. Simple formulas can be used in every case, however, to calculate the expected value and variance of output $\tilde{Q}$ (t+1) [BENJAMIN and CORNELL, 1970].

Output function regards total water-related costs incurring during state t in the function of input, state variable and decision vector:

$$\tilde{r}(t) = D_t R_t \left[\tilde{Q}(t),\ \Delta\tilde{Q}(t),\ \underline{d}(t)\right] \qquad (2)$$

where D_t is the discount factor in order to calculate present values /mostly for t = 0/ of costs incurring in different stages; R_t is the output function which covers water-related costs of investment, operation and maintainance during stage t.

In practice, function R_t is generally nonlinear, estimated in discrete points and given graphically or in table. It can be seen that as a result of the random state variable, output function $\tilde{r}(t)$ is also random.

4.3. Goal function

Such a mine water control system is sought that water-related costs be minimum throughout the total life-time. Thus the goal function is

$$\underset{\sim}{Z} = \sum_{t=1}^{T} \underset{\sim}{r}(t) \qquad (3)$$

This goal function is to be minimized by finding a sequence of decisions, $\underline{d}_1^*$, $\underline{d}_2^*$, ... $\underline{d}_T^*$ that

$$\underset{\sim}{Z}^* = \min_{\underline{d}_1^*, \underline{d}_2^*, \ldots, \underline{d}_T^*} \sum_{t=1}^{T} \underset{\sim}{r}(t) \qquad (4)$$

Since members of the goal function are not independent, it is not possible to minimize from stage to stage. This can be seen directly from state transition function (1), since $\underline{d}(t)$ realized in stage t affects inputs for all later stages, thus all output functions $\underset{\sim}{r}$. In reality, this may mean that it not advisable to drain high yields in the initial stages of mining, that is, some sealing is required in order to eliminate excessively high inputs $\underset{\sim}{Q}(t)$ in later stages.

It is a further problem that for each random value $\underset{\sim}{Z}$ of the goal function an optimum sequence of decisions could be found. In such case the expected value of the goal function is common to be minimized:

$$Z^* = \min E \left[\sum_{t=1}^{T} \underset{\sim}{r}(t) \right] \qquad (5)$$

Output $\underset{\sim}{Q}(T)$ of the last stage T corresponds to the highest amount of karstic water drained. For environmental reasons a maximum amount Q can be specified. This upper limit means that a high probability, α should be prescribed that output $\underset{\sim}{Q}(T)$ will be less than the environmental limit:

$$P\left[Q(T) < Q\right] \geq \alpha$$

4.4. DP algorithm

Model of mine water control /Fig. 2/ constitutes a model with serial elements /stages/. Since output in t equals input in (t+1), optimization of the goal function (5) can be performed by dynamic programming [BELLMAN, 1962]. It is a final value problem since an upper limit for $\underset{\sim}{Q}(T)$ is prescribed. As a consequence forward dynamic programming can be used, with the recursive equation

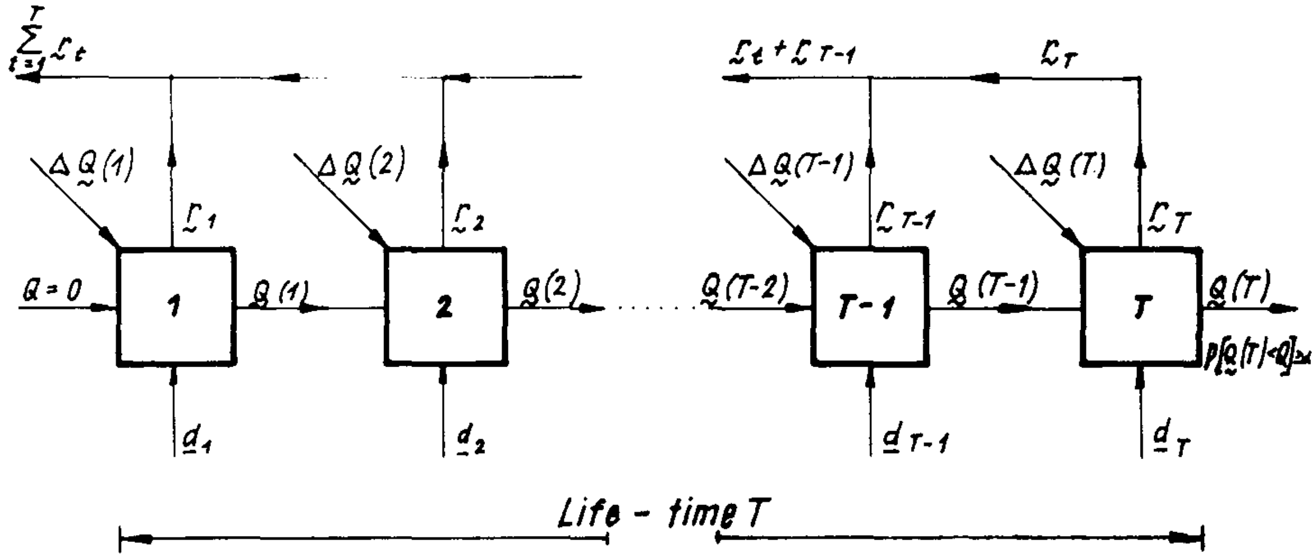

Fig. 2 .

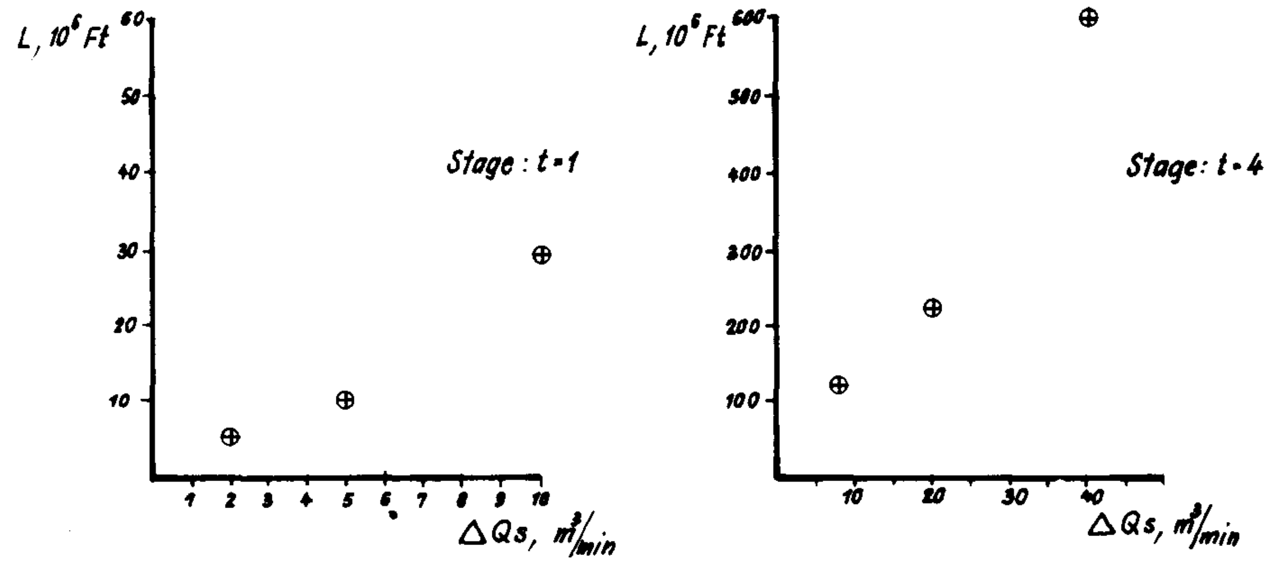

Fig. 3.

$$b_{i+1}\left[Q(i+1)\right] = \min_{\underset{\sim}{d}_{i+1}} \left\{ E\left[\underset{\sim}{r}_{i+1}\left(\underset{\sim}{d}_{i+1}, \underset{\sim}{Q}(i+1)\right)\right] + b_i\left[\underset{\sim}{d}_{i+1}, \underset{\sim}{Q}(i+1)\right] \right. \quad (6)$$

where b is the minimum of the expected value sum of output functions $\underset{\sim}{r}$ until stages 1, 2, ..., i:

$$b(i) = \min E\left[\sum_{t=1}^{i} \underset{\sim}{r}(t)\right] \quad (7)$$

Thus, recursively, from stage to the next stage the final stage T can be reached and b(T) will be expressed in the function of Q(T). Then the environmental limit Q, that is, the final value can be substituted in the recursive equation for b(T), and b(T-1), b(T-2) ..., b(1) can be calculated backward by the help of state transition functions, and the optimal sequence of decisions, $d^*(T)$, $d^*(T-1)$ ..., $d^*(1)$ can be found.

Due to the random state variable stochastic DP must be applied [METLER et al., 1975], which does not mean the change of DP principles but multiplies computation requirements. In that respect, the type of pdf for the state variable is of great importance. In the case of discrete probabilities or some basic distributions /e.g. normal/ difficulties are not expected, but often simulation is the only available tool to optimize numerically by the DP algorithm.

In the next Section data referring to a planned mine in Hungary are given.

5. EXAMPLE DATA FOR THE MODEL

In this Section a real-life mine water control problem of a planned Hungarian mine is regarded. The necessary data for using the model are given in order to facilitate model application in other cases.

5.1. Stages and mine water inrushes per stages.

Table 1 contains characteristic time periods, that is, stages for a mine with a total life-time T = 30 years. Also, statistics /mean and standard deviation, s.d./ of total steady flow of inrushes per stages, $\Delta \underset{\sim}{Q}(t)$ are given.

Table 1

Period t	Duration years	$\Delta \tilde{Q}(t)$, Total flow m^3/min mean	s.d.
1	3	10	7
2	7	15	7
3	8	20	7
4	7	40	10
5	5	5	5

The pdf of $\Delta \underset{\sim}{Q}(t)$ can be taken as lognormal.

5.2. Decision set

$$\underline{d}(t) = [d_c(t),\ d_d(t),\ d_s(t)]$$

$d_c(t)$: total length of cuts for "instantan" drainage during period t, in thousands of meter;

$d_c(t)$: total length of drillings for "instantan" drainage during period t, in thousands of meter;

$d_s(t)$: total amount of sealing during period t, in thousands of m^3.

From the theoretically infinite number of decision alternatives, a discrete set of possible alternatives has been selected for that example. Table 2 shows that in each stage 8 possible decisions are assumed. In real life the number of alternatives may be much higher but model principles will not change.

Table 2

Discrete set of decision alternatives

Period, t		decision alternatives 1	2	3	4	5	6	7	8
1	d_c	0	3	3	3	3	3	3	3
	d_d	0	0	6	10	6	6	10	10
	d_s	0	0	0	0	4	7	4	7
2	d_c	0	36	36	36	36	36	36	36
	d_d	0	0	72	110	72	72	110	110
	d_s	0	0	0	0	6	15	6	20
3	d_c	0	40	40	40	40	40	40	40
	d_d	0	0	80	140	80	80	140	140
	d_s	0	0	0	0	8	16	8	20
4	d_c	0	40	40	40	40	40	40	40
	d_d	0	0	80	140	80	80	140	140
	d_s	0	0	0	0	14	40	14	50
5	d_c	0	6	6	6	6	6	6	6
	d_d	0	0	12	20	12	12	20	20
	d_s	0	0	0	0	2	6	2	8

5.3. State transition function

$$Q\ (t+1) = Q\ (t) + \Delta Q\ (t) + \Delta Q\ \left[d_s (t) \right] \qquad (8)$$

where $\Delta Q\ [d_s(t)]$ is the sealed flow of inrushes in t. The total flow $\Delta Q\ (t)$ to be pumped up to the surface, can be expressed

$$\Delta Q\ (t) = \Delta Q\ \left[d_c(t),\ d_d(t) \right] + \Delta Q_s(t) \qquad (9)$$

where $\Delta Q\ [d_c(t)\ ,\ d_d\ (t)]$ is the flow of inrushes drained in cuts (d_c) and drillings (d_d) of instantan control;

ΔQ_s (t) is the portion of total flow of inrushes appearing in mining operation spaces and causing economic losses.

For the sequential calculation of state transition function (9) it is necessary to fix Q(o) = 0 and P $[Q(T) \leqslant Q = 120\ m^3/min] \geqslant \alpha = 0,95$. In addition, values of $\Delta Q(d_s)$, $\Delta Q\ (d_c,\ d_d)$ and ΔQ_s are given for every stage and decision alternatives in Table 3 after KAPOLYI [1976].

Table 3

Period, t stage		Decision alternatives 1	2	3	4	5	6	7	8
	$\Delta Q\ (d_s)$	0	0	0	0	6	8	8	10
1	$\Delta Q\ (d_c, d_d)$	0	5	8	10	2	0	2	0
	ΔQ_s	10	5	2	0	2	2	0	0
	$\Delta Q\ (d_s)$	0	0	0	0	7	12	10	15
2	$\Delta Q\ (d_c, d_d)$	0	8	12	15	5	0	5	0
	ΔQ_s	15	7	3	0	3	3	0	0
	$\Delta Q\ (d_s)$	0	0	0	0	12	16	15	20
3	$\Delta Q\ (d_c, d_d)$	0	10	16	20	4	0	5	0
	Q_s	20	10	4	0	4	4	0	0
	$\Delta Q\ (d_s)$	0	0	0	0	22	32	30	40
4	$\Delta Q\ (d_c, d_d)$	0	20	32	40	10	0	10	0
	ΔQ_s	40	20	8	0	8	8	0	0
	$\Delta Q\ (d_s)$	0	0	0	0	2	3	4	5
5	$\Delta Q\ (d_c, d_d)$	0	3	4	5	1	0	1	0
	ΔQ_s	5	2	1	0	2	2	0	0

Data in Table 3 represent mean values. Coefficient of variation in ΔQ (d_c, d_d) is the same as in $\Delta Q(t)$. However, the effect of sealing, ΔQ (d_s) also exhibits uncertainties with a coefficient of variation: 20 %.

5.4. Total costs per stages
According to equation (2) total costs r(t) per stages can be written

$$r(t) = D_t \Big\{ \text{pumping} \left[Q(t)\right] + \text{losses} \left[\Delta Q_s(t)\right] + \text{cut cost} \left[d_c(t)\right] + \text{drilling cost} \quad d_d \, t \; + \text{sealing cost} \left[d_s(t)\right] \Big\}$$

Costs will be given in 10^6 Forints /1 Ft equals about 5 US cents/.

a./ Pumping costs = a(t) . Q (t)

If Q(t) is in m^3/min:

	t = 1	2	3	4	5
a (t)	1,0	2,3	2,7	2,3	1,7

b./ Cut costs = 10 $d_c(t)$

c./ Drilling costs = 0,9 $d_d(t)$

d./ Loss function due to mine water can be estimated from experiences in existing mines in some discrete points at most. Loss functions are different in different stages. The difference is caused by changing mining conditions and technology as well as mineral production rate. Naturally, lower losses occur at the initial and last stages, t = 1 and 5 than in time of full operation, t = 3 and 4 . As an example Fig. 3 shows estimated loss function values for stage 1 and 4.

Given the above numerical data and functions for the DP model, the solution is straightforward on the basis of the recursive equation (6). Because of limited space numerical results and sensitivity analysis will be discussed in a separate paper.

6. CONCLUSIONS AND RECOMMENDATIONS
Main conclusions reached so far and recommendation for further research can be summarized as follows:

a./ Systems approach means an effective tool to design and operate mine water control systems.

b./ For the satisfaction of various objectives of mine water control a complex system is warranted.

c./ DP is an efficient modelling tool for the sequential economic design of mine water control systems, with due allowance to environmental constraints.

d./ Under certain hydraulic and/or geologic conditions, subsequent inrushes per stage, $\Delta Q(t)$ are not independent; in fact the flow of earlier inrushes may decrease as more and mor new inrushes occur [SCHMIEDER et al., 1975]. Present DP model assumes no hydraulic interrelationship, thus needs further development in the case this assumption does not hold.

e./ In the case of several mines in a region, a joint system of mine water control seems necessary since there are regional objectives of economics and the environment DP model similar to that introduced in this paper is capable of the design of such joint system [CASTI, 1977].

f./ Though several models of mine water control are available, there is a need to develop a general systems model which is connected both to the mining system and the environment.

REFERENCES

BELLMAN, R. and S. DREYFUS, 1962. Applied Dynamic Programming, Princeton University Press, Princeton, N.Y.

BENJAMIN, J.R. and C.A.CORNELL, 1970. Probability, statistics and Decision for Civil Engineers, McGraw-Hill Book Company.

DUCKSTEIN, L., I.BOGÁRDI and J.CASTI, 1978. Control model of underground flooding, Spring Nat. Meeting of ORSA, New York.

CASTI, J., 1977. Dynamic Systems and Their Application: Linear Theory, Academic Press.

KAPOLYI, L., 1976. New trends and research in protection against mine water. Proc. of the 7th Conference on Mine Water Control. Tom.1. Budapest.

KAPOLYI, L., 1977. Role of natural resources in the structure of Hungarian economics, IIASA-TEKHA Conference on Complex Utilization of Natural Resources, Sopron, Hungary.

KESSERÜ, Zs. and J.PRUZSINA, 1970. Risk and economy in mine water control and in water mining /in Russian/. Publ. of the Hung. Min. Research Inst. No.14.

KESSERÜ, Zs., 1976. Untersuchung der hangendseitigen Schutzschichten von Velenje. BKI Forschungsbericht, Nr. 13-7/75. Budapest

KESSERÜ, Zs., 1978. Methodology and application of analysing rock-water interaction endangering mines, SIAMOS, Granada.

METLER, W., I.BOGÁRDI, L.DUCKSTEIN, 1975. Effect of wind waves and wind tides on the optimum control of large lakes, Water Resources Research, Vol.11. No.3. Jun.

SCHMIEDER, A., 1971. A stochastic-hydraulic model for forecasting karst water hazard in mines /in Russian/, Publ. of the Hungarian Mining Research Institute, No.14.

SCHMIEDER, A., Zs.KESSERÜ, J.JUHÁSZ, T.WILLEMS and F.MARTOS, 1975. Water Hazard and Water Management in Mining /in Hungarian/, Müszaki Könyvkiadó, Budapest.

SCHMIEDER, A., 1978. Protection strategy in mines against karstic water inrushes, SIAMOS, Granada.