# WORKING PAPER

MINE

A game for the Analysis of Regional Water Policies in Open-Pit Lignite Mining Areas

E. Weigkricht
S. Kaden

July 1985
WP-85-46

IIASA
International Institute
for Applied Systems Analysis

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# PREFACE

The Regional Water Policies project of IIASA focuses on regions with intense socio-economic development where both groundwater and surfacewater are integrating elements of the environment.

Regions with open-pit lignite mining are one of the conspicuous examples of complex interactions in socio-economic and environmental systems. The activities of the mining industry interfere hardly with the interests of different water users in such regions, having severe repercussions on both the regional economy and on nature areas.

There is an apparent need for the analysis of long-term regional water policies to reconcile conflicting interest in regions with open-pit lignite mining, taking into account national socio-economical objectives. Within the Regional Water Policies project in collaboration with research institutes in the GDR and Poland methods and models are under development to support this analysis. Besides purely mathematical approaches, e.g. for multi-criteria analysis, less formal approaches are studied, considering behavioral aspects of the decision makers. One of these approaches is "gaming".

The paper describes the game MINE as a first attempt to apply "gaming". This work is done mainly by E. Weigkricht in partial fulfillment of her Diplom thesis at the Vienna University. It has been initiated and supported by Dennis Meadows within the Integrative and Special Studies project at IIASA.

S. Orlovski
Project Leader
Regional Water Policies Project

## ACKNOWLEDGEMENT

The authors express their gratitude to Dennis Meadows for the initiation of this work and the manifold valuable advice during its realization.

## ABSTRACT

The game MINE has been developed for the analysis of regional water policies in open-pit lignite mining areas. It is implemented for a GDR test area. The purpose of the game is above all to teach decision makers and their staff in mining regions in order to get a better understanding of the complex interrelated socio-economic processes with respect to water management in such regions. The game is designed to be played by five groups of players representing municipal and industrial water supply, agriculture, environmental protection and lignite mining. Two versions are available, one in BASIC for simple micro-computers as the Apple II combined with a gaming board, another one in FORTRAN for the VAX or ALTOS combined with sophisticated color graphics.

The paper describes the game, its practical application and first experiences in playing the game.

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## A Game for the Analysis of Regional Water Policies in Open-Pit Lignite Mining Areas

*E. Weigkricht and S. Kaden*

## 1. BACKGROUND

The impact of lignite mining on water resources creates significant conflicts between the different water users in mining regions. A detailed analysis is given by Kaden et al. 1985a,b. The most important interest groups consist of mining, municipal and industrial water supply groups in the region, and in many cases also down-stream water users, as well as agricultural groups and environmental protection areas. There is an apparent need for the analysis of long-term regional water policies to reconcile conflicting interests in regions with open-pit lignite mining.

The IIASA study "Water Policies: Regions with Open-Pit Lignite Mining" within the Regional Water Policies project is directed towards the development of methods and models to support such analysis. This research is based on a test area in the GDR, for a description see Kaden et al. 1985a. In Figure 1 a scheme of the test area is given, indicating both the interest groups and the control actions for regional water management.

Two principle problems have to be solved for the long-term development of open-pit lignite mining areas (Kadan et al. 1985a):

1. To find "good" long-term strategies oriented towards achieving a proper balance between national and regional economic needs, regional social needs and the regional preservation of the environment.
2. To find and realize controlling policies in order to direct the regional development according to the estimated "good" long-term strategies.

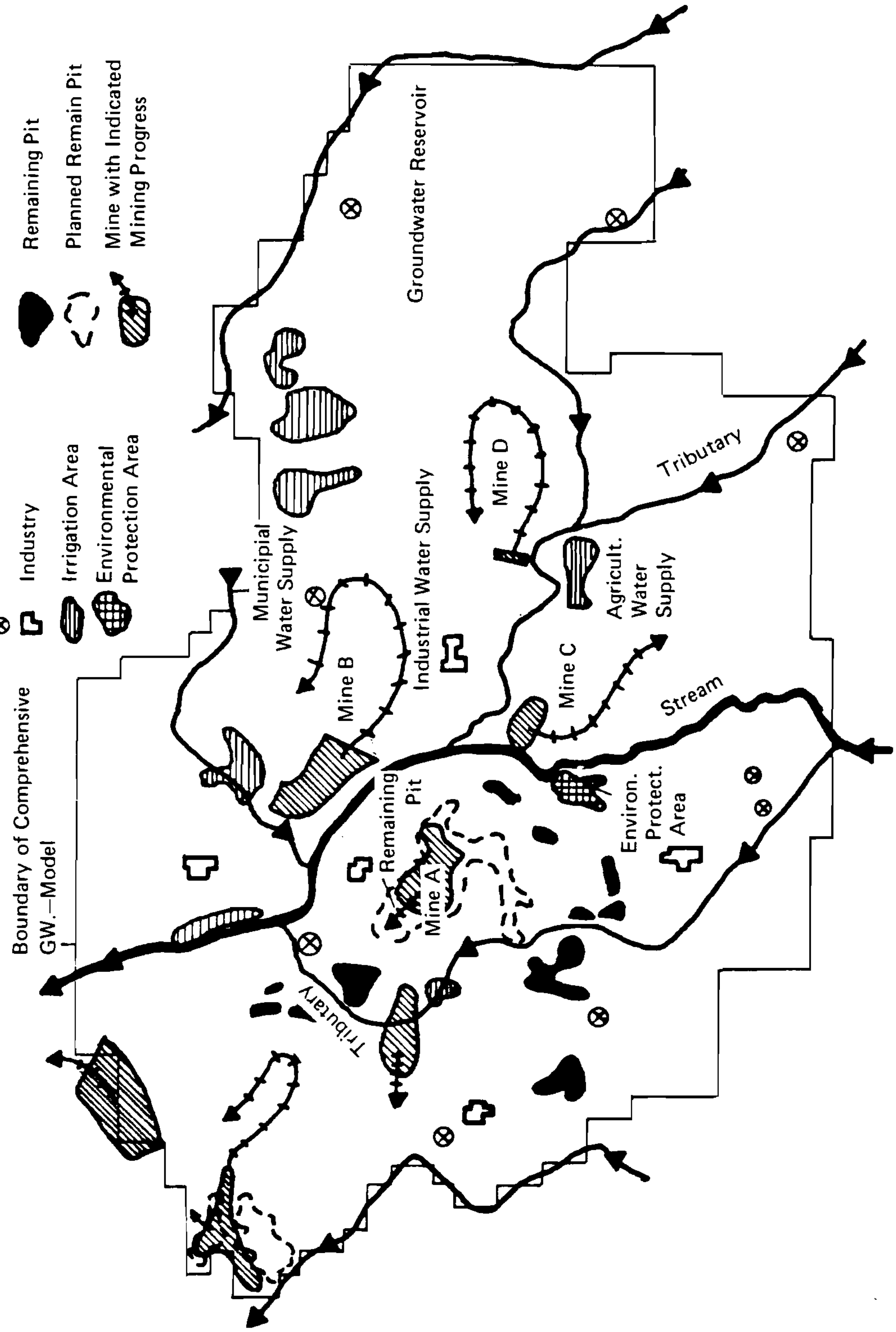


**Figure 1.** GDR Test Area

Based on that the *first stage* of analysis is directed towards generating rational scenarios of the long-term regional development based on preferences of a Central Planning Authority. In the *second stage* feasible regulation policies are studied in order to direct the behavior of water users and consequently the regional development along the reference scenarios obtained at the first stage.

The fundamental tool for both stages of analysis is an appropriate model system suitable for analyzing long-term regional water policies. The methodological approach for such a system is described by Kaden et al. 1985a. To summarize, taking into account the policy-making reality related to long-term regional water management and planning two different step-sizes discretizing the *planning horizon* $T$ ($\approx$ 50 years) are considered:

- the *planning periods* between 1 and 15 years as the time step for principal management/technological decisions (e.g. water allocation from mines, water treatment)
- the *management periods* of one month for management decisions within one year related to short-term criteria as the satisfaction of monthly water demand.

Based on that the model system consists of two major components.

- the *planning model* for dynamic multi-criteria analysis for all planning periods in the planning horizon,
- the *management model* for the stochastic simulation of monthly systems behavior in the planning horizon.

Whereas the *first stage* of analysis is based on the application of purely mathematical tools the *second stage* has to consider behavioral aspects by the help of less formal approaches. One attempt therefore is the application of "gaming". It opens an easy way for the involvement of the decision making process into mathematical modeling and improves the communication between scientists and decision makers.

The game MINE being described in the following is a first attempt to apply gaming for the problems under study. In developing the game we are following the basic four phases of game design (Greenblatt and Duke, 1980):

(1) *Initiation:* take into consideration the nature of the client, the intended use, the constraints of costs and time, etc.

(2) *Design:* develop the style and format of the game

(3) *Construction:* create the game, load data, test

(4) *Use.*

## 2. PURPOSE OF THE GAME MINE

According to Shubik 1983 the following five major subdivisions of gaming concerning its use may be distinguished:

(1) *Training* : to illustrate some aspects without going into conceptual details

(2) *Teaching* : to get across concepts and abstracts

(3) *Operational gaming* : (a) policy formulation, (b) dress rehearsals, (c) gaming for sensitivity analysis and commentary on plans

(4) *Experimentation* : (a) theory validation and (b) theory generation

(5) *Futures studies* : i.e., structural brain storming

The game MINE is designed for decision makers in open-pit mining areas to minimize pollution of water resources due to mining activities and to satisfy the water demand (using mine drainage water) with minimal cost. It should be played by the policy makers or the representatives of the different interest groups that are concerned. In order to simplify the game, a schematized policy-making process is assumed, see Figure 2.

The activities of each of the interest groups more or less modify the water resources system, and, at the same time, modify the conditions for the other water users. MINE should help to choose a policy in consideration of every interest group in the area, and, beyond that, of the desire to preserve natural ecosystems and recreational areas.

The players should learn:

- the interdependency between the different elements of the area,
- the consequences of the actions and decisions of the policy makers and the interest groups,
- all the different circumstances of a chosen policy,
- the necessary coordination of the demands and actions,

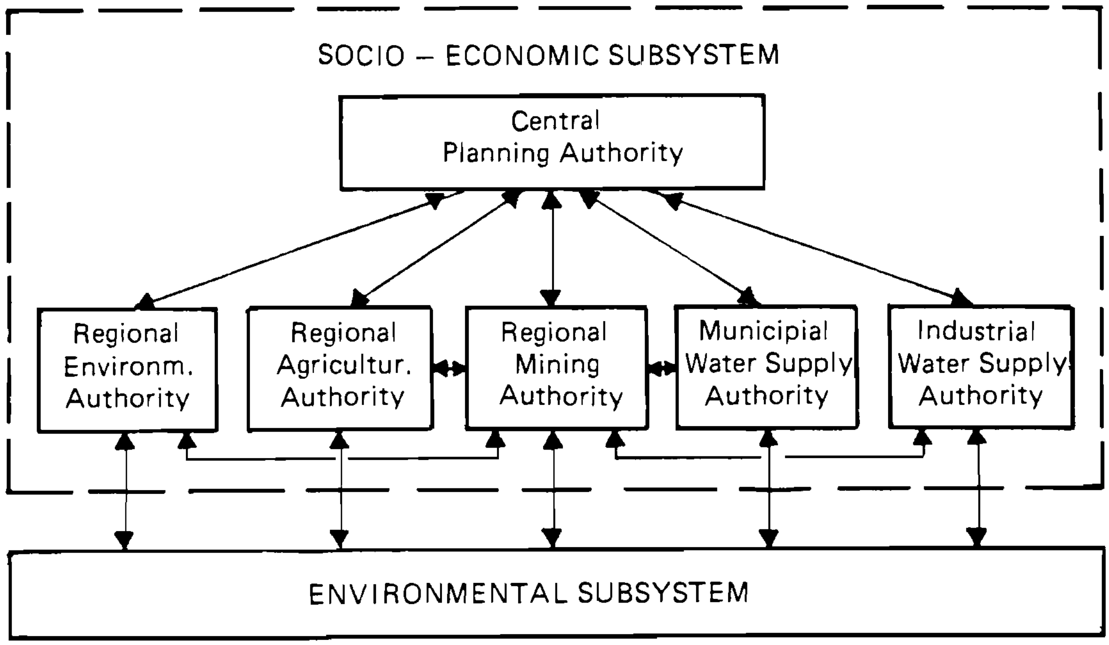


Figure 2. Schematized policy-making process

- to pay attention also to the long-term consequences, to the global goal, to the reason of activities of other groups.

Consequently, MINE is first of all a ***teaching game***. Its extension to an ***operational game*** will be decided based on practical experiences playing the game with decision makers. Other purposes of the game, with regard to the game operator and the scientists are:

- test, validation, verification of the model,
- new aspects on the decision making process: there may be elements that are not considered in the model, as well as psychological, social and subjective aspects that are difficult to quantify.

With this respect MINE may be viewed as an ***experimental game***.

## 3. INSTRUCTIONS FOR THE GAME

The game is implemented for a test area in the GDR.

We assume five players or playing groups (corresponding to the decision making process described in Figure 2), each group has at least one player:

[1] *Municipality*

[2] *Industry*

[3] *Agriculture* (irrigation; the water demand is increasing depending on mine drainage)

[4] *Environmental protection area and Down-stream water user*

[5] *Mining group representing the following mines:*

- Mine a (closes during the planning horizon and becomes a remaining pit),
- Mine b,
- Mine c,
- Mine d is not working at the beginning of the game, water drainage has to be started before it opens.

There may be an additional group, representing the central planning authority, who is deciding in conflict situations. An other possibility is to make these decisions together, by vote.

The submodels of the game are based on the same mathematical models as the Decision Support Model System under development for the GDR test area. In Kaden et al. 1985a all models are described in detail.

The game is designed for 10 planning periods (cycles). In Table 1 the time steps are given.

Table 1: Planning periods

| Planning period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Years | 1 | 2 | 4 | 6 | 8 | 10 | 17 | 25 | 35 | 50 |
| Time steps | | 1 | 2 | 2 | 2 | 2 | 7 | 8 | 10 | 15 |

Mine a closes in period 10. Mine drainage for mine d may start in period 2, mining of mine d starts in period 4.

The operation of the game takes about five hours at maximum for the whole planning horizon.

To run the game, please refer to APPENDIX B.

### 3.1. Basic Rules

There is a certain amount of water available in the region, provided by mine drainage, groundwater, remaining pit, river, tributary or water import. The users have a certain demand of water, that they should try to satisfy with the water being available. They have to decide how much water they would like to have from where. The mining people decide about the amount of lime they are adding to the water (which could influence the possibilities of water allocation, because the users have to satisfy certain quality restrictions) and where they are releasing the water not being used (the mines have to be "empty" of water at the end of each period). After this, if no constraint is violated, the results per year of the last playing period, and the accumulated results of the periods already being played are printed. If some constraints are violated (this happens usually, when no attention is paid to the decisions of the other players), the decisions have to be taken together (the majority decides) or an other playing group, the central planning authority, can join the game and decides, what strategy would be the best and which are the priorities.

### 3.2. Goals and Roles for the Players

The criteria for the quality of the decisions are economic criterias (cost, benefits), the satisfaction of the demands, and the quality of the water. Consider that these are long term and global goals: for example the decisions in a playing period where one has higher costs than necessary, but the total costs of the whole horizon are quit low, are better than decisions, where all the interest groups try to minimize their own costs. Notice that you should not play against each other, but that you have a common goal.

[1] *Municipality*

Your objective is to provide water for the municipal drinking water supply and to minimize costs (with regard to the total costs and the satisfaction of all water users).

Your water demand can be satisfied by the following water allocations:

g — groundwater extraction

im — water import into one region

b — drainage water from mine b

s — stream.

The following pipe capacity restrictions have to be considered:
Table 2: Capacity of pipelines for municipal water supply ($m^3$/sec.).

| | Period 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| s | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| g | 0.2 | 0.2 | 0.2 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| im | 0 | 0 | 0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| b | 0 | 0 | 0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

Example : in the first period the maximum water allocation from the stream is $0.5m^3$/sec.

As the drinking water supply is very important, you have the highest priority, i.e. to decide first. (It has to be proven whether this is a realistic assumption!).

[2] *Industry*

Your objective is to satisfy the industrial water demand and to minimize costs (with regard to the total costs and the satisfaction of all water users).

Your water demand can be satisfied by the following water allocations:

s — stream

c — drainage water from mine c

d — drainage water from mine d.

You have to consider the following pipe capacity restrictions:

Table 3: Capacity of pipelines for industrial water supply ($m^3$/sec.).

| | Period 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| s | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| c | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| d | 0 | 0 | 1 | 1.1 | 2 | 2 | 2 | 2 | 2 | 0.3 |

Example : in the last period the maximal water allocation from mine d is 0.3 $m^3$/sec. You have second priority after drinking water supply. Notice that your used water is of a bad quality and is released into the tributary.

[3] *Agriculture*

Your objective is to satisfy the agricultural water demand (depending on the groundwater table, itself depending on the drainage activities of the mines) and to minimize costs (with regard to the total costs and the satisfaction of all water users).

Your water demand can be satisfied by the following water allocations:

- s – stream
- c – drainage water from mine c
- d – drainage water from mine d.

The following pipe capacity restrictions are valid:

Table 4: Capacity of pipelines for agricultural water supply ($m^3$/sec.).

| | Period | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| s | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| c | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| d | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

You have priority 3. You don't have any demand at the beginning, but because of the mining activities, your demand is increasing (especially when mine d is going into operation).

[4] *Environmental protection area and Down-stream water user*

Your objective is to satisfy the water demand of the environmental protection area (take care of the quality). The down-stream water user are getting the water left in the stream (the quality depends on the quality of the water released from mines and industry). Try also to minimize total costs.

Your water demand can be satisfied by the following water allocations:

- p – remaining pit (after closing of mine a)
- c – drainage water from mine c

You have to consider the following pipe capacity restrictions:

Table 5: Capacity of pipelines for environmental protection ($m^3$/sec.).

| | Period | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| p | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.3 | 0.5 |
| c | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 0.1 | 0.05 |

Notice that you have no priority at all. If you order more water than left, the constraints are not satisfied and the decisions have to be made a second time all together.

[5] *Mining group*

You have to allocate the mine drainage water with regard to the minimum of total costs for mine water drainage and allocation. You can sell your water, if an other user requires it, and if the quality is good enough. You can add lime hydrate for water treatment so that the quality becomes better. The water that you could not sell to the users has to be released into the river; if it is of bad quality, you have to pay a fine for that.

You have to allocate the amount of lime that has to be added. For the possibilities of water allocation see Table 6 below.

Table 6: Capacity of pipelines for mine water allocation ($m^3$/sec.).

| $\alpha,\beta$* \ Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| a,s | 4.1 | 3.9 | 3.3 | 2.8 | 2.2 | 1.8 | 1.5 | 0 | 0 | 0 |
| a,ex | 1.8 | 1.7 | 1.2 | 1.4 | 1.4 | 1.6 | 1.5 | 0 | 0 | 0 |
| b,s | 3 | 3.2 | 3.4 | 3.5 | 3.9 | 4.1 | 5 | 6.4 | 5.4 | 3 |
| b,p | 1.2 | 1.3 | 1.5 | 1.6 | 1.9 | 2 | 2 | 2 | 2 | |
| b,ex | 1.2 | 1.3 | 1.5 | 1.6 | 2 | 2 | 2 | 2 | 2 | 2 |
| c,s | 2.1 | 2.3 | 2.7 | 2.3 | 2.5 | 2.6 | 2.8 | 2.9 | 3.2 | |
| d,s | 0 | 0 | 1 | 1.1 | 3.8 | 3.9 | 4.3 | 4.3 | 3.1 | 0.3 |
| d,ex | 0 | 0 | 0 | 0.9 | 1.9 | 2 | 2 | 1.5 | 0 | |
| p,s | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 1 | 1.5 |
| s,p | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 |

* $\alpha,\beta$ means from $\alpha$ to $\beta$.

Example : the maximum amount of water from mine b to export in the first period is 1.2 $m^3$/sec.

### 3.3. Steps of the Game

For each planning period the following steps have to be done:

(1) Calculation and output of water allocation, i.e. quantity and quality of water being available in the current playing period.

(2) Calculation and output of the water demand for each user.

(3) Input of the decision of the water users about the water allocation through the different pipelines according to their priority (MINE version 1 : fill out the corresponding form, see APPENDIX A).

(4) Check of the constraints 1:

- water demand less or equal pipeline capacities,
- sum of demand from different mines less or equal than water in mine,
- water table in remaining pit greater or equal 110 m,
- water quality of municipality ok?

(5) If the constraints 1 were not ok, go back to point 3 and make a coordinated decision.

(6) Output of the amount of water left in the mines (the mines have to be "empty" at the end of each playing period).

(7) Input of the decisions of the mining group:

- the amount of lime that has to be added,
- allocation of the rest of water in the mines (possible allocations are export, release to the stream or to the remaining pit).

(8) Check of the constraints 1: if not ok, go back to point 3 and make a coordinated decision.

(9) Check of the constraints 2:

- are the water quality for the different user, of the exported water and of the water discharged into the stream within the limits,
- are the mines "empty" (water balance),
- is the water treatment over the limit?

(10) If the constraints 2 are not ok, go back to point 3 and make a coordinated decision.

(11) Calculation and output of the qualities of all water allocations (mines, stream, groundwater).

(12) Calculation and output of the results per year of the last playing period:

- the costs for all users and the different mines,
- the degree of satisfaction of the users,
- the quality satisfaction of remaining pit, stream and environmental protection area.

(13) Calculation and output of the total results of the periods played up to now: costs and satisfaction of the demand.

(14) Next playing period.

## 4. DIFFERENT VERSIONS OF THE GAME

The first version of the game – MINE 1 – was implemented in BASIC on an APPLE IIe, so that it can be used on a wide variety of small microcomputers. For example it has also been implemented on a NEC/PC 8201A, easily portable because of its small size. A playing board with appropriate pieces is associated to the computer. During the game, the players are sitting around the board, filling out different forms with their decisions. The computer with the model is running in the background, the input of the decisions is made by the game operator. The communication between model and decision makers is realized by pieces moved on the board. All model outputs as allocation and quality of water, results, etc. are printed on an additional printer.

The second version – MINE 2 – is implemented in FORTRAN 77 on the VAX and the ALTOS. A graphic terminal can be associated, that corresponds to the board in MINE 1. The input of the decisions is made by the players or by the game operator on the computer.

The gaming board for MINE 1 and the graphic schema for MINE 2 represent a schematical map of the test area (see Figure 3). They also show the stream, the two tributaries, the groundwater extraction possibility, the possibility of import and export. The lines between these items represent the pipelines for water allocation.

*On the board*, water is represented by coins with different amounts, the quality is represented by icons of different colors. Those pieces are moved around by the players and replaced by the game operator after each playing period.

*On the graphic*, the lines representing the pipes are more or less thick, depending on the amount of water. The color of the items on the screen represents the corresponding water quality. The input of the decisions is made on an additional terminal. The costs and the amount of lime added is shown next to the items concerned. All this information can be updated after each playing period. The other results per period, as well as the accumulated results are shown on the additional terminal, from where the game and the graphic terminal are operated as well.

## 5. EXPERIENCES

Beside the tests, the game was running three times under the first version MINE 1 and once under the second version MINE 2. Both versions are built after the same model, have the same decisions and steps. However, after those four runs we noticed, that we have two different games. The implementation with graphics on the VAX was also intended to give the game a more professional and serious touch because the word "gaming" has a wide meaning, including activities that are not taken too serious. We can define " ... *a 'game' as a certain type of 'model', it is appropriate to regard the playing of a game as a kind of 'human manipulation' of this model*" (Stahl,1983). A board with pieces that have to be moved around suggests leisure-time occupation.

Contrary to all expectations, the board game MINE 1 was a bigger success. Only to make people sit around a that board brought already a feedback. The fact, that they had to move those pieces, visible and obvious for all players, increased the communication between the players, this kind of 'language' being much better than the numbers on the screen. The results were discussed in the group, what intensified the motivation. The game was running almost on its own.

Running the second version, it was much more difficult to make the people play, they had to be motivated by the game operator to keep the game going on. Each group made its decisions alone, no real discussion came up.

Running the first version of MINE three times, we noticed the following differences in results and behavior: The first and second time, MINE was played at the *Working Session on Mathematical Modeling of the Environmental Subsystems for the Analysis of Regional Water Policies in Neunzehnhain, Erzgebirge, GDR, June 25-30, 1984.* Some of the participants were the scientists, that built parts of the model. They played the second run. The first run was played by other participants of the conference, that are familiar with environmental problems and region-

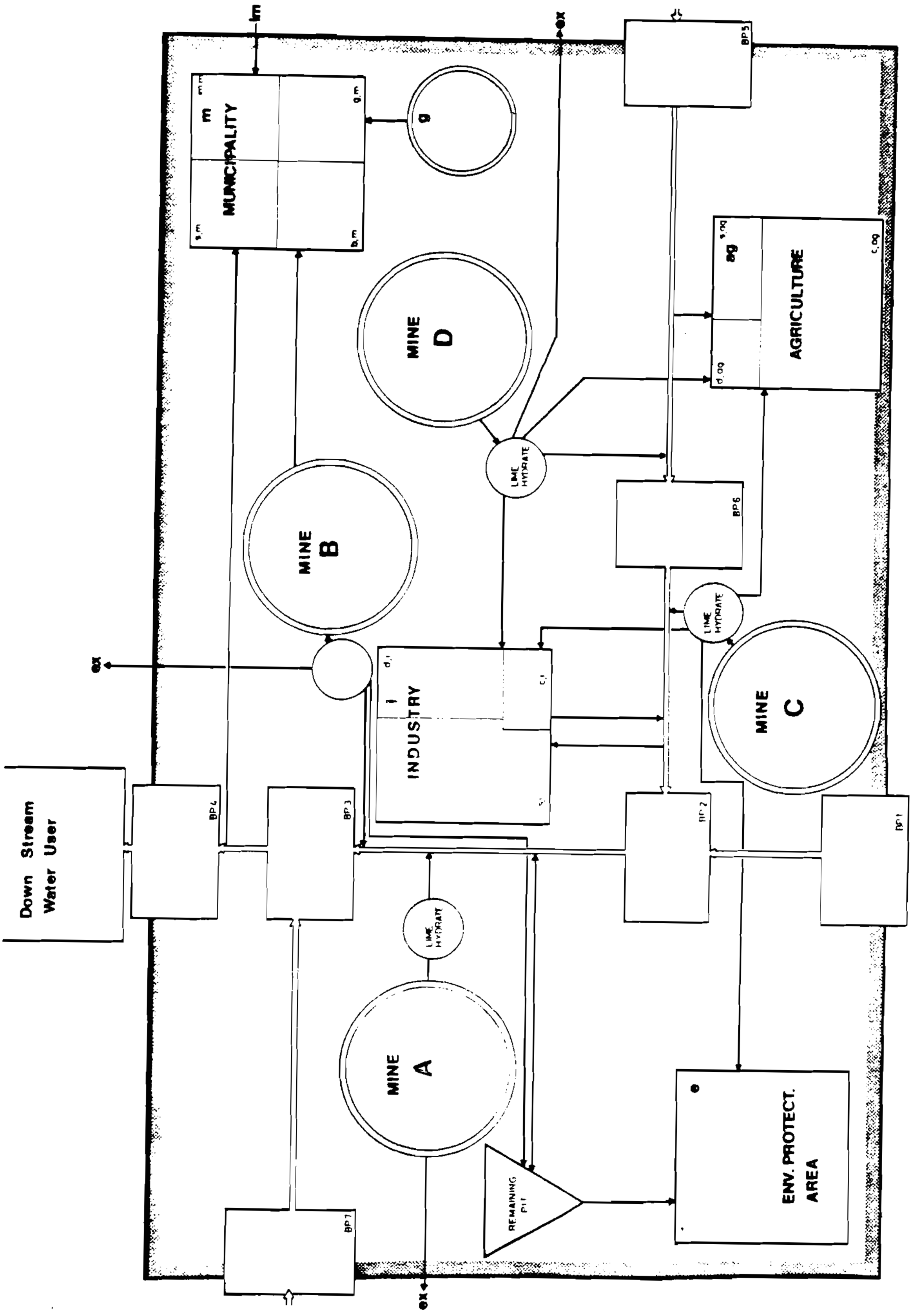


*Figure 3. Board of the game*

al water policies. Already here we found a different behavior: they tried to work together a good as possible, their strategy was to minimize the sum of all costs. They had quiet good results after the second playing period, when they found out about the mechanism of the game and the behavior of the model on specific actions. Playing with the group of "experts" that built the model, it was difficult to get the game going on: they started to discuss some of the submodels, arguing on the parameters, etc. Each playing group consisted of the corresponding experts. They tried to minimize their own costs, playing against each other, what made the constraints fail quiet often. At the end, they had the best total results, because of one of the basic decisions of the game, the starting period of the drainage of mine d. The players of the mining group took the optimal choice. Finally there was a general discussion, where some points of the model were questioned. The importance of communication was emphasized.

The third time, MINE run at the International Institute of Applied Systems Analysis with an arbitrary group of people. It came out, that the degree of information was too low for people from other areas. To play the first period took a long time, many questions had to be answered by the game operator. After some rounds the basic aspects of the problem came out. As MINE is designed for decision makers in open pit mining areas, it should be played with people familiar with this problem.

.The second version of the game was operated on a Task Force Meeting on the Analysis of Regional Water Policies, November 27-29, 1984, at the International Institute for Applied Systems Analysis, Laxenburg, Austria. Several graphic terminals and usual terminals were placed in the room, visible for the players. Each playing group consisted of two players and had his own terminals. Contrary to the board, which increased the communication, the terminals decreased it. No discussions came up, it was difficult to keep the game going and to motivate the players.

## 6. CONCLUSIONS

The game MINE offers a supplementary tool for the analysis of regional water policies in open-pit lignite mining areas. In the present form the game is an experimental and above all teaching game. The first gaming sessions indicate that it is very useful in order to get a better understanding of the complex interrelated socio-economic processes in lignite mining regions for decision makers and their staff. In analyzing such gaming sessions behavioral aspects become obvious which hardly can be formalized.

For teaching purposes the simpler version MINE 1 with a gaming board is favorable due to its communication character. The game MINE 1 should be improved for this purpose by modification of the data in order to emphasize the significant processes within the system. The sophisticated computerized game MINE 2 seems to be only useful if it is extended to an operational game for practical problem solutions. By combination of the game with algorithms for multi-criteria analysis a very powerful support tool would be available. But there is one bottleneck – the availability of decision makers for gaming sessions. It is doubtful whether *decision makers representing the interest groups can be identified and, if this is done,* can be stimulated to play the game together. This question is not to be solved academatically at IIASA, it requires practical attempts in the region of interest.

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# APPENDIX A

*Example of MINE 1*

Information for the operator on the situation at the beginning of the current playing period: This information has to be visible on the board (QS are the corresponding balance points along the stream).

PERIOD 1

WATER AVAILABLE :

| | |
|---|---|
| MINE a | 4.1 |
| MINE b | 2.95 |
| MINE c | 2.05 |
| MINE d | 0 |
| QS1 | 9 |
| QS5 | 1.5 |
| QS7 | 5.5 |
| QS6 | 3.17 |
| QS2 | 12.46 |
| QS3 | 18.66 |
| QS4 | 20.25 |

DEMAND :

| | |
|---|---|
| MUNICIPALITY | .2 |
| INDUSTRY | 3 |
| AGRICULTURE | 0 |
| ENVIRONMENT. PROTECT. AREA | .02 |
| DOWN-STREAM WATER USER | 25 |

*Now the corresponding form 1 for the users has to be filled out.* After data input by the operator the constraints are checked:

CHECK OF THE CONSTRAINTS
THE CONSTRAINTS 1 ARE OK
AMOUNT OF WATER THAT HAS TO BE DISTRIBUTED:

| | |
|---|---|
| MINE a: | 4.1 |
| MINE b: | 2.95 |
| MINE c: | 2.03 |

*Now Form 2 has to be filled out by the mining players. After data input the constraints are checked and the results are printed: (CS is the quality in the balance points of the stream)*

CHECK OF THE CONSTRAINTS
CONSTRAINTS 1 ARE OK
ALL CONSTRAINTS ARE OK

WATER QUALITY

| | | |
|---|---|---|
| a | = | 2 |
| b | = | 2 |
| c | = | 2 |
| CS1 | = | 1 |
| CS5 | = | 1 |
| CS7 | = | 3 |
| CS6 | = | 1 |

| | | |
|---|---|---|
| CS2 | = | 1 |
| CS3 | = | 2 |
| CS4 | = | 2 |
| CP | = | 1 |

RESULTS OF PERIOD 1=1981 (Mill. Mark/year)

COSTS:

| | |
|---|---|
| COSTS FOR MINE a | 45.67 |
| COSTS FOR MINE b | 24.44 |
| COSTS FOR MINE c | 8.89 |
| SUM OF COSTS FOR MINING | 79 |
| COSTS FOR MUNICIPAL WATER SUPPLY | 1.95 |
| COSTS FOR INDUSTRIAL WATER SUPPLY | 26.49 |
| COSTS FOR AGRICULTURAL WATER SUPPLY | .02 |
| COSTS FOR DOWN STREAM WATER USER | 0 |
| COSTS FOR ENVIRONMENTAL PROTECT. AREA | .08 |

NOT SATISFIED DEMAND:

| | |
|---|---|
| MUNICIPALITY | 0 |
| INDUSTRY | 0 |
| AGRICULTURE | 0 |
| DOWN STREAM WATER USER | 1.97 |
| ENVIRONMENTAL PROTECT. AREA | 0 |

WATER QUALITY:

| | |
|---|---|
| STREAM | 2 |
| ENVIRONMENTAL PROTECT. AREA | 1 |

PERIOD:

User

| Water allocation | m | i | ag | e | ds |
|---|---|---|---|---|---|
| s | | | | | |
| g | | | | | |
| im | | | | | |
| a | | | | | |
| b | | | | | |
| c | | | | | |
| d | | | | | |
| p | | | | | |

| | |
|---|---|
| s | Stream |
| g | Groundwater reservoir |
| im | Import |
| a,b,c,d | Mines |
| p | Remaining pit |
| m | Municipality |
| i | Industry |
| ag | Agriculture |
| e | Env. protect. area |
| ds | Down-stream water user |

DEMAND:

m :

i : 3.0

ag :

e :

ds :

*Form 1: Water allocation for water users*

PERIOD:

Quantity of lime: a :

b :

c :

d :

p :

Distribution of water left in mines:

| | ex | p | s |
|---|---|---|---|
| a | | | |
| b | | | |
| c | | | |
| d | | | |

*Form 2: Mine water allocation and treatment*

# APPENDIX B
## How to Run the Game

### VERSION 1

To run the game, see also Appendix A for the playing steps. You need an APPLE II e (and a floppy disk with the game MINE) or an NEC/PC (and a cassette with the game), a board and the corresponding pieces and coins, two kinds of forms at least for each playing period and a short description of the role with the pipeline restrictions for each player. This role description has to be read from the players before the run. The information on the amount of capacity restriction is needed during the whole game. The information of water available and water qualities has to be put on the board at the beginning of each playing period, using the coins and the pieces. The demand printed out for each period has to be put on form 1. Making a decision means to move the coins on the board: in the sequence of their priority, the players of the water users have to make these decisions and to fill out the corresponding row in form 1. At the beginning of period 2, the decision on the starting time for the drainage of mine d has to be made. These decisions have to be put by the operator on the computer. The constraints 1 are checked, if they are not ok, an information on the reason for the failure is printed out. A new form has to be filled out by the players (decisions made by an additional playing group for the central planning authority or by all players together). Now the players of the mining group have to make their decisions on the amount of lime they have to add and the allocation of the rest of the water left in the mines. They have to fill out the form 2, the decisions are put on the computer by the operator. The constraints 1 are checked first , then the constraints 2. If one of them is not ok, additional information on the reason is printed out and the whole period has to be played again. If all constraints are ok, the results are printed out and can be shown to the players. Give them enough time for discussion, but at the same time, keep the game going. Put in, which period you want to play next and continue. In Figure 4 a flow diagram of this version is given.

FLOW DIAGRAM

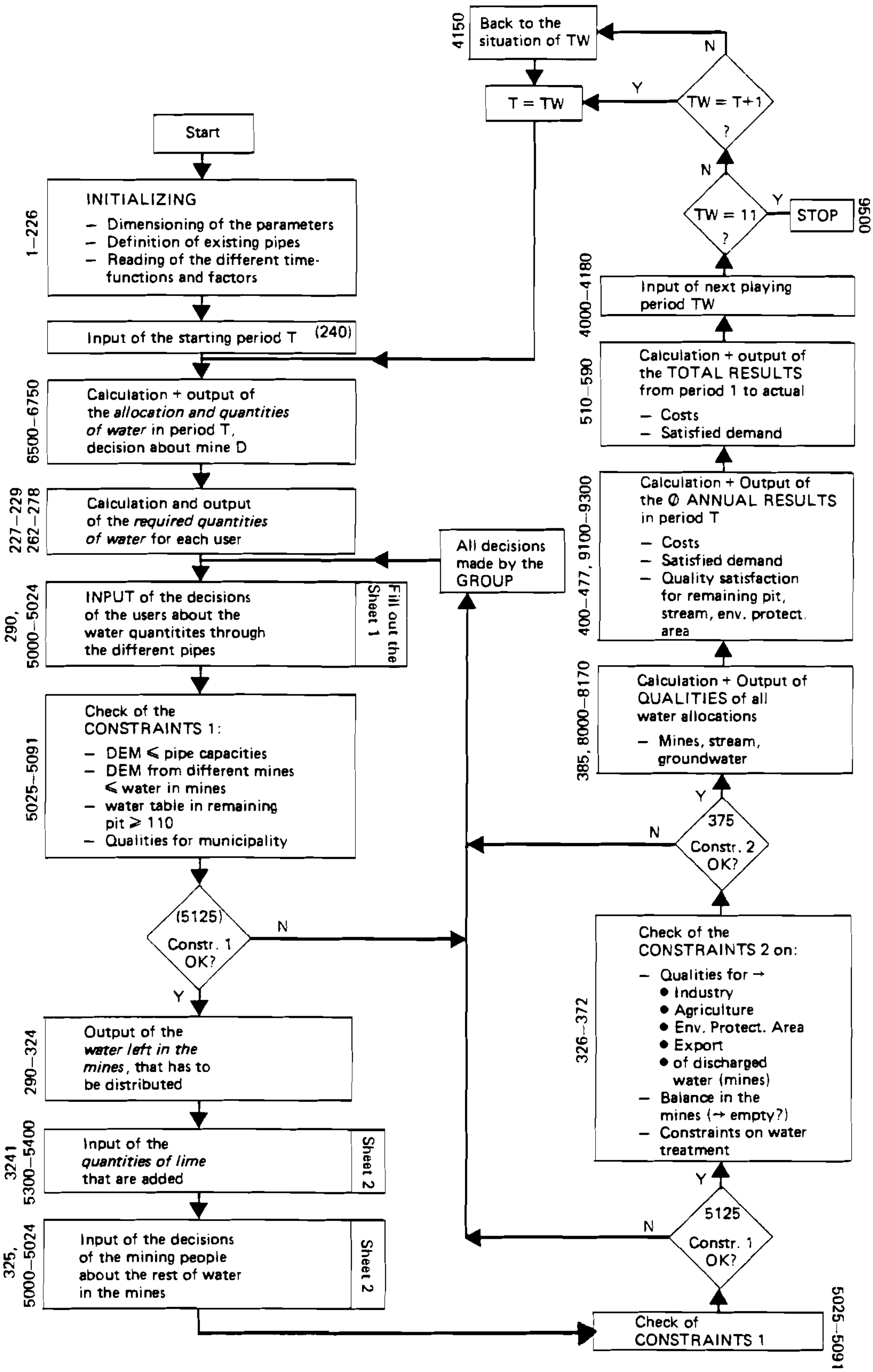


Figure 4. Flow diagram of MINE, VERSION 1

**VERSION 2**

Beside the adequate computer (VAX or ALTOS), you may use an AED graphic terminal with the corresponding software. The sequence of the game steps is the same than in version 1. The water available as well as the water quality are shown on the computer graphic, the demand of the users on the terminal, as well as the menu for the following steps: you can ask for additional information before you have to decide, or go on with the water demand. The screen shows a matrix with the pipeline restrictions and the amount of water already ordered, that you have to fill out with your decisions (at the same time, some basic constraints, like pipeline capacities, are checked). At every time, you have the possibility to go back to the last step, to see your demand or to apply for additional information. At the beginning of period 2, the decision on the beginning of the drainage of mine d has to be made. The next step would be that the players for the mining group have to fill out a similar matrix with the amounts of lime and the distribution of the rest of water. The constraints are checked, if they are not ok, you go back to the beginning of this period; if they are ok, you can update the graphic and see the results (quality and annual costs on the graphic, accumulated results and satisfaction of the demand on the screen). Go on with the next playing period.

Plan enough time for a later discussion on the whole game!