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Decision Support Model Systems for Regional Water Policies In Open-Pit Lignite Mining Areas

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ABSTRACT

The impact of open-pit lignite mining on water resources creates significant conflicts between different interest groups, such as the mining industry, water supply agencies, and agriculture in the mining region. The activities of each of the interest groups modify the water resources system and at the same time the conditions for resources use by other groups. Consequently, there is an apparent need for the analysis of regional water policies to reconcile the conflicting interests within such socio-economic environmental systems. On that, a collaborative study between the International Institute for Applied Systems Analysis and Research Institutes in the German Democratic Republic (GDR) and Poland is directed.

Starting with a description of the main conflicts in open-pit lignite mining areas the necessity of appropriate decision support model systems is substantiated. The paper outlines the state-of-the-art of such systems and the requirements for their further development. Finally, a decision support model system for a case region in the GDR is presented.

CONFLICTS OF WATER RESOURCES USE AND ENVIRONMENT CAUSED BY OPEN-PIT LIGNITE MINING

In general, open-pit mining results in significant impacts on the environment as well as creates conflicts within the socio-economic system in mining regions. Open-pit *lignite* mining is one of the conspicuous examples therefore. Those problems concern especially countries in Central and Eastern Europe, in particular the GDR, FRG, CSSR, and Poland, but also in Asia and the USA [1]. In the following we will outline such problems with special regard to the considerations in the GDR.

The GDR is the country with the largest lignite production (almost one-third of the world production). More than two-thirds of the total output of primary energy is based on lignite extracted exclusively by open-pit mining. The annual output of lignite amounts to about 300 million tons in 1985. To satisfy the geo-mechanical stability of the slopes and the bottom of the open-pit mines, especially in loose rocks [2], it is necessary to pump out about $1.7 \cdot 10^9$ m^3/annum mine water. Therefore, about 7000 dewatering wells are used. During the next years, the lignite output will further increase. Compared with the stable runoff of the GDR of about 9.10^9 m^3/annum the amount of mine water is expected to exceed 20% of the stable runoff of the whole country. Hence, in the mining area itself the water resources system is mainly determined by the mining activities.

Especially in sandy aquifers due to the dewatering of the mines large regional cone-shaped depressions are formed. These cones of depression are one of the main impacts on the environment in mining regions, resulting in water resources use conflicts.

The goal of the ***mining industry*** to satisfy the geostability of the open-pit mines by lowering the groundwater table conflicts with the goals:

- to satisfy water demand in a certain quality and quantity for ***municipal, industrial and agricultural*** water supply

- to satisfy optimal soil-moisture conditions for plant growth by the help of capillary rise, irrigation and drainage.

- and to satisfy optimal ecological conditions for a worthy natural human environment.

The satisfaction of the municipal, industrial and agricultural water demand is a difficult problem in mining regions, because wells for groundwater extraction of water works fall often dry due to the groundwater depletion, little rivers fall dry or larger ones lose a part of their runoff by infiltration into the cone of depression. For the agricultural crop production difficulties arise from the lowering of the groundwater surface. In general, the moisture supply of the plants cannot be satisfied by capillary rise. To satisfy a stable crop production supplementary irrigation becomes necessary that means higher cost and a higher agricultural water demand in comparison with natural conditions. Besides the mentioned water quantity problems in the mining areas significant water quality problems occur [3]:

In lignite mining regions the groundwater quality and consequently the quality of mine drainage water is frequently strongly affected by the oxidation of ferrous minerals (e.g. pyrite) in the dewatered ground. In the cone of depression the overburden is aerated. With the natural groundwater recharge the oxidation products are flushed out, and the percolated water becomes very acid. Consequently the acidity of the groundwater increases. The same effect occurs during the groundwater rise after the closing of mines. Especially the acidity of groundwater in spoils is very high, if the geological formations have a low neutralisation capacity. In the GDR sulphate concentration in the groundwater of spoils greater than 700 mg/l have been estimated [4].

In mining areas many industrial activities, especially disposals of liquid and solid wastes are connected with serious contamination risks for groundwater and mine drainage water. Typical contaminants are heavy metals, organics (phenols etc.) and others. In such regions it is very difficult or even practically impossible to protect drinking water resources by protection zones.

Another risk is related to salt water intrusion or salt water upconing. In several lignite deposits in the GDR salt water is situated not deep below the lignite seams. Hence, pumpage causes the risk of salt water upconing. High salt content of mine drainage water results in many difficulties in water treatment technology. The discharge of the polluted mine water into streams may effect down-stream water yields significantly.

Another problem caused by mine drainage is the land subsidence resulting from groundwater lowering [2]. In the post-mining time, when the groundwater table rises up to its former elevation, its depth under the soil surface might be less than in the pre-mining time, sometimes artificial drainage systems are necessary to protect municipalities and factories in such post-mining areas. Also, agricultural land and forest have to be drained in such districts frequently.

Last not least the ecological equilibrium is often disturbed by lowering the groundwater level. Especially old areas or park landscapes are in great danger when the groundwater table falls down.

The above-mentioned examples illustrate the significant conflicts between different interest groups caused by the impact of open-pit lignite mining on water resources. The activities of each of the interest groups modify more or less the water resources system and at the same time the conditions for resources use by other groups. It is also important that these activities might lead to a deterioration of the natural environment.

Due to the complexity of the socio-economic environmental processes in mining areas, the design of water management strategies and water use technologies as well as mine drainage can only be done properly based on appropriate mathematical models.

These models should serve as tools to match the criteria of the interest groups and to reconcile conflicting interests.

MATHEMATICAL MODELS FOR WATER PROBLEMS IN OPEN-PIT LIGNITE MINING AREAS

In general the time variant impacts of mining on the water resources system and the time variability of this system necessitate the application of *nonsteady* or *dynamic* models. The most common models are SIMULATION MODELS.

The dynamic systems development is determined by *environmental inputs*, e.g. geological structure, initial groundwater table, boundary conditions, as well as by *decisions* (control actions), e.g. wells for groundwater extraction. The simulation model describes the systems state development, (e.g. groundwater table, water quality) in terms of the systems inputs, decisions, and systems past.

The systems development can be controlled by the decisions only. Using simulation models, it is assumed to know the decisions explicitly. The simulation model has to be used in an iterative procedure to find decisions for systems states satisfying given preferences. A typical example is the use of groundwater flow models for the design of drainage wells, if the desired groundwater tables for some points in space and time are given.

Especially *groundwater flow models* (finite difference and finite elements) have found a wide application in the design of mine drainage systems and the forecast of other environmental impacts [5-7]. Such models developed and used as so-called Continuously Working Models (CWM) are an accepted basis for water related decision making in open-pit lignite mining in the GDR [5,7]. But analysing critically the features and application of CWM's it has to be emphasized that the CWM's or more general simulation models are a helpful tool in medium-term planning and design as well as short-term control. Their applicability for long-term planning as an integrated part of the regional policy-making process is restricted.

What are the main obstacles to their use in the long-term policy-making process? *First*, the CWM's are tools to analyse an environmental system without considering socio-economic aspects. Economic modeling of groundwater management in mining areas is not done or economic models are not coupled with CWM's. The key role of the interactions between the socio-economic development and the environmental processes is not considered implicitly. *Second*, there is a gap between the complicated sophisticated models and the existence and quality of the relevant data, the latter being uncertain. Unreliable results may discredit models with the policy makers. *Third*, frequently the available time and budget for model structuring is incompatible to the necessary effort of collecting and verifying of the required data. This incompatibility is especially apparent when one considers groundwater quality and groundwater-surface water interactions. *Fourth*, management/ technological alternatives have to be fixed exogenously for the simulation models. This is the common procedure for problems in tight connection with groundwater hydraulics (groundwater stresses such as pumping and recharge). The decisions are pumping rates, location and number of wells and so on. Economic indicators are considered explicitly by evaluation of the alternatives. In the case of complex environmental-socio-economic interactions (multiple criterias and decision makers) that we have to deal with concerning the mining regions, the manual selection of efficient alternatives (scenarios) is very difficult and time as well as money consuming, or even impossible.

In the past years in water management NORMATIVE MODELS implicitly considering environmental-socio-economic interdependencies found more and more applications. Normative models are used to estimate efficient alternatives based on scalar or vector optimization techniques. In terms of the *criteria functions* both, environmental criteria (e.g. groundwater quality), and economical criteria (e.g. cost of mine drainage) are used. For mine water problems especially in Hungary and the USA powerful models have been developed [8-10]. These applications are related to underground coal and bauxite mining in carstic aquifers. For open-pit lignite mining areas in sandy aquifers the authors did not find applicable normative models. This might be caused by the complicated water flow (nonlinear, groundwater-surface-water interaction) and water quality problems (acidification of mine drainage water). Common linear programming methods in this case are not applicable. Consequently, their is an appaarent need for the development of normative models as decision support models for the analysis of regional water policies in open-pit lignite mining areas.

DECISION SUPPORT MODEL SYSTEM FOR A CASE REGION IN THE GDR

Methodological Approach

The regional systems under study is viewed to consist of two major subsystems—the environmental subsystem and the socio-economic subsystem [11]. Between and within both subsystems manifold interrelationships occur. Socio-economic activities result in strains on the environment, in our case in the depletion and pollution of water resources. On the other hand, the deterioration of the environmental subsystem leads to restrictions in its use as natural resources for the socio-economic development.

The policy making process in mining areas includes in a centrally planned economic system as in the GDR all decision levels from the government (Central Planning Authority, different Ministries), regional authorities (District Planning Authority, Regional Water Authority, etc.) up to the lowest level (mines, farms, municipal water supply agencies etc.) interacting directly with the water resources system. These interactions depend on the mining and mine drainage technology, on the demands and sources for water supply of different water users, on the agricultural land use practice and technologies, on the waste-disposal and waste water treatment technology and allocation etc.

The upper level elements of the socio-economic system have preferences based on a national or regional point of view, above others related to the social welfare. Characteristic aspects are both, a high national income, and the preservation of the environment as an important social component. The upper level elements of the socio-economic system generally do not directly control the interactions of the lowest level users with the environment, but they have principal regulation power for influencing their behaviour using legislative, economic and/or other types of policies or mechanisms. Typical policies include imposing constraints on water usage and allocation of waste water (based on the water law of the GDR), various economic measures including investment, pricing, taxing, subsidizing and others.

Below Figure 1 gives a rough overview on the complex hierarchical structure of the socio-economic system under study.

Typical for a socio-economic system is its division in upper elements, representing national and regional perspectives, and lower elements — the water users. Obviously, a two-level representation of the system becomes a realistic assumption. Our analysis is based on the schematized policy-making system shown in Figure 2.

We assume a two-level system with a Central Planning Authority and Regional Authorities for mining, municipal and industrial water supply, agriculture and environmental protection. A Regional Authority represents both, the global interest of a sector of economy, and its regional interest. The Central Planning Authority represents global economic and social preferences.

For the long-term development of open-pit lignite mining areas two principle problems have to be solved:

1. *To find "good" long-term strategies oriented towards achieving a proper balance between both national and regional economic needs, regional social needs and the regional preservation of the environment.*

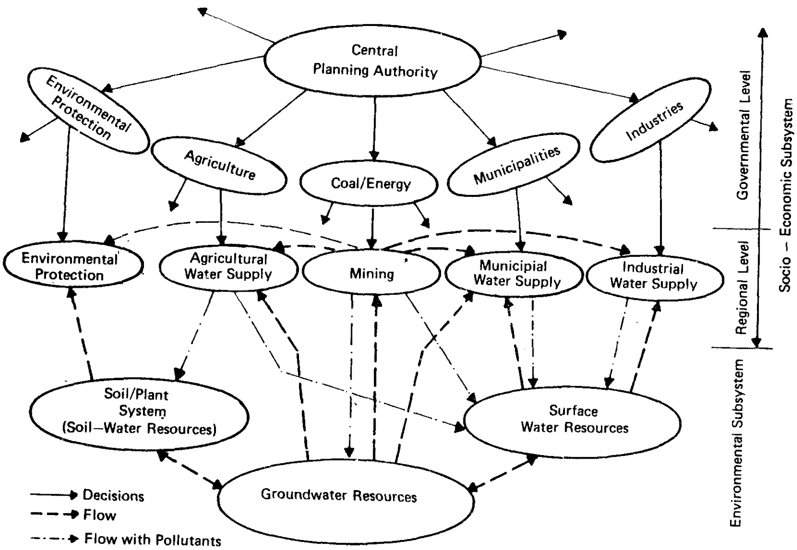

Figure 1: Schematic environmental/socio-economic system in open-pit lignite mining areas.

2. *To find and realize controlling policies in order to direct the regional development according to the estimated "good" long-term strategies.*

According to these problems our research is based on a two-stage decomposition approach, proposed by Orlovski [11]. The first stage of the analysis is directed towards generating rational scenarios of the long-term regional development based on preferences of the Central Planning Authority. Behavioural aspects of the lower-level water users are considered only in terms of general regional socio-economic preferences of the corresponding economic sector.

Based on more detailed considerations of behavioural aspects, in the second stage of analysis feasible regulation policies will be studied in order to direct the behaviour 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 analysing long-term regional water policies. From the systems analytical point of view such an analysis might be seen as a problem of dynamic multicriteria, multiple-decision maker choice taking into account the fuzziness pertaining to human behaviour, uncertainties and imprecisions resulting from limited understanding of the complex processes under study and the lack of data. According to our discussion above, this choice is embedded in a complicated policy making process and it is based on "hard" criteria as costs, water supply etc., as well as on "soft" social and political criteria, e.g. the quality of life in the region. We are not able to develop a model system considering all the complexity of the policy making

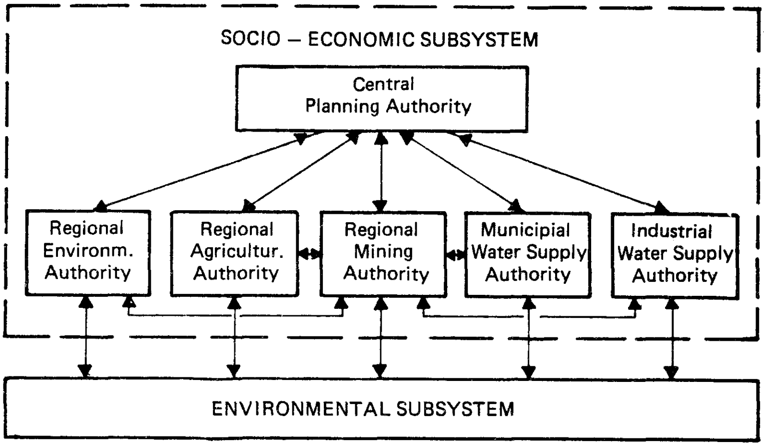

Figure 2: Schematized policy-making process.

reality, anticipating the decisions of the policy makers. However, we can support the policy maker in analysing appropriate decisions by the help of a *Decision Support Model System*. Such a DSMS should reflect the policy making process and the goals of the conflicting interest groups and integrate the essential interactions between as well as within the environmental subsystem and the socio-economic subsystem.

In general, dynamic problems of the studied type are approached by time-discrete dynamic systems models. The step size depends on the variability in time of the processes to be considered, on the required criteria and their reliability, and on the frequency of decisions (control actions) effecting the systems development. 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 (of about 50 years) are of major interest:

- the *planning periods* $\Delta T_j, j = 1, \ldots, J$ $(T = \sum_{j=1}^{J} \Delta T_j)$ as the time step for principal management/technological decisions, (e.g. water allocation from mines, water treatment, drainage technology),

- the *management periods* of one month for management decisions within the year related to short-term criteria as the satisfaction of monthly water demand (the classical criteria for long-term water resources planning).

The discretization of the planning horizon into a restricted number of planning periods enables principally to apply optimization techniques for multi-criteria analysis. Small time steps (for instance, $\Delta T_j = 1$ year) for the planning periods are favourable from the point of view of the evidence and accuracy of model results. Otherwise the number of planning periods should be minimized with respect to the available methods for multi-criteria analysis, computational facilities, and budget as well as time for analysis. As a compromise our DSMS is based on variable planning periods, starting with one year and increasing with time. Taking into account the uncertainties of long-term predictions of model inputs (water demand, decisions on investment, etc.) and the required accuracy, decreasing with time, this approach is quite reasonable.

For monthly time steps (600 for a planning horizon of 50 years) the application of any optimization technique becomes unrealistic. To study monthly systems behavior systems simulation is the only applicable tool. Furthermore this simulation opens an easy way to consider stochastic inputs (hydrological data, water demand etc.) applying the Monte-Carlo-Method for stochastic simulation.

Based on these assumptions we develop a heuristic two-level model system [12, 13] consisting of

- *planning model* for dynamic multi-criteria analysis for all planning periods in the planning horizon

- *management model* for the stochastic simulation of monthly systems behaviour in the planning horizon.

In Figure 3 the general structure of the DSMS is depicted.

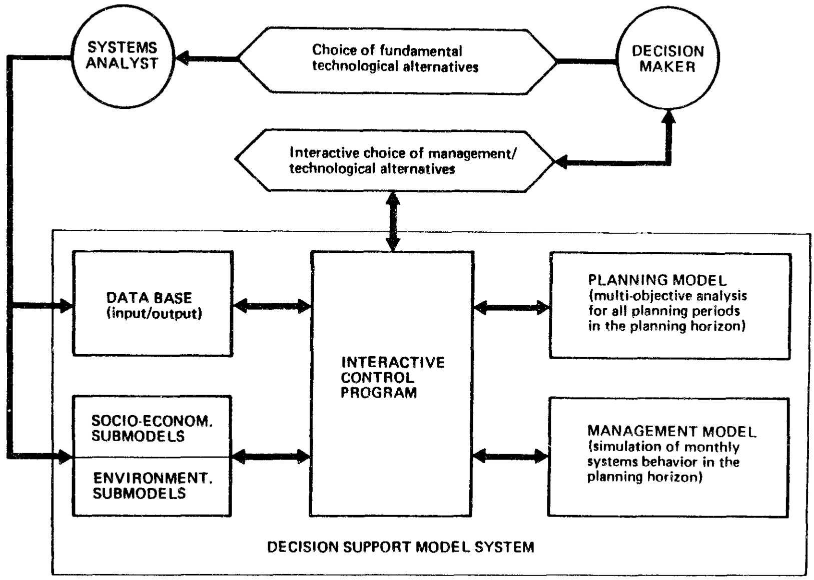

Figure 3: Structure of the Decision support model system.

As the figure illustrates, the choice of fundamental technological alternatives (e.g. decisions on the construction of a treatment plant, of a pipeline, the dimension of pipes, etc.) are supposed to be fixed exogenously and might be considered as different scenarios. For the time being the DSMS analyses continuous management/technological decisions for planning periods only.

To characterize the model system we use in the following capital Roman letters for the planning model (deterministic inputs and outputs) and capital Greek letters for the management model (partly random inputs and outputs). The letter **f** defines a vector function. Generally all values/parameters under consideration represent mean values for the given time step. In the following the models are compared.

PLANNING MODEL ($j = 1,\ldots,J$)	**MANAGEMENT MODEL** ($m = 1,\ldots,M$)

SYSTEMS INPUT

Hydrological input (noncontrolable input as precipitation, stream flow, evapotranspiration)

$\mathbf{I}_{hy}(j)$	$\Phi_{hy}(m)$

Socio-economic input (noncontrolable input as water demand, investment, prices etc.)

$\mathbf{I}_{se}(j)$	$\Phi_{se}(m)$

DECISIONS ON SYSTEMS DEVELOPMENT

Control variables for planning periods (water allocation, etc.)

$\mathbf{D}(j)$	$\Psi(m)$
with bounds $\min\mathbf{D}(j) \le \mathbf{D}(j) \le \max\mathbf{D}(j)$	with the deterministic rule $\Psi(m) = \mathbf{f}\Psi(m, \Gamma_d(m-1), \Psi(m-1), \Gamma_v(m), \Gamma_v(m-1), \ldots)$

Total control variables for the planning horizon

$\mathbf{DT}$	not considered
with bounds $\min\mathbf{DT} \le \mathbf{DT} \le \max\mathbf{DT}$	

DESCRIPTORS OF SYSTEMS DEVELOPMENT

Systems descriptive values (auxiliary parameters characterizing the systems behaviour in the planning period; not explicitely depending on previous planning periods, e.g. surface water flow)

$\mathbf{S}_d(j)$	$\Gamma_d(m)$

with the *systems descriptive functions*

$\mathbf{S}_d(j)=\mathbf{fS}_d\ (j,\mathbf{D}(j),\mathbf{S}_v(j),\mathbf{I}_{hy}(j))$	$\Gamma_d(m)=\mathbf{f}\Gamma_d(m,\Psi(m),\Gamma_d(m),\Phi_{hy}(m))$

State variables (dynamic parameters depending explicitely on the previous planning periods, e.g. water table in the remaining pit)

$\mathbf{S}_v(j)$	$\Gamma_v(m)$

with the *state transition functions*

$\mathbf{S}_v(j+1)=\mathbf{fS}_v(j,\mathbf{D}(j),\mathbf{S}_d(j),$ $\mathbf{S}_v(j),\mathbf{S}_v(j-1),\ldots)$	$\Gamma_v(m+1)=\mathbf{f}\Gamma_v(m,\Psi(m),\Gamma_d(m),$ $\Gamma_v(m),\Gamma_v(m-1),\ldots)$

CRITERIA (OUTCOME) OF SYSTEMS DEVELOPMENT

Criteria for planning periods (e.g. deviation water supply-demand)

$\mathbf{O}(j)=>Min.!$	$\overline{\Omega}(j)$

with the *criteria functions*

$\mathbf{O}(j)=\mathbf{fO}(j,\mathbf{D}(j),\mathbf{S}_d(j),$ $\mathbf{S}_v(j),\mathbf{I}_{se}(j))$ and bounds $\min\mathbf{O}(j)\le\mathbf{O}(j)\le\max\mathbf{O}(j)$	$\overline{\Omega}(j)=\mathbf{f}\overline{\Omega}(\ldots,\Omega(m),\cdots)_{m\,\varepsilon j}$ $\Omega(m)=\mathbf{f}\Omega(m,\Psi(m),\Gamma_d(m),$ $\Gamma_v(m),\Phi_{hy}(m),\Phi_{se}(m))$

Total criteria for the planning horizon

$\mathbf{OT}=>Min.$	$\Omega\mathrm{T}$

with the *total criteria function*

$\mathbf{OT}=\mathbf{fOT}(\mathbf{O}(1),\ldots,\mathbf{O}(J))$ and bounds $\min\mathbf{OT}\le\mathbf{OT}\le\max\mathbf{OT}$	$\Omega\mathrm{T}=\mathbf{f}\Omega\mathbf{T}(\Omega(1),\ldots,\Omega(J))$

CONSTRAINTS ON SYSTEMS DEVELOPMENT

$\mathbf{C}(j)=\mathbf{fC}(j,\mathbf{D}(j),S_d(j),$ $(\mathbf{S}_v(j),\mathbf{I}_{se}(j))\ge 0$	not considered

For the planning model a nonlinear multi-criteria programming system has been developed, using the reference point approach [15]. The method is based on the idea of "satisficing". Starting from aspiration levels of decision makers for the indicators of systems development (reference points) efficient responses are generated (Pareto points "closest" to the reference points). The best-suited solution considering the preferences of the decision maker can be obtained by correcting the aspiration levels in an interactive procedure. The program system is based on the nonlinear multi-criteria programming package DIDASS/N [14] coupled with the nonlinear programming system MSPN, developed at the Institute of Automated Control, Technical University Warsaw by Kreglewski et al.

In the case of many criteria the reference point procedure and the comparability of solutions might become complicated for the decision making. For this reason the DSMS renders the interactive determination of criteria to be minimized, for the remaining criteria their bounds are considered.

The *planning model* of the DSMS is applied first, resulting in an efficient solution for planning periods. The determined control variables $D(j)$ are used to estimate the parameters of a deterministic decision rule $\Psi(m)$ for the management model. Based on that, the *management model* serves as a stochastic simulation model, simulating monthly systems behaviour. The Monte-Carlo-Method is used to generate random inputs $(\Gamma_{hy}, \Gamma_{se})$. From this simulation we obtain empirical distribution functions or frequency distributions for systems behaviour.

The submodels for the socio-economic and environmental subprocesses have to be characterized by two major features. On the one hand, they should be simple enough mathematically (even as simple as possible) to be integrated in a complex model system suitable for an interactive use. On the other hand, they have to reflect the important socio-economic and environmental processes with an accuracy required for making appropriate decisions based on the model system. Obviously, these features may be contradictory and a compromise should be found. Depending on the state-of-the-art of modeling of a given process, the availability of comprehensive models and data, different methods for the development of submodels have to be used [13].

The GDR Test Area

The test area is located in the Lusatian Lignite District in the lowlands of the south-eastern part of the GDR. Its area amounts to approximately 500 km^2. In Figure 4 an overview is given.

The quarternary tertiary aquifer system of the test area can be schematized in three aquifers (the first being unconfined), separated by aquitards (lignite).

The boundary of the test area is not identical to the subsurface catchment area. Groundwater inflow, outflow respectively have to be considered. The region is crossed by a stream and some tributaries. The groundwater and surface water resources are closely interrelated (baseflow into surface waters under natural conditions, infiltration of surface water into the aquifer in the course of groundwater lowering due to mine drainage). The inflows into the region from the stream and the tributaries are natural ones depending on the hydro-meteorological situation in the upstream catchment areas. Consequently, the actual inflows are random values.

From the point of view of geohydrochemistry, in the first and second aquifer the processes of weathering of ferrous-disulphide minerals are most important. In the underground ferrous-disulphide are oxidized by oxygen in the air. At the same time originate iron(II)-, sulphate-ions and protons. The acidity increases in the groundwater. The reaction products are flushed out with the percolated water from aerated zones and transported by the rise of groundwater. Especially high is the iron and acid concentration in the percolated water in spoils. Furthermore, the groundwater is characterized by increased concentrations of CO_2 resulting

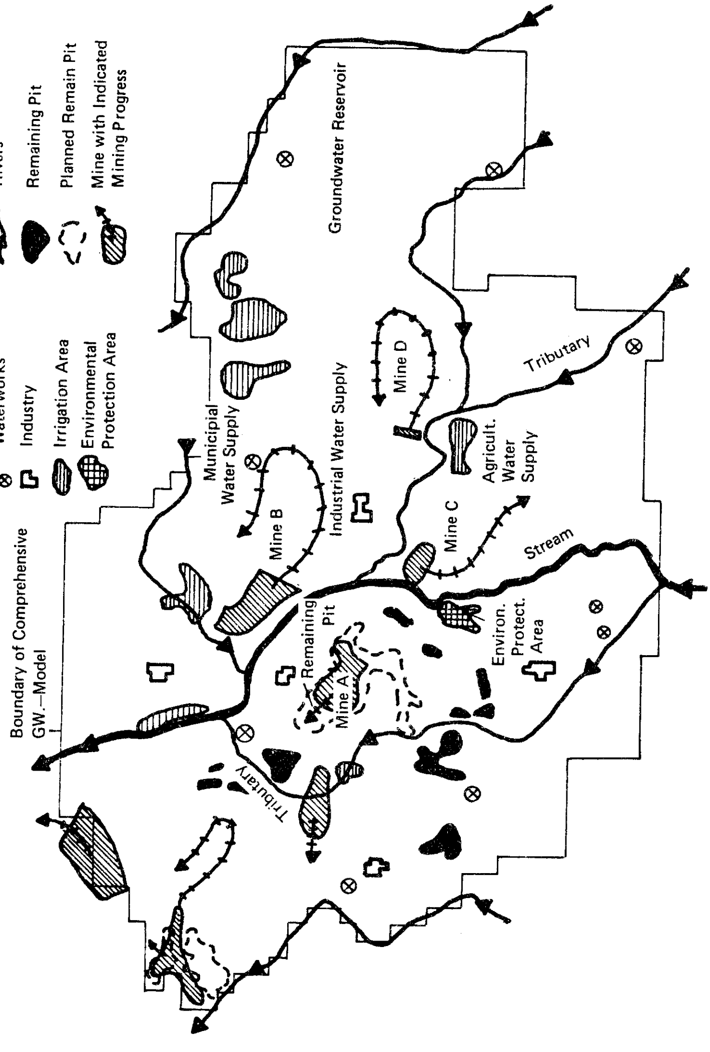

Figure 4: GDR test area

from biochemical degradation processes. The discharge of acid ferruginous mine-water into the stream or remaining pit is the decisive quality impact caused by mining.

The deepest third aquifer frequently contains highly mineralized groundwater (natrium chloride, etc.). Processes of salt-water upconing have to be considered (this will be done in further research).

The regional development is primarily determined by 4 open-pit lignite mines:

MINE A going out of operation within the planning horizon; the REMAINING PIT will be used as a water reservoir,

MINE B operating within the whole planning horizon; one selected drainage well gallery has been especially designed for municipal water supply,

MINE C operating within the whole planning horizon,

MINE D opening within the planning horizon.

The mine drainage is done by extraction wells surrounding the mines (border well galleries) and within the mine-field (field well galleries). The dates of mining (closing mine A, opening mine D), as well as the mining capacities are supposed to be fixed. Consequently, the groundwater tables within the mines during the operation time are fixed. The amount of mine water to be pumped can be only controlled by the timing of mine drainage activities and by the filling process of the remaining pit. For the test region we consider as decisions the time of opening the mine drainage for mine D and the filling of the remaining pit as well as its management as decisions.

The mine drainage resulting in a large cone-shaped groundwater depression effects above all:

1. *Groundwater Extraction for Municipal Water Supply.* The capacity of extraction wells depends on the groundwater table near the wells. A production well can only operate if the groundwater table is above the well screen. To satisfy the municipal water demand additional more costly sources have to be used. Principle alternatives are surface water (with complicated and expensive water treatment), water import from other regions (high cost for water allocation), and above all mine water (MINE B) from especially designed mine drainage galleries.

2. *Agricultural Water Supply.* The agricultural crop production as an important economic sector also in mining regions is above others a function of the moisture in the rootzone. In case of shallow groundwater tables, a substantial part of the moisture required for crop growth is supplied by capillary rise from the aquifer to the rootzone. With decreasing groundwater tables the capillary rise decreases and supplementary irrigation becomes necessary (sometimes additional to already implemented irrigation).

The water demand for supplementary irrigation might be satisfied by both, surface water, and mine drainage water (MINEs C and D).

3. *Environmental Protection Area.* The survival of valuable flora depends on stable groundwater tables and groundwater quality within a small range. Based on the assumption that the mining activities are fixed the groundwater regime in the environmental protection area can only be controlled by artificial groundwater recharge. Taking into account the insufficient water quality in the stream as

sources for the recharge mine drainage water (MINE C) and water from the REMAINING PIT might only be used.

4. *Infiltration Between the Stream/Tributaries and the Groundwater Reservoir.* Depending on the groundwater and the surface water table we have to deal with baseflow to the stream or infiltration from the stream into the aquifer.

Increased infiltration losses may affect both, DOWN-STREAM WATER YIELDS and the INDUSTRIAL WATER SUPPLY in the region. The possibility of mine drainage water use for industrial water supply has to be considered.

5. *Filling Process of the Remaining Pit.* The remaining pit will be used as a reservoir to control the surface water flow for down-stream water users. Therefore, a technologically substantiated minimum water table has to be reached. Consequently, from the water management point of view the artificial filling of the remaining pit with surface water or mine drainage water becomes favourable to fasten the filling process. Otherwise, high water tables in the remaining pit increase the amount of mine water drainage (and cost) for MINE B.

6. *Quality of the Water in the Groundwater Reservoir and the Remaining Pit.* The most important chemical processes has been characterized above.

The mine drainage water is either allocated to different water users (including water export) or discharged into surface water resources. To satisfy quality constraints, quality requirements of surface water users respectively, it has to be treated in special MINE WATER TREATMENT PLANTS. The necessary purification degree depends on the quality of the mine drainage water, the quality requirements of users and on the self-purification in surface water resources. The purification degree in the treatment plant is above all controlled by the adding of lime hydrate. By adding lime hydrate into the remaining pit a certain purification affect may also be expected there.

All mining activities cause mainly long-term changes in the system. Medium-term variations (within the year) of mining activities are negligible. For the surface water flow medium-term variations (monthly) have to be considered, caused by random changes in hydro-meteorological conditions. Partly correlated to these conditions, the water demand of water users is also characterized by monthly variations. The monthly time step is typical for long-term water management and planning. Short-term variations (daily) are negligible for problems of the studied type in flat regions as the mining regions are.

The Interactive Decisions Support Model System

To be accepted and used by the decision makers a Decision Support Model System must fit in the decision making reality (compatibility with common planning and decision making practice), and it has to be user-friendly, reliable, robust and credible.

The development of an interactive decision support model system for the analysis of regional water policies in open-pit lignite mining areas is oriented towards those goals. With the described methodological approach the policy making reality is reflected sufficiently, as we believe. The model system focuses on the necessary decisions and common criteria for long-term water management. The underlying time discretization corresponds to the common planning practice.

Based on the reference point approach for multi-criteria analysis coupled with a stochastic simulation the model system is methodologically suitable for an interactive use. In addition the model handling and data management has to be designed interactively and user-friendly. We consider the following aspects in the model system:

- hierarchical data base (input and output data) with a robust screen oriented data display and editing system,

- style and language of model use according to the planning and decision making reality,

- use of computer colour graphics for visual display of computational results.

The use of the hierarchical data base is menu-driven. Each data base level characterizes a menu and the user can either move downwards according to the menu or upwards to the previous level, or return to one of the models.

For the data editing a simple screen editor has been developed. Data checks realize the graceful recovery from failures. For the menu description we use as far as possible linguistic elements according to the practical language . For the visual display of model results a flow chart representation of the Test Area is used on a colour monitor. The water quantity (flow) is characterized by the thickness of lines, and the water quality by the colour. These graphical symbols correspond to given ranges of data which might be defined as linguistic variables (water quality—excellent, fair, bad, very bad). To compare the criteria of different scenarios bar charts may be used.

Computational results of the study will be presented in a next paper.

References

1. Weise, H., Brown Coal—An Important Energy Resource. In: Long-Term Energy Resources, Vol. I, Int. Conference Montreal 1979, Pitman (1981), pp. 263-272.

2. Luckner, L., Groundwater and Geotechnical Problems, Int. J. of Mine Water, Vol. 2, No. 1, pp. 31-41 (1983).

3. Luckner, L. and Hummel, J., Modelling and prediction of the quality of mine drainage water used for the drinking water supply in the GDR. 1st Int. Mine Water Congress of the IMWA, Budapest, Proc. D, pp. 25-36 (1982).

4. Starke, W., Nutzung von Grubenwasser der Braunkohlentagebaue zur Trinkwasserversorgung (Utilization of Mine Water of Open-Cast Lignite Mines for Drinking Water Supply), WWT Berlin, 30(1980), No. 7, pp. 219-222.

5. Peukert, D., Reissner, H., and Kunze, W., Application of a continuously working model for the prognosis of a regional groundwater situation caused by open-cast mine dewatering measures. 1st Int. Mine Water Congress of the IMWA, Budapest, Hungary, Proc. A, pp. 209-225 (1982).

6. Boehm, B., Conceptual plan for water management schemes in the northern part of the Rheinish lignite mining district. In: Groundwater in Water Resources Planning, Proceedings of a symposium in Koblenz, FRG, pp. 571-580 (1983).

7. Kaden, S. and Luckner, L., Groundwater management in open-pit lignite mining areas. Int. Symposium on Groundwater Resources Utilization and Contaminant Hydrogeology, Montreal, Canada, May 21-23, Proceedings, Vol. I, pp. 69-78 (1984).

8. Bardossy, A. and Bogardi, I., Decision models for bauxite mining under water hazard, 1st Int. Mine Water Congress of the IMWA, Budapest, Proc. C, pp. 18-39 (1982).

9. Szidarovszky, F., Bogardi, I. and Gershon, M., Multiobjective analysis of regional mine water control and environmental protection, 1st Int. Mine Water Congress of the IMWA, Budapest, Proc. C, pp. 129-143 (1982).

10. Bogardi, I., Bardossy, A. and Druckstein, L., Regional Management of an Aquifer for Mining Under Fuzzy Environmental Objectives, Water Resources Research, Vol. 19, No. 6, pp. 1394-1402 (1983).

11. Orlovski, S.A. and Van Walsum, P.E.V., Water policies: regions with intense agriculture, WP-84-40, IIASA, Laxenburg, Austria, p. 54 (1984).

12. Kaden, S., Analysis of regional water policies in open-pit mining areas—a multicriteria approach. In: A. Wierzbicki and M. Grauer (Eds.), *Interactive Decision Analysis and Interpretative Computer Intelligence*, Proceedings of an IIASA Workshop 1983, Springer Verlag, pp. 218-226 (1984).

13. Kaden, S. et al., Water policies: regions with open-pit lignite mining, WP-85-04, IIASA, Laxenburg, Austria, p. 67 (1985).

14. Grauer, M. and Kaden, S., A nonlinear dynamic interactive decision analysis and support system (DIDASS/N), WP-84-23, IIASA, Laxenburg, Austria, p. 50 (1984).

15. Wierzbicki, A.P., A mathematical basis for satisficing decision making, Mathematical Modeling, USA, 3:391-405 (1982).