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SZCZYRK CONFERENCE PAPERS--PART II
COAL: ISSUES FOR THE EIGHTIES

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Editor

September 1980
CP-80-24

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PREFACE

This volume is the second of two Collaborative Papers which contain the technical papers presented at an IIASA Seminar under the generic title 'Coal: Issues for the Eighties' which was held in Szczyrk, Poland in November 1979. The seminar was jointly organized by IIASA and the Polish institutes collaborating in this study. The papers are here reproduced for the convenience of those attending the seminar and for reference by those involved in this continuing industry study. The first volume contains those papers concerning the organization, management and computer, and planning for planning issues, CP-80-23.

The primary objective of the seminar was to identify and define specific studies to be conducted as part of the Coal: Issues for the Eighties program. Seminar participants discussed papers on several coal related environmental issues, including papers on integration of regional environmental goals into coal production and utilization strategies, management of air pollutant effects resulting from coal use, strip mining impacts on ground water resources, environmental aspects of advanced coal utilization technologies, comprehensive coal/environment planning approaches in selected countries, and problems of environmental protection in the coal mining industry.

The topics "Evaluation of advanced coal utilization and conversion technologies, with an emphasis on environmental aspects and technology costs", and "Analyses of transboundary air pollution issues related to future coal developments" were subsequently recommended by seminar participants for further collaborative study at IIASA. These recommendations were based on the fact that joint efforts between IIASA and collaborating institutions on these two topics are interrelated, and thus would best be undertaken jointly.

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COAL--ISSUES FOR THE EIGHTIES

Jan Stachowicz
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GENERAL INTRODUCTION

The papers set out in these two Collaborative Papers were presented at an IIASA Seminar for Industry Studies, namely, "Coal: Issues for the Eighties", which was held in Szczyrk, Poland, in November 1979. The seminar was, on this occasion, jointly organized by IIASA and the Polish institutes collaborating in this study with IIASA, i.e., Institute for Organization and Management Problems of the Polish Academy of Sciences, Bytom and the Computer Center of the Mining Industry in Katowice.

It may be worth saying something about the general concept lying behind the IIASA Industry Studies, particularly "Coal: Issues for the Eighties." The purpose of these Industry Studies was to bring together specialists, both managers and analysts, from different countries to identify the main issues which the industry faces over the next ten years, to identify the way and approach in which systems analysis can assist in major policy and decisions and to engage in a collaborate program of information exchange and research.

The coal mining industry is particularly appropriate for such a comprehensive study because it is a critical energy industry faced with expectations of greatly increased demand before the end of the century, and with the need to make major investment to decisions at a time when existing capacity is not fully utilized. Markets in the future may be very differently located from the present, and the transport situation needs to be reassessed. The future use of the product is uncertain--it might be needed for electricity generation, gasification, liquefaction or other end uses. The production technology is undergoing change, and the impact of the computer is only just beginning. At the same time, concern about pollution of earth, water and air is growing--leading to major regulatory controls of various kinds. It is an industry in transition, and most of these critical issues are appropriate subjects for systems analysis.

Moreover, the coal mining industry has developed over a long period of time under a variety of conditions, and has a good record of international collaboration. This gives a good basis for comparative studies that can be used to provide results of general applicability. Two recent meetings, the 10th World Mining Congress in Istanbul in 1977 and the UNO Coal Seminar in Katowice, Poland in 1979, have confirmed the potential return from developing international scientific cooperation in the scope of coal mining. Systems analysis has, as we have said, a major part to play in tackling the problems of coal mining development. "Coal: Issues for the Eighties" is intended to contribute towards these, and the Szczyrk seminar was a step in this process:

The main purposes of the seminar were:

-- to present papers on those topics identified at the Inaugural Task Force meeting held at IIASA in March 1979;
-- to facilitate the exchange of experience, results, methods, etc.;
-- to establish a plan for the future.

The seminar was attended by participants from Austria, CSSR, FRG, Hungary, Italy, United Kingdom, USSR, USA and Poland. Eighteen presentations were made by participants from six countries and three by IIASA participants. Most of the presentations concentrated on the main seminar topics, i.e.,

-- management, organization and the computer;
-- planning for planning;
-- environmental issues.

Some of the presentations, however, were devoted to more general problems in the coal mining industry. Four papers were wholly devoted to the question of "planning for planning" and two presentations covered this topic in part. Taken together they provided an overview of OR and systems applications in mine planning as well as presenting a good deal of useful experiences on the use of computers in support for planning in the coal mining industry.

The next group of papers was concerned with "management, organization, and computers" in coal mining. The presentations and discussions on this subject focused on two main aspects:

-- general problems of organization and management in the coal mining industry, and
-- the exchange of results and experience on the use of computers for management.

Three papers dealt entirely with this area and two partially.

The third group of papers dealt with "environmental issues" such as management of air pollution with regard to effects from coal use, groundwater depletion and other effects from coal extraction, and other effects from coal utilization technologies and comprehensive coal/environment planning approaches in selected countries.

All the papers presented here are as given at the seminar, without editing. The purpose is to make them readily available to those who took part in the meeting and to their colleagues. Many will appear in a modified form in the literature. A report on the conference as a whole is available as an IIASA working paper WP-80-140.

The seminar was successful in two respects. Firstly, it had provided the opportunity for the exchange of experience and an insight into different methodological approaches to problems, that could not have been obtained in any other way. No other meeting currently catered for this need. Secondly, it had made it possible to identify the direction that future collaborative studies might take. Such studies need not in fact be narrowly related to the coal industry but could concern, for example, the role of coal mining in global industrial development. The work was also relevant to many other IIASA studies, e.g., related to management under uncertainty, computer/ management interactions, innovation, etc.

We would like to take this opportunity of thanking the Institute for Organization and Management Problems of the Polish Academy of Sciences in Bytom and the Computer Center of the Mining Industry for their efforts to ensure good work conditions for this meeting and for their hospitality. It was another example of successful international cooperation.

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A FRAMEWORK FOR INTEGRATING REGIONAL ENVIRONMENTAL GOALS INTO COAL PRODUCTION AND UTILIZATION STRATEGIES

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Presented at the Coal: Issues for the Eighties Program Planning Workshop in Szczyrk, Poland, November 5-9, 1979

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PREFACE

This paper summarizes a proposed approach for incorporating more fully specific regional environmental goals into a coal-based energy planning process. The primary purpose of the paper is to provide a framework for discussion of environmental issues at the IIASA Coal: Issues For The Eighties Program Planning Workshop in Katowice, Poland, November 5-9, 1979.

The overall objectives of the IIASA Coal: Issues For The Eighties program is to bring together representatives of energy and environmental policy makers and the coal industry from many countries; to identify key issues which these groups will jointly face over the next 10-20 years; to identify the ways in which systems analysis can assist in the major policy and inventment decisions; and to engage in a collaborative program of information exchange and research. IIASA's role is essentially catalytic. It is IIASA's task to identify needs and seek to create the conditions in which they can be satisfied through collaborative research. Its unique international -- but non-governmental -- position in the systems analysis field, and the fact that it works in many fields of related concern (Energy, Resources, Environment, Manpower and Health, Management, Technology, etc.) makes it an ideal base for a creative exchange of information, methods and ideas. The collaborative nature of this program is seen to be fundamental to its success in providing improved information and methodologies for those involved in policy decisions.

In conjunction with the consideration of environmental issues, additional program components are focusing on the development and application of procedures for planning, organization, management, and introduction of innovative technology in the coal extraction industry. Those study components are not directly addressed in this paper.

ABSTRACT

This paper presents a framework for incorporating more fully specific regional environmental goals into a coal-based energy planning process. The framework utilizes the developed theory of multiattribute decision analysis to structure the problem of attaining a preferred balance between interrelated coal use and environmental goals. The decision analysis method of "satisficing" is proposed as an approach for focusing on a major regional environmental issue in view of other constraints on coal use target levels, cost, technology, and overall environmental planning. Included is a discussion of the mechanisms for involving decision makers, scientists and other specialists in the assessment process. The proposed framework is illustrated by a hypothetical application to the issue of limiting coal related acid rain and other air pollutant effects in the U.S.-Canadian border regions.

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A FRAMEWORK FOR INTEGRATING REGIONAL ENVIRONMENTAL GOALS INTO COAL PRODUCTION AND UTILIZATION STRATEGIES

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INTRODUCTION

Recognition of the limitations of present energy use patterns that rely heavily on increasingly scare supplies of natural gas and oil has led to extensive assessments of the potential for the utilization of alternative more abundant energy resources. Coal has been identified in a number of studies and in several government policy statements as a resource that could provide an increasing proportion of energy requirements for specific countries. Specific regulatory policies have been developed to stimulate substituting coal in the industrial and utility sectors for dwindling supplies of natural gas. At the same time, significant increases in coal-related research and development efforts have occurred to provide the technological basis for increased coal use. Furthermore, policy analysts are evaluating the potential for a world coal market, including both raw coal and coal derived products, such as methanol.

Parallel to the interest in increased coal use, coal related environmental policies and standards have become more demanding in all phases of the coal fuel cycle. In addition to tighter standards on air quality emissions, surface water conservation, and mining area reclamation, new environmental programs for solid waste disposal, resource recovery, and groundwater conservation have been implemented or are being proposed. The full ramifications of these environmental programs to both the coal industry and the overall environment are unknown.

From an industry standpoint, the uncertainties in the coal environmental policy framework make production and use decisions difficult. These environmental considerations are increasingly being recognized as having importance often equalling, or even exceeding, the importance of economic development considerations.

From an environmental standpoint, changes in coal technologies and utilization patterns that result from specific energy or environmental policies can have impacts or tradeoffs in all environmental areas. Technologies required for air emission control, for example, could have significant implications for waste disposal problems. Alternatively, a regional siting pattern and coal technology mix that emphasizes water conservation in water shortage areas will also affect the level and distribution of atmospheric emissions and solid wastes generation.

The first part of this paper provides an analytical structure for dealing with a broad range of coal and environmental planning needs based on modern decision analysis methods. Typical planning constraints and attributes of desired solutions appropriate to program objectives are included. The second part of the paper illustrates the potential application of this methodology to a case study of alternate strategies for limiting acid rain effects of future coal use in the U.S.-Canadian border regions.

A DECISION ANALYSIS FRAMEWORK

The generic procedure for national or regional coal-based energy planning, as illustrated in Figure 1, generally proceeds from projections of future coal demand based on economic analyses of total energy demand and consideration of alternate energy resources and technologies. The more detailed identification of viable coal strategies to achieve target supply levels typically takes into account additional regional factors, one of which is environmental impacts. Variations in coal use strategies which can have an impact on environmental impacts include alternatives in siting patterns, final energy form (e.g., synthetic oil or gas vs. electricity), end use (e.g., industrial vs. residential applications), coal characteristics (e.g., high vs. low sulfur), coal extraction technologies (e.g., deep vs. surface mines), and environmental control technologies. Each of these alternatives may present specific environmental advantages, for example, reduced water impacts, but often with a resultant trade-off of higher economic cost or increased impacts in other environmental areas such as waste disposal and land use.

The overall objective of the environmental component of the IIASA study is to develop and test procedures for obtaining an "acceptable" balance between coal use strategies and environmental goals. Conflicts between coal-related environmental impacts and environmental goals may force changes in the economic and resource based projection of future coal demands. However, the proposed study approach will at least initially focus on approaches for coal/environmental planning for fixed regional coal demand projections. This serves the purpose of limiting the initial program objectives but, as will be shown

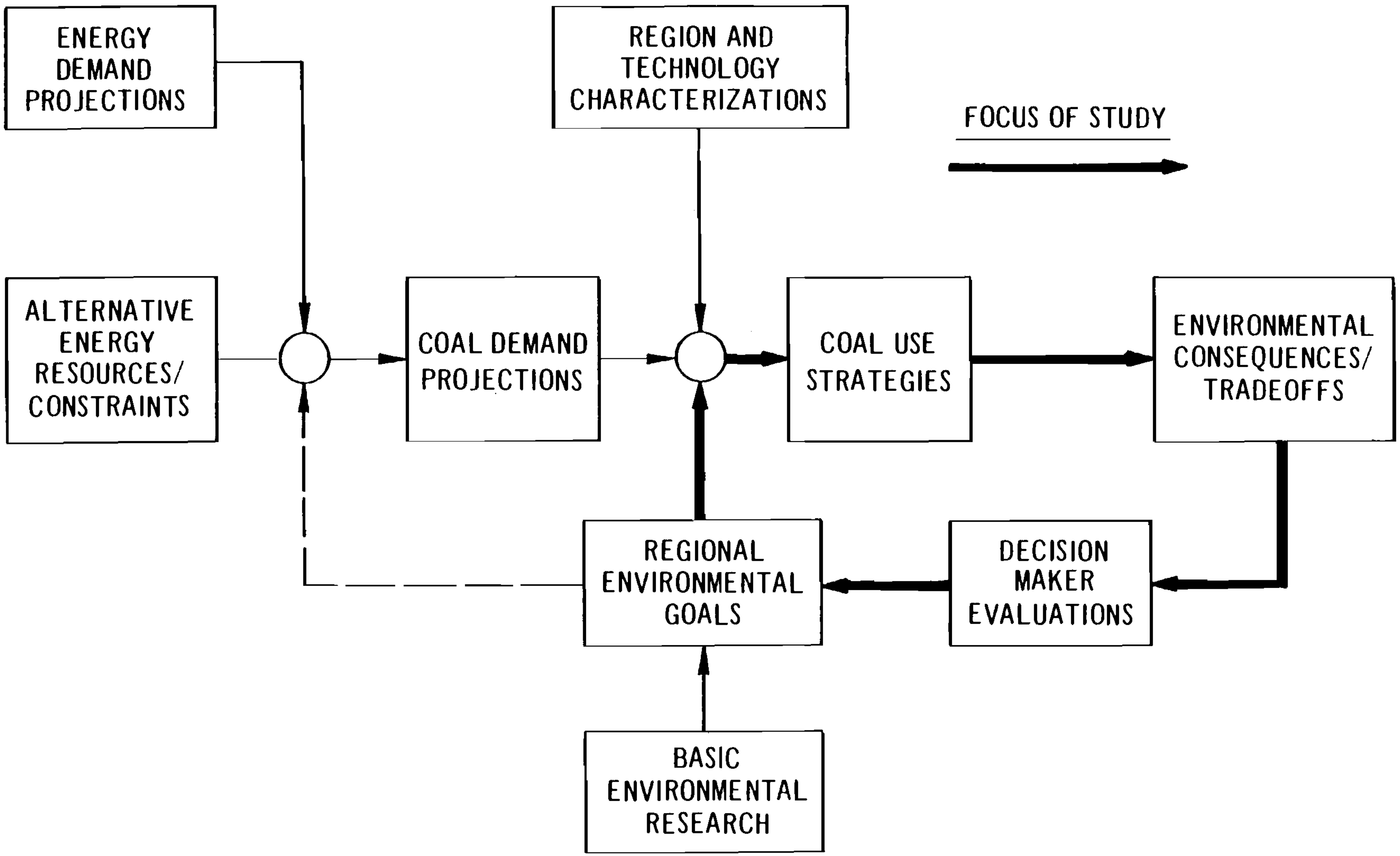

Figure 1. Generalized process for integrating regional environmental goals into coal production and use strategies.

later, these results can be consistently linked through a hierarchical framework to the broader problem of environmental goal impact on future coal demand projections.

The basic problem of selecting a coal use strategy that achieves an acceptable balance between various environmental impacts, costs and other factors as stated above can be set in a multi-attribute decision analysis formulation as follows:

Define:

E: Set of possible coal use strategies

$E_p \varepsilon E$: Possible strategies producting target coal use level, and meeting other hard (technology) constraints

$Q_p = f(E_p)$: Possible consequences of coal use strategy options, for example,

$$Q_p = \text{range of} \begin{bmatrix} \text{costs} \\ \text{air pollution} \\ \text{water use} \\ \text{water pollution} \\ \text{etc.} \end{bmatrix}$$

Problem:

Find the strategy $\underline{X} \varepsilon E_p$ that has a set of consequences Q_o that are minimum according to the decision makers' preferences.

Some basic features of this problem formulation and its solution are graphically illustrated in Figure 2 for the case where two coal strategy consequences, cost of energy produced and sulfate (SO_4) air pollution levels are considered. With this simplified problem, it is easily seen that the preferred strategy is one with consequences somewhere on the boundary indicated with a solid line. For all strategies with consequences on this line (referred to as Pareto-optimal solutions) a decrease in sulfate level can only be achieved by an increase in cost, and vice versa.

To obtain a unique solution, the analyst may specify all consequences in equivalent units, for example monetary value of environmental parameters such as increased air pollutant levels. This approach is severely limited by current inability to adequately place a monetary value on environmental quality. Alternatively, a unique solution is obtained through knowledge of decision-makers' preferrences, or utility function, that in effect weight the relative importance placed by those persons on each consequence.

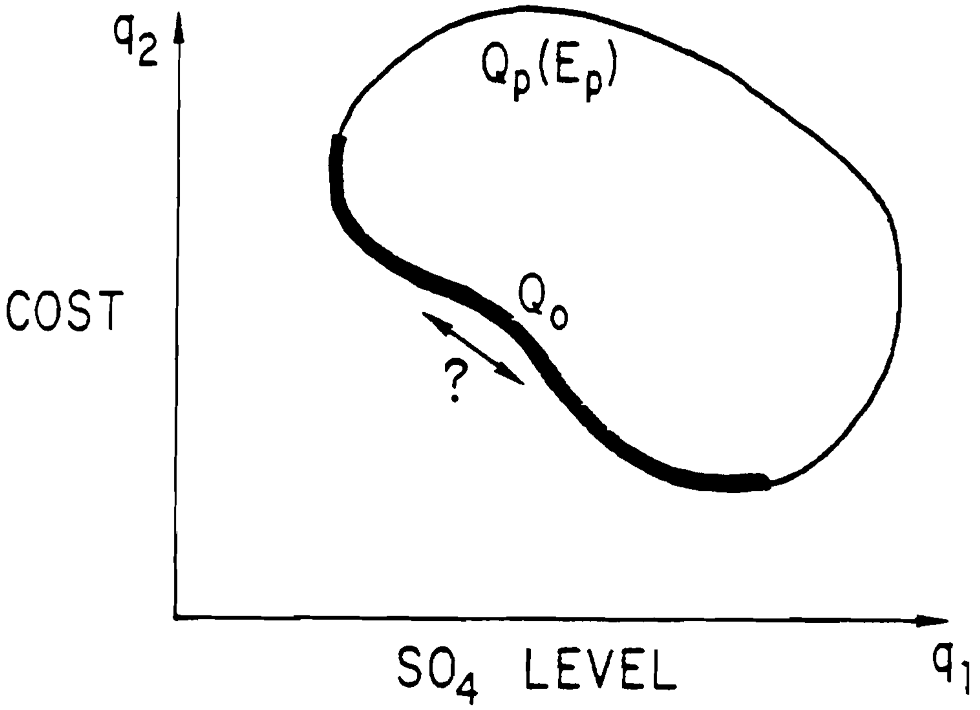

Figure 2. Typical cost and SO_4 level tradeoffs for coal use strategies. Points on heavy line are Pareto-optimal.

The use of utility functions has been well developed theoretically, including procedures for extracting decision-maker relative preferrences, or utility functions, and application of statistical approaches to take into account uncertainty and risks. Reviews of these approaches can be found in the literature. (See for example, references 1,2,3).

Although the theory of multi-attribute decision analysis is well-developed, its practical application often encounters considerable difficulties. These problems of applications typically relate to the following type of issues encountered in obtaining decision-maker relative preferences;

- Time required of decision-makers
- Decision-makers' inconsistency over time
- Modeling difficulties in portraying impacts and tradeoffs of primary concern
- Decision-makers tend to think in terms of independent "acceptable" goals for each consequence.

These pragmatic problems of application have led researchers to seek alternate approaches. One such approach, the method of "successive concessions," initially requires only a ranking of consequence priority. [4] This ranking, which is in general easier to determine than a quantitative weighting, is conceptually compatible with the approach commonly use by environmental regulatory agencies when focusing on the real or perceived central environmental issues in a region.

To illustrate the method of successive concessions, assume a consequence ranking:

$$Q = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} SO_4 \text{ level} \\ \text{Cost} \\ \text{Water use} \end{bmatrix}$$

Step 1

Find the strategy with minimum SO_4 level $= q_1^o$ (Scalar Optimization)

Step 2

Find the strategy with minimum cost q_2^o, given the constraint

$$q_1 \leq q_1^o + \Delta q_1 \quad \text{(Concession on } SO_4 \text{ level)}$$

Step 3

Find the strategy with minimum water use q_3^o, given the constraints

$$q_1 \leq q_1^o + \Delta q_1$$

$$q_2 \leq q_2^o + \Delta q_2 \quad \text{(Concession on cost)}$$

An illustration of the first two steps is given in Figure 3. This approach generally requires an iterative procedure to obtain an acceptable solution.

To apply the method of concessions at least some information is assumed available to make acceptable concessions. For example this information may include:

- Cost of coal derived energy that is competitive with oil, gas, nuclear, etc.
- Regional water availability and competing demands
- Water quality standards
- Cost/benefit analysis of environmental impacts
- Information on unavoidable consequences from previous analysis

As an alternate to the method of successive concessions, an approach under the generic title of "satisficing" makes use of this information to set acceptable levels for the lower

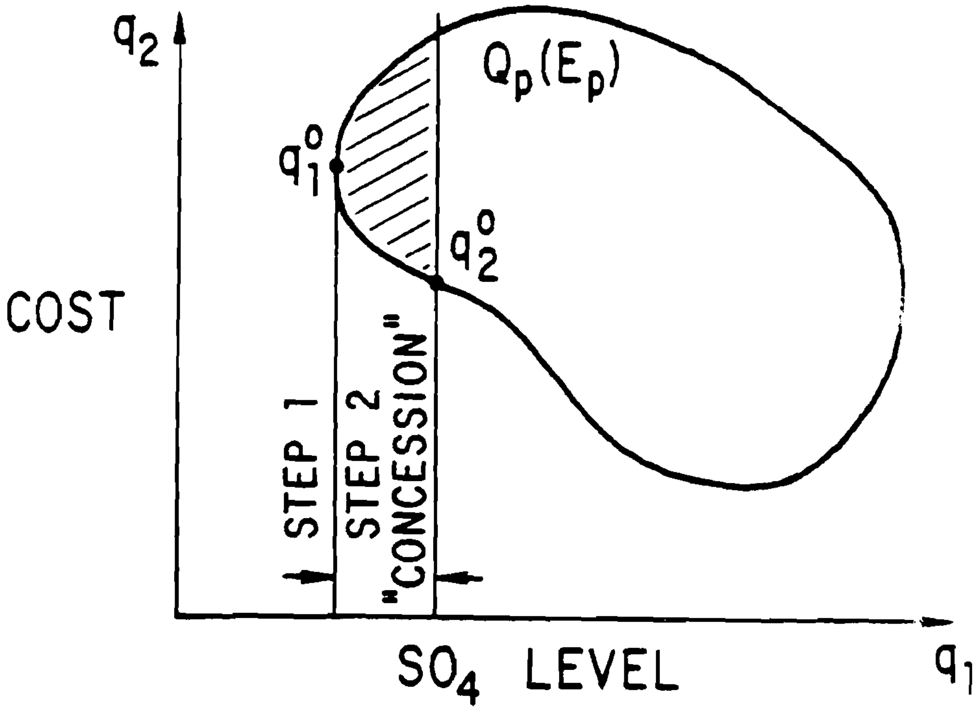

Figure 3. Method of successive concessions with minimum cost given concession on optimal SO_4 level.

priority objectives, thereby converting those objectives into initial soft constraints that may be revised as necessary in subsequent iterations.[5]

To illustrate the method of satsificing, the following approach would be utilized in the previous example:

Step 1

Identify the priority consequence, say $q_1 = SO_4$ level.

Step 2

Establish initial estimates of constraints for the remaining consequences

$$q_2 \leq q_2' \text{ (cost)}$$

$$q_3 \leq q_3' \text{ (water use)}$$

Step 3

Determine minimum q_1^o (Scalar Optimization)

Step 4

DM decides "is the solution acceptable?", with the following possibilities.

A) Yes -- problem is solved
B) No -- would like to reduce q_1, SO_4 level. Return to Step 2 with relaxed constraints selected by DM. For example, since q_3, water use, is low priority

$$q_3 \leq q_3' + \Delta q_3$$

Return to Step 3 to find new minimum $q_1^{o\prime}$
C) No -- willing to increase q_1^o to reduce, say, q_2, the second priority consequence. Set constraint

$$q_1 \leq q_1^o + \Delta q_1$$

Find minimum q_2^o (Scalar Optimization)

The first three steps of this approach are illustrated in Figure 4 for the 2-dimensional case of cost and sulfate (SO_4) air pollution consequences. Again an iterative procedure is generally required to achieve an acceptable solution.

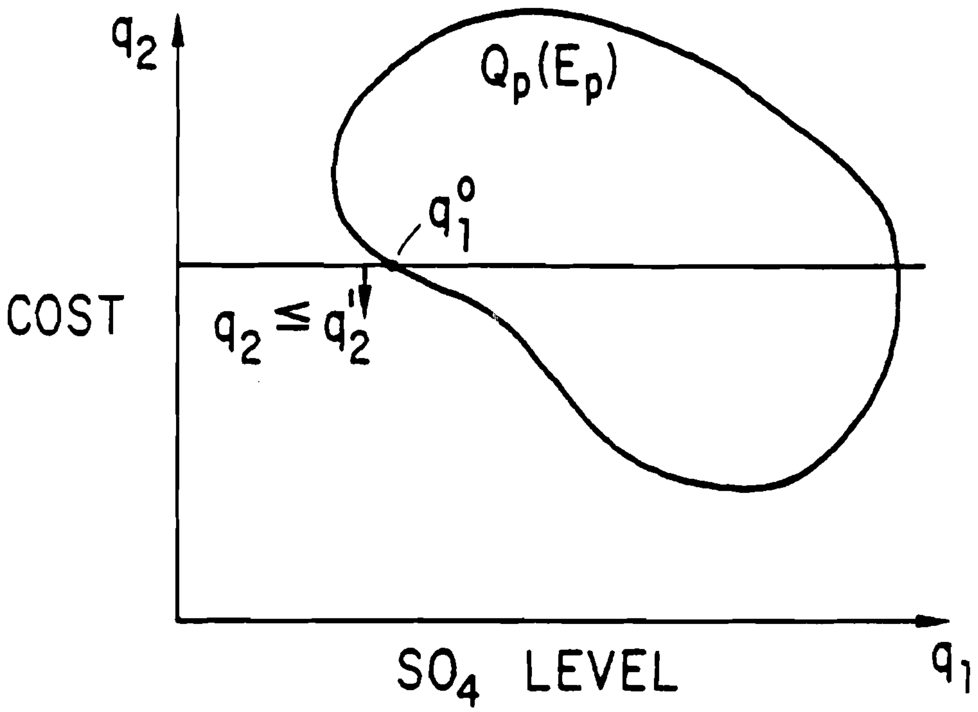

Figure 4. Method of satisficing with minimum SO_4 level given constraint on maximum cost.

Consideration of the above approaches leading to a determination of "acceptable" solutions naturally leads to the question of the relation of these solutions to the "optimal" solution of the multiattribute decision analysis problem as originally formulated. A theoretical link to the optimization problem has in fact been established through the use of a hierarchical analysis as illustrated in Figure 5 [6]. If the scalar optimization as outlined above for the priority consequences is also performed separately for each of the other consequences, with or without constraints for the non-optimized consequences, the combination of these separate solutions using an appropriate weighting function produces the overall optimal solution. Furthermore, the hierarchical approach to finding the optimal solution can be extended to a still higher level to include determination of an optimal level of coal use relative to other energy forms. Although this relation has been theoretically demonstrated, its application is complicated by the requirement for determining a related Lagragian function. Thus, although obtaining the overall optimization may in practice not be easily achievable using these approaches, the theoretical compatibility of "acceptable" and "optimal" solutions lends further credibility to the use of "acceptable" solutions as proposed in this paper.

An additional variation in approaches to achieving acceptable solutions, which is under development at IIASA and elsewhere, proceeds by initially identifying reference objectives (i.e., desired goals) for all of the consequences[7]. A solution is obtained by determining the set of Pareto optimal consequences that are "closest" to the reference objectives according to a

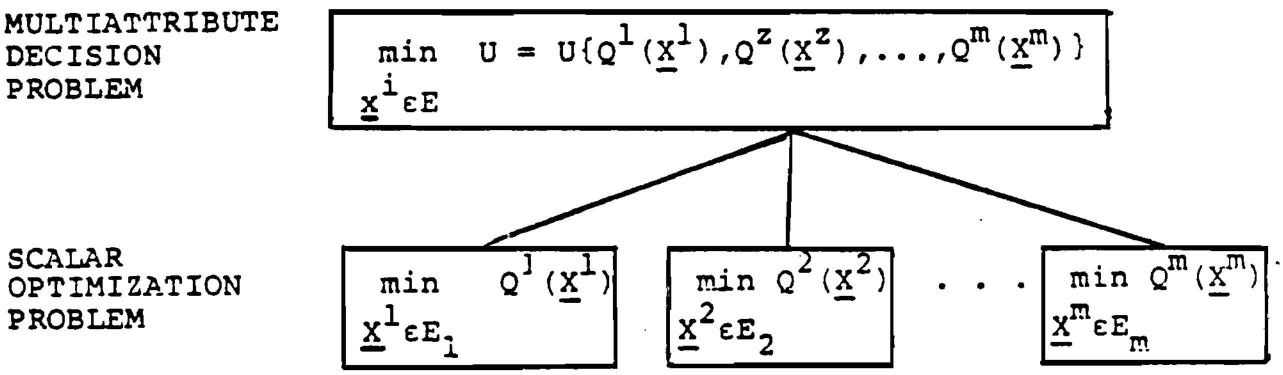

Figure 5. Hierarchical multiattribute decision analysis based on constrained scalar optimization of individual attributes.

defined norm. This resultant solution can be retroactively used to identify a utility function that would give the same solution if used in an optimization approach.

The involvement of decision makers is a key element in each of the above approaches and thus warrants further consideration. Considerable research has been conducted into procedures for making this involvement effective (see for example references 1,2,3), including psychologically oriented "soft-science" aspects related to human interactions. The discussion in this paper will be restricted to a summary of an apparently effective approach reported by C.S. Holling (ed.) and based on a previous collaborative IIASA study to develop an adaptive approach to environmental impact assessment and management [8]. From this study evolved recommendations for specific procedures for decision making based on a number of studies of renewable resource problems in different national settings: renewable resource management and disease control in Venezuela and Argentina; range and wildlife management in the United States; developmental and oceanographic problems in Europe; ecological process studies in the Soviet Union; renewable resource and pest management systems in Canada. Although these issues are not directly related to environmental problems associated with coal use, the successful development of effective approaches to decision making with a variety of environmental issues provides the impetus for the consideration of adopting these broadly defined techniques in the Coal: Issues for the Eighties program.

A basic element of the proposed procedure is the convening of a series of workshops involving a core group of analysts and key specialists including policy makers, environment and resource managers, and scientists. The role of the specialists is to focus the analysis on the issues critical to decision making, to define viable strategy options, and to provide the analysts with an access to relavent input data. An important function at the initial workshop is the development of the basic structure of the model to be used for assessing strategy options. Compared to the more familiar approach of having analysts independently develop the modeling tools, participation by decision makers and scientists ensures that the model output will produce results related to relavent decision issues and that state-of-the-art knowledge on dynamics of environmental impacts is included.

The role of the core group is to coordinate workshop activities and to implement the defined assessment model for the iterative determination of optimal or acceptable strategies as described previously in this paper. Subsequent workshop sessions are convened to evaluate interim model results and prescribe further steps in considering additional alternatives, or possible modelling revisions as required to move toward an acceptable balance between tradeoffs.

A CASE STUDY EXAMPLE

To illustrate the approaches proposed in the preceeding discussion for integrating regional environmental goals into coal production and utilization strategies, this section of the paper considers various aspects of an ongoing decision making process for limiting transboundary air pollutant effects related to coal utilization in the U.S. and Canada boundary regions. The decision making process in this example centers on the jointly announced intention of the U.S. and Canadian governments to develop a formal cooperative bilateral air quality agreement [9].

This recognized need to control transboundary air pollutants stems from various factors. A primary factor is recent data that shows that precipitation in these regions has become increasingly more acidic, as illustrated in Figure 6. This increase in acid precipitation is at least partially due to increases in sulfur and nitrogen air pollutant compounds [10]. There is increasing concern that this acidic precipitation can have a profound impact on the prevalent natural aquatic and terrestrial ecosystems in parts of this region where geological conditions provide minimal buffering capacity [11,12,13]. In addition to impacts on natural ecosystems, these air pollutants can also have a deleterious effect on human health, visibility, building materials, and commercial forest and crop production.

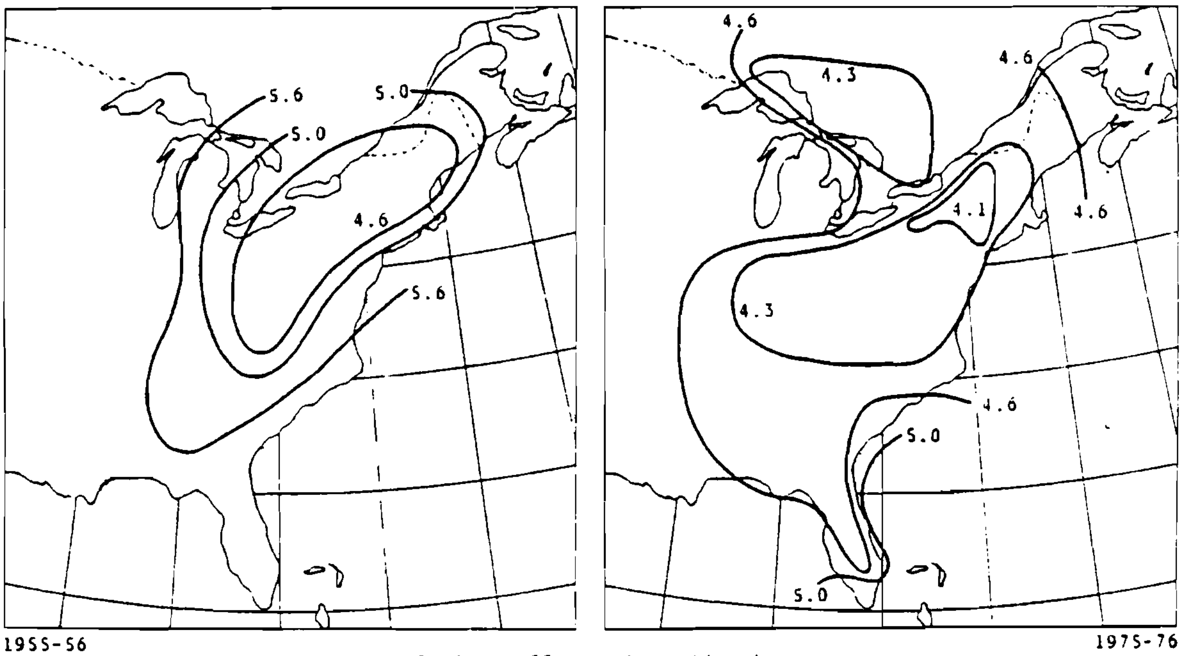

Figure 6. Isopleths showing annual average pH of precipitation in eastern North America (adapted from ref. 10).

Limiting the levels of these air pollutants and their effects in this region involves a much larger geographic area since the residence time of certain nitrogen and sulfur compounds in the atmosphere may be several days during which they may be transported several hundreds to thousands of kilometers--distances that are comparable to the extent of eastern North America.

Although the relative impacts of individual air pollutant emission sources on this region is not directly available, an indication of their importance can be obtained by considering national emission data files. It has been estimated [14,15,16] that of the total 1975 SO_2 anthropogenic emissions of 25.7 million metric tons per year in the U.S., 81% result from utility and other combustion facilities. For Canada 32% of the total of 5.0 million metric tons per year of SO_2 emissions is from combustion sources and 44% is from non-ferrous smelters. For 1975 NO_x emissions, 52% of 22.2 million metric tons per year total emissions in the U.S. is from combustion sources, and 32% of 1.9 million metric tons per year total in Canada are from such sources. A significant percentage of NO_x emissions - 45% in the U.S. and 63% in Canada - results from transportation emissions.

The high percentage of sulfur and nitrogen emissions from combustion sources clearly indicates the important role that must be given to controlling both current and future sources of this type in strategies for limiting future acid precipitation in the U.S. and Canada. For sulfur emissions in particular, the involvement of strategy planning for future coal use, and possibly further controlling emissions on existing coal use, is critical. The necessity of considering coal strategy options in the environmental planning is given increased emphasis because of the current U.S. policy for increased reliance on coal as an energy source with as much as a doubling, or more, of U.S. coal production and use projected for the 1975-1990 period [17].

With this as background, the decision making or planning process for limiting U.S.-Canadian transboundary air pollutants in view of increased coal use can be discussed in relation to the proposed generalized framework described in the preceeding section. As of this writing this ongoing decision making process has not been explicitly structured to conform to the generalized framework described in this paper and the following discussion is not intended to be a critical review of the ongoing process which takes into account various unique controlling technical, institutional, and legal factors that are beyond the scope of this paper. Rather, the purpose of the following is to discuss from a broader perspective how components of the proposed framework could in general be effectively utilized in a realistic situation based on observations of an ongoing coal/environmental planning problem.

Following the decision analysis methodology termed "satisficing" in the previous section the following components are required:

- Organizing workshops involving a core analysis group and policy makers, scientists and other specialists
- Defining coal utilization objectives
- Definding coal strategy constraints for energy costs, siting, technology options, and environmental impacts other than transboundary air pollutants
- Determining strategies for minimizing transboundary air pollutants in view of defined constraints
- Iterations to obtain an "acceptable" balance of tradeoffs.

As a minimum the workshop should include representatives of energy and environmental planners from both the U.S. and Canada, preferrably from both national and state or province levels. The administrative level of persons to be involved is dependent on whether the output of this process is a final decision to be implemented or only recommendations to be provided to higher level authorities responsible for final decision making. But in either case the participants should be familiar with objectives and constraints of the final decisions to be made. The scientists' role is to transmit the best available information on the known and potential impacts of the air pollutants and the physical mechanisms of pollutant transport and available models. In the case of acid precipitation and its effects, significant gaps currently remain in this desired knowledge and thus the scientists role in this case, as with many issues involving environmental impacts, includes providing a clear indication of the limits of knowledge. In view of the available scientific information and uncertainties the initial workshop sessions would be oriented toward defining air quality objectives, expected coal use levels, coal strategy alternatives and constraints for achieving those levels, and outlining the basis for modeling strategy alternatives to assess tradeoffs. In the actual ongoing decision making process related to the U.S.-Canada transboundary air pollutants, various diverse groups of scientists and planners have in fact been convened to discuss these issues, albeit often with more limited objectives or somewhat different strategies for achieving decisions or recommendations for decisions that can be implemented.

The proposed approach for coal/environmental planning assumes availability of projections for total regional coal utilization. For the U.S. and Canada these projections are available from studies by utilities, industry, and national and regional energy planners. Thus for this case study what is required is a consolidation of these studies into a single projection or range of projections. As required these projections can be provided in detail which give limits on: coal availability of different types, coal use by sectors of the economy, coal conversion technology, emission control technology, regional siting patterns, etc. In addition to physical and technology constraints, limitations on cost of coal-derived energy must be included so that coal remains competitive with other energy forms.

Under the proposed approach the coal strategy options for limiting air pollution are to be constrained by a limitation in impacts on other environmental media such as water, solid waste, and land use. As a minimum these limitations should be compatible with existing environmental protection regulations or plans.

Having defined the constraints for the coal strategy options, the analysis proceeds by determining the minimum air quality impact achievable within the range of strategy options. Various air quality criteria may be used for determination of an optimal strategy given the constraints. The most straightforward criteria is minimizing total emissions. More refined criteria that make use of information on pollutant transport and impact mechanisms could be a minimization of cumulative human exposure in all regions, minimization of peak exposure, or a minimization of exposure in regions with sensitive ecosystems.

In general, it can be expected that additional coal strategy options and constraints will need to be iteratively considered to obtain the desired "acceptable" balance between the minimized air quality impact and other associated environmental tradeoffs.

A generalized mathematical formulation for the constrained air quality minimization problem is presented in the Appendix.

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APPENDIX: CASE STUDY MODEL FORMULATION

This appendix provides a conceptual mathematical formulation for a coal strategy optimization problem that minimizes air quality impact under various constraints. The basic variable is:

$X_{ij\ldots t}$: Level of coal-derived energy consumed where

- i: final energy form (electricity, synfuels)
- j: user (industry, residential, transportation)
- k: user location (region)
- l: coal conversion technology
- m: conversion siting
- n: coal source, classification
- o: coal preprocessing technology
- t: time

<u>Constraints*</u>

1. Total coal derived energy consumed in the region

$$X_t \geq \bar{X}_t^1$$

2. Sector and region market potential for specific energy forms

$$X_{ijkt} \leq \bar{X}_{ijkt}^2$$

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*$X_{a\ldots b} \equiv \sum X_{ij\ldots t}$, where the summation is over all subscripts except a...b

3. Maximum cost for energy form that is competitive. Let $P_{ij...t}$: unit production cost for $X_{ij...t}$, then

   $x_{ij...t} = 0$, for $P_{ij...t} > \bar{P}_{ijkt}$ (competing energy price)

4. Maximum transport distance for coal and final energy form. Transport distance limitations can be included as part of total production cost limitations in 3.

5. Maximum quantities of coal and energy in final form that can be transported.

   $x_{kmt} \leq \bar{X}^3_{kmt}$, $x_{mnt} \leq \bar{X}^4_{mnt}$

6. Siting and technology limitations due to other environmental goals. In the most general linear form,

   $\sum \underline{C}_{i'ij...t} \; x_{ij..t} \leq \bar{\underline{\underline{X}}}^5_{i't}$,

   where $\underline{C}$ is the impact transfer vector, and $\bar{\underline{\underline{X}}}^5_{i't}$ is the maximum allowable impact in region i´ at time t.

7. Limits on availability of new technology

   $x_{1t} \leq \bar{X}^6_{1t}$, $x_{ot} \leq \bar{X}^7_{ot}$

8. Limits on regional coal extraction

   $x_{nt} \leq \bar{X}^8_{nt}$

9. Coal import limits

   $$x_{m'n't} \equiv \sum_{\substack{m \varepsilon m_1 \\ m \varepsilon n_1}} x_{mnt} \leq \bar{X}^9_{m'n't} \text{ (see constraint 5)}$$

The solution requires a minimization of air quality impact (or other impact) which is expressed in the form (see constraint 6)

$$q_1 = \sum c^a_{i'ij...t} \; x_{ij...t}$$

The final "acceptable" solution may require a concession on air quality limits or other previously defined constraints.

PROBLEMS OF ENVIRONMENTAL PROTECTION IN THE POLISH COAL MINING INDUSTRY

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PROBLEMS OF ENVIRONMENTAL PROTECTION IN THE POLISH COAL MINING INDUSTRY

1. Introduction

In People's Poland the mining industry plays an important role in development of national economy particular part in this respect falling to the hard coal output increasing dynamically. This increase is illustrated by following quotas of yearly output:

1950 - 78 mln tons

1960 - 104 mln tons

1970 - 140 mln tons

1980 - over 200 mln tons.

Actually about 98 % of total output is obtained from mines of Upper Silesian Coal Basin and only 2 % from mines of Lower Silesian Coal Basin. In next years the output will begin flowing also from mines of Lublin Coal Basin.

To ensure the greater and greater output the extension of existing mines and construction of new ones in the Upper Silesian Industrial Region is necessary; perspective mining areas foreseen for localization of new mines are: the Rybnik Coal Basin area and the Vistula area.

2. Effects of mining work resulting in transformation of environment

The mining work both by underground and opencast methods causes changes and transformations of the structure of lands covered by mining activities the noxious effects of these transformations manifesting themselves there in conditions of high concentration of population and compact settlement of lands. Typical effects of mining activities exerting a noxious influence on the living conditions are:

- transformation of earth surface and destruction of fertile earth layer connected with it (opencast workings, heaps, collapse sink holes etc.),
- noxious disturbances of water conditions underground and on the surface (disappearance of water, fens, water pollution etc.),
- result changes in natural environment (moult, degradation of soil fertility),
- air pollution (burning heaps).

Among typical negative effects of activities of mining plants is also numbered the deterioration of technical condition and utility degree of building and engineering objects. So, on the one hand mining the mineral raw material resources renders accessible and delivers the national economy indispensable raw materials and on the other hand this mining provokes a number of negative effects on the surface. Therefore a need arises for appropriate activities within:

a. mining work,
b. utilization and building-up of the surface,
c. protection of the essential man's interests through maximum environmental protection.

The efficacy of these activities depends primarily on local natural, demographic and technical conditions and on the way and degree of utilization of mineral resources.

3. Development of mining coal seams occurring in safety pillars in Poland

In the post-war period and especially in the last two decades a large scale mining work was developed in Poland of coal seams occurring in safety pillars of towns and industrial plants, including pillars for objects most sensible to ground movements, such as steel mills, coke plants, power stations. The necessity for undertaking mining work in safety pillars was dictated by decrease and at times by exhaustion of resources occurring under not built-up lands.

The attractiveness of mining coal seams in safety pillars lies primarily in its high profitability. The industrial resources of hard coal in the safety pillars of Polish mines amount to more than 5 milliard tons. The majority of these resources has been already developed which considerably increases their value for national economy. Their extraction does not require engagement of major investment outlays.

The development of mining of coal deposits in safety pillars is a consequence of the permanent technical progress in the range of technology of deposits extraction and methods of protection of existing and newly erected buildings on mining lands. In the period from 1950 to 1975 one milliard tons of coal were extracted from safety pillars. The part of coal output from safety pillars in relation to the total production is of about 40 %.

On the area of the Upper Silesian Coal Basin mining work is performed under almost all towns including centre of Katowice and such industrial plants as steel mills Pokój, Bobrek, Ferrum, power station Szombierki and Technical Equipment Plant "Zgoda".

4. Main directions of activity of the coal mining industry in the range of environmental protection

Main directions of activity of the coal mining industry in the range of environmental protection include:

- utilization of wastes and liquidation of over-level waste dumps (heaps),
- economic utilization of water in coal preparation plants (closed cycles),
- desalination of mine water,
- protection of buildings and objects against mining damage and efficient removal of the latter,
- liquidation of fens and underfloodings of the land caused by mining work.

4.1. Utilization of wastes and liquidation of over-level waste dumps (heaps)

Further dynamic increase of hard coal output forecast for following years will require resolution of a number of essential and difficult problems to which belongs i.a. the utilization of stone coming both from development work and coal dressing plants.

The total of waste stone extracted from coal mines amounted in 1976 to about 44 mln m^3. It is foreseen that the relative part of stone in the output of mines will not change, but in absolute quantities an increase is foreseen of the amount of the extracted stone in following years to about 48 mln m^3 in 1980 and 56 mln m^3 in 1990.

The increase of waste output from mines will arise as consequence of:

- increase of coal output,
- execution of increasing amount of dead work and coal-dead work,

- increase of mechanisation of coal getting and loading,
- exhaustion of coal seams with low impurities content,
- increasing requirements relating quality of coal being sold.

4.1.1. Wastes utilization

To ensure environmental protection the mining department foresees with preference following directions of wastes utilization, namely for:

- hydraulic stowage in mines,
- pneumatic stowing and direct location in mine,
- processing for aggregate e.g. by Haldex Plant,
- engineering work and production of building materials,
- land levelling (central and mine dumping grounds).

4.2. Liquidation and utilization of heaps

On the premises of hard coal mines there are 104 over-level heaps occupying an area of 860 ha with 157 mln m^3 of capacity.

Since many years the mining department has undertaken energetic steps towards stopping the increase of over-level heaps and also gradual pulling them down and using the heap material for stowing, building and other useful purposes. As result of this activity only 10 % of wastes from current production is dumped on heaps and at the same time the number of mines dumping stones on over-level heaps diminishes systematically. The main directions of activity in this range are:

- pulling down the heaps with assignment of material for economic purposes
- reclamation of heaps or their afforestation.

For realization of these tasks a specialistic Reclaiming Plant in the framework of the Stowing Materials Enterprise has been organized by the mining department. On the area of the Upper Silesian Coal Basin yearly land reclamations are following:

- pulling down (liquidation of heaps . . . . . . about 40 ha
- reclamation and afforestation of heaps . . . . . about 50 ha

Many heaps have been utilized as industrial grounds of mines, settling ponds for washery effluents, sports grounds and recreation grounds.

A separate method of heap utilization is their reclamation and afforestation. The utilization of heaps through introduction on them of suitable vegetation requires meticulous research and studies in the way of adaptation of trees and bushes individually to the kind and structure of the dumped heap material. Investigations in this range are conducted i.a. by the Establishment for Environmental Protection of Industrial Areas in Zabrze.

5. Water economics in coal dressing plants (closed water-slurry cycles)

Coal cleaning is at the present time generally achieved in the water medium; the correct solution of the water cycle technology as well as its equipment with highly efficient machines and installations is very much important and directly affects the results of operation of the coal preparation plant.

The considerations of environmental protection require that the water-slurry cycle should be closed. Until quite lately, in spite of using many complex appliances a full closing of the water-slurry cycle has been impossible bocause of difficulties with clearing and dewatering the suspensions from the last degrees of regeneration of circulating water.

A vital turn in solutions of the water-slurry cycle took place as soon as the production of new flocculants was started and introduced into industrial practice.

New technologies of closing water-slurry cycles have been applied both in existing and newly designed dressing plants. The technological solutions of water closing have been based on machines equipment and flocculants of home production. The industrial application of closed cycles technology in the coal preparation plants brings the national economy considerable profits which i.a. find expression in:

- limiting the fresh water consumption which does not exceed 0.1 m^3 of water per ton of cleaned coal,
- improvement of coal quality parameters,
- liquidation of open water contaminations by industrial wastes.

Actually about 80 % of coal preparation plants have got closed water-slurry cycles.

6. Desalination of mine water

One of main potential contaminations of rivers in the Upper Silesian Coal Basin is their salinity by mine water. In this connection intense work has been undertaken for protection of superficial water courses against excessive salinity.

In total about 900 000 m^3/day are being pumped from mines of the Upper Silesian Coal Basin onto the surface. In this amount saline water makes about 250 000 m^3/day with total salt content of about 3300 t/day. In the Oder basin the mines pump about 110 000 m^3/day of saline water with a salt content of about 2100 t/day. The principal component of dry residue is sodium chloride which predisposes it for utilization as chemical raw material.

The salinity of underground water occurs also in the region of Vistula basin. The construction of further new mines in this region depends i.a. on the solution of the problem of protection of Vistula river and its courses against excessive salinity.

To solve this problem two methods have been developed:

- utilization method developed by the Central Mining Institute,
- hydrotechnical method developed by the Main Office of Study and Mining Design of the Coal Mining Industry.

The utilization method consists in separation of table salt and usable water from the total amount of saline mine water. This method applies to strongly salted mine water (more than 70 g/l).

The prototypical industrial plant with processing capacity of 2400 m^3/d of brine of 100 g/l of concentration has been started at the mine Dębieńsko. The research work is in progress. The results of it will become a basis for construction of further plants of this kind.

The hydrotechnical method consists in disposal from mines of saline water by special collectors to the batching reservoirs and then to the riversOder or Vistula in such a way as to keep in them permanently the same salt concentration in the admissible standard limits. For protection of the Oder river the collector Olza and the batching reservoir on Oder river will be constructed. For protection of the Vistula river preliminary work has been already started with erection of batching reservoirs for the mines Silesia, Brzeszcze and Piast.

In consideration of the present state of advancement of scientific and research work on the utilization method it is foreseen that hydrotechnical method will be used at least as late as till 1990. In the future a complex solution is foreseen of rivers protection against salting by mine water by means of combination of the utilization and hydrotechnical methods.

7. Reclaiming lands following opencast mining of stowing sand

In the Polish hard coal mining industry also hydraulic stowage is used on a large scale for filling mined out workings. Yearly consumption of stowing sand for this purpose is of about 36 mln m^3. The stowing sand is mined by opencast method. In consequence of this mining activity waste lands arise in form of sand workings not utilized for the time being. Also on lands adjoining the open pit changes are taking place in water conditions affecting negatively husbandry and forestry.

Recovery of lands following opencast mining, i.e. so called reclaiming activity consists of two principal stages:

- technical reclamation,
- proper management (forestry, husbandry, water reservoirs).

To the range of reclaiming work belong:

- shaping the relief according to requirements of the established management direction,
- regulation of hydrological conditions,
- reproduction of soil conditions appropriate for vegetation,
- introduction of flora of pioneer nature and technico-biological lining of slopes to ensure their stability,
- construction of indispensable network of access roads.

Shaping the relief belongs as a rule to the most labour-consuming and expensive procedures. It results from the fact that technical conditions and ground possibilities restrained as a rule dictate the methods and technologies of dumping grounds erection.

The reproduction of soil conditions is attained through suitable fertilization and neutralization of toxic lands. These operations are preceded by detailed field and laboratory tests of physical and chemical properties of reclaimed grounds, as on all dumping grounds there is great variation of lithological constitution of soils both in vertical and horizontal section.

It results from lithological structure of overburden. The afore--said tests are carried out by scientific and research stations of the Polish Academy of Sciences and of Academy of Mining and Metallurgy in Kraków co-operating with the industry. In consequence of these tests the mining plants obtain detailed guidelines concerning the method, kind and quantities of fertilizers and neutralizers to be used.

The performance of measures connected with mineral fertilization and neutralization is followed by the introduction of vegetation of pioneer and partly of final nature as biological lining of top areas and the whole slope system. The lining is made out of grassy herbaceous, shrubby and arborescent plants.

The observations made proved that in many cases full lining can be resigned without prejudice for its principal function which with sometimes very short (spring-autumn) seeding periods gives moreover the possibility of more systematic and direct erosion prevention in the reclaiming work cycle.

The reclamation of opencast mined sand workings consists in afforestation of mined out lands and in building of water reservoirs. The Enterprise for Stowing Materials adopted the method patented in Poland of fertilizing barren sandy lands with bentonite silts and more precisely with so called sorbent fertilizers produced on the basis of the latter. By introducing them on lands being reclaimed an essential increase of sorptivity and water capacity of sandy lands has been attained.

At the same time implementation to the reclaiming practice of results of tests and scientific experiments allowed the reclaiming costs to be reduced considerably, on the average from 120 000 zł/ha to about 60 000 zł/ha.

A favourable consequence of reclamation by afforestation is building plantations composed mainly of deciduous species resistant to effects of gases, dusts and smokes emitted by the industry to the atmosphere.

Hence the fundamental condition of growing economic value and extraproductive function of the forest is not only the increase of afforested area but also its parallel action in the way of radical limitation of dust and smoke emission to atmosphere. Apart from afforestation equivalent functions in environmental protection are accomplished on the areas of industrial and urban centres by appropriate forms of dispersed tree-planting.

The sand workings are utilized also for building water reservoirs. Considering the water deficit incessantly deepening on the scale of the whole country, which according to estimates will attain 1.5 mld m^3 in 1980 and even 5 mld m^3 in 1990, building of multi-role water reservoirs was started on the sand workings to be utilized for following purposes:

- recreation of inhabitants of large urban centres,
- retention of water to keep optimum water flow in external receivers,
- water intake for municipal, farming and industrial needs.

An example of such solutions are water reservoirs built lately, namely:

- Chechło-Nakło with an area of 85 ha
- Pławniowice with an area of 245 ha
- Gołonóg II with an area of 206 ha
- Dziećkowice with an area of 463 ha.

In consequence of reclaiming activity of lands mined out for stowing sand following areas have been recovered:

- for forestry about 1500 ha
- for water economics about 1300 ha.

In subsequent years about 200 ha a year of sand workings is foreseen on the average for reclaiming.

8. Effect of mining work on the change of water conditions

As a result of mining work a change of hydrogeological conditions is taking place manifesting itself by direct and indirect drainage, lowering or rising of underground water surface, change of hydraulic gradients in aquiferous layers, change of declines in surface water courses.

In consequence of mining work being carried on, the mines pump out great quantities of water thus exhausting static reserves of underground water. This water is many a time drained off outside the basin area. The whole complex of overburden rocks together with the surface provokes when lowering a change of the existing water conditions not only within the subsidence trough but also outside its range.

When considering the area of the Upper Silesian Coal Basin two principal types of geological structure can be distinguished.

In the geological structure of the first type waterproof formations are missing in overburden of Carboniferous which could isolate surface and underground waters from Carboniferous strata drained directly by mining excavations.

In the geological structure of the second type there is in overburden of Carboniferous one or more impermeable layers isolating surface and shallow underground waters from aquiferous horizons in Carboniferous measures.

<u>In the first hydrogeological system</u> we have to do with the phenomenon of direct drainage which is characterized by considerable expansion. Lowering of the primary water surface can be here seen, drying of farm wells, reduction of underground intake yield, drying of farming and forest lands, water infiltration from surface courses and reservoirs. In majority of cases, however, a complete dewatering of strata does not take place as simultaneously with drainage goes on their supply through infiltration of precipitations or water courses and surface reservoirs. Also heterogeneity of geological structure - occurrence of lenses of limited permeability - - contributes to the reduction of negative drainage effects.

Dewatering of lands owing to drainage effect takes place on large areas of eastern and northern part of the Upper Silesian Coal Basin in the region of Jaworzno, Siersza, Chrzanów, Mysłowice, Bytom, Olkusz, Katowice, Murcki and Mikołów.

<u>In the second hydrogeological system</u> the occurrence of permanent isolating strata decidedly prevents the drainage process of aquiferous horizons occurring in overburden of Carboniferous measures. In this case there is a phenomenon of indirect drainage consisting in slow trickling of water from higher aquiferous horizons to Carboniferous measures being drained off directly by mining excavations. On areas of surface subsidence caused by mining work the surface of underground water is rising. In the case of formation of troughs without outflow the subsidence will ocasion an outflow of underground water and in consequence underflooding of land and formation of fens. These phenomena occur in western and southern part of the Upper Silesian Coal Basin and particularly in the region of mines Brzeszcze and Silesia (Soła and Białka rivers), in the region of mines Makoszowy, Sośnica, Szczygłowice, Knurów, Gli-

wice (basin of Kłodnica river) and in the region of the Rybnik Coal Basin. Further mining will bring about the increase of existing troughs without outflow and formation of further ones in the region of mines Chwałowice, Marcel, Jankowice and in the region of mines Jastrzębie, Moszczenica, Manifest Lipcowy, Świerklany. This problem becomes presently extremely important with regard to the dimensions of the phenomenon. The value of land subsidence owing to mining work will reach up to 10 m and in places more and the area of underfloodings and fens - if no hydrotechnical measures were undertaken - cancover a considerable part of the mining region.

The lowerings of land surface entail at the same time changes of inclines of surface water courses. The decrease of incline causes also the reduction of speed, flow and increase of thickness of water layer in the course, while the increase of incline - the growth of underground erosion and drainage of aquiferous layer.

To counteract these negative effects regulation of courses is accomplished. These measures are most often carried eout together with drainage off of adjoining lands. The costs of these operations are very high, so for instance the regulation of Kłodnica river and drainage of lands adjoining to it at the length of about 15 km is told to amount more than 1 milliard złotys.

9. Surface protection against mining damages

Occurrence of mining damages is connected inseparably with mining work and manifests itself as surface deformations, damages to objects and equipment and excessive dryings or floodings of land.

Counteracting the afore-said effects of mining activity towards their maximum limitation is attained by using primarily structural prophylaxis consisting in adaptation of existing and designed objects and equipment on the surface to receive the defined mining effects. Parallelly or in mutual connection mining prophylaxis is used consisting i.a. in filling excavations with sand and barren rock and in appropriate choice of mining fronts (so called co-ordinated mining).

Every year the mining department expends considerable sums for prophylactic protection of objects and equipment and for removal of damages caused by mining work.

On the basis of the analysis of sums spent on removal of mining damages considerable increase of outlays has been ascertained on:

- removal of damages in objects and railway routes,
- regulation of rivers and water courses,
- renovation of roads and streets,
- substitute building engineering.

This trend towards increase of outlays for removal of mining damages will be kept up in subsequent years. Total expenditure and overheads per 1 ton of output in the period till 2000 are foreseen in following amounts (according prices from 1975):

1980: 3200 mln zł and 16.0 zł/t of overheads

1990: 5200 mln zł and 20.0 zł/t of overheads

2000: 7500 mln zł and 25.0 zł/t of overheads.

Particularly high increase of outlays for mining damages will fall to:

- regulation of rivers and water courses and draining off fens about 20 % of total outlays for mining damages removal,
- substitute building engineering about 40 % of total outlays for damages removal.

The considerable increase of outlays for substitute housing building results from conducting mining work under large urban agglomerations (about 30 % of coal resources occur in safety pillars). The existing development of town of the Upper Silesian Coal Basin is not adapted for receiving mining effects. Considerable wear of buildings (their age of more than 50 years) and the low standard of equipment do not justify technical and economic usefulness of performing in such objects protections (building prophylaxis) or repairs of damaged buildings.

10. Recapitulation

It results from the presented survey of problems of environmental protection on lands connected with coal extraction, particularly on the area of the Upper Silesian Coal Basin (more than 98 % of coal production is obtained from this basin) where on a relatively small area apart from the coal mining industry are located the heavy, chemical, machine-building industries and where develop towns with compact settlement and dense population that the solution of a number of problems connected with environmental protection of man against effects of coal mining activities were a true and large success.

As consequence of mining work conducted under towns and industrial plants considerable resources of coal were recovered which enabled the life time of mines with exhausted resources to be prolonged without engaging considerable investment outlays which would be necessary for construction of new mines. The achievements in the range of environmental protection are result of the common activity of the science and practice of looking into these problems by the mining department and also are effect of positive attitude towards these plans of municipal and provincial offices.

The development and study of problems of environmental protection will allow further mining of coal in the region of Upper and

Lower Silesia and even improvement of ecological conditions of the region.

To ensure execution of activities in the way of environmental protection the mining department develops the Establishment for Reclamation and Hydrotechnics at the Enterprise of Stowing Materials of the Coal Mining Industry and creates a reclaiming department at the mine Borynia which afterwards will be transformed into self-dependent Enterprise for Land Reclamation and Environmental Protection for the whole Rybnik Coal Basin.

The Polish science in the close connection with mining practice persists for many years to endeavour at finding optimum solutions enabling maximum recovery of coal resources from safety pillars with simultaneous assurance of correct development and protection of environment.

The scientific and research work is conducted by many high schools and scientific institutes and first of all by the Polish Academy of Sciences, Establishment of Mining Mechanics in Kraków, Academy of Mining and Metallurgy, Silesian Polytechnic Institute and Central Mining Institute.

An important inspiring role in this range is accomplished by the permanent interdepartamental Committee of Surface Protection acting at the Central Inspectorate of Mines.

Considering the fact of continuing further intense coal mining and also that this mining work will be conducted in more and more complex and difficult conditions of coal deposition it is to be stated that the mining science and practice will be confronted with a number of new and essential problems calling for urgent solution.

In the last several years a particular importance has been given to the substitute building aiming not only at loss prevention of housing substance due to mining damages but to the essential contribution to the increase of number of dwellings and the improvement of building standard on mining lands.

In all investment proceedings of mining lands an extremely important role in the range of correct utilization of mining lands falls to town and country planning; for in its activity it should take into account on a broad basis the interests of all surface users complying, however, with the principle of rational and maximum extraction of mineral and of environmental protection, well, of the preference of mining interests in the region of occurrence of mineral deposits assuming permanent improvement of principles of mining lands protection. It requires improvement of methods of co-ordination of town and country planning with mining design and a close co-operation and collaboration of mining plants with surface users at every stage of laying out utilization plans. To this end the principles of making up forecasts of mining effects for long-range planning purposes will be improved as well as methods of qualifying lands for town and country planning from the viewpoint of environmental protection.

Construction of mines in the new Lublin Coal Basin with different from Upper Silesian Basin geological and hydrogeological conditions requires undertaking for this region investigations on a broad basis in the way of surface and environmental protection. Among many problems of environmental protection in the Lublin Coal Basin one of more essential is the definition of principles of modification of natural environment resulting from changes of surface morphology and of water conditions occasioned by the designed mining work. The investigations on this field will be conducted in full range in order to establish the course of changes caused by mining work since the initial moment of influence of mining on the environment.

In order to counteract the effects of mining activity and prevent the degradation of natural environment research work will be continued on full utilization of mining wastes and on liquidation or utilization of heaps.

Intensified will be study on utilization of lands following stowing sand mining and of post-industrial lands as well as on efficacity of forest and water reclamation of lands, so important for mining regions with dense population.

For development of the mining industry in the Upper Silesian Coal Basin and for protection of water of the Oder and Vistula rivers extremely important becomes the solution of the problem of mine water desalination. Studies are developed on utilization method of mine water desalination and research work aiming at development of economic methods of desalination of weakly mineralised mine water.

Common action of the coal mining industry with the surface users and the units of research background will go to make a guarantee of correct assurance of environmental protection and modification on lands covered by mining of coal deposits.

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ENVIRONMENTAL ASSESSMENTS OF ALTERNATIVE ENERGY STRATEGIES IN THE UNITED STATES

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November 1979

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This work was sponsored by the Regional Assessments Division, directed by Dr. Joan Hock, in the Office of Technology Impacts, Assisstant Secretary for the Environment, U.S. Department of Energy.

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INTRODUCTION

Energy planning in the U.S. has changed radically over the past decade. Two of the major influences contributing to this change were the 1973 oil embargo and subsequent disruption of oil flows into the U.S., and the increased public environmental consciousness that occurred in the late sixties. These two influences have resulted in an increased level of activity in the evaluation of both conventional and non-conventional energy technologies, especially for their environmental, social, and economic acceptability. The increased environmental awareness of the public and, consequently, of elected officials has resulted in the promulgation of many environmental regulations. In addition, the stress placed on the American economy due to oil shortfalls has resulted in the increased interest by the U.S. Department of Energy (DOE) to develop new sources of energy resources and/or improved efficiencies of conventional technologies. Because of the environmental regulatory constraints imposed on new technology development, long-term energy planning by DOE requires a thorough analysis of these energy technologies with respect to the environmental, health, social and economic implications. Unlike the site-specific environmental impact statements that are required under NEPA[1] or similar state-promulgated legislation, the emphasis of the DOE assessment is regional. The focus is usually on ten multi-state regions designated by the Environmental Protection Agency (EPA)(Figure 1). The regional approach is based on the premise that significant regional differences exist regarding the environmental, institutional, social, and public acceptability of different energy technologies. These assessments are not site specific (i.e., projected energy facility siting is not specified or it is specified at only a county level) because the temporal range of a scenario may extend from 1975 to 2000, and, therefore, go well beyond specific utility or industrial development planning.

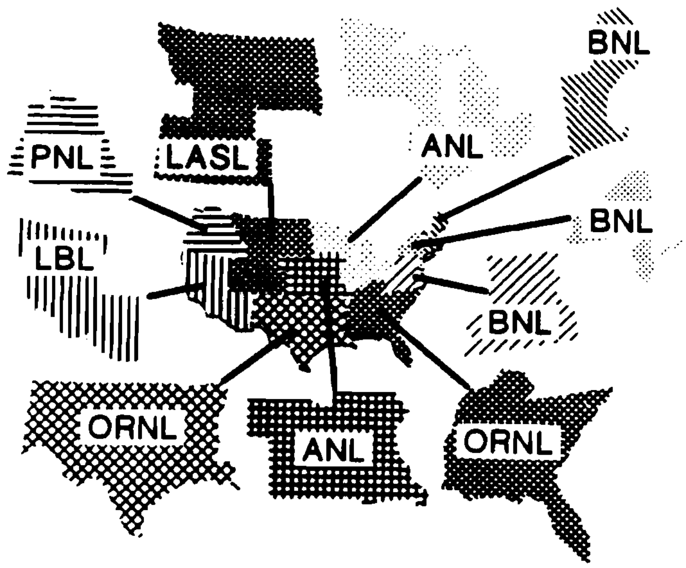

Figure 1. Federal EPA regions and designated National Laboratory responsibilities.

Increased coal production and use in the U.S. is expected under most scenarios. Constraints to coal use, however, are severe because of the different kinds of environmental regulations that have been imposed on industries and utilities. This paper will describe some of these regulations and their effects on coal use in the U.S. by using the results of a recent assessment of the Project Independence Evaluation System (PIES) Mid-Mid Range Scenario. The impacts in Federal Region V are analyzed in this paper because of the region's high level of coal production and consumption. The complete analysis of Region V has been published by Ballou et al. (1979a).

PROGRAM DESCRIPTION

The Regional Issues Identification and Assessment (RIIA) program is an evaluation of the regional impacts of future energy development. These studies are conducted for the Department of Energy. The impacts described in this paper for 1990 are based on a national energy projection (scenario) that assumes medium energy demand and fuel supply through 1990, but does not incorporate the policies of the 1978 National Energy Act. The scenario is one of six possible energy futures produced by the Energy Information Administration of the Department of Energy for the Department's 1977 Annual Report to Congress.

The RIIA study plan uses the predicted fuel mixes derived from the PIES scenario as a starting point for its analysis. County level patterns for utility, industry and mining activities for 1990 were then developed from the federal region totals. Energy sources addressed were coal, nuclear, oil, oil shale, gas, geothermal, hydroelectric, and solar.

Six of the national laboratories, Argonne (ANL), Brookhaven (BNL), Lawrence Berkeley (LBL), Los Alamos (LASL), Oak Ridge (ORNL), and Pacific Northwest (PNL), undertook major responsibilities to analyze the impact of these county-level patterns of utility, industry, and mining activities on the air, water, and land resources of the country and on the socioeconomic and health and safety aspects of the nation's welfare. Each laboratory had specific regional responsibilities for conducting the environmental assessment (Figure 1).

Projected total energy production and consumption by 1990 for the U.S. was about 80 and 109 Quads respectively. In Region V, a 36% increase in coal-fired electrical capacity was projected for 1990 (Table 1).

Table 1. Projected Electrical Generating Capacity, Coal Extraction, and Industrial Fuel Use - Region V

Energy Source	1975	1985	1990
Electrical Generating Capacity (10^3 MW)			
Coal	63.9	79.5	86.9
Oil	15.5	22.0	26.2
Gas	2.4	4.7	4.1
Nuclear	9.7	24.3	34.5
Combined Cycle	0.2	0.2	5.6
Hydro	3.1	3.1	3.2
Solar	0	0.1	0.6
Geothermal	0	0	0
Other	0	2.2	2.2
Total	94.8	136.1	163.3
Coal Production (10^6 tons)			
Deep Mines	476.6	629.8	669.9
Surface Mines	839.1	851.7	795.3
Total	1315.7	1481.5	1465.2
Industrial Fuel Use (10^{12} Btu)			
Coal	16.3	1056.7	1109.4
Oil	296.3	459.3	531.8
Gas	0.4	0.3	0.3
Total	313.0	1516.3	1641.5

Oak Ridge National Laboratory assigned the projected increases to particular counties according to economic (accessibility to rail and barge transport, nearest source of coal, etc.) and site (population density, geological conditions, water availability, etc.) considerations. Increased sited capacity for Region V showed major electric increases in counties in the Chicago area, eastern Michigan, southern Indiana, and southern Ohio. The following analysis highlights major environmental impediments to such an increase.

EFFECTS OF ENVIRONMENTAL REGULATIONS ON PROJECTED COAL USE IN REGION V

Region V has over 63,000 MW of installed coal burning utility capacity. This represents the greatest use of utility coal in the nation. Industrial coal use is also the highest in the nation. Major environmental problems associated with such coal use include air, water, solid waste, land use, crop damage, socioeconomic, and health impacts.

Long-Range Transport, Visibility

Although states have traditionally established and enforced regulations restricting the placement and character of air pollutant sources, the federal government has expanded its role in the establishment of national programs that have an impact on development of new major sources across the country. Most of the national issues that have local and regional impacts have been dealt with in the Clean Air Act Amendments of 1977. Such issues include the establishment and promulgation of National Ambient Air Quality Standards (NAAQS), designation of Prevention of Significant Deterioration (PSD) Class I federal areas,[2] visibility protection for clean and pristine areas, federal new source performance standards (NSPS), national emission standards for hazardous air pollutants (NESHAP) and requirements for new state implementation plans (SIPs) in nonattainment areas, i.e., areas that have not attained national air quality standards. A description of these regulations and their effects on national coal policy has been recently prepared by the Office of Technology Assessment (1979).

Total exposure of the population to existing concentrations of SO_2 and sulfates is high in Region V--average SO_2 and sulfate concentrations due to long-range transport rank third in the nation. Long-range transport of these pollutants adds to the impact of local air quality, and the contributions to ambient air quality from long-range transport increments of SO_2 and sulfate could make areas that currently have marginal air quality into nonattainment areas. The number of "marginal attainment" areas in Region V is large enough so that long-range transport would be considered in attainment planning, although it is not likely that long-range transport will have severe impact on energy development in the Midwest.

Another interregional impact of long-range transport is that on local visibility. Congress has taken steps toward assuring visibility protection in Class I areas. Although EPA regulations will not be promulgated until 1980, it is safe to assume that significant plume blights or significant decreases in visibility will not be permitted in Class I areas. Region V has two states where visibility protection regulations could influence projected coal facility siting. In northeastern Minnesota, approximately one-seventh of the proposed coal growth could be subject to visibility protection regulations. In northern Michigan, small increases in oil, coal, and combined-cycle generating capacities are projected for counties adjacent to protected areas and may be subject to visibility standards.

Local Air Quality

In Region V, Michigan, Wisconsin, and Ohio are the states most likely to experience regulatory impediments as a result of the scenario-projected energy development (Figure 2). Michigan's primary air quality problems are expected to be in the eastern portion of the state where utility coal growth is projected to occur in nonattainment areas. Wisconsin has similar problems in its southeastern and central portions. Additional emission offsets and improved control efficiencies will not significantly mitigate air quality problems in these areas. Nearly 30% of the projected utility coal growth in Ohio could be restricted because of air quality regulations, primarily NAAQS.

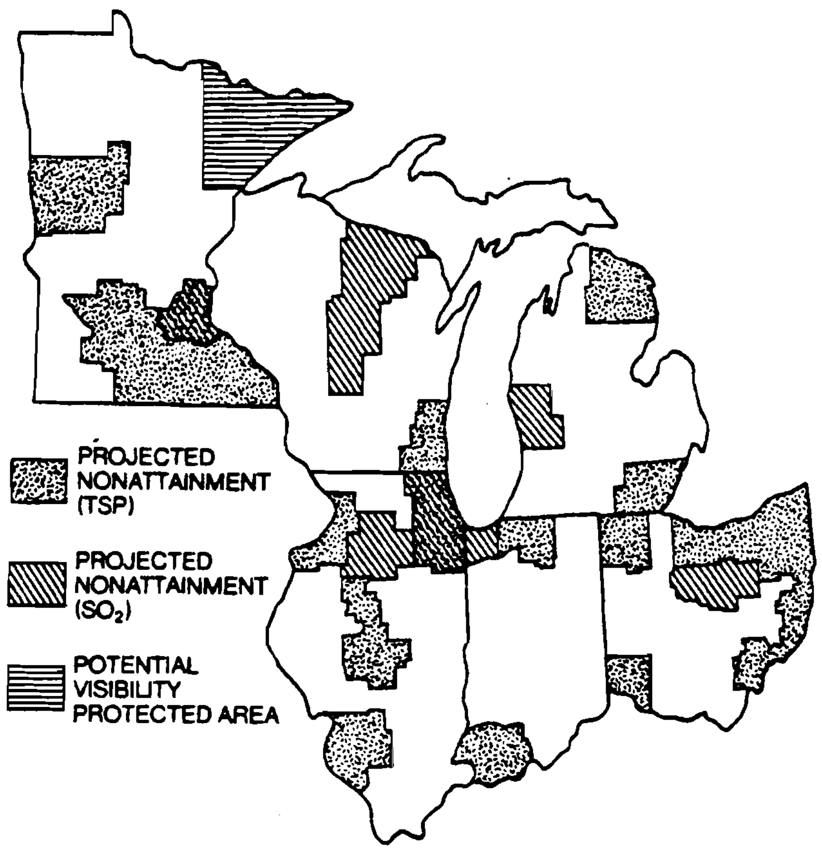

Figure 2. Region V areas with potential air quality constraints.

The projected growth of utility oil capacity in nonattainment areas appears to be greatest in the industrial states in Illinois, Indiana, and Ohio. Mitigation of impacts through fuel purchasing practices could greatly reduce the air quality impact from these facilities. Specific areas, such as the four-county nonattainment area surrounding Chicago, might require special attention.

Industrial growth projected by the scenario could be restricted by nonattainment air quality regulations in industrialized areas like Chicago, St. Louis, Detroit, and Cleveland. Specific restrictions will depend on fuel selection and available emission offsets in each locality.

Water Quality, Availability

The Clean Water Act regulates effluents from surface and deep mining, preparation plants, and combustion facilities. Among other things, the act requires monitoring of chemical effluents; the number of effluents requiring such monitoring has increased substantially over the past several years.

The utility activities analyzed for water-related impacts were coal, gas, oil, combined-cycle (assuming coal type) and nuclear. Of these categories, 8.8% of the projected incremental increase in utility activity up to 1990 was identified as having a potential water-related impact (assuming that effluent treatment beyond statutory point-source requirements is implemented and/or that the 7-day/10-year low flow is maintained). This fraction represents 2.1% of the total utility activity projected by 1990 for Region V.

Initiatives to improve water quality in the Great Lakes, involving waste load reductions and limitations on additional loads, particularly to Lake Erie and Lake Michigan, are likely to be an issue in realizing the projected increases in utility activity. Technologies with phosphorus effluents (primarily coal-fired utilities and industries) will conflict with efforts to slow eutrophication in Great Lakes bays and shorelines, and advanced waste treatment involving phosphorus loading reductions of 80-90% may be required. A United States Supreme Court ruling that limits water withdrawals from Lake Michigan in Illinois will constrain energy development on the Illinois shoreline. Projected increases would result in further allocations of withdrawals and may create regional water-use conflicts.

Inland and Coastal Water Resources

The water quality of the Great Lakes is a matter of international treaty between the United States and Canada, and adverse impacts from energy-related activity would be addressed by the two countries. Therefore, effluent discharges from energy activity to the lakes are expected to be closely monitored and movement of energy activity away from the Lakes may be necessary. The water levels of Lake Michigan are a subject of regional concern. Energy activity withdrawals sufficient to affect lake levels may create interstate conflicts in Wisconsin, Michigan, Illinois, and Indiana.

Solid Waste

The quantity of residuals generated from industrial coal use is the highest in the nation (3.7 million tons in 1975). Industrial coal use is projected to increase 38% by 1990; however, land requirements for solid waste disposal are expected to grow by nearly 400% because the application of flue gas desulfurization (FGD) systems will increase the amount of solid waste generation.

Industrial disposal requires a large number of small sites. Some industries have their own disposal sites, and others use municipal facilities. In crowded urban and industrialized areas, finding available land can be a problem; however, the institutional constraints associated with siting a new disposal facility can be an even greater problem. In most areas, technically feasible and environmentally acceptable sites can be found, but local opposition may block the construction of new landfills in those areas.

The Resource Conservation and Recovery Act (RCRA) of 1976 seeks to control open dumping. All types of wastes are covered including hazardous and non-hazardous substances. The New Source Performance Standards will create substantially more wastes in the form of FGD sludge (Figure 3).

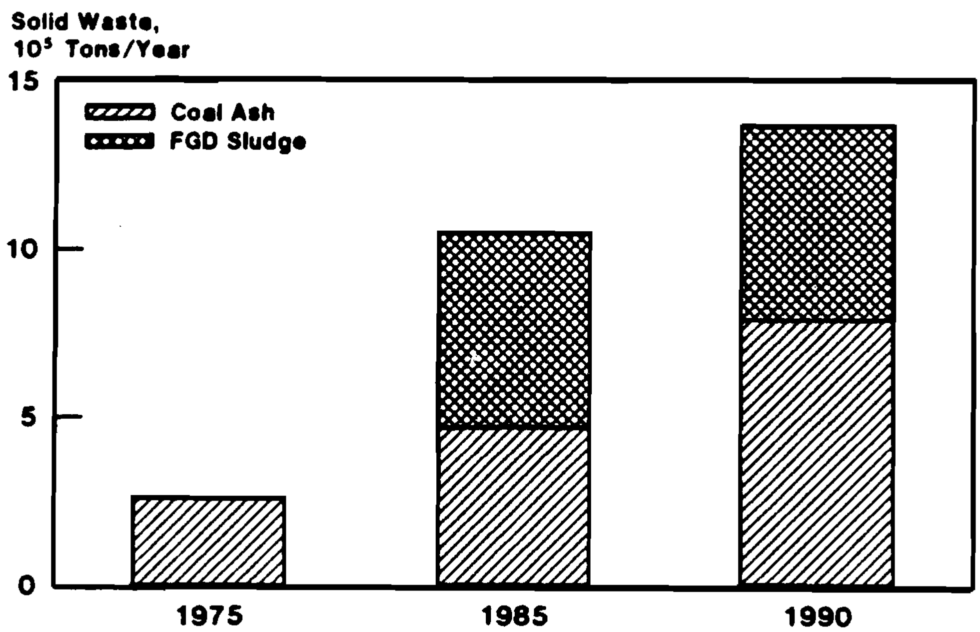

Figure 3. Projected increases in solid waste production for the years 1985 and 1990.

There are uncertainties about the RCRA program and the ability of both state and federal governments to implement it. The Environmental Protection Agency's (EPA) solid waste program has been small, with no regulatory responsibilities, and most states have limited solid waste management programs. When the 1970 Clean Air Act and the 1972 Water Pollution Control Act were enacted, there already existed extensive pollution control programs operated on a state and regional basis by both EPA and well-staffed state agencies. The implementation of this ambitious new regulatory program will be an extremely important issue in this region.

Ecology/Land Use

The large acreages disturbed by surface mining present the greatest possibility for adverse ecological and land use impacts in the region. Mining in the region is projected to occur in central and southern Illinois, southwestern Indiana, and eastern Ohio, areas where the present land use is a mix of forested tracts and row crop agriculture (Figure 4). The Surface Mining Control and Reclamation Act of 1977 was promulgated to change coal mining practices that generate severe social and environmental costs and to prohibit mining in areas that cannot be reclaimed. The act requires that mined lands be returned to their original productivity and land use. Reclamation costs in Region V will be high since mining in the region is most likely to disturb row crops or forested land. Mining in forested areas will have additional ecological impacts since restoration of the original ecosystem, if it occurs at all, would have to occur naturally over a long period of time (Council of Environmental Quality, 1979).

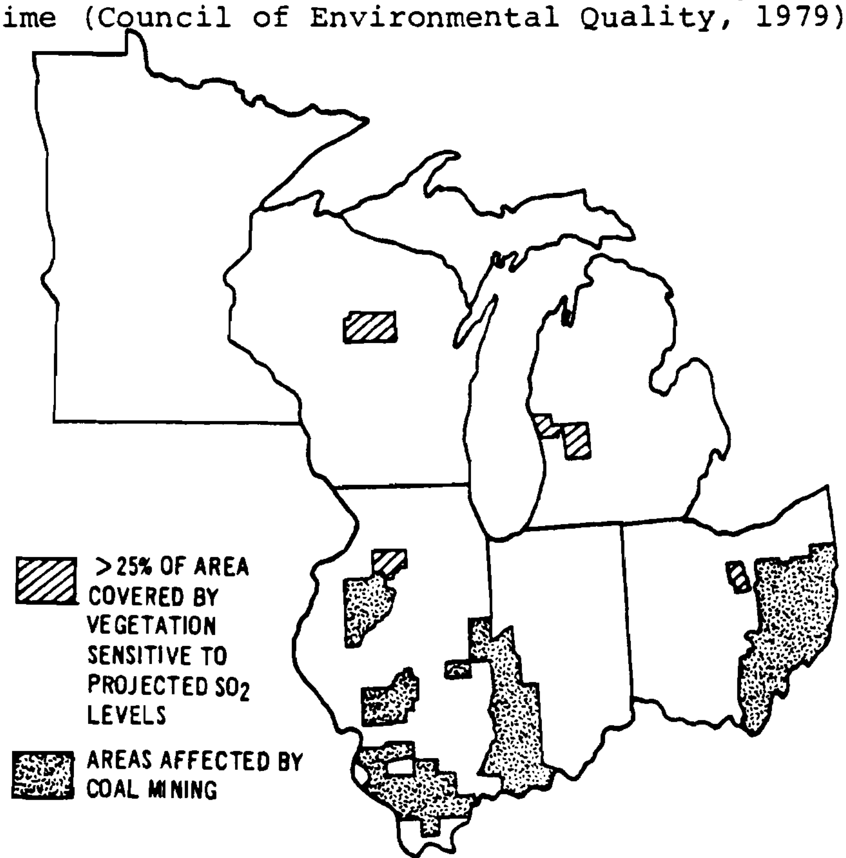

Figure 4. Coal mining areas and potential SO_2-induced vegetation damage.

An analysis of the acute effects of increased sulfur dioxide (SO_2) on crops and natural vegetation was conducted at ANL. The analytical procedure identified SO_2 sensitive vegetation and their geographic distribution, and established reported damage levels for 46 crops (Ballou et al., 1979b). The analysis indicated that levels of SO_2 are projected to decrease below damage thresholds throughout the region in 1985, but in some urban-industrialized areas they are projected to increase again in 1990, primarily because of industrial coal use. Levels would be high enough in these areas to cause damage to regionally important crops such as soybeans, wheat, and fruit trees (Figure 4).

Socioeconomic

A great amount of attention has been given to the community impacts resulting from rapid development in sparsely populated regions of the U.S. Changes caused by the rapid in-migration of construction workers with different social values has caused disruption in community patterns of living. These communities, commonly referred to as "boom towns" have experienced increased pressures on community facilities, such as schools, shopping areas, housing, etc. To evaluate the potential effects of projected energy development in areas throughout the U.S., a model (SEAM) has been developed and used in the regional assessments (Stenejhem, 1978). The approach classifies all counties in the U.S. into 4 classes depending upon the county's ability to adequately assimilate increased in-migration. The model evaluates at the county-level all projected energy activities and identifies areas where socioeconomic disruptions may occur.

For the PIES evaluation, the scenario indicates that the majority of new sited facilities are to be located in low and extra-low assimilative capacity counties. Depending on the proposed timing of the developments, size of the facilities, and the types of technologies to be sited, adverse socioeconomic impacts (resulting from a population increase greater than 10% during only one year) will occur in many of these counties (Figure 5). There are other sited energy developments throughout the region that will incur adverse impacts, but the negative effects encountered will be overshadowed by increases in employment, growth in local income and tax base, and other beneficial socioeconomic effects. These counties possess a moderate or high assimilative capacity and because of their economic and demographic characteristics, the projected population growth due to the employment and capital requirements of the sited development(s) did not exceed 10% of the baseline population.

Severe socioeconomic impacts are projected in counties absorbing 25% of the region's proposed coal-capacity increases, 23% of the nuclear increases, 7% of the oil increases, 21% of the combined-cycle increases, and 20% of the new mine workers. These capacity increases represent from 1% to 8% of total regional generating capacity. This conservatively-estimated range indicates the percentage of the megawatt capacity increases projected for

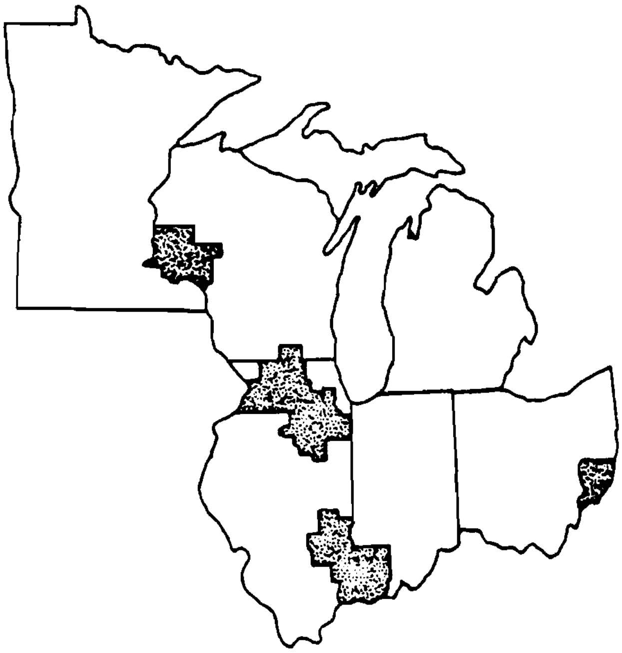

Figure 5. Areas in Region V potentially subject to adverse socio-economic impacts.

the region that would cause socioeconomic and societal impacts if the present siting distribution is realized. There are seven counties in Region V that could experience rapid population increases, extensive economic growth, sociocultural impacts, and institutional problems. These counties are expected to incur more of the negative adverse consequences of resource development since their existing workforce and infrastructure are insufficient to satisfy the manpower demands during the construction phase(s) and, therefore, require the in-migration of a transient labor force. In Indiana, Illinois, and Wisconsin the negative effects of development are primarily attributable to coal and nuclear facility construction. The states of Michigan and Minnesota are not projected to incur severe negative impacts; Ohio has the potential of a larger than marginal impact if demands for the state's high sulfur coal are increased beyond the scenario specification.

The effects of the energy developments are projected to be pervasive within the seven susceptible counties. It is expected that the communities in these areas will experience shortfalls in facilities and services needed to house and provide for the in-migrants and that the frustrations caused by an overburdened social infrastructure will tend to increase turnover at the workplace with increasingly frequent in- and out-migration. Such experiences are not uncommon in these situations and often lead to social dissolution and deterioration (Baldwin and Poetsch, 1977; Stenejhem et al., 1977; Metzger et al., 1978). Such impacts and their effects on energy development cannot be aggregated to a regional level and, therefore, must remain a component of site-specific analysis.

The affected counties are expected to experience a population increase of 30,000 new permanent employees and their dependents by 1990, or 0.07% of the current regional population (1976). This estimate of the extent of in-migration is conservative since it is based on a projected population growth profile of the region that did not incorporate a detailed skill classification category. The exclusion of this variable may understate the true external workforce requirements for the affected sub-regions, and consequently, the region as a whole.

Health and Safety

Environmental regulations, such as the Clean Air Act, the Federal Mine Safety and Health Act, the Resource Conservation Act, the Toxic Substances Control Act, and others, were promulgated primarily because of public or occupational health concerns. As part of the regional analysis, public and occupational health hazards are addressed for areas within the region where these, and other acts, are projected to be violated. The analysis attempts to answer the question, "What are the public health risks when violations occur"?

Extraction, specifically coal extraction, presents the highest risk of occupational health impacts. Occupational impacts of deep mining--injuries, disease, and deaths--are historically more severe than those from strip mining because of differences in dust exposure and accident risk (U.S. Department of Labor, 1975). Illinois, Indiana, and Ohio contain the major coal reserves found in Region V. Death, injuries, and disease from coal extraction in Region V account for approximately three-quarters of all energy-related occupational health impacts even if all requirements of the Mine Safety and Health Act are met. Regional impacts of oil and gas extraction and refining and electricity generation are minimal, although these activities account for a significant percentage of the health and safety impacts in Michigan, Wisconsin, Minnesota; states where coal extraction does not occur.

The scenario projects an overall 11% increase in tons of coal extracted in Region V, and an increase in the proportion mined underground (from 36% in 1975 to 45% in 1990). This could cause a 20-40% increase in the number of accidental deaths and injuries due to coal mining (Figure 6) during the scenario timeframe. Cases of chronic respiratory disease (CRD) and deaths due to CRD could increase 35-40% (Figure 7).

Public health impacts that may result from increased energy demands are dependent on the amount and type of pollutants released throughout the energy cycle and on the magnitude, age structure, and location of the exposed population. Utility and industrial fossil fuel use is the primary source of energy-related effluents that affect public health in Region V.

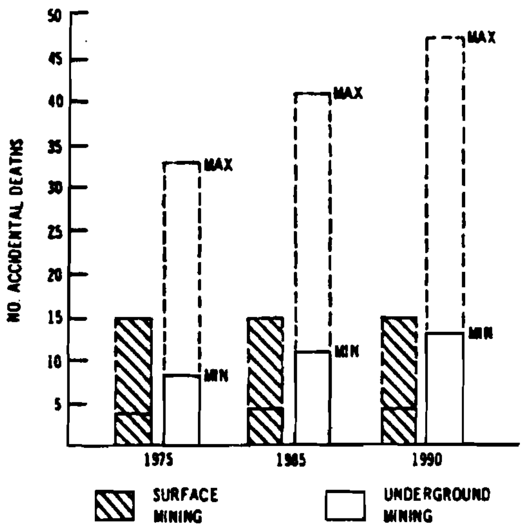

Figure 6. Range of potential accidental deaths in Region V coal mines due to implementation of the Mid-Mid Scenario.

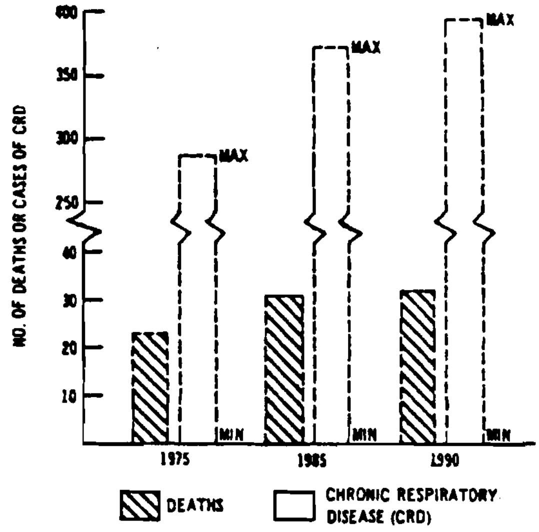

Figure 7. Range of potential deaths and cases of chronic respiratory disease (CRD) in Region V due to coal mining occupational exposure under the Mid-Mid scenario.

Most fossil fuel use occurs near densely populated areas, which increases the probability of adverse health impacts. Although combustion of fossil fuels produces many effluents, the adverse impacts of sulfur oxides (SO_2) and particulates are best documented. Inhalation of these pollutants can adversely affect exposed populations. Most severely affected would be the high risk groups such as asthmatics and yound children, cardio-vascular patients and the elderly (Calabrise, 1978). Currently, fifty to sixty percent of all deaths in Region V are attributable to cardiovascular and respiratory diseases, both of which are aggravated by emissicns from fossil fuel use (Public Health Service, 1977).

Public health impacts of sulfates released from industrial and utility fuel combustion in Region V are projected to decrease despite an increase in electricity generation of 40% and an increase in industrial fuel use of 240% by 1990. The decrease is primarilv due to sulfur emission controls expected to be instituted during the assessment time frame as dictated by the Clean Air Act. Public health impacts, measured in terms of individual risk and potential number of deaths, will drop by 48% and 35% respectively. The interregional, easterly dispersion pattern and long residence time of sulfate in the atmosphere can increase the adverse health impact in the eastern sections of the region.

SUMMARY

Environmental regulations in the U.S. play a significant role in developing long-term energy policies in the U.S. These regulations act to constrain the ease with which energy development can occur. In Region V, for instance, increased coal consumption is likely to be constrained by air and water quality regulations and by conflicts in land use as follows:

- In those areas of eastern Michigan and southeastern and central Wisconsin that have not attained National Ambient Air Quality Standards (NAAQS), there will be limited opportunities for mitigation of impacts from utility coal growth through emission offsets or improved control efficiencies. In Ohio, 30% of utility coal growth could be restricted primarily because of NAAQS nonattainment. Illinois, Indiana, and Ohio may also experience problems with oil-fired utilities in nonattainment areas, but fuel purchasing practices could reduce the air quality impacts.

- Utility and industrial siting along Lake Erie may require extensive pretreatment of effluents discharged into the Lake. Allocation of water from Lake Michigan for new facilities may become an issue in Wisconsin and Illinois where large water-for-energy demands conflict with other water uses.

- Surface mining activities in Illinois, Indiana, and Ohio are projected to disturb approximately 200,000 acres in the period 1975-1990, causing temporary or permanent shifts in productivity and land use. Much of the land in the mining area is presently in forest and crops.

This analysis illustrates the regional-level, multidisciplinary assessments currently underway for the U.S. Department of Energy. Additional assessments will be done in the future using different scenarios reflecting a high market penetration of solar technologies, increased synfuel production and use, and other energy strategies in the U.S. These studies will contribute to an analysis of the potential energy, economic, and environmental trade-offs required by proposed energy policies. The regional analysis provides the Department of Energy and other energy policy makers with a regional viewpoint that can contribute to sensitive and responsible planning by identifying issues unique to particular states or regions that may significantly affect the costs and benefits of chosen energy policies.

NOTES

1. The National Environmental Policy Act (NEPA) requires that an Environmental Impact Statement be prepared for all actions judged "significant" that occur on federal facilities, or that involve federal funding.

2. The Prevention of Significant Deterioration (PSD) program was promulgated to protect areas where air quality was already cleaner than required by the National Air Quality Standards. The program divides "clean" air areas into 3 classes and specifies the maximum increases in ambient levels of pollutants for each class. Class I areas include national parks and wilderness areas and are subject to the lowest PSD increments. The rest of the country, except those areas already exceeding NAAQS, is designated as Class II, with larger increments allowed. Class II areas can be redesignated as Class I or Class III upon petition by the area's government. The largest increments are allowed in Class III areas, though the resultant concentrations must not exceed the national standard.

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COLLABORATIVE RESEARCH ON THE ECONOMICS OF COAL-BASED ENERGY

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Paper to the IIASA Workshop on "Coal: Issues for the Eighties" in Szczyrk, Poland, 5-9 November, 1979

COLLABORATIVE RESEARCH ON THE ECONOMICS OF COAL-BASED ENERGY

Paper to the IIASA workshop on "Coal - Issues for the Eighties" in Szczyrk, Poland, 5-9 November 1979 by Hugh Mellanby Lee (Economic Assessment Service, IEA Coal Research)

The expansion of coal as an energy source will require a worldwide change in the pattern of coal production, transport, conversion and utilization. This paper describes some of the collaborative research on coal being done under the auspices of the International Energy Agency; particular emphasis is given to some of the conclusions reached so far by the Economic Assessment Service.

The International Energy Agency (IEA) is an inter-government body. The member countries are the USA and Canada, Japan, Australia and New Zealand and most of Western Europe (Austria, Belgium, Denmark, the Federal Republic of Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Spain Sweden, Switzerland, Turkey and the United Kingdom). It was established within the framework of the OECD (Organisation for Economic Co-operation and Development) in November 1974 after the energy crisis of the previous winter. The purpose of the IEA is co-operation among its member countries to reduce excessive dependence on oil through energy conservation and development of alternative energy sources, including coal.

Among its many activities, the IEA has a Working Party on Coal Research and Development. This working Party has identified various projects where international colloborative research would be beneficial and would further the aims of the IEA. (See Figure 1.) So far 14 coal projects have been established. Each of these projects is funded by some, but not all, of the IEA member countries. One particular country is designated the "Operating Agent" but some of the staff are often supplied by some of the other countries. (See Figure 2)

Four of these coal projects are particularly interesting to this IIASA workshop. They are the Technical Information Service, the World Coal Reserves and Resources Data Bank, the Mining Technology Clearing House and the Economic Assessment Service.

The objective of the Technical Information Service (TIS) is to disseminate information related to all aspects of coal. It has created a computerised data base of abstracts on published articles on coal from technical journals, research reports and conference papers. A Coal Thesourus has been developed to index this data base and it is hoped that on-line access to it will be available soon. By the end of 1979 some 25 000 abstracts will have been incorporated. These abstracts come not only from the countries funding TIS but also from many other countries; for example, about a hundred Eastern European journals are covered.

TIS publishes a monthly periodical 'Coal Abstracts' which contains all the abstracts which have been added to the data base. The index does not contain a specific entry for Systems Analysis or Operational Research but any paper published in this field is included in 'Coal Abstracts'. It also includes the Coal Calendar giving details of all forthcoming conferences and other events relevant to the coal industry.

TIS also publishes technical reviews. These are critical literature reviews, with extensive bibliographies, of selected subjects in or related to the field of coal production and use. Seven of these reviews have been published so far including one on underground transport and another on methane prediction.

The World Coal Reserves and Resources Data Bank (WCRRDB) is establishing a computerised data bank on coal in place. It is collecting physical and chemical data (depth, seam thickness, energy content etc.) on every coalfield in the world from the literature, supplemented by direct enquiry. The information from different countries is being stored, both in its original form and in comparable terms, on a computerised data bank which has considerable flexibility. WCRRDB is also developing a lexicon of the terms used in assessing reserves and resources in different countries. Some research has also been done on the relationship between mining costs and the physical data on coal in place.

The purpose of the Mining Technology Clearing House (MTCH) is to help increase the effectiveness of the coal mining R&D (research and development) in its funding countries. It covers all activities connected with coal mining from exploration to market preparation of the product. It collects information on the mining R&D projects being carried out in each country and then collates and analyses it in order to facilitate the exchange of information between countries and to promote active liaison and collaboration. It is compiling a number of registers of R&D projects in the same field, including one on 'Planning and Management' which broadly covers all systems analysis and operational research projects.

MTCH has published over twenty papers and reports. Some of these are register critiques which analyse the number and nature of projects in a particular field; they indicate where valuable experience lies which may be of use to other countries. Some of the papers are technical investigations which have included 'Hydrotransport of Solids Underground' and 'Mining Methods to Improve Reserve Recovery'. MTCH have also organised technical meetings of researchers working in the same field.

The purpose of the Economic Assessment Service (EAS) is to provide economic studies to support the development of the international coal industry. It makes economic assessments of coal production, transport, conversion and utilisation in order to assist the funding countries in the formulation of new research projects and in evaluating the application of coal technologies to their own needs. With a professional staff of eight, it is not set up to provide its own basic data; rather its aim is

- to review reported information, and accept or adjust it in the light of developing knowledge and personal visits,

- to put the information on a consistent and relatively independent basis, particularly with regard to economic conventions, and

- to extract any message, free of conventions, pointing out where uncertainty remains.

The work programme of EAS is divided into four areas:

- Coal supply, transport and trade
- Economics of coal conversion technologies
- Environmental studies
- Relative economics of coal-based energy.

Eight reports have been published covering a variety of topics in these areas and several more are in draft. A number of interesting conclusions have been reached so far: these are described in the rest of the paper.

Nearly all the published studies on energy supply and demand agree that world coal demand will increase substantially by the end of the century. There are arguments for and against a number of different scenarios: a high energy growth scenario (based mainly on a rapid expansion of nuclear energy) gives an increase in coal demand of about 250% by the year 2000 and a low energy growth scenario (based on substantial energy conservation) gives an increase in coal demand of 65%.

A central view of coal demand is given in Figure 3. This shows that the largest increase in demand (in absolute terms) will come from the electricity generation market. However, this market will only account for 50% of the total demand and each of the other markets will be important: for example, synthetic oil and gas will only account for about 5% of the demand but this represents over 200 Mtce.

This increase in coal demand will be supplied by only a relatively small number of countries. There are eight countries which could increase their coal production by 100 Mtce or more between now and the end of the century: Australia, Canada, China, India, Poland, South Africa, the USA and the USSR. The other coal producing countries and potential coal producing countries will only be significant at the margin.

International trade in coal will also increase considerably. At present most of the coal trade is in coking coal and most of the steam coal trade is between nearby countries. This situation will be reversed by the year 2000: most of the trade will be steam coal and it will be between distant countries. In particular, Western Europe and Japan will be importing substantial quantities of steam coal because they cannot expand their own coal production sufficiently.

There is a limit to the export capability of most of the eight countries mentioned above which could expand their coal production by 100 Mtce or more. India and Poland will probably consume internally all the extra coal they produce and China and the USSR will not be able to export very much coal for the same reasons. Australia, Canada and South Africa will increase their exports enormously but there are constraints in these countries on both the expansion of production and the expansion of transport and port facilities. This leaves the USA which will become the marginal world supplier of coal, despite the fact that at present it is not exporting any steam coal (except to Canada) because its prices are too high.

There are a number of factors which will cause a real increase in coal mining costs, especially in those coalfields whose output is going to rise substantially. In order to recruit more miners it will be necessary to increase their wages more than other workers (whose wages tend to increase by 1% per year in real terms in any case). In any particular coalfield there are unlikely to be great improvements i productivity to offset this wages increase and, in some cases, environmental regulations will have a negative effect on productivity. Materials costs per tonne have also been increasing in real terms in the past decade and this is likely to continue. Finally, capital charges will increase because the extra investment will require a higher rate of return.

All these factors will lend to a significant increase in the cost of coal at the mine-mouth. However, the increase in the delivered cost of coal will not be so great because much of the increase in production will come from lower-cost coalfields and because transport costs will not rise by so much. Moreover, the rise in world oil prices is likely to be much higher than the increase in coal cost. The price of coal will not be linked to the price of oil because there will be sufficient competition between the different coal producing countries: in the USA, where there is competition between the coal producing companies, the price of coal relative to the price of oil has varied enormously over the past decade.

The increase in production will mainly come from coalfields which are a very long distance from their markets. For example, the extra coal in the USSR will come from the Siberian and other Eastern coalfields which are some thousands of kilometres from the main demand centre in the European part of the country. Similarly the extra production in Australia, Canada, South Africa and the USA will be a long way away from the home or export markets. So the transport of coal or coal-based energy will become more important than it has been in the past.

Most technologies for transporting coal use oil as the motive power. Typically fuel costs are about a third of the total costs per tonne transported; thus coal transport costs will tend to increase as world oil prices increase. However, there are some potential improvements or changes in transport technology. The unit-train concept has already reduced rail transport costs considerably and there is a very large potential to improve the labour productivity of the railways in most countries; in addition, railway electrification will reduce the dependence on oil. Coal slurry pipelines offer a viable alternative for overland transport and they could be cheaper than rail transport for long distances and high throughputs, partly because pipeline pumps can be powered by electricity; more research needs to be done on the dewatering of coal slurry to reduce its costs and environmental effects. Cable belt conveyors can also be competitive with rail transport for high throughputs and distances up to 100 km. However, neither slurry pipelines nor conveyor belts are as flexible as rail transport.

For journeys by sea, larger ships have already reduced coal transport costs considerably and this trend will continue. Self-unloading ships are the only mode of coal transport on the Great Lakes of North America; this concept could profitably be extended to the short sea distances within Europe and it could be used for much longer distances if it saved the cost of constructing an expensive new port for a new coal conversion plant. The technology of slurry ships for coal has not yet been commercialised but it could offer savings if it is used in conjunction with slurry pipelines in both the exporting and importing countries.

There are a number of systems problems associated with coal transport. The choice between flexibility and cost has already been hinted at above. The coal industry is not vertically integrated in comparison with the oil industry: coal production, coal transport and coal conversion are usually done by separate companies. This makes the systems problems more difficult to solve. A coal converting company usually wants a diversity of coal suppliers for security but this can add to the coal quality and blending problems. This is also inhibiting the development of large new mines because sales contracts with several different consumers and their associated transport contracts have to be arranged first.

When coal is to be converted into electricity, it is usually cheaper to transport the coal as coal and to site the generation plant near to the demand for electricity. However, when rail prices are expensive and no other mode of coal transport is practical, it can be cheaper to generate the electricity at the mine-mouth and to transmit it by overhead direct current lines. When coal is to be converted into gas, it is always cheaper to transport the coal and convert in near to the centre of the demand for gas. When coal is to be converted into a liquid fuels, it is always cheaper to do this at the mine-mouth and transport the liquids; however, where international trade is involved, the importing country may prefer to have the coal liquefaction plant within its borders for security and because of its value to the economy.

There is a well established technology for generating electricity from coal: the pulverised fuel boiler with a steam cycle. For delivered coal costs of 1 to 2 $/GJ, the final electricity costs are similar to those for nuclear generation and the choice between coal and nuclear is made on grounds other than cost.

Three new technologies for generating electricity from coal are under development and could be commercial by the mid 1990's. These are:

- The atmospheric fluidised bed boiler incorporating limestone addition for sulphur removal and using a steam cycle for electricity generation.

- The pressurised fluidised bed boiler incorporating dolomite addition for sulphur removal. Electricity generation is by combined cycle using both gas and steam turbines.

- Air-blown coal gasification to produce a clean fuel gas which is used to generate electricity in a combined cycle system. A number of process variants are under development.

The advantage of these new technologies is that they promise a significant saving in electricity costs when environmental regulations require sulphur removal. That is when they are compared with a conventional furnace burning pulverised fuel, using a steam cycle for electricity generation and with a wet limestone scrubber for removal of sulphur dioxide from the stack gas. All three new technologies give a similar saving of 11-16% for high sulphur (3.5%) coal and 85% sulphur removal; the actual saving depends on the coal price, discounted rate of return, the taxation policy etc. For low to moderate coal prices the atmospheric fluidised bed is the most economic; for high coal prices either of the other two new technologies appear to be more attractive. When sulphur control is not necessary, the pressurised fluidised bed is the most favourable option, but the savings are only 7-9% compared with a conventional pulverised fuel boiler.

The cost of converting coal to substitute natural gas (SNG) is 3 to 4 dollars per GigaJoule of SNG. The efficiency is about 65% and so, when the cost of the coal is added in, the total cost of SNG is 4 to 9 $/GJ. The lower end of this range corresponds broadly with the upper end of the range of costs for 'frontier' gas and LNG (liquid natural gas) from overseas gas fields. This suggests that SNG from coal is not a viable short-term option. Moreover, the costs of converting coal to low or medium energy content gases are only slightly less, so these are also not viable options.

There are three borad routes for converting coal to liquids: pyrolysis, synthesis and solvent extraction with hydrogenation. All three require some coal gasification.

Pyrolysis is the distillation of coal to separate a liquid/gas fraction from a char residue. The main disadvantage of this route is the low yield of liquids and gases.

Synthesis is the gasification of coal in oxygen to produce a carbon-monoxide and hydrogen mixture from which liquids and gases can be more or less selectively synthesized. The advantages of this route are, firstly, it is already working on a commercial scale at the SASOL plant in South Africa, secondly, it is easier to produce transport fuels and, thirdly, much of the cheaper coal is high in oxygen and water which is advantageous for this route.

Solvent extraction with hydrogenation involves dissolution of the coal in a solvent, followed by some degree of hydrogenation and subsequent separation of liquids/gases by filtration and/or distillation. The newer processes being developed for this direct route promise significant improvements over the Second World War state of the art, but none of these processes have yet worked on a sizeable scale.

All coal liquefaction processes produce more than one product. Moreover, each of the processes has a different range of products, which makes comparisons between them difficult. In general, processes with a low investment and a high efficiency produce more boiler fuel, while the high investment low efficiency processes tend to produce more products from the top end of the barrel, which are more valuable.

At present no coal liquefaction process seems to be commercial viable, except in the special circumstances of South Africa where a combination of cheap coal and a desire to be independent of foreign oil supplies has led to the development of the Fischer-Tropsch process on a commercial scale by SASOL. As oil prices increase coal liquefaction will become viable provided that coal prices and plant investment costs do not increase at the same rate.

Figure 1

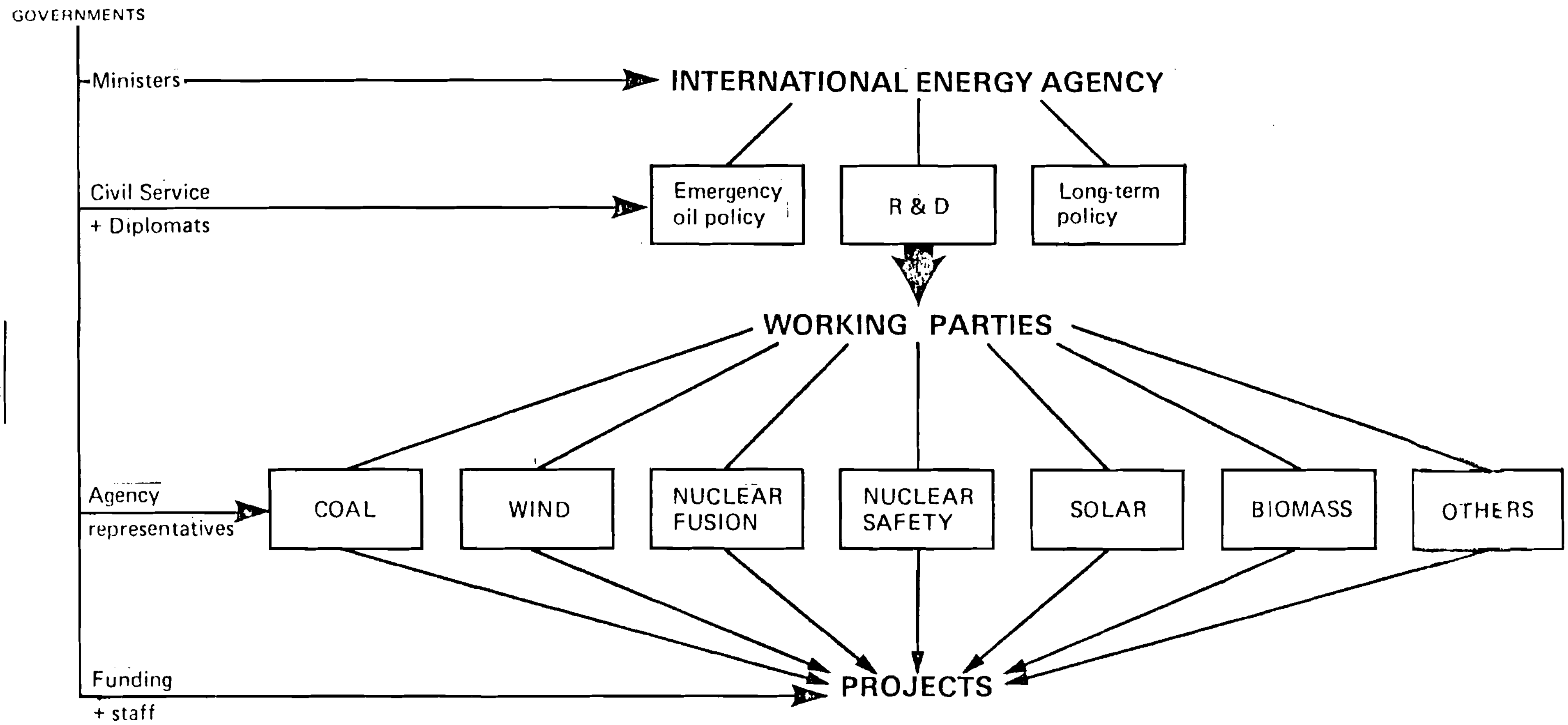

GOVERNMENTS
Ministers
Civil Service
+ Diplomats
Agency
representatives
Funding
+ staff
INTERNATIONAL ENERGY AGENCY
Emergency oil policy
R & D
Long-term policy
WORKING PARTIES
COAL
WIND
NUCLEAR FUSION
NUCLEAR SAFETY
SOLAR
BIOMASS
OTHERS
PROJECTS

Figure 2

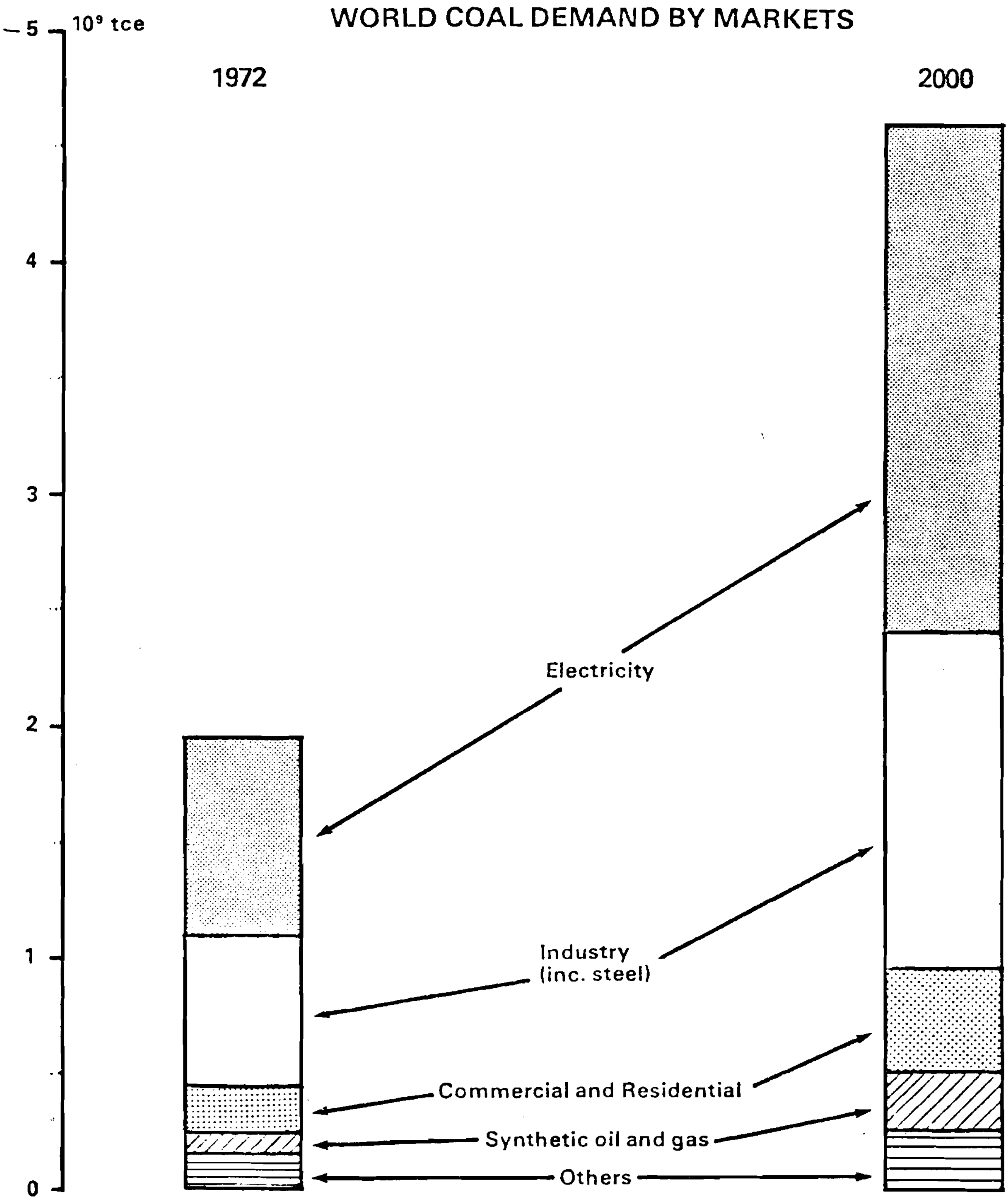
COUNTRY PARTICIPATION IN IEA COAL TECHNOLOGY PROJECTS

	Austria	Belgium	Canada	Denmark	Germany	Ireland	Italy	Japan	Netherlands	New Zealand	Norway	Spain	Sweden	Switzerland	UK	USA
Technical Information Service	X	X	X	X	X	X	X	X	X	X		X	X		(X)	X
Economic Assessment Service			X	X	X	X	X		X			X	X		(X)	X
World Coal Reserves and Resources Data-Bank		X	X		X		X			X					(X)	X
Mining Technology Clearing-House		X	X		X							X			(X)	X
Pressurised Fluidised-Bed Combustion					X										(X)	X
Atmospheric Fluidised-Bed Combustion				X							X			X		
Low-BTU Coal Gasification					(X)											X
Coal Pyrolysis					(X)								X		X	
Coal Liquefaction					X			X								X
Treatment of Coal Gasifier Effluent Liquors									X						X	X
Coal Dry Feeding					(X)										X	
Low NO_x Coal Burner			X	X					X				X			(X)
Coal-Oil Mixtures - Utility Boilers			X													X
Coal-Oil Mixtures - Industrial/District Heating Boilers				X	X				X				(X)			

X Participant

(X) Operating Agent

Figure 3


WORLD COAL DEMAND BY MARKETS
10⁹ tce
5
4
3
2
1
0
1972
2000
Electricity
Industry
(inc. steel)
Commercial and Residential
Synthetic oil and gas
Others

MODELLING STRIP MINING IMPACTS ON GROUNDWATER RESOURCES FOR USE IN COAL DEVELOPMENT PLANNING

K.-H. Zwirnmann

ABSTRACT

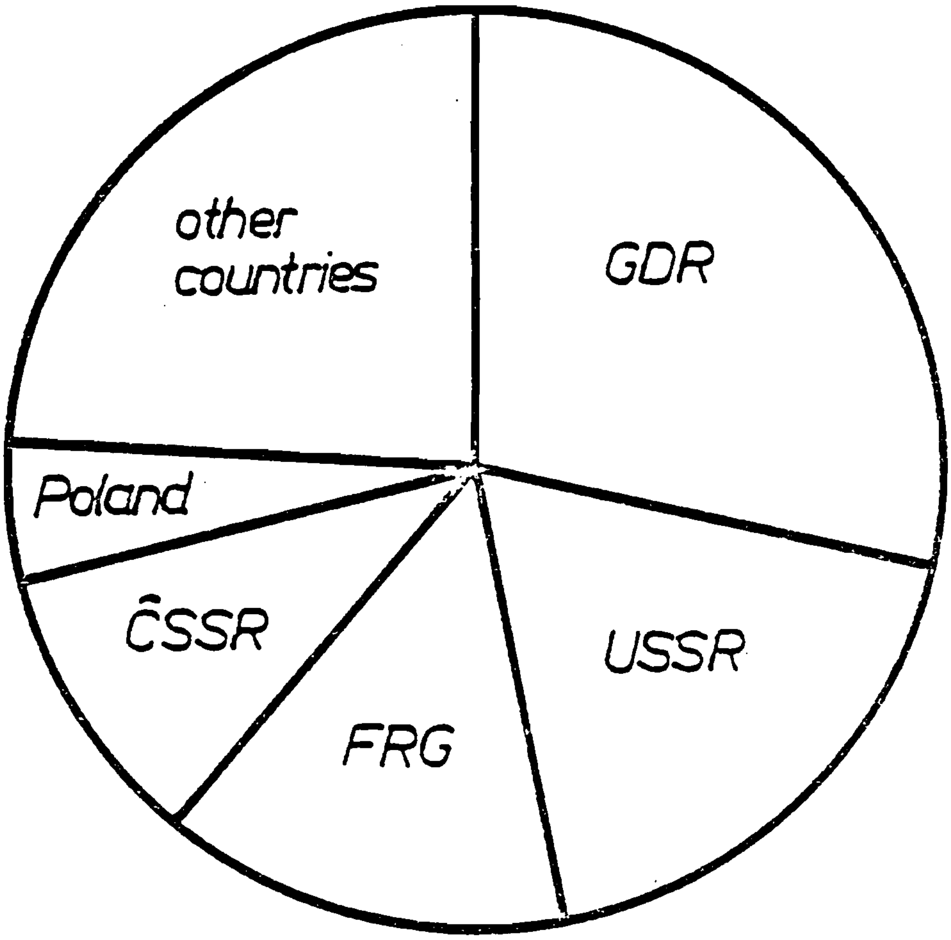
The impacts of strip mining on groundwater resources can be demonstrated with examples from the East Lusatia area in the GDR. Analysis and prediction of such impacts are done by using a hierarchical system of numerical groundwater flow models. This system is subdivided into three categories: regional, strip mine, and operational modelling. Each of them uses different horizons of time and space as well as respective modelling techniques such as one- or two-dimensional groundwater flow simulation. Results obtained from regional modelling are shown and their influence on the feedback of coal development planning and environmental decision making is discussed.

OBJECTIVE AND SCOPE OF THE PAPER

Being faced by the changing dynamics of energy consumption, production, and economics, many countries are planning their energy policy, at least for the near future, around their large coal reserves. Lignite especially plays an important role for several countries, because of a relatively favorable production technique - strip mining.

Figure 1 depicts the lignite mining of the world in 1975 and shows the GDR as the greatest lignite producer. With an annual output of about 250 million tons, the GDR produces about 30% of the total world output of lignite. Because of this high production rate, and because of the author's knowledge of strip mining in the GDR, a strip mining affected area from there is chosen for demonstrating groundwater modelling as a useful tool in coal development planning. However, the author believes that the presented problems and results can be useful in general terms for other countries.

In general, the strip mining impacts on groundwater resources are twofold, affecting both the flow and the quality of usable groundwater in a given region. This paper, however, deals only with flow modelling. Since the paper is intended to serve as a first contribution to IIASA's work on assessment of mining impacts on the environment done in the proposed task "Coal - Issues for the Eighties", no detailed description of groundwater modelling is expounded. Rather, emphasis is placed on a general modelling approach and its decision making context in coal development planning.



Source: Ufer and Gerisch, 1979

Figure 1: World lignite mining in 1975.

STRIP MINING IMPACTS ON GROUNDWATER RESOURCES

The GDR's energy supply is based on a primary energy structure which is rather unusual for developed countries. As Figure 2 shows, two thirds of the total output of primary energy is provided by lignite extracted exclusively by strip mining. In this connection, it is important to mention the very high water content of lignite, which amounts to 50%. Moreover, as the seams are now at greater depth than previously, an ever increasing amount of water must be pumped out and drained off. This development can be seen in Figure 3. The general importance of the lowering of groundwater for ensuring strip mining is evident when one considers that the cost for doing this amounts to about 20% of the total cost of coal production at present.

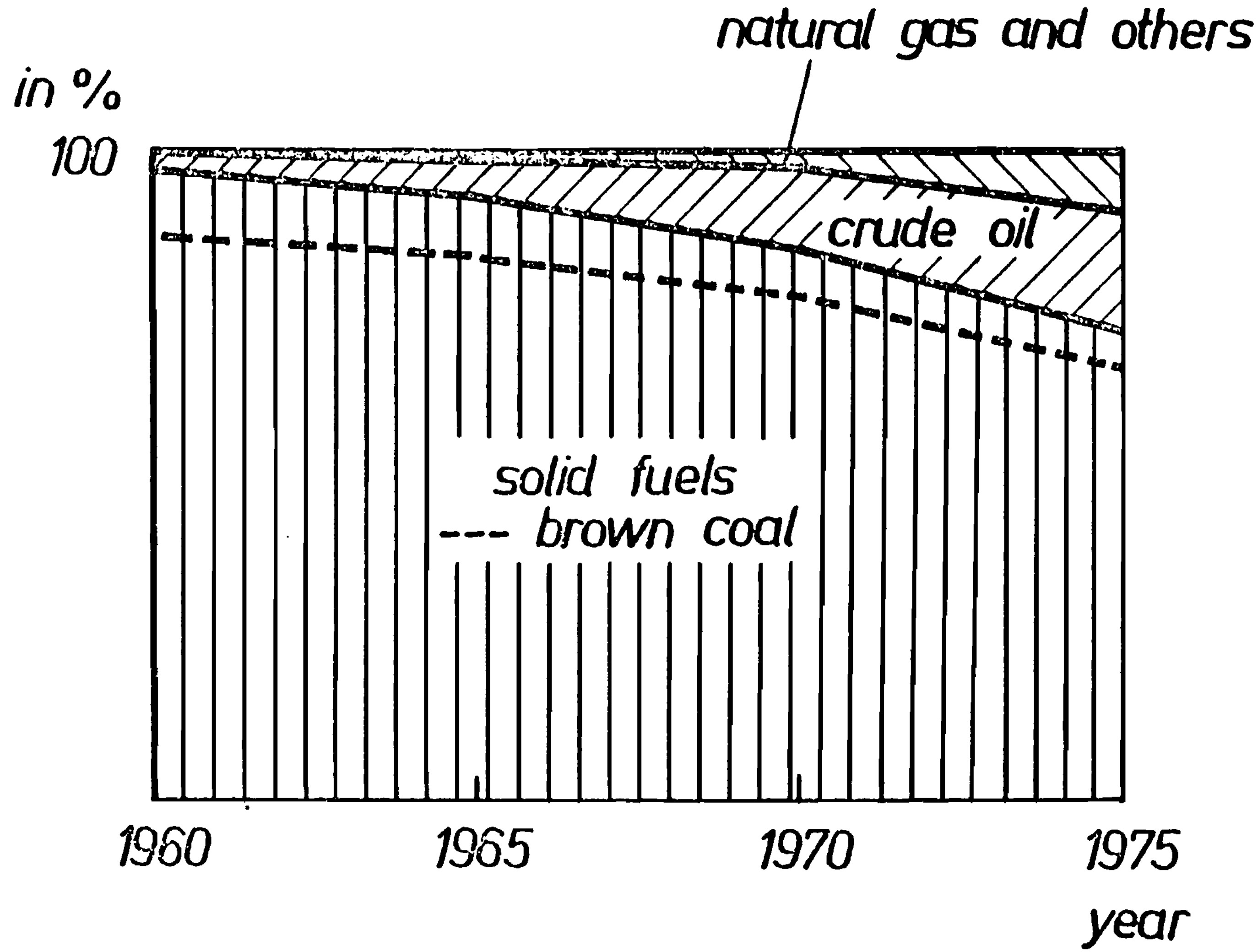
Strip mining leads to specific environmental problems which will be explained for the East Lusatia area situated in the southeast of the GDR. Figure 4 depicts this region, which is characterized especially by four large mines, rest pits, waterworks, irrigated agricultural areas, and streams. This region (about 1000 km^2) where lignite mining dates back to the beginning of the century, is affected by the lowering of the groundwater table up to 20 to 30 meters. In some mines, the amount of water to be pumped exceeds the output of coal ten to one hundred times. Because of this and mines of 40 to 60 meters in depth, large regional cone-shaped depressions were formed.

In areas where the problem of depressions has been in existence for two generations, the artificially changed groundwater table was often considered as permanent and was either not considered or not sufficiently taken into account when erecting buildings. The problem resulting from this grows more evident as mining moves from the south to the north, creating a progressive rise of the groundwater table in the south, which has already reached its initial level in some former mining areas. In these areas, the groundwater must be prevented, through artificial means, from rising to its former natural level, in order to protect the structures which have been built in the meantime.

Another phenomenon is the worked-out mines, which are of great importance either for use by water management or for community recreation. The storage capacity of the future lakes which will be formed in the worked-out mines in the Lusatian area amounts to 50×10^6 and $250 \times 10^6 m^3$, each mine having a water surface area between 300 and 1200 hectares.

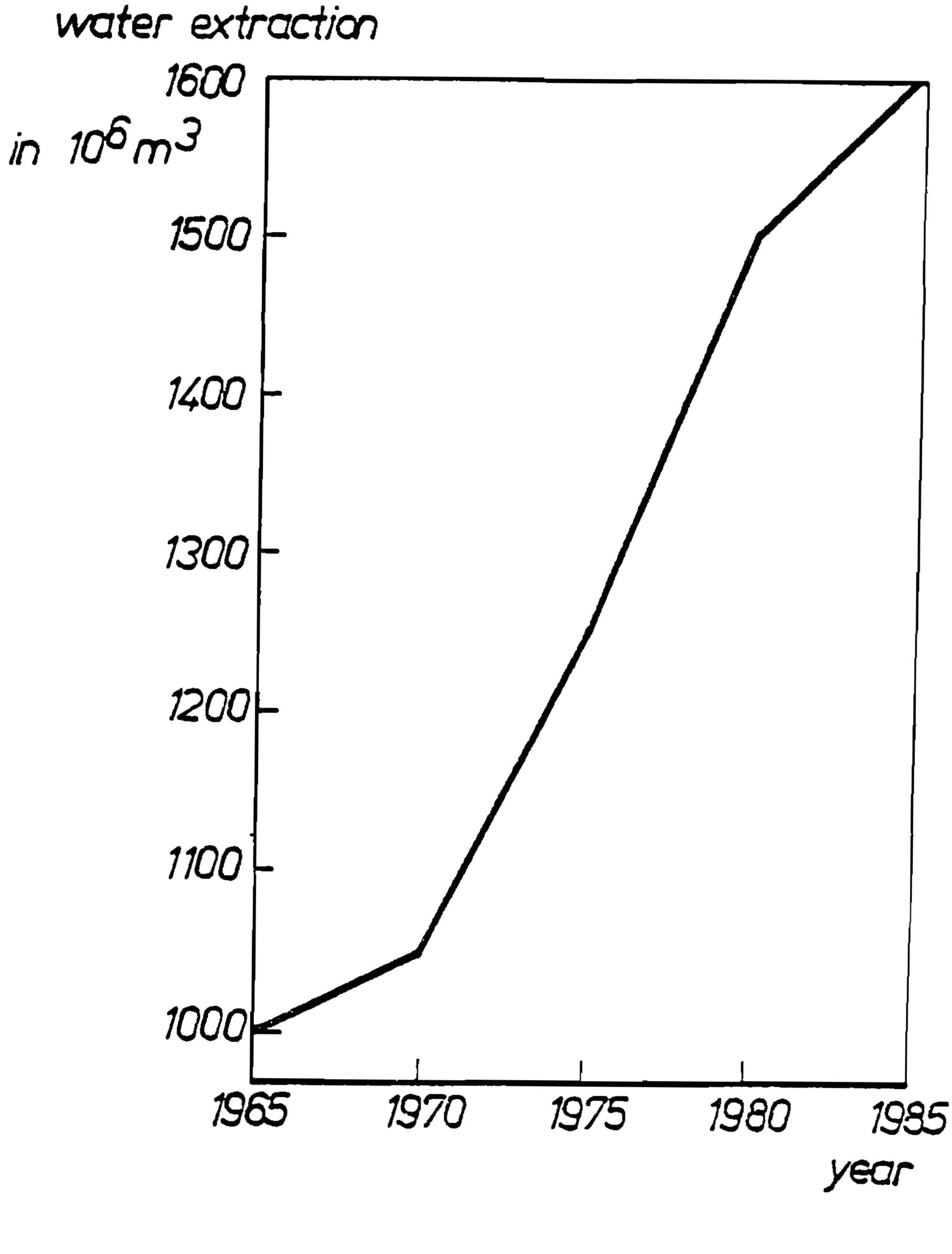
When considering the situation described above with respect to regional environmental protection, the following tasks will arise:

- Limiting the areas where an artificial change of the natural groundwater balance is allowed to occur; concomitant recording of the progressive changes.
- Determining the zones where changes in the hydrological regime of streams are to be expected as a result of the



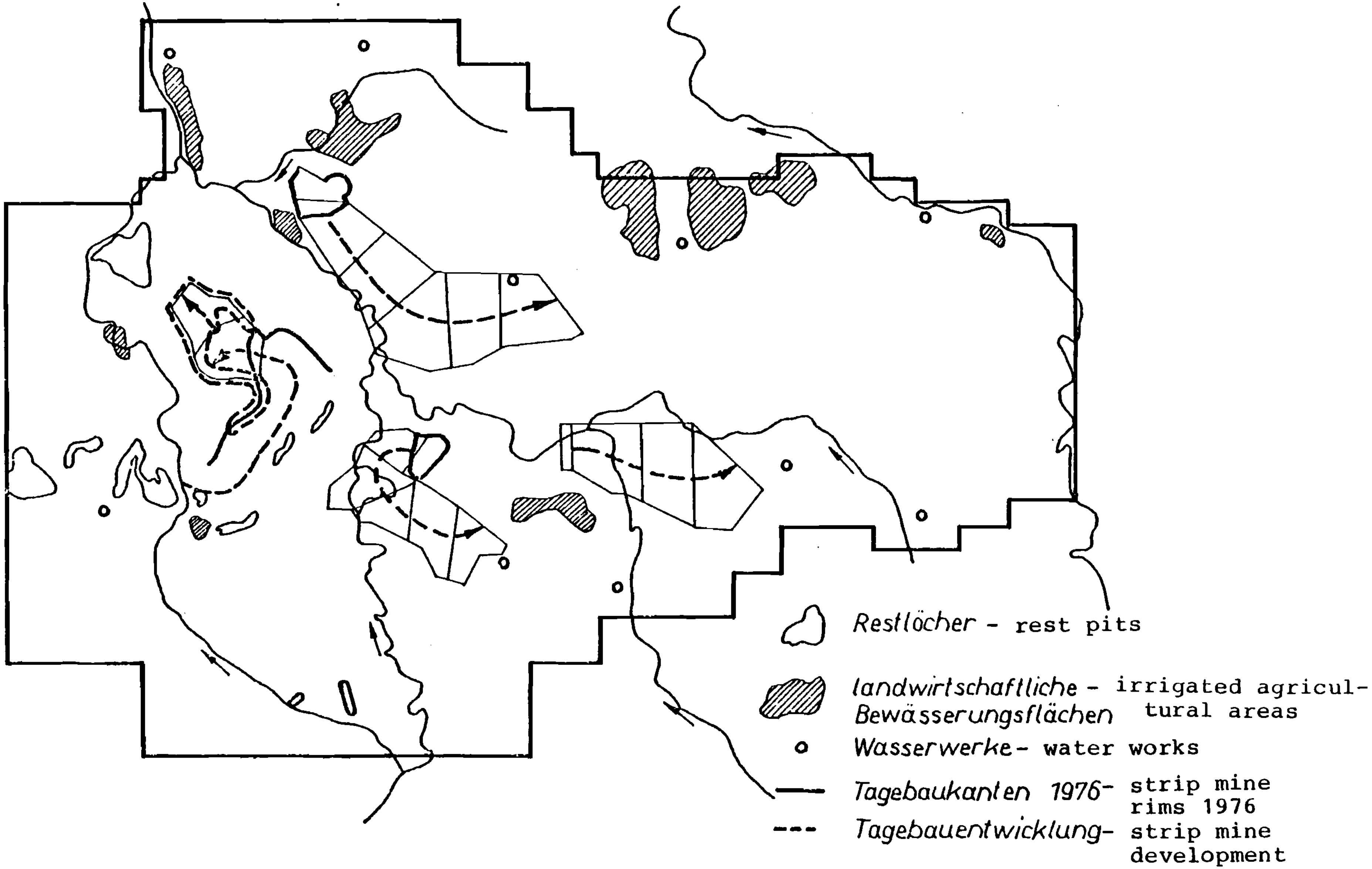
Source: Ufer and Gerisch, 1979

Figure 2: Primary energy structure of the GDR.



Source: Strzodka, 1979

Figure 3: Development of the removal of the water in the lignite industry of the GDR.



Source: Peukert, 1979

Figure 4: East Lusathia investigation area (scale: 1:50000).

artificial change in the groundwater regime. Both the extent of the expected change and its variability with regard to time and space should be considered. For this, three phases should be distinguished:

a) When opening the mine, a cone-shaped depression will be produced, whereby the pumped out water should be discharged into streams, if possible, below the affected area. In the affected area there is, however, water simultaneously extracted from the channels because of infiltration of surface water or because of groundwater inflow into the streams.

b) In the phase of mine operation, the unavoidable and also necessary cone-shaped depression shifts its location as the site of the mine shifts. The groundwater delivery during this period - lateral groundwater inflow into the cone-shaped depression and groundwater recharge in its zone - will also be discharged to a stream. With regard to the possible extraction of water from streams, the same is true as mentioned in a).

c) In the raising phase, the gradual refilling of the cone-shaped depression and the filling of the lakes in the worked-out mines with lateral groundwater and recharged groundwater begins, and if necessary, it will be supplemented by water artificially supplied from channels or from other mines.

In summary, it can be stated that planned coal development policy can only be successfully implemented after identifying and assessing the following possible consequences of the policy:

- Design of drainage structures
- Expected lowering of the groundwater level
- Limitation of the affected area
- Expected effects on the water balance of the territory (e.g., change of the stream flow by infiltration or discharge)
- Regional characterization of groundwater rise after closing down of mines, especially the prediction of the final groundwater level to be expected
- Characterization of the filling of lakes in worked-out mines, especially with regard to the final level of the open water surfaces
- Interaction between lowering and rising zones
- Possible damages, e.g., in water supply, agriculture, and forresting.

MODELLING - TECHNIQUES, ORGANIZATION, AND RESULTS

Taking into account the complexity and the long-term effects of the problems mentioned above, the need for appropriate investigative techniques becomes evident. In order to optimize the decision making process with respect to the required control measures, including necessary costs, such techniques must be capable of simulating all substantial impacts on the groundwater resources resulting from a given coal development policy. Above all, this requires a sufficient consideration not only of administrative measures, but also of changing policy elements stemming from new developments in technology and economics.

Because the very slow groundwater flow processes react to external influences only with strong damping and phase shifting, all impacts and resulting control measures should be determined for a long-range time period. Therefore, before introducing manmade changes to the flow process, one should select those interferences considered to be technologically and economically feasible, simulate the dynamical flow processes, and examine the consequences of these interferences on the simulation model. Then, one can choose among the most favorable variants for practical application.

The highest efficiency in using this kind of determination of control measures will be gained when acquisition of information, information processing, and implementation of the determined control measures in practice form a feedback system which is constantly improved in the course of its use by adapting and learning. In this connection, parallel with the process to be controlled, so-called continuously working models (CWM) will run the subsystem information processing.

In practicial terms, such an aquifer model encompasses two main parts - a numerical simulation model for information processing and a special data bank for information storing. With only one model, it is impossible to simulate the regional groundwater flow, and at the same time to derive detailed control strategies for specific control devices, e.g., for the optimal operation of a single well and its pump. Therefore, a great deal of effort has been expended to build up a hierarchical system of aquifer models as depicted in Figure 5.

The regional model is ranked as first in this hierarchy. Regional models generally serve for analysing and predicting the regional groundwater flow. The aim is to evaluate the groundwater resources as they affect and are affected by different coal development strategies, and thus, to provide a basis for long-term planning in the coal industry as well as in the field of environmental protection. Furthermore, this modelling level serves for specifying boundary conditions and constraints for the models succeeding the regional model in the hierarchy.

Due to the regional character of the flow process, a nonsteady, two-dimensional simulation model is usually used. For its efficient operation, large computer facilities and a well organized data bank are needed. The model should be run every

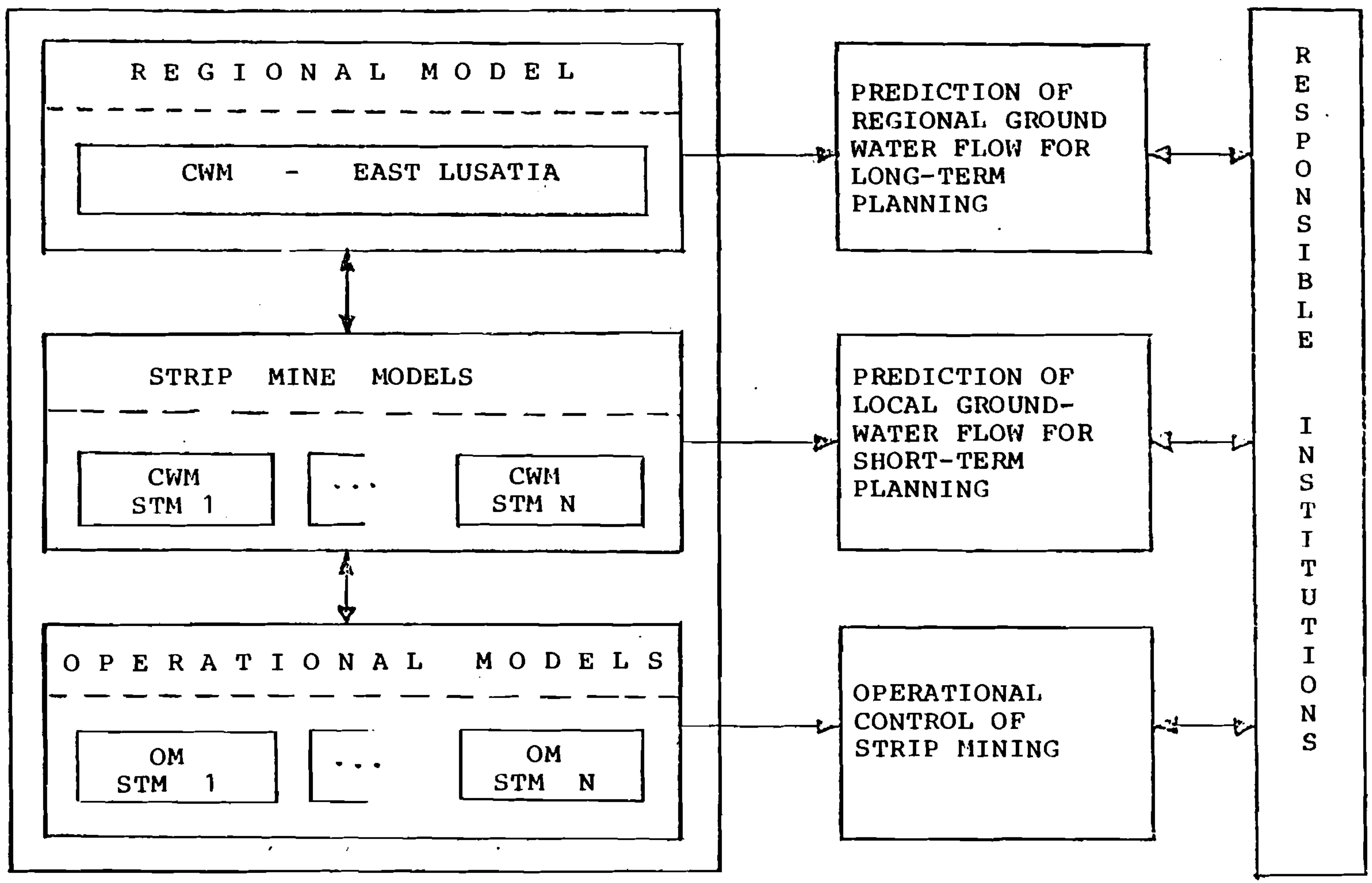


Figure 5: Hierarchical groundwater flow modelling for coal development planning.

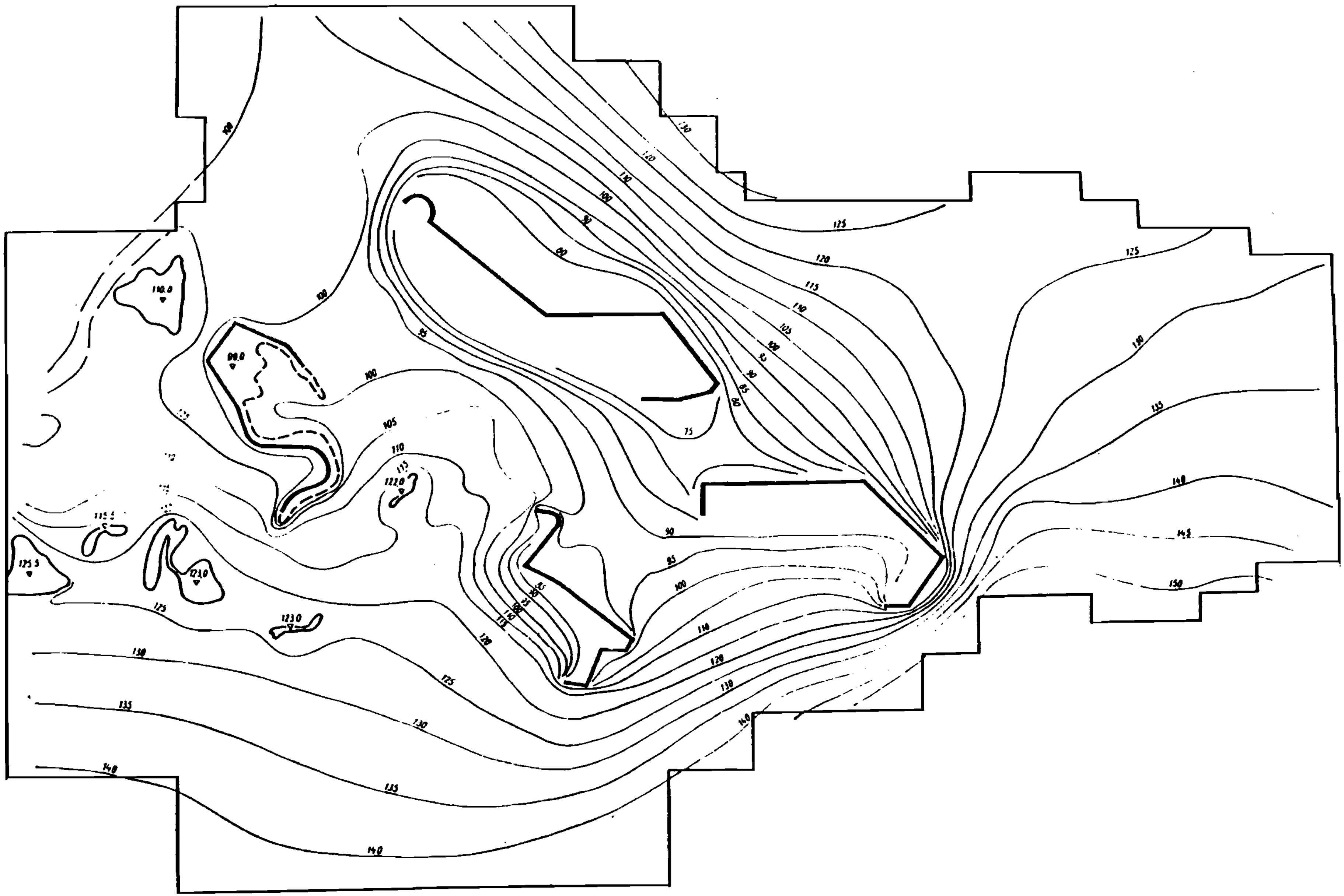
two to five years, and in the meantime, the updating of the data base is the most important task.

The second type of model in the hierarchy is the strip mine model dealing with the local strip mine area itself, including all control elements for drainage operations. This model aims to simulate the local groundwater flow as a basis for short-term planning. In most cases a two-dimensional simulation, such as that mentioned above, is used. If the groundwater flow can be modelled by using spatial and temporal constant stream tubes, a one-dimensional simulation is sufficient. In any case, a more detailed structured data base is needed than in the case of the regional model. The main outputs of this modelling level are: the projection of the control structures of the strip mine and a preliminary balance of drainage water and material. The strip mine model should be run every one to two years.

The operational model is the third one in the hierarchy of aquifer models. Its main concern is that of the annual operation of a strip mine. In principle, the same data base and models as for the strip mine model can be used, but for practical reasons, one-dimensional modelling is often preferred. This level of modelling aims not only for an exact evaluation of the operation of the drainage wells during the whole drainage period, but also for an evaluation of the discharge and water levels to be expected. According to specific strip mine conditions, the operational model should run in periods of two months to one year.

In the case of the Lusatia area considered in this paper, a regional model has been built and used. Before demonstrating the modelling results, it must be stated that regional modelling is not only related to scientific and technical questions, but also to a great extent, to organizational and institutional aspects. Only the close cooperation of all concerned institutions (e.g., universities, applied research institutes for water management and coal development planning, coal and water authorities, regional and environmental planning committees) can ensure access to all the necessary data, as was the case in Lusatia. Another aspect of such cooperation is the feedback of information on changed development concepts and ensuing modelling results.

The typical output of the regional model is depicted in Figure 6, which shows the groundwater level forecasted for the year 2000. Such a forecast enables the planner to assess, among other things, the negative effects of strip mine drainage on the operation of well fields in waterworks which must be closed in some cases. Thus, necessary investment decisions resulting from this can be made well ahead of time. Furthermore, the operation of drainage structures of neighboring strip mines which affect each other, as well as the influence of filling rest pits, can be determined, and thus the boundary conditions for designing drainage structures can be assessed in their spatial and temporal development. This results in cost-saving projects, an increase in strip mining security, and better sizing of mining protection areas.



Source: Peukert, 1979.

Figure 6: Regional groundwater level in 2000 (scale: 1:50000).

CONCLUSIONS

Strip mining causes specific environmental impacts which have to be taken into account in coal development planning. Due to the complexity and the long-term effects of such impacts, appropriate investigative techniques are needed. Hierarchical groundwater modelling has proved to be a very appropriate tool for determining the groundwater resources as they affect and are affected by given coal development strategies. Thus, it provides a common basis for long-term planning in the coal industry as well as in the field of environmental protection. Besides scientific and technical questions with respect to the development of models and adequate data banks, organizational and institutional aspects have to be considered as important.

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A DATA BASE FOR COAL MINES

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A. Astakhov, M. Grenon, A. Grübler

The studies made in IIASA's Energy Program have shown the potential and constraints of a future world coal market. IIASA's Resources Group is contributing to these studies a critical and independent evaluation of world coal resources and, by application of the WELMM (Water, Energy, Land, Materials and Manpower) method, is studying the impacts on natural and/or human resources of large-scale coal utilization.

Within this context the Facility Data Base (FDB) is used very extensively. It is relatively easy to define standard types of facilities at the top end of the coal chain (conversion and transportation) - for example, coal unit trains of 10000 tons, gasification complexes of 2300 million m^3 per year or coal-fired power plants in the 600 to 1000 MWe range - especially when one considers the increasing trend of standardization of the size of energy installations. On the other hand, it is practically impossible to reduce the great number of coal mines, opencast or underground to a few representative examples.

A great number of factors influence coal mining activities: the geology of the deposit, the degree of mechanization, the cost of manpower, the extraction technology used ... these are only a few examples.

The Resources Group has therefore launched a detailed statistical study of a great number of large-scale coal mines. The main objectives are firstly to collect and secondly to analyze in detail WELMM data for a great number of coal mines, representing about 100 major coal basins in the world. Naturally, the greatest attention has been attributed to those basins which are capable of making a considerable contribution to a potential world coal market.

For each basin, representative mines from the point of view of technology and geology (depth, number and thickness of seams, coal quality etc...) are studied, in order to obtain a sufficient number of mines to classify them according to their size, the technology used, their WELMM requirements and the conditions of each basin. Mines in the following countries are being studied: Australia, Austria, Canada, France, the F.R.G., the G.D.R., Hungary, India, Poland, the Republic of South Africa, the U.K., the U.S.A., and the U.S.S.R. [1].

In addition to this, coal basins in general have been studied (e.g. the Lorraine Basin in France) in order to consider geological conditions which may vary considerably even within the same basin.

It is obvious that this type of approach - based on a few "typical" mines per basin - although representing considerable progress with respect to the methodology developed in the United States (e.g. the Bechtel Corporation, where the whole modelling effort of the coal mining activities in their Energy Supply Planning Model is based on only four mines for the U.S.) does not allow in all cases the study of aspects of coal exploitation in a certain basin with the same degree of accuracy. Of course this depends on how many representative mines there are for the basin in the Data Base and how much the conditions vary within the basin. A detailed study of the relations between geological parameters and the consumption of natural resources is therefore being made. This study is based on a sufficiently large number of mines to enable statistical analysis in order to find out which technology (and which equipment) is used in certain conditions, what the cost of exploitation is - expressed in terms of natural/human resources - and to achieve a better understanding of problems of scale.

This effort of modelling coal mines has already shown interesting results (e.g. the work of Fluor Utah [2] and the U.S. Bureau of Mines [3]) in the United States, but their examples are too few and are too country specific (e.g. the United States) to allow geological analysis of coal basins on a global level.

Other possible applications of the Coal Mines Data Base are in the process of being developed. The data have already been used to compare energy chains. Further applications include the study of mining impacts of energy scenarios or the impacts of a large-scale development of coal production in a given region (e.g. impacts on manpower and land) either by extrapolations from "typical" mines or by a more detailed analysis using the same methodology.

Finally, in combining the data on coal mines and the data relating to other facilities of the coal chain (transportation, conversion ...) from the Facility Data Base, the WELMM impact of a large-scale development of the world coal market can be studied.

METHODOLOGY AND STATUS OF THE STUDY

Data are obtained from the review of literature (Environmental Impact Statements are of especial interest) and for the purpose of data collection, a questionnaire has been developed at IIASA in cooperation with coal experts. The questionnaire consists of about 160 questions, half of which characterize the mines and the geological conditions. These questions correspond to the parameters listed in the Appendix where an example of a mine is presented. Some 30 questions follow regarding the WELMM requirements for the construction of the mine (including cost data) and finally there are about 50 questions regarding the resource requirements for operation. The status of the survey is resumed in Figure 1.

All data in the data base are stored in the same order as the questions in the questionnaire. In addition the data base is organized in a very flexible way so that the number of parameters can be easily increased. Like the Facility Data Base, IIASA's Resources Data Base uses the INGRES interactive natural language system. We are currently also implementing a hierarchical TREE structure (developed by S. Medow) on the coal mine data which may be interactively accessed. Information will be stored at each node of the branches of the TREE and connections to the geographical Resource Data Base (with more-detailed information on environmental characteristics) can be made.

FIGURE 1. STATUS OF COAL MINES STUDY.

Data collected and analyzed

• 65 MINES	IN :		AUSTRALIA	(5)
			AUSTRIA	(3)
			FRG	(1)
			UK	(2)
			USA	(33)
			USSR	(21)
• GENERAL CHARACTERISTICS	:	80	80% COMPLETE	
• WELMM REQUIREMENTS FOR CONSTRUCTION	:	31	20% COMPLETE	
• WELMM REQUIREMENTS FOR OPERATION	:	51	60% COMPLETE	
		162	60% AVERAGE	

Table 1 presents a list of mines for which data have already been computerized, showing the country, region and basin in which the mine is situated; the name of the mine ("hypothetical" refers to mines defined for technological and geological conditions not necessarily linked to a real basin - "Model" indicates that the mine has been modelled according to the precise technological and geographical conditions of a given basin); the technology used and finally the annual capacity in millions of tons. Appendix 1 shows data for one of the mines stored in the Data Base.

EXAMPLE OF APPLICATION

As already mentioned, the data stored in the Coal Mines Data Base (CMDB) have already been used in analyzing the extraction part of coal energy chains.

Other examples of application in the study consist of correlations between geological/technological parameters and the consumption of natural resources. This study allows a better assessment of which natural and human resources have to be mobilized in order to extract coal under given conditions and to obtain a first evaluation of the impacts of development of a coal field when detailed project studies are not yet available. This analysis covers the following aspects:

- Relations between extraction technology and coal resources and reserves.
- Evaluation of technology with time, as reflected in productivity, size of mines ...
- Consumption of natural resources (WELMM) for coal exploitation (Figure 2)
- Relations between geological/technological parameters and the costs of investment and operation.

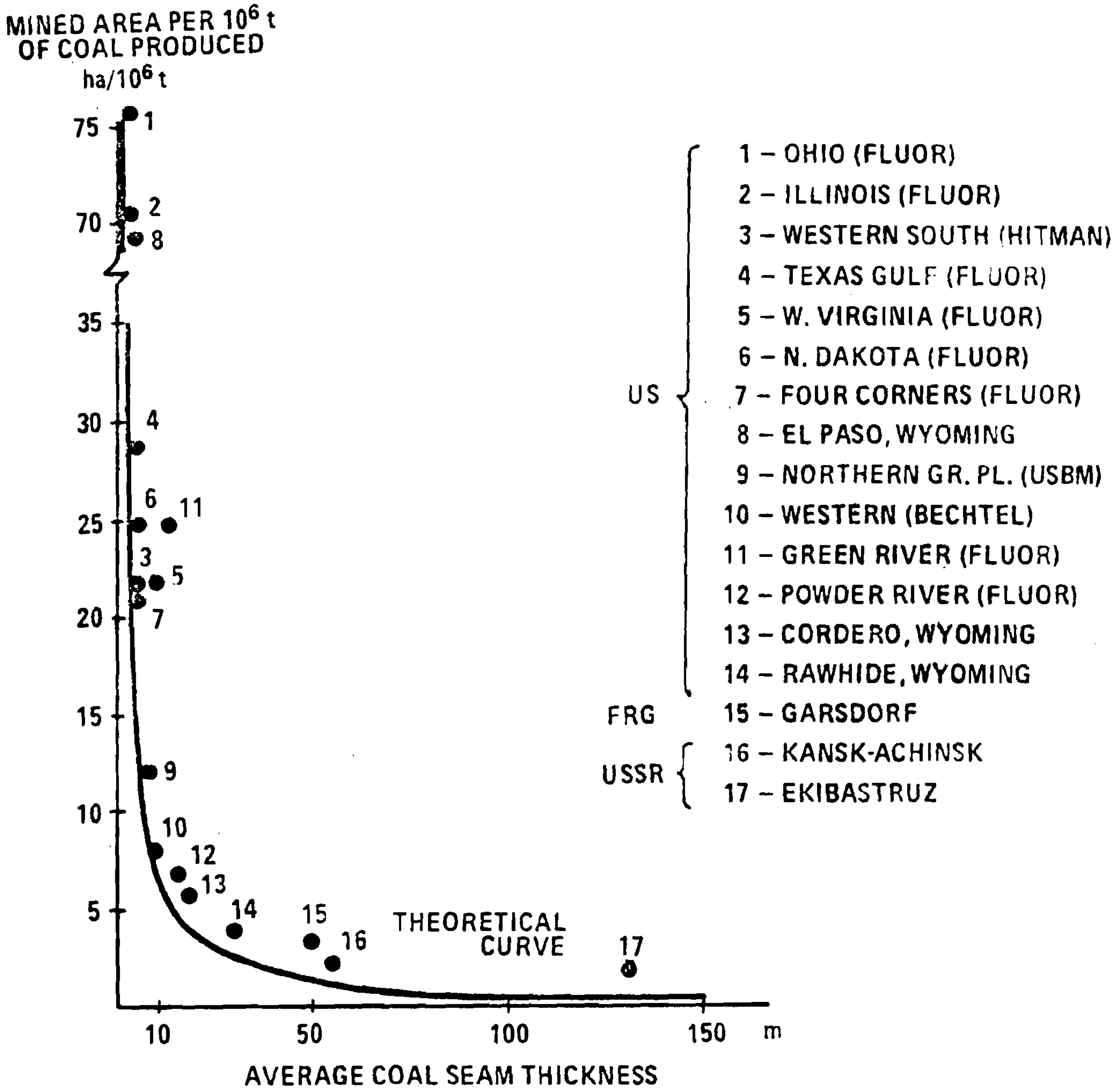
In conclusion, the Data Bank for Coal Mines being developed at IIASA can also serve outside users and this could be an incentive to compare the data and the results with national studies.

TABLE 1: MINES FOR WHICH DATA HAVE ALREADY BEEN COMPUTERIZED

country	region	basin	minename	techno	ancey
australia	eastern	bowen	gregory	surf	3.[illegible]
australia	eastern	bowen	hypothetical	surf	5.[illegible]
australia	eastern	bowen	hypothetical	surf	[illegible]
australia	southern	gippsland	yallourn	surf	12.900
australia	southern	sydney	tahmoor	undcon	2.600
austria	western	hausruck	schmitzberg-hinterschlagen	undcon	0.500
austria	western	hausruck	trimmelkam	undcon	[illegible].600
austria	western styria	voitsberg-koeflach	oberdorf	surf	1.250
germany west	rheinland		fortuna garsdorf	surf	[illegible]
united kingdom	midlands	north derbyshire	furnace hillock	surf	0.140
united kingdom	yorkshire	northern yorkshire	selby	undcon	10.[illegible]
united states			hypothetical	undcon	0.930
united states			hypothetical	undcon	0.960
united states			hypothetical	undcon	1.350
united states			hypothetical	undcon	1.860
united states			hypothetical	undcon	2.810
united states			hypothetical	undcon	2.930
united states			hypothetical	undcon	4.540
united states			hypothetical	undcon	4.550
united states	eastern		hypothetical	surf	4.350
united states	eastern	appalachian	model fluor utah	surf	0.790
united states	eastern	appalachian	model fluor utah	surf	1.530
united states	eastern	illinois	model bechtel sri	surf	3.630
united states	eastern	illinois	model fluor utah	surf	1.550
united states	eastern	texas gulf	model fluor utah	surf	[illegible].320
united states	eastern	west kentucky	model bechtel sri	undcon	1.810
united states	interior		hypothetical	surf	6.100
united states	western		hypothetical	surf	2.720
united states	western	green river	model fluor utah	surf	0.360
united states	western	north great plains	hypothetical	surf	6.340
united states	western	north great plains	model fluor utah	surf	2.680
united states	western	powder river	absalaka	surf	15.[illegible]
united states	western	powder river	caballo	surf	12.000
united states	western	powder river	coal creek	surf	10.000
united states	western	powder river	cordero	surf	12.300
united states	western	powder river	eagle butte	surf	20.[illegible]
united states	western	powder river	east decker	surf	6.7[illegible]
united states	western	powder river	east gilette	surf	8.[illegible]
united states	western	powder river	model fluor utah	surf	3.650
united states	western	powder river	north extention	surf	2.[illegible]
united states	western	powder river	pronghorn	surf	5.[illegible]
united states	western	san juan(new mexico)	el paso consol	surf	17.[illegible]
united states	western	san juan 4 corners	model fluor utah	surf	2.190
united states	western	wyoming	model bechtel sri	surf	5.140
ussr	asian	kazaks karagandinsky	gorbatshov	undcon	2.[illegible]
ussr	asian	kazaks karagandinsky	kazakstanskaya	undcon	2.[illegible]
ussr	asian	kazaks karagandinsky	kostenko	undcon	3.150
ussr	asian	kazaks karagandinsky	lenin	undcon	2.650
ussr	asian	kazakstan ekibastus	hypothetical	surf	30.[illegible]
ussr	asian	russia kansk achinsk	hypothetical	surf	[illegible]
ussr	asian	russia kuzbas	hypothetical	surf	20.[illegible]
ussr	asian	russia kuzbas	hypothetical	surf	36.[illegible]
ussr	asian	russia kuzbas	karataylinskaya	undcon	1.[illegible]
ussr	asian	russia kuzbas	num1 [illegible]skaya	undcon	1.[illegible]
ussr	asian	russia kuzbas	num2 jubileynaya	undhyd	[illegible]
ussr	asian	russia kuzbas	zaryechnaya	undhyd	[illegible]
ussr	european	russia donbas	50.letiya octyabrya	undcon	[illegible]
ussr	european	russia donbas	gukovskaya	undcon	[illegible]
ussr	european	russia pechorsky	intinskaya	undcon	[illegible]
ussr	european	ukraine donbas	abacumoff	undcon	[illegible]
ussr	european	ukraine donbas	hypothetical	undcon	[illegible]
ussr	european	ukraine donbas	krasnoarmeyskaya	undcon	[illegible]
ussr	european	ukraine donbas	novopavlovskaya	undcon	[illegible].75[illegible]
ussr	european	ukraine donbas	num1 zdanovskaya [illegible]	undcon	[illegible]
ussr	european	ukraine donbas	rossiya	undcon	[illegible]

FIGURE 2

RELATION BETWEEN SEAM THICKNESS AND MINED AREA



APPENDIX

EXAMPLE OF COAL MINE IN THE IIASA COAL MINES DATA BASE (CMDB)

country	region	basin	minename	mcode
austria	western styria	voitsberg-koeflach	oberdorf	CMINE049

G E N E R A L   C H A R A C T E R I S T I C S   O F   T H E   M I N E

process	m+p	mining+preparation
type of technology	surf	surface
data origin	projkf	projected for a certain field
reference year of data	1984	year
total number of coal seams	2	number of seams
including seams to be mined out	2	number of seams
seams supposed to be mined out in ref year	1	number of seams
lower thickness of coal seams	2.000	meters
average upper ash content of seams mined out	30.000	percent
average thickness of coal seams in ref year	7.000	meters
total mining seams thickness	25.000	meters
overburden to coal ratio	4.452	m3 per metric ton
dip of coal seams in degrees	flat	flat coal seams
maximum depth of mining in ref year	60	meters
marginal depth of mining	180	meters
methane emanation	3.000	m3 per metric ton daily output
tectonic distortions description	regbedd	regular bedding
coal density in situ	1.275	metric tons per m3
rock (overburden) density	1.950	metric tons per m3
necessity of rock explosion(only surf)	no	no
necessity of coal explosion(only surf)	no	no
surface landscape	hmfoga	hilly mountain forest grazing agricultur
average january temperature	-1.001	grade celsius
average july temperature	15	grade celsius
range of annual precipitation-minimum	-1	millimeters
range of annual precipitation-maximum	-1	millimeters
range of ground freezing-minimum	0.000	meters
range of ground freezing-maximum	0.000	meters
average depth of ground freezing	0.000	meters
degree of industrial developement of the region	devdp	developped industry great population den
long distance transportation possibilities	exloc	existing transportation facilities but c
total remaining geological resources in ref year	33.000	10e6 metric tons
econ. and techn. recoverable reserves in ref yea	30.000	10e6 metric tons
recovery rate	0.900	ratio resources in ground/reserves
grade of coal	brown	brown coal
range of moisture content of coal-min	26.000	percent
range of moisture content of coal-max	38.000	percent
average moisture content of coal	32.245	percent
range of ash content of coal-min	20.000	percent
range of ash content of coal-max	47.000	percent
average ash content of dry coal	33.430	percent
min caloric content of coal	1985	kcal per kg
max caloric content of coal	2985	kcal per kg
avg caloric content of coal (ash and moisture fr	2505	kcal per kg
annual capacity	1.250	10e6 metric tons
construction duration	6.000	years
period of initial increasing mine output	3.000	years
total lifetime of the mine	27	years
year of beginning of exploitation	1980	year
coal output in ref year	1.250	10e6 metric tons
number of operating faces	2.000	number of operating faces
average output from a face	2500	metric tons per day
number of working days per year:coal winning	250	number of days per year
number of working days per year: overburden movi	250	number of days per year
number of working shifts per day:coal winning	3	number per day
number of working shifts per day for overburden	3	number per day
system of seam opening(underground mining)	0	this is a surface mine!
position of main shafts	0	this is a surface mine!
number of main shafts	0	number of main shafts
method of mining	stripbw	stripping with bucket wheel excavator

N.B. : Values of -1/-1.000 correspond to data not available

WELMM REQUIREMENTS FOR CONSTRUCTION

name	resquan	unit
specific capital investment	37.333	us $ 1975 per t ann capacity
infrastructure investment	14.986	us $ 1975 per t ann capacity
direct investment total	22.346	us $ 1975 per t ann capacity
water inflow during construction	1.009	m3 per t ann capacity
water used during construction	0.000	m3 per t ann capacity
electricity	40.000	kwh per t ann capacity
motor fuel	0.002	tce per t ann capacity
process heat fuel	0.000	gallons per t produced
land affected by construction	0.150	ha per 10E3 t ann capacity
total land leased incl waste rock piles	0.150	ha per 10E3 t ann capacity
land occupied by mine buildings	0.000	ha per 10E3 t ann capacity
land for railways & worker villages	0.000	ha per 10E3 t ann capacity
non manual technical manpower	20.000	manyears per 10E6 t ann capaci
non manual non technical manpower	72.000	manyears per 10E6 t ann capaci
manual technical manpower	308.000	manyears per 10E6 t ann capaci
manual non technical manpower	-1.000	manyears per 10E6 t ann capaci
total manpower	400.000	manyears per 10E6 t ann capaci
incl underground manpower	0.000	manyears per 10E6 t ann capaci
wood	-1.000	m3 per 10E3 t ann capacity
field metals	-1.000	t per 10E3 t ann capacity
concrete cement	-1.000	m3 per 10E3 t ann capacity
waste rock mined & stored during constr.	-1.000	m3 per 10E3 t ann capacity

W E L M M   R E Q U I R E M E N T S   F O R   O P E R A T I O N

name	resquan	unit
water withdrawn from environment	0.210	m3 per t ann capacity
water used by the mine	0.000	m3 per t ann capacity
electricity	17.800	kwh per t produced
process heat fuel	0.118	gallons per t produced
land undermined	0.000	m2 per t ann output
land disturbed by mining	0.062	m2 per t ann output
height of topsoil	0.300	meters
land reclamation	0.060	m2 per t of output
disturbance duration	30.000	years
non manual technical manpower	0.001	manshifts per t output
non manual non technical manpower	0.007	manshifts per t output
manual technical manpower	0.039	manshifts per t output
manual non technical manpower	0.016	manshifts per t output
total manpower	0.064	manshifts per t output
incl underground manpower	0.000	manshifts per t output
number of miners on books	318.000	men
labour productivity	17.857	t per manshift
wood	0.000	m3 per t produced
explosives	0.000	kg per t produced
metal supports wo hydraulic	0.000	t per t produced
other metals	-1.000	t per t produced
other materials	-1.000	us $ 1975 per t produced
total materials wo fuel	-1.000	us $ 1975 per t produced
solid waste to be disposed at surface	8.677	t per t produced
so2 emission	0.000	lb per 10E6 btu

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SIMULATION OF SHORT AND LONG-RANGE DISPERSION OF SULPHUR COMPOUNDS

E. Runca

Paper presented at Coal: Issues for the Eighties Meeting in Szczyrk, Poland, 5-9 November 1979

Paper presented at:

COAL-ISSUES FOR THE EIGHTIES MEETING IN SZCZYRK, POLAND

6-9 November, 1979

SIMULATION OF SHORT AND LONG-RANGE DISPERSION OF SULPHUR COMPOUNDS

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INTRODUCTION

Recent estimates of the sulphur global budget (Granat et al. 1976) indicate that the total sulphur released in the atmosphere is approximately 10^7 tons/year. Sixty five per cent is due to anthropogenic sources, the remainder to biogenic sources. Approximately ninety five per cent of the anthropogenic sulphur is emitted as sulphur dioxide. Since most (~94%) of the man made sulphur originates from the industrial and urban areas of the Northern Hemisphere, focus is mainly put on local and regional-continental aspects of sulphur pollution. Global effects might be also important, however, so far, not too much attention has been paid to them.

Simulation of sulphur dispersion is achieved both by deterministic and stochastics mathematical models. The deterministic approach can be either Lagrangian or Eulerian (see, e. g., Csanady, 1973).

The Lagrangian model computes the concentration (ensemble average) as the probability that a pollutant particle will be at point x at time t. It has the general form:

$$C(\underline{x},t) = \iint_0^t p(\underline{x},t\,|\,\underline{\xi},\tau)\, S(\underline{\xi},\tau)\, d\tau\, d\underline{\xi} \qquad (1)$$

where C is the concentration, S the source, $p(\underline{x},t|\underline{\xi},\tau)$ the transition probability density that a particle at point $\underline{\xi}$ at τ will be at $\underline{x}$ at t. The application of the Lagrangian model requires the definition of the transition probability density. Assuming the turbulence homogeneous and stationary the transition probability density can be expressed by a Gaussian function. Accordingly models based on this approximation are named Gaussian. Due to the limiting assumptions on which Gaussian models are based, they are generally applied to the computation of long-term average (seasonal, annual) concentration (see, e. g., Runca et al., 1976). However, there is some example of application of these models to simulation of short-term (hourly, daily) concentration (see, e. g., Shieh et al., 1972). Application of equation (1) with direct evaluation of the transition probability density from the turbulent flow dynamics has been also done (see, e. g., Lamb, 1978).

The Eulerian model computes the time variation of the concentration at a given point as the combined result of the fluxes due to the mean flow, the turbulent motion, sources and removal-transformation processes. In other words, the Eulerian model originates from the mass balance equation for the considered pollutant. Its application requires the evaluation of the turbulent flux. By analogy with molecular diffusion Prandtl (see, e. g., Leslie, 1973) proposed to compute the turbulent flux as the product of an eddy diffusion coefficient and the concentration gradient. Other approaches have been more recently proposed (Lumley and Khajeh-Nouri, 1974; Lewellen and Teske, 1976; Berkowicz and Prahm, 1979), but due to theoretical and computational difficulties they are not yet of common use. Thus most of the Eulerian models are based on Prandtl's theory. They are named gradient transfer theory models (K-models) and take the form:

$$\frac{\partial c}{\partial t} + \underline{\nabla} \cdot (\underline{v} c) = \underline{\nabla} \cdot (\bar{\bar{K}} \cdot \underline{\nabla} c) + S(\underline{x}, t) + R(\underline{x}, t) \qquad (2)$$

where $\underline{V}$ is the wind vector, $\bar{\bar{K}}$ the diffusivity tensor, S the source term and R the removal-transformation term. K-models are more adequate than Gaussian models to treat time dependent situations in which wind and diffusivity are spatially not uniform. However, due to Prandtl's theory assumptions, they can only describe variations in the concentration field which are much larger than the time and length scales of the atmospheric turbulence. Analysis of K-models limitations can be found, e. g., in Lamb (1973) and in Corrsin (1974).

Stochastic models do not establish a priori a model equation of the process. Relationship between variables relevant to the process are determined by statistical analysis of measured data. They have the following general forms:

Autoregressive models

$$\{ c \}_{t-i} \rightarrow SM \rightarrow \{ \hat{c} \}_{t+j} \qquad (3)$$

in which the stochastic model SM predicts, on the basis of the concentration values known up to the time t-i, the estimated values $\hat{C}$ at t+j.

Multiple regression models

$$\{C + M + E\}_{t-i} \rightarrow SM \rightarrow \{\hat{C}\}_{t+j} \tag{4}$$

in which SM predicts $\hat{C}$ at t+j on the basis of concentration, meteorological and emission data known up to t-i.

Description of the statistical techniques which allow to define SM can be found, e. g., in Box and Jenkins, 1970. Examples of application of stochastic models are given, e. g., by Finzi et al., 1979.

In addition to the above models, Desalu et al., 1974, proposed a technique, which has proved (Bankoff and Hanzevack, 1975; Fronza et al., 1979) to improve the prediction of concentration temporal evolution. This technique links together stochastic and deterministic models and has the following general structure:

$$\{C + M + E + \hat{C}\}_{t-i} \rightarrow [DM + SM] \rightarrow \{\hat{C}\}_{t+j} \tag{5}$$

in which both estimated and measured concentration values at time t-i are used by the deterministic model DM and the stochastic one to predict estimates $\hat{C}$ at t+j.

Some results achievable by mathematical models as well as some problems connected to their application are discussed in the next chapters.

SHORT-RANGE DISPERSION

On local scale, i. e. on distances of the order of 10 km, removal processes are not relevant to the computation of sulphur dioxide concentration which constitutes, in this case, the main sulphur compound. Sulphur local scale pollution problems arise mainly from high concentration values and from large pollutant deposition rates to soils, vegetation and other receptors.

Computation of concentration by mathematical models requires data on: a) emission with spatial resolution of the order of 1 km^2; b) local air flow circulation and c) turbulent structure of the planetary boundary layer. In general, emission rate is given on yearly basis, and local air flow as well as atmospheric turbulence have to be parametrized on the basis of meteorological data taken at ground level. Data inaccuracies and approximations in the mathematical formulation limit both the performance and the applicability of mathematical models.

The Gaussian model has proved, as mentioned in the introduction, to provide a satisfactory description of seasonal air pollution patterns. Results achieved by this modelling approach applied to the Venetian area (see Fig. 1) are shown in Figs. 2 and 3 which compare simulated and measured sulphur dioxide values at monitoring stations located both in urban (Fig. 2) and industrial (Fig. 3) areas. Simulated values are reported for two different approximations of the model dispersion parameters. Plots indicate that modification of parameters given in literature (Pasquill, 1974) according to the characteristics of the area improve the model results. This confirms the need of adequate data for model applications.

Analysis of air pollution in the Venetian area shows the occurrence of high short lasting episodes mainly in the region near by the industrial area. These episodes can be caused either by a temporary increase of the emission or by the occurrence of meteorological situations which favor accumulation of pollutants close to the ground. Emission and meteorologcal data necessary to simulate these episodes are generally not complete. Mixed models are an attempt to cope with both data and theoretical uncertanties by filtering the information coming from both simulated and measured concentrations.

Improvement achievable by this technique is shown in Fig. 4 which compares hourly concentration values at station nine of the monitoring network (see Fig. 1) with the ones predicted four hour ahead by a three dimensional Eulerian model (solid line) developed by Runca et al. (1979) and a mixed model (dashed line) developed by Fronza et al. (1979). The simulated values were predicted a posteriori, thus the meteorological data input to the model were the ones measured at the monitoring meteo-station. Results with forecast meteorological data are shown in Fig. 4 by the dashed-dotted line which refers to the values predicted by the mixed model assuming that meteorology recorded at the time when the model is applied will persist for the next four hours, and by the dashed-double dotted line in which meteorology is forecast by means of statistics made over the meteorological time series.

LONG-RANGE DISPERSION

On regional-continental scale, i. e. on distances of the order of 100-1000 km, pollution problems arise mainly from the damage caused by deposition of acid sulphur compounds at Earth's surface, and possible effects on climate. The main

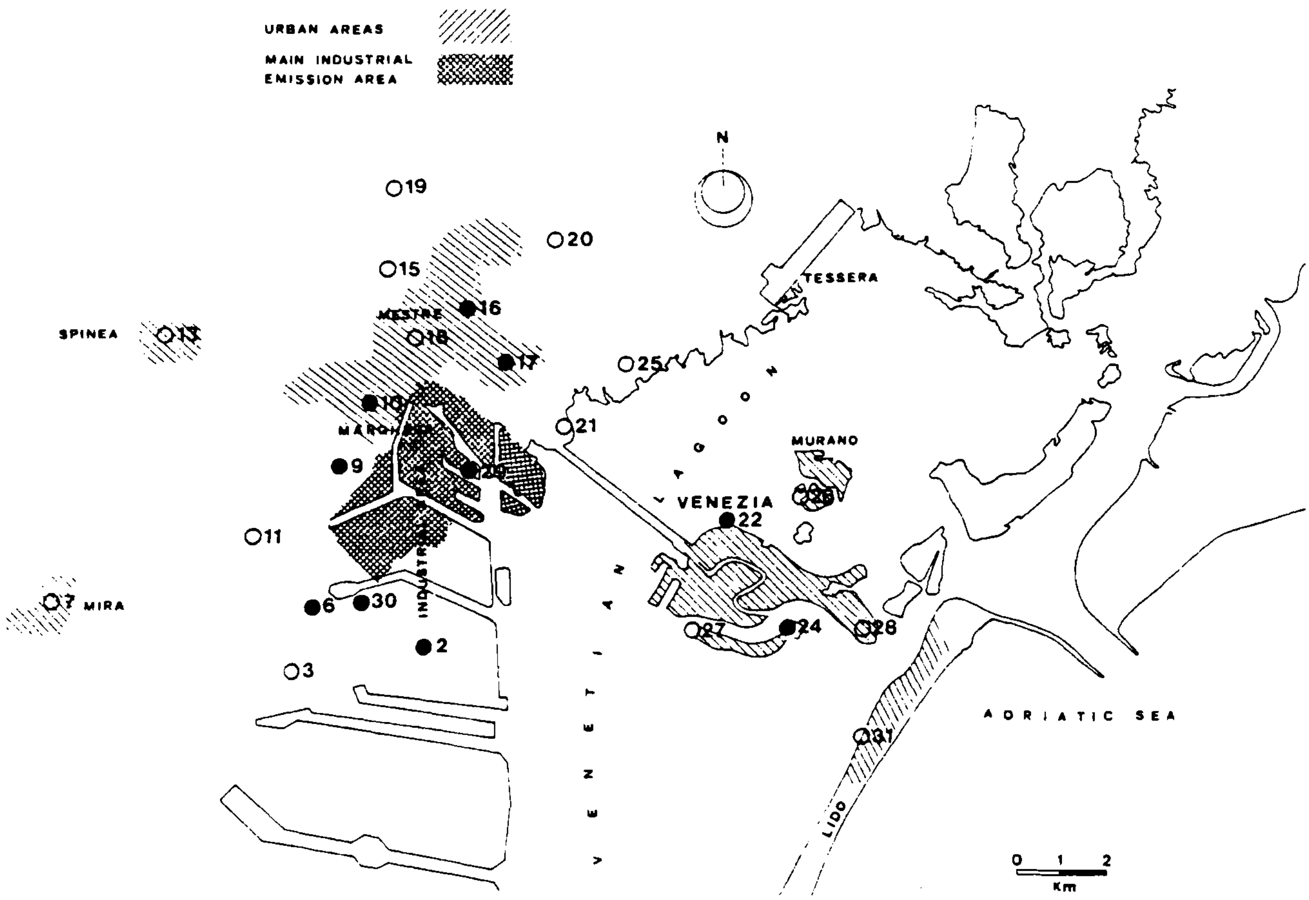

Fig. 1 - Venetian area including the monitoring stations installed by Tecneco by appointment of Italian Governmental Health Department. Black dots indicate stations operating since February 1973, white dots stations put into operation one year later.

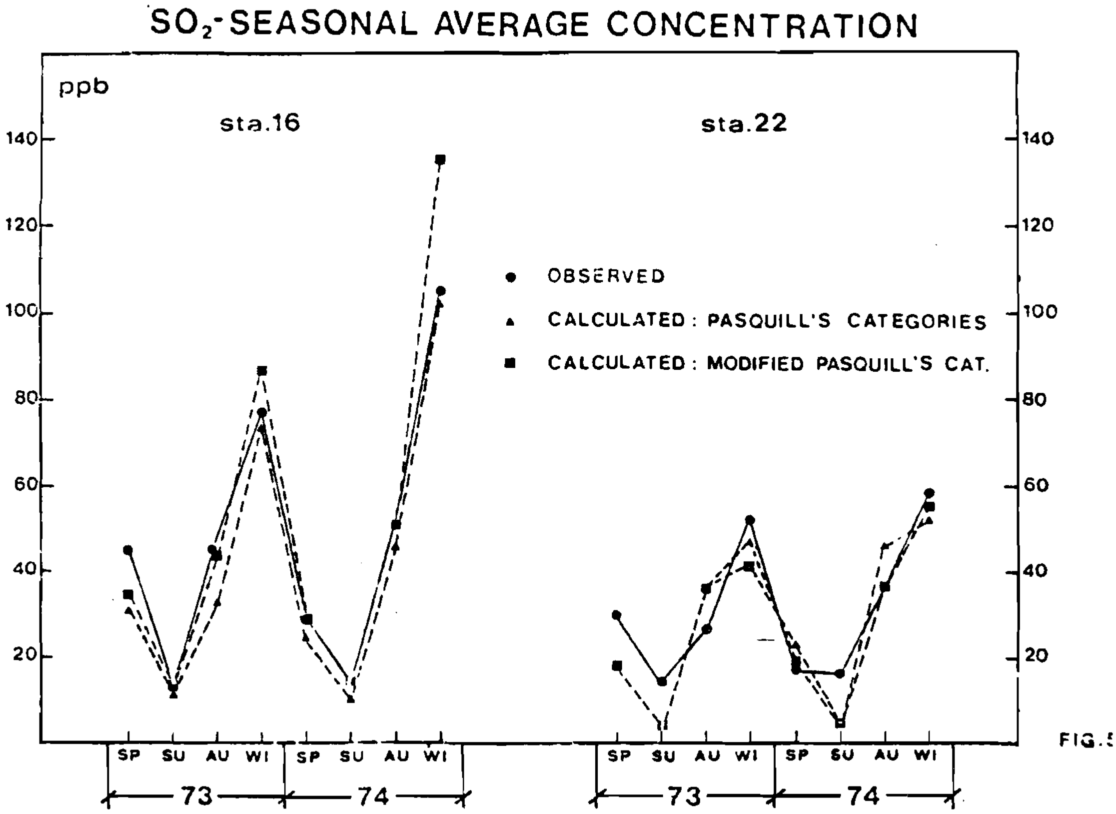

Fig. 2 - Observed and calculated three-monthly average SO_2 concentration at stations 16 and 22 (Sp: March, April, May; Su: June, July, August; Au: September, October, November; Wi: December, January, February).

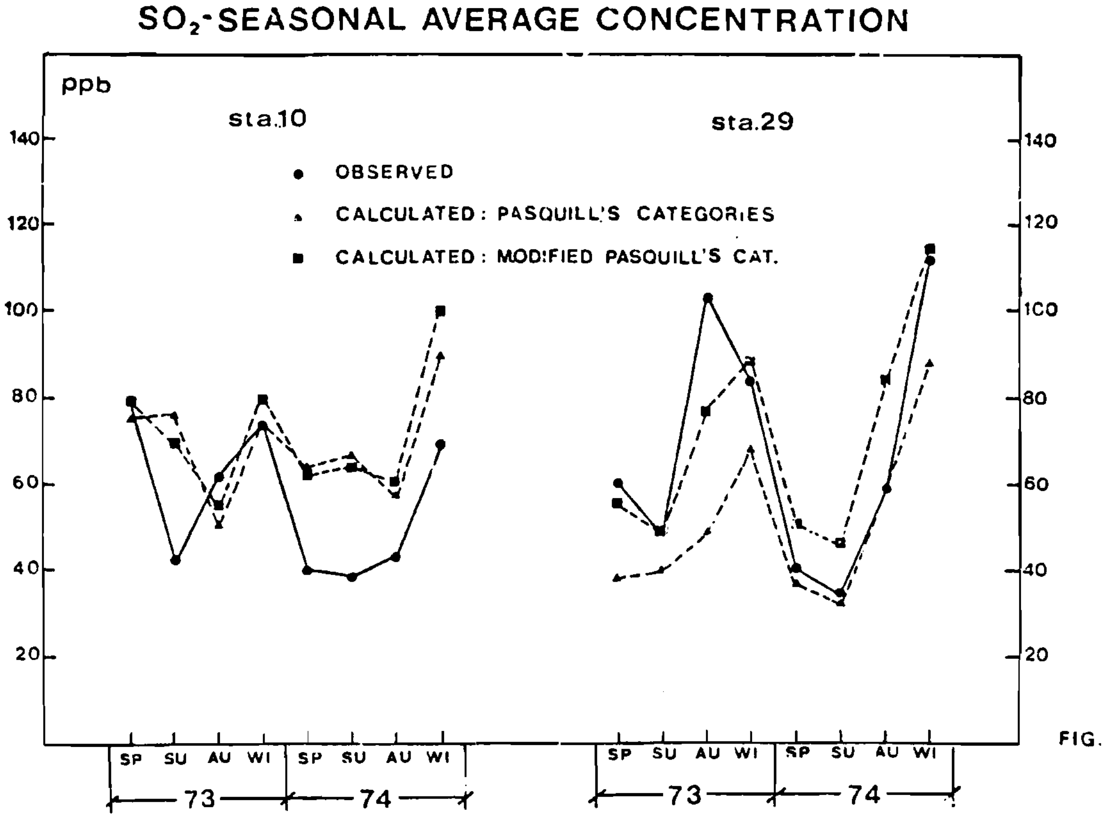

Fig.3 - As in Fig. 2 but for stations 1C and 29.

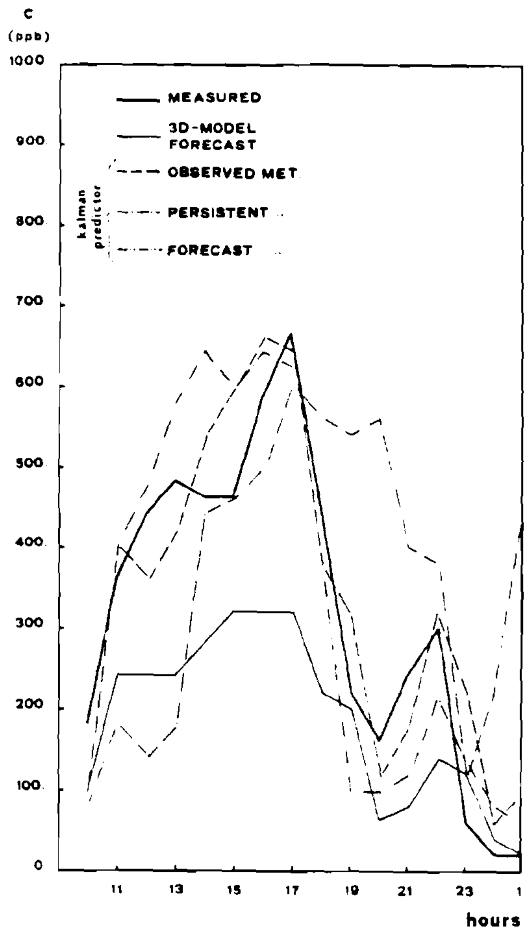

Fig. 4 - Observed and forecast hourly concentrations at station 9 during the episode occurring on April 7th, 1973. See text for symbol explanations.

sulphur compounds to be considered are sulphur dioxide and sulfate ($SO_4^=$). Simulation of long-range sulphur dispersion cannot neglect removal and transformation processes.

Computation of sulphur dioxide and sulfate concentration requires data on: a) removal and transformation rate; b) emission with a spatial resolution of the order of 10-100 km ; c) sinoptic meteorology and d) turbulence structure of the planetary boundary layer.

Comparison with the similar considerations reported in the short-range dispersion problem shows that, in addition to a change in the scale of the meteorological and emission data, new information are needed in order to model removal processes and transformation of sulphur to sulfate.

The additional processes to be described are dry and wet deposition of both sulphur dioxide and sulfate, and the transformation of sulphur dioxide to sulfate. A summary of the studies done on this subject can be found in Whelpdale (1978) who also reports an extensive bibliography.

Sulphur removal and transformation rate depends on intensity of the atmospheric turbulence, type of Earth's surface and chemical composition of the atmosphere. Removal and tranformation rates are time space dependent functions. In practical applications, they are mostly approximated by constant values.

Briefly, the dry deposition velocity for sulphur dioxide is of the order of 1 cm/sec, while for sulfate is ten times smaller. Wet deposition, i. e. in cloud and below cloud capture of sulphur dioxide and sulfate, is a discontinuous process, which depends on the latitude of the considered region. On annual basis, at Northern Hemisphere latitudes where most of emission occurs, it can be comparable with dry deposition. Due to dry and wet deposition removal rate can be estimated about few per cent per hour. Transformation of sulphur dioxide to sulfate can take place both by homogeneous and heterogeneous reactions. Transformation rate for both gas-phase (homogeneous reactions) and liquid phase (heterogeneous reactions) oxidation of sulphur dioxide is of the order of 1% h . No rate data are so far available on sulphur dioxide oxidation on the surface of solid particles.

Simulation studies of sulphur long range dispersion have been undertaken by applying both Lagrangian and Eulerian techniques. Lagrangian models (see, e. g., Eliassen and Saltbones, 1975; Sheih, 1977) are based on the computation of trajectories by using either 850 mb or geostrophic wind. Concentration is computed either by considering the sulphur mass balance of an air parcel which moves along a trajectory or by a Gaussian type model after estimating plume dimension by trajectory analysis.

In the Eulerian approach (see, e. g., Prahm and Christensen, 1977) sulphur dioxide mass balance equation is coupled with the sulfate ($SO_4^=$) mass balance equation to give the system:

$$\frac{\partial C_1}{\partial t} + \underline{\nabla} \cdot (\underline{V} C_1) = \underline{\nabla} \cdot (\overline{\overline{K}} \cdot \nabla C_1) + S_1 - K_1 C_1 \qquad (6)$$

$$\frac{\partial C_2}{\partial t} + \underline{\nabla} \cdot (\underline{V} C_2) = \underline{\nabla} \cdot (\overline{\overline{K}} \cdot \nabla C_2) + S_2 + K_3 C_1 - K_2 C_2 \qquad (7)$$

in which C_1 is SO_2 concentration, C_2 is $SO_4^=$ concentration, k_1 is SO_2 decay rate, k_2 $SO_4^=$ decay rate and k_3 $SO_2 \rightarrow SO_4^=$ transformation rate.

Long range dispersion modelling has been less experimented than the local one. This is due to the complexity of the data required. However, results given by the above mentioned authors are in general agreement with experimental data.

CONCLUSION

In the Northern Hemisphere the man made sulphur emission dominates the natural one. Expected increase of sulphur emission due to the increase of fossil fuel consumption, which has been forecast for the next years, poses the urgency of predicting in advance impact of new sources on air pollution and climate.

Since air pollution episodes occurred mainly at local scale, a certain expertise has been acquired in the application of models to simulate short range dispersion situations. On local scale, models proved to be able to simulate concentration patterns. Therefore they provide a valid tool to identify and apply optimal air pollution planning and control strategies.

Mathematical simulation of long-range dispersion has not yet been experimented as the one on local scale. Additional difficulties are caused by the parametrization of removal and transformation processes. International cooperation is required in order to provide data for model applications (see, e. g., OECD report, 1977). Results achieved so far by long-range dispersion studies lead to the conclusion that mathematical models can cope with this problem and can be used to evaluate interregional effects of sulphur pollution.

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EFFLUENTS FROM COAL GASIFICATION PLANTS

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Effluents from Coal Gasification Plants

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Plants for the conversion of coal are big industrial facilities which handle some millions of coal per year. Since these plants are so big and handle such tremendous streams of coal, their impact on the local environment may be considerable even if the effluents are relatively small streams. Figure 1 shows that gasification is one of the possible routes to produce forms of energy which may be easily transported and used without pollution.

The gasification process, however, produce effluents which may cause serious pollution if they are not handled properly. Besides, there exist solid, liquid and gaseous effluents, as well as other emissions. These emissions and the possible sources within the gasification plant are:

ODOR

Odors may escape from the following parts of a gasification plant:

-- sulfur-recovery,
-- wet slag and ash disposal,
-- different aqueous effluents,
-- tar treatment (depending on the type of process).

TOXIC GASES

The raw gas product which comes out of the gasification reactor must be treated. Before treatment it contains the toxic components CO, H_2S, HCN, COS. These gases do not escape during normal operation, but will be separated and/or converted to harmless and useful products like elemental sulfur. During start up, shut down, and periods of bad operation the gas flow will be burned in a flare, which is designed to handle the total gas flow. The amount of gas which might escape in case of an accident is small, and therefore has no serious impact on the environment.

NOISE

Noise may come from the coal preparation section especially the grinding, drying and storage equipment. But the air separation plant (most gasification processes use pure oxygen) may also be a source of noise. These noise emissions stem from machinery which is commonly known, and may be controlled by conventional means, if required.

VISIBLE PLUME

Visible plumes may rise from the flare stack, and from the cooling tower. The flare will be in operation only during start up, shut down, and in case of abnormal operation. The gas that will be burnt does not tend to form smoke. As a result, the plume of the flare will not be a serious problem. If a wet cooling tower is used, wet plume will rise like from any wet cooling tower. The capacity of the cooling tower will be somewhat less than in a coal fired power plant with the same coal intake, since the conversion efficiency in gasification is higher than in power generation. Cooling towers as such are generally accepted.

SOLIDS

Coal contains ash. Ash is produced as a solid residue. It depends on the kind of process whether the ash is susceptible to contamination by toxic substances or not. Generally it can be said that ash produced at high temperatures does not differ from the commonly known fly ash in conventional power stations, if it does not become wet while it is in contact with the toxic components of the gas product.

In a countercurrent process like a Lurgi-fixed-bed reactor ash is produced, and quenched with water at a point of the process where no gas product exists but only oxygen, and steam as gaseous components. In this case ash is produced as a wet product, but there is no contact of the wet ash with the gas product.

In entrained, i.e., concurrent processes it is necessary to remove as much as possible of the total ash in a dry state. An additional wet stage will always be necessary, since the gas product has to be completely solid-free before any catalytical treatment may be done. A number of schemes have been proposed, that facilitate the removal of a big part of the fly ash in a dry state. The wet fly ash needs treatment to remove the toxic compounds that are formed during the contact with water and gas product. Disposal of untreated wet fly ash may give rise to ground water pollution.

LIQUIDS

All coal gasification processes produce aqueous effluents to be distinguished from the organic liquids produced during some processes, since these organic liquids are useful as chemicals, or at least as a fuel. They are not effluents.

Aqueous effluents differ widely in quantity and the type of pollutant depending on which type of process is being used. The biggest stream of aqueous effluents is produced in gasification processes, that use the Lurgi-fixed-bed, nonslagging gasifier. The fixed-bed slagging process produces a smaller flow of aqueous effluent, that is laden more with contaminants. This process is not yet commercial, however, it has very good prospects in the future for economic reasons. Although there are no data from commercial scale plants, data from the pilot plant at the Ground Forks Technology research center are available.

A scheme of the Ground Forks pilot plant is given in Figure 2. The gas, that comes out of the gasifier, is being quenched in a spray washer. Part of the circulating liquid is discharged as a "gas liquor". This gas liquor is the main aqueous effluent. A smaller portion is obtained as a condensate from the gas cooler.

As an example, a material balance of a commercial gasifier is given in Table 1. "A condensate" is a portion of the aqueous effluent produced. Typical effluent data from a spray washer sample are given in Table 2. These data, as well as the data from Table 2 stem from reference 1, and reference 2, where additional information may be found.

Material In	kg	Percent
Steam......................	6,802	10.5
Oxygen....................	12,091	18.7
Fuel......................	43,400	66.9
Purge gas................	2,550	3.9
TOTAL................	64,843	100.0
Product gas...............	47,624	73.5
Slag......................	1,964	3.0
Condensate................	14,161	21.8
Unaccounted for loss......	1,094	1.7
TOTAL................	64,843	100.0

Tab 1 Material balance of a typical gasification process

TAR:		
Tar generated (dry basis):		
	lb/ton MAF coal	70.6
	gal/ton MAF coal	8.5
LIQUOR:		
Water generated	lb/ton MAF coal	822
pH		8.56
Alkalinity, ppm as $CaCO_3$		--
Turbidity, JTU		--
Conductivity, MHO		--
TOC, concentration[a/]	ppm	21,040
TOC generated	lb/ton MAF coal	17.3
NH_3, concentration[a/]	ppm	7,420
NH_3 generated	lb/ton MAF coal	6.1
Total dissolved solids[a/]	ppm	5,261
Inorganic dissolved solids[a/]	ppm	352
Sulfur, concentration[a/]	ppm	
Sulfur, generated	lb/ton MAF coal	
Sulfide, concentration[a/]	ppm	
Sulfide, generated	lb/ton MAF coal	
TOTAL EFFLUENT (LIQUOR & TAR):		
Carbon in effluent	lb/ton MAF coal	78.6
Nitrogen in effluent	lb/ton MAF coal	6.6
Sulfur in effluent	lb/ton MAF coal	
Pct of coal carbon in effluent		5.7
Pct of coal nitrogen in effluent		28.6
Pct of coal sulfur in effluent		

a/ All concentrations are calculated on the basis of total contaminant weight per volume liquid effluent produced, approximating probable steady state effluent concentrations

Tab 2 Typical effluent data from composite spray washer samples

Component	ppm	Percent
Phenol..............................	5,647	56.4
Cresol..............................	1,965	19.6
Xylenol.............................	453	4.5
Methylnaphthalene...................	34	0.3
Biphenyl............................	19	0.2
Dimethylnaphthalene.................	26	0.3
Fluorene............................	17	0.2
Carbazole...........................	9	0.1
Dibenzofuran........................	74	0.7
Phenanthrene........................	318	3.2
Methyldibenzofuran..................	101	1.0
Methylphenanthrene..................	76	0.7
Pyrene/Fluoranthene.................	100	1.0
Methylpyrene........................	178	1.8
Benzonaphthofuran...................	68	0.7
Chrysene............................	12	0.1
Benzopyrene.........................	71	0.7

Tab 3 Mass spectrometer analysis of organics liquor in aqueous fraction

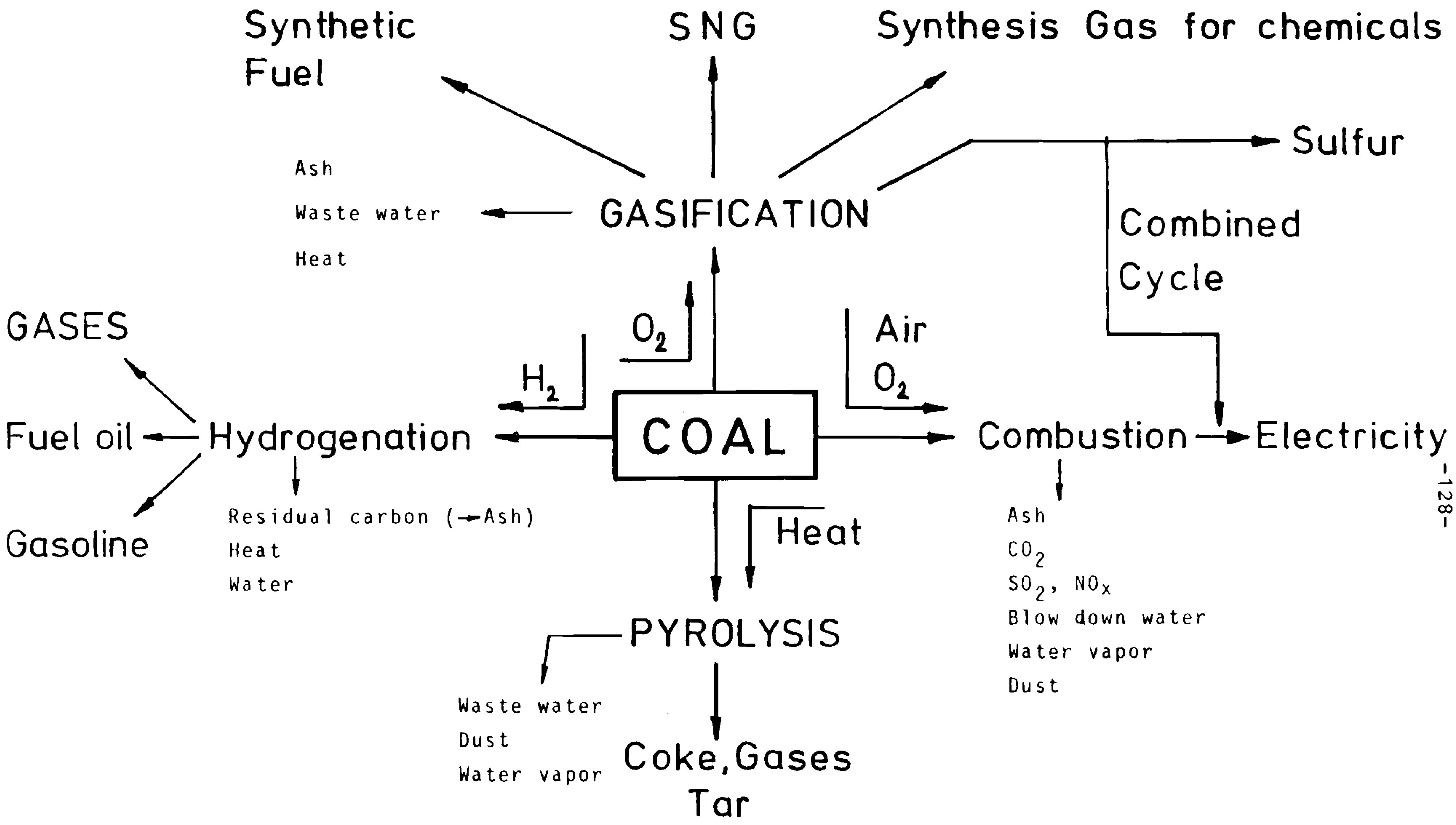

Fig 1. Common routes for conversion of coal

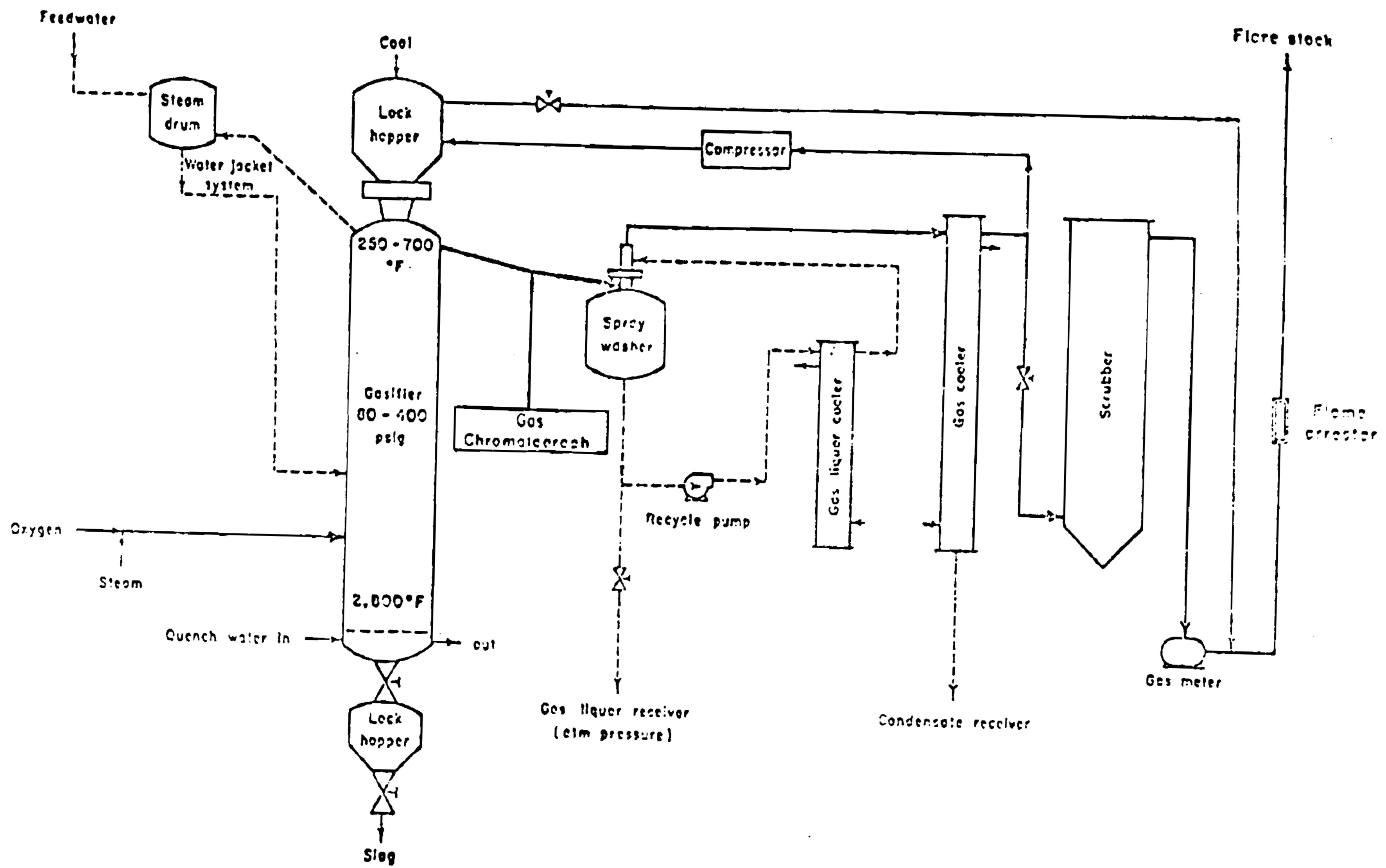

Fig 2. Schematic of gasifier pilot plant showing sampling locations

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