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# System Dynamics Simulation Modeling Applied to Western Coal Development Environmental Impact Analysis



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## Summary

This report, which was originally prepared in 1977 as an administrative report, evaluates the Geological Survey's first attempt to use simulation modeling in the environmental impact statement (EIS) process. It discusses the background of the modeling project, evaluates the usefulness of that project to the Northern Powder River Basin regional EIS task force, and recommends procedures for implementing future modeling efforts in regional environmental impact analyses. Major points are summarized below:

1. A system dynamics model (PRB) consisting of industrial, mining, demographic, and land use sectors was produced for the EIS region.

2. The modeling team helped the task force understand the proposed action and alternatives as time series scenarios.

3. The modeling team may have helped the task force develop a more holistic view of the relations between regional resource development and associated environmental impacts. This cannot be evaluated until the draft EIS is reviewed.

4. Several factors limited the usefulness of the modeling project to the EIS task force:

a) The 5-county model for southeastern Montana (WCR) was developed prior to the creation of the task force. The EIS regional model was based on the 5-county model, and received minimal input from the task force. Because they did not build the models, the task force did not adequately understand them.

b) The modeling team and the task force apparently held vastly different views of the modeling effort.

The Reston EIA staff and, to some extent, the task force apparently wanted a universal model into which one could put data for a proposed development in a specific area and retrieve a prediction of the related environmental impacts. The modeling team viewed the model building process as being an important

step to understanding causal relations and feedback mechanisms which operate between resource development and environmental impacts. To them, building the model was as important as using the model for environmental impact analysis.

c) Communication between the modeling team and the task force was poor--partly because of difficulties associated with this EIS, partly because of physical separation, and partly because the EIS task force and the modeling team had differing views of the role of the EIS and the modeling.

5. We still believe that simulation modeling has an important role in the EIS process. To fulfill that role, however, the following provisions appear necessary.

a) If simulation modeling is used in future regional EIS analyses, the task force must 'build' the models.

b) Someone on the task force ( ideally, one member of each work group) should have experience with simulation modeling.

c) Such a task force must be located in the same area, preferably within the EIS region.

d) The model must be viewed as a learning and integrating device to help the task force analyze impacts associated with a broad range of regional resource development options.

6. The modeling <u>concept</u> is transferrable from region to region. Possibly, parts of existing models can be adapted to different regions, but it is not possible to create a universal model framework to accept data from any region dealing with any resource.

## Introduction and Chronology

This report summarizes the work, conclusions, and recommendations of the Environmental Analysis Project concerning the application of simulation modeling to the EIS process. The project in computer simulation modeling of impacts associated with energy resource development began July 1, 1975, under the direction of Richard Doell. It was part of the newly developed program in Environmental Aspects of Energy Development begun that year in the Office of Environmental Geology. An original objective of the project was to produce a system dynamics model that would simulate major environmental impacts associated with coal development scenarios proposed for the Northern Great Plains. (1) Differences in attitudes, customs, and legislation regarding mining, reclamation, land use, water rights, etc., required that the project scope be limited to five counties in southeastern Montana. This region was chosen because it had experienced some coal mining in the past and had coal resources to support greatly expanded development. A new town (Colstrip) developed around an energy conversion facility (Colstrip 1 and 2) that was experiencing institutional delays in expanding (Colstrip 3 and 4). A varied cultural and demographic base existed including two Indian reservations underlain by large coal resources. In addition, a great wealth of information was available in the Northern Great Plains Resources Report and the state of Montana had an active Energy Research Council under the direction of then Lieut. Governor Christiansen, who was interested in the modeling project.

The Western Coal Region model (WCR) developed for the 5 counties in southeastern Montana is composed of six sectors; industrial, water, land, demographic, environmental indicators, and political. Many of the ideas used in conceptualizing the impacts of coal development in this region came from discussion with officials in various Montana state agencies. A draft report discussing the modeling methodology, assumptions and parameters in the 5 county model was prepared in September 1976. A revised version of that model has been published (Mark and others, 1978).

At the request of Assistant Director Balsley the modeling team made a presentation of the 5 county model to the Director and his staff late in September 1976. Following that presentation the modeling team met with the chief of the Environmental Impact Analysis Program and his staff to outline a

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(1) For a general description of the system dynamics methodology see Forrester (1961) and Goodmam (1974). For other examples of system dynamics modeling applied in the context of western coal development see Jacobsen (1975) and Ford (1976).

feasibility study to test simulation modeling by working with the task force preparing the Northern Powder River EIS. Because the modeling effort was new and untried in the EIS process, it was agreed that the EIS was not to be dependent on the modeling effort. The first meeting with the EIS task force took place in Billings, Montana, on October 5 & 6, 1976.

While the EIS task force was being organized, the modeling team prepared and circulated a draft report entitled: A Role for Simulation Modeling in the EIS Process; a Western Coal Region Example. This report, based on the 5 county simulation model, attempts to show how simulation modeling might be used by a decision maker faced with the requirement of attempting to minimize environmental damage while attempting to accomplish other objectives. The report (revised), is included here as Appendix A.

At initial meetings with the EIS task force we described the existing 5 county model in order to familiarize them with the methodology, the structure of the model, and the type of data required by the simulation modeling project. In June 1977, it was agreed that, because of time and manpower constraints, we would revise only the industrial, demographic, and land sectors, making them more compatible with the Northern Powder River EIS area. The revised three sector Powder River Basin (PRB) model and a discussion of it is included as Appendix B.

## Results

A complex interactive system dynamics model has been developed as a learning, planning, and impact analysis tool. It was not meant to predict the future, but to assess the relative impacts of alternative regional energy development scenarios in the five-county Northern Great Plains region. It also serves as a basis to evaluate the role of simulation modeling in the EIS process. The important result is not necessarily the model, but the first application of system dynamics simulation modeling to the EIS process. Our evaluation of the effectiveness of the modeling project obviously reflects some bias and a complete evaluation must include an analysis by the EIS task force as well.

In our opinion the modeling project has not been very useful to the task force during the past year (FY '77). It is possible, however, that the Powder River Basin model, described in Appendix B, will be useful when the task force collects, evaluates, and synthesizes the various topical chapters and site specific studies into a draft regional EIS.

Despite our pessimistic evaluation of the overall effectiveness of the modeling project as an aid to the task force, we think the modeling effort helped them to a limited degree in some areas. First, by exposing the members of the force to the methods of system dynamics modeling they became aware of a more holistic approach to the problems of resource development and associated impacts in the region. Whether or not that approach will be implemented is unknown at this time but may become clear when the draft EIS is available. Secondly, we believe the modeling project helped the task force understand and appreciate the proposed action and alternatives as time-series scenarios. For example, the modeling team demonstrated graphically the dramatic and unrealistic decrease in coal for export implied in the constant total coal production and increasing electricity generation plans described in an early version of scenario II. Again, we do not know if the task force will graphically analyze both development and impacts as time-series data in the EIS, but we think we demonstrated the validity and strength of such an approach. Thirdly, the modeling teams need for quantitative data, even if it represented a "best guess" of the numbers, identified gaps in the data base being compiled by the task force.

## Problem Areas

Although this section is considerably longer than the previous, the intent is not to be critical of technical and administrative support, but rather provide guidance for possible future activities. It is evident that only with full-time task force involvement can a project of this nature be successful.

Several factors led to the limited effectiveness of the modeling project. Perhaps the most important was a lack of understanding and enthusiasm for the modeling process by most members of the task force. The responsibility for this limitation lies, for the most part, with the modeling team. We arrived in Billings with a prefabricated, very complex model which the task force did not help build. Our presentations of the model, both oral and written, apparently did not impart understanding or generate significant enthusiasm for the method of analysis. Any interest generated while in Billings or Helena generally evaporated when we left. For more than a year, no one on the task force worked with the model and only during the last few months has anyone on the task force worked directly with the modeling team to help develop data and structural relationships for the Powder River Basin model.

Lack of communication between the modeling team and the task force adversely affected the use of modeling in the EIS process. To some extent the dispersed teams of the task force were difficult targets for the modeling team to interact with. Communication between the modeling team and the task force, as well as between units of the task force itself, would have been improved if all the members were centrally located in the EIS region. Obviously, this was impossible. Also the view points or paradigm of the modeling team and the task force apparently differed sufficiently to reduce communication. The modeling team views the EIS as a tool to analyze major planning options. We believe that a detailed analysis of the major issues, with particular attention to evaluating a wide range of reasonable alternatives to the "proposed action" (perhaps with the assistance of simulation modeling) would better satisfy the intent of the National Environmental Policy Act (NEPA). It might help to demonstrate the agency's environmental concern to the public better than a more traditional EIS. We perceived that the state team, moreso than the federal team, shared our view that the EIS is a planning tool. Unfortunately our aggregated model could not answer the site specific type of development options the state team wished to test.

We feel the effectiveness of the modeling effort was reduced somewhat because the task force lacked timely information about critical items such as the EIS boundary, the exclusion or inclusion of the Indian reservations, and the proposed action and alternatives to be considered in the EIS. Much of the responsibility for this information gap apparently lies outside the task force and may reflect a state of indecision in the Bureau or the Department, or both. The task force could have tried to influence and expedite decisions on critical issues regarding the regional EIS, but their impact was small if they had any at all. It took over a year for the task force to generate a table of scenarios on the proposed action and alternatives. The modeling team helped to reformulate the table of possible development steps into specific time series scenarios. Because the scenarios are the driving functions for the model, our Powder River Basin model was without any real input functions until July 1977. In August 1977 the task force was advised to expedite preparation of the Spring Creek site specific study and recess the regional EIS pending a decision on the Energy Minerals Activity Recommendation System (EMARS) program. As we have indicated, the model is not designed to look at site specific impacts so this action further separated the modeling team and the task force.

In summary, therefore, it appears the limited effectiveness of the modeling effort stemmed from lack of communication, lack of enthusiasm for the methodology , lack of close coordination and direction, lack of timely decisions on regional matters, and a lack of understanding or, at least, crossed paradigms regarding the major role of the EIS.

## Recommendations for Future Action

Based on the two years experience the modeling team has had, the following recommendations are given for future simulation modeling efforts. These recommendations are intended to improve an agency's impact analysis procedures in the EIS process.

1. The task force must build its own models in order to understand them and use them effectively. A prefabricated model is usually too difficult to

grasp without considerable work and too easy to ignore or distrust after a casual inspection.

2. The team should have available the benefit of previous modeling efforts and should include someone skilled in simulation modeling.

3. The model itself represented only a small part of the benefits of the modeling process. Building a model develops a holistic approach to the causal relationship between resource development and environmental impacts in the region.

4. Building a model is an excellent learning experience. It is a way for all of the task force to become familiar with many of the problems in the region. It fosters communications within the task force and between the task force and the affected groups within the region.

5. Building a model requires the task force to define the major issues explicitly. This is particularly important in a regional EIS where the proposed action is often less clearly defined than in a site-specific EIS. With the major issues clearly defined, the task force would be more efficient in gathering and organizing data pertinent to the analysis of the major problems.

6. The process of building a model helps to identify gaps in the data base and points clearly to areas of needed research.

7. Building a model may identify problems excluded from the regional EIS charter or guidelines. If so, the task force should be encouraged to point out these shortcomings to the agency in an attempt to improve the analysis.

8. Running a model can be an effective aid in analyzing a broad range of possible development scenarios and portraying graphically the possible levels of associated impacts over long time horizons.

Obviously, we still believe that simulation modeling could play an important role in the EIS process. For modeling to fulfill that role, however, an agency must look upon the EIS as a valuable planning document backed by reliable data and oriented toward analyzing policy options.

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# APPENDIX A

## A role for simulation modeling in the EIS process: A western coal region example

## Preface

On May 24, 1977, President Carter signed Executive Order 11991 directing the Council on Environmental Quality to issue regulations to Federal agencies for the implementation of the procedural provisions of the National Environmental Policy Act of 1969. That order stated-----"Such regulations shall be developed after consultation with affected agencies and after such public hearings as may be appropriate. They will be designed to make the environmental impact statement process more useful to decision makers and the public; and to reduce paperwork and the accumulation of extraneous background data, in order to emphasize the need to focus on real environmental issues and alternatives. They will require impact statements to be concise, clear, and to the point, and supported by evidence that agencies have made the necessary environmental analysis."

We hope this report shows how simulation modeling can help make the environmental impact statement process more useful to decision makers.

Abstract

The environmental impact statement (EIS) has not approached its full potential as a planning tool and a decision-influencing document. Typical EIS's for major Federal actions contain a large volume of information but lack a clear, concise analysis of the important impacts associated with both the proposed action and a comprehensive set of reasonable alternatives. System-dynamics simulation modeling could be useful in conducting such an analysis. Models may be particularly useful in the comparison of impacts as a function of the level and timing of development. In many cases modeling might be used as a working tool by an EIS task force for early identification of key issues.

## Introduction

Anyone reading an environmental impact statement (EIS) for a major project is immediately overwhelmed by volumes of information of various degrees of relevance. It is usually difficult, and it may be impossible, to determine how these data can be used to guide the agency's decision or action. In most cases the data have not been adequately synthesized into a clear analysis of the impacts associated with either the proposed action or any of the alternatives (see Carter, 1976). Whether by intent or evolutionary pressure, the EIS has become largely a catalog of data. Its value as a planning document to help the agency and the public analyze impacts associated with various policy options is thus diminished, and the decision maker is discouraged from fully using the EIS.

In an interesting analysis of the first five years of the National Environmental Policy Act of 1969 (NEPA), Dreyfus and Ingraham (1976) point out that the drafters of NEPA expected the EIS and the EIS process to modify, shape, and improve internal agency procedures for formulating and designing projects in the general public interest with minimal environmental impact. Instead, they maintain (p. 259) that the EIS has evolved into a "long, disjointed, and complex" document aimed at convincing outside interest groups and the courts that the agency is in compliance with NEPA. On the other hand, the number of environmental impact statements challenged in the courts indicates that outside interests and many agencies still interpret the letter and intent of NEPA quite differently. In addition to specific problems, critics of most impact statements allege inadequate coverage of alternatives to the proposed action, minimal attention to hard-to-quantify problems such as social impact (Friesema and Culhane, 1976), and belated, generally token public participation in the EIS process.

Simulation modeling may be a useful tool to streamline and clarify the impact statement itself and to help correct some of the general shortcomings of the process. The flexibility, ease, and speed with which simulation models can investigate a variety of development scenarios and their impacts make them logical tools to help evaluate alternative actions.

Simulation modeling is also a powerful learning device and can be an excellent means to stimulate a meaningful interchange of ideas. In some cases it may be possible to construct a simulation model through joint efforts of the agency and interested parties that would benefit all concerned. Defining the elements of the problem and their interrelation through open discussions early in the process and having a model incorporated in the EIS as a way of considering the impacts of policy decisions and alternatives could help focus the EIS process on important issues.

This report discusses output from a system dynamics simulation model. Although a comprehensive discussion of system dynamics modeling is well beyond the scope or purpose of this report, a brief summary of the basic concepts may be useful in understanding how the graphical relationships presented in a following section were obtained.

In the context of system dynamics, a system is a collection of elements that interact through time. A system dynamics model is a set of statements describing the elements of a system and how they interrelate to create some observed behavior. Such a model is a set of assumptions about a real world problem that is comprehensive enough to approach the behavior of a complex system yet is simple enough to be understandable and to have explanatory and perhaps predictive value. Because a system dynamics model is a simplification and abstraction of reality, it should be evaluated on its ability to reproduce the dynamic tendencies of a system whether they are growth, decline, oscillation, stability, or instability, rather than on its ability to provide precise values for the elements of a system at some future time. In this regard, our discussion of the graphical output from our Western Coal Region Model presented in the following section emphasizes the trend of variables under a given set of assumptions and not the exact numbers attached to the variables in future years.

An underlying thesis of system dynamics modeling is that the behavior of a system is determined by its internal structure. System dynamics models are constructed of two principal types of building blocks: 1. state variables, or levels, measure the state or condition of the system at any given time and 2. decision rules, or rates, determine the direction and rate of movement of measurable quantities in the system through time. At each point in time the state variables determine the rates. In our Western Coal Region Model examples of quantities accumulated in levels include total population, total area of surface mined land, water storage capacity, and coal reserves.

Comparable examples of rate variables include net migration rate of industrial labor, mined land reclamation rate, reservoir construction rate, and coal reserve proving rate.

Rate and level variables are interconnected in the model by feedback loops which are the basic structures of system dynamics models. A feedback loop is termed negative if a change in one element is propagated around the loop to result in a counteracting change in that same element. Starting from a given set of initial conditions our Western Coal Region Model, for example, responds to coal development scenarios that call for increased electric generating facilities in the region. The number of construction workers already in the region is compared to the number required to meet the scenario and if a discrepancy exists, the model simulates a net in-migration of construction labor until a sufficient labor force is accumulated in the construction labor level. At that point the in-migration of construction workers ceases. From this example it is obvious why negative feedback loops are called goal-seeking or self-correcting loops. A positive feedback loop, on the other hand, shows self-reinforcing characteristics that can lead to exponential change. One of the most important positive feedback loops in our Western Coal Region Model deals with the effects of boom town growth on industrial development. That behavior pattern starts when a greatly increased need for construction labor causes a rapid increase in population in a rural area. Because of institutional and information delays, public and private services are unable to increase at a rate to meet the needs of the expanding population; morale and productivity of the industrial workers decline forcing the influx of more labor to meet production schedules. This, in turn, creates an added burden on services already in short supply and exaccerbates boom town problems in a tendency toward an ever increasing spiral. It is the interplay of positive and negative feedback loops that gives system dynamics models their unique characteristics and ability to replicate behavior of complex systems. The particular value of a system dynamics model to a decision maker comes from its ability to identify pressure points, where simulated policy changes can be made and the model run again to test the outcome of that simulated action.

In the following sections we discuss briefly our Western Coal Region Model (Mark and others, 1977) and show how output from such a model might be used to consider and evaluate some policy alternatives and impacts of regional coal development in the western United States.

## Synopsis of the Western Coal Region Model

The Western Coal Region Model uses the methods of system dynamics (Forrester, 1961, 1968, 1969, 1971) to simulate what we consider to be some of the major interactions in western coal development. Most of the data comes from five counties in southeastern Montana. (1) The model is an abstraction and simplification of reality, and as such it does not and cannot predict the future. Essentially, the model is driven by a scenario of coal production and conversion chosen by the investigator. It provides graphical simulations of various impacts associated with that scenario between the years 1970 and 2000.

The model has six sectors: industrial, water, land, demographic, environmental indicators, and political. All variables are aggregated or averaged over the region, and no spatial distinctions are made. The industrial sector models development of surface mines, export facilities, electric generating plants, and synthetic fuel facilities in response to coal development scenarios such as those shown in figure 1.

The magnitude of industrial activity drives all other sectors of the model. Coal development and conversion facilities are developed to meet the indicated requirements of the scenario. Traditional land use in the region changes to new uses, monitored in the land sector, in response to industrial growth and its secondary effects. Water projects, possibly required for energy conversion plants or slurry pipelines, are simulated in the water sector. The demographic character of the region changes largely because of industrial labor requirements. Public and private services must expand, often rapidly, to meet the burgeoning demand of transitory construction workers and their dependents. All of these primary and secondary activities generate impacts on the land, water, and air; some of these impacts are modeled in the environmental sector.

In the political sector we have tried to indicate possible reactions to changes in the region that might lead to legal and governmental actions affecting the primary industries themselves. This type of process, where

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(1) Bighorn, Custer, Powder River, Rosebud, and Treasure Counties

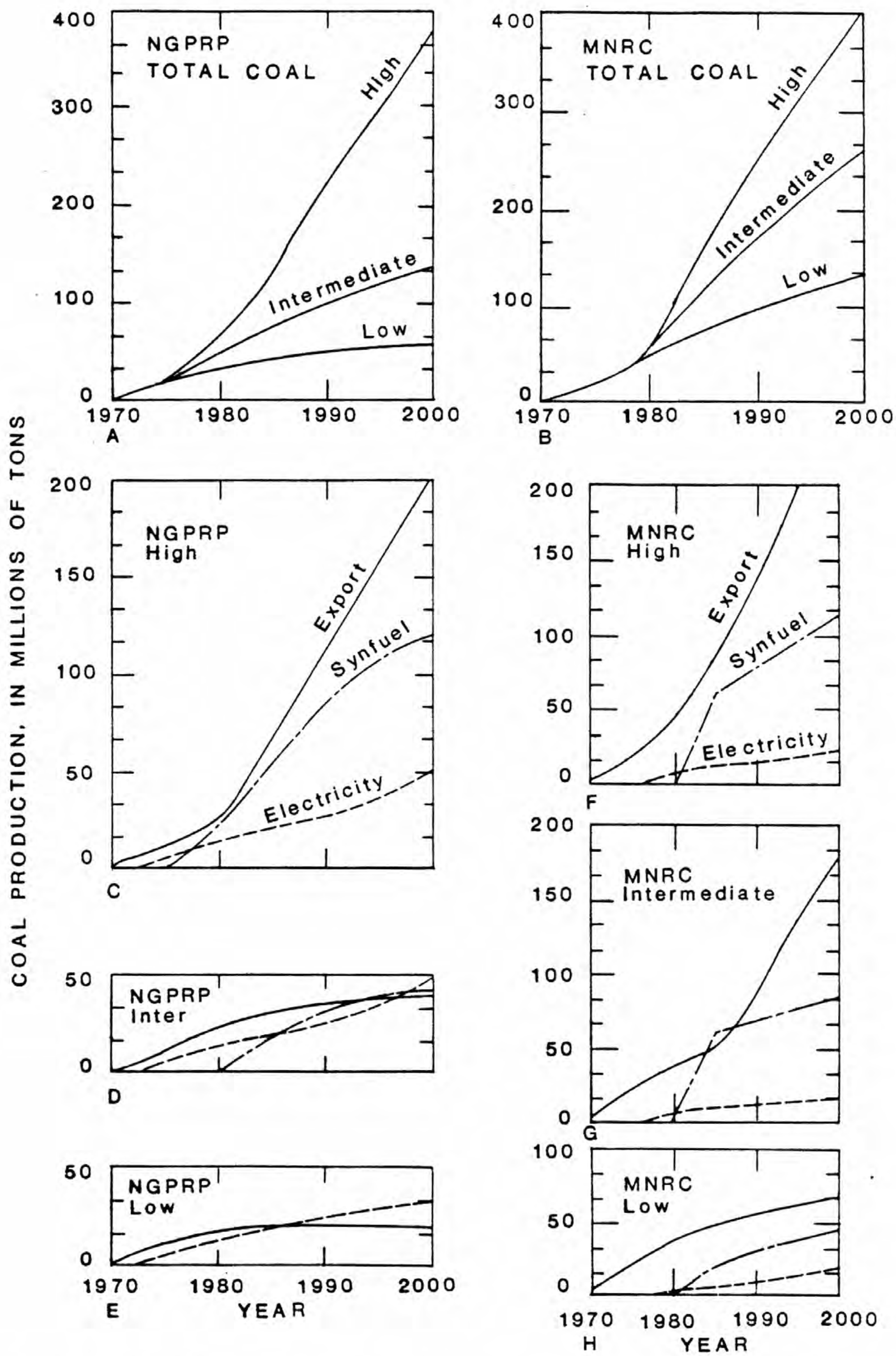


Figure 1.--Coal production scenarios used as exogenous input functions for Western Coal Region Model. A, Total coal production scenario proposed by Northern Great Plains Resources Program (NGPRP) and (B) by Montana Department of Natural Resources and Conservation (MNRC). C, D, and E Breakdown of "high", "intermediate", and "low" scenarios of A into export, synthetic fuel, and electric generation facilities. F, G, and H, Similar breakdown of scenario shown in B.

action in one part of the system affects itself through the operations of another part, is called a feedback loop. It is the mechanism that gives system-dynamic models their special character and ability to portray the dynamic, often counter-intuitive behavior of complex systems. For example, as industrial development progresses in the model, the "political climate for industrialization" improves, which in turn reduces the time required to obtain construction and operating permits, thus increasing, at least temporarily, the rate of industrial development. The most important feedback loop in the model simulates the adverse effects of boom town growth on industrial productivity and the social structure of the region.

In applying the model to a regional EIS, it is necessary to investigate problems and policy questions that are at the same scale, in time and space, and at the same level of aggregation as that of the model. The following section shows the type and scope of policy questions that might be investigated by a model such as the system-dynamic Western Coal Region Model.

Application of simulation modeling to a regional EIS

Obviously, a simulation model is just a tool and cannot be expected to fulfill singlehandedly all the requirements of Section 102 of NEPA. A model, after all, is constructed from the data and an understanding of causal relations gained by multidisciplinary research on the possible impacts of a proposed action in a specific region. However, a model provides an explicit structure with which to evaluate and better understand some of the long-term consequences of a proposed action relative to a wide range of alternatives. A system-dynamics model is particularly suited to the examination of dynamic effects of project timing and the overshoot effects of inherent system delays. (1)

In the following discussion, the coal production and conversion scenarios shown in figure 1 play the role of the proposed action and the alternatives to be evaluated in the EIS.

Any action, even the so-called "no-action" alternative, will produce changes

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(1) Overshoot is a phenomenon in which goals are surpassed due to delays inherent in the perception and correction process.

over time that may be perceived as benefits or adverse impacts depending on the outlook of the viewer. Of the many possible changes, a rapid increase in the population of a rural area and the stress it places on existing social institutions is generally viewed as an adverse impact. Figure 2 shows simulated changes in total population associated with the scenarios given in figure 1.

The "intermediate" scenarios more than double the initial population and the "high" scenarios more than quadruple the total population in the region over the 30-year time frame (fig. 2). Except for the "NGPRP low" scenario, all population curves show a boom-and-bust cycle which is particularly pronounced in the "intermediate" and "high" MNRC scenarios. It is interesting to note that the peak and trough of a boom-and-bust cycle might be so closely spaced that they would be missed if population projections were calculated at a few specific times and given in tabular form, as is commonly done in many EIS's. The graphs of figure 2 immediately raise the question,

"What causes the boom and bust cycle in projected population and why is it more pronounced in certain scenarios?"

In figure 3 we have plotted the simulated changes in specific segments of the population associated with the "NGPRP intermediate" scenario. The curves for agricultural labor and the Indian population are projections of historic trends in the region, which in fact may not continue into the future and which have relatively small offsetting effects on total population. Major changes in population are related to large changes in industrial construction and operations labor. The boom-and-bust cycle is clearly related to a large influx of construction labor for a relatively short time early in the development period. Figure 3_B_ shows that the severity of the boom-and-bust cycle in construction labor could be related to abrupt changes in the rate of development of synthetic fuel capacity. Intuitively, it appears that one possible way to mitigate the boom-and-bust effect in population is to avoid plans requiring abrupt changes in the rate of within-region construction. In light of this possible mitigating procedure, a decision maker reading the EIS might ask:

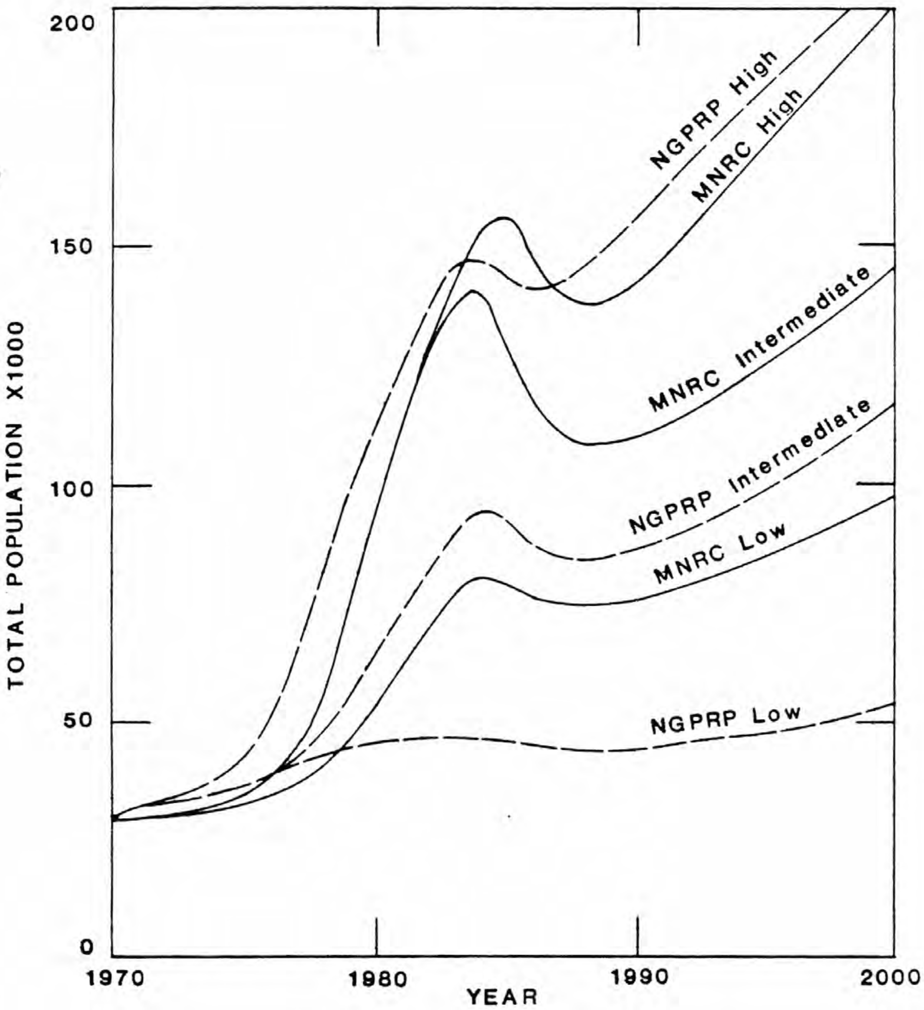
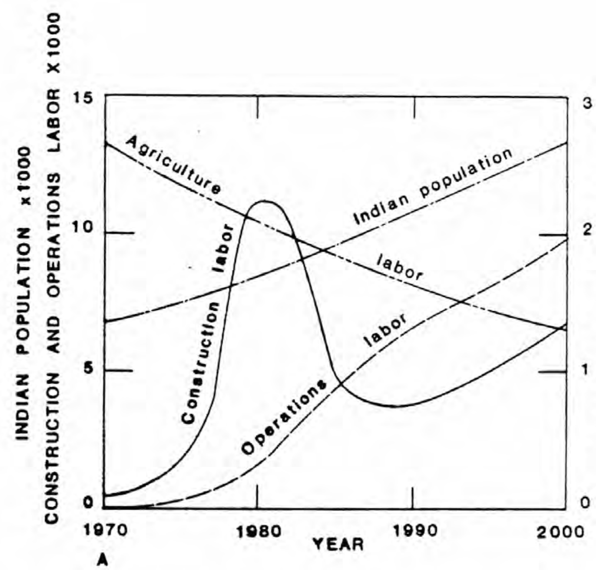



Figure 2.--Simulated population changes in western coal region as a result of coal production scenarios shown in figure 1. NGPRP, Northern Great Plains Resources Program; MNRC, Montana Department of Natural Resources and Conservation. Population decreases around 1985 are discussed in text.



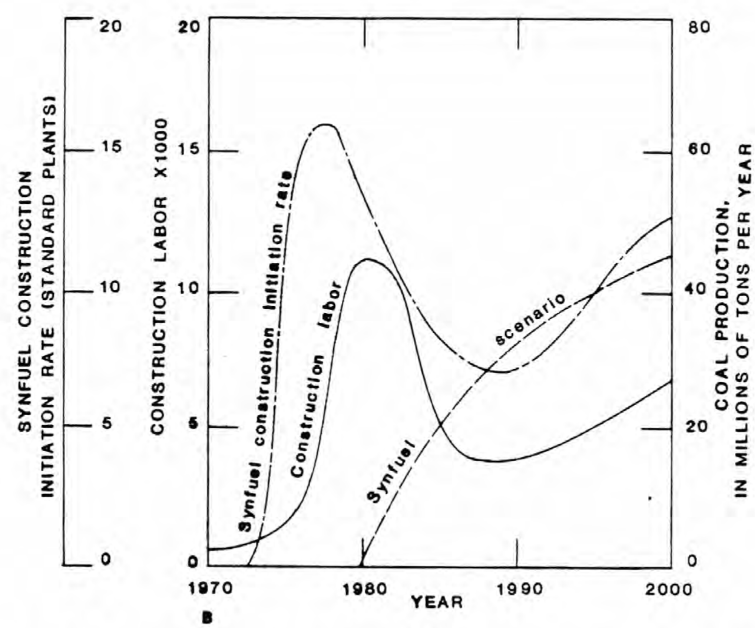




Figure 3.—A, Changes in specific elements of simulated population in western coal region assuming development according to "NGPRP intermediate" scenario (fig. 1D). Compare sharp boom-and-bust cycle in construction labor with boom-and-bust cycle in total population (fig. 2, NGPRP intermediate). B, Relation between "NGPRP intermediate" synthetic fuel (synfuel) scenario, synfuel plant construction initiation rate, and construction labor. Model assumes seven-year lead time between initiation and operation of synfuel plants. Abrupt beginning and rapid rate of synfuel plant construction about 1980 followed by significant decrease in rate of synfuel plant development after 1985 results in boom-and-bust cycle in construction labor.

"What would be the effect on population in the region if all the coal were exported?"

Under the "NGPRP intermediate" scenario, simulated total population more than doubles in the 30-year time frame (fig. 4). The average annual population increase is about 4-1/2 percent, with much higher growth rates during periods of rapid synthetic-fuel plant construction (fig. 1D). In contrast to that rate of population growth, the "all-export" option (fig. 4) results in approximately 1-1/2 percent growth per year or about a 60 percent increase in population over the 30-year period.

The stress placed on community life and social structures by rapid population growth has been given new emphasis in recent analyses of western energy boom towns. Gilmore and Duff (1975), for example, found that the failure of social services to keep pace with the rapid influx of construction labor in Sweetwater County, Wyoming, resulted in social disruption, reduced morale, and lower industrial productivity. Because much of the capital for new social services came from the new industrial tax base, lower industrial productivity meant less revenue and fewer social services which, in turn, led to higher turnover rates in labor and ever lower industrial productivity.

This type of system behavior, clearly a feedback mechanism commonly called a vicious circle, can be simulated. For example, someone using the model to help determine the level of future coal development within a region might ask:

"How much private and public service development is associated with various scenarios?" and, "If it takes an average of three years to establish the required public services, how well will services meet the demand?"

Figure 5 shows the relative levels of needed service labor for the three NGPRP scenarios.

In the early 1980's, the "low" scenario simulates a need for about 2000 public service workers in the region, which is about one-third the number called for by the "intermediate" scenario and only about one-fifth as many as required by the "high" scenario. With respect to mitigation of adverse boom-town effects, however, the level of services, represented here by service labor, is not as

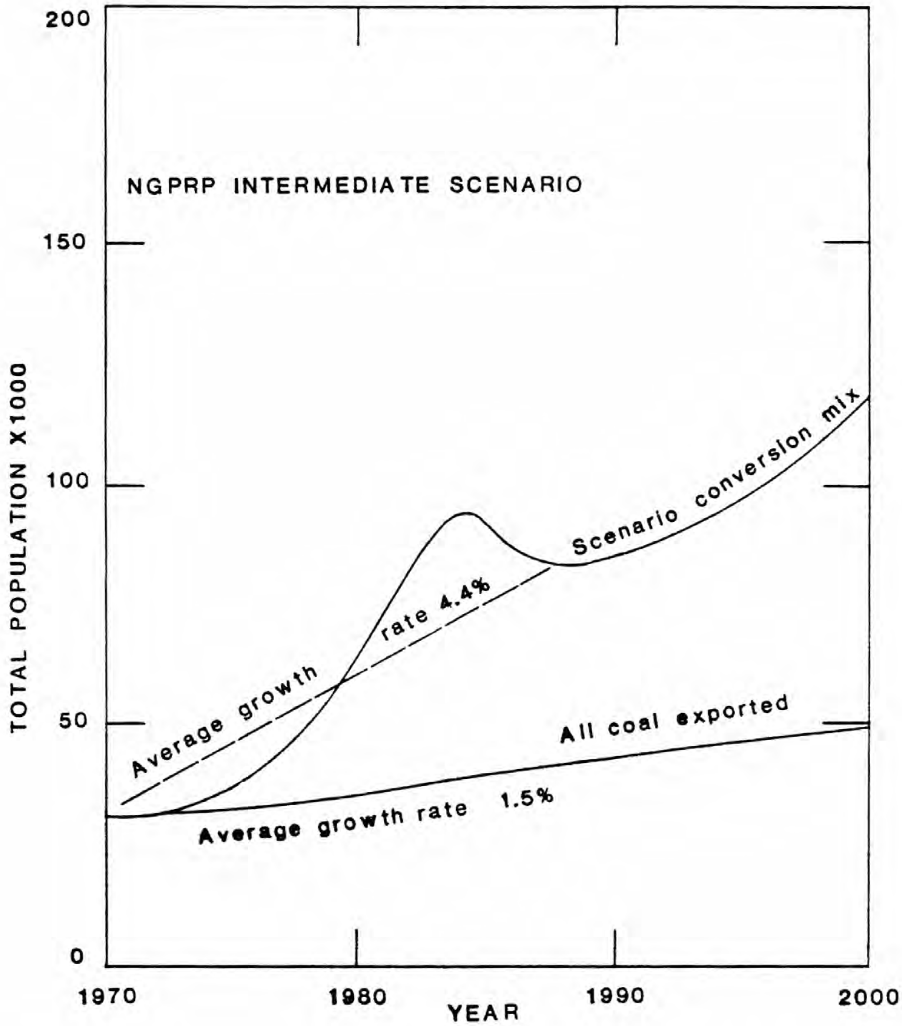



Figure 4.--Simulated population changes under "all export" option and proposed "NGPRP intermediate" scenario (fig. 1D). Gilmore and Duff (1975) suggest that 5 percent of annual growth is about as much as a small community can comfortably absorb.

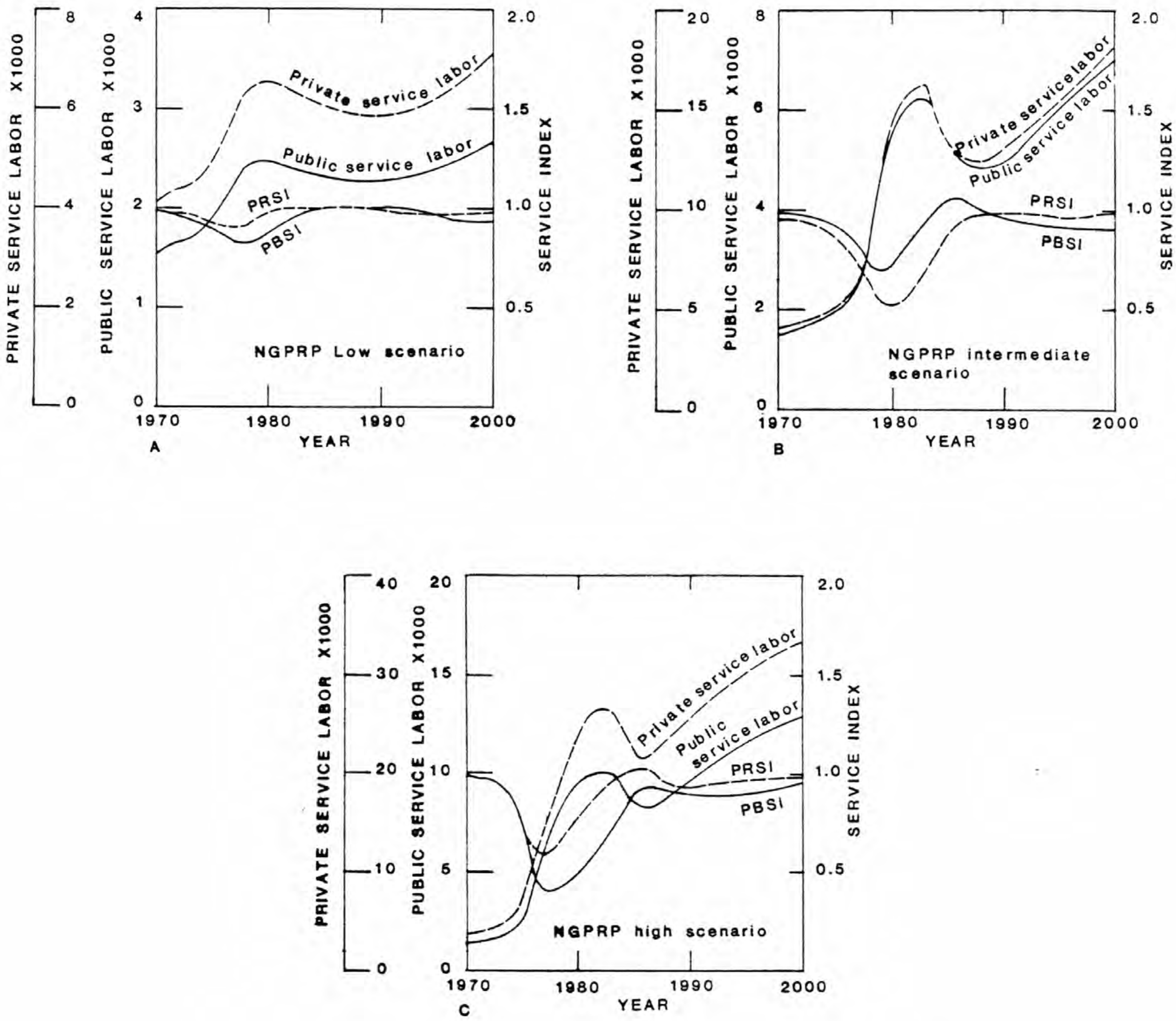



Figure 5.—Public and private service labor called for by NGPRP "low" (A), "intermediate" (B), and "high" (C) scenarios. Available public and private service labor within the region is time-delayed function of that required by scenario. Shortages or surpluses of service labor may develop if demand changes rapidly and rate of service development fails to keep pace. Shortage or surplus of service labor is indicated by service indices, where public service index (PBSI) and private service index (PRSI) are defined as ratio of indicated public or private service labor to available public or private service labor. Service indices less than 1 indicate shortage of service labor. In this run of the model delay time between indicated public service labor and available service labor is 3 years; that for indicated and available private service labor is 1 year.

important as the ratio of services available to services required. In the model, this ratio is identified as the service index (fig. 5) and is determined for both public and private service labor. In the model it is assumed that it takes an average of three years to set up a public service and one year to set up a functioning private service. The deviation of the service indices from 1 indicates a shortage (less than 1) or surplus (greater than 1) of service labor. Major shortages of service labor occur in the "intermediate" and "high" scenarios during the period of rapid industrial development (fig. 1D), which requires the greatest influx of construction labor (fig. 3).

Section 102 of NEPA requires an EIS to specifically identify those adverse impacts that cannot be avoided should the proposed action be taken. This has been interpreted to mean that some mitigating plan or plans should be devised for all adverse impacts simply to determine which cannot be avoided. In the past, few environmental statements have identified adequate plans to mitigate the major social impacts related to development, either because those impacts were ignored or because their solution was unknown or outside the scope of the agency preparing the EIS. Simulation modeling provides a way to manipulate a broad range of factors that may influence an adverse impact, and to test the consequences of possible mitigating plans on the rest of the model system. For example, an EIS that identified possible or probable service shortages in the region should respond to the question:

"What steps might be taken to lessen the shortage of public and private services?"

Figure 6 shows the effect of the all-export option of the "NGPRP intermediate" scenario on both the required services and the service indices. This option eliminates the boom-bust cycle in service labor shown in figure 5B and indicates that services are approximately meeting the needs of the region. The adverse impact of lagging service development in this option is avoided by reducing the rate of change in the number of people in the region (see fig. 4).

If the all-export option is not feasible, a possible solution to the service lag might involve shortening the development time for the required services.

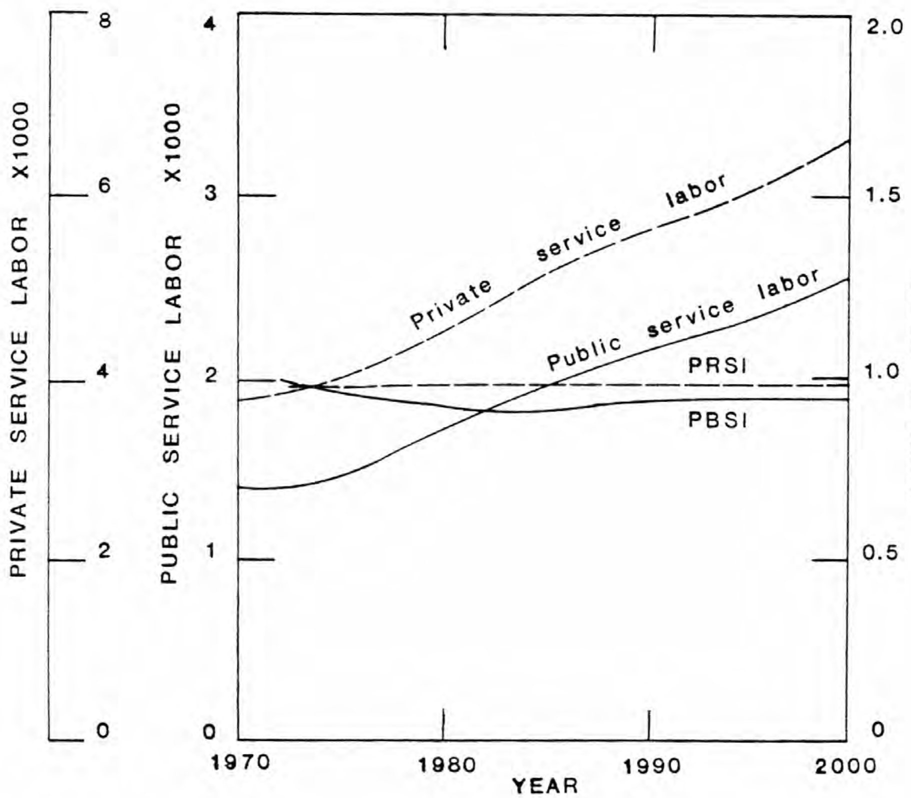



Figure 6.--Effect of "all export"option of "NGPRP intermediate" scenario on indicated public and private service labor and service indices. Delay times between indicated and available public and private service labor are 3 years and 1 year, respectively, the same as in the model runs shown in figure 5.

In reality this might be accomplished through more comprehensive advanced-planning by representatives of state and local government and industry and possibly by requiring industry to prepay part of their taxes for a specific time period to provide services during the construction period. In the model this effect can be simulated by reducing the delay time for the development of private services from 1 year to 6 months and that for public services from 3 years to 1 year. The results of this option are shown in figure 7.

In addition to impacts associated with possible rapid population growth, the potential impact of large-scale industrial water use is a general concern in the semiarid western coal regions. If water availability were identified as a problem in a specific EIS region, a decision maker might ask:

"What would be the difference in industrial water use within the region between (1) the "NGPRP intermediate" scenario, (2) the all-export option using 1/2 rail and 1/2 slurry pipeline and (3) the all-export option using only slurry pipelines?"

Figure 8 shows the relative industrial water use in these three options.

Up to this point we have looked at some of the impacts related to within-region development scenarios and their alternatives. Conceivably, national changes could produce impacts within the region that should be evaluated in a regional EIS. Consider, for example, a decision to significantly change national air quality standards.

In spite of its lower energy content and higher transportation cost, western coal is competitive with midwestern coal primarily because of its lower sulfur content. This competitive edge could be lost if air-quality standards were lowered allowing midwestern coal to be burned locally without the added cost of cleaning the coal or scrubbing the stack gas. Alternatively, if air-quality standards were raised to the point where all plants had to install scrubbing devices, whether they used western coal or not, the rate of western coal development might be changed significantly. The impact on a western coal region would depend on industry's response to a change in standards as well as to the time the change occurred with respect to the level and rate of

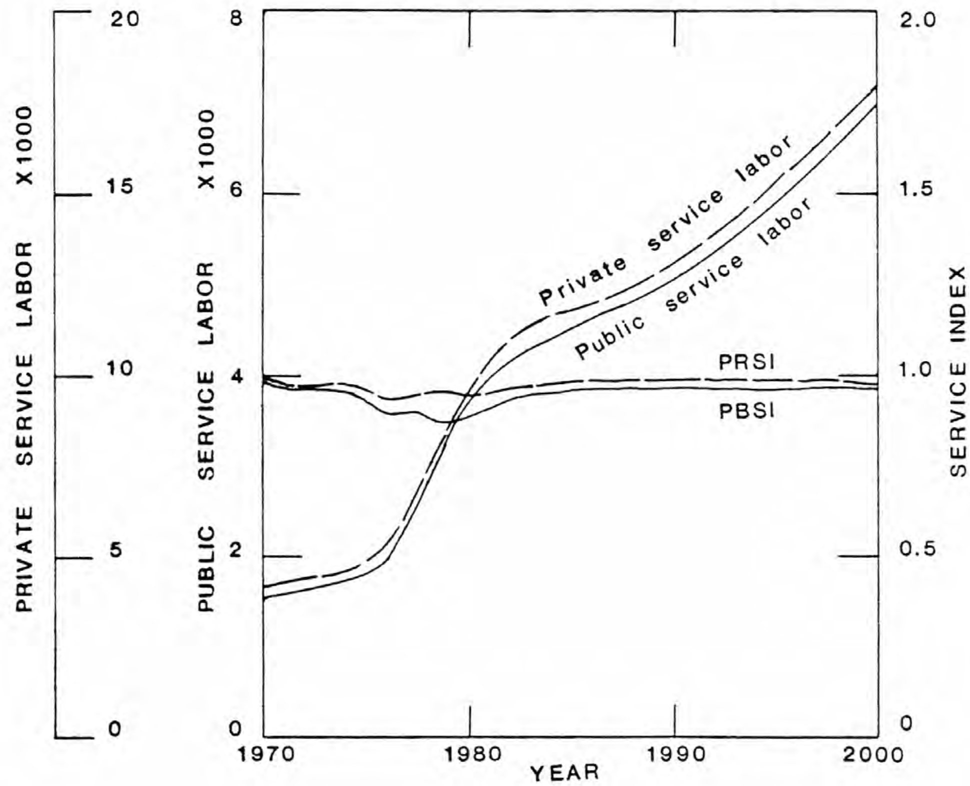



Figure 7.--Effect of "reduced service-development time" option of "NGPRP intermediate" scenario on amount of public and private service labor in the region and on service indices. Here, delay time between indicated and available public and private service labor is set at 1 year and 6 months, respectively; compare with figure 5B.

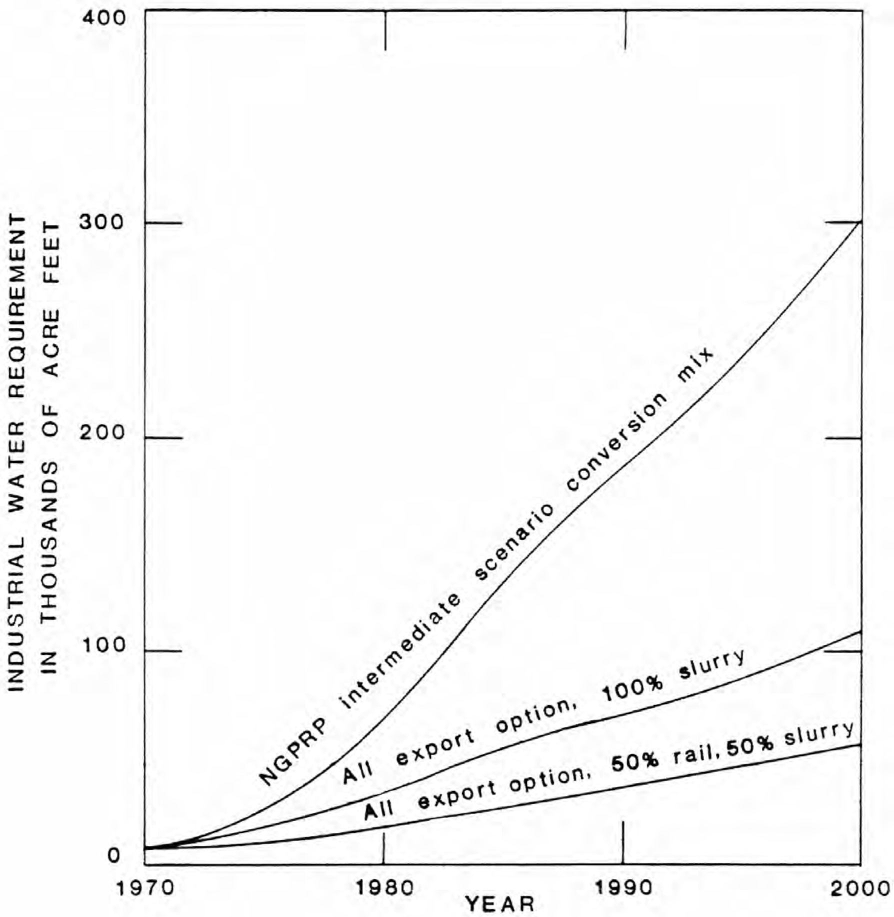



Figure 8.--Industrial water requirements for "NGPRP intermediate" scenario using (1) scenario conversion mix of export, synfuel, and electrical generation shown in figure 1D, (2) all-export option using only slurry pipeline transport, and (3) all-export option using half rail transport and half slurry pipeline.

development in the region. Clearly, the number of variables involved in analyzing such far-reaching changes outstrip the ability of most mental models. Few EIS's attempt such an analysis. Yet, this type of problem is a major concern to individuals and local governments within an EIS region who must plan for and finance private and public service facilities over long time periods.

An EIS task force, using simulation modeling, could not predict the exact regional response to a national policy change, but it could simulate a range of possible responses to a corresponding set of assumptions. For example, if we assume that (1) development in the region was progressing according to the "NGPRP intermediate" scenario, and (2) coal production and conversion facility development were constant after an unanticipated national policy change, we might ask:

"What would be the relative impact on total population and the availability of public service facilities if the policy change occurred in 1978, 1980, 1985, or 1990?"

Figure 9 shows total indicated coal production for the "NGPRP intermediate" scenario and the various indicated levels of production if the electric generation, synthetic fuel, and export levels were held constant beginning in 1978,1980, 1985, and 1990. The truncated coal production and conversion scenarios shown in figure 9 drive the simulation runs investigating the effects of a national policy change that limits interest in western coal. Due to an overbuilding of capacity (overshoot) and its subsequent depreciation, the curves for coal conversion and export facilities are not abruptly truncated or horizontal after the decision year. They are shown in figure 10.

Limiting western coal development in 1978 or 1980 under the assumptions mentioned above and those inherent in the model causes abrupt major drops in total population (fig. 11A) and correspondingly large surpluses in the public service index (fig. 11B). The unanticipated reduction in coal development and conversion facilities in 1978 or 1980 hits the region during the period of major synfuel plant construction (fig. 3B) therefore the consequences are more pronounced than in later years. Limiting coal development in 1985 or 1990

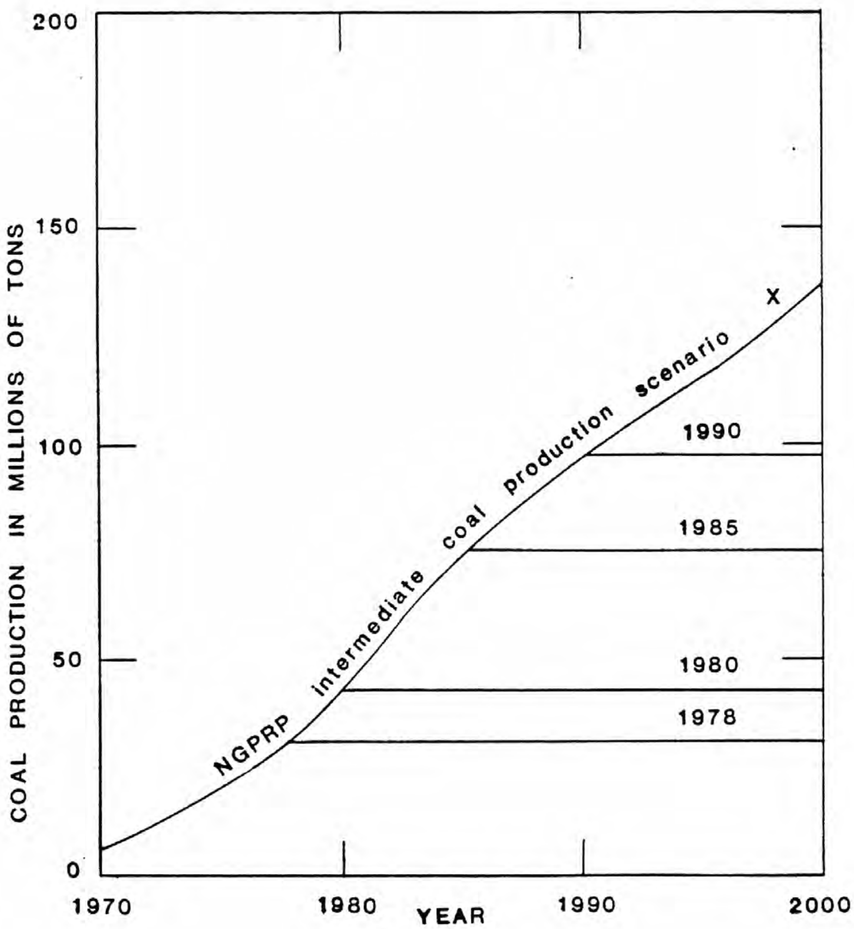
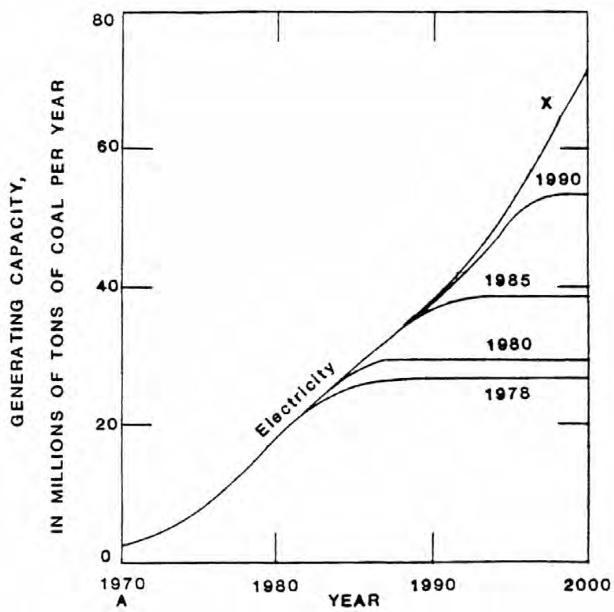
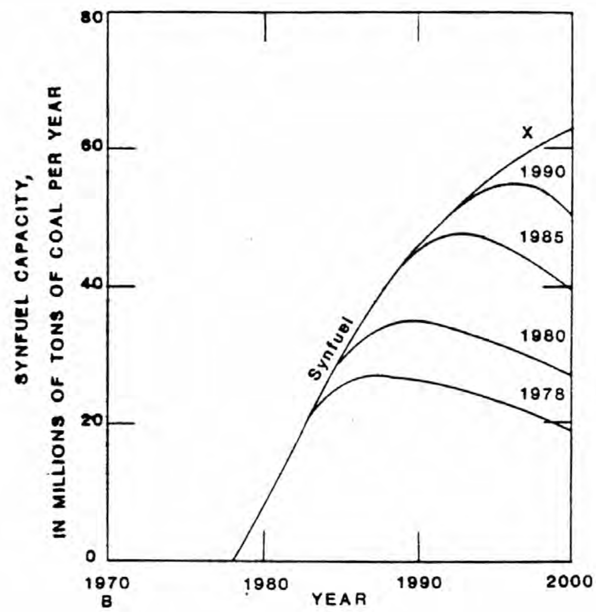



Figure 9.--Total indicated coal production for "NGPRP intermediate" scenario (x) and various truncated versions of that scenario in which indicated coal production is held constant at 1978, 1980, 1985, and 1990 levels in response to hypothetical national policy decision.



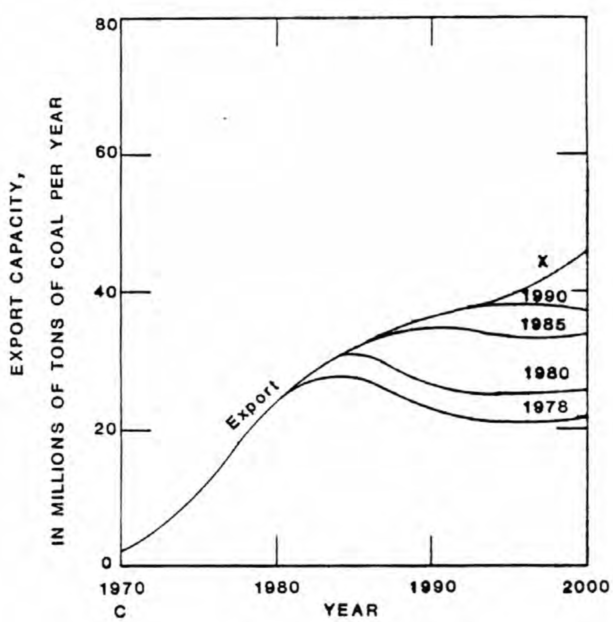
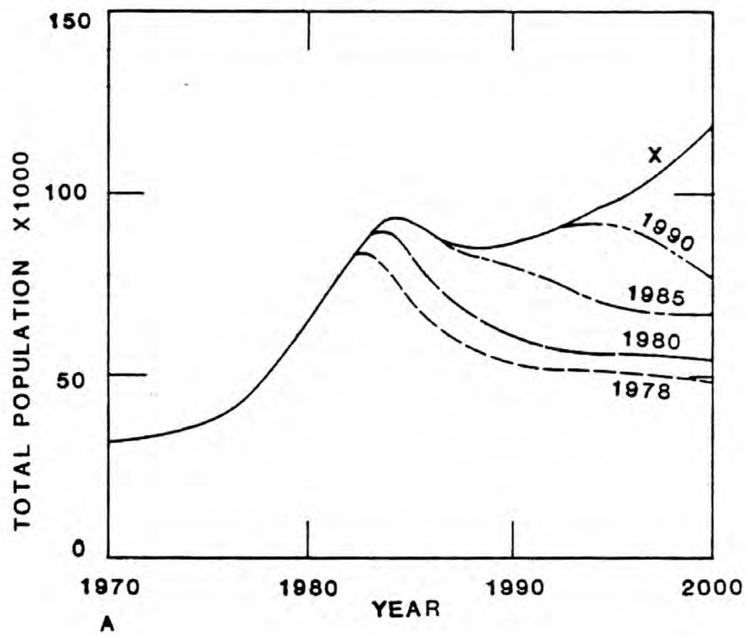




Figure 10.--Levels of coal export, synfuel, and electric generating capacity developed in the region in response to unanticipated national policy decision resulting in constant intended coal production in 1978, 1980, 1985, or 1990. Negative slope of synfuel and export facility curves after decision years indicates simulated depreciation of existing facilities. The model derates electrical facilities rather than depreciating them off-line. These curves simulate the impact on industrial development in the region caused by the hypothetical national policy decision, and they drive the model in runs investigating effects of decision on other sectors of model.



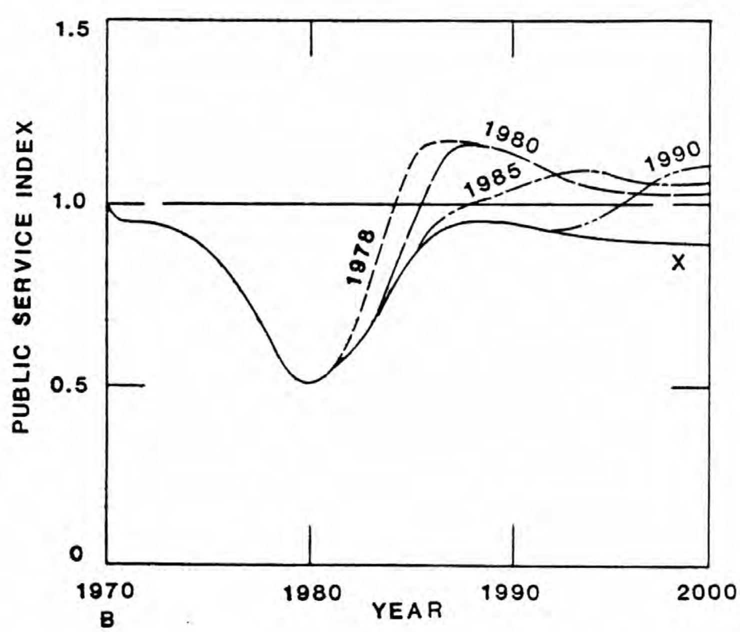




Figure 11.--Effects on total population (A) and public service index (B) if unanticipated national policy decision resulting in constant coal production were made in 1978, 1980, 1985, or 1990. Unclipped "NGPRP intermediate" scenario curves for total population and public service index are shown by (x) for comparison. Note large surplus of public service labor after decision year.

results in a somewhat less rapid decrease or bust in the population of the region than during the scenario truncated in 1978 or 1980, but the decrease in population is still sufficient to produce public service indices in excess of one. This indicates more public service labor (and capital) in the region than is required (fig. 11B).

The amount of land disturbed at any given time by surface mining can be estimated for the various truncated scenarios and compared to the amount associated with the unrestricted scenario (fig. 12). Because of the present uncertainties regarding the reclamation potential of semiarid western land, however, the cumulative amount of disturbed land may be more representative of the impact on the land in a western coal region than the amount of land disturbed at any given time. Figure 13 shows the cumulative amount of surface-mined land associated with the "NGPRP intermediate" scenario, and the relative amounts of land undergoing reclamation from surface mining according to that scenario if one assumes a 5-year or a 25-year reclamation time. It is possible that neither the 5-year nor the 25-year reclamation time curve in figure 13 is applicable to a specific region, but they may bracket the appropriate time and thus give a planner a reasonable estimate of the amount of land undergoing reclamation from any scenario.

This analysis of policy options and their impacts is far from exhaustive. It was not intended to be. Rather, we have tried to demonstrate the scope of questions that could be investigated by simulation modeling and a range of possible impacts associated with various alternatives. We hope that the examples given here will prompt agencies to consider simulation modeling as a tool in their EIS process.

## Implementing modeling in the EIS process

A period of testing is required to gain experience with applications of simulation modeling in the EIS process. Initial testing could involve internal modeling efforts either after or during the normal EIS process. The next step could be the internal use of simulation models by an EIS team. If this proved successful, the model could actually be incorporated on a limited basis into the EIS.

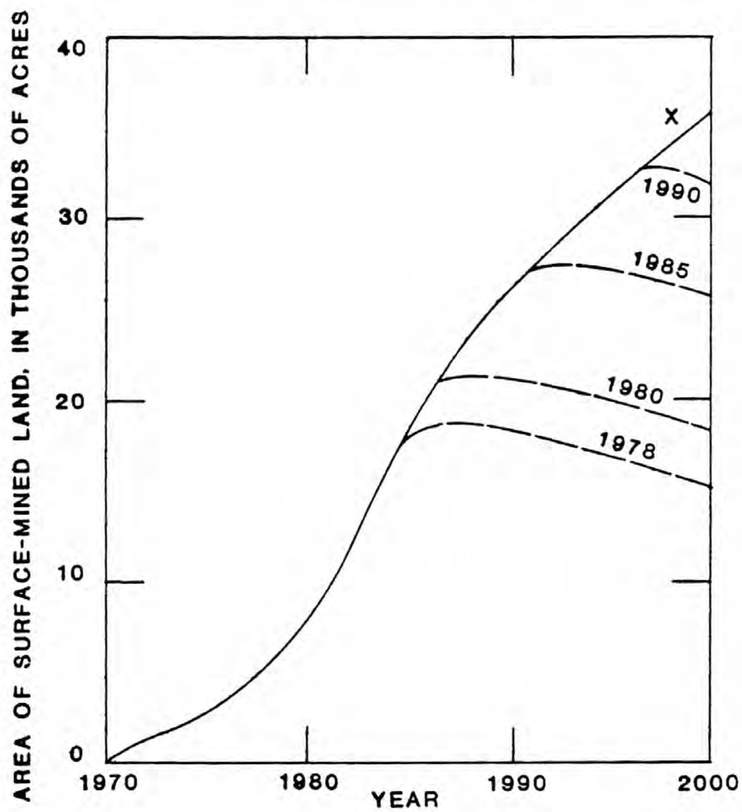



Figure 12.--Relative amounts of surface-mined land resulting from "NGPRP intermediate" scenario (x) and that scenario truncated by national policy decision at 1978, 1980, 1985, or 1990. Amount of surface-mined land decreases after year of policy decision because assumed rate of reclamation exceeds stripping assumed rate.

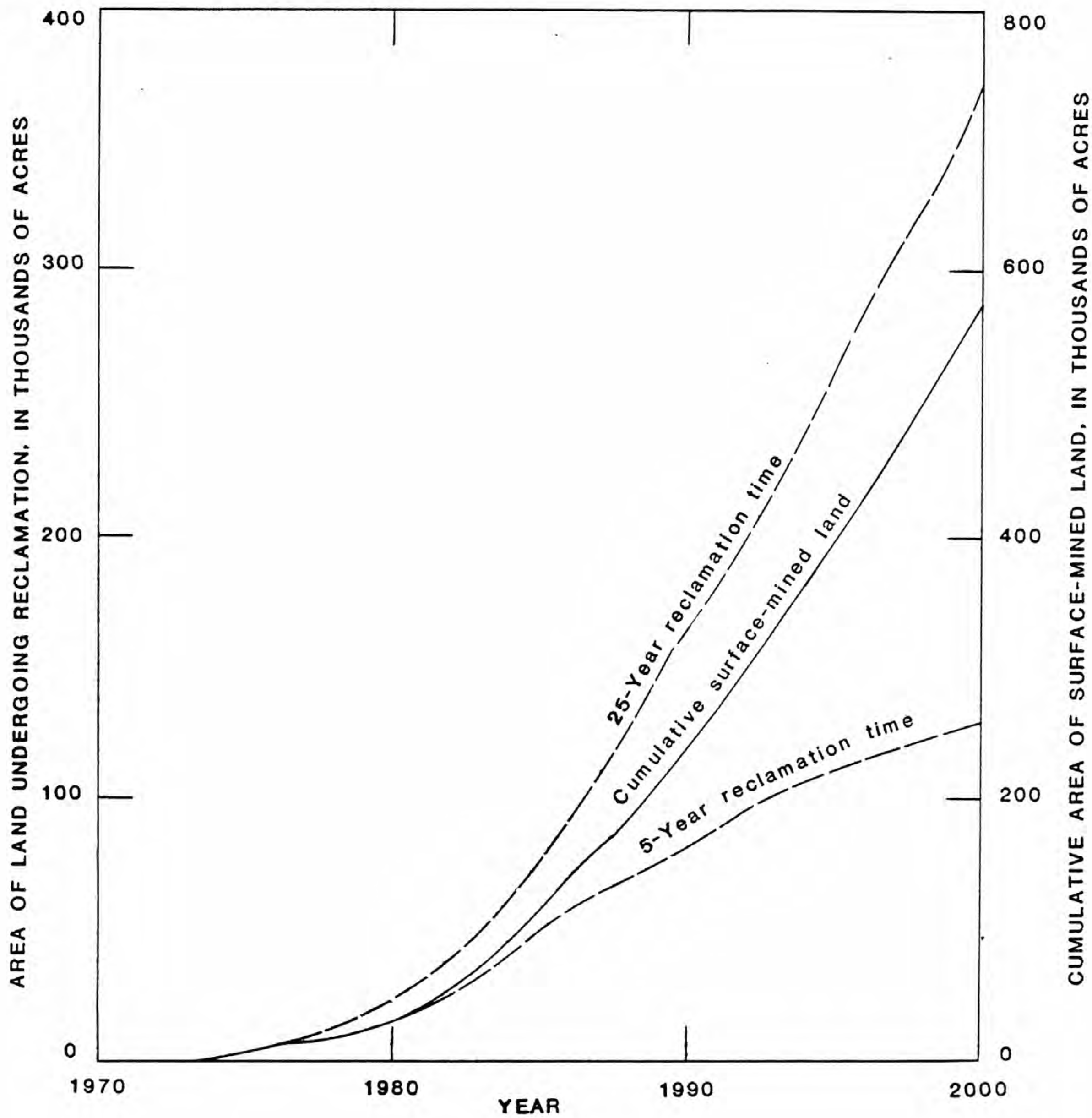



Figure 13.--Cumulative surface-mined land (solid line; right scale) and land undergoing reclamation (dashed lines, left scale) assuming 25- and 5-year reclamation times. Curves are related to "NGPRP intermediate" scenario.

Even if an agency used modeling only internally (that is, without public participation to help build the model), to aid in determining and displaying possible impacts of various actions, we feel this could make the EIS a more effective document and could strengthen the decision making process. In addition to aiding internal analysis, a limited modeling approach could demonstrate to a concerned public that alternatives have been considered and an attempt made to evaluate their impacts. Limited use of modeling in no way assures that a concerned public will accept the EIS or the agency's decision based upon it any more readily than under the present system. It is essential that models not become "black boxes", whose assumptions and limitations become opaque to the users. If this can be avoided then such an approach could make the governmental decision making process clearer to the public and thus help relieve frustration over what may be viewed now as arbitrary decisions by an unconcerned bureaucracy. An agency probably could incorporate simulation modeling on a limited internal basis without making major changes in its EIS procedure.

At the other end of the implementation spectrum, simulation modeling could be used to stimulate early, broad, and responsible participation by all parties concerned with a regional EIS. The availability of even a generic model with approximate parameters would help both a new EIS team and the public develop an overview from a system perspective. It would guide the team toward an analysis based upon cause-effect relations and help identify the type of data needed. Because simulation modeling emphasizes causal relations, it should be an effective tool to stimulate and focus early discussions between government, industry, and the public. The really difficult problem in simulation modeling is determining which factors are important and how they interrelate in either growing or stabilizing feedback relations. Different interest groups naturally see the components of a problem from different points of view. We think the EIS process would be better served if these various viewpoints were voiced and possibly incorporated into the simulation model at the very beginning of the process rather than after a draft EIS is written. Constructing a model incorporating either a consensus view or alternative views of a problem would be a major communication and learning experience. Not only would the public be heard, but their ideas would be included in a dynamic model that would evaluate a wide range of actions and alternatives in a holistic framework they helped devise. Once again, building a model to investigate the effects of an action will not ensure a course of action that will minimize adverse impacts, but it might help.

We recognize that broad use of modeling to invite and focus wide participation in the EIS process could require major changes in the EIS procedure of most agencies. More time might be spent preparing the EIS than is taken now, but this time might be recouped by eliminating litigation on the resulting EIS. Perhaps the use of modeling would help everyone involved in an EIS view the process as an opportunity to achieve a better decision and a better result and thus reduce the need for judicial enforcement of NEPA.

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Appendix B

Powder River Basin Model

## Model Characteristics

The Powder River Basin model (PRB) is a simplified version of the WCR model, and is limited to the industrial, mining, demographic and land sectors (Fig. 1). Both models are system dynamics simulation models which average or aggregate over the region of interest and are thus not applicable in site specific analysis. They are driven by development scenarios which we envision as alternative actions. For PRB, the scenarios specify synthetic fuel capacity, electric generation capacity, coal mining capacity, and rail route mileage as a function of time. Since both these models were originally designed to deal with a large number of facilities, subsector capacities are modeled as a continuous variable which cannot exactly follow the step function scenario of a single power plant or rail line.

The time horizon used in PRB is 1970 to 2000 and the model is only appropriate for examining effects which occur on a multiple year time scale. As with any simulation model, simplifying assumptions have been made. Where necessary, constants have been estimated. Simulation models should be regarded and evaluated as tools. This model is not intended to predict the future.

## Industry and Mining Sectors

The industry sector of the model is divided into three subsectors, synfuel production, electricity generation, and rail export. Although there are minor differences specific to the different activities, the basic model relationships of each sector are depicted in figure 2. The mining sector is also similar. The decisive process for each of the subsectors is the ordering and construction of new facilities . It is assumed that the scenarios represent economically and/or politically "desirable" developments which utility management will try to attain. New capacity is ordered so as to be on line as required by the scenario being simulated. Each scenario, specified by the EIS task force, can be considered an alternative action. Desired ordering, planning, and construction procedure can be affected by feed-back from elsewhere in the model. For example, a construction labor shortage due in part to boom-town-growth effects on worker productivity modeled in the demographic sector can lengthen the time of construction beyond that originally perceived.

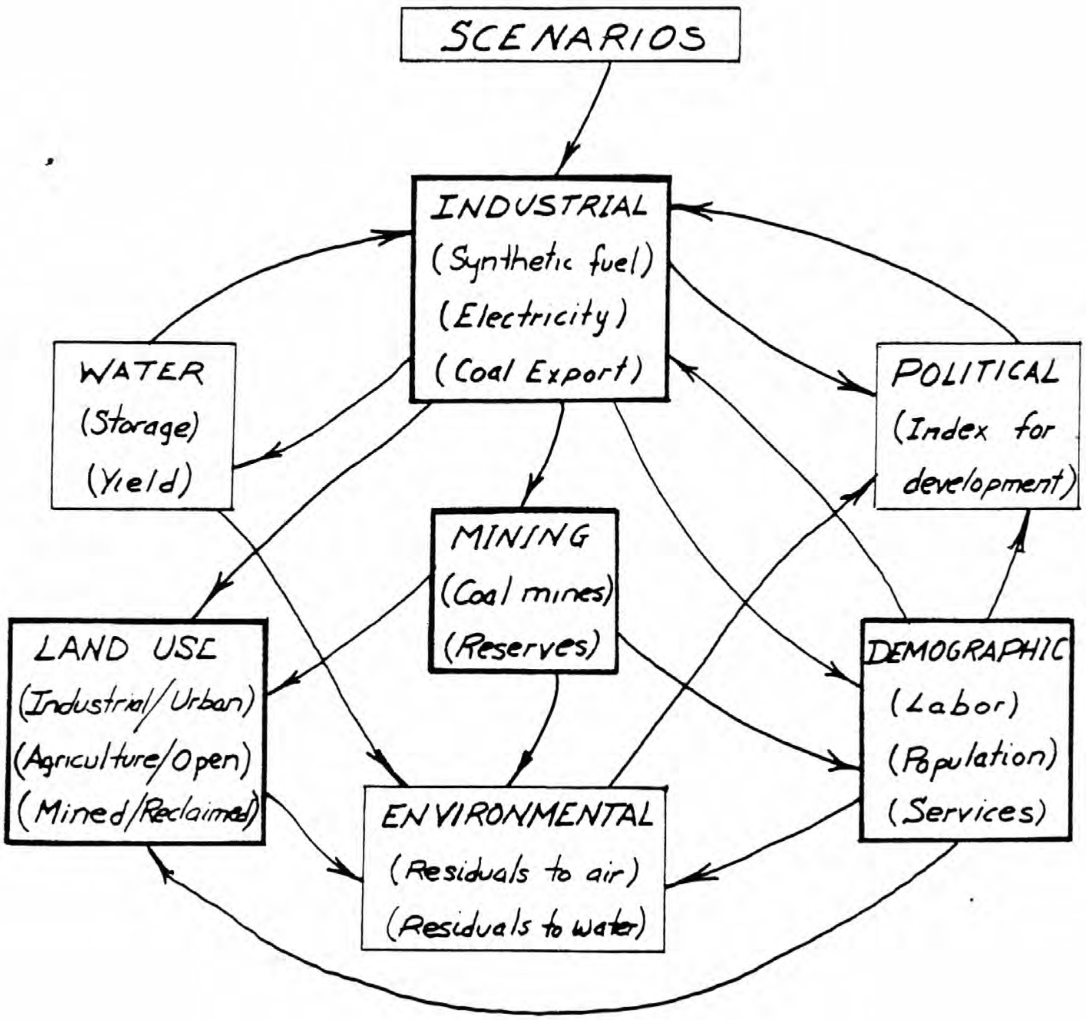

SCENARIOS
INDUSTRIAL
(Synthetic fuel)
(Electricity)
(Coal Export)
WATER
(Storage)
(Yield)
POLITICAL
(Index for development)
MINING
(Coal mines)
(Reserves)
LAND USE
(Industrial/Urban)
(Agriculture/Open)
(Mined/Reclaimed)
DEMOGRAPHIC
(Labor)
(Population)
(Services)
ENVIRONMENTAL
(Residuals to air)
(Residuals to water)

Figure 1

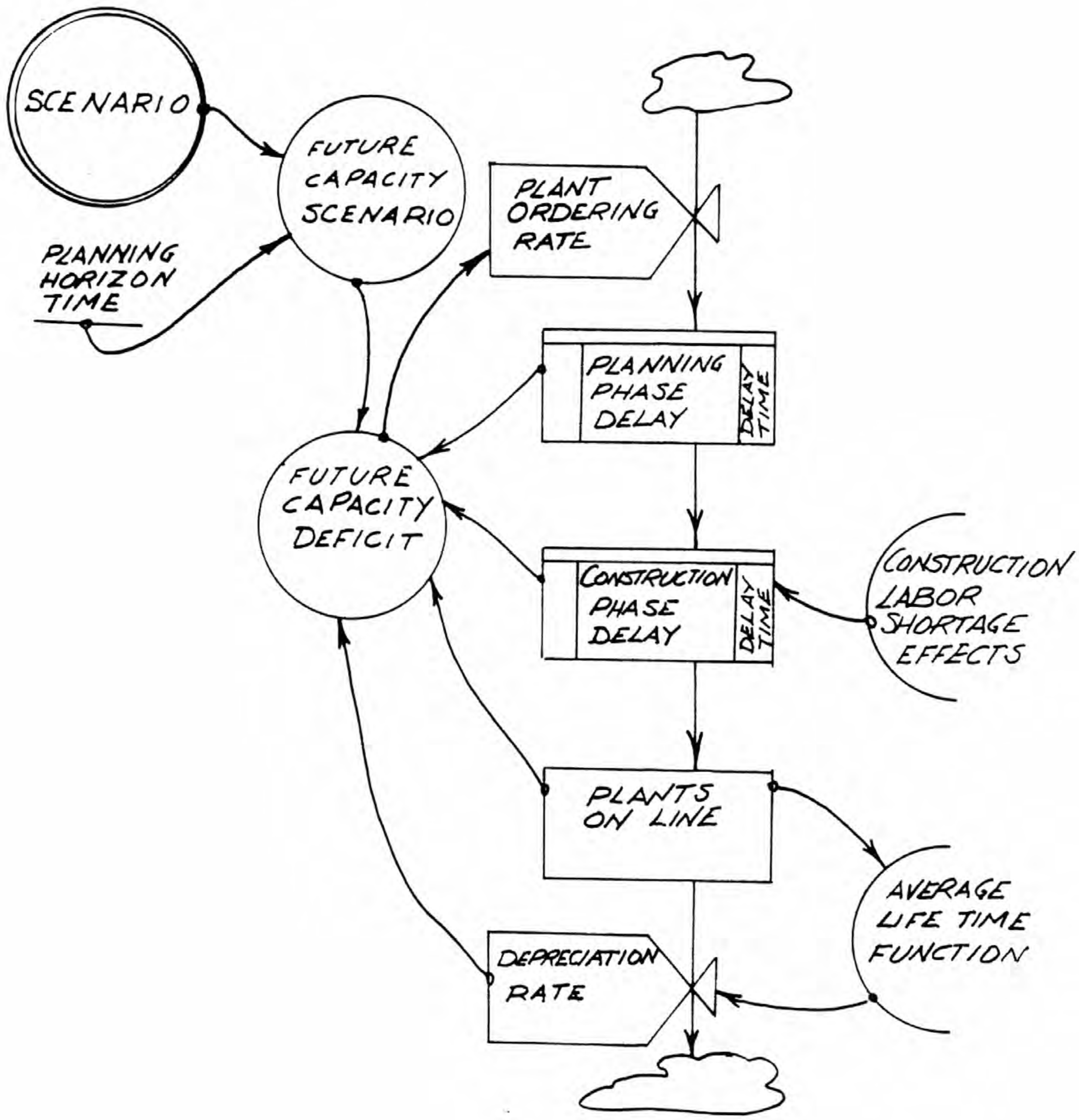

SCENARIO
FUTURE CAPACITY SCENARIO
PLANNING HORIZON TIME
PLANT ORDERING RATE
PLANNING PHASE DELAY
DELAY TIME
FUTURE CAPACITY DEFICIT
CONSTRUCTION PHASE DELAY
DELAY TIME
CONSTRUCTION LABOR SHORTAGE EFFECTS
PLANTS ON LINE
AVERAGE LIFE TIME FUNCTION
DEPRECIATION RATE

Figure 2

Demographic Sector

An important attribute of the model is its ability to indicate the demographic changes that may occur with various levels of industrial development.

The demographic sector of the model is driven by the industrial sector. That means the number of transient construction laborers that will move into the region is determined by the amount and rate of construction required to meet the projected development scenarios. The model calculates the number of construction workers needed to meet the scenario (see figure 3), compares that number with the laborers present, and adjusts the in-migration rate to meet any deficit between these values. The same procedure is followed to determine the operations labor required to run the plants after they are constructed. Both the construction work force and the operations work force is separated into Indian and non-Indian categories to provide for the possibility that coal leases on Indian lands may carry specific requirements for the employment of Indians in the industrial work force.

The construction labor and the operations labor variables work through a series of multipliers to determine the secondary labor required in the region. Specifically, secondary labor is divided into a public service category and a private service category. The required public service labor and the required private service labor are compared with the number of these service people actually in the region at any given time to calculate private and public service indices. The service indices provide a crude estimate of the ability of the region to maintain a reasonable degree of service amenities and to attract additional needed services. The construction and operations labor and the public and private service labor contribute, through family multipliers, to the total population in the region. In addition to the industrial and service labor, the model calculates a time varying agricultural population and Indian population in the region based on projections of historic trends.

The important feedbacks within the demographic sector relate the productivity of construction workers and the service development delay time to the private and public service indices through the boom index (Gilmore and Duff, 1975; Ford, 1976). It is felt that if services are not provided to meet indicated requirements, the quality of life will decline, construction productivity will decline, and industry will experience difficulty in attracting needed construction personnel. Thus, the variable, fractional

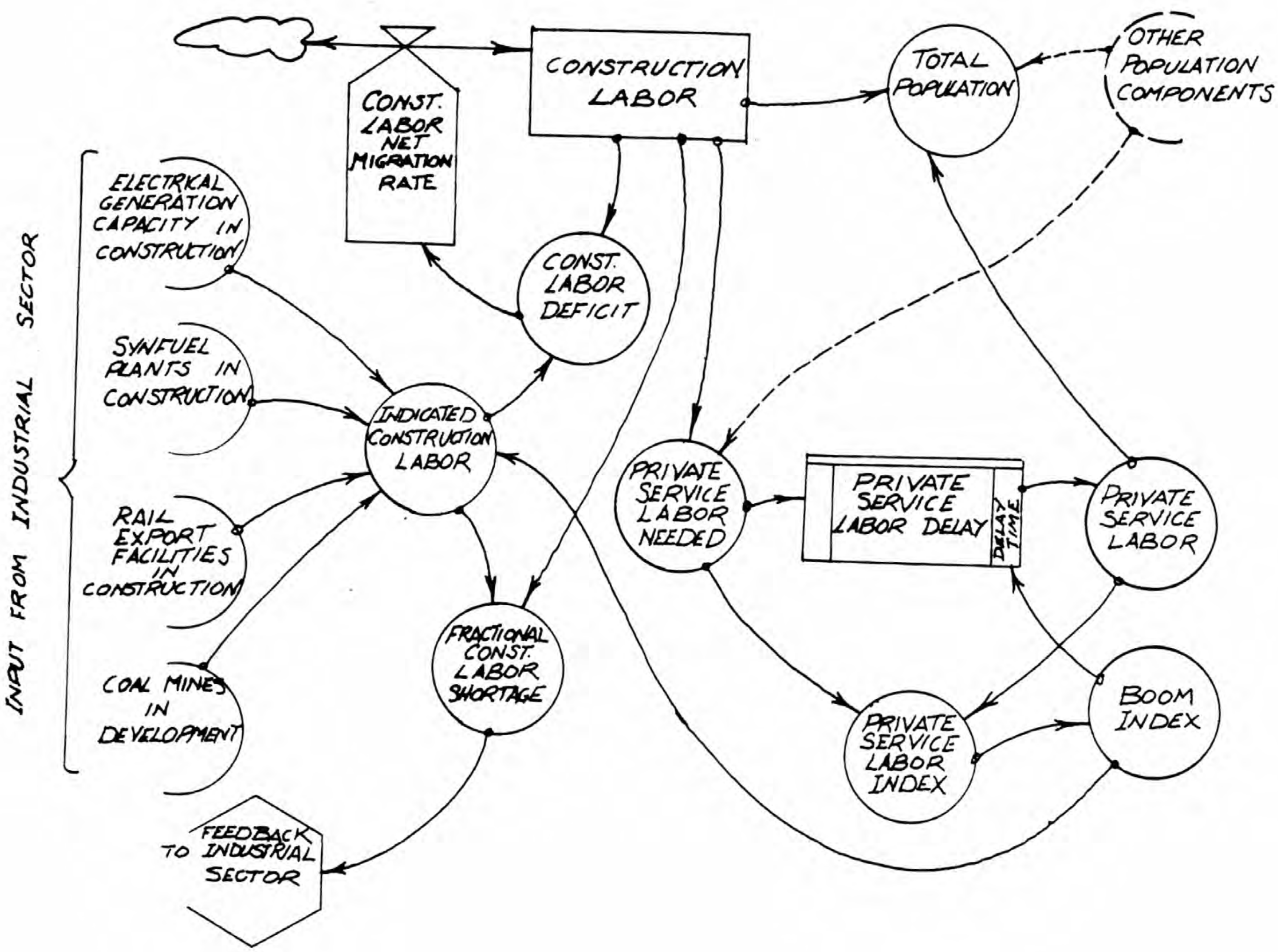

CONSTRUCTION LABOR
CONST. LABOR NET MIGRATION RATE
TOTAL POPULATION
OTHER POPULATION COMPONENTS
ELECTRICAL GENERATION CAPACITY IN CONSTRUCTION
SYNFUEL PLANTS IN CONSTRUCTION
RAIL EXPORT FACILITIES IN CONSTRUCTION
COAL MINES IN DEVELOPMENT
INPUT FROM INDUSTRIAL SECTOR
CONST. LABOR DEFICIT
INDICATED CONSTRUCTION LABOR
FRACTIONAL CONST. LABOR SHORTAGE
FEEDBACK TO INDUSTRIAL SECTOR
PRIVATE SERVICE LABOR NEEDED
PRIVATE SERVICE LABOR DELAY
DELAY TIME
PRIVATE SERVICE LABOR
PRIVATE SERVICE LABOR INDEX
BOOM INDEX

Figure 3

labor shortage, is used to alter the time constants for construction in the industry sector.

In this regionally aggregated model there is no way of analyzing local "boom and bust" cycles related to local development. It is conceivable that specific towns within the region will experience a relatively large influx of construction labor and related service personnel and, after the construction phase is completed, the construction labor will move to a new site still within the region but far enough away from the first site so that town experiences a "bust" in population. Such an effect could not be recorded in this aggregated model. However, if there is not significant intraregion migration of construction labor possibly because districts within the region experience similar construction schedules, then the modeling problem of local boom and bust cycles will not arise and the boom town growth phenomena for the entire region will be simulated.

Land Sector

This sector monitors land use in the region. Land use changes may be considered impacts themselves or they could be used to derive other impacts. Three major catagories of land use are considered: (1) agriculture and open-space land (range and forest land, dry crop land, and irrigated crop land), (2) land used for urban and industrial purposes, and (3) stripmined and reclaimed land (including land in the reclamation process). This sector also accounts for badlands induced through improper or neglected reclamation procedures.

The transfer of land from agriculture and open-space categories to urban and industrial uses is governed by the indicated requirements for industrial development and the growing non-agrarian portion of the population. Agriculture and open space land is also reduced by conversion to stripmined land in response to the land stripping rate determined in the mining sector. The stripmined land is then converted to either an unreclaimed category or, after a reclamation delay, to an interim reclaimed category. Finally, previously mined land may be modeled to return to agricultural and open space categories or to remain as unreclaimed land (ie. either land not subject to reclamation, or induced badlands).

Listing of Powder River Basin Model (prb)

Subroutines common to the Western Coal Region Model (wcr) are in Mark and others (1978) and are not repeated.

```
c ********** Northern Powder River Basin (10-06-77) *************
c
c This is the "master" program for the northern Powder River  Basin
c model.   Its major functions are to call the various model sector
c subroutines as they are needed, store the proper calculation  for
c the output, and  construct the output tables and graphs.  It also
c includes  a  few  data  statements, but like all other constants,
c some of these can be altered by the set statements.
c
c A detailed understanding of this master program is not needed  in
c order to run the model.
c
c To run the model:  Type  "ec prb" (terminate all lines with
c a "return")
c program prb (subroutine output) prompts "n:".
c Type "0" to set new plot variables
c      "9" to retain plot variables from previous run (if any)
c  or "99" to stop
c
c  prb (subroutine prbcat) then prompts "type show, set, or run"
c "show" is used to examine constants and is terminated by ";"
c  for example:
c          type show, set, or run:  show
c               show:    c(10)
c          c(10) = 5.0
c               show:    ;
c          type show, set, or run:
c
c "set" is used to change constants.  Changes remain in effect
c  until reset or the run is terminated.  "set" is also
c  terminated by ";" .
c  for example:
c          type show, set, or run:  set
c               set: c(10)=7.0,tc(6)=3.5,switch(99)=1;
c          type show, set, or run:
c    note, switch(99)=1 turns on the table printout
c
c "run" is used to begin execution
c
c ******************* start program statements ****************
c
      common time
      common/dt/dt
      common /t/ tnam(35),tmxx(35),ttim(35),tcnt(35)
      common/graph/put,max,min,flo,fup,opsym,ii,nput
      common/system/v(1000),c(1000),tc(1000),t1
      common/scenario/ctime
      common/switch/switch(100)
      integer switch
      integer indgo, lndgo, wtrgo, demgo, polgo, envgo
      integer opsym(10),ii(10)
      real flo(10),fup(10)
      real put(10),max(10),min(10)
c
c model termination date, iteration time interval, and
c time between ordering decisions.
      tstop=2000.0
      dt=1.0/32.0
      t1=1.0
c time after which development scenario is held constant
      ctime=0.0
c data needed for plot routine
      nprint=32
      nput=6
c default value for coal development scenario being simulated
      ncdp=2
c
c
c switch array  (0 is off, 1 is on)
c
      do 5 i=1,100
      switch(i)=0
 5    continue
c
c subroutine switches (0 is off, 1 is on)
```

```
c
      indgo=1
      wtrgo=1
      lndgo=1
      demgo=1
      polgo=1
      envgo=1
      mingo=1
c
c output arrays
c
      do 6 i=1,10
      flo(i)=0.
      fup(i)=0.
 6    continue
c
c set output symbols
c
      data opsym/0,'1','2','3','4','5',4*' '/
c -----------------------------------------------------------
c initialize constants
c
      call prbco
c
10    continue
c prompts for 5 variables to be plotted
      call output(ii)
c
c initialize dictionaries
      call indic
      do 305 i=1,35
305   tnam(i)=0.0
      do 315 i=1,10
      max(i)=-1.0e10
      min(i)=+1.0e10
315   continue
c
c initialize variable array
c
      do 101 i=1,1000
      v(i)=0.0
101   continue
c initialize levels
c
      call prbin
      time=1970.0
c following statement permits the use of set statements to
c alter constants, initial values, default values, etc.
c for any given simulation. (see instructions for making
c simulations). prbcat is written in pl1.
c
      call prbcat (v,c,tc,switch,ncdp,flo,fup,tstop,ctime)
c
c switch(98) can be used to reset dt   use power of 2
      if(switch(98).ne.0) dt =1.0/switch(98)
      if(switch(98).ne.0) nprint=switch(98)
c
c tpy = tons per year
c initial synthetic fuel capacity   million tpy
      v(14)=scenario(3,ncdp,1970.0)/c(3)
c initial electrical generation nominal capacity   tpy
      v(55)=scenario(1,ncdp,1970.)
c initial coal export capacity  million tpy
      v(80)=scenario(2,ncdp,1970.0)
c initial coal mine capacity   million tpy
      v(825)=totcoal(ncdp,1970.0)
c -----------------------------------------------------
c
      krate=1
      go to 500
c
20    continue
      kput = 1
      go to 600
c
```

```
40    continue
      if(time.ge.tstop) goto 95
      krate = 2
      kput = 2
50    continue
      kpr=0
55    time=time+dt
      go to 500
c
70    continue
      kpr=kpr+1
      if(kpr .le. nprint-1) goto 55
      go to 600
c
90    continue
      if(time .lt. tstop-dt) go to 50
c ------------------------------------------------
95    continue
      if (switch(99).eq.1) write(21,98)
c format to write octal 014 (form feed)
98    format(' 014')
      rewind 20
c
      call graph
c
      go to 10
c ------------------------------------------------------
c preliminary output subroutine
c
600   continue
c
c put(*)=output var
c
      put(1)=time
      do 700 i=1,nput-1
      put(i+1)=v(ii(i))
700   continue
      do 620 i=2,nput
      if(max(i).lt.put(i)) max(i)=put(i)
      if(min(i).gt.put(i)) min(i)=put(i)
620   continue
      write(20) (put(i),i=1,nput)
c
c for output table, set switch(99)=1
      if(switch(99).eq.1)write(6,99)(put(i),i=1,nput)
      if(switch(99).eq.1)write(21,99)(put(i),i=1,nput)
99    format(1h ,6f10.2)
c
      go to (40,90), kput
c
c ---------------------------------------------------
c
500   continue
c
c sector subroutines
c
      call prbind(ncdp,indgo)
      call prbmin(ncdp,mingo)
      call prbwtr(wtrgo)
      call prbdem(demgo)
      call prblnd(lndgo)
      call prbpol(polgo,ncdp)
c
      go to (20,70), krate
      end
```

```
c    *************** Industry Sector (09-12-77) ***************
c
c This   sector   simulates   the   growth of the   coal   industries  in
c the  region,    so  as  to  provide  data  for  impacts  of  these
c industries in other model sectors, and to accept feedback   which
c may   influence  the   growth   of the industries.  The sector is
c divided   into   three   subsectors:   synthetic  fuel   production,
c electrical    generation,  and   rail    export.   There  are three
c principle exogenous inputs to the sector: these are  the  assumed
c scenarios  for synthetic  fuels, electricity,  and  for coal rail
c facilities in the region.   These  exogenous  variables  are  the
c primary  "driving  forces" of the model and  thus  determine  the
c relative  magnitude  of   development, impacts, etc.
c
c The decisive process for each of the subsectors  is the  ordering
c and  construction  of  new   facilities .   It  is  assumed  that
c the   scenarios   represent   economically   and/or   politically
c "desirable"  developments which  utility  management will try  to
c attain.   However,  the  desired rates of acquiring  new capacity
c may    be    modified    by    several    other    factors,    such    as
c "political climate" for industrial growth, labor shortages, water
c shortages, etc.
c
c The  basic  unit  of  energy is one million tons of coal (at 9000
c btu/lb).  In addition, for the  electrical  generation  subsector
c the model also calculates the  number  of "standard 1000 megawatt
c electrical generation (mwe) plants", and  for the  synthetic fuel
c subsector the number of "standard 250 million standard cubic feet
c per day (scfpd) plants".
c
c The   following   text   generally  describes all  three  subsectors.
c The program begins in  each  subsector  by  calculating  scenario
c planned capacities v(3),v(38),v(73) for each of the industries by
c calling   the   function  "scenario" which contains the data for
c the scenarios being modeled.  Note that these three  calculations
c are  made   for  times tc(3), tc(38), and tc(73) into the future;
c these planning  horizon  time   constants   are   the   perceived
c times   for  construction   of   the   three   different types of
c facilities.  For synthetic fuels  the scenario  must  be  divided
c by    the    nominal    capacity    utilizations   of  this industry,
c c(3), since the scenario is  for  energy output  and  the  model
c calculates plant capacity.  By setting  switch (02) to a value of
c 1,   the  model  will  transfer all  demand  for  energy  to  the
c rail   export   sector.  One may also  change  the   scenarios   by
c use    of    the   exogenous   scenario modification  variables;  for
c example, if one wished to model the effects of a flue gas   clean
c up  technology  breakthrough  at  a future  date  (making midwest
c coal suddenly more attractive), one could program these variables
c to take on values less than one  at the desired time.
c
c The   next   actions   are  to determine construction, planning, and
c regulatory delays that may be influenced by labor  shortages  and
c political   climate  for  industrial  growth, and to set the delay
c variables  in  the  subsectors.   Following   this,   the   model
c determines  plant and capacity depreciation rates. In the case of
c electrical   generation  the  plants  are  derated   rather   than
c depreciated  since  older plants are generally used less and less
c for base load as they age.
c
c The variables which initiate ordering are the capacity initiation
c rates v(5),v(40),v(75).  They are  calculated  from  the  deficit
c between scenario planned capacities and what is expected to be on
c line at the planning horizon times (present capacities plus those
c in  planning and construction less those that will have also been
c depreciated).
c
c applicable switches in the sector    (default value is 0)
c
c      switch number            function
c          01            hypothetical water shortage feedback
c                           (not implemented in prb)
c          02            total export option   (default off)
c          40            political climate feedback
c                           (not implenented in prb)
c          04            construction labor shortage feedback
```

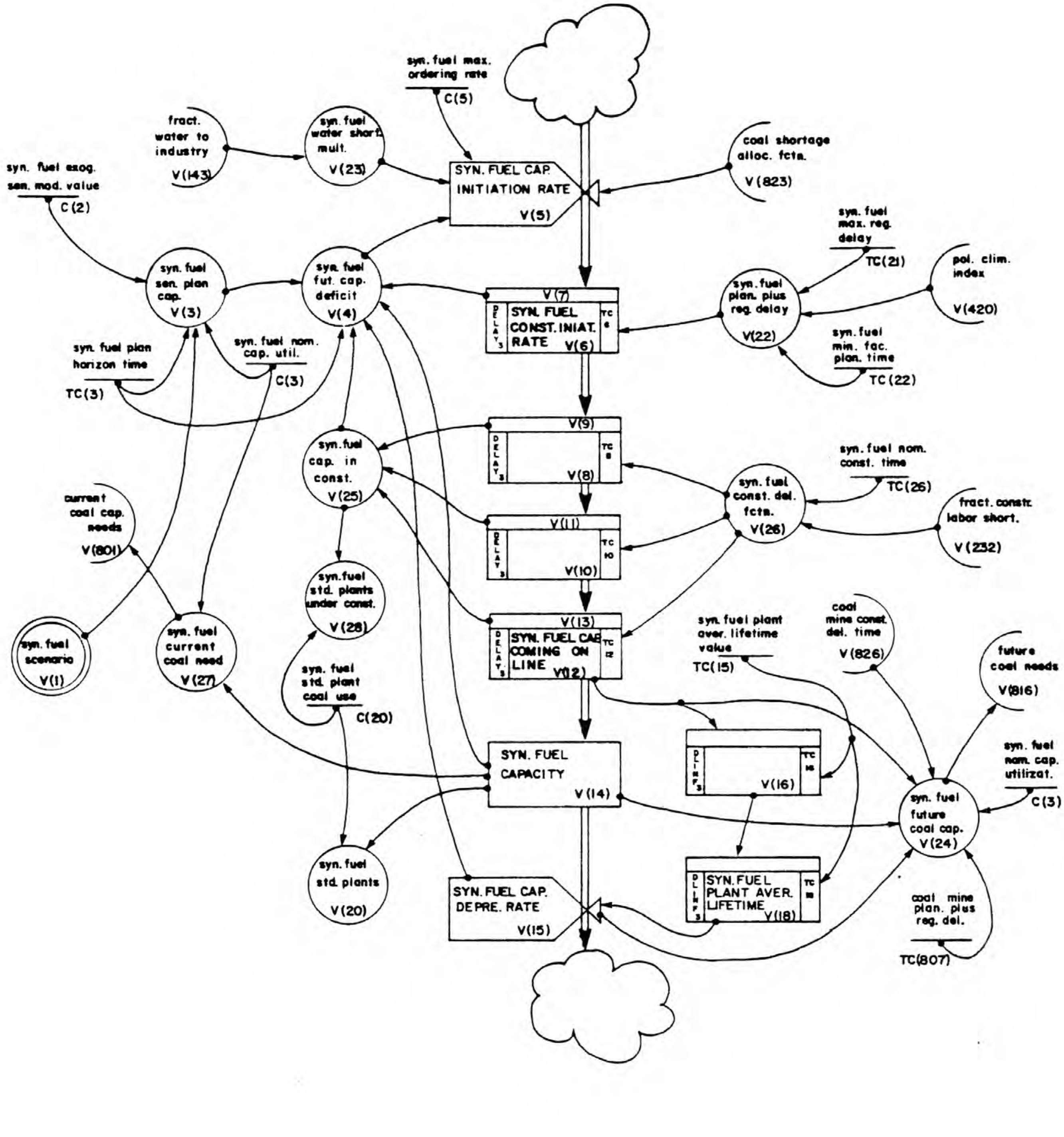
```
c                              (default on)
c
c
c    ***************** start program statements ****************
c
c industrial sector file name
      subroutine prbind(ncdp,indgo)
      integer indgo
c
c common statements
      common/system/v(1000),c(1000),tc(1000),t1
      common time
      common/dt/dt
c
c
c switch statements
      common/switch/switch(100)
      integer switch
c if indgo=0, subroutine is not executed.  if indgo=1 (de-
c fault value), subroutine is executed for all iterations.
c if indgo=-n, subroutine is executed for n iterations only.
      if(indgo.eq.0) return
      if(indgo.gt.0) go to 10
      if(indgo.lt.0) indgo=indgo+1
10    continue
c
c coal mine planning delay plus regulatory delay   years
c (minimum planning time plus maximum regulatory delay
c times Fermi function of political climate index.
c Fermi has a value of 1/2 at an index of -0.1)
      pci=c(420)
      if(time.gt.1970.0) pci=v(420)
      v(819)=tc(819)+tc(818)/(1.0+exp((pci+0.1)/0.15))
      tc(807)=v(819)
c
c coal mine construction delay time  (nominal time divided by one
c less the fractional constructional labor shortage)   years
      v(826)=tc(826)
      if(v(232).lt.0.0) v(232)=0.0
      if(switch(04).eq.1) v(826)=tc(826)/(1.0-v(232))
c ------------------ synthetic fuel subsector -------------------
c
c tpy is an abbreviation for tons per year
c synthetic fuel scenario (output)   million tpy
      v(1)=energy(3,ncdp,time)
c syn fuel scenario planned capacity   million tpy   (tcsf is the
c planning horizon time, tc(3), shortened by the Fermi function
c for times near the model starting time)
      tcsf=tc(3)*(1.0-(1.0/(1.0+exp((time-1970.0)/1.7))))
      v(3)=c(2)*energy(3,ncdp,time+tcsf)/c(3)
c total export option
      if(switch(02).eq.1) v(3)=0
c synthetic fuel planning delay plus regulatory delay   years
c (see also analagous note for coal mine planning delay)
      v(22)=tc(22)+tc(21)/(1.0+exp((pci+0.1)/0.15))
      tc(6)=v(22)
c synthetic fuel construction delay time (nominal time divided
c by one less the fractional construction labor shorage)   years
c (the total delay is apportioned into the three delay macro
c functions in a manner to better model the construction
c process)
      v(26)=tc(26)
      if(switch(04).eq.1) v(26)=tc(26)/(1.0-v(232))
c synthetic fuel construction time constants   years
      tc(8)=0.1875*v(26)
      tc(10)=0.1875*v(26)
      tc(12)=0.6250*v(26)
c synthetic fuel water shortage multiplier (hypothetical)
c (modeled as the sine squared of the fractional water to industry)
      v(23)=1.0
      if(switch(01).eq.1) v(23)=(sin(v(143)*3.14159/2.0))**2.0
c initialize synthetic fuel capacity in planning and in construc-
c tion to steady state in 1970  (for syn fuel, nothing is assumed
c to be in planning or in construction in 1970)
      if(time.gt.1970.0) go to 20
```

```
      vtemp1=0.0
      v(6)=delay3('v5',vtemp1,tc(6),v(7))
      v(8)=delay3('v6',vtemp1,tc(8),v(9))
      v(10)=delay3('v8',vtemp1,tc(10),v(11))
      v(12)=delay3('v10',vtemp1,tc(12),v(13))
20    continue
c synthetic fuel plant average lifetime   years   (initialize as
c if all previous plants were new in 1970)
      tc(16)=tc(15)/2.0
      tc(18)=tc(15)/2.0
      if(time.eq.1970.0) v(16)=dlinf3('v12',0.0,tc(16))
      if(time.gt.1970.0) v(16)=dlinf3('v12',v(12),tc(16))
      v(18)=dlinf3('v16',v(16),tc(18))
c synthetic fuel capacity depreciation rate   million tpy/year
      v(15)=v(18)
c synthetic fuel capacity in construction   million tpy
c (v(9), v(11), and v(13) are the capacities within the delays)
      v(25)=v(9)+v(11)+v(13)
c synthetic fuel future capacity deficit   million tpy
c (if an excess is evident, the deficit is taken as 0)
      v(4)=amax1(v(3)-(v(14)+v(25)+v(7)-v(15)*tc(3)),0.0)
c synthetic fuel capacity initiation rate   million tpy/year
c (the functional relationships are to prevent unreal
c ordering rates even when deficits are very large; c(5) is max rate)
      v(5)=v(23)*(c(5)*sin(1.11*v(4)/c(5))/t1)
      if(v(4).gt.1.42*c(5)) v(5)=c(5)
c synthetic fuel construction initiation rate   million tpy/year
      v(6)=delay3('v5',v(5),tc(6),v(7))
c synthetic fuel capacity coming on line   million tpy/year
c (that is,  the amount coming out of the last delay macro, v(12))
      v(8)=delay3('v6',v(6),tc(8),v(9))
      v(10)=delay3('v8',v(8),tc(10),v(11))
      v(12)=delay3('v10',v(10),tc(12),v(13))
c synthetic fuel standard plants (number)
      v(20)=v(14)/c(20)
c synthetic fuel standard plants under construction (number)
      v(28)=v(25)/c(20)
c synthetic fuel future coal capacity   million tpy
c (present capacity + current mine planning and construction
c delay times multiplied by the difference between current
c synfuel plant completion and depreciation rates times the
c nominal capacity utilization factor.  This number is used
c for planning new coal mine development)
      v(24)=(v(14)+(tc(807)+v(826))*(v(12)-v(15)))*c(3)
c synthetic fuel current coal needs   million tpy
      v(27)=v(14)*c(3)
c
c synthetic fuel capacity level equation   million tpy
      v(14)=v(14)+dt*(v(12)-v(15))
c
c -------------- electrical generation subsector ----------------
c
c electric generation scenario (coal input)    million tpy
      v(37)=scenario(1,ncdp,time)
c electrical generation scenario planned capacity   million tpy
c (see also the note for analogous synfuel statement)
      tceg=tc(38)*(1.0-(1.0/(1.0+exp((time-1970.0)/1.7))))
      v(38)=c(36)*scenario(1,ncdp,time+tceg)
c total export option
      if(switch(02).eq.1) v(38)=0.0
c electrical generation planning plus regulatory delay   years
c (see also the note above for analogous coal mine delays)
      v(56)=tc(56)+tc(55)/(1.0+exp((pci+0.1)/0.15))
      tc(41)=v(56)
c electrical generation construction delay function (including
c labor shortage effects   years   (see also the note for
c analogous synfuel statement)
      v(61)=tc(61)
      if(switch(04).eq.1) v(61)=tc(61)/(1.0-v(232))
c electrical generation construction time constants   years
      tc(43)=0.1875*v(61)
      tc(45)=0.1875*v(61)
      tc(47)=0.6250*v(61)
c electrical generation water shortage multiplier (hypothetical)
c (see also note for analogous synfuel statement)
```

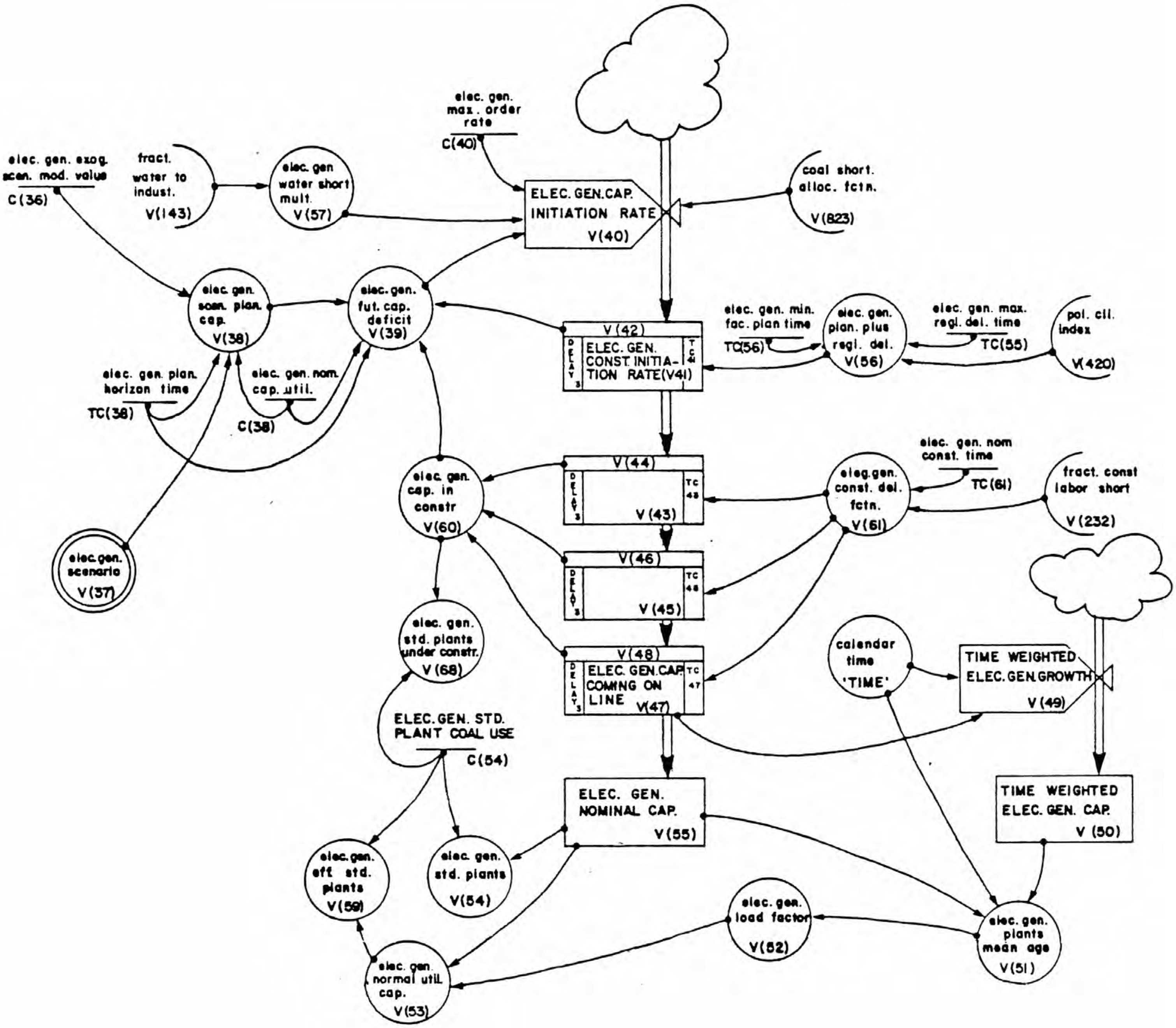
```
      v(57)=1.0
      if(switch(01).eq.1) v(57)=(sin(v(143)*3.14159/2.0))**2.0
c initialize electrical generation capacity in planning and in
c construction to steady state in 1970
c (difference in 1970 between future planned capacity and
c present existing capacity divided by 1 + the total time
c through the planning and construction processes)
      if(time.gt.1970.0) go to 30
      vtemp2=(v(38)-v(55))/(1.0+v(61)+tc(41))
      v(41)=delay3('v40',vtemp2,tc(41),v(42))
      v(43)=delay3('v41',vtemp2,tc(43),v(44))
      v(45)=delay3('v43',vtemp2,tc(45),v(46))
      v(47)=delay3('v45',vtemp2,tc(47),v(48))
30    continue
c electrical generation plants mean age   years
c (in the model the electrical plants are not physically
c depreciated because it is assumed that the modeling time
c does not go out far enough.  However, their utilization
c factors are degraded with time.  A mean age
c is needed for this)
      if(time.eq.1970.0) v(50)=v(55)*time
      v(51)=0.0
      if(v(55).gt.0.0) v(51)=time-v(50)/v(55)
c electrical generation load factor
c (new plants are assumed to operate at a load factor of
c 80% for the first 9 years)
      v(52)=0.8-0.4*(v(51)-9.0)/28.0
      if(v(52).lt.0.0) v(52)=0.0
      if(v(51).lt.9.0) v(52)=0.8
c electrical generation normal utilized capacity   million tpy
      v(53)=v(52)*v(55)/0.8
c electrical generation capacity in construction   million tpy
      v(60)=v(44)+v(46)+v(48)
c electrical generation future capacity deficit   million tpy
c no replacement of derated capacity
      v(39)=amax1(v(38)-(v(55)+v(60)+v(42)),0.0)
c electrical generation capacity initiation rate   million tpy/yr
c (the functions prevent unduly large ordering rates)
      v(40)=v(57)*(c(40)*sin(1.11*v(39)/c(40))/t1)
      if(v(39).gt.1.42*c(40)) v(40)=c(40)
c electrical generation construction initiation rate   million
c tpy/year
      v(41)=delay3('v40',v(40),tc(41),v(42))
c electrical generation capacity coming on line   million tpy/yr
c (see also note for analogous synfuel statements)
      v(43)=delay3('v41',v(41),tc(43),v(44))
      v(45)=delay3('v43',v(43),tc(45),v(46))
      v(47)=delay3('v45',v(45),tc(47),v(48))
c electrical generation standard 1000 mwe plants (number)
      v(54)=v(55)/c(54)
c electrical generation effective standard 1000 mwe plants
      v(59)=v(53)/(c(54)*0.8)
c electrical generation standard plants under construction (number)
      v(68)=v(60)/c(54)
c time weighted electrical generation growth
      v(49)=v(47)*time
c
c electrical generation level equations
c electrical generation nominal capacity   million tpy
      v(55)=v(55)+dt*v(47)
c time weighted electrical generation capacity
      v(50)=v(50)+dt*v(49)
c
c --------------- rail subsector -------------------------
c
c rail scenario   track miles
      v(71)=scenario(2,ncdp,time)
c rail senario planned capacity   track miles
c (see also note for analogous synfuel statements)
      tcrl=tc(73)*(1.0-(1.0/(1.0+exp((time-1970.0)/1.7))))
      v(73)=c(72)*scenario(2,ncdp,time+tcrl)
c rail planning plus regulatory delay   years
c (see also note for analogous statements concerning coal
c mine planning at the beginning of this sector description)
      v(87)=tc(87)+tc(86)/(1.0+exp((pci+0.1)/0.15))
```

```
      tc(76)=v(87)
c rail construction delay function (including labor shortage
c effects)   years   (see also note for analogous synfuel)
      v(91)=tc(91)
      if(switch(04).eq.1) v(91)=tc(91)/(1.0-v(232))
      tc(78)=0.1875*v(91)
      tc(92)=0.1875*v(91)
      tc(94)=0.6250*v(91)
c initialize rail capacity in planning and construction to
c steady state in 1970.  (see also note for analogous statements
c in electrical generation subsector)
      if(time.gt.1970.0) go to 40
      vtemp3=(v(73)-v(80))/(1.0+tc(76)+v(91))
      v(76)=delay3('v75',vtemp3,tc(76),v(77))
      v(78)=delay3('v76',vtemp3,tc(78),v(79))
      v(92)=delay3('v78',vtemp3,tc(92),v(93))
      v(94)=delay3('v92',vtemp3,tc(94),v(95))
40    continue
c rail capacity under construction   track miles
      v(86)=v(79)+v(93)+v(95)
c rail future capacity deficit   track miles
      v(74)=amax1(v(73)-(v(80)+v(86)+v(77)),0.0)
c rail capacity initiation rate   track miles/year
c (see also note for analogous synfuel statements)
      v(75)=c(75)*sin(1.11*v(74)/c(75))/t1
      if(v(74).gt.1.42*c(75)) v(75)=c(75)
c rail capacity construction initiation rate   track
c miles/year/year
      v(76)=delay3('v75',v(75),tc(76),v(77))
c rail capacity coming on line   track miles/year
      v(78)=delay3('v76',v(76),tc(78),v(79))
      v(92)=delay3('v78',v(78),tc(92),v(93))
      v(94)=delay3('v92',v(92),tc(94),v(95))
c
c rail capacity level equation   track miles
      v(80)=v(80)+dt*v(94)
c
c
      return
      end
```

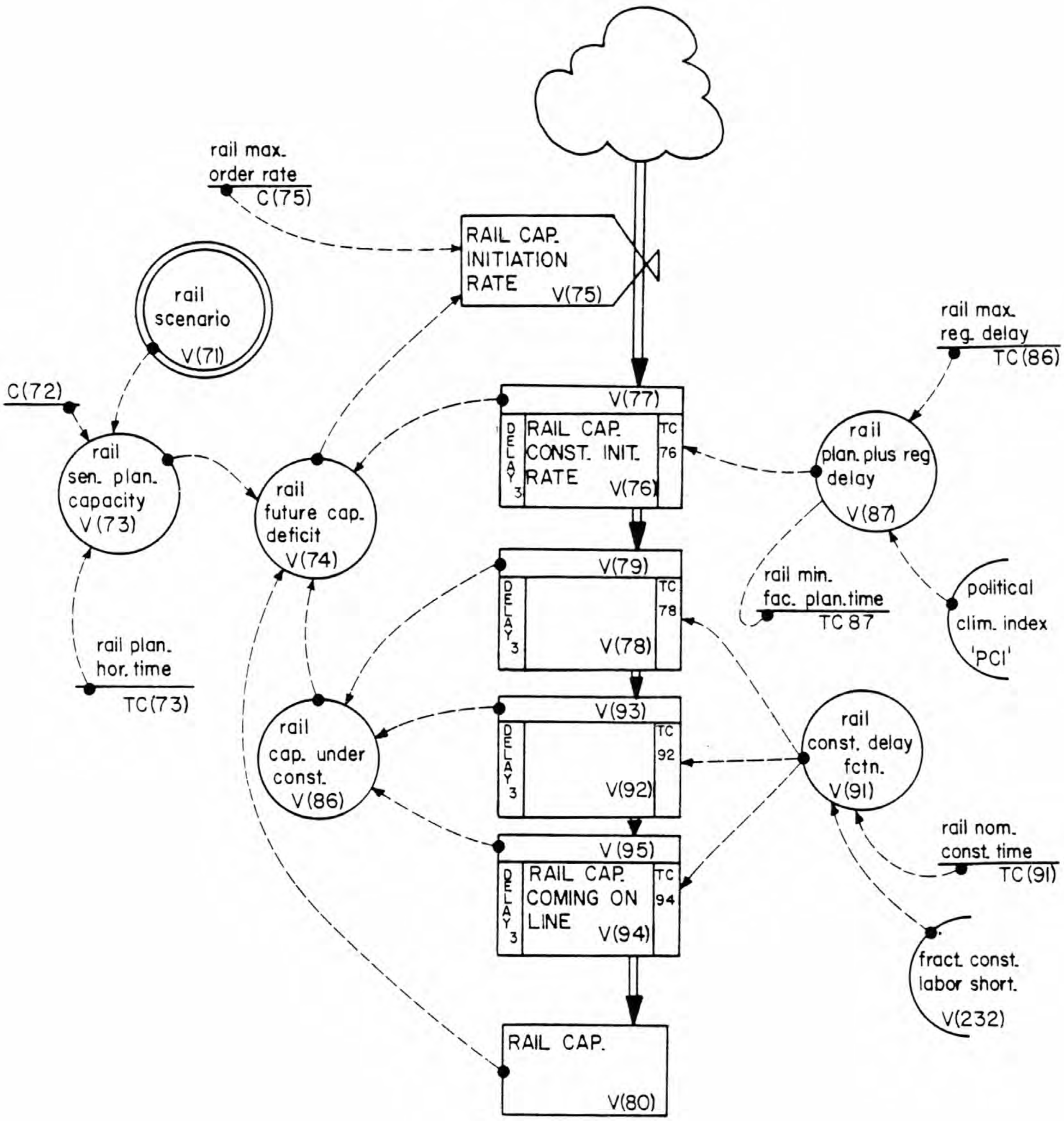
## SYNTHETIC FUEL SUBSECTOR
## WCRIND



## ELECTRICAL GENERATION SUBSECTOR
## IND



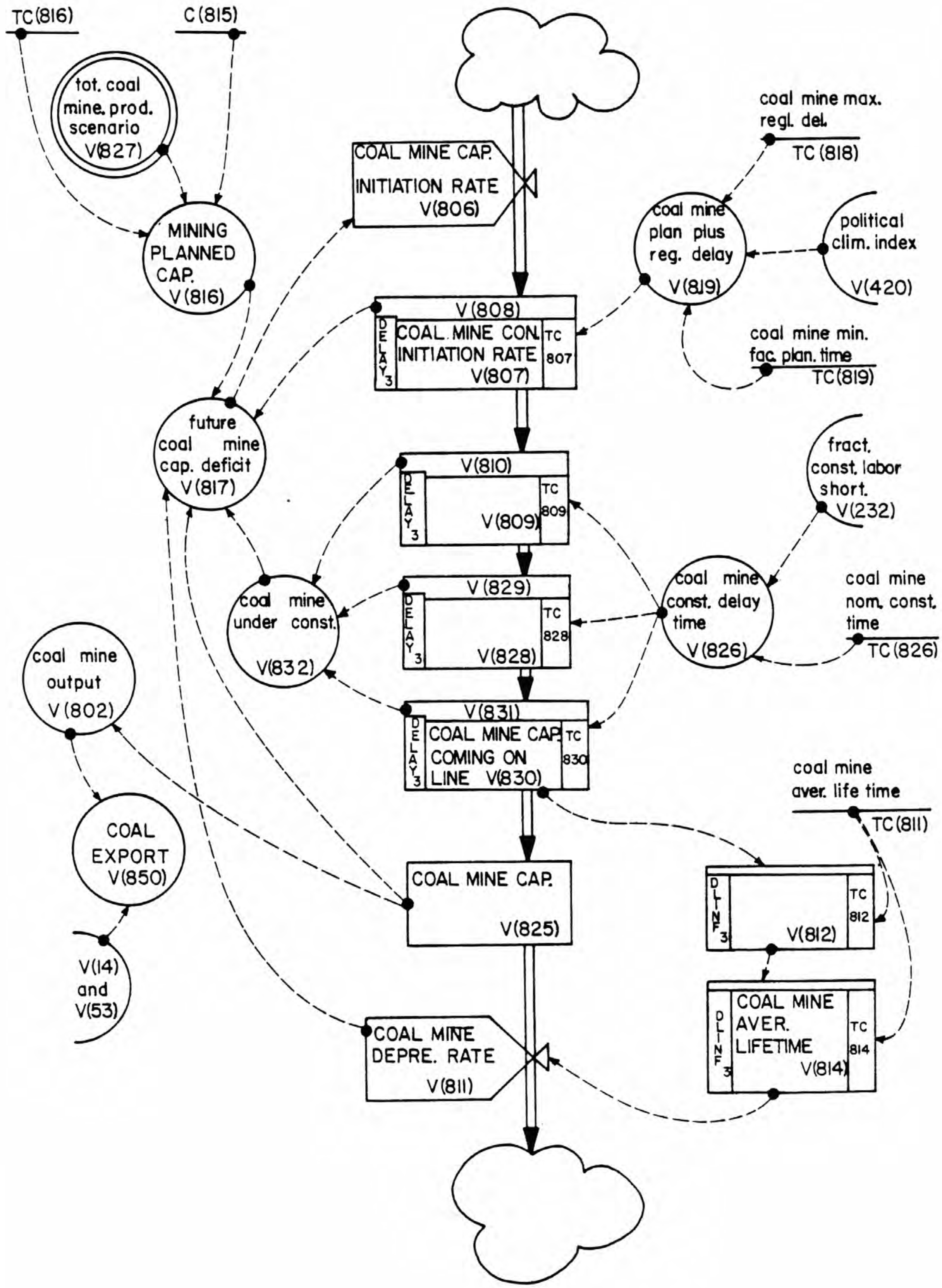
# RAIL SUBSECTOR
# PRBIND



```
c **************** Mining Sector (09-07-77) ************************
c
c The coal mining subsector functions very similarly to the user
c industries, and the annotation for prbind will explain the
c modeling rational.
c
c mining sector file name
      subroutine prbmin(ncdp,mingo)
      integer mingo
c
c common statements
      common/system/v(1000),c(1000),tc(1000),t1
      common time
      common/dt/dt
c
c switch link statements
      common/switch/switch(100)
      integer switch
c (also see note concerning analogous indgo in industry sector)
      if(mingo.eq.0) return
      if(mingo.gt.0) go to 10
      if(mingo.lt.0) mingo=mingo+1
10    continue
c
c ----------------- coal mining subsector -----------------------
c
c coal mine planning delay plus regulatory delay   years
c calculated in prbind
c coal mine construction delay time (including labor
c shortage effects)   years   calculated in prbind
c coal mine construction time constants   years
      tc(809)=0.1875*v(826)
      tc(828)=0.1875*v(826)
      tc(830)=0.6250*v(826)
c tpy = tons per year
c total coal mine production scenario   million tpy
      v(827)=totcoal(ncdp,time)
c coal mining scenario planned capacity  million tpy
      tccm=tc(816)*(1.0-(1.0/(1.0+exp((time-1970.0)/1.7))))
      v(816)=c(815)*totcoal(ncdp,time+tccm)
c initialize coal mine capacity in planning and construction to
c steady state in 1970
      if(time.gt.1970.0) go to 20
      vtemp4=(v(816)-v(825))/(1.0+tc(807)+v(826))
      v(807)=delay3('v806',vtemp4,tc(807),v(808))
      v(809)=delay3('v807',vtemp4,tc(809),v(810))
      v(828)=delay3('v809',vtemp4,tc(828),v(829))
      v(830)=delay3('v828',vtemp4,tc(830),v(831))
20    continue
c coal mine average lifetime   years   (initialize as if all
c mines are new in 1970)
      tc(812)=tc(811)/2.0
      tc(814)=tc(811)/2.0
      if(time.eq.1970.0) v(812)=dlinf3('v830',0.0,tc(812))
      if(time.gt.1970.0) v(812)=dlinf3('v830',v(830),tc(812))
      v(814)=dlinf3('v812',v(812),tc(814))
c coal mine depreciation rate   million tpy/year
      v(811)=v(814)
c coal mines under construction   million tpy
      v(832)=v(810)+v(829)+v(831)
c future coal mine capacity deficit   million tpy
      v(817)=amax1(v(816)-(v(825)+v(832)+v(808)-v(811)),0.0)
c coal mine capacity initiation rate   million tpy/year
      v(806)=amax1(v(817)/t1,0.0)
c coal mine construction initiation rate   million tpy/year
      v(807)=delay3('v806',v(806),tc(807),v(808))
c coal mine capacity coming on line   million tpy/year
      v(809)=delay3('v807',v(807),tc(809),v(810))
      v(828)=delay3('v809',v(809),tc(828),v(829))
      v(830)=delay3('v828',v(828),tc(830),v(831))
c
c coal mine output    million tpy
      v(802)=v(825)
c coal grade land stripping multiplier
      v(853)=1.0
```

```
c
c coal export   million tpy
      v(850)=v(802)-v(14)-v(53)
c
c coal mine capacity level equation   million tpy
      v(825)=v(825)+dt*(v(830)-v(811))
c
c
      return
      end
```

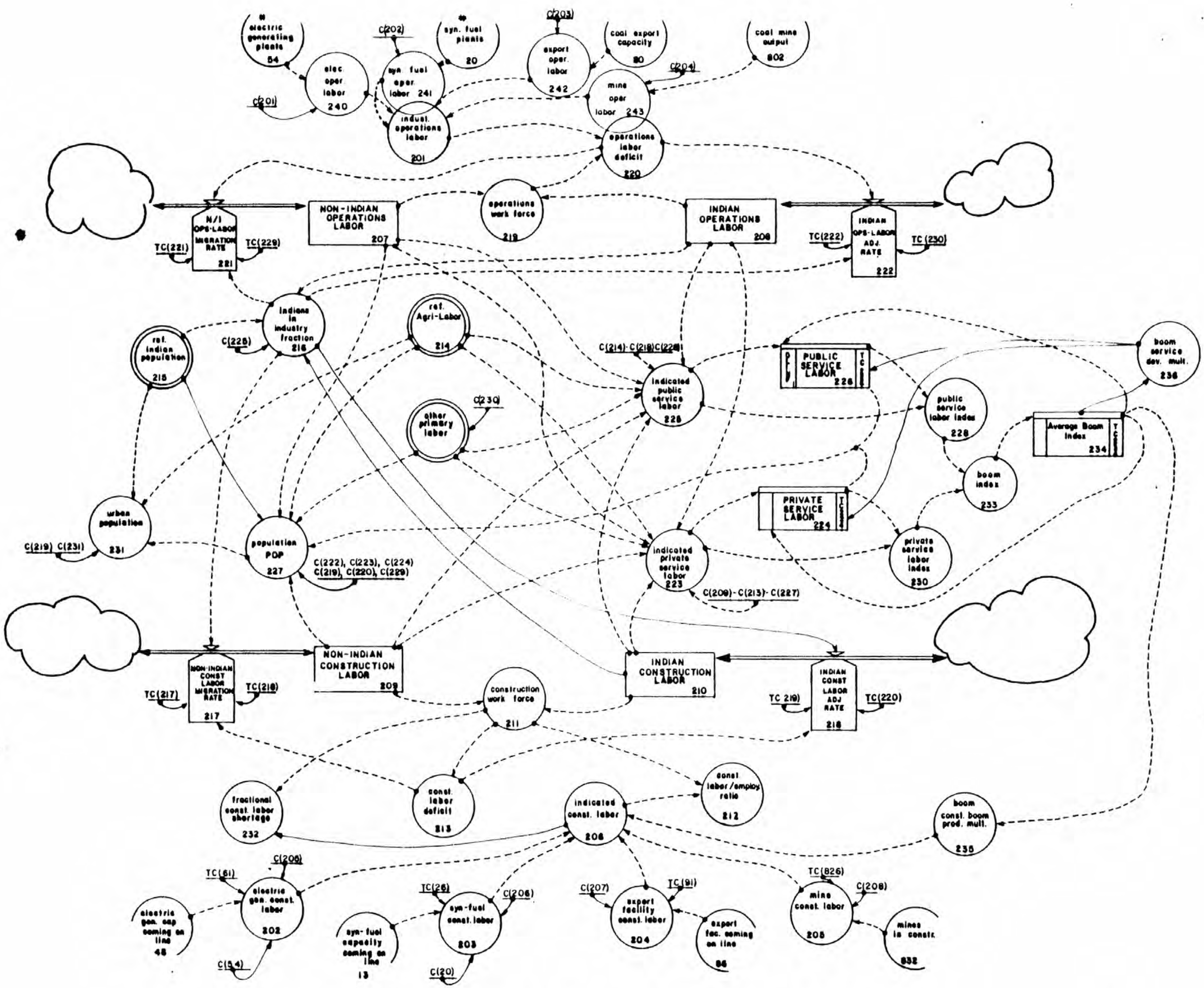
# COAL MINING SUBSECTOR
# PRBMIN



```
c ********************Demographic Sector (09-08-77)***********
c
c       The demographic sector calculates the number of laborers
c  required to construct and operate the mines, conversion plants
c  and export facilities specified by the industrial sector of the
c  model.   This   industrial   labor   force   together with  an
c  exogenously determined agricultural labor force v(214) and other
c  primary  labor  v(229)  (primary manufacturing, recreation, etc.)
c  work through multipliers  to determine the needed  public  v(225)
c  and private v(223) service labor.  The  available  service  labor
c  v(226,224) is a time delayed function  of  the  indicated service
c  labor categories.   Public and private service indices v(228,230)
c  are indications of how well the need for service labor  is  being
c  met.
c
c     Total population v(227) is  determined  by  applying  specific
c  family  multipliers  to  the  various  labor  forces   plus   the
c  exogenously determined indian population v(215).   Indians in the
c  industrial   labor   force   are   accounted   for    separately
c  v(208,210,216).   This  allows  some  flexibility  to  accomodate
c  possible large and abrupt increases in indian employment  through
c  specific  indian  employment clauses in future leases for coal on
c  the reservations.
c
c    A  boom  index   (  A.  Ford,1976  )  is  calculated v(233) as a
c  function of service shortages.  Boom conditions cause a  decrease
c  in   construction   worker  productivity  v(235)  and an increase
c  in  service  delay  times  v(236),  thus  aggravating  the   boom
c  conditions.
c
c
c Demographic variables are aggregated over the entire region.
c
c     switches (default value = 0)
c
c        set switch(21)=1 to exclude indian reservations population
c        set switch(22)=1 to stabilize agricultural labor at 1975 level
c
c ****************** start program statements ******************
      subroutine prbdem(demgo)
      integer demgo
      common/system/v(1000),c(1000),tc(1000),t1
      common time
      common/dt/dt
c
c switch array
c
      common/switch/switch(100)
      integer switch
c
c
      if (demgo.eq.0) return
      if (demgo.gt.0) goto 10
      if (demgo.lt.0) demgo=demgo+1
10    continue
c
c electrical operations labor
        v(240)=c(201)*v(54)
c synfuel operations labor
        v(241)=c(202)*v(20)
c railroad operations labor
        v(242)=c(203)*v(80)+c(237)*v(850)
c mine operations labor
        v(243)=c(204)*v(802)
c industrial operations labor
        v(201)=v(240)+v(241)+v(242)+v(243)
c electrical generation construction labor
      v(202)=c(205)*v(48)/(tc(61)*0.6250*c(54))
c synthetic fuel construction labor
      v(203)=c(206)*v(13)/(tc(26)*0.6250*c(20))
c rail construction labor
      v(204)=c(207)*v(95)/tc(94)
c mining construction labor
      v(205)=c(208)*v(832)/tc(826)
c indicated industrial construction labor
```

```
      v(206)=v(202)+v(203)+v(204)+v(205)
c boom construction productivity multiplier
      v(235)=0.5+0.5/(1.0+exp((v(234)-0.21)/0.055))
c industrial construction labor
      if(switch(25).eq.0)v(206)=v(206)/v(235)
c construction work force
      v(211)=v(209)+v(210)
c construction labor/employment ratio
      if(v(211).eq.0.0)v(212)=1.0
      if(v(211).gt.0.0)v(212)=v(206)/v(211)
c construction labor deficit
      v(213)=v(206)-v(211)
c reference  agricultural labor
      v(214)=0.63*4292.0*exp(-0.0239*(time-1970.0))
      if(switch(22).eq.1.and.time.ge.1975.0) v(214)=2400.0
c reference indian population
      v(215)=4125.0*exp(0.0164*(time-1970.0))+2674*exp(0.0301*(time-1970
     1.0))
      if(switch(21).eq.1) v(215)=0.0
c indian industrial work force fraction
      v(216)=0.0
      if(v(215).gt.0.0) v(216)=c(225)/(1.0+exp((((v(208)+v(210))/v(215))
     1-0.13)/0.025))
c nonindian construction labor transfer rate
      if(v(213).ge.0.0)v(217)=(1.0-v(216))*v(213)/tc(217)
      if(v(213).lt.0.0)v(217)=(1.0-v(216))*v(213)/tc(218)
c indian construction labor transfer rate
      if(v(213).ge.0.0)v(218)=v(216)*v(213)/tc(219)
      if(v(213).lt.0.0)v(218)=v(216)*v(213)/tc(220)
c operations work force
      v(219)=v(207)+v(208)
c operations labor deficit
      v(220)=v(201)-v(219)
c nonindian operation labor transfer rate
      if(v(220).ge.0.0)v(221)=(1.0-v(216))*v(220)/tc(221)
      if(v(220).lt.0.0)v(221)=(1.0-v(216))*v(220)/tc(229)
c indian operation labor transfer rate
      if(v(220).ge.0.0)v(222)=v(216)*v(220)/tc(222)
      if(v(220).lt.0.0)v(222)=v(216)*v(220)/tc(230)
c other primary labor
      v(229)=c(230)
c indicated private service labor
      v(223)=c(209)*v(214)+c(210)*v(208)+c(211)*v(207)+c(212)*v(209)+c(2
     113)*v(210)+c(227)*v(229)
c boom service development multiplier
      v(236)=0.5+0.5/(1.0+exp((v(234)-0.165)/0.04))
c private service labor
      v(237)=tc(224)
      if(switch(26).eq.0)v(237)=v(237)/v(236)
      v(224)=dlinf1('v224',v(223),v(237))
c indicated public service labor
      v(225)=c(214)*v(214)+c(215)*v(208)+c(216)*v(207)+c(217)*v(209)+c(2
     118)*v(210)+c(228)*v(229)
c public service labor
      v(238)=tc(226)
      if(switch(26).eq.0)v(238)=v(238)/v(236)
      v(226)=dlinf1('v226',v(225),v(238))
c total population
      v(227)=c(219)*v(214)+c(220)*v(207)+v(215)+c(222)*v(226)+c(223)*v(2
     124)+c(224)*v(209)+c(229)*v(229)
      if (switch(25).eq.0)v(227)=c(219)*v(214)+c(220)*v(207)+v(215)+c(22
     12)*v(226)+c(223)*v(224)+(c(224)*(.5+.5/(1.+exp((v(234)-.33)/.08)))
     2*v(209))+c(229)*v(229)
c public service labor index
      v(228)=v(226)/v(225)
c private service labor index
      v(230)=v(224)/v(223)
c boom index
      v(233)=((0.5/v(228))+(0.5/v(230)))-1.0
c average boom index
      v(234)=dlinf1('v234',v(233),tc(234))
c urban population
      v(231)=c(231)*(v(227)-v(215)+v(214)*c(219))
c fractional construction labor shortage
      v(232)=0.0
```

```
      if(v(206).ne.0.0) v(232)=(v(206)-v(211))/v(206)
c
c level equations
c
c nonindian operations labor
      v(207)=v(207)+dt*v(221)
c indian operations labor
      v(208)=v(208)+dt*v(222)
c nonindian construction labor
      v(209)=v(209)+dt*v(217)
c indian construction labor
      v(210)=v(210)+dt*v(218)
      return
      end
```

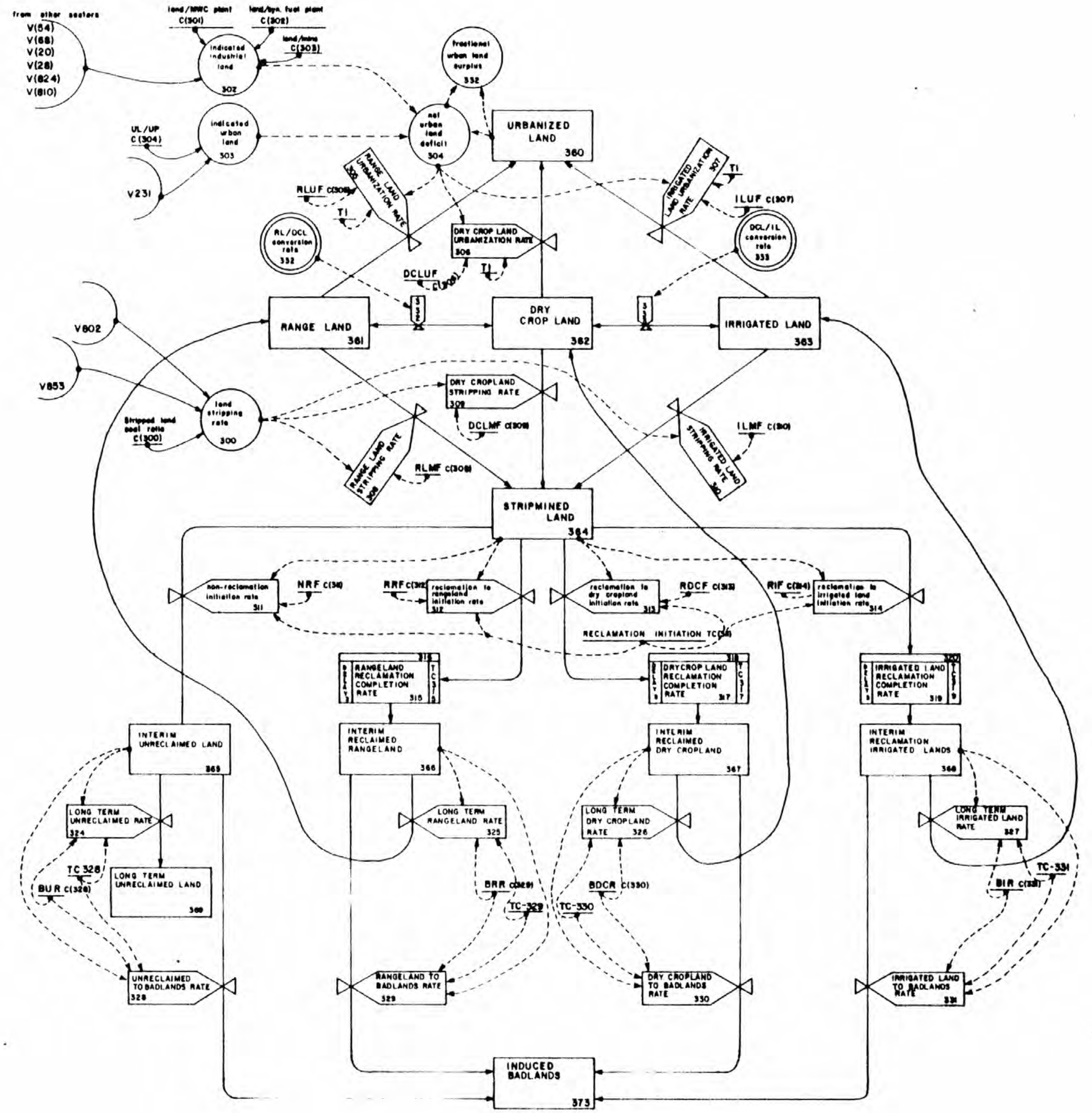



# DEMOGRAPHIC SECTOR

WCRDEM

```
c **************** Land Sector (08-26-77) ***********************
c
c The land sector keeps track of land used  in  agricultural/  open
c space,  urban/industrial,  and  mine/reclamation catagories.  The
c agricultural/open space catagories  are  range  and  forest  land
c v(361),   dry  crop  land  v(362),  and  irrigated  land  v(363).
c Provision  is   made  for  exogenous  transitions  between  these
c catagories  v(332,333).     Lands     are     converted     from
c agricultural   to  urban/industrial  v(360)   in   responce   to
c indicated    requirements    v(302,303)     calculated      from
c industrial   development  and  urban population.  Conversion from
c agriculture/open space  to  stripmined  land v(364)  is  governed
c by  the  land  stripping  rate  v(300).   Mined  lands,  after  a
c mining   and   reclamation    delay    ( tc315,tc317,tc319 )   is
c converted  to  interim  reclaimed  (or non-reclaimed) catagories.
c Lands undergoing reclamation are in  v(316)   (to   range  land),
c v(318)  (to  dry crop land), or v(320) (to irrigated land).  From
c the   interim   catagories,   land   either   returns   to   the
c agriculturel/open  space  catagories  or  deteriorates to induced
c badlands v(373).
c
c        units are 10e3 acres.
c
c *************** start program statements *************************
      subroutine prblnd(lndgo)
      integer lndgo
      common/system/v(1000),c(1000),tc(1000),t1
      common time
      common/dt/dt
      if (lndgo.eq.0) return
      if (lndgo.gt.0) goto 10
      if (lndgo.lt.0) lndgo=lndgo+1
10    continue
c
c land stripping rate
      v(300)=v(802)*v(853)*c(300)
c indicated industrial land
      v(302)=(v(54)+v(68))*c(301)+(v(20)+v(28))*c(302)+(v(824)+v(8
     110))*c(303)
c indicated urban land
      v(303)= c(304)*v(231)
c net urban land deficit
      v(304)=v(302)+v(303)-v(360)
c fractional urban land surplus
      v(332)=amax1(-v(304),0.0)/v(360)
c range land urbanization rate
      v(305)=amax1(v(304),0.0)*c(305)/t1
c dry crop land urbanization rate
      v(306)=amax1(v(304),0.0)*c(306)/t1
c irrigated land urbanization rate
      v(307)=amax1(v(304),0.0)*c(307)/t1
c range land/dry crop land conversion rate
      v(332)=0.0
c dry crop land/irrigated land conversion rate
      v(333)=0.0
c range land stripping rate
      v(308)=v(300)*c(308)
c dry crop land stripping rate
      v(309)=v(300)*c(309)
c irrigated land stripping rate
      v(310)=v(300)*c(310)
c non-reclamation initiation rate
      v(311)=v(364)*c(311)/tc(311)
c reclamation to range land initiation rate
      v(312)=v(364)*c(312)/tc(311)
c reclamation to dry crop land initiation rate
      v(313)=v(364)*c(313)/tc(311)
c reclamation to irrigated land initiation rate
      v(314)=v(364)*c(314)/tc(311)
c range land reclamation completion rate
      v(315)=delay3('v312',v(312),tc(315),v(316))
c dry crop land reclamation completion rate
      v(317)=delay3('v313',v(313),tc(317),v(318))
c irrigated land reclamation completion rate
      v(319)=delay3('v314',v(314),tc(319),v(320))
```

```
c long term unreclaimed rate
      v(324)=v(365)*(1.0-c(328))/tc(328)
c unreclaimed to badlands rate
      v(328)=v(365)*c(328)/tc(328)
c long term range land rate
      v(325)=v(366)*(1.0-c(329))/tc(329)
c range land to badlands rate
      v(329)=v(366)*c(329)/tc(329)
c long term dry crop land rate
      v(326)=v(367)*(1.0-c(330))/tc(330)
c dry crop land to badlands rate
      v(330)=v(367)*c(330)/tc(330)
c long term irrigated land rate
      v(327)=v(368)*(1.0-c(331))/tc(331)
c irrigated lands to badlands rate
      v(331)=v(368)*c(331)/tc(331)
c total land
      v(399)=v(360)+v(361)+v(362)+v(363)+v(364)+v(316)+v(318)+v(320)+v(3
     165)+v(366)+v(367)+v(368)+v(369)+v(373)
c
c level equations
c
c urbanized land
      v(360)=v(360)+dt*(v(305)+v(306)+v(307))
c range land
      v(361)=v(361)-dt*(v(305)+v(308)+v(332)-v(325))
c dry crop land
      v(362)=v(362)-dt*(v(306)+v(309)+v(333)-v(332)-v(326))
c irrigated land
      v(363)=v(363)-dt*(v(307)+v(310)-v(333)-v(327))
c stripmined land
      v(364)=v(364)+dt*(v(308)+v(309)+v(310)-v(311)-v(312)-v(313)-v(314)
     1)
c interim unreclaimed land
      v(365)=v(365)+dt*(v(311)-v(324)-v(328))
c interim reclaimed range land
      v(366)=v(366)+dt*(v(315)-v(325)-v(329))
c interim reclaimed dry crop land
      v(367)=v(367)+dt*(v(317)-v(326)-v(330))
c interim reclaimed irrigated land
      v(368)=v(368)+dt*(v(319)-v(327)-v(331))
c long term unreclaimed land
      v(369)=v(369)+dt*v(324)
c induced badlands
      v(373)=v(373)+dt*(v(328)+v(329)+v(330)+v(331))
c cumulative stripped land
      v(374)=v(374)+dt*v(300)
c total mining disturbed land
      v(375)=v(399)-v(361)-v(362)-v(363)-v(360)
c land undergoing reclamation
      v(376)=v(316)+v(318)+v(320)
      return
      end
```




# LAND SECTOR

**WCRLND**

```
c ************ Water Sector (07/20/77)***************************
      subroutine prbwtr(wtrgo)
      integer wtrgo
      common/system/v(1000),c(1000),tc(1000),t1
      common time
      common/dt/dt
c switch array  (0 is off, 1 is on)
      common/switch/switch(100)
      integer switch
c (see note for analogous indgo in industry sector description)
      if (wtrgo.eq.0) return
      if (wtrgo.gt.0) goto 10
      if (wtrgo.lt.0) wtrgo=wtrgo+1
10    continue
c
c indicated industrial water requirements     (in region)
      v(128)=v(20)*c(132)+v(59)*c(131)+v(802)*c(133)
c developing industrial water requirements
      v(129)=v(128)+v(28)*c(132)+v(68)*c(131)+v(810)*c(133)
c fractional water to industry
      v(143)=1.0
c
      return
      end
```

```
c **************** Political Sector (09-07-77) ****************
c
c
      subroutine prbpol(polgo,ncdp)
c
      integer polgo,ncdp
      common/system/v(1000),c(1000),tc(1000),t1
      common time
      common/dt/dt
c
c switch link statements
c
      common/switch/switch(100)
      integer switch
c
c (see note for analogous indgo in industrial sector description)
c
      if(polgo.eq.0) return
      if(polgo.gt.0) go to 10
      if(polgo.lt.0) polgo=polgo+1
10    continue
c
c political climate output to other sectors
        v(420)=c(420)
        return
        end
```

```
c *****************real function scenario(08/23/77)**************
c
c Scenario is the driving function for the industrial sector.
c ncdp (no. coal development profile) selects the scenario.
c
c        ncdp          scenario
c
c         1            EIS scenario 2
c         2            EIS scenario 3 ("most probable")
c         3            EIS scenario 4
c         4            step function test for electric generation
c         5            step function test for rail
c         6            step function test for mining
c
      real function scenario(ntyp,ncdp,etime)
      common/system/v(1000),c(1000),tc(1000),t1
      common rtime
      common/scenario/ctime
c
c
c rtime is real time, ctime is clip time, etime is scenario planning
c time, and time is a local variable.
      real elec3(25),elec4(25)
c
c data for table look up function (tlu)
c
      data elec3/'ele3',1.0,1970.0,1990.0,0.0,0.0,0.0,0.0,0.0,0.0,3.0,
     13.0,3.0,3.0,3.0,3.0,9.0,9.0,9.0,9.0,9.0,9.0,9.0,9.0,9.0/
      data elec4/'ele4',1.0,1970.0,1990.0,0.0,0.0,0.0,0.0,0.0,0.0,3.0,
     13.0,3.0,3.0,3.0,3.0,9.0,9.0,9.0,12.0,12.0,12.0,12.0,12.0,12.0/
c
c if ctime > 1970 then scenarios are clipped after rtime > ctime
c to scenario value at ctime.
c
      time=etime
      if(ctime.gt.1970.0.and.rtime.gt.ctime) time=amin1(etime,ctime)
      if(time.gt.1990.0) time=1990.0
c
      if(ncdp.gt.6) pause'ncdp out of bounds'
c
      scenario=0.0
c
      goto(200,300,100),ntyp
c
c ------------------------------------------------------
c
c synthetic fuel  mty
c
100   scenario=0.0
c
      return
c
c ------------------------------------------------------
c
c electric generation  mty
c
200   goto(210,220,230,240,250,250),ncdp
210   scenario=0.0
      if(time.ge.1976.0) scenario=3.0
      return
220   scenario=tlu(elec3,time)
      return
230   scenario=tlu(elec4,time)
      return
c test scenario 4: colstrip 3 and 4 in 1980 w/o rail or mining
240   if(time.ge.1980.0) scenario=6.0
      return
c test scenario 5,6: rail or mining w/o electric generation
250   return
c
c ------------------------------------------------------
c
c rail  miles
c
300   goto(310,320,330,350,340,350),ncdp
```

```
c
310    scenario=c(71)
       return
320    scenario=c(71)
       if(time.ge.1982.0) scenario=c(71)+44.0
       return
330    scenario=c(71)
       if(time.ge.1982.0) scenario=c(71)+44.0
       if(time.ge.1984.0) scenario=c(71)+105.0
       return
c test scenario 5: 44 miles of rail in 1980 w/o mining or elec. gen.
340    if(time.ge.1980.0) scenario=44.0
       return
c test scenarios 4,6:elect. gen. and mining w/o rail
350    return
c
       end
```

```
c *****************real function totcoal(08/23/77)**************
c
c Totcoal is the driving function for the mining sector.
c ncdp (no. coal development profile) selects the scenario.
c
c         ncdp          scenario
c
c          1            EIS scenario 2
c          2            EIS scenario 3 ("most probable")
c          3            EIS scenario 4
c          4            step function test for electric generation
c          5            step function test for rail
c          6            step function test for mining
c
c
      real function totcoal(ncdp,etime)
      common/system/v(1000),c(1000),tc(1000),t1
      common rtime
      common/scenario/ctime
c
c
c rtime is real time, ctime is clip time, etime is totcoal planning
c time, and time is a local variable.
      real tc2(25),tc3(25),tc4(25)
c
c data for table look up function (tlu)
c
      data tc2/'tc2',1.0,1970.0,1990.0,3.2,6.6,7.9,10.4,12.3,17.8,
     120.0,14*22.2/
      data tc3/'tc3',1.0,1970.0,1990.0,3.2,6.6,7.9,10.4,12.3,17.8,22.0,
     122.2,23.7,26.9,37.4,48.7,56.7,64.7,69.2,71.5,73.4,73.8,73.1,72.6,
     273.4/
      data tc4/'tc4',1.0,1970.0,1990.0,3.2,6.6,7.9,10.4,12.3,17.8,22.0,
     122.2,23.7,26.9,37.4,48.7,56.7,64.7,69.2,87.5,94.2,99.4,103.5,107.8
     2,113.4/
c
c if ctime > 1970 then scenarios are clipped after rtime > ctime
c to totcoal value at ctime.
c
      time=etime
      if(ctime.gt.1970.0.and.rtime.gt.ctime) time=amin1(etime,ctime)
      if(time.gt.1990.0) time=1990.0
c
      if(ncdp.gt.6) pause'ncdp out of bounds'
      goto(110,130,140,150,150,160),ncdp
c
110   totcoal=tlu(tc2,time)
      return
130   totcoal=tlu(tc3,time)
      return
140   totcoal=tlu(tc4,time)
      return
c
c test scenarios 4 and 5:elec. gen. or rail w/o mining
150   totcoal=0.0
      return
c test scenario 6: 6 million tpy mine in 1980 w/o elec. gen. or rail
160   totcoal=0.0
      if(time.ge.1980.0) totcoal=6.0
      return
c
      end
```

```
C     ****************** Constants List (09-07-77)*************************
c
c all time constants (tc) in years.
c
      subroutine prbco
      common/system/v(1000),c(1000),tc(1000),t1
c
c rate at which plant ordering decisions are made  years
      t1=1.0
c
c            abbreviations list
c
c 1.0e6      million
c syn.       synthetic
c tpy        tons per year
c mscfpd     million standard cubic feet per day
c btu        british thermal unit
c lb         pound
c elec.      electrical
c gen.       generation
c mwe        megawatt electric
c 1.0e3      thousand
c af         acre-feet
c std.       standard
c misc.      miscellaneous
c ac         acres
c sed.       sediment
c ds         dissolved solids
c eis        environmental impact statement
c bod        biochemical oxygen demand
c org.       organics
c so2        sulpher dioxide
c nox        nitrous oxides
c part.      particulates
c nsps       new source performance standards
c
c -------------------------------------------------------
c industrial constants (energy in million tons coal)
c
c syn. fuel exogenous scenario modification value
      c(2)=1.0
c syn. fuel nominal capacity utilization
      c(3)=0.7
c syn. fuel maximum ordering rate   million tpy/year
      c(5)=35.0
c syn. fuel standard plant coal use
c million tpy/250 mscfpd std. plant at 9000 btu/lb
      c(20)=8.0
c syn. fuel planning horizon time   years
      tc(3)=7.0
c syn. fuel plant average lifetime   years
      tc(15)=25.0
c syn. fuel maximum regulatory delay time const    years
      tc(21)=3.0
c syn. fuel minimum facility planning time const   years
      tc(22)=1.0
c syn. fuel nominal construction time const   years
      tc(26)=1.5
c -------------------------------------------------------
c elec. gen. exogenous scenario modification value
      c(36)=1.0
c elec. gen. maximum ordering rate   million tpy/year
      c(40)=4.2
c elec. gen. standard plant coal use
c million tpy/1000 mwe std. plant at 8200 btu/lb
      c(54)=4.4
c elec. gen. planning horizon time   years
      tc(38)=7.0
c elec. gen. maximum regulatory delay time const   years
      tc(55)=3.0
c elec gen. minimum facility planning time const   years
      tc(56)=1.0
c elec. gen. nominal construction time const   years
      tc(61)=1.5
c -------------------------------------------------------
```

```
c existing coal rail    miles
      c(71)=36.0
c rail exogenous scenario modification value
      c(72)=1.0
c rail maximum ordering rate   miles/year
      c(75)=100.0
c rail planning horizon time   years
      tc(73)=4.0
c rail maximum regulatory delay time const   years
      tc(83)=3.0
c rail minimum facility planning time const   years
      tc(87)=1.0
c rail nominal construction time const   years
      tc(91)=0.75
c ------------------------------------------------------------
c coal mine exogenous scenario modifier
      c(815)=1.0
c coal mine average lifetime   years
      tc(811)=40.0
c mine planning horizon time   years
      tc(816)=4.0
c coal mine maximum regulatory delay time const   years
      tc(818)=2.0
c coal mine minimum facility planning time const   years
      tc(819)=1.0
c coal mine nominal construction time const   years
      tc(826)=0.75
c ------------------------------------------------------
c water sector constants (101-199)(water in 1.0e3 acre-feet)
c
c water (1.0e3 af/yr)/1000 mwe plant
c changed from 15.0
      c(131)=16.5
c water (1.0e3 af/yr)/250 mscfpd syn. fuel plant
      c(132)=10.0
c water/mining  (1.0e3 af/1.0e6 tons coal)
      c(133)=0.05
c water/export by slurry pipeline   (1.0e3 af/1.0e6 tons coal)
      c(134)=0.7
c ------------------------------------------------------
c demographic sector constants (workers/1.0e6 tons coal/year)
c
c operations workers/1000 mwe plant
      c(201)=100.0
c operations workers/250 mscfpd syn. fuel plant
      c(202)=600.0
c operations workers/track mile **no data**
      c(203)=1.0
c rail operation workers/mty coal transported  **no data**
      c(237)=2.0
c operations workers/1.0e6 tpy mined
      c(204)=25.0
c construction worker-years/1000 mwe plant
      c(205)=3500.0
c construction worker-years/250 mscfpd syn. fuel plant
      c(206)=5400.0
c construction worker-years/track mile
      c(207)=4.1
c construction worker-years/1.0e6 tpy coal mine capacity
      c(208)=60.0
c private service/agri labor
      c(209)=0.99
c private service indian industrial operations labor
      c(210)=0.99
c private service/nonindian industrial operations labor
      c(211)=0.99
c private service/nonindian industrial construction labor
      c(212)=0.99
c private service/indian industrial construction labor
      c(213)=0.99
c public service/agri-labor
      c(214)=0.38
c public service/indian industrial operations labor
      c(215)=0.38
c public service/nonindian industrial operations labor
```

```
      c(216)=0.38
c public service/nonindian industrial construction labor
      c(217)=0.38
c public service/indian industrial construction labor
      c(218)=0.38
c agri-labor family multiplier
      c(219)=2.77
c nonindian operations labor family multiplier
      c(220)=2.0
c public service family multiplier
      c(222)=2.77
c private service family multiplier
      c(223)=2.77
c nonindian construction labor family multiplier
      c(224)=2.3
c indians in industry
      c(225)=0.1
c private service/other primary labor
      c(227)=0.99
c public service/other primary labor
      c(228)=0.38
c other primary labor family multiplier
      c(229)=2.0
c other primary labor-indiginous
      c(230)=1000.0
c urban fraction of non-indian & non-agri.
      c(231)=.66
c nonindian construction labor in-migration time
      tc(217)=1.0
c nonindian construction labor out-migration time
      tc(218)=1.0
c indian construction labor in-transfer time
      tc(219)=1.0
c indian construction labor out-transfer time
      tc(220)=1.0
c nonindian operation labor in-migration time
      tc(221)=1.0
c nonindian operation labor out-migration time
      tc(229)=1.0
c indian operation labor in-transfer time
      tc(222)=1.0
c indian operation labor out-transfer time
      tc(230)=1.0
c private service labor time constant
      tc(224)=1.0
c public service labor time constant
      tc(226)=3.0
c boom index smoothing time
      tc(234)=.5
c ----------------------------------------------------------
c land sector constants (land in 1.0e3 acres)
c
c stripped land/coal ratio (1.0e3 acres/1.0e6 tons coal)
c changed from 0.024
      c(300)=0.015
c land (1.0e3 ac)/1000 mwe plant
      c(301)=0.5
c land (1.0e3 ac)/250 mscfpd syn. fuel plant
      c(302)=1.0
c land (1.0e3 ac)/1.0e6 tpy mining capacity
      c(303)=0.06
c urban land/urban population (1.0e3 ac/capita)
      c(304)=0.0003
c rangeland urbanization fraction
      c(305)=0.85
c dry crop land urbanization fraction
      c(306)=0.10
c irrigated land urbanization fraction
      c(307)=0.05
c rangeland mining fraction
      c(308)=0.88
c dry crop land mining fraction
      c(309)=0.04
c irrigated land mining fraction
      c(310)=0.08
```

```
c non-reclamation fraction
      c(311)=0.20
c reclamation to rangeland fraction
      c(312)=1.00
c reclamation to dry crop land fraction
      c(313)=0.0
c reclamation to irrigated land fraction
      c(314)=0.0
c unreclaimed to badlands fraction
      c(328)=0.75
c 'reclaimed rangeland' to badlands fraction
      c(329)=0.25
c 'reclaimed dry crop land' to badlands fraction
      c(330)=0.10
c 'reclaimed irrigated land' to badlands fraction
      c(331)=0.05
c time constants
c reclamation initiation
      tc(311)=1.0
c rangeland reclamation
      tc(315)=5.0
c dry crop land reclamation
      tc(317)=5.0
c irrigated land reclamation
      tc(319)=5.0
c unreclaimed/badlands
      tc(328)=10.0
c 'reclaimed rangeland'/badlands
      tc(329)=25.0
c 'reclaimed dry crop land'/badlands
      tc(330)=25.0
c 'reclaimed irrigated land'/badlands
      tc(331)=30.0
c
c ----------------------------------------------------------
c political sector constants (1.0e6 dollars/1.0e6 tons coal)
c
c related agriculture revenue
      c(401)=2.0
c coal severance tax rate
      c(402)=0.3
c 1970 political unit revenue
      c(403)=500.0
c capital ($1.0e6)/1000 mwe plant
      c(404)=250.0
c capital ($1.0e6)/250 mscfpd synthetic fuel plant
      c(405)=450.0
c export capital/output ratio     ($1.0e6/1.0e6 tpy coal)
      c(406)=0.0
c mining capital/output ratio  ($1.0e6/1.0e6 tpy coal)
      c(407)=0.7
c capital normalizer
      c(408)=1000.0
c conversion / lifestyle weight
      c(416)=0.8
c mining / lifestyle weight
      c(417)=0.2
c lifestyle perception time
      tc(409)=15.0
c agriculture revenue index weight
      c(409)=7.0
c coal revenue index weight
      c(410)=10.0
c industrial capital index weight
      c(411)=10.0
c perceived industrial climate index weight
      c(412)=5.0
c environmental index weight
      c(413)=5.0
c future shock index weight
      c(414)=7.0
c energy gap index weight
      c(415)=8.0
c political adjustment time
      tc(414)=3.0
```

```
c political perception time
      tc(415)=2.0
c political climate optional constant
      c(420)=0.0
c
      return
      end
```

```
c *************** Initial Levels (09-07-77) ***************
c
      subroutine prbin
      common/system/v(1000),c(1000),tc(1000),t1
c
c
c     Industrial Sector  (million tons coal)
c
c initial time weighted electrical generation capacity
      v(50)=0.0
c
c
c     Demographic Sector  (number of workers)
c
c nonindian operations labor
      v(207)=0.0
c nonindian construction labor
      v(209)=0.0
c
c
c     Land Sector  (thousand acres)
c
c urbanized land
      v(360)=3.0
c (indicated urban land)
      v(303)=v(360)
c range land
      v(361)=4602.0
c dry crop land
      v(362)=148.0
c irrigated land
      v(363)=75.0
c stripmined land
      v(364)=0.0
c reclamation land
      v(365)=0.0
      v(366)=0.0
      v(367)=0.0
      v(368)=0.0
      v(369)=0.0
c induced badlands
      v(373)=0.0
c
      return
      end
```

Typical output from the prb model.

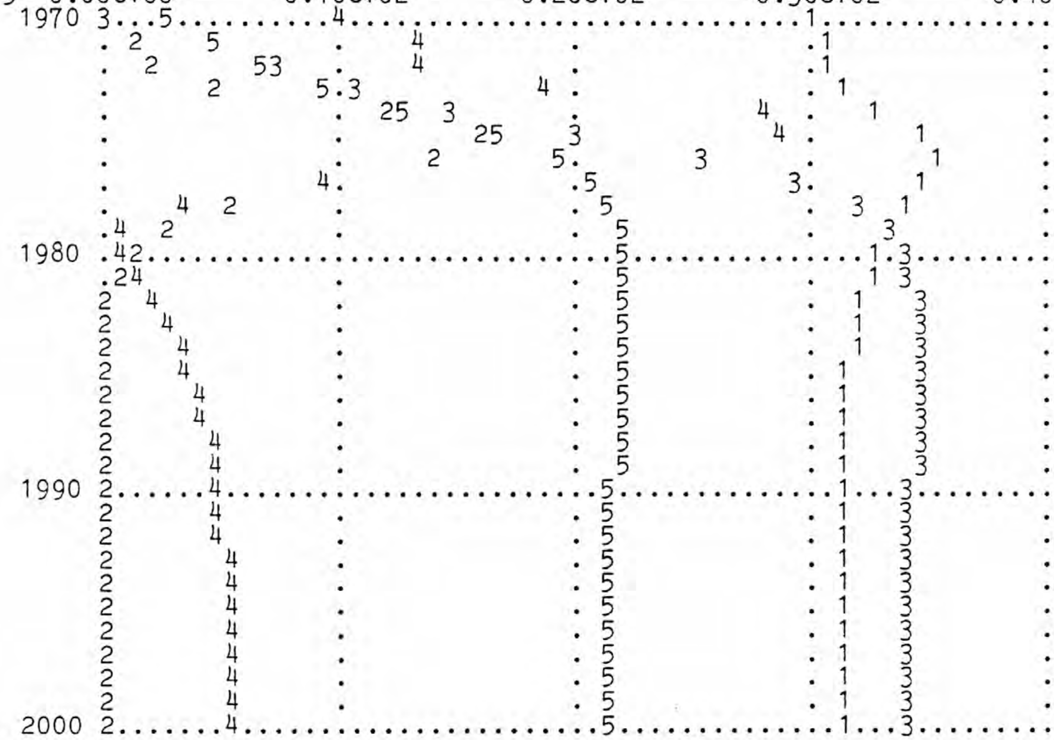
Text in square brackets were not generated by the model.

[scenario 2]

227 211 219 233 825

08/31/77 1452.7 pdt Wed

```
1  0.00e+00        0.10e+05        0.20e+05        0.30e+05        0.40e+05    [population]
2  0.00e+00        0.50e+03        0.10e+04        0.15e+04        0.20e+04    [constr. labor]
3  0.00e+00        0.20e+03        0.40e+03        0.60e+03        0.80e+03    [oper. labor]
4  -.50e-01        0.00e+00        0.50e-01        0.10e+00        0.15e+00    [boom index]
5  0.00e+00        0.10e+02        0.20e+02        0.30e+02        0.40e+02    [coal output]
```



[optional table printed when switch(99)=1]

ncdp= 1;

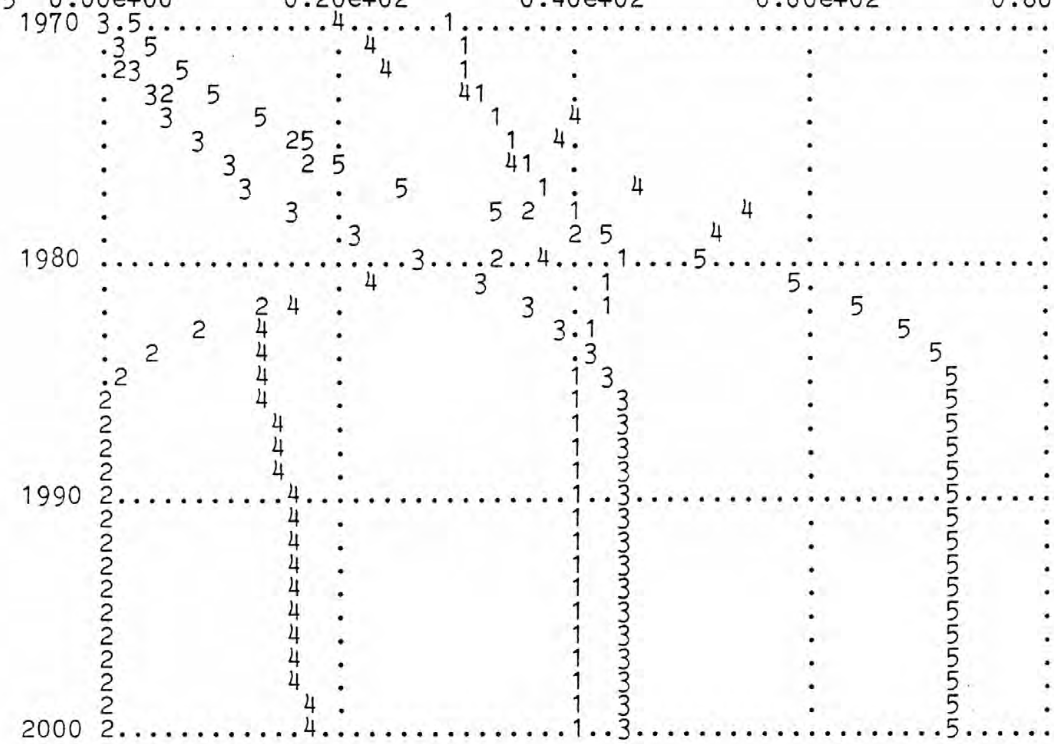
| | | | | | |
|---|---|---|---|---|---|
| 1970.00 | 30345.13 | 0.00 | 0.00 | 0.00 | 3.25 |
| 1971.00 | 30765.06 | 67.66 | 95.05 | 0.02 | 4.99 |
| 1972.00 | 31108.58 | 104.97 | 159.93 | 0.02 | 6.83 |
| 1973.00 | 31787.03 | 264.23 | 221.08 | 0.04 | 9.44 |
| 1974.00 | 33324.13 | 605.69 | 303.47 | 0.09 | 13.22 |
| 1975.00 | 34833.30 | 801.46 | 410.28 | 0.10 | 17.04 |
| 1976.00 | 35425.03 | 710.10 | 515.43 | 0.05 | 19.69 |
| 1977.00 | 35116.11 | 486.43 | 595.06 | -0.00 | 21.12 |
| 1978.00 | 34406.69 | 284.11 | 644.91 | -0.03 | 21.76 |
| 1979.00 | 33690.19 | 149.17 | 672.25 | -0.04 | 22.03 |
| 1980.00 | 33117.98 | 72.66 | 685.91 | -0.05 | 22.13 |
| 1981.00 | 32701.90 | 33.63 | 692.24 | -0.04 | 22.16 |
| 1982.00 | 32406.29 | 15.24 | 694.95 | -0.04 | 22.17 |
| 1983.00 | 32192.38 | 7.19 | 695.95 | -0.04 | 22.16 |
| 1984.00 | 32031.67 | 4.04 | 696.15 | -0.03 | 22.14 |
| 1985.00 | 31906.47 | 3.16 | 695.96 | -0.03 | 22.13 |
| 1986.00 | 31806.80 | 3.36 | 695.61 | -0.03 | 22.10 |
| 1987.00 | 31727.10 | 4.10 | 695.15 | -0.03 | 22.08 |
| 1988.00 | 31664.35 | 5.15 | 694.61 | -0.03 | 22.05 |
| 1989.00 | 31616.92 | 6.43 | 693.99 | -0.03 | 22.02 |
| 1990.00 | 31583.87 | 7.86 | 693.32 | -0.02 | 21.99 |
| 1991.00 | 31564.66 | 9.43 | 692.62 | -0.02 | 21.96 |
| 1992.00 | 31558.93 | 11.08 | 691.89 | -0.02 | 21.93 |
| 1993.00 | 31566.44 | 12.80 | 691.15 | -0.02 | 21.90 |
| 1994.00 | 31587.01 | 14.56 | 690.42 | -0.02 | 21.87 |
| 1995.00 | 31620.49 | 16.33 | 689.72 | -0.02 | 21.84 |
| 1996.00 | 31666.79 | 18.07 | 689.04 | -0.02 | 21.81 |
| 1997.00 | 31725.82 | 19.77 | 688.42 | -0.02 | 21.79 |
| 1998.00 | 31797.51 | 21.40 | 687.84 | -0.02 | 21.76 |
| 1999.00 | 31881.85 | 22.94 | 687.32 | -0.02 | 21.74 |
| 2000.00 | 31978.80 | 24.37 | 686.87 | -0.02 | 21.73 |

[scenario 3]

227 211 219 233 825

08/31/77 1455.7 pdt Wed

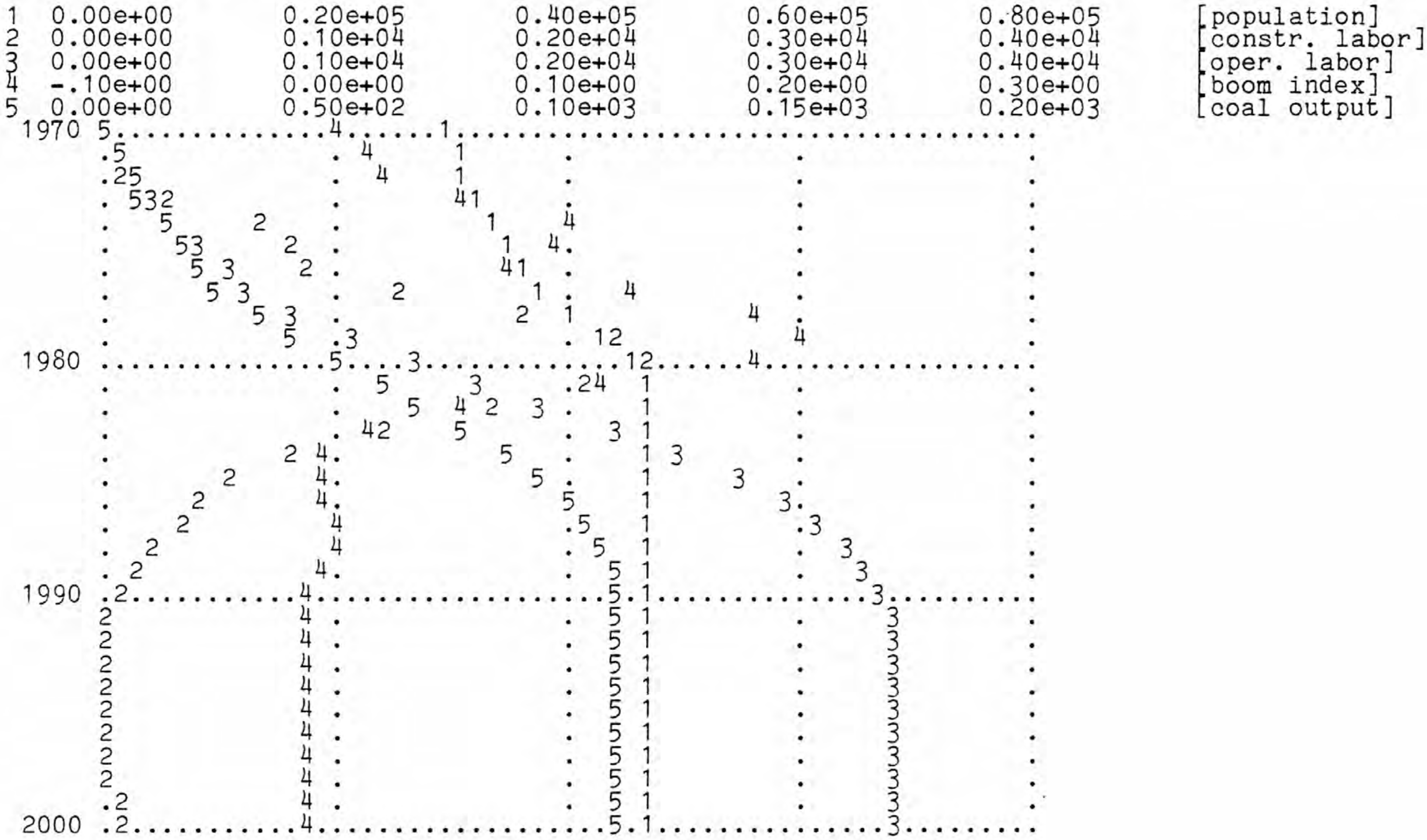
```
1  0.00e+00      0.20e+05      0.40e+05      0.60e+05      0.80e+05   [population]
2  0.00e+00      0.10e+04      0.20e+04      0.30e+04      0.40e+04   [constr. labor]
3  0.00e+00      0.10e+04      0.20e+04      0.30e+04      0.40e+04   [oper. labor]
4  -.10e+00      0.00e+00      0.10e+00      0.20e+00      0.30e+00   [boom index]
5  0.00e+00      0.20e+02      0.40e+02      0.60e+02      0.80e+02   [coal output]
```



[scenario 4]

227 211 219 233 825

08/31/77 1458.8 pdt Wed

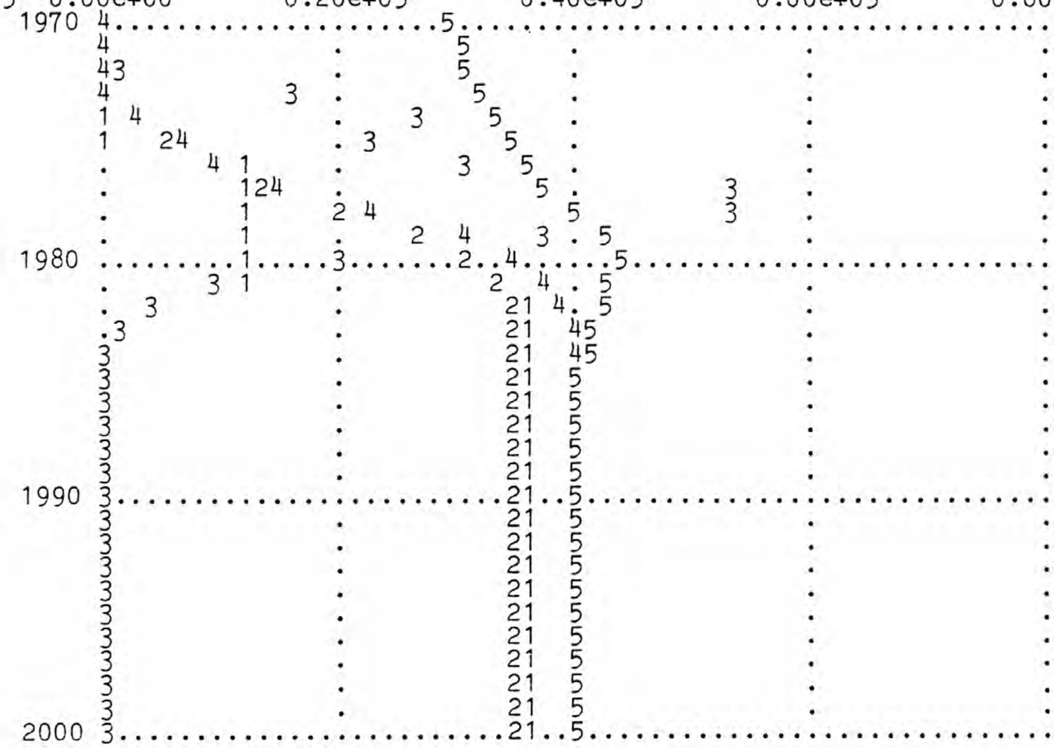


[scenario 3 - electric generation subsector]

37  55 202 240 227

08/31/77  1505.7 pdt Wed

```
1  0.00e+00     0.50e+01     0.10e+02     0.15e+02     0.20e+02   [scenario]
2  0.00e+00     0.50e+01     0.10e+02     0.15e+02     0.20e+02   [capacity]
3  0.00e+00     0.50e+03     0.10e+04     0.15e+04     0.20e+04   [constr. labor]
4  0.00e+00     0.10e+03     0.20e+03     0.30e+03     0.40e+03   [oper. labor]
5  0.00e+00     0.20e+05     0.40e+05     0.60e+05     0.80e+05   [population]
```



[scenario 4 - electric generation subsector]

37  55 202 240 227

08/31/77  1509.3 pdt Wed

```
1  0.00e+00        0.50e+01        0.10e+02        0.15e+02        0.20e+02   [scenario]
2  0.00e+00        0.50e+01        0.10e+02        0.15e+02        0.20e+02   [capacity]
3  0.00e+00        0.50e+03        0.10e+04        0.15e+04        0.20e+04   [constr. labor]
4  0.00e+00        0.10e+03        0.20e+03        0.30e+03        0.40e+03   [oper. labor]
5  0.00e+00        0.20e+05        0.40e+05        0.60e+05        0.80e+05   [population]
1970 4.....................5......................................
     4              .       5      .              .              .
     43             .       5      .              .              .
     4           3  .        5     .              .              .
     1 4            .    3    5    .              .              .
     1   24         . 3        5   .              .              .
     .      4 1     .       3   5  .              .              .
     .        124   .            5 .         3    .              .
     .        1     2 4            5            3 .              .
     .        1     .    2  4      . 5        3   .              .
1980 .........1................2..4....53.........................
     .        1     .        3     2   45         .              .
     .            3 .           1  .  2 5 4       .              .
     .     3        .           1  .   25   4     .              .
     . 3            .           1  .    5    4    .              .
     .3             .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
1990 3..................................51...4....................
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
     3              .              .    51   4    .              .
2000 3..................................51...4....................
```

[scenario 3 - rail subsector]

71  80 204 242 211

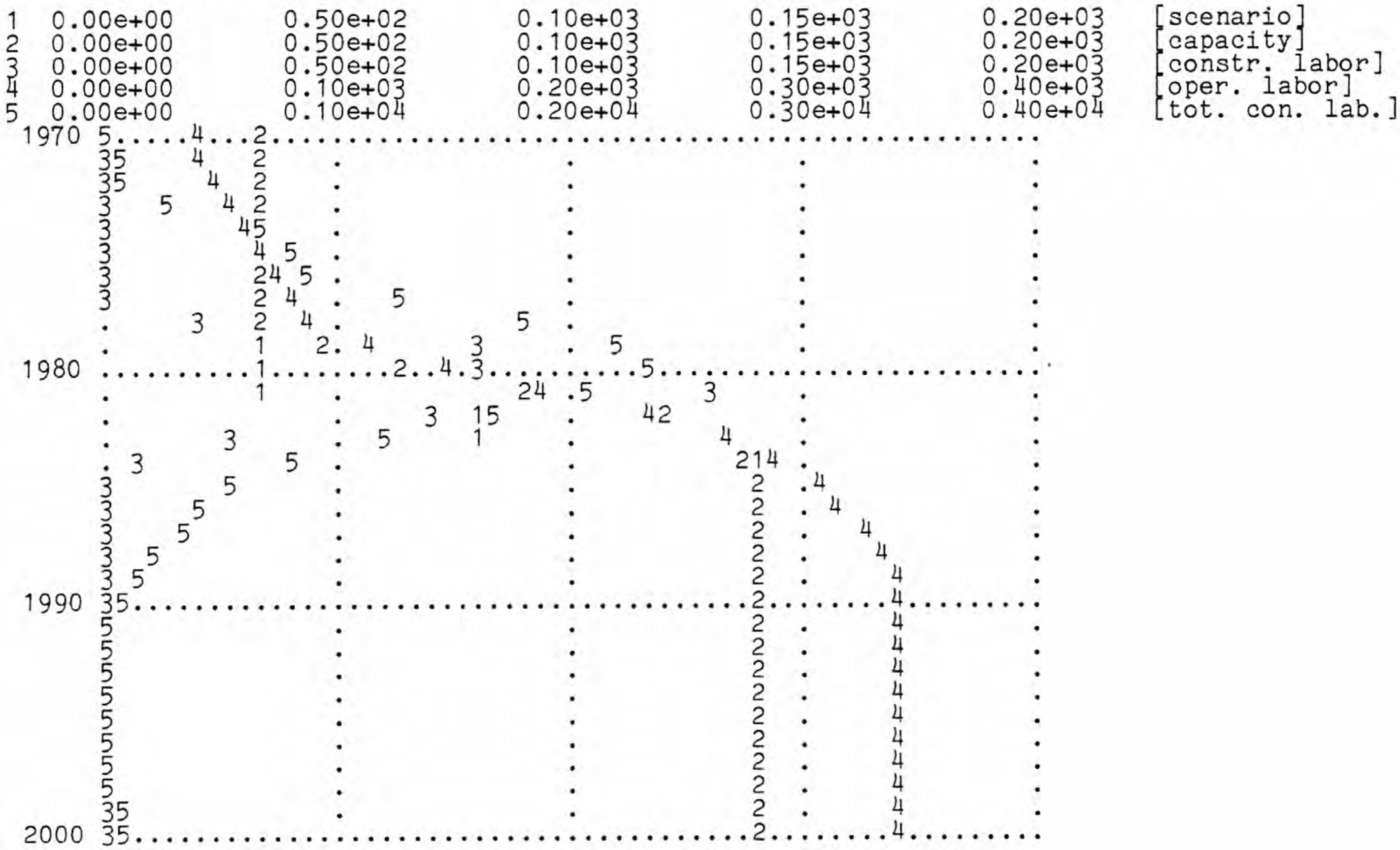
08/31/77  1512.6 pdt Wed

```
1  0.00e+00        0.20e+02        0.40e+02        0.60e+02        0.80e+02    [scenario]
2  0.00e+00        0.20e+02        0.40e+02        0.60e+02        0.80e+02    [capacity]
3  0.00e+00        0.50e+02        0.10e+03        0.15e+03        0.20e+03    [constr. labor]
4  0.00e+00        0.10e+03        0.20e+03        0.30e+03        0.40e+03    [oper. labor]
5  0.00e+00        0.10e+04        0.20e+04        0.30e+04        0.40e+04    [tot. con. lab.]
1970 5.....4....................2.................................
     35    4        .           2  .              .              .
     35     4       .           2  .              .              .
     3   5   4      .           2  .              .              .
     3        45    .           2  .              .              .
     3         4 5  .           2  .              .              .
     3          4 5 .           2  .              .              .
     3           4  .   5       2  .              .              .
     .     3      4 .           5  .              .              .
     .              . 4      3  1  5     2        .              .
1980 ..............3.......4..5.1.....................2...........
     .    3         . 5        41  .              .          2   .
     .3        5    .            4 .              .            2 1
     3     5        .             4.              .             21
     3  5           .              4              .             21
     35             .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
1990 5..............................4...........................21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
     5              .              .4             .             21
2000 5..............................4...........................21
```

[scenario 4 - rail subsector]

71  80 204 242 211

08/31/77  1515.7 pdt Wed

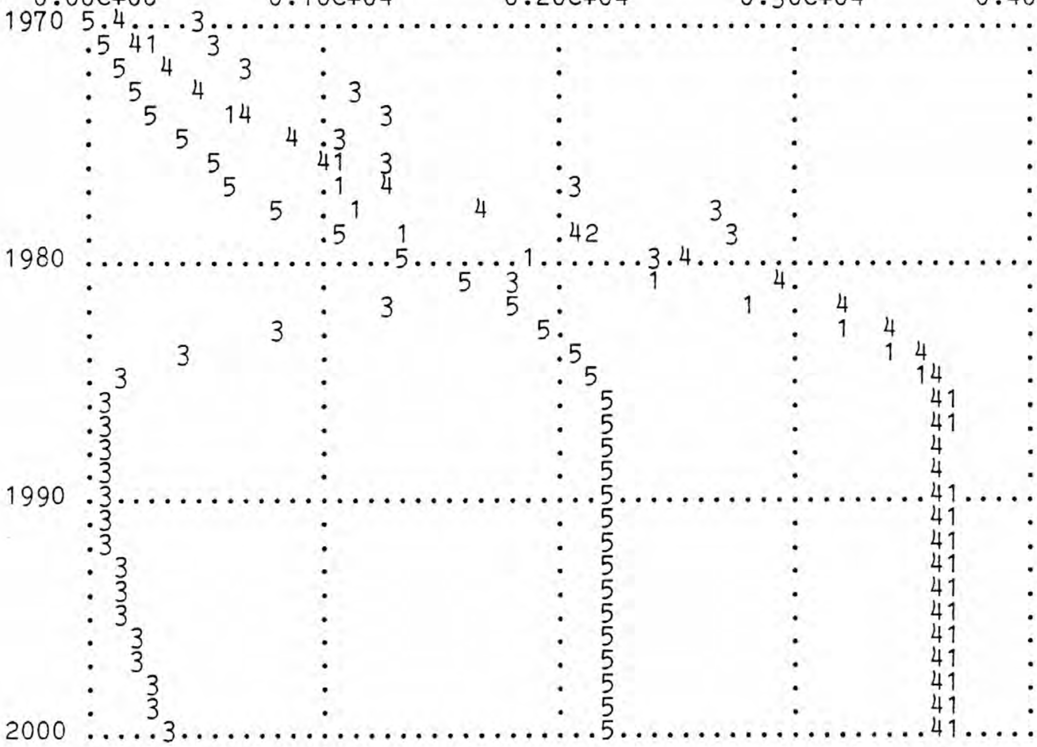


[scenario 3 - mining sector]

827 825 205 243 219

08/31/77  1519.0 pdt Wed

```
1  0.00e+00        0.20e+02        0.40e+02        0.60e+02        0.80e+02    [scenario]
2  0.00e+00        0.20e+02        0.40e+02        0.60e+02        0.80e+02    [capacity]
3  0.00e+00        0.20e+03        0.40e+03        0.60e+03        0.80e+03    [constr. labor]
4  0.00e+00        0.50e+03        0.10e+04        0.15e+04        0.20e+04    [oper. labor]
5  0.00e+00        0.10e+04        0.20e+04        0.30e+04        0.40e+04    [tot. op. lab.]
```

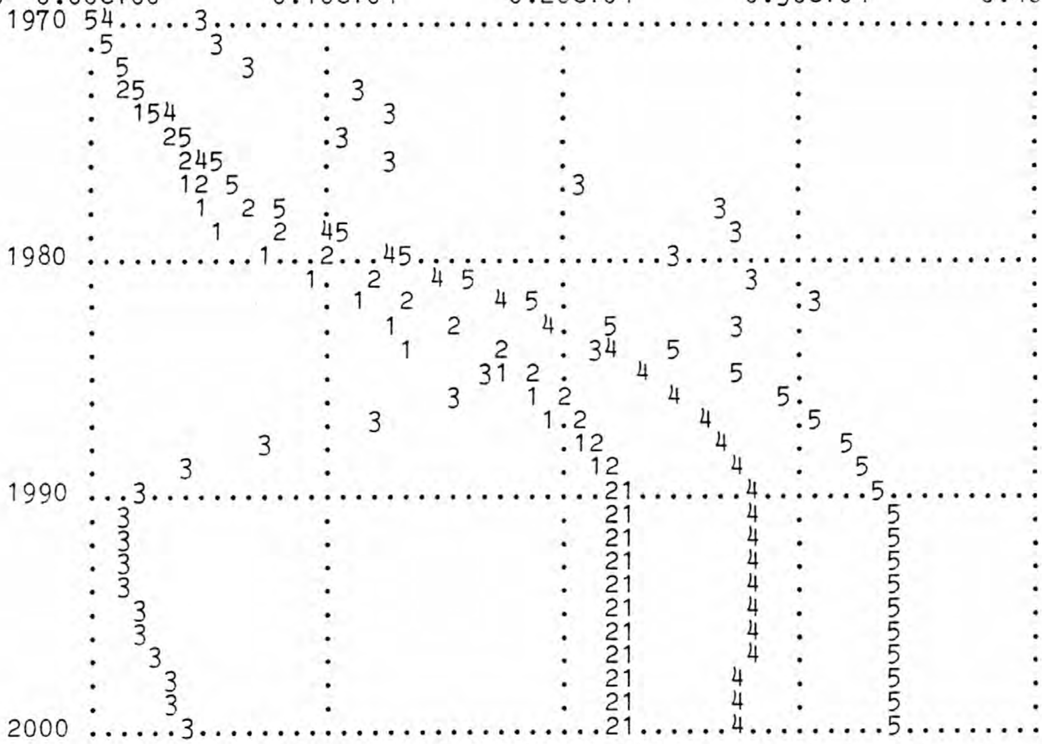


[scenario 4 - mining sector]

827 825 205 243 219

08/31/77  1522.5 pdt Wed

```
1  0.00e+00       0.50e+02       0.10e+03       0.15e+03       0.20e+03   [scenario]
2  0.00e+00       0.50e+02       0.10e+03       0.15e+03       0.20e+03   [capacity]
3  0.00e+00       0.20e+03       0.40e+03       0.60e+03       0.80e+03   [constr. labor]
4  0.00e+00       0.10e+04       0.20e+04       0.30e+04       0.40e+04   [oper. labor]
5  0.00e+00       0.10e+04       0.20e+04       0.30e+04       0.40e+04   [tot. op. lab.]
```

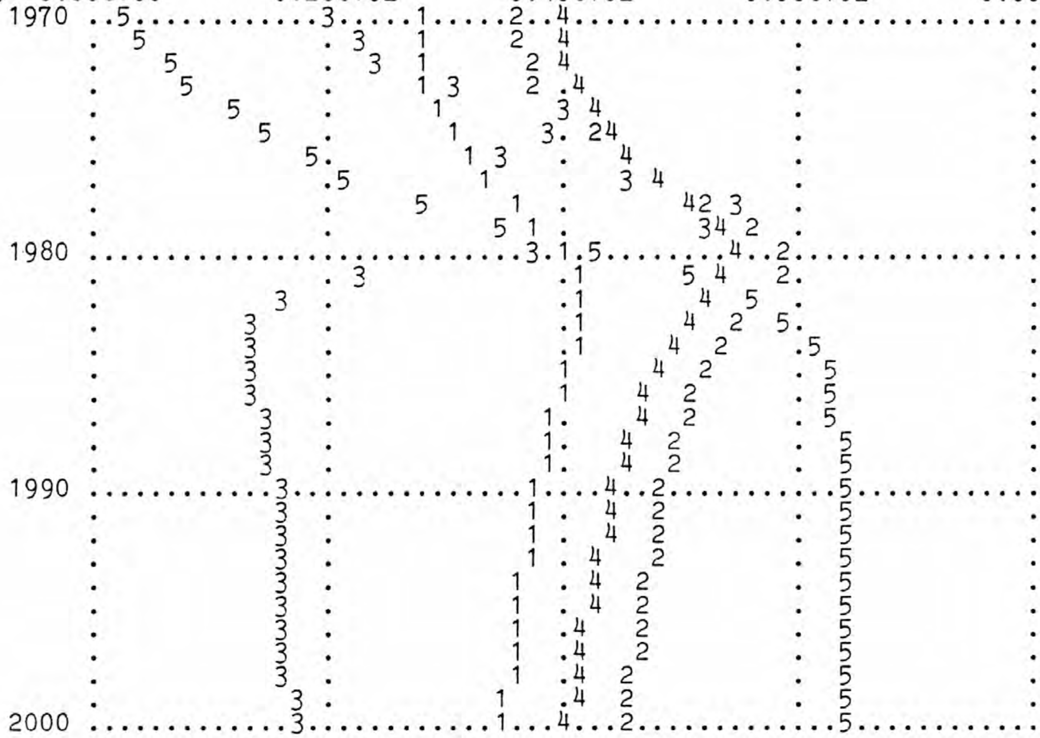


[scenario 3 - demographic sector]

226 224 233 231 850

08/31/77  1525.9 pdt Wed

```
1  0.00e+00        0.10e+04        0.20e+04        0.30e+04        0.40e+04    [pub. serv. labor]
2  0.00e+00        0.20e+04        0.40e+04        0.60e+04        0.80e+04    [priv.. serv. labor
3  -.10e+00        0.00e+00        0.10e+00        0.20e+00        0.30e+00    [boom index]
4  0.00e+00        0.10e+05        0.20e+05        0.30e+05        0.40e+05    [urban pop.]
5  0.00e+00        0.20e+02        0.40e+02        0.60e+02        0.80e+02    [coal export]
```



[scenario 4 - demographic sector]

226 224 233 231 850

08/31/77  1528.9 pdt Wed

```
1  0.00e+00      0.10e+04      0.20e+04      0.30e+04      0.40e+04   [pub. serv. labor]
2  0.00e+00      0.20e+04      0.40e+04      0.60e+04      0.80e+04   [priv. serv. labor]
3  -.10e+00      0.00e+00      0.10e+00      0.20e+00      0.30e+00   [boom index]
4  0.00e+00      0.10e+05      0.20e+05      0.30e+05      0.40e+05   [urban pop.]
5  0.00e+00      0.50e+02      0.10e+03      0.15e+03      0.20e+03   [coal export]
```