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NATIONAL COAL UTILIZATION ASSESSMENT

A Preliminary Assessment of
Coal Utilization in the South

Report to
Assistant Secretary for Environment
Department of Energy

Project Manager

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A list of all agencies contacted during the conduct of this assessment is included as Appendix A to this report.

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ABSTRACT

The National Coal Utilization Assessment (NCUA) is a program sponsored by the Assistant Secretary for Environment, Department of Energy (DOE), to assess the potential environmental, social, and economic effects of coal development and use at the national and regional levels. The assessment has been designed primarily to provide DOE with the information needed to ensure that environmental and social concerns receive appropriate emphasis in DOE's coal research, development, and demonstration (RD&D) programs. This report presents the results from the first year of work conducted under the coal assessment. In general, the report identifies and assesses some of the major problems and issues related to coal development and use in the South assuming a base-case energy scenario for the next 45 years. This scenario assumes a midrange of coal use and a relatively high rate of nuclear use over the forecast period. The first-year assessment has emphasized coal extraction and coal use by utilities. The second year of the assessment, which is currently under way, is adding alternative energy scenarios to the analysis that are more representative of the National Energy Plan and is addressing an analysis of the industrial use of coal that may result from the adoption of the National Energy Plan and other federal initiatives.

The potential impacts from coal development and use in the South are significant, particularly in the 1990-2020 time period. Practically all available sites considered suitable for power plant development in the assessment will be utilized by 2020. Major clusters of power generation are forecasted for counties located near principal rivers. While regional water availability impacts appear moderate, water consumption exceeds current water policy allocations for energy in a number of local areas. Overall, sulfur dioxide increases are well below the annual primary standard; however, several local hot-spot areas were identified. In addition, sulfate concentrations increased significantly, particularly over Virginia, West Virginia, and northern Kentucky. Coal mining is expected to affect 6 of the 12 major ecological regions in the South. Coal mining can be expected to increase average suspended sediment concentrations significantly in some river basins, and special measures will be required to control acid discharges from active mines in pyritic regions. The increased mining and subsequent sulfur dioxide increases from the combustion of coal may also give rise to a land-use confrontation with food and fiber production. Potential health effects from population exposure to sulfur dioxide and sulfates are expected to increase rapidly in several areas, particularly in parts of Kentucky, Maryland, District of Columbia, and Georgia. Regional socioeconomic impacts from coal-related developments were moderate. Regional social costs were relatively low, although some site-specific costs are expected to be very high.

Alternative energy technologies, careful siting selection, and deployment of environmental control technologies and operating policies will be required to reduce or mitigate these potential impacts in the future. Many of these options are currently under investigation and will be discussed in subsequent assessment reports.

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SUMMARY OF MAJOR FINDINGS

The National Coal Utilization Assessment (NCUA) is a program designed to assess the potential environmental, social, and economic effects of coal development and use at the national and regional levels. The Oak Ridge National Laboratory (ORNL) has been responsible for assessing these potential impacts in the South. This report presents the results from ORNL's first year of work under the assessment and emphasizes the potential impacts from coal extraction and use by utilities assuming a base-case energy future scenario that extends over the next 45 years. The scenario used represents a high energy consumption growth rate including a midrange of coal use and a relatively high rate of nuclear use over the forecast period. Thus, the scenario used in this preliminary assessment represents an upper limit impact analysis which is being supplemented by lower scenarios during the second year of the assessment. The report describes the regional and subregional energy supply and demand relationships expected under the scenario and presents a plausible utility power plant siting pattern that could develop from these supply/demand relationships. The analysis uses this pattern of coal extraction and use to assess the environmental, social, and economic effects that could occur in the region. The potential impacts in the South are significant, particularly in the 1990-2020 time period. The major findings of our first-year assessment follow.

ENERGY SUPPLY AND DEMAND IN THE SOUTH

OBERS projections show that the South's population and employment will increase slightly relative to the nation over the forecast period. The region's share of total energy consumption is also projected to increase from 29% in 1975 to 32% in 2020.

The South contains roughly one-quarter of the nation's population and employment. Coal extraction could significantly affect the growth in population and employment in mining states, particularly in West Virginia and, to a lesser extent, in Kentucky and Tennessee.

Future electricity forecasts for the region increase at an average annual rate of 3.6% per year under the base-case scenario — a rate slightly lower than the nation as a whole. In contrast, coal, petroleum products, and natural gas used for heat, power, and feedstocks will increase relative to the total U.S. consumption. Coal used for heat and power will increase most significantly in Tennessee, Kentucky, and West Virginia.

Revitalization of the coal mining industry will significantly affect the Appalachian portion of the South where important reserves are located. West Virginia is likely to regain its position as the leading coal producing state in the region. Lignite mining will expand rapidly in the future, particularly in Texas.

PROJECTING ENERGY FACILITY DEVELOPMENT IN THE SOUTH

Total electrical generation requirements are projected to increase from 192,000 megawatts in 1975 to slightly over 1 million megawatts in 2020 — an increase of 445% in the region.

Plausible county siting patterns developed by ORNL for coal-fired power plants, synfuel plants, and surface- and deep-mining activities to meet this electrical generation demand involve adding generating capacity in 142 counties in the region. By the year 2000 many of the counties presently considered suitable for power development will receive additional generating capacity (Fig. 1). Total capacity of 8000 MWe may be necessary in some counties adjacent to principal rivers in the region by the year 2020. Coal-fired power plants will probably be introduced extensively in such states as Texas, Louisiana, and Florida, which have historically relied on other fuels.

REGIONAL AIR-QUALITY IMPACTS

Air quality may be affected significantly by the siting patterns, particularly where clusters of coal-fired facilities are located.

The results of the air-quality analysis indicate that in the vicinity of some facilities large fractions of the allowable Prevention of Significant Deterioration (PSD) increments will be used up even though most areas of the South should remain below the National Ambient Air Quality Standards (NAAQS). Potential sulfur dioxide and sulfate loadings associated with the plausible siting patterns of future coal-fired power plants were calculated for 1975, 1985, 2000, and 2020 (Fig. 2). The annual average sulfur dioxide concentration from all coal-fired utilities expected to be on line in 2020 is projected to be below 10 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) except for areas close to large generating facilities. The annual primary standard for sulfur dioxide is 80 $\mu\text{g}/\text{m}^3$. Calculations do not exceed the annual primary standard even where there are clusters of generating plants (total capacity approximating 5000 MWe is projected for a number of counties). However, the addition of industrial pollutant loadings may change this outlook. Sulfate concentrations show a distinct buildup from west to east with highest concentrations in 2000 occurring over Virginia, West Virginia, and northern Kentucky.

REGIONAL WATER RESOURCES IMPACTS

Water availability will become a major constraint on future energy development in the region.

Water availability has become a prime determinant for locating future energy facilities because of the need to dissipate waste heat by means of cooling towers or once-through cooling. In the humid East, planners

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Fig. 1: Plausible coal-fired steam-electric generating capacity for the year 2000, NCUA base-case scenario.

Fig. 2. Calculated concentrations of sulfur dioxide for the year 2000, NCUA base-case scenario. Interval limits: (1) <0.1 , (2) $0.1-1.0$, (3) $1.0-3.0$, (4) $3.0-10.0$, (5) $>10.0 \mu\text{g}/\text{m}^3$.

normally allocate 10% of the 7-day/10-year low flow^a for energy use. The ORNL analysis indicates that over 30% of available flow will be consumed in several subbasins by 2000 including parts of the Ohio, Susquehanna, and Monongahela. Water shortages already exist in parts of Florida, Texas, Oklahoma, and Arkansas. This pattern of water use becomes progressively worse by 2020, which means generating plants in some of these basins will probably have to use saline or groundwater for cooling or use dry-cooling technologies.

REGIONAL WATER-QUALITY IMPACTS

Mining can be expected to increase average suspended sediment concentrations up to a factor of about 100 over those for undisturbed basins, even when the Surface Mining Control and Reclamation Act is fully enforced.

Point-source discharges associated with coal combustion and conversion will be subject to the effluent limitations of the Federal Water Pollution Control Act and Amendments. While the point-source effluents will presumably be controlled to avoid deleterious effects on water quality, as the magnitude of coal use increases, the amount of potentially harmful residuals, concentrated at specific locations, will also increase. Effluent control then becomes part of an integrated solid, liquid, and gaseous waste-management problem and should be studied as such.

Nonpoint-source effluents are more difficult to control than those from point sources. Even when the provisions of the Surface Mining Control and Reclamation Act are met, storm flows in surface-mined watersheds could carry suspended sediment loads 100 times greater than similar flows in undisturbed basins. To a large extent, acid mine drainage reflects an area's geology and past mining history. Where pyritic materials occur in or near coal seams, special measures will be required to control acid discharges from active mines, while inactive or abandoned sites may continue to leak acids to streams.

REGIONAL ECOLOGICAL IMPACTS

Important impacts on regional ecology may be experienced because of both coal mining and coal utilization in the South.

Analyses were performed (1) to evaluate the ecological impacts of increased coal utilization on the southern region as a complete system, and (2) to key on some critical aspects of basic ecological processes and parameters within the region. The preliminary major findings are:

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^a7-day/10-year low flow is the lowest stream flow which is likely to occur for a duration of seven consecutive days in any ten-year period.

Coal mining impacts will affect 6 of the 12 major ecological regions of the South. Some impacts related to coal use, such as waste disposal, will be localized near the point of use. Others, such as low-flow problems caused by water consumption, will affect whole regions.

Due to the increase in coal utilization by power generation facilities, a potential air pollution confrontation may exist with fiber (softwood) and food (predominantly soybeans) production.

The counties containing strippable coal reserves occupy nearly 80 million acres of land. Of this, 13.2% is agricultural, 21.7% is in grazing systems, and 58.8% is forestland. Again, there is a potential conflict between food and fiber production and coal utilization.

Of the 219 counties in the southern United States which have strip-pable or deep-mine coal reserves, 70% contain potential habitat for threatened or endangered mammal or bird species.

Preliminary studies of the effects of perturbations, such as an increase in the concentration of pollutants, on the long-term forest dynamics indicate a potential for change in the fundamental character of the growth and succession and for alteration of species composition.

If the concentration of carbon dioxide in the atmosphere continues to increase at the general rate of the last several decades, the concentration may double within about 75 years. Climate modification may result, leading to widespread impact on the earth's biota.

REGIONAL HEALTH IMPACTS

Population exposure to sulfur dioxide and sulfates will increase rapidly in several areas of the South by the year 2000.

The analysis of health effects identified those areas within the southern region which are of greatest interest from the standpoint of population exposure to sulfur dioxide and sulfates. In general, the same areas have the highest estimated exposure levels in each of the three time periods. Jefferson County, Kentucky; Baltimore County, Maryland; Washington, District of Columbia; and Fulton County, Georgia, are assigned the highest sulfur dioxide exposure levels in the years 1975, 1985, and 2000.

REGIONAL SOCIOECONOMIC IMPACTS

Important regional economic benefits as well as local social costs may result from the NCUA siting pattern.

ORNL's preliminary assessment of the socioeconomic impacts of coal development and use in the South indicates two economic benefits: (1) increased purchase of coal plant construction materials (largest increases

ORNL-DWG 78-11634

Fig. 3. New county retail sales (direct and indirect) from construction worker expenditures during the period 1985 to 2000, NCUA base-case scenario (millions \$ 1967 equivalents).

occurring in populated urban areas) and (2) growth in local business trade resulting from increased wage expenditures by new work forces in counties with coal development (Fig. 3). Possible negative social effects from new energy-facility development would be those resulting from the "boom town" phenomenon, such as increased in-migration creating a demand for local services which cannot be met by local government.

Both the beneficial and negative impacts from increased coal development are a direct function of the siting plan developed. In general, rural areas would encounter serious infrastructure constraints and limited potential benefit from the siting pattern. On the average, host areas were calculated to provide 31% of the materials required for the construction of coal-fired power plants. Rural areas, such as those commonly found in the South, generally could provide only 25% or less of these materials. Trade multipliers, although lower for rural counties, are important sources of revenue for rural counties in the region. In terms of social costs, the analysis indicates that out of the 186 counties likely to host generating stations, synthetic fuel plants, or additional coal mining between now and 2020, 54 counties should have growth rates above 15% due to coal related facilities. Most of these counties are located in Kentucky, Texas, and West Virginia. Past experience in the West indicates that annual growth rates of 15% or greater frequently exceed the capacity of local governments to supply required services.

1. INTRODUCTION

1. INTRODUCTION

1.1 Purpose, Scope, and Audience

The National Coal Utilization Assessment (NCUA), sponsored by the Assistant Secretary for Environment, Department of Energy (DOE), is designed to assess the potential environmental, social, and economic effects of coal development and use at the national and regional levels. The assessment was initiated primarily to provide DOE with information needed to ensure that environmental and social concerns received appropriate emphasis in DOE's coal research, development, and demonstration (RD&D) programs and to ensure that constraints and mitigation strategies for increased coal use were identified and analyzed at the regional level.

This report presents the results of the first year of the assessment and is based on an analysis of the impacts associated with siting coal-fired electric power plants, synthetic fuel plants, and coal mining required in the southern region under a base-case scenario that extends over the next 45 years. This scenario assumes a midrange of coal use and a relatively high rate of nuclear use over the forecast period. The second year of the assessment, which is currently under way, is adding alternative energy scenarios that are more representative of the National Energy Plan. It is also adding an analysis of the industrial use of coal that may result from the adoption of the National Energy Plan and other federal initiatives. A detailed comparison of these scenarios is presented later in this chapter in Table 1.2.

The Oak Ridge National Laboratory (ORNL) is one of six national laboratories participating in the coal assessment (Fig. 1.1). Each of the national laboratories is assessing the potential impacts of coal development and use in its respective region for the period 1975-2020. ORNL's primary responsibility is to conduct the assessment in a 12-state southern region consisting of Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia, and West Virginia. As will be shown in this report, the distributional effects of coal development and use are likely to vary widely in the South over the next 45 years. These effects will require a range of mitigation strategies and environmental control options to maintain and improve the environmental quality of the southern region. Several of these strategies and options are under investigation and will be discussed at the completion of the second year of the assessment.

The National Coal Utilization Assessment has been designed primarily to provide information on the potential environmental, social, and economic effects of increased coal development and use to DOE's coal RD&D planners. Extensive contact has been maintained with federal officials throughout the design and conduct of the assessment in order to ensure that the results of our analyses will receive appropriate emphasis in DOE's coal RD&D programs.

ASSESSMENT PARTICIPANTS

SIX NATIONAL LABORATORIES ARE PARTICIPANTS IN THE NCUA

Fig. 1.1. Regional responsibilities for laboratories participating in the NCUA.

In addition, a major effort was made to identify the important coal-related issues and problems confronting state and regional energy planners in the South and to ensure that their major concerns were also considered. To ensure that the assessment results are relevant to the concerns of these officials and that the assessment maintains a regional as well as national perspective, a special effort was made early in the program to identify the major issues and constraints associated with increased coal development and use as seen by regional officials.¹ These issues and constraints are summarized in the next section.

1.2 Regional Coal Issues and Constraints

One of the first major tasks of the NCUA was to identify major coal-related issues and constraints on coal development and use in the South. ORNL staff met with each of the 12 state energy offices, five state universities, two federal regional centers, and four southern regional commissions and boards as well as the Tennessee Valley Authority and several public-interest groups to solicit their views on coal-related issues and constraints in the region (see Appendix A). In addition to interviewing these officials, meetings were held with numerous state officials and collected and analyzed numerous state and regional reports relevant to the NCUA.

It is very difficult, perhaps impossible, to compact an analysis of many documents and the content of many hours of conversation into a summary. Nevertheless, Table 1.1 attempts to show, in a very condensed format, the major constraints on increased coal utilization as identified from interviews with regional officials and from analysis of key state reports.

Some states, such as Florida and South Carolina, had few comments regarding coal because they neither produce nor use large amounts of it at present. Comments from the remainder of the states showed a reasonably consistent pattern.

- Federal regulations involving coal mining and coal use appear too inflexible and not sensitive to regional differences.
- Lack of a firm federal energy policy and a clear commitment to coal inhibits the private sector's decision to invest heavily in switching from oil and gas to coal.
- Inadequate regional and local transportation and distribution facilities to transport coal from mine to user were viewed as a serious constraint in several states.
- Shortages of critical materials and skilled labor were cited as limiting factors to rapid expansion of coal production and use.
- Shortage of risk capital to finance expensive switching from oil and gas systems to coal systems will hinder the switch to coal.

Table 1.1. Major issues and constraints related to increased coal production and use in the South

State	From interviews with officials									From state and regional reports							
	Federal regulations hinder production or use	Lack of federal energy policy regarding coal	Lack of coal transportation	Shortage of materials and skilled manpower	Water shortage	Lack of capital investment in coal	Lack of information regarding coal technology	Public reaction to environmental damage	Other	Federal regulations hinder production or use	Lack of federal energy policy regarding coal	Lack of coal transportation	Shortage of materials and skilled manpower	Lack of capital investment in coal	Lack of market structure	Public reaction to environmental damage	Other
Alabama	X			X				X								X	X
Florida									X								
Georgia	X		X	X	X		X		X		X					X	X
Kentucky		X	X	X		X			X	X	X	X	X	X	X		X
Louisiana		X	X							X	X			X		X	X
Mississippi	X	X	X		X		X		X	X			X		X	X	
North Carolina	X	X							X	X	X						X
South Carolina	X					X				X			X			X	X
Tennessee	X																
Texas	X				X					X		X		X			X
Virginia	X		X					X	X	X			X		X		X
West Virginia	X		X	X				X	X								

Derived from F. D. Boercker et al., *Coal and Energy: A Southern Perspective*, ORNL/TM-5900 (August 1977).

- Shortages of water for energy development and use were viewed as constraints on major coal or nuclear plant expansion.
- Adverse public reaction to environmental damage caused by mining and burning of coal would hamper its development and use in the region.
- Lack of information regarding the status of new coal technologies would limit the introduction and deployment of synthetic fuel technologies.
- Lack of a developed coal market and distribution system, particularly in states with little or no previous coal use experience, was viewed as a major constraint.

These state and regional issues and constraints were added to the regional research and analysis agenda² currently being developed by ORNL and are discussed in this and subsequent reports planned under the NCUA.

1.3 Regional Perspective and Background

1.3.1 Socioeconomic

The South has a number of historic and contemporary socioeconomic characteristics that will influence its energy future. An important and very basic characteristic of the region is that in recent years it has been one of the fastest growing in the country. Overall, the 12-state region is currently increasing in population at about twice the rate of the nation. The South has undergone a dramatic reversal of migration patterns during the past 70 years. Between 1900 and 1960 there was a net emigration from the region, but since 1960 there has been a large in-migration. As with other characteristics, the growth rate varies markedly from state to state within the region. For example, from 1970 to 1976 the population of Florida increased 24% as compared with an increase of only 4% for West Virginia. In the recent past, the existence of plentiful and uninterrupted supplies of energy at relatively low prices has frequently been cited as an important factor in attracting new industry to the South. While increasing energy costs may moderate this trend, the availability of current and future basic energy resources will continue to make this region competitively attractive.

Socioeconomically, the South is a paradox: Despite its recent high growth trend and influx of new industries, the overall economic status of the region is still relatively poor compared with that of the rest of the nation. For example, income increased somewhat more rapidly in the South than the rest of the country over the past five years, but regional income was still much less than the national average.³ In 1975, per capita income ranged from \$4052 in Mississippi to \$5785 in Virginia, while national per capita income for the same year averaged \$5902. As a consequence of the lower per capita income, almost one-fourth of the population of the 12-state region is below the federal definition of poverty, as compared with about one-seventh for the nation as a whole.

Obviously, the region has attractions that are not simply economic. Some have suggested that mild climate, abundant and varied recreational facilities, and the beauty of its physical landscapes compensate for the other factors. Since these environmental elements are important to the residents of the region and its tourist economy, it is even more important that the development of energy resources and industries should be planned to minimize negative impacts upon this environment.

1.3.2 Institutional

Historically, energy has been of major importance to the people of the South. This concern is reflected in the large and growing number of state and regional agencies that deal with energy-related matters as the states of the region are becoming better organized to deal with energy problems. Since 1973 each of the 12 states has created a special energy office to look after energy matters internally as well as coordinate them externally with the many other state and national agencies that are concerned with energy.¹ Generally, the state energy office is assigned administratively to the governor's office and has the responsibility for five major functions: (1) preparation of an emergency fuel allocation plan, (2) education of the public regarding conservation practices, (3) compilation of energy data and analysis of future demands, (4) liaison with federal energy agencies, and (5) recommendation of energy policies for consideration by the governor and/or the legislature.

Because energy-related issues pervade almost all aspects of the citizen's life, a great variety of agencies within the state must be concerned directly with these issues. A recent survey of southern states summarizes the principal energy-related agencies in addition to the 12 state energy offices.⁴ The survey reports 82 agencies that are concerned directly with energy matters in the 12-state region. The proliferation of these agencies reflects the scope of state concerns related to energy, including discovery and extraction of mineral energy; protection of air, water, and land quality; transportation of energy resources; energy price regulation; basic research related to energy; energy factors involved in planning for economic growth; concern for public health, including mine safety; and conservation of the states' natural resources.

In addition to the state-level agencies there are a number of regional agencies concerned with energy issues in the South. These include the Federal Regional Centers in Atlanta and Dallas, with representatives from DOE, EPA, DOI, and other agencies; Southern States Energy Board; Appalachian Regional Commission; Ozarks Regional Commission; Coastal Plains Regional Commission; Southern Growth Policies Board; and the Tennessee Valley Authority. Thus, a substantial institutional machinery is in place to deal with the energy future of the South.

1.3.3 Energy

There are several important energy characteristics of the 12-state region that summarize its energy background. First, the region is an important net-energy producer. For example, in 1974 the region produced about 36 quadrillion Btu (quads) of energy (60% of U.S. domestic production) and consumed about 22 quads of energy. Historically, the region has been rich in coal, natural gas, and oil. The people of the region consider an abundance of natural energy resources to be a great attraction to industry and a source of stable employment.

A second important characteristic is that the energy resources in the region are highly concentrated in only a few states (Fig. 1.2). Few generalizations can be made about the energy conditions within the region that would not obscure the great variability among the states. Some states supply much more energy than they consume (Kentucky, Louisiana, Texas, and West Virginia); some produce very little energy, remaining dependent upon imported energy (Florida, Georgia, North Carolina, and South Carolina); in the remainder, energy production and consumption are almost in balance. The four major energy-producing states fall into two groups: (1) the coal-producing states of Kentucky and West Virginia and (2) the oil- and gas-producing states of Louisiana and Texas. These four states account for over 90% of the total energy production of the region and over half the total United States domestic production. Patterns of consumption of primary fuels also vary from state to state. Alabama, Kentucky, Tennessee, and West Virginia are heavy coal users, and each is a producer of coal. Virginia, Texas, Georgia, and Florida are heavy users of petroleum, but all except Texas must import it. As might be expected, Louisiana and Texas are highly dependent upon natural gas. The southern region is, therefore, quite heterogeneous in terms of its energy resources and its pattern of energy consumption.

A third energy characteristic of the region is the well-known mismatch between current energy production and proved energy resources. Petroleum and natural gas account for only 14% of the region's proved reserves. Yet these two fuels account for approximately 80% of the region's current production (Fig. 1.3). Coal is by far the major fossil-fuel energy resource of the region, but it lags behind natural gas and petroleum in production.

The uneven distribution of energy resources in the region forms the background for many of the issues that have developed around the National Energy Plan and its policy to shift from the use of oil and natural gas to the use of coal. People in Louisiana and Texas question why they should be forced to sell their gas and oil at regulated prices and then be forced to convert to coal and import that coal at market price. Most of the reserves of coal for the region are concentrated in Kentucky, West Virginia, and Virginia. Much of the coal tends to be relatively high in sulfur content. Widespread switching by utilities and industries from the use of oil and gas to the use of coal in the region would require transporting large quantities of coal from coal-rich states or lower-sulfur coal from distant western fields to supply these new markets in

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REGIONAL TOTALS: CONSUMPTION = 21.4 Q, PRODUCTION = 35.7 Q

Fig. 1.2. Energy balance by state and region, quadrillion Btu, 1974. Data are approximate only for the year 1974 and have been taken from various available reports published by state and regional agencies. Derived from F. D. Boercker et al., *Coal and Energy: A Southern Perspective*, ORNL/TM-5900 (August 1977).

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THE REGIONAL CHARACTERIZATION REPORT SUMMARIZES
THE ENERGY BASELINE FOR THE SOUTHERN REGION

Fig. 1.3. Proved reserves and annual production, in quads, for the 12-state region, 1972. Derived from F. D. Boercker et al., *Coal and Energy: A Southern Perspective*, ORNL/TM-5900 (August 1977).

the East. Implementation of a best-available control technology provision as part of the National Energy Plan would, of course, favor the development and use of coal from coal fields in the East.

The future energy forecasts for the South are dominated by coal. In 1972, the 12 southern states contained approximately 5000 quads of coal in proved reserves and had an annual production of 7.5 quads. This represented approximately 50% of total U.S. domestic production in 1972. In 1974, production increased slightly to 8 quads; however, since then forecasts for future coal production have increased sharply based on the region's extensive reserves and the president's recent initiatives to increase coal use and reduce dependence on oil and gas. Accelerated surface and underground mining of these reserves will potentially disrupt the environmental, social, and economic patterns of the region. These forecasts are viewed with mixed feelings by local and state residents. While many see the rebirth of the mining industry as a stimulus to economic growth, others do not want growth if it is accompanied by high environmental, social, and economic costs.

1.3.4 Environmental

The environmental composition of the South is extremely complicated. The physiography of the region ranges from the Smoky Mountains to the Florida Keys, and from the megalopolis of the Washington, D.C.-Arlington, Virginia, area to the Chihuahuan Desert of West Texas. The complexity and diversity of these environmental systems are described in Sect. 7 (for additional information see Boercker et al.¹).

The region is one of great ecological variety and characterized by generally high biological productivity (except for western Texas and Oklahoma). For the most part the ecosystems of the South are probably quite resilient in comparison to those of more climatically rigorous areas (e.g., tundra, desert). Because of this resiliency, due primarily to their extreme biotic richness, the natural communities of the South can withstand substantial human pressure. However, as is described in Sect. 7, there are some subtle and striking changes which will occur within these ecosystems due to the increasing use of coal. Furthermore, the massive disruption and destruction of the ecosystems through surface mining exceed the capacity of the most resilient biota to recover.

Expanding urbanization in the South undoubtedly places as much pressure on the environmental systems as does the present use of coal. This expanding urbanization from the rising population of the region is primarily due to its favorable climate and abundance of natural resources. The climate is dominated by warm temperatures with the major variable being the amount of precipitation. The precipitation varies from 10 in. (25 cm) a year in the extreme West to over 60 in. (155 cm) in the Southeast. The amount of moisture plays a major role in coal extraction and consumption. Low moisture availability makes it more difficult to revegetate areas which have been mined and leads to the unavailability of water for cooling purposes in power generation. High rainfall aggravates mining operations through erosion and siltation of streams, rivers, and receiving lakes.

1.4 General Study Approach and Limitations

ORNL developed and used a stepwise approach to conducting the NCUA to identify the potential region-wide effects of accelerated coal development and use (Fig. 1.4). This approach was consistent with that used by the other national laboratories participating in the coal assessment. We started by selecting national energy scenarios for the future which were disaggregated to the Bureau of Economic Analysis (BEA) level to derive subregional energy demand. BEA areas are functional economic units that reflect regional economic activity and, consequently, provide a useful unit for analyzing regional energy demand in the future. As shown in Fig. 1.4, we next characterized current and future energy technologies in terms of their resource requirements and potential pollutant effluents. The forecast of regional energy demand was compared with the utilities' forecasts of planned generation capacity to identify where future power plants would be required. Based on the regional energy supply-demand forecasts and the technologies available, we selected a mix of technologies to meet the forecasted energy needs of the region. We screened and selected candidate areas by applying region-specific criteria such as availability of water, coal, and transportation, as well as environmental constraints such as air quality and socioeconomic constraints such as population distributions. These candidate areas were assumed to be plausible sites for future energy development and were used to assess the potential social, economic, and environmental effects of the proposed energy facilities in the region. The siting criteria or technology mix was revised until an acceptable siting pattern was developed.

In the NCUA, we started with a base-case energy scenario provided by the Brookhaven National Laboratory and disaggregated this scenario to the BEA level using projections of economic activity from the Office of Bureau of Economic Research Service. This base-case scenario assumed that energy consumption growth rates prevalent in the early 1970s continue into the future. For example, this base case assumed a relatively high national energy consumption growth rate of 2.7% last year. By comparison, recent federal policy has been designed to achieve a rate of approximately 2.0% per year or less. Further, the base-case scenario represents a relatively high rate of oil, gas, and nuclear fuel use and only a moderate coal-use pattern in the future. Thus, the first scenario used in the NCUA analysis represents a continuation of energy-use trends prevalent in the late 1960s and early 1970s. Since the initiation of the NCUA, several alternative scenarios have been suggested as part of the National Energy Plan and other federal initiatives. Some of these scenarios, which are compared in Table 1.2, will be considered as part of the second year of the coal assessment.

The scenario approach used in the NCUA has a number of advantages. First, it provides a common basis for conducting all the regional assessments and comparing the impacts for all regions on a consistent basis. While we started with a high oil, gas, and nuclear scenario, it represents a national energy future that would have been expected based on energy trends prior to the international oil embargo of 1973.

Fig. 1.4. ORNL approach to integrated regional assessments.

Table 1.2. Comparison of selected national scenarios
(Resource consumption in quadrillion Btu. To convert to joules, multiply by 1.055×10^{18})

Scenario	1985						2000						2020					
	Coal	Oil	Gas	Nuclear ^a	Other ^b	Total	Coal	Oil	Gas	Nuclear ^a	Other ^b	Total	Coal	Oil	Gas	Nuclear ^a	Other ^b	Total
NCUA																		
Base case	21.0	40.8	25.9	9.9	3.9	101.5	31.7	50.7	23.8	28.5	7.4	142.1	56.7	61.0	9.8	89.4	14.2	231.1
Accelerated synthetic fuels	22.2	40.8	25.0	9.9	3.9	101.8	40.2	50.0	18.3	28.5	7.4	144.4	67.8	58.7	3.6	89.4	14.2	233.7
High-coal electric	21.0	40.8	25.9	9.9	3.9	101.5	38.4	50.7	23.8	21.7	7.4	142.0	71.4	61.0	9.8	74.4	14.2	230.8
Accelerated synthetic fuel and high-coal electric	22.2	40.8	25.0	9.9	3.9	101.8	45.9	50.1	19.0	21.7	7.4	144.1	80.2	59.2	4.9	74.4	14.2	232.9
Water Resources Council																		
Base case	Same as NCUA base case, 1985 to 2000																	
Accelerated synthetic fuels	Same as NCUA accelerated synthetic fuels, 1985 to 2000																	
National Energy Plan																		
Base case	21.9	45.2	18.8	7.4	3.5	96.8												
Initiative	26.7	36.0	18.8	7.6	3.5	92.6												

^aValued in fossil-fuel equivalents.

^bIncludes hydro, solar, and geothermal.

Second, by adding alternative energy scenarios as part of the second year of the program, we will be able to identify the sensitivity of national and regional environmental conditions with the level of energy demand as well as the mix of technology deployed.

The approach adopted in the NCUA to identify and analyze the potential consequences of alternative energy futures also has its limitations. It is emphasized that the results presented in this and subsequent reports issued on the coal assessment must be interpreted as representative of probable impacts under the energy scenarios incorporated in the assessment. The scope of the NCUA is also limited by time and other available resources. This report is not a comprehensive integrated regional assessment; rather, its purpose is to provide information and evaluations of selected issues and impact areas that can contribute to an eventual integrated assessment. For the first year, the scope was limited to assessment categories that were standardized for all regions to facilitate interregional comparisons. The material included in each category was limited by time, fiscal and manpower resources, and the fact that the current state of knowledge about many of the impact categories suggests more questions than it provides answers.

At this time, summarizing what is known about the impacts of increased coal utilization in the United States is like taking a snapshot of a moving train. Not only are many other summaries being prepared based on different guidelines and sources of information,⁵ but the current research effort to determine coal development impacts amounts to a substantial increase over past levels. Working from a very small base of past studies, compared to research on the impacts of nuclear energy, we are augmenting our knowledge at a rapid rate. This quickly outdates a report.

Consequently, it is important to put this report in perspective. The characterization of impacts is incomplete because some important issues are not discussed. For instance, aquatic ecology is not considered nor are solid waste impacts on terrestrial ecology. Water-quality impacts of coal combustion are not included. Most other impacts of coal utilization on central power station power plants are discussed, but the impacts of coal use on the industrial sector, as well as on secondary population growth and economic development, have been deferred to the second year of the program in most cases.

Table 1.3 is provided to clarify the scope of the following sections and indicates the categories of issues that are covered, as well as categories that will be included in future NCUA reports. In those cases where impacts have been assessed, coal utilization has been primarily interpreted narrowly as utilization in electric power plants or synthetic fuel facilities.

1.5 Report Organization

This report is organized into nine major sections. Following this introduction, Sect. 2 describes the major economic and energy supply

Table 1.3. Categories and treatment of regional issues covered in first-year NCUA report

Impact category	Report status		Apparent seriousness		
	Reported in this volume	To be reported in future volume	Major regional problem	Locally serious problem	Unknown
AIR IMPACTS					
Air quality	<i>a</i>		X		
Impacts on climate and weather	<i>b</i>				X
WATER IMPACTS					
Water quantity	<i>c</i>		X		
Water quality					
Mining	<i>a</i>			X	
Combustion		X		X	
Waste disposal	<i>b</i>			X	
LAND IMPACTS					
Mining	<i>b</i>		X		
Combustion		X		X	
Waste disposal		X		X	
SOCIAL AND ECONOMIC IMPACTS					
Economic growth	<i>a</i>		X		
Public services	<i>b</i>			X	
Sectoral change	<i>b</i>			X	
Community change	<i>a</i>			X	
Interregional flows	<i>b</i>			X	
ECOLOGICAL IMPACTS					
Terrestrial					
Mining	<i>a</i>		X		
Air pollution	<i>a</i>		X		
Land use	<i>b</i>			X	
Solid waste	<i>b</i>			X	
Aquatic					
Mining		X	X		
Combustion		X		X	
Rare and endangered species	<i>c</i>		X		
Climate changes	<i>b</i>			X	
HEALTH IMPACTS					
Public health					
Respiratory disease	<i>a</i>		X		
Cancer and toxic substances	<i>b</i>		X		
Occupational health and safety		X			
Mining	<i>a</i>		X		
Cancer and toxic substances	<i>b</i>		X		
SAFETY IMPACTS					
	<i>b</i>			X	
AESTHETIC IMPACTS					
Mining	<i>b</i>		X		
Transportation	<i>b</i>			X	
Combustion	<i>b</i>			X	

^aCoverage in depth of selected subissues.^bOverview treatment of limited information.^cRelatively comprehensive coverage.

and demand trends projected for the South as well as attendant coal production and employment expected in the region. Section 3 describes the results of our siting analysis designed to develop plausible siting patterns for future electric power stations and synthetic fuel facilities expected in the region. Sections 4, 5, 6, 7, 8, and 9 discuss the results of our analysis of the impact of these energy development patterns on air quality, water quantity, water quality, regional ecology, health, and socioeconomic conditions in the region respectively.

In addition to the main text, the report includes a number of supporting appendixes. Appendix A lists the names of agencies that contributed useful input and suggestions to the design and conduct of the assessment. Appendix B describes the detailed methodology and approach we used in siting future power plants and coal synthetic fuel facilities. Appendix C contains supplemental information on the air-quality analysis. Appendix D describes the geoecology data base. Appendix E gives a description of the data-base system for distribution of animal species within the southeastern United States. A discussion of the possible impacts caused by an increase in atmospheric CO₂ is given in Appendix F. Appendix G describes the computations required in completing the socioeconomic impact assessment, and Appendix H presents the characterization of energy technologies used as input to the regional assessment.

REFERENCES FOR SECTION 1

1. F. D. Boercker et al., *Coal and Energy: A Southern Perspective*, ORNL/TM-5900 (August 1977).
2. F. D. Boercker and R. M. Davis, *Review of Energy and Environmental Issues in the South*, ORNL/TM-6280 (forthcoming).
3. Southern Growth Policies Board, *Future of the South* (1975).
4. Southern Interstate Nuclear Board, *State-Level Energy Agencies in the South* (February 1977).
5. Assessment of the Direct Use of Coal for Energy Program, Office of Technology Assessment, U.S. Congress (in progress).

2. ENERGY SUPPLY AND DEMAND IN THE SOUTH

2.1 Introduction

Energy and economic activity have long been correlated, and there is little to suggest that the relationship will be severely altered in the future. On the consumption side, efforts at conservation may cause the ratio of energy to gross national product (or similar indicators) to decline, but concentrations of activity will remain the most powerful determinant of demand. On the production side, the concentration of fuel resources will cause continued domination of a few local economies by extraction industries, and upturns or downturns in these industries will continue to lead economic prosperity or decline. The South is a land of rapid economic growth and rapid decline; it is also a major fuel producer. Yet, there are significant land areas with no fuel resources. This sets the stage for differentiating between economic and energy growth and decline. These differences must be quantitatively measured to assess resource, environmental, and socioeconomic impacts.

This section provides an overview of the projected energy and economic conditions on which much of this overall assessment is based. Discussion focuses on these conditions for the South as a whole and for individual states in the South; these same data are selectively reviewed at much finer levels of disaggregation in the following sections. The purpose of discussing the level, level change, composition, and spatial distribution of energy and socioeconomic activity for the years 1985, 2000, and 2020 at this point is to provide a backdrop against which the more detailed analyses that follow may be viewed.

Two sets of assumptions (scenarios) underlie the projections discussed below. The first consists of a baseline description of national energy conditions disaggregated to the census region level.¹ This chapter deals only with one energy growth path, a path that can be best described as a continuation of "recent trends," as they were perceived prior to the delivery of the Carter energy message.² Recent trends, in this context, are broadly interpreted to include technology planning and, implicitly, technology acceptance. It is recognized that in many ways this baseline is at variance with the current National Energy Plan (NEP). Nonetheless, we have not attempted to reconcile the Carter assumptions with our recent-trends assumptions in a systematic way. Instead, obvious differences between the two are pointed out in the text, with the observation that we will prepare the systematic analysis at a later date.

The second set of assumptions consists of the economic and demographic projections prepared by the Office of Bureau of Economic Research Service in 1972 for the nation and various subnational grids.³ Once again, it is clear that these projections are now somewhat dated, and we have not attempted a systematic revision at this time. However, in conjunction with our analysis of the Carter energy plan, we will prepare new, more representative economic and demographic projections.

With the two sets of assumptions in hand, ORNL prepared the state-level energy and socioeconomic summaries discussed below. In doing this, it was necessary to disaggregate the regional energy projections to the state grid and, for work discussed in succeeding chapters, to substate grids. The methods used in this work are discussed and referenced below. The reader should bear in mind, however, that this chapter describes the socioeconomic and energy assumptions on which this assessment is based, not original forecasts or predictions and, emphatically, not an optimal path for planners to seek to achieve.

2.1.1 Summary of scenario implications

1. At present, the South contains roughly one-quarter of the nation's population and employment. The Office of Bureau of Economic Research Service projects both to increase slightly over the projection period (1970-2020). Florida, Virginia, and Texas are presently viewed as the prime recipients of this growth. However, increased coal extraction activity could significantly affect mining states, particularly West Virginia, a state currently projected to stabilize in population and employment levels. Moreover, recent publications have identified a general shift of economic activity and population to sun-belt areas that could affect the economy and the energy consumption level in the South substantially.

2. In 1975, the South consumed 29% of the nation's energy (including nuclear and hydroelectric), a proportion somewhat in excess of its population share. This share is projected to increase to 31% of the nation's energy in 2020. Growth due to coal-mining activity could cause this share to increase even more greatly and would tend to shift additional energy consumption to the mining states.

3. Historically, the South has been a heavy user of electricity. While electricity use is forecast to increase at an average annual rate of 3.6% in the South, the share of total U.S. electricity consumed is projected to decrease from 34% to 32%. In contrast, the shares of coal, petroleum products, and natural gas used for heat, power, and feedstocks will increase relative to total U.S. consumption. Coal used for heat and power (nonelectrical generation) will increase significantly in Tennessee, Kentucky, and West Virginia.

4. To generate electricity, the South has relied heavily on natural gas in the recent past. It used 64% of all gas put to this purpose in the United States in 1975. This share is projected to decline but will nonetheless remain high. Texas and Louisiana consumed most of the natural gas used to generate electricity. The degree to which coal may be substituted for natural gas and petroleum products is particularly dependent on policy, because retrofitting would be necessary if existing facilities were to be converted.

5. Major employment shifts, notably the movement of manufacturing activity southward, contribute to the relatively higher projected use of fuels. The South's share of manufacturing employment is projected by

the Office of Bureau of Economic Research Service to increase from 23% to 27% between 1970 and 2020. Moreover, in the two most energy-intensive industries, chemicals and petroleum refining, the South has historically possessed a disproportionately high share of employment, which is projected to increase over the study period. Petroleum refining is forecast to remain concentrated in Texas and Louisiana, while growth in chemical employment is more ubiquitous, with major concentrations in Texas, Louisiana, Tennessee, and North and South Carolina. This growth, coupled with growth in electrical generating capacity, gives rise to the possibility of extensive cogeneration potential.

6. Total coal use in the South is projected to increase from 4 to 19 quadrillion Btu (quads) between 1975 and 2020, a rate of growth that roughly matches that of the United States as a whole. Coal burned for heat and power will increase relative to that used to generate electricity, but electricity generation will remain the primary coal use. Synthetic fuel production will consume 13 quads of coal by 2020 and will account for approximately one-quarter of the total regional coal consumption.

7. This increasing production and use of coal will significantly affect the Appalachian portion of the South, where major coal reserves are located. We project West Virginia to regain its position of leading coal-producing state. It also appears that the already developing coal-mining industry based on Texas lignite deposits will continue to grow. Historically, the South has contained more than half the nation's total coal-mining activity. If the increased mining activity in the scenarios occurs, it is likely that the South will fall in its share of total mining activity but will increase significantly in its absolute level of activity.

2.1.2 National energy projections

Originally, a set of four scenarios was prepared for the NCUA. One of these four, the recent-trends case, was discussed above. The other three cases contained alternative levels of coal production that were to be consumed through (1) the substitution of coal for nuclear fuel in electrical generation stations, (2) the substitution of imported or domestically produced natural crude oil and natural gas with synthetically produced oil and gas from coal, or (3) a combination of cases 1 and 2. Thus, for the four scenarios, energy end use was to be essentially identical and resource use highly similar (varying from 231 quads to 234 quads in 2020). These scenarios are presented in Table 1.2 in the preceding section. The ORNL work plan called for the recent-trends scenario to be examined during the first year of the assessment and the additional three scenarios during the second year. However, with the advent of a new national energy program, it was decided to drop the latter three scenarios from consideration and, at a later time, to examine the new energy plan in more detail.

The recent-trends scenario is shown in Fig. 2.1. The data in this figure are in terms of energy content of fuels at time of consumption. For this reason, there are differences between this data set and the set contained in Table 1.2, where the energy content is measured at time of extraction. For example, in 1975 these differences were due to an estimated 3% loss of

Fig. 2.1. National fuel consumption, NCUA recent-trends case. In quadrillion Btu. National fuel consumption figures are presented in the graph as taken from the candidate scenarios prepared in the unpublished report. Detail may not add to totals due to rounding. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

coal during cleaning, 7% loss of crude oil during refining, and an 8% loss of natural gas. Thus, we report 66 quads total consumption in 1975 rather than the 73 quads (including feed stocks) that would result from measurement of equivalent energy flows at the time of extraction. Moreover, for later time periods (1985-2020), coal consumption depicted in Fig. 2.1 excludes coal used to produce synfuels but aggregates synfuel products under the oil and gas categories.

The reader will also note that by any standards our baseline scenario is highly optimistic regarding the emplacement of nuclear power stations. Undoubtedly, an update of this scenario would show nuclear in a somewhat less prominent role.

By these measurements for the nation as a whole, fuel consumption is shown as growing from 66 quads to 220 quads between 1975 and 2020, with the majority of the increase attributed to electricity generated in nuclear power reactors. Coal consumption increases from 13 to 42 quads in this scenario; natural gas is shown to reach its zenith in 1985, remain constant through 2000, and decline thereafter to 15 quads in 2020, slightly less than its 1975 level.

2.1.3 State and subregional energy projections

The basic approach used to prepare the regional energy demand estimates was to disaggregate demand scenarios by census region levels to the state and substate levels according to three criteria: (1) historical energy use per unit activity, (2) projected activity (population and employment) levels, and (3) region-specific energy use conditions (for example, port locations). These factors are brought together through a set of computer codes referred to as the ORNL Regional Energy Balance System.⁴

This system, in several different forms, has been used in the past by ORNL to provide projections of energy consumption at a variety of spatial grids.⁵ The projections, which are used to provide input for siting electrical generating facilities, were prepared across a set of county groups that divide Bureau of Economic Analysis functional economic areas into state portions. To ensure congruency between the ORNL work and that of other participants in the NCUA, all demand projections were reconciled with the census-region-level control totals.

2.1.4 Economic growth assumptions

Because of the importance of using consistent economic information in carrying out the scenario analysis, it was necessary to adopt a set of economic projections early in our work. We used the 1972 OBERS Series E projections of population and earnings (modified to employment measures), with several attendant difficulties. Particularly, these projections do not permit scenario analysis that incorporates the economic effects accompanying coal development. Also, in many ways the OBERS projections are now dated and do not consider recent development in the South. Thus, for selected issue analyses to be conducted during the next year, we will substitute ORNL-produced projections in place of the OBERS series.

The remainder of Sect. 2 is organized into three parts. Section 2.2 considers the South as a whole and makes comparisons with U.S. energy and economic conditions. Section 2.3 takes up these same topics for the states of the South, and Sect. 2.4 examines coal-mining employment.

2.2 The South

Although there is danger in treating a diverse group of states such as those found in the South as an aggregate entity (particularly since a major complaint of southern officials is that federal programs tend to do just this), there is insight to be gained by contrasting projected southern economic and energy conditions with those projected for the nation as a whole. This section summarizes projected energy conditions in the South with the intention of highlighting topics that should be examined more carefully at the state level and below.

2.2.1 Total fuel consumption

Figure 2.2 shows that total fuels consumed in the South are projected to grow from 19 quads in 1975 to 70 quads in 2020, an average annual rate of growth of 2.9%. All fuels are projected to grow in importance, with nuclear energy the most rapid growth component, showing a 7% annual growth rate. Natural gas consumption is indicated to increase from 6 quads to 8 quads, with a peak in 2000, for a rate of growth of slightly less than 1% annually. Coal consumption in 2020 is projected to stand at 16 quads (excluding coal used in synfuels), a fourfold increase over 1975 use.

Relative to the United States as a whole, the use of all fuels in the South is projected to comprise 31% of national fuel consumption by 2020, up from 29% in 1975 but also down slightly from the figure of 34% for the intermediate years of 1985 and 2000 (Fig. 2.3). This latter phenomenon is due largely to the rest of the nation's catching up to the South in the use of nuclear energy as an electrical power source. Of particular note is natural gas, which, although declining in absolute use between 2000 and 2020, is projected to increase as a share of total national usage. The relatively high assumption concerning natural gas stems from the business-as-usual character of the scenario under consideration and has been a focus of attention in the National Energy Plan.² The plan, in fact, calls for a massive shift in natural gas consumption away from producing regions, with the use of coal as a substitute fuel. Thus, a long-term scenario representing the president's National Energy Plan would likely show coal playing a much more prominent role as an end-use energy source. The current scenario views coal primarily as a source of electrical power and to a lesser extent as an input to synthetic fuel conversion processes.

Fig. 2.2. Southern region fuel consumption, NCUA recent-trends case. In quadrillion Btu. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

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Fig. 2.3. Projected fuels consumed in the South as a percentage of the U.S. Excludes coal used for synthetic fuels. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

2.2.2 Fuels for electricity generation

When only fuels used to generate electricity are considered, the southern share of total fuels used by electrical stations is projected to drop from 35% in 1975 to 32% by 2020 (Fig. 2.4). These projections show the South continuing to be a major natural gas consumer for generating electricity by using 54% of the natural gas used nationally for this purpose in 2020. Coal and nuclear energy remain nearly proportionate to the total figure until 2020, when nuclear drops and coal rises.

Also, it is noteworthy that the South's share of oil consumption for electricity generation is expected to increase from 26% to 46% over the projection period, while coal increases to 40% in 2020. In absolute terms, these shares are indicative of an absolute increase in natural gas usage between 1975 and 2000 (from nearly 3 quads in 1975 to 3.4 quads in 2000) and thereafter a decline to 1.6 quads in 2020. In absolute terms, oil for electricity generation increases similarly to the year 2000 and declines thereafter.

In contrast to this scenario, the National Energy Plan seeks to bring about these declines well before the year 2000. With exemptions for peak-load plants and for certain instances where undue hardship would be brought, the act as presented to the Congress would largely prohibit the use of petroleum products for new electrical generation from the time of its passage (Sect. 601) and would effectively prohibit the use of natural gas after 1990 (Sect. 601). Thus, although the recent-trends scenario properly includes proportionately larger roles for coal and nuclear energy in electricity generation, it also affords natural gas and petroleum more prominence than the Carter plan would permit.

2.2.3 Population and economic activity

In 1970, the South contained 26% of the national population and 25% of the employment (Table 2.1). Through 2020, OBERS projects only modest (perhaps too modest) increases for these activity measures. In broad terms, the South in 1975 was characterized by levels of mining activity significantly exceeding those of the United States as a whole and by somewhat more activity in agriculture and government. Activities in manufacturing; finance, insurance, and real estate; and services fell below the national average.

OBERS projects only moderate shifts in economic activity over our study period but does indicate significant growth in manufacturing, where the regional proportion is projected to increase from 23% to 27% over the study period. This growth tends to increase energy consumption and to provide the opportunity for implementation of advanced energy-using technologies. Increases in the office-oriented activities of finance, insurance, and real estate provide the only additional area of relative region-wide growth. OBERS shows the regional share of this industry increasing from 23% to 27% over the period. For reasons discussed below, OBERS projections for mining, the only industry in which the South enjoys a majority of national employment, are likely to be inadequate for the present purpose.

ORNL-DWG 78-9245

Fig. 2.4. Projected fuels consumed for electricity generation in the South as a percentage of U.S. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

Table 2.1. Southern population, total employment, and major economic activities as percentages of U.S.

	1970	1985	2000	2020
Population	26	27	28	28
Employment	25	26	27	27
Agriculture	32	32	31	31
Mining	54	55	54	55
Contract construction	27	27	28	28
Manufacturing	23	26	27	27
Transportation, communications, and public utilities	25	26	27	27
Wholesale and retail	26	26	27	28
Finance, insurance, and real estate	23	25	26	27
Services	24	24	24	25
Government	30	30	29	29

Derived from *OBERS Projections (Series E)*, vol. 4. *States*, 1972. Modified by Oak Ridge National Laboratory Regional Economic Analysis Group to employment equivalents.

In individual manufacturing sectors, OBERS projects an across-the-board increase in employment levels. However, five sectors — textiles, apparel, chemicals, lumber and products, and petroleum refining — are of particular interest because of the heavy concentrations present in 1970 and projected to continue (Fig. 2.5).

In 1970, the South contained 71% of the nation's textile employment, a share projected to increase to 80% by 2020. Of the remaining four industries, each possessed approximately one-third of the nation's employment in 1970. Apparel is projected to increase to nearly half the nation's employment by 2020, while more modest increases are shown for chemicals, petroleum refining, and lumber and products.

Of these five growth industries, chemicals and petroleum refining are significant users of energy on a per-worker basis and should tend to push energy consumption for the overall southern manufacturing sector upward. Apparel is a relatively light user; however, textiles and lumber and lumber products are moderate energy users on a per-worker basis, and these industries could effect some overall change. Clearly, the predominance of textile activity in the South suggests that technological changes modifying energy use in this sector would be of particular interest to the southern region.

ORNL-DWG 78-9246

Fig. 2.5. Projected employment in the South by selected sectors as percentages of U.S. Derived from *OBERS Projections (Series E)*, vol. 4. *States*, 1972, modified by Oak Ridge National Laboratory Regional Economic Analysis Group to employment equivalents.

2.2.4 Energy end-use consumption

The seeming anomaly of a proportionately decreasing amount of national fuels consumption for electrical generation is clarified somewhat in Fig. 2.6. This figure indicates that the South is a relatively heavier user of electricity in 1975 than the United States as a whole but also indicates that this tendency will decrease as other portions of the nation substitute electricity for other energy forms more rapidly than the South does. Moreover, the South shows a proportionate increase in energy for end uses that exceeds its share of total fuels. The South is projected to consume 34% of the total energy for end uses in 2020. During this same period, the South is projected to fall from using 34% of total national electricity in 1975 to 32% in 2020.

The fact that the South's share of electrical consumption will decrease in the future does not mean that the time path of electrical demands in the South will attenuate but means instead that a slightly higher electricity growth rate has been projected for other parts of the nation. On an average annual (compound) basis, the South is projected to increase electrical consumption at 4.2%, while for the nation the rate is 4.4%. Coal consumption in the South for electrical generation will increase relative to the United States as a whole but at a lesser rate than overall energy consumption.

2.2.5 Coal consumption by use

Coal consumption in the South is projected to increase by an average annual rate of 3.5% in this scenario (Table 2.2). This contrasts with a national average growth rate of 3.3%. Thus the proportion of total national coal production used in the South will increase from 30% to 35% between 1975 and 2020.

In terms of use, most coal consumed in 1975 was burned for electrical generation, and this tendency will continue. Over the study period, however, the importance of coal in heat and power will increase. In 2020, this use is projected to equal about three-quarters of the amount used by generating stations in the South.

By the year 2000, commercial synthetic fuel plants that can convert coal to liquid and gaseous hydrocarbon products will significantly affect coal demand. By 2020, synthetic fuels are projected to account for roughly half the coal consumption for direct combustion. The South will therefore lag somewhat behind the United States as a whole in synfuel production. Nonetheless, this is an amount of coal equal to nearly four times the coal currently consumed in the South through direct combustion.

Relative to the nation, the South will increase its use of coal for direct combustion to a level exceeding its population share, will remain roughly constant in coal used for electrical generation (again at a level exceeding its population share) until 2020 when significant increases will occur, and will fall somewhat behind the remainder of the nation in coal used for synthetic fuels.

ORNL-DWG 78-9247

Fig. 2.6. Projected energy consumed by end use in the South as a percentage of U.S. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

Table 2.2. Projected total coal use in the South

	1975	1985	2000	2020
Coal used in southern region, 10 ¹⁵ Btu				
Direct combustion	0.78	1.66	3.06	6.15
Electrical generation	3.02	4.75	5.95	8.33
Synthetic fuel			1.21	3.00
Total	3.80	6.39	10.22	17.49
Coal used in U.S., 10 ¹⁵ Btu				
Direct combustion	3.87	6.06	9.13	17.44
Electrical generation	8.92	13.90	18.04	25.18
Synthetic fuel		0.41	3.66	12.76
Total	12.79	19.96	30.84	55.39
South's use as portion of U.S. total use, %				
Direct combustion	21	27	34	35
Electrical generation	34	34	33	34
Synthetic fuel	0	03	33	24
Total	30	32	33	32

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

2.3 The States

2.3.1 Overview

Viewed individually, the southern states appear much less homogeneous than is implied by the previous discussion. Texas, containing 21% of the southern population in 1975, is the largest southern state, whether viewed by land area, population, or employment (Fig. 2.7). West Virginia, with 3% of the South's population in 1975, is the smallest in all three categories. Florida contains the second-largest levels of population and employment (roughly two-thirds of those of Texas), and Mississippi, with 4% of the South's population, stands next to West Virginia as second smallest. The remaining states were arrayed between 5% and 10% of the South's population in 1975.

More important, however, differential changes in population and employment are likely to affect southern socioeconomic activity distributions in a manner that will cause some rearrangement of the rank orderings and may cause substantial changes in energy use. The rapidity

Fig. 2.7. Projected population as a percentage of the South by state. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

with which this change will occur and, in fact, has occurred suggests that energy planners should carefully monitor southern growth patterns. OBERS projects the most dramatic change in southern activity to occur in Florida, where the share of the regional population is projected to increase from 13% to 19%. Slight increases in population share are shown for Tennessee and Alabama; the remaining states are projected to remain constant or fall in population share.

Underlying these shares, substantial changes in numbers of people and numbers of jobs could provide new issues for energy policy, as well as a challenge for policy solutions. OBERS projects that nearly 8,000,000 new residents will add to Florida's already burdened environment between 1975 and 2020 and that more than 5,000,000 additional persons will become Texans over the projection period. In marked contrast, the total population in West Virginia is projected to remain nearly constant, while employment is projected to increase slightly. The remaining states are projected to share more or less equally in the overall 1% annual rate of growth OBERS projects, with Tennessee and Virginia enjoying slight advantages.

Two issues, however, tend to cloud the projected business-as-usual scenario. First, increased coal usage could substantially alter the time paths projected for West Virginia and Kentucky. With linkage effects considered, surrounding states would be affected as well. This topic will be considered in more detail below. Second, the degree to which these projections mirror recent trends has recently been called into question through a series of articles depicting a "second war between the states" in which Northern industries, frustrated by high costs and low productivity, are seeking out new southern homes at rates giving northern officials cause for concern.⁶ Whether or not this trend is long-term and will be modified or influenced by coal utilization policy holds varied implications for southern states, which, having finally shaken their image of economic lethargy, will not easily accept policies that could stem a welcome tide.

2.3.2 Fuel consumption characteristics

Total fuel consumption in the South generally tends to mirror the distribution of employment and population, the general tendency being for energy-producing states to consume disproportionate amounts of their domestic fuels. The aggregate employment measure does not, however, reveal the differences in economic structure that account for much of the excess consumption. The rightmost column of Table 2.3 indicates that Texas is projected to remain the largest consumer of total fuels among the southern states but that its share will decline somewhat over time. Texas currently consumes little coal but is projected to increase its share rapidly while converting from oil and gas to coal for electricity generation; it is projected to then decrease its coal share in the latter part of the study period (Table 2.4). Texas is not projected to markedly increase its coal usage for direct combustion. Texas currently uses substantial amounts of natural gas to generate electricity, some 73% of the gas put to this use in the South in 1975. Without significant policy changes, Texas would

Table 2.3. Projected fuels consumed by states in the South as a fraction of the regional total
(Including electricity generation)

	Coal				Oil				Gas				Nuclear				Other				Total			
	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020
Alabama	0.14	0.13	0.10	0.10	0.05	0.05	0.05	0.05	0.03	0.02	0.04	0.05	0.20	0.12	0.09	0.09	0.23	0.22	0.12	0.10	0.07	0.07	0.08	0.08
Florida	0.03	0.03	0.03	0.08	0.13	0.13	0.18	0.18	0.03	0.02	0.02	0.04	0.12	0.08	0.12	0.10	0	0	0	0.33	0.09	0.08	0.09	0.11
Georgia	0.10	0.09	0.06	0.05	0.03	0.03	0.08	0.10	0.04	0.03	0.03	0.02	0.15	0.08	0.05	0.07	0.15	0.15	0.21	0.34	0.08	0.07	0.06	0.07
Kentucky	0.14	0.10	0.18	0.23	0.05	0.05	0.04	0.05	0.03	0.04	0.02	0.03	0	0	0	0.09	0.07	0.07	0.03	0.35	0.06	0.05	0.06	0.11
Louisiana	0	0.01	0.04	0.04	0.03	0.09	0.11	0.11	0.18	0.20	0.20	0.22	0	0.05	0.16	0.10	0	0.03	0.07	0.36	0.09	0.10	0.13	0.10
Mississippi	0.01	0.02	0.02	0.02	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0	0.08	0.05	0.05	0	0	0.01	0.35	0.03	0.04	0.03	0.03
N. Carolina	0.13	0.10	0.09	0.06	0.03	0.09	0.08	0.08	0.02	0.02	0.02	0.01	0.07	0.08	0.12	0.10	0.20	0.16	0.21	0.39	0.07	0.06	0.06	0.07
S. Carolina	0.04	0.04	0.06	0.05	0.03	0.04	0.04	0.04	0.02	0.02	0.01	0.01	0.31	0.13	0.06	0.05	0.10	0.09	0.05	0.34	0.05	0.04	0.04	0.04
Tennessee	0.13	0.09	0.09	0.08	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0	0.20	0.07	0.09	0.20	0.18	0.11	0.37	0.06	0.08	0.06	0.07
Texas	0.05	0.20	0.12	0.09	0.22	0.21	0.23	0.23	0.53	0.52	0.56	0.52	0	0.08	0.19	0.15	0.02	0.05	0.11	0.29	0.27	0.28	0.28	0.20
Virginia	0.05	0.04	0.06	0.05	0.09	0.09	0.09	0.09	0.02	0.02	0.02	0.02	0.15	0.09	0.08	0.09	0.03	0.07	0.08	0.11	0.06	0.06	0.07	0.07
W. Virginia	0.19	0.19	0.18	0.16	0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0	0	0	0.01	0	0	0	0.36	0.06	0.06	0.05	0.05

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

Table 2.4. Projected fuels consumed for electricity generation by states in the South as a fraction of the regional total

	Coal				Oil				Gas				Nuclear				Other				Total			
	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020
Alabama	0.12	0.10	0.08	0.07	0	0	0	0.01	0	0	0	0.01	0.20	0.12	0.10	0.06	0.23	0.22	0.14	0.11	0.09	0.09	0.08	0.07
Tennessee	0.13	0.08	0.07	0.08	0	0	0	0.01	0.01	0.01	0.01	0	0	0.20	0.07	0.06	0.20	0.18	0.12	0.32	0.07	0.11	0.06	0.06
Kentucky	0.15	0.09	0.12	0.16	0.03	0.32	0.02	0.02	0	0	0	0	0	0	0	0.09	0.07	0.06	0.03	0.34	0.07	0.04	0.04	0.11
Mississippi	0.01	0.02	0.02	0.02	0.07	0.35	0.05	0.05	0.03	0.03	0.03	0.07	0	0.08	0.05	0.05	0	0	0	0.31	0.02	0.04	0.04	0.05
Texas	0.05	0.25	0.19	0.13	0.07	0.37	0.07	0.10	0.73	0.72	0.74	0.44	0	0.08	0.19	0.15	0.02	0.05	0.03	0.22	0.23	0.25	0.23	0.17
Louisiana	0	0.01	0.06	0.02	0.04	0.35	0.05	0.05	0.21	0.21	0.21	0.45	0	0.05	0.16	0.10	0	0.02	0.02	0.32	0.06	0.06	0.13	0.09
Florida	0.03	0.04	0.04	0.13	0.52	0.57	0.56	0.54	0.01	0.01	0.01	0.02	0.12	0.08	0.12	0.10	0	0	0	0.32	0.09	0.09	0.10	0.13
Georgia	0.12	0.11	0.09	0.07	0.02	0.34	0.05	0.04	0.01	0.01	0.01	0.01	0.15	0.08	0.05	0.07	0.15	0.15	0.26	0.35	0.08	0.08	0.06	0.07
N. Carolina	0.15	0.12	0.12	0.07	0.04	0.33	0.03	0.05	0	0	0	0	0.07	0.08	0.12	0.10	0.20	0.16	0.26	0.13	0.09	0.08	0.11	0.10
S. Carolina	0.05	0.03	0.07	0.05	0.06	0.34	0.04	0.04	0	0	0	0	0.31	0.13	0.06	0.05	0.10	0.09	0.06	0.35	0.07	0.06	0.05	0.05
Virginia	0.04	0.03	0.05	0.03	0.16	0.12	0.12	0.10	0	0	0	0	0.15	0.09	0.01	0.09	0.03	0.07	0.09	0.17	0.05	0.05	0.06	0.08
W. Virginia	0.15	0.12	0.09	0.18	0	0	0	0.01	0	0	0	0	0	0	0	0.01	0	0	0	0.32	0.07	0.05	0.03	0.03

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

likely continue to claim large amounts of natural gas for this purpose. Similarly, Texas has tended to use natural gas for nongeneration purposes and is projected to increase this use (Table 2.5). Moreover, Texas is projected to implement solar energy systems that will account for nearly half the solar energy consumed in the South by 2020. Whether or not these projections remain realistic depends largely on the acceptance of the National Energy Plan now before Congress. It is, however, worthy of note that the Texas Railroad Commission has recently issued a ruling that places significant constraints on using natural gas or petroleum products in new electrical generating stations, a move that will increase the use of coal regardless of national policy.

Louisiana is projected to follow a course similar to that of Texas. Louisiana currently uses disproportionate amounts of natural gas, a practice projected to continue under the baseline assumptions. Louisiana has not used coal in the recent past but is projected to do so in rather substantial quantities by the end of the century.

Unlike Texas and Louisiana, the coal-producing states tend to use little or no natural gas or petroleum to produce electricity but use substantial amounts of coal for this purpose. West Virginia, for example, used 15% of the coal burned in the region for electrical generation despite having only 3% of the region's population and employment. Kentucky, Tennessee, and Virginia also used large amounts of coal for generating electricity.

Nonenergy-producing states, led by Florida, tended to consume smaller amounts of energy than population or employment shares would suggest. In fact, even considering its rapid growth in population, Florida's total fuel consumption is projected to increase only modestly over the study period. In 1975, Florida consumed 9% of the region's total fuel but contained 13% of the population; for 2020, these figures are projected at 11% and 19% respectively.

Thus, in general, these projections indicate that the most abrupt shifts in fuel consumption will occur in states that produce natural gas and oil, where large amounts of scarce fuels have traditionally been used for electricity generation. Less abrupt changes should be evident in coal-producing states; however, nonproducing states, notably Florida, may find it difficult to maintain the use of petroleum products in electricity generation.

In fact, as is shown in Table 2.6, increased coal utilization is synonymous not only with no growth in natural gas and slow growth in oil but also with high growth in electricity. Whereas several states show declines in natural gas consumption over the study period, growth in oil is highly attenuated, and growth of electricity for each state exceeds that of total final energy.

2.3.3 Economic characteristics

In Sect. 2.2.3, several industries were singled out as holding particular importance for southern economic development because of high concentrations of activity in the South. On a per-worker basis, chemicals

Table 2.5. Projected final energy consumed by states in the South as a fraction of the regional total

	Electricity				Coal				Oil				Gas				Solar				Total			
	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020	1975	1985	2000	2020
Florida	0.12	0.12	0.12	0.12	0.01	0.01	0.01	0.02	0.14	0.15	0.15	0.16	0.03	0.03	0.02	0.02	0	0	0.04	0.05	0.13	0.09	0.09	0.10
Georgia	0.07	0.07	0.07	0.07	0.01	0.02	0.02	0.03	0.09	0.09	0.09	0.09	0.05	0.04	0.03	0.02	0	0	0.02	0.03	0.07	0.06	0.06	0.06
Kentucky	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.04	0.05	0.05	0.03	0.03	0	0	0.02	0.07	0.06	0.06	0.05	0.06
Louisiana	0.07	0.07	0.06	0.06	0	0	0	0	0.08	0.09	0.11	0.12	0.17	0.18	0.20	0.19	0	0.20	0.19	0.13	0.10	0.11	0.11	0.10
Mississippi	0.04	0.03	0.03	0.03	0	0	0	0.01	0.03	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0	0	0.02	0.03	0.03	0.03	0.03	0.02
N. Carolina	0.08	0.09	0.09	0.09	0.04	0.05	0.06	0.07	0.09	0.09	0.09	0.08	0.03	0.02	0.02	0.02	0	0	0.02	0.04	0.07	0.05	0.07	0.07
S. Carolina	0.05	0.05	0.06	0.05	0.04	0.04	0.05	0.06	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.01	0	0	0.01	0.02	0.04	0.04	0.04	0.04
Tennessee	0.10	0.10	0.10	0.11	0.13	0.12	0.14	0.16	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0	0	0.05	0.08	0.07	0.07	0.07	0.09
Texas	0.22	0.20	0.20	0.19	0.05	0.04	0.04	0.04	0.24	0.23	0.24	0.25	0.43	0.45	0.52	0.54	0	0.80	0.58	0.44	0.28	0.29	0.29	0.25
Virginia	0.06	0.07	0.06	0.06	0.08	0.10	0.10	0.11	0.09	0.09	0.08	0.08	0.04	0.03	0.02	0.02	0	0	0.02	0.03	0.07	0.07	0.06	0.07
W. Virginia	0.04	0.04	0.04	0.04	0.34	0.32	0.29	0.24	0.03	0.03	0.02	0.02	0.04	0.03	0.03	0.02	0	0	0	0.02	0.05	0.05	0.05	0.06
Alabama	0.08	0.07	0.07	0.08	0.21	0.20	0.18	0.17	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0	0	0.03	0.05	0.07	0.07	0.07	0.08

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

Table 2.6. Average annual percentage growth rates in final energy by state

	Electricity	Coal	Oil	Gas	Total
Alabama	4.3	4.3	1.5	1.5	2.9
Florida	4.3	7.5	2.2	-0.5	1.9
Georgia	4.3	6.0	1.9	-1.1	2.3
Kentucky	4.6	4.6	1.6	0.2	2.8
Louisiana	4.0	4.7	2.8	1.3	2.4
Mississippi	4.0	8.3	1.5	0.3	2.0
N. Carolina	4.4	5.9	1.8	-0.2	2.7
S. Carolina	4.6	6.1	1.9	2.4	3.0
Tennessee	4.5	5.3	1.8	0.9	3.2
Texas	4.0	4.2	2.1	1.5	2.3
Virginia	4.3	5.4	1.7	-0.5	2.6
W. Virginia	4.2	3.8	1.2	-0.3	2.7
Region	4.3	4.7	2.0	1.0	2.6
Nation	4.4	3.4	1.6	-0.2	2.1

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

and petroleum refining were indicated to be large users of energy, textiles and lumber products to be medium users of energy, and apparel to be a light user of energy. It is also useful to consider primary metals, which, although not concentrated in the South, constitute an area of potential growth that is a heavy energy user.

In 1970, the South contained 32% of the national petroleum refining activity. Nationally, this industry has consumed about 11% of total energy in manufacturing, mostly through use of natural gas and petroleum products.⁷ Not surprisingly, this activity is concentrated in Texas and Louisiana, where 68% and 19%, respectively, of Southern refining activity take place (Table 2.7). Future concentrations are projected by OBERS to remain relatively constant (synthetic fuel employment is not considered in this projection).

A second major energy-consuming industry, chemicals, also had located roughly one-third of its workers in the South by 1970. Nationally, the chemical industry consumes 22% of total energy for heat and power by manufacturing enterprise. Texas contained 20% of southern employment in 1970, and this share is projected to increase to 24% by the close of the study period. In this case, however, Tennessee appears as the second-largest chemical state, with a slightly declining share projected.

Table 2.7. Selected fractions of southern industrial activity by state

	Petroleum refining		Chemicals		Primary metals		Textiles		Lumber		Apparel	
	1975	2020	1975	2020	1975	2020	1975	2020	1975	2020	1975	2020
Alabama	0.02	0.02	0.04	0.05	0.29	0.22	0.06	0.07	0.07	0.07	0.09	0.09
Florida	0.01	0.02	0.05	0.04	0.01	0.02	0	0.01	0.06	0.06	0.04	0.07
Georgia	0.01	0.02	0.04	0.04	0.04	0.05	0.16	0.17	0.08	0.08	0.14	0.13
Kentucky	0.02	0.04	0.04	0.03	0.08	0.10	0.01	0.01	0.04	0.03	0.05	0.05
Louisiana	0.19	0.17	0.08	0.08	0.03	0.03	0	0	0.04	0.04	0.02	0.01
Mississippi	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.10	0.11	0.08	0.07
N. Carolina	0	0	0.07	0.10	0.03	0.04	0.39	0.39	0.23	0.23	0.14	0.16
S. Carolina	0	0.01	0.08	0.09	0.01	0.02	0.25	0.22	0.05	0.04	0.09	0.08
Tennessee	0.01	0.02	0.18	0.16	0.10	0.12	0.05	0.05	0.10	0.10	0.13	0.11
Texas	0.68	0.65	0.20	0.24	0.17	0.22	0.01	0.01	0.09	0.11	0.12	0.13
Virginia	0	0	0.12	0.10	0.06	0.06	0.06	0.06	0.12	0.12	0.08	0.09
W. Virginia	0.01	0.02	0.08	0.06	0.17	0.12	0	0	0.02	0.02	0.01	0.01

Derived from *OBERS Projections (Series E)*, vol. 4. *States*, 1972, modified by Oak Ridge National Laboratory Regional Economic Analysis Group to employment equivalents.

Primary metals, the third energy-intensive industry considered here, made up a smaller share of southern economic activity (15%) in 1970 than the industries just discussed and is not projected to increase dramatically. Nonetheless, it is foreseeable that changing energy conditions could modify the OBERS scenario substantially, and if present trends in southern industrialization continue, a desire for increased access to this industry could provide an impetus for development. At present, Alabama contains about 29% of the southern share of primary metals, a share that is projected to decrease over time. West Virginia and Texas each stood at 17% of the southern total in 1970. West Virginia, however, is projected to fall to 12% over the study period, whereas Texas is projected to increase to 22%.

The remaining three industries selected for examination at this time (textiles, lumber, and apparel) are less important from an energy standpoint than those just considered and constitute about 5% of total manufacturing energy consumption. Still, they form a stable base for the southern economy.

To generalize, two points stand out when viewing these industries. All tend to be concentrated in North Carolina, and all tend not to be attracted to West Virginia. Beyond this, with the exception of textiles in North Carolina, South Carolina, and Georgia, these industries tend to be relatively evenly spread across the remainder of the South, a tendency that OBERS projects to continue.

2.3.4 Coal consumption

Table 2.8 summarizes coal consumption for the southern states by direct combustion, utility combustion, and synthetic uses. The general pattern portrayed by projected coal production is that the largest current use is by utilities, only Alabama and West Virginia exhibiting significant levels of direct combustion for heat and power. By 1985, Texas emerges as a major consumer of coal in the South, with the bulk of this coal used to fire utility boilers. West Virginia and Alabama will remain the major users of coal for nongenerating purposes; yet in nearly every state, coal used for heat and power doubles. At this time, Louisiana will begin burning coal for electricity generation. Still, only meager amounts of coal will be used for synthetic fuels.

The turn of the century is projected to see the development of synthetic industries in Texas, Kentucky, Louisiana, and West Virginia. Coal use for utilities in Texas is projected to stabilize; rapid increases in nuclear power reactors will contribute the differential steam source. Direct combustion of coal in West Virginia is projected to exceed utility coal use substantially and to contribute significantly to heat and power in all states, with the exceptions of Louisiana and Mississippi and, to a lesser extent, Florida and Georgia.

In the final time period, this basic pattern continues, with the major exception that Florida is projected to become a substantial user of coal to produce electricity. Mississippi and Louisiana remain the smallest users of coal in the South, and Kentucky and West Virginia, the major coal-producing states, remain the largest ones.

Table 2.8. Projected total coal use in southern states
(10¹² Btu)

	1975				1985				2000				2020			
	Direct	Utility	Synthetic fuel	Total	Direct	Utility	Synthetic fuel	Total	Direct	Utility	Synthetic fuel	Total	Direct	Utility	Synthetic fuel	Total
Alabama	162	360	0	522	330	491	0	821	548	512	0	1060	1076	680	0	1756
Tennessee	98	384	0	482	195	384	0	579	435	428	0	863	1016	355	0	1371
Kentucky	80	440	0	520	160	449	0	609	290	722	410	1795	597	1604	900	4083
Mississippi	1	43	0	44	3	116	0	119	13	110	0	123	36	236	0	272
Texas	37	144	0	181	72	1198	0	1270	120	1130	300	1250	236	1332	780	1568
Louisiana	1	0	0	1	2	33	0	35	4	367	100	398	8	240	360	622
Florida	4	103	0	107	10	174	0	184	37	229	0	266	102	1287	0	1389
Georgia	15	367	0	382	29	515	0	544	65	532	0	597	154	678	0	832
N. Carolina	32	451	0	483	80	549	0	629	178	693	0	871	422	667	0	1089
S. Carolina	28	140	0	168	72	153	0	225	164	395	0	559	396	466	0	862
Virginia	63	120	0	183	160	120	0	280	314	279	0	593	670	251	0	921
W. Virginia	267	464	0	731	520	596	0	1116	900	545	400	1850	1449	532	990	2733

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

Although it is not possible to detail the range of possible outcomes at this time, it is clear from this simple review of economic and energy conditions, coupled with the recent trend toward increased southern industrialization, that a reshuffling of energy policies could cause similar realignment in the forces influencing future southern industrialization. Of the southern states, Texas, Louisiana, West Virginia, and Kentucky are most likely to be directly affected. Spillover effects could, nonetheless, bring about ramifications for the whole of the southern economy, particularly in view of the large amounts of capital investment associated with coal mining and synthetic fuels. While at present one can merely speculate on eventual outcomes, past evidence would tend to indicate that gains in activity in the South will likely be traded off against activity losses in the industrialized northeast and north central regions.

2.4 Coal Production and Employment

The most direct and, for several states, the most substantial impact arising from increased utilization of coal will be the employment associated with coal extraction. To address this issue, ORNL has prepared a simple computer algorithm that allocates the NCUA scenario coal production figures to counties within each state on the basis of historical production and coal reserves. (These scenarios contain net exports of coal to other regions as well as locally used coal.) At a later point, we will integrate this algorithm with the synthetic fuel plant siting process; at present, we have relied on this algorithm for our state and substate projections of coal production for all coal uses.

2.4.1 Coal production algorithm

The county-level estimates of coal production and employment are derived from a computer algorithm that combines the following information: (1) large-region control totals from the scenario, (2) historic levels of production, (3) reserve base, and (4) employment by type of extraction. The algorithm operates in five-year time steps from 1975 to 2020. Control totals (for census regions) from the scenarios were interpolated to provide boundary conditions for each interval.

The calculations first assume that production for each county in any given period is equal to last period's production. This level is tested against the county's reserve base and, if sufficient, is summed for all counties in the control region. If the control total exceeds the lagged values, the difference is allocated to all counties in the region according to the coal reserves. If the control total is less, the difference is subtracted proportionately with last period's production. This process is repeated for each time period.⁸

Graphical displays obtained from this coal algorithm are shown in Figs. 2.8-2.10. Figure 2.8 shows coal production in 1974. Note that major production occurs in the traditional Appalachian coal belt and

Fig. 2.8. 1974 coal production. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

Fig. 2.9. 1974-1985 change in total coal production. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory Chicago, Sept. 1, 1976.

Fig. 2.10. 1985-2000 change in total coal production. Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

in western Kentucky, with smaller levels of production in Texas. Oklahoma and Arkansas (shown here for completeness) had several small mining operations in this year. Figure 2.9 shows the change to 1985, and Fig. 2.10 shows changes between 1985 and 2000. In essence, these figures show the opening of substantial new mining areas in Texas, Oklahoma, Arkansas, and Mississippi, with smaller new operations visible in North Carolina and Virginia. Although this particular algorithm is not sensitive to the rate at which these areas come on line, it does provide an indication of which additional areas are likely to be impacted by new mine openings. These impacts are discussed in Sect. 6.

2.4.2 Coal employment

To calculate employment, it is necessary to divide production into strip mining and deep mining. This is done by assuming that production is divided between the two in proportions equal to the reserve fraction for each county that is strippable or deep minable. This level is multiplied by the following employment rate for each type of extraction and then summed, yielding an employment level for each county:⁹ (1) 11,660 man-years per quad for underground coal production and (2) 4,060 man-years per quad for strip-mined coal production.

As discussed in Sect. 6, there is reason to believe that some productivity improvements may occur in coal production based on the past two decades, but sufficient uncertainty regarding the character of new mines brought into production and regarding environmental restrictions exists to preclude simple analysis. Hence, we will assume simply that productivity in deep- and strip-mining activities remains constant over the study period for this report and rely on the difference between deep- and strip-mining output levels per worker to capture productivity changes resulting from shifts between the two mining techniques.

Table 2.9 shows the results of applying the coal-production algorithm and employment assumptions to the NCUA base-case scenario and to two additional NCUA scenarios and of aggregating to state totals. Because of production similarities and lack of a detailed siting analysis, we have not considered the high coal and synthetic fuel scenario at this time. The first two columns of this table provide a reference with respect to the accuracy of this approach. In general, the OBERS coal employment numbers for 1970 fall in relatively close step with the 1974 estimates based upon actual coal production. The major difference is exhibited for West Virginia, where a 40% decline in employment is evident — roughly an 18,000-worker difference. However, since coal production decreased in West Virginia by about 30% over this period, this difference appears reasonable.¹⁰

These projections indicate that, based on the base-case scenario, coal-mining employment in the South could increase from 77,000 workers in 1974 to 181,000 workers in 2020 or to as much as 258,000 in 2020 under highly accelerated coal use for electricity generation and synthetic fuel production. Although the latter two scenarios will be replaced with scenarios reflective of the president's plan in subsequent assessments,

Table 2.9. Projected coal employment levels under alternative scenarios

	1985					2000			2020		
	1974 OBERS	1974 Estimate	Recent trends	High coal electricity	High coal electrical and synthetic fuel	Recent trends	High coal electricity	High coal electrical and synthetic fuel	Recent trends	High coal electricity	High coal electrical and synthetic fuel
Alabama	5,971	5,739	5,898	5,865	5,869	6,735	7,274	8,078	7,986	8,839	9,807
Florida	0	0	0	0	0	0	0	0	0	0	0
Georgia	0	0	0	0	0	0	0	0	0	0	0
Kentucky	23,856	31,239	33,346	33,132	33,133	41,144	46,231	53,725	52,805	60,827	69,850
Louisiana	0	0	0	0	0	0	0	0	0	0	0
Mississippi	0	0	0	0	0	0	0	0	0	0	0
N. Carolina	0	0	0	0	0	19	23	31	52	68	88
S. Carolina	0	0	0	0	0	0	0	0	0	0	0
Tennessee	1,754	1,801	1,865	1,855	1,855	2,163	2,356	2,643	2,609	2,914	3,259
Texas	25	732	2,730	2,939	2,939	4,501	7,780	8,738	8,403	13,237	15,369
Virginia	12,328	9,359	10,043	10,095	10,095	11,521	11,964	12,966	15,337	17,153	19,507
W. Virginia	46,559	28,051	35,630	36,199	36,199	52,010	56,920	68,020	94,358	114,500	140,616
Regional total	90,557	76,921	89,519	90,097	90,097	111,359	132,459	154,203	181,552	217,540	258,525
National total	145,640	150,048	194,649	203,839	203,839	292,101	360,645	414,166	516,394	611,342	725,774
Percentage of nation	0.60	0.51	0.46	0.44	0.44	0.38	0.37	0.37	0.35	0.36	0.36

Derived from Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment, unpublished report, Argonne National Laboratory, Chicago, Sept. 1, 1976.

the results of the additional NCUA scenarios are included in this section only due to the admitted simplicity of the projection technique applied. National coal employment could move from 150,000 workers in 1974 under the base case to 725,000 workers in 2020 under the accelerated coal-use case. Herein lies the difficulty in applying the OBERS projections as a base. OBERS projects coal employment in the South to fall to 78,000 workers by 2020 and to fall nationally to 121,997 by this same year. For mining states such as West Virginia and Kentucky, these changes can cause abrupt differences in the total state economy, particularly in subportions of the state. This change could affect a sizable fraction of the other analyses conducted at ORNL through the NCUA. Thus, in early FY 1979, we will reconstruct our subregional scenarios using projections adjusted to account for coal-mining employment increases.

Perhaps the major point to arise from this analysis is the fact that, despite the rapid increase in coal-mining activities possible in the South, even greater activity changes will occur in other portions of the nation. Whereas pre-energy-crisis projections (OBERS) saw the South declining in coal-mining activity, yet increasing to 64% of national employment by virtue of declines elsewhere in the nation, our current projections show the South falling to about 35% of national coal-mining employment. In other words, this same difficulty is even more greatly manifested in other coal-mining regions. Increases in population and employment will likely be quite dramatic if accelerated coal development occurs.

These projections, based largely on reserve availabilities, show West Virginia regaining its position as the major coal producer in the South, with Kentucky and Virginia following. In addition, it appears that the coal industry in Texas may continue to develop. This is consistent with the increasing use of lignite in that state.

In summary, these projections are meant to illustrate a possible set of growth conditions that may accompany coal development and are not to be viewed as forecasts or predictions. Nonetheless, they do point to the significant economic changes that could accompany coal development.

Nonsouthern states are shown to hold the potential for large coal extraction increases. In the South, such increases could spell major changes from the sluggish economic projections for West Virginia that were quite credible prior to the emerging of energy as a major issue.

REFERENCES FOR SECTION 2

1. Gregory Krohm et al., "Candidate Scenarios for the National Coal Utilization Assessment," Argonne National Laboratory (unpublished), Sept. 1, 1976.
2. Executive Office of the President, Energy Policy and Planning, *The National Energy Plan* (USGPO, Washington, D.C.), April 1977.
3. *OBERS Projections (Series E)*, vol. 4. States, 1972. This series has been modified by the ORNL Regional Economic Analysis Group into employment levels equivalent to the earnings levels in which it was originally published.
4. This system is discussed in detail in P. L. Rice and D. P. Vogt, *Energy Availabilities for State and Local Development: A Methodological and Data Overview*, ORNL/TM-5890, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1977. Although this document refers to a different study, this same approach has been used for the present project.
5. The various uses of this system are discussed and referred to in Sect. 3.5 of *The Energy Division Annual Progress Report for the Period Ending September 20, 1977*, ORNL-5364, April 1978.
6. See, for example, C. L. Jusenius and L. C. Ledebur, "A Myth in the Making: The Southern Economic Challenge and the Northern Economic Decline," Office of Economic Research, Economic Development Administration, U.S. Department of Commerce, November 1976, and Gurney Brenkenfeld, "Business Loves the Sunbelt (and Vice Versa)," *Fortune*, June 1977.
7. U.S. Bureau of the Census, "Fuels and Electric Energy Consumed," *Annual Survey of Manufacturers*, 1974.
8. The reader will note that this technique is unsophisticated, as well as devoid of behavioral influence. Moreover, several reviewers have pointed out the difficulties in using reserve data which may or may not fully capture the quantities of coal that may be mined at future prices. However, due to the resources available for this task, it was decided that a more elaborate approach was not feasible. In fact, although many would emphasize the need for improving our approach in this area, a decision to move to a highly elaborate county-based coal model is probably equally open to criticism.
9. These values were derived by reconciling Bechtel engineering estimates of coal employment with historical data series. See Bechtel Corporation, "Manpower, Materials, and Capital Cost for Energy-Related Facilities," San Francisco, April 1976.
10. U.S. Bureau of Mines, *Minerals Yearbook*, 1972.

3. PROJECTING ENERGY FACILITY DEVELOPMENT IN THE SOUTH

3.1 Major Findings

Plausible energy facility siting patterns have been developed at the county level for 12 southern states under the NCUA base-case scenario for the period 1975-2020. The siting patterns for coal-based and other energy technologies were utilized to assess the resource, health, ecosystem, social, and economic impacts of coal development and use in the South. The technology mixes (i.e., the amounts of nuclear capacity, coal capacity, etc., required to meet demand) for each census region were specified in the scenario input data provided by Brookhaven National Laboratory (BNL). These technology mixes, however, were modified according to information provided by utilities distributing power in the southern United States. The patterns developed provide county totals for specific technologies and not for specific sites within counties.

By the year 2020, virtually all counties presently considered highly suitable for energy development will be utilized, and generating capacities of 8000 MWe may be located in some counties adjacent to major rivers in the southern region. (For comparison, in 1975 the largest installed capacity in a single county was 6000 MWe in Los Angeles County, California. This installed capacity will jump to 10,000 MWe by 1985.) More significantly, however, the Ohio River could be bounded by a chain of power plants from Pittsburgh, Pennsylvania, to Paducah, Kentucky, with water consumption for cooling running about 40% of the seven-day-ten-year low flow by the year 2020. Many smaller streams in the South Atlantic and Gulf Coast regions will be approaching a similar level of development.

By the year 2020 major concentrations of energy production are expected in (1) the Chesapeake and Middle Atlantic area, concentrating around Baltimore and Washington, D.C., (2) the Nashville-Knoxville-Atlanta-northern Alabama region, (3) southern Florida, (4) the middle and upper Ohio Valley, and (5) the Houston-New Orleans coastal area (Fig. 3.1). Major conclusions suggested from the regional siting analysis are:

- Continued use of traditional cooling technologies (wet cooling towers or once-through cooling) limits future siting options significantly. Dry cooling or use of brackish water would increase siting options.
- Neither a dispersed generating facility pattern nor a concentrated pattern of energy centers will eliminate problems if future electrical demands are of the magnitude projected by the base-case NCUA scenario. If growth rates can be reduced, a combination of energy parks wherever resources permit, with dispersed facilities along all tributary streams, may be a reasonable pattern in the South. Conservation or negative growth may be the only hope for some environmentally critical areas, such as southern Florida.

Fig. 3.1. Projected total generating capacity in the South by county for the year 2020.

3.2 Siting Patterns for the Southern NCUA Region

This section presents a general discussion of siting patterns for coal-related energy facilities as well as of other technologies such as nuclear, oil, and gas in the southern United States. The siting patterns were developed for the recent-trends scenario used in the NCUA. A detailed description of the methodology utilized is contained in Appendix B. Figures B.9 to B.20 portray the siting patterns for other technologies (nuclear, gas, and oil) developed for the base-case NCUA scenario.

Results of the siting analysis are summarized for each state in ORNL's region, including Maryland, Delaware, Arkansas, and Oklahoma. These states were not originally included in the ORNL region but were subsequently included in our analysis because they were part of the three census divisions (South Atlantic, East South Central, and West South Central) that comprised ORNL's region.

Figures 3.2-3.5 present the sited capacity developed for the coal-fired electric plants for each county for the years 1975 to 2020 based on the NCUA recent-trends scenario. General siting patterns for coal-conversion development are also presented by state in the discussion (see Figs. 3.6 and 3.7). The reader should refer to these maps while reading the following state summaries. Table 3.1 provides a summary of capacity by state and year for the study region.

3.2.1 Delaware

Proximity to adequate water (fresh and brackish) and low population density contribute to Delaware's high suitability for both nuclear and coal-fired electric plants. Northern Delaware has some potential for coal-conversion development, mostly because of its close proximity to Pennsylvania coal fields, but no facilities were sited because of the base-case scenario.

Delaware's total installed generating capacity in 1975 was only 1650 MWe; by 1985 the utilities' plans will expand this only to 2000 MWe (half of which is coal-fired). Because of large demand growth in New York, Baltimore, and other load centers in the Middle Atlantic region, our siting analysis increased capacity to 8700 MWe in 2000 and 24,200 MWe by 2020.

Such levels are probably unrealistic on several points. The most important of these are Delaware's coastal development restrictions. With present standards for desirable sites these capacity levels will exhaust most of the siting potential in the state, and future demand will probably have to be satisfied from outside the state or from coastal facilities.

ORNL DWG 78-7430A

Fig. 3.2. 1975 coal-fired electrical generation capacity by county: southeastern subregion.

ORNL DWG 78-7415A

Fig. 3.3. 1985 projected coal-fired electrical generation capacity by county: southeastern subregion.

Fig. 3.4. 2000 projected coal-fired electrical generation capacity by county: southeastern subregion.

Fig. 3.5. 2020 projected coal-fired electrical generation capacity by county: southeastern subregion.

Fig. 3.6. 2000 coal conversion siting pattern by county: southeast subregion.

2020 COAL CONVERSION

MMCFD LOW BTU

- 250
- 500
- 750

MMCFD HIGH BTU

- 250
- 500
- 750

BBL/D SYNCRU

- ▲ 50,000
- ▲ 100,000
- ▲ 150,000

Fig. 3.7. 2020 coal conversion siting pattern by county: southeast subregion.

Table 3.1. NCUA electrical generating capacity by state and year
(In megawatts)

State	1975			1985			2000			2020		
	Coal	Nuclear	Total	Coal	Nuclear	Total	Coal	Nuclear	Total	Coal	Nuclear	Total
Delaware	340	0	1,654	740	0	2,060	3,347	3,842	8,774	7,045	14,471	24,158
Maryland ^a	1,704	800	9,061	2,504	2,843	13,641	7,389	20,616	37,726	7,389	40,469	60,384
Virginia	2,757	1,576	9,198	2,757	5,320	15,939	9,436	18,363	37,908	9,436	49,853	82,468
North Carolina	10,333	790	14,839	14,003	6,151	23,905	16,565	21,893	45,513	16,863	47,799	80,924
South Carolina	3,222	3,278	10,336	3,502	7,764	16,142	9,457	10,324	24,647	13,025	23,047	43,283
Georgia	8,416	1,586	13,627	12,612	4,689	22,504	12,848	8,739	30,384	12,848	33,300	62,226
Florida	2,453	1,332	13,126	4,413	4,901	29,685	7,036	22,393	51,272	22,192	52,192	105,193
West Virginia	10,646	0	10,731	13,028	0	13,113	14,162	0	14,517	47,759	7,211	62,783
Kentucky	10,583	0	12,172	16,901	0	18,680	19,425	9,789	30,993	39,318	46,989	91,012
Tennessee	9,241	0	13,243	9,241	14,515	29,058	13,322	19,386	38,010	23,732	49,031	83,265
Alabama	8,785	2,128	13,955	11,810	7,309	22,645	14,291	18,680	36,911	20,164	42,563	70,572
Mississippi	1,037	0	4,649	3,490	5,033	12,138	5,811	7,222	16,648	10,103	23,113	37,905
Arkansas	126	836	4,790	4,854	1,748	10,227	5,943	5,113	14,681	12,990	7,113	30,395
Louisiana	0	0	11,176	2,690	3,048	17,764	5,260	32,969	56,308	5,260	54,792	88,690
Oklahoma	0	0	7,198	3,990	2,300	14,323	4,657	5,182	17,872	6,532	8,309	24,342
Texas	2,300	0	40,139	19,134	4,300	64,989	19,134	34,340	98,324	23,929	77,812	165,431
Region total	71,940	12,326	194,894	125,669	70,418	326,813	167,782	238,851	560,498	278,585	578,064	1,113,031

^aData for Washington, D.C., is included with Maryland.

3.2.2 Maryland

The better siting regions in Maryland for both coal and nuclear facilities are located around the Chesapeake Bay area and midstate near Frederick. Air quality maintenance area restrictions around Baltimore and Washington restrict the siting of coal facilities (see Fig. B.4).

Total electric generating capacity for Maryland in 1975 was 9000 MWe, but 1985 planned capacity increases the total to 13,500 MWe. By 2020, however, the total capacity may increase to 60,000 MWe. Because this level of development will deplete existing supplies of fresh water, new reservoir development and the use of brackish water will be the only alternatives to sustain such growth. New generating capacity for the scenario was located near (less than 150 miles from) Washington, D.C., and Baltimore to satisfy the large increases in demand forecasted for these areas. Alternate and more distant siting areas were utilized to satisfy new demand in load centers located in Virginia, Pennsylvania, and West Virginia. The result is a heavy concentration of new capacity around the Washington-Baltimore area, which might otherwise seem unreasonable at first.

3.2.3 Virginia

Virginia's better siting regions are located in the central portion of the state and northeast of Richmond. In 1975, Virginia had 9000 MWe of installed capacity. This is scheduled to increase to 16,000 MWe in 1985 according to utility plans, but to meet new demand, the total capacity was increased to 38,000 MWe in 2000, and to 82,000 MWe by 2020. No coal-conversion facilities were located in Virginia, although coal resources exist in the western portion of the state. By increasing the reservoir development throughout the state and by using a dispersed pattern, growth in electrical generating capacity probably could be accommodated to 2020. However, increasing total capacity beyond that forecasted for 2020 will present problems.

3.2.4 North Carolina

North Carolina has good siting potential for both nuclear and coal generation across most of the state. Installed capacity in 1975 was 15,000 MWe. By 1985, total capacity is scheduled to increase to 24,000 MWe, and capacity sited for 2020 increases this level to 81,000 MWe. Because of good siting potential this level probably can be accommodated; however, additional analysis of industrial and residential growth is needed to determine whether the siting potential will deteriorate with time. Nevertheless, the state should be able to meet the demand with new reservoir development or perhaps with alternative technologies not dependent upon cooling water.

3.2.5 South Carolina

The better siting regions in South Carolina for both coal and nuclear facilities are located in the midstate and eastern coastal areas. Siting potential for coal plants is well distributed throughout the state; however, nuclear plants are restricted in the vicinity of Charleston because of increased seismic risk.

Utilities are presently operating at 10,000 MWe generating capacity in South Carolina. This level increases to 16,000 MWe by 1985 and to 43,000 MWe in 2020.

Future electric energy demands in South Carolina increase at a much lower rate than in surrounding states, and the potential for meeting these demands is reasonable. However, 43,000 MWe is a significant amount of capacity for a small state with limited water resources and significant air quality restrictions. Consequently, new development beyond the levels forecasted for 2020 will become increasingly difficult to site.

3.2.6 Georgia

According to ORNL electricity demand projections, Georgia is predicted to be a high-growth area until 1985, with major growth centers around Atlanta, Macon, and Augusta. The areas most suitable for locating new coal and nuclear capacity are found in the south-central region along the Altamaha River and along lower reaches of the Chattahoochee and Savannah rivers (see Fig. B.3).

Utilities have planned to locate new capacity in the upper Chattahoochee River basin, in order to be near Birmingham and Chattanooga as well as Atlanta. Most of this siting potential is depleted by 2000, however.

Installed capacity for all types of generating units is 13,000 MWe in 1975. This capacity increases to 22,500 MWe by 1985, and the forecasted capacity increases to 30,384 MWe by 2000. By 2020 the total is 62,000. Only 12,800 MWe of this is coal-fired.

3.2.7 Florida

The best regions for siting additional generating capacity in Florida are along the St. Johns, Suwannee, and Withlacoochee rivers, located midstate and in the panhandle region. The greatest increases in demand, however, are forecasted for south Florida. Consequently, the midstate and northern areas may be pressed to supply electricity for the southern peninsula unless brackish water is utilized. In our analysis we have assumed that ocean cooling or alternative cooling will permit development to occur in south Florida.

Installed capacity in 1975 was 18,000 MWe, most of which is oil- or gas-fired. Utility plans for 1985 push the total capacity to 30,000 MWe, two-thirds of which is still scheduled to be oil-fired. By

2000, new capacity sited advances the total to 51,000 MWe, only 10% of this total being coal-fired. By 2020, total capacity sited soars to 105,000 MWe with coal-fired plants accounting for about 20%.

The high levels of capacity are unrealistic with the present practice of using wet cooling towers and cannot be accommodated without going to brackish water for cooling. Unless brackish water is used, Florida has the worst energy problems of any state in the southern region.

3.2.8 West Virginia

West Virginia has the potential for accepting large amounts of coal- and nuclear-fired generation as well as coal-conversion (synfuel) facilities along the Ohio and Kanawha rivers. By 2020, however, new capacity sited to meet projected demand will exhaust the ideal sites, and less desirable areas will have to be utilized.

To meet forecast production levels for synfuel products required by the scenario, two 250×10^6 -ft³/day, high-Btu plants, one 50,000-bbl/day, synthetic crude plant, and one 250×10^6 -ft³/day, low-Btu plant must be sited by 2000. The 2020 production levels will require two additional 250×10^6 -ft³/day, high-Btu plants, and the expansion of one plant sited in 2000 to 500×10^6 ft³/day. The one synthetic crude plant sited in 2000 was increased to 100,000 bbl/day in 2020 (see Figs. 3.6 and 3.7).

In 1975, West Virginia had an installed electrical generating capacity of 10,700 MWe. According to Federal Power Commission data, utilities plan to expand to 13,000 MWe by 1985. New capacity to meet projected increases in demand raise this total to 15,000 MWe in 2000 and 63,000 MWe in 2020. A significant portion of the new capacity hypothetically sited between 1985 and 2020 is coal-fired. New capacity installed between 2000 and 2020 requires 7200 MWe of nuclear capacity (48%) but new coal-fired capacity increases to 47,700 MWe.

3.2.9 Kentucky

Most of Kentucky's energy facility siting potential is located in counties along the Ohio River, with less desirable counties located along the Cumberland, Green, and Kentucky rivers. By 2020, most of the better siting areas should be utilized (in many areas over 8000 MWe per county), and consequently either less desirable areas will have to be utilized or larger amounts of capacity (over 8000 MWe per county) will have to be concentrated along the Ohio River.

According to utility plans, Kentucky's generating capacity will expand from 12,000 MWe in 1975 to 19,000 MWe by 1985. New capacity sited to meet in-state demand as well as new demand in Indiana and Illinois will require 31,000 MWe in 2000 and 91,000 MWe in 2020.

In 2000, two 250×10^6 -ft³/day, high-Btu gasification plants, one 250×10^6 -ft³/day, low-Btu gas plant, and one 100,000-bbl/day, synthetic crude plant were sited to match production levels forecasted by the

scenario. In 2020, the synthetic crude plant was expanded to 150,000 bbl/day, and two additional high-Btu gasification plants were added. Also, one 250×10^6 -ft³/day plant and one 500×10^6 -ft³/day plant were added. Finally, the existing low-Btu plant was expanded to 500×10^6 ft³/day. These energy developments, along with the increased electricity generating capacity, will seriously tax the water resources in the state by 2020.

3.2.10 Tennessee

Tennessee's total generating capacity in 1975 was 13,000 MWe, most of which was operated by the Tennessee Valley Authority (TVA). By 2000, total demand will require 38,000 MWe (based upon projected growth), and by 2020 the total may be as large as 83,000 MWe. Despite present dependence on coal-fired generation in the state, coal-fired capacity will only amount to 26% in 2020, according to the scenario.

Site suitability is generally poor for nuclear facilities in Tennessee, and there are only a few good sites for coal-fired plants. Coal-conversion suitability is also generally poor in the state. Because TVA's reservoirs increase the potential for siting new capacity, new generating capacity problems can be handled to 2020; however, the spacing of plants along the Tennessee River and major tributaries may be less than 20 miles by 2020 along some portions.

3.2.11 Alabama

Alabama is well endowed with suitable areas for siting both coal and nuclear power plants. Almost half the counties in Alabama have fair to excellent suitability for both nuclear and coal plants. Coal-conversion suitability is also good in the central-western portion of the state; however, no plants were sited by 2020.

Capacity expansions planned by the utilities for 1985 increase the 1975 total from 14,000 MWe to 22,000 MWe. Our analysis increased capacity to 36,900 MWe in 2000 and to 71,000 MWe in 2020. Only 30% of the 2020 capacity is coal-fired.

Potential for additional expansion exists throughout the state, but, as in Tennessee, the spacing would become close along major rivers. Proposed new reservoir capacity in the upper reaches of the Tombigbee and Chattahoochee river basins will enhance siting potential in those areas. Consequently, Alabama should be able to meet in-state demand beyond 2020 levels, assuming that industrial and agricultural growth do not significantly compete for resources.

3.2.12 Mississippi

In 1975, Mississippi had an installed generating capacity of only 4600 MWe. By 1985, this capacity will expand to 12,000 MWe. In 2000 the total new capacity sited is 16,600 MWe, and in 2020 it is 38,000 MWe.

Suitability for coal and nuclear power plants is best along the Mississippi River and along the Gulf Coast. Addition of new capacity beyond the 2020 level is possible because of the vast water resources of the Mississippi River; consequently, Mississippi should be able to accommodate in-state requirements with ease.

3.2.13 Arkansas

Arkansas's best siting areas are located in the southwestern portion of the state, along the Red and Arkansas rivers as they join the Mississippi River. Siting potential for the remainder of the state is generally poor, although some potential for siting coal-conversion plants is located in the western portion of the state.

The 1975 generating capacity was 4800 MWe, and the 1985 capacity is scheduled to be 10,000 MWe. The capacity will increase to 14,600 MWe in 2000 and to over 30,000 MWe by 2020. Almost half this capacity is forecast to be coal-fired. Water availability will be the controlling factor in western Arkansas, as with most other southern states west of the Mississippi River. New plants sited along the Red River will have to depend upon reservoir storage. However, because of the high volumes of water in the Mississippi, the potential to expand capacity in the eastern portion will remain high well beyond 2020.

3.2.14 Louisiana

Because of abundant water supplies from the Mississippi River and its tributaries, Louisiana has good siting potential over most of the state, with the best areas concentrated along the Sabine, Red, and lower Mississippi rivers. Installed capacity in 1975 was 11,000 MWe. In 1985, the capacity is expected to be 18,000 MWe. Based upon scenario estimates, this level will have to expand to 56,000 MWe in 2000 and to 89,000 MWe in 2020.

Although coal reserves are scarce within the state, a survey of industry plans indicated that some potential for coal-conversion development exists, largely because of water availability, the capacity for barge shipment, and the historical use of oil and natural gas within the state. In 2000, a 250×10^6 -ft³/day, low-Btu plant was sited in southern Louisiana along the Gulf. By 2020, an additional plant, a high-Btu 500×10^6 -ft³/day plant, was sited in northwestern Louisiana to use lignite from Texas.

If problems in transmitting power to northern or western load centers can be overcome, tremendous generating capacities could be easily managed through large power parks located along the Mississippi.

3.2.15 Oklahoma

Only a few counties highly suitable for coal and nuclear facilities can be found in Oklahoma, mainly because of low water availability. Most of the counties suitable to even a low degree are located midstate and to the east. Fortunately, demand in the state is forecasted to be low, so new capacity requirements can be met by expanding existing capacity. Some siting potential for coal-conversion plants exists in the eastern portion of the state and to meet the scenario requirements, one 250×10^6 -ft³/day plant was sited in 2000. This was expanded to 500×10^6 ft³/day in 2020.

In 1975, installed capacity was 7,198 MWe, mostly gas-fired. This is scheduled to increase to 14,000 MWe in 1985. By 2000 this level will increase only to 18,000 and in 2020 to 24,000 MWe (30% nuclear and 25% coal-fired). Water shortage problems inherent to the region will keep the potential for new capacity down unless dry cooling technologies or groundwater are used.

3.2.16 Texas

As in Oklahoma, almost all of Texas's potential for nuclear and coal-fired plants is located in the eastern portion of the state. Some coal production potential also exists in the eastern lignite coal field. Most of the available siting potential is gone by 2020, and it is assumed that reservoirs will augment flows to support much of the 2020 capacity. Although the possibility of importing water from the Mississippi has been suggested, consideration of the net gains after accounting for the energy required for pumping may negate the possibility.

Two coal conversion plants were sited in Texas in 2000, one a 500×10^6 -ft³/day, high-Btu gasification plant and the other a 50,000-bbl/day liquefaction plant. The high-Btu plant was expanded to 750×10^6 ft³/day in 2020 and the liquefaction plant to 150,000 bbl/day.

In 1975, Texas had 40,000 MWe of installed generating capacity, but only 2300 MWe of that was coal-fired capacity. The remaining capacity was either gas- or oil-fired. By 1985, the utilities plan to increase this to 65,000 MWe, of which 33% is coal-fired and almost none gas- or oil-fired. Additional capacity was sited to bring the level to 98,000 MWe in 2000, with 19,000 MWe coal-fired. Total capacity sited to meet demand in 2020 jumped to 165,000 MWe, but only 15% was coal-fired and 47% nuclear.

The 165,000 MWe in 2020 will be possible only if dry cooling or brackish-water cooling is utilized or if extensive groundwater pumping occurs. Cooling water in the interior of Texas is in short supply, and only in the eastern portion of the state can adequate water supplies be found. Like Florida, Texas will have significant environmental problems in meeting forecasted demand.

3.3 Effects of Interregional Electricity Exports and Imports on NCUA Siting Patterns

Examination of recent Federal Energy Regulatory Commission data on import and export of electricity between various National Electric Reliability Council regions indicates that significant amounts of electricity presently cross from one NCUA region to another, and this practice can be expected to continue. To accommodate these overlaps, we have sited capacity to satisfy forecasted new demand out to 200 miles beyond our region. To date, these overlap problems have not been resolved with the other laboratories; consequently, some irregularities in matching sited capacities to capacities required by the scenario will occur. These differences, however, are not sufficient to affect the assessment, particularly in view of the large differences between the Federal Power Commission technology mixes and the scenario technology mixes that also must be resolved. We have discovered for our census regions that the total capacities planned by the utilities in specific technology types differ significantly (more than 30%) from the capacities called for by the scenario. For this reason we have tended to rely upon the utilities' plans in the years 1975-1985 and out to 1990 and gradually adjust the mixes in 2000 and 2020 to match the scenario's.

4. ASSESSMENT OF REGIONAL AIR-QUALITY EFFECTS (DETERIORATION)

4.1 Summary of Regional Air-Quality Problems and Constraints

This section discusses the potential atmospheric pollutant loading patterns associated with projected siting arrangements for coal-fired generating plants. Siting patterns for 1985, 2000, and 2020 are considered. For comparison, the pollutant loading picture associated with 1975 siting patterns is also calculated.

Regional patterns of atmospheric pollutant loading have been deduced for the years studied. These have emphasized sulfur dioxide and sulfates and estimates for the case of nitrogen oxides and small particulates are also discussed. For the year 1985, ground-level concentrations of sulfur dioxide, nitrogen oxides, and total suspended particulates (TSP) are estimated for the vicinity of a number of power plants in the region. The analyses reported here are restricted to coal-burning utilities. The industrial section will, of course, add substantially to the pollution problem.

The analysis reported here shows that most areas of the South that are some distance from large generating facilities (e.g., 50 km) will be below the National Ambient Air Quality Standards (NAAQS) for sulfur dioxide. By extension, this can also be said in the case of nitrogen oxides. Where there are large concentrations of generating capacity, our calculations show that NAAQS will probably not be violated either. However, in the case of sulfur dioxide, prevention of significant deterioration (PSD) considerations are of more importance than NAAQS. For the vicinity of some projected utility sites we see large parts of the allowable increment for class II being used up. This situation is also likely to arise with nitrogen oxides (and possibly other pollutants) as in accordance with the 1977 Clean Air Act Amendments, regulations are promulgated to prevent significant deterioration of air quality resulting from these other pollutants.

One should keep in mind that short-range air-quality calculations are generally believed to be accurate to within a factor of 2 at best. With the addition of pollution from the industrial sector this raises the possibility of violations of standards and/or accounting for large portions of the allowable PSD increments. It is also possible that problems could arise with 24-hr standards where such exist. Detailed studies of this problem require much analysis of historical weather data because information on persistence is needed. These types of studies are planned for the future.

A result which is more troublesome than the erosion of class II PSD increments in the vicinity of power plants, however, is the erosion of class I increments due to the long-range transport of sulfur dioxide into wilderness areas, etc., particularly in the eastern sections of the region. There are about 20 class I areas in the region at the present time. About half of these are located in the East where our calculations predict values of the order of the allowable class I increments.

Source strength estimates for this study were based on New Source Performance Standards (NSPS). The passing into law of the Clean Air Act Amendments of 1977 means that NSPS may, in fact, be an upper limit for emissions. Hence, our estimates may be on the high side. It is not possible to be certain as to what possible future emission levels will be until emission standards are set. Keep in mind that these standards will require both a percentage reduction and an upper emissions limit. Furthermore, because of the percentage reduction requirement, it is likely that low-sulfur western coal will be burned in the west of the region and high-sulfur coal in the east. Our estimates should therefore be regarded as applying to one set of emission criteria. As fuel use options become better known as time evolves, our estimates should be weighted by the appropriate factors.

4.2 Introduction

Atmospheric emissions from coal-burning facilities are known to be the cause of much environmental insult. Important constituents of these emissions are sulfur dioxide, nitrogen oxides, and particulate matter.

Sulfur dioxide has long been studied as a pollutant. Recently there has been an emphasis on the long-range transport of sulfur pollutants because of an interest in chronic (as opposed to acute) ecological and health effects. In these long-range studies, the oxidation products of sulfur dioxide become important, because they introduce another set of problems in addition to those posed by sulfur dioxide. The oxidation products of sulfur dioxide are generally referred to as sulfates. However, the environmental impacts of the oxidation products are not all of equal importance. Upon oxidation, sulfur dioxide becomes sulfur trioxide, the anhydride of sulfuric acid. In the presence of atmospheric moisture, sulfuric acid can be produced, which gives rise to acid precipitation with its attendant environmental problems,^{1,2} that is, damage to sensitive plant species such as soybeans and conifers. Of course, not all of the sulfuric acid may reach the earth's surface as acid precipitation. Some of it will form sulfate salts (e.g., ammonium sulfate). Aerosols containing sulfate salts are believed to be quite common.³

Oxides of nitrogen also produce an acid (nitric acid) and, in turn, nitrate salts. This nitric acid also contributes to the acid precipitation problem, and it is believed that its contribution is quite significant.^{4,5} Oxides of nitrogen represent an important component of the atmospheric pollutant problem in another context. In the presence of sunlight, they lead to ozone formation.⁶

Particulate matter can be a problem near the emission source either because of its visibility in plumes or, in the case of larger particles, its deposition on the ground. The particulates transported over large distances will be those whose effective diameters are on the order of a few microns. They are likely to contain inorganic salts.

Projected air pollutant concentrations near the emission source (within 50 km) have been studied. Such studies are of interest mainly

in connection with high levels of exposure and in cases where the cumulative effects of a number of nearby sources might be of concern. In the siting of a number of energy-generating facilities in close proximity to one another, such studies can identify areas that, because of local wind patterns, may prove to be troublesome from the point of view of air quality.

As was pointed out above, the long-range transport of atmospheric pollutants has been receiving more attention recently because of the emphasis on chronic effects of pollutants and an interest in chemical transformations that take place during transport over large distances. When studying regional siting patterns, long-range pollutant transport calculations are useful in identifying the nature and extent of pollutant exposure throughout the region. The spatial resolution of such calculations is generally consistent with the precision with which future siting is known. If siting plans are known more accurately, meaningful short-range calculations of pollutant loading are possible. However, such calculations are mainly of interest when studying the interactions of a number of clustered generating facilities.

4.3 Short-Range Impacts

A group of 11 localities in the South has been chosen for special study of atmospheric loading patterns. These areas were selected from among the 1985 siting projections because of the local concentration of large generating capacity and/or the proximity to large population centers. The areas are displayed in Fig. 4.1 and are listed in Table 4.1. Depending on the distance between sources, a circular region of 50- or 100-km radius was chosen in each case. The circular study areas are also shown in Fig. 4.1. Ground-level concentrations of sulfur dioxide, nitrogen oxides, and total suspended particulates were calculated as annual averages for these study areas. These calculations were carried out using a Gaussian plume model of atmospheric pollutant transport.⁷ A brief description of the model can be found in Appendix B. Dispersion climatologies in the form of annual averages were used for locations within or near each study area (Table 4.1).

The source term for each plant was calculated on the assumption that the emissions would not exceed the NSPS.⁸ For coal-fired steam generators, these standards are listed in Table 4.2. The plants were assumed to convert 35% of the heat energy derived from burning coal into electrical energy. The calculated emissions, per 1 MWe of generating capacity, are 0.123 g/sec TSP, 1.48 g/sec sulfur dioxide, and 0.86 g/sec nitrogen oxides. If the NSPS values should change and/or generating efficiencies should differ, all of our results will need to be adjusted by a multiplicative constant. In making these predictions, particularly for times far in the future, one of the most vexing problems encountered has been the estimation of technological capabilities; here we chose to take the approach of using values representative of present-day technology. It may be that reasonable expectations of future technological development make this a conservative approach. In the light of the 1977 Clean Air Act Amendments, it appears that NSPS do represent a conservative approach. If so, our estimates can be revised or altered. Alternatively, they can be used to calculate the improvements in performance required to meet certain goals.

Fig. 4.1. Selected short-range air-quality assessments.

Table 4.1. Areas studied

State	County	Generating capacity (MWe)	Dispersion climatology
Alabama	Jefferson	2732	Birmingham
	Shelby	1965	
	Walker	1802	
	Mobile	1587	Mobile
	Washington	490	
Florida	Hillsborough	2649	Tampa
	Polk	236	
Georgia	Bartow	3174	Atlanta
	Cobb	514	
	Floyd	713	
	Carroll	1792	Atlanta
	Coweta	1322	
	Bibb	175	Macon
Mississippi	Monroe	3300	
	Harrison	1034	Biloxi
	Jackson	1036	
North Carolina	Catawba	2024	Charlotte
	Cleveland	771	
	Gaston	1599	
	Person	5375	Raleigh
	Franklin	1500	
Texas	Titus	3484	Tyler
	Fort Bend	2820	Houston

Table 4.2. Emission limits for coal-fired electrical generating plants according to New Source Performance Standards

Pollutant	Emission standard per 10^6 Btu (lb)
Sulfur dioxide	1.2
Nitrogen oxides	0.7
Total suspended particulates	0.1

Some other assumptions had to be made when doing the short-range or near-in pollutant-transport calculations. Projected siting patterns are only capable of placing generating plants or clusters in a particular county; they do not predict locations within counties. For meaningful short-range transport studies, precise locations must be chosen. Unless evidence to the contrary was found, we chose our locations by assuming that future generating capacity in each county would be at the site of the largest power plant presently existing in the county. For future generating capacity, a stack height of 300 ft was assumed in all cases. (The effect of stack height is illustrated in Appendix C.) Furthermore, assumptions were made on stack-gas parameters. Values typical of some present-day sources were used for these parameters. Since such calculations involve a number of assumptions, any real expectation of accuracy could not be had for beyond 1985.

In Figs. 4.2-4.7, isopleths of annual average ground-level concentrations of sulfur dioxide, nitrogen oxide, and TSP are shown for a location in northeastern Texas (Franklin and Titus counties) and for the region surrounding Person County, North Carolina. These two sites are associated with large generating capacities in the 1985 scenario. The Texas location shows high concentrations to the north because of a predominant southerly component in the wind rose. The North Carolina location, on the other hand, has a more isotropic wind rose and shows concentrations that are more typical of other locations in the region. Results of calculations for the remainder of these locations are shown in Appendix C.

4.4 Long-Range Impacts

Projected siting patterns for power generation facilities for the years 1985, 2000, and 2020 are discussed in Sect. 3. The details of the siting projections are discussed there also. These projections give power generating capacity per county in terms of megawatts. We have used these (and actual 1975 siting patterns for comparison) to estimate regional atmospheric loading patterns. We have used the emission standards listed in Table 4.2 to estimate the sulfur dioxide emissions for the corresponding counties. The state totals are given in Table 4.3 for 1975, 1985, 2000, and 2020. Also listed in Table 4.3 are the total sulfur dioxide emissions

ORNL-DWG 77-20169

Fig. 4.2. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Franklin and Titus counties, Texas. Locations of power plants and county outlines are shown.

ORNL-DWG 77-20168

Fig. 4.3. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Franklin and Titus counties, Texas.

ORNL-DWG 77-20170

Fig. 4.4. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Franklin and Titus counties, Texas.

ORNL-DWG 77-20159

Fig. 4.5. Annual average calculated ground-level concentration of sulfur dioxide from a coal-fired steam plant in Person County, North Carolina.

ORNL-DWG 77-20160

Fig. 4.6. Annual average calculated ground-level concentration of nitrogen oxides from a coal-fired steam plant in Person County, North Carolina.

ORNL-DWG 77-20161

Fig. 4.7. Annual average calculated ground-level concentration of total suspended particulates from a coal-fired steam plant in Person County, North Carolina.

Table 4.3. Comparison of various sulfur dioxide emission rates
(million kg) by state

State	Total emissions ^a	Estimated coal-fired utility emissions			
	1975	1975	1985	2000	2020
Alabama	762	408	549	664	938
Arkansas	82	5	225	276	604
Delaware	<i>b</i>	15	34	141	327
Florida	1118	114	205	327	1028
Georgia	410	381	577	597	597
Kentucky	1434	483	755	903	1829
Louisiana	541	0	125	244	244
Maryland	<i>b</i>	77	108	343	343
Mississippi	41	48	162	270	468
North Carolina	433	472	643	770	784
Oklahoma	96	0	185	216	303
South Carolina	269	130	143	439	605
Tennessee	3072	429	429	619	1103
Texas	430	106	888	888	1113
Virginia	<i>b</i>	100	100	438	438
West Virginia	<i>b</i>	495	606	658	2219

^aNational Emissions Data System, EPA.^bData not available.

for 1975 from all sources as tabulated by the National Emissions Data System. For some states, such as Arkansas and Oklahoma, the sulfur dioxide emissions from coal-fired plants represent only a small fraction of the total sulfur dioxide emissions. For other states, such as Georgia, Mississippi, and North Carolina, the sulfur dioxide emissions from coal-fired plants account for nearly all of the state totals.

The estimation of regional loading patterns required calculations of the long-range transport of pollutants (to distances of hundreds to thousands of kilometers). Such calculations require the specification of wind fields and require some assumptions on the diffusion of pollutants as they are advected by the mean wind. The approach adopted here is based on that of Heffter et al.,⁹ which is explained in more detail by Begovich et al.¹⁰ The technique uses upper-air wind data available for about 200

stations in the continental United States. This is an extensive data source involving wind observations at many heights, twice (and sometimes four times) per day; however, it must be recognized that its spatial resolution is limited. As a consequence, siting patterns that give information on a county basis are sufficiently accurate for such a model. In fact, the resolution of the wind data is coarser than the dimensions of a typical county. We were able, therefore, to aggregate some clusters of adjacent counties and thus reduce the effective number of pollutant sources in the region for the model input. As a result, roughly 80 sources were used in calculating the 1985, 2000, and 2020 loading patterns, representing 160 counties in 2020. Included were a number of sources outside the region itself (in Missouri, Illinois, Indiana, Ohio, and Pennsylvania) from which pollutants would be advected into the region. As in the case of the short-range calculations, NSPS were used to estimate pollutant emissions, and 35% efficiency was assumed for all power plants.

January was chosen as the climatological period for this study because of a shallow mixing layer and probability of high power demand. It was assumed that the pollutant will be mixed throughout the depth of the afternoon mixing layer. Furthermore, actual variations in atmospheric turbulence are not considered in determining the lateral and vertical spread of pollutant about the individual trajectories. Even if atmospheric turbulence were considered in this detail, it is doubtful whether one could successfully assign realistic diffusion parameters at large distances from the pollutant source. However, time-dependent vertical and horizontal diffusion parameters were used that represent an average of a large number of observations, and, although less than ideal, they represent the best available data for this type of calculation (see Heffter¹¹ and Begovich et al.¹⁰). These parameters are to be considered as representative of neutral stability conditions.

In modeling the long-range transport of pollutants, we allowed for some important depletion processes — in particular, dry deposition, washout by precipitation, and, in the case of sulfur dioxide, transformation to sulfate. The parameters used to model these depletion processes are receiving much attention, and it should be appreciated that the results of calculations such as these may change significantly when different values of depletion parameters are chosen.

The sulfur dioxide and sulfate loading pictures are very dependent on the transformation rate between sulfur dioxide and sulfate. This transformation rate depends on many atmospheric conditions, and one can only hope to characterize it with a value that is meaningful in a time-averaged sense (keeping in mind that this value may be a function of the time of year and region of the country). Values for the sulfur dioxide to sulfate transformation rate have been deduced and vary from about 1% per hour to 14% per hour.¹² A value of 5% per hour was used for these calculations. Values around 5% per hour are believed to be appropriate for time-averaged calculations, although the subject needs further study.

The dry deposition velocity for sulfur dioxide was chosen as 1 cm/sec with a washout rate of 6.7×10^{-6} per second. For the oxidation products of sulfur dioxide, the corresponding values are believed to be about 10%

of the sulfur dioxide values. In these calculations, washout and dry deposition rates were assumed to be zero for sulfates. This may make our sulfate calculations conservative.

The ground-level concentrations of sulfur dioxide resulting from these calculations are shown in Figs. 4.8-4.11 for 1975, 1985, 2000, and 2020 respectively. The sulfate results for the same years are shown in Figs. 4.12-4.15.

There are slight increases in the areas exhibiting higher concentrations for the later time periods. These are summarized for sulfur dioxide in Table 4.4. In 1975 no concentrations exceeded $30 \mu\text{g}/\text{m}^3$. Even by the year 2000 only a very small area exceeded this value. By 2020 0.50% of the area had concentrations between 20 and $40 \mu\text{g}/\text{m}^3$ with only 0.29% of the area exceeding a concentration of $40 \mu\text{g}/\text{m}^3$. In the case of sulfates no areas had concentrations exceeding $20 \mu\text{g}/\text{m}^3$ until 2020. At that time, 0.83% of the area had concentrations between 20 and $25 \mu\text{g}/\text{m}^3$, but no areas exceeded $25 \mu\text{g}/\text{m}^3$.

Table 4.4. Sulfur dioxide air-quality projections for the 16-state study area for the period 1975-2020

Year	Percentage of total area with concentrations ($\mu\text{g}/\text{m}^3$) within a given range of:		
	20-30	30-40	>40
1975	0.10	0	0
1985	0.19	0.01	0
2000	0.20	0.01	0
2020	0.99	0.59	0.29

Similar long-range calculations were not performed for nitrogen oxides and particulates. The various transformation processes involving nitrogen oxides were not considered to be well enough known. However, a rough indication of the nitrogen oxide loading can be obtained from the sulfur dioxide values and from noting that on the basis of NSPS the source terms for nitrogen oxides would be 60% of the corresponding values for sulfur dioxide. Depletion of particulate plumes depends on particle size. However, the values for sulfur dioxide can give an indication of the situation with fine particles (less than a few microns). If one uses NSPS for TSP (see Table 4.2) it would appear that particulate loading should be about an order of magnitude below sulfur dioxide loading. However, one should keep in mind that the majority of air-quality control regions are classified as nonattainment areas from the viewpoint of particulates.

Fig. 4.8. Calculated regional concentrations of sulfur dioxide: NCUA base-case scenario, 1975. Interval limits: (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 $\mu\text{g}/\text{m}^3$.

Fig. 4.9. Calculated regional concentrations of sulfur dioxide: NCUA base-case scenario, 1985. Interval limits: (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 $\mu\text{g}/\text{m}^3$.

Fig. 4.10. Calculated regional concentrations of sulfur dioxide: NCUA base-case scenario, 2000. Interval limits: (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 $\mu\text{g}/\text{m}^3$.

Fig. 4.11. Calculated regional concentrations of sulfur dioxide: NCUA base-case scenario, 2020. Interval limits: (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 $\mu\text{g}/\text{m}^3$.

Fig. 4.12. Calculated regional concentrations of sulfates: NCUA base-case scenario, 1975. Interval limits: (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 $\mu\text{g}/\text{m}^3$.

Fig. 4.13. Calculated regional concentrations of sulfates: NCLA base-case scenario, 1985. Interval limits: (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 µg/m³.

Fig. 4.14. Calculated regional concentrations of sulfates: NCUA base-case scenario, 2000. Interval limits: (1) <0.01, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0 $\mu\text{g}/\text{m}^3$.

Radioactive substances represent another class of pollutant which is an important constituent of coal-plant effluents. The recent Clean Air Act Amendments also address the problem of radioactive effluents. In a recent study¹³ the radiological impact of naturally occurring radionuclides emitted in the airborne effluent of a coal-fired steam plant was evaluated and compared with the impact of radioactive emissions from a light-water reactor. On the basis of the coal containing 1 ppm uranium and 2 ppm thorium and releasing to the atmosphere 1% of the total ash in the coal (equivalent to 0.1 lb/10⁶ Btu for coal with an ash content of 12% and a heat content of 12,000 Btu/lb), the whole-body and all organ doses for both the coal and nuclear plants were within the same order of magnitude (2-4 millirems per year). Currently, coal-fired plants release 10-20 times more fly ash than assumed in this study and so have a correspondingly higher radiological impact.

4.5 Discussion of Major Findings

In considering the cumulative effects of all the sited capacity projected for the years 1985, 2000, and 2020, the same general comments apply for all three periods. There are some areas where the average sulfur dioxide concentrations will exceed 10 $\mu\text{g}/\text{m}^3$ in the month of January, a month when power demand is likely to be high and the depth of the afternoon mixing layer is likely to be minimal. These areas are more extensive for the later years, and for 2020 most areas in the Ohio River region are projected to be above 10 $\mu\text{g}/\text{m}^3$ although few areas exceed 20 $\mu\text{g}/\text{m}^3$ (see Table 4.3). Apart from the areas where sulfur dioxide levels in excess of 10 $\mu\text{g}/\text{m}^3$ exist, atmospheric loadings between 1 and 10 $\mu\text{g}/\text{m}^3$ are predicted for most of the north and east portions of the southeastern region. Values below 1 $\mu\text{g}/\text{m}^3$ are predicted for the far south and west portions of the region. Although these values, for a specific month, are likely to be high the yearly pattern is expected to be much the same, with the actual values being somewhat lower. Based on the depth of the mixing layer, the reduction can be expected to be on the order of 30%.

In the case of sulfates (see Figs. 4.12-4.15) the pattern of sulfate loading becomes progressively worse from year to year, as expected. Sulfate concentrations in excess of 10 $\mu\text{g}/\text{m}^3$ are predicted for the northeast portion of the region. The area affected by the higher concentrations is significantly larger in 2020 than in 1975 or 1985. Concentrations in excess of 1 $\mu\text{g}/\text{m}^3$ are predicted for essentially all of the region except west Texas and west Oklahoma for all years studied.

We now consider concentration values predicted in and around major clusters of generating capacity in 1985. The highest average annual ground-level concentration of sulfur dioxide predicted by our short-range calculations is 30 $\mu\text{g}/\text{m}^3$ for Franklin and Titus counties, Texas. The other ten locations studied (see Fig. 4.1) show maximum values of about one-half to one-third of this. The high value predicted for the two Texas counties can be ascribed to a very nonisotropic wind rose having a predominant southerly component. This would seem to indicate problems with PSD requirements of the Clean Air Act Amendments of 1977, since the permitted increments in the case of sulfur dioxide are 20 $\mu\text{g}/\text{m}^3$ and 40 $\mu\text{g}/\text{m}^3$ for class II and class III regions respectively.

Calculations for oxides of nitrogen show one maximum value of $20 \mu\text{g}/\text{m}^3$ for the nearby ground-level concentration, again for Franklin and Titus counties in Texas, but values around half of this are more common at the other high-concentration locations. The NAAQS for nitrogen dioxide is $100 \mu\text{g}/\text{m}^3$ (annual arithmetic mean). Keep in mind, however, that PSD increments are likely to be promulgated for nitrogen oxides.

Calculations of the dispersion of particulates indicate that the highest values of ground-level concentrations of total suspended particulates are between 1 and $2 \mu\text{g}/\text{m}^3$, well below the NAAQS ($75 \mu\text{g}/\text{m}^3$ primary and $60 \mu\text{g}/\text{m}^3$ secondary annual). However, most air-quality control regions report violations of NAAQS for suspended particulates, presumably due to fugitive dust.

In considering the results of the short-range calculations, one should keep in mind that some important assumptions have been made on the precise locations of the power plants, the physical stack height, and stack-gas exit parameters (see Appendix B for a discussion of stack height effects). Therefore, these results should be considered as representative of situations that might occur in 1985.

There are indications of problems connected with the PSD requirements of the 1977 Clean Air Act when one considers these results. In areas close to large generating plants, values corresponding to significant fractions of the allowable class II increments are predicted. Keep in mind, however, that our assumptions on emission rates and stack heights may tend to overestimate concentrations.

In the case of the long-range transport of sulfur dioxide it is likely from our calculations that the extra generating capacity in future years may add significant amounts of allowable increments to class I areas, particularly in the eastern states. If emissions are lower than NSPS values, of course, the magnitude will be correspondingly reduced.

4.6 Implications for Coal Technology Siting Patterns

When comparing the 1975 pollutant loadings with those of 1985, 2000, and 2020, one sees a noticeable increase in regional air pollution associated with the expanded use of coal. Of course, this is no surprise. It has been anticipated,^{14,15} and these calculations serve merely to give an idea of its magnitude.

The present administration has emphasized the importance of air-quality considerations in industrial planning (President Carter's Environmental Message to Congress, May 23, 1977). With the enactment of the Clean Air Act Amendments of 1977,¹⁶ it appears inevitable that coal-fired electrical generating facilities will be constrained in size, location, and type.

In this section, the arrangement of coal facilities that minimizes air pollutant exposure is discussed. An optimization model for siting of energy facilities to minimize exposure to air pollutants is used in

the analysis.¹⁷ The siting of coal combustion facilities among counties to minimize the exposure of human populations to air-dispersed sulfur pollutants is considered. Ground-level concentrations of pollutants are calculated for the region of interest using the long-range pollutant transport model described earlier. The population exposure is then calculated based on 1970 census data. Power plant capacities are assigned to the counties to minimize this exposure. The results provide insight into facility siting patterns that minimize air pollution problems.

In this preliminary assessment, we consider the area between 81° and 89° west longitude and 31° and 34° north latitude. This is shown in Fig. 4.16. The area contains the drainage basin of the Tennessee River and parts of the basins of the Ohio and Cumberland rivers. The region has a large coal resource, and coal combustion power plants form a large part of the existing power system. An expansion in the nation's coal power system is likely to be evident in this area, which has a long history of coal use.

Five counties (see Sect. 3 for details of techniques) were chosen for this study. These are Colbert, Morgan, and Jackson in Alabama and Rhea and Hawkins in Tennessee. Each candidate site has an upper limit on the facility size. These five counties were further examined through a topographic map study aimed at identifying potential water sources which is, generally, the limiting factor on site suitability for coal combustion facilities. All five counties provide adequate water resources for a large power plant (perhaps 1500 MWe) if one disregards consideration of the availability of that water (competing user, etc.). For this analysis, we assume a maximum capacity of 1500 MWe, with a total demand for the five counties being 5000 MWe.

Based on the results of the pollutant transport model and the use of 1970 census data to minimize exposure of human population, generating capacities were assigned as follows: 1500 MWe to Sites 1, 4, and 5 (Colbert, Rhea, and Hawkins counties) and 500 MWe to Site 3 (Jackson County). No capacity was assigned to Site 2 (Morgan County).

Since Sites 2 and 3 are clustered around the Huntsville demand center in northern Alabama, a simple inference can be drawn that planning for minimum exposure of population to air pollutants drives the facility siting pattern away from this type of clustering. The trajectories of pollutants from Sites 1, 2, 3, and 4 overlap, combine, and result in high pollutant concentrations. These areas of high concentrations correspond closely with the nearby population centers. Note that Site 5, assigned a high activity level, is reasonably isolated. If a small plant at Site 3 is not feasible, an alternative fuel resulting in different pollutants or the use of improved abatement procedures may be reasonable alternatives.

Fig. 4.16. The region of the optimization study. The counties studied are numbered, and the major cities in the area are shown as black dots.

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5. REGIONAL WATER-RESOURCES IMPACTS

5.1 Major Findings

Water availability has become a prime locational determinant in the siting of future energy facilities because of the need for dissipating waste heat. The Environmental Protection Agency's restrictions on heat rise in the recipient stream now encourage the use of water-consuming systems such as wet cooling towers. Our analysis indicates that by 2000, and possibly by 1985, significant impacts on water resource availability may occur during low-flow periods as the result of the siting patterns for new energy facilities developed for the NCUA scenario. The analysis assumes continued use of water-consuming cooling technologies. Our analysis for the ORNL southern region indicates the following conclusions:

1. Water consumption problems for all uses already exist in selected drainage basins in Texas, Oklahoma, Arkansas, and Florida. Energy will become an increasing contributor to these problems by 1985.
2. The potential for significant water consumption problems in 2000 exists in West Virginia and Pennsylvania in the Monongahela River basin and along other tributaries to the Ohio River.
3. Several states, notably Florida, Delaware, and Maryland, will have to use brackish-water cooling to alleviate their problems without major efforts toward water conservation and/or limiting growth.
4. Major electricity conservation efforts or shifts to dry cooling technologies will be required by the year 2000 to avoid significant water consumption impacts projected in this assessment.

5.2 Analysis of Regional Water Quantity Impacts

This analysis is primarily concerned with water withdrawal and consumption associated with new energy development in the southern United States. A more detailed analysis was completed for the Ohio River basin as a first step toward the rest of the United States. Although water may be withdrawn and used several times as it flows downstream in a river, excessive withdrawal levels can lead to adverse environmental consequences such as water temperature increases, deterioration of fish and other aquatic habitats, and increased water pollution. High water consumption rates concentrate pollutant loadings and reduce the flow available to meet instream flow requirements. Impacts associated with decreased stream flow will become more significant as new power plants using more consumptive cooling technologies are brought on line.

We have completed an analysis of water availability to 2020 for each Aggregated Subarea (ASA) in the southern region (ASAs are combinations of tributary drainage basins defined by the Water Resources Council for the 1975 National Water Assessment)¹ examining the effects of energy development and other water uses. In addition, an in-depth

study of water availability for energy has been done for the Ohio River basin. The Ohio study was conducted at the request of DOE to assist the Ohio River Basin Commission (ORBC) and is included as an example to illustrate that county-level analysis is required to identify water consumption problems associated with energy facilities.

5.3 Development of Water Availability Measures

In the results of our siting analysis discussed in Sect. 3 and in the explanation of the siting methodology discussed in Appendix B, we have indicated water availability to be a primary variable in calculating site suitability for energy facilities at the county level. The primary water availability factor considered in the siting analysis was proximity to sufficient stream flow. The stream flow information was developed and mapped by the Water Resources Branch of the U.S. Geological Survey² and represents the input of professional insight as well as quantitative data. ORNL has digitized these data by county for the United States and entered them into a county-level information system (Fig. B.2).

A more appropriate water availability analysis is an examination of water demands during a typical low-flow period. Electricity demand periods that coincide with droughts in July, August, or September are considered to be the most likely times when water availability problems will occur in the southern United States. Low-flow and peak electricity demand information is being compiled for ORNL's study region utilizing a water availability model developed at ORNL.³ (Detailed information has been completed only for the Ohio River basin area to date.) Our analysis of water problems for the southern study region is based upon the flow that will be exceeded 95% of the time in each critical month and adjusted to reflect the effects of surface water storage.⁴

These estimates are being revised, but to date the revised data are not available. Comparing flow rates calculated by ORNL for the Ohio region, we have observed the low-flow estimates for aggregated subareas to be as much as 30% greater than our calculated seven-day/ten-year low-flow values, but the numbers used in the analysis represent the best available data for ASAs.

Finally, only 10% of the water available during the low-flow period is considered available for energy use. This water use guideline has tentatively been adopted by several river basin planning agencies in the eastern U.S. including the Ohio River Basin Commission. The 10% value was agreed upon as reasonable by the NCUA water resource and siting work groups because of the general lack of information concerning minimum instream flow requirements defined either for water quality or for maintenance of wildlife habitat. Minimum-requirement values currently being developed by the U.S. Wildlife Service will perhaps provide a better measure of instream flow needs when they are available.

5.4 Water Withdrawal and Consumption Use Patterns for Aggregated Subareas in the South

The total generating capacity and the portion powered by each type of fuel are supplied at the census region level by Brookhaven National Laboratory. The proportions are utilized in siting new generating capacity within census regions (Sect. 3).

Plant type and cooling mode have a significant effect on water resource requirements. For example, steam turbines with wet cooling towers require substantial amounts of water while internal combustion engines require only negligible amounts (Table 5.1). Similarly, the choice of fuel affects water use, because certain fuels can be used at higher temperatures than others and thereby attain higher thermal efficiencies. For example, since conventional fossil-fueled plants operate at higher temperatures than conventional nuclear plants, their potential thermal efficiencies are higher (approximately 40%, as opposed to 33%), and, consequently, water consumption is only 60% of that of nuclear plants.⁵

Average daily water consumption is also affected by the choice of plant and fuel type because capacity factors differ substantially among the various types. Conventional coal-fired plants, for example, often have capacity factors as high as 0.70, while conventional oil-fired facilities are as low as 0.36. All of these considerations have been factored into our water withdrawal and consumption calculations.

Descriptions of the base-case scenario siting patterns for coal at the county level for 1975, 1985, 2000, and 2020 are found in Sect. 3 and Appendix B. Water consumption and withdrawal rates under maximum base load conditions have been calculated for all facilities in each scenario year and aggregated to the ASA level (Fig. 5.1). Comparisons of these withdrawal and consumption levels with available water supplies indicate that several drainage regions will begin to experience problems during critical flow periods by 2000, with serious problems likely by 2020. Local problems may exist in other basins because many ASAs encompass more than 20,000 km² (10,000 sq miles), and some water consumption problems will not become evident until county-level accounting for water use is completed.

Tables 5.2-5.5 and Figs. 5.2-5.5 present water withdrawal and consumption compared with estimated total surface water availability for each scenario year to 2020. Graduated circles proportional to surface flow are used to reflect water availability. The size of the circle varies with the available water supply for each ASA, and the shaded wedge indicates the portion of water withdrawn or consumed. When consumption levels equal or exceed the 10% level, a potential problem is defined to exist. Withdrawal rates approaching or exceeding the critical supply may also indicate water quality problems.

Because most existing steam electric generating facilities utilize once-through cooling as opposed to wet cooling towers, withdrawal rates for many ASAs (mostly in Texas) were already approaching critical flow rates in 1975. By 2000, several Eastern streams (notably the

Table 5.1. Unit water requirements by plant type, fuel type, and cooling option

Plant type or activity	Fuel type	Cooling option	Withdrawal (Mgd)	Consumption (Mgd)	Plant capacity
Steam electric generation	Nuclear	Once through	1400	4	1000 MWe
		Cooling pond	42	26	1000 MWe
		Wet cooling tower	28	17	1000 MWe
		Dry cooling tower	0.3	0	1000 MWe
		Natural-draft cooling tower	28	17	1000 MWe
		Mechanical-draft cooling tower	28	17	1000 MWe
		Canal	42	26	1000 MWe
	Fossil ^a	Once through	830	3	1000 MWe
		Cooling pond	25	15	1000 MWe
		Wet cooling tower	17	10	1000 MWe
		Dry cooling tower	0.2	0	1000 MWe
		Natural-draft cooling tower	17	10	1000 MWe
		Mechanical-draft cooling tower	17	10	1000 MWe
		Canal	25	15	1000 MWe
Coal liquefaction			20	20	50,000 bbl/day
Coal gasification			19	16	250 MMscfd
Oil refining			10	0.5	50,000 bbl/day (crude charge)
Underground coal mining					
Appalachian Reserve			0.0033	0.00027	1 million short tons/year
Eastern Interior Reserve			0.0036	0.00027	1 million short tons/year
All western reserves			0.036	0.036	1 million short tons/year
Surface coal mining					
Appalachian Reserve			0.0030	0.00008	1 million short tons/year
Eastern Interior Reserve			0.0033	0.00012	1 million short tons/year
All western reserves			0.20	0.20	1 million short tons/year

^aScrubbers add 1 Mgd to withdrawal and consumption rates.

Derived from T. H. Pigford et al., *Comprehensive Standards: The Power Generation Case*, Teknekron Inc., (March 1975); G. A. Samuels, *Assessment of Water Resources for Nuclear Energy Centers*, ORNL-5097 (September 1976); Ted Williams, *Preliminary Energy Technologies Data Book*, Annual Environmental Assessment Report (AEAR), ERDA (April 28, 1977); and engineering studies at ANL, LASL, and ORNL.

Fig. 5.1. Water Resources Council's Aggregated Subareas (ASAs).

Table 5.2. 1975 water consumption and withdrawal
by steam electric plants

ASA#	ASA NAME	AVAILABLE WATER* (Mgd)	PERCENTAGE CONSUMED	PERCENTAGE WITHDRAWN
203	DELAWARE	3022.0	0.5	94.1
205	CHESAPEAKE BAY	5761.2	1.1	57.6
206	POTOMAC	1326.2	1.6	103.6
301	ROANOKE-CAPE FEAR	2325.6	1.7	42.3
302	PEE DEE-Santee	5409.1	0.6	44.9
303	SAVANNAH-ST MARYS	5082.7	1.1	19.3
304	ST JOHNS-SUWANNEE	5320.1	0.3	33.9
305	SOUTHERN FLORIDA	3830.4	0.8	26.6
306	APALACHICOLA	5847.2	0.2	12.2
307	ALABAMA	11309.1	0.2	9.0
308	TOMBIGBEE	6014.0	0.1	23.3
309	PASCAGOULA-PEARL	2250.5	0.4	9.6
501	ALLEG-MONG	1619.6	2.7	45.2
502	UPPER OHIO	6009.8	1.1	102.0
504	KANAWHA	1262.9	0.9	65.2
505	LOWER OHIO	28964.6	0.3	12.3
507	CUMBERLAND	2654.1	0.2	61.9
601	UPPER TENNESSEE	12239.5	0.1	11.0
602	LOWER TENNESSEE	15561.8	0.1	11.4
801	MISS-ST FRANCIS	80604.9	0.2	1.2
802	MISS-YAZOO-QUACHITA	95482.2	0.2	0.9
803	MISS-LA COAST-DELTA	98653.5	0.2	2.6
1101	WHITE	2605.6	0.0	0.1
1103	CIMARRON-ARKANSAS	4152.7	0.2	1.1
1104	LOWER ARKANSAS	4709.7	0.5	21.1
1105	CANADIAN	4123.0	0.4	5.5
1106	RED-WASHITA	5314.2	0.1	0.2
1107	LOWER RED	635.3	1.1	7.5
1201	SABINE-NECHES	705.1	1.1	125.9
1202	TRINITY	816.1	10.4	66.4
1203	BRAZOS	784.8	4.0	25.0
1204	COLORADO-LLANO	909.8	1.6	59.1
1205	GUADALUPE-NUECES	1652.1	1.3	20.6
1302	UPPER RIO GRANDE	642.3	0.0	1.6
1303	RIO GRANDE-L PECOS	1285.9	0.0	0.5
1304	UPPER PECOS	200.0	0.1	0.2
1305	LOWER RIO GRANDE	1843.4	0.0	0.2

*ESTIMATED AVAILABLE SURFACE WATER FOR THE CRITICAL SUPPLY MONTH

Fig. 5.2. NCUA base-case 1975 water consumption and withdrawal by steam electric plants as a percentage of the estimated total surface supply for the critical supply month.

Table 5.3. 1985 water consumption and withdrawal
by steam electric plants

AS#	ASA NAME	AVAILABLE WATER* (Mgd)	PERCENTAGE CONSUMED	PERCENTAGE WITHDRAWN
203	DELAWARE	3022.0	3.5	203.8
205	CHESAPEAKE BAY	5761.2	3.2	58.4
206	POTOMAC	1326.2	3.1	106.0
301	ROANKE-CAPE FEAR	2325.6	3.1	78.7
302	PEE DEE-Santee	5409.1	2.8	48.5
303	SAVANNAH-ST MARYS	5082.7	2.2	21.1
304	ST JOHNS-SWANNEE	5320.1	0.7	54.1
305	SOUTHERN FLORIDA	3830.4	1.6	68.1
306	APALACHICOLA	5847.2	0.6	12.8
307	ALABAMA	11309.1	0.3	9.1
308	TOMBIGBEE	6014.0	0.3	22.9
309	PASCAGOULA-PEARL	2250.5	0.9	10.4
501	ALLEG-MONG	1619.6	3.2	45.9
502	UPPER OHIO	6009.8	1.4	101.5
504	KANAWHA	1262.9	1.4	60.4
505	LOWER OHIO	28964.6	1.2	12.0
507	CUMBERLAND	2654.1	2.5	65.5
601	UPPER TENNESSEE	12239.5	1.0	12.5
602	LOWER TENNESSEE	15561.8	0.8	12.1
801	MISS-ST FRANCIS	80604.9	0.6	1.5
802	MISS-YAZOO-QUACHITA	95482.2	0.5	1.2
803	MISS-LA COAST-DELTA	98653.5	0.5	4.0
1101	WHITE	2605.6	0.0	0.1
1103	CIMARRON-ARKANSAS	4152.7	0.2	15.6
1104	LOWER ARKANSAS	4709.7	0.5	23.1
1105	CANALIAN	4123.0	0.4	5.4
1106	RED-WASHITA	5314.2	0.2	6.4
1107	LOWER RED	635.3	2.0	16.5
1201	SABINE-NECHES	705.1	5.9	133.9
1202	TRINITY	816.1	14.5	73.1
1203	ERAZOS	784.8	11.9	38.1
1204	COICFADC-ILANC	909.8	6.3	61.8
1205	GUADALUPE-NUECES	1652.1	2.5	41.6
1302	UPPER RIO GRANDE	642.3	0.0	1.8
1303	RIO GRANDE-I PECCS	1285.9	0.0	0.4
1304	UPPER PECCS	200.0	0.1	0.2
1305	LOWER RIO GRANDE	1843.4	0.0	0.2

*ESTIMATED AVAILABLE SURFACE WATER FOR THE CRITICAL SUPPLY MONTH

Fig. 5.3. NCUA base-case 1985 water consumption and withdrawal by steam electric plants as a percentage of the estimated total surface supply for the critical supply month.

Table 5.4. 2000 water consumption and withdrawal
by steam electric plants

ASA#	ASA NAME	AVAILABLE WATER* (Mgd)	PERCENTAGE CONSUMED	PERCENTAGE WITHDRAWN
203	DELAWARE	3022.0	16.9	313.7
205	CHESAPEAKE BAY	5761.2	12.0	61.3
206	POTOMAC	1326.2	15.9	123.1
301	ROANOKE-CAPP FEAR	2325.6	9.1	82.7
302	PEE DEE-Santee	5409.1	4.1	45.4
303	SAVANNAH-ST MARYS	5082.7	2.2	19.0
304	ST JOHNS-SUWANNEE	5320.1	2.9	56.1
305	SOUTHERN FLORIDA	3830.4	3.6	70.5
306	APALACHICOLA	5847.2	1.7	13.2
307	ALABAMA	11309.1	0.3	8.2
308	TOMBIGBEE	6014.0	1.0	22.0
309	PASCAGOULA-PEARL	2250.5	0.8	9.7
501	ALLEG-MONG	1619.6	4.0	41.9
502	UPPER OHIO	6009.8	2.2	96.5
504	KANAWHA	1262.9	1.2	51.4
505	LOWER OHIO	28964.6	1.6	11.6
507	CUMBERLAND	2654.1	2.3	60.3
601	UPPER TENNESSEE	12239.5	1.6	12.5
602	LOWER TENNESSEE	15561.8	1.3	11.9
801	MISS-ST FRANCIS	80604.9	0.8	1.3
802	MISS-YAZOO-QUACHITA	95482.2	0.7	1.5
803	MISS-IA CCAST-DELTA	98653.5	0.7	4.0
1101	WHITE	2605.6	0.0	0.1
1103	CIMARRON-ARKANSAS	4152.7	0.2	10.0
1104	LOWER ARKANSAS	4709.7	0.4	21.4
1105	CANADIAN	4123.0	0.3	4.9
1106	RED-WASHITA	5314.2	0.2	0.3
1107	LOWER RED	635.3	1.4	11.4
1201	SAVINE-NECHES	705.1	7.0	122.4
1202	TRINITY	816.1	11.7	63.2
1203	ERAZOS	784.8	10.1	34.6
1204	COLORADO-LLANO	909.8	5.5	54.0
1205	GUADALUPE-NECHES	1652.1	1.9	31.4
1302	UPPER RIO GRANDE	642.3	0.0	1.9
1303	RIO GRANDE-L PECOS	1285.9	0.0	0.4
1304	UPPER PECOS	200.0	0.2	0.2
1305	LOWER RIO GRANDE	1843.4	0.0	0.2

*ESTIMATED AVAILABLE SURFACE WATER FOR THE CRITICAL SUPPLY MONTH

Fig. 5.4. NCUA base-case 2000 water consumption and withdrawal by steam electric plants as a percentage of the estimated total surface supply for the critical supply month.

Table 5.5. 2020 water consumption and withdrawal
by steam electric plants

ASA#	ASA NAME	AVAILABLE WATER* (Mgd)	PERCENTAGE CONSUMED	PERCENTAGE WITHDRAWN
203	DELAWARE	3022.0	30.3	335.6
205	CHESAPEAKE BAY	5761.2	22.3	72.2
206	ECTCMAC	1326.2	28.6	143.8
301	ROANOKE-CAPE FEAR	2325.6	20.7	101.7
302	PEE DEE-SANTEF	5409.1	8.2	52.0
303	SAVANNAH-ST MARYS	5082.7	4.2	22.3
304	ST JOHNS-SUWANNEE	5320.1	7.0	62.8
305	SOUTHERN FLORIDA	3830.4	7.5	76.8
306	APALACHICOLA	5847.2	4.6	18.0
307	ALABAMA	11309.1	1.1	9.5
308	TOMIGBEE	6014.0	1.5	22.7
309	PASCAGOULA-PEARL	2250.5	4.3	15.5
501	ALLEG-MONG	1619.6	4.3	42.5
502	UPPER OHIO	6009.8	3.1	109.1
504	KANAWHA	1262.9	4.3	56.5
505	LOWER OHIO	28964.6	2.9	13.6
507	CUMBERLAND	2654.1	6.6	67.3
601	UPPER TENNESSEE	12239.5	3.5	15.6
602	LOWER TENNESSEE	15561.8	2.8	14.5
801	MISS-ST FRANCIS	80604.9	1.3	1.4
802	MISS-YAZOO-QUACHITA	95482.2	1.2	1.8
803	MISS-LA COAST-DELTA	98653.5	1.2	4.3
1101	WHITE	2605.6	0.0	0.1
1103	CIMARRON-ARKANSAS	4152.7	0.2	10.0
1104	LOWER ARKANSAS	4709.7	0.4	21.8
1105	CANALIAN	4123.0	0.3	4.9
1106	RED-WASHITA	5314.2	1.9	3.1
1107	LOWER RED	635.3	16.0	30.4
1201	SAFONE-NECHES	705.1	32.4	163.9
1202	TRINITY	816.1	19.7	76.4
1203	ERAZOS	784.8	15.7	43.7
1204	COLCADO-ILLINOIS	909.8	10.6	62.3
1205	GUADALUPE-NECHES	1652.1	7.6	40.8
1302	UPPER RIO GRANDE	642.3	0.0	4.8
1303	RIO GRANDE-L PECOS	1285.9	0.0	0.4
1304	UPPER PECOS	200.0	0.2	0.2
1305	LOWER RIO GRANDE	1843.4	0.0	1.9

*ESTIMATED AVAILABLE SURFACE WATER FOR THE CRITICAL SUPPLY MONTH

Fig. 5.5. NCUA base-case 2020 water consumption and withdrawal by steam electric plants as a percentage of the estimated total surface supply for the critical supply month.

Potomac and Delaware) may be experiencing water withdrawal in excess of actual stream flows. This, of course, indicates that water is being cycled through more than one plant and thus could pose water quality problems such as thermal loading and concentration of pollutants. Water withdrawal will increase at a slower rate beyond 1985 because it is assumed that new facilities will use cooling towers, which withdraw small amounts of water.

Water consumption problems become progressively greater after 1985. In 1975 and 1985, very little water is consumed except in Texas, where surface water is naturally scarce. By 2000, however, significant problems begin to appear in the Chesapeake Bay, Delaware, and Potomac River basins. Water consumption problems also become worse in Texas.

In 2020, 14 of 34 drainage basins will potentially experience water consumption problems using the 10% availability criterion. The most notable are those in the upper Ohio River basin, where energy development is expected to constitute a major water use. Except for the Ohio River Basin and Lower Red River of Arkansas, all other problem areas have the option of utilizing saltwater cooling. All ASAs may use dry cooling towers but dry towers cause lowered thermal efficiencies and result in a reduction of net power production. In the case of ocean cooling, losses will occur due to longer transmission distances to load centers and saline fouling of cooling equipment.

An alternative policy option is energy conservation either by limiting growth in water-scarce regions or by requiring greater efficiencies in end use of electrical energy. In some areas, such as along the Middle Atlantic coast or the Florida peninsula, conservation may be the prime alternative to avoid serious environmental consequences.

This analysis of water resource problems at the ASA level indicates some acute problem areas where water use exceeds reasonable estimates of availabilities and other areas where water use for energy is high enough to warrant more detailed analysis. One such area is the Ohio River basin.

5.5 Detailed Analysis of Water Availability for Energy Development in the Ohio River Basin Region

Our analysis of water availability problems associated with potential developments of energy in the Ohio River Basin is presented in this section. The maps and discussion presented in Sect. 5.4 indicate that water consumption at the ASA level does not become significant in the Ohio River region until 2020 and then only in the upper Ohio River region. Our county-level analysis based upon an allocation of 10% of the seven-day/ten-year low flow, however, indicates that water consumption for energy will exceed the 10% level as early as 1985 in selected tributaries of the Ohio; and by 2020, new capacity sited to meet projected demand could consume nearly 40% of the low flow upstream from the confluence of the Ohio and Wabash rivers. These conclusions are based upon the assumption of wet cooling options for all new plants (which is now required by EPA)

and that no new reservoirs are built to improve low flow beyond the number of reservoirs already proposed by the U.S. Army Corps of Engineers (some of those proposed have now been canceled). A more detailed explanation of the Ohio River basin study follows.

5.6 Analysis Results for Ohio Study⁶

Electricity demand figures for each state represented on the Ohio River Basin Commission (ORBC) were provided to ORNL's Regional Economic Analysis Group for spatial disaggregation to Bureau of Economic Analysis areas and state portions of Bureau of Economic Analysis areas by the Argonne National Laboratory (ANL). Electricity demand values for the state of Bureau of Economic Analysis areas were converted to estimates of needed generation capacity under the assumption of an August maximum base load situation and were mapped for the ORBC region. These values represent a worst-case situation in electricity demand and assume a 20% generation reserve margin for all utilities. Embedded in the calculations are estimates of technology mixes by state and estimates of water consumption according to the type of power plant and cooling option.

In addition to the maximum base load analysis, calculations of low flow for the Ohio River and its major tributaries were developed using ORNL's water analysis system (WAS) model. These values were adjusted along the main stem of the Ohio River to reflect the augmentation by reservoirs, as calculated by the U.S. Army Corps of Engineers. The flow rates do not necessarily reflect the actual present flows along the main channel but rather what is theoretically possible if regulation conditions are ideal and if all proposed reservoirs in the basin are constructed.

For our analysis, the ORBC designated that only 10% of the seven-day/ten-year low flow should be considered available for energy production. Consequently, only 10% of the low flow as calculated by the WAS model or as provided by the Corps is shown in Fig. 5.6. The flow rates are indicated by county shading.

Using the information on demand and water availability, members of the ORNL Resource Analysis Group employed a spatial analysis approach to locate energy facility sites to satisfy electricity demand for each forecast year (1985, 2000, 2020). Counties in which plants would be difficult to site were eliminated from the allocation process. For example, counties were excluded from siting consideration if they were in a seismic III risk zone⁷ (which would restrict nuclear plants) and/or if they were designated an air quality maintenance area (which would inhibit the siting of fossil-fueled plants). Only streams capable of sustaining at least one 1000-MWe fossil-fueled plant [$0.5 \text{ m}^3/\text{sec}$ (18 cfs)] were considered.

Starting with the tributaries in the upper Ohio River watershed (the Allegheny and Monongahela rivers), new capacity was allocated to surrounding demand centers, using four different power transmission constraints. The ORBC requested that we examine the possibility of satisfying surrounding demand out to 80, 160, and 240 km (50, 100, and 150 miles) and only within the East Central Area Reliability Council Region (ECAR) with Michigan deleted.

Fig. 5.6. Water availability for energy development. 10% of seven-day-ten-year low flow.

Power plants were sited along the Ohio main stem and tributaries, and a cumulative accounting system was used to keep track of water consumed. No site allocation was made if the running account of stream flow was not sufficient to satisfy the consumptive needs of one plant (at least 0.5 m³/sec) or the county was excluded from consideration because of seismicity, air quality, or other siting constraints. When water consumption exceeded the 10% guidelines, the county stream reach was designated as a problem area. All required capacity was sited.

Figures 5.7-5.14 illustrate the water consumption problems resulting from our siting analysis to the year 2020. The 1985 sited capacity is based upon Federal Power Commission data on proposed and existing power plants in the ECAR region. In 1985, our analysis indicates that the utilities in ECAR will have approximately a 27% reserve in generation capacity (based upon a 5.5% growth rate in electricity demand) above maximum base load demand. This is quickly lost, however, by growth in electrical demand by the year 2000. Note that new capacity sited to meet forecasted demand in 2000 exceeds the 10% water use criterion along most of the Ohio main stem to the confluence of the Ohio with the Cumberland and Tennessee rivers. By 2020, water consumption approaches 40% of the low flow.

Several caveats should be considered along with the results of this analysis. First, maximum base load demand coinciding with a low flow situation does not occur frequently or uniformly over the entire area considered in the analysis. Dry cooling towers represent an existing technology that could eliminate many water consumption problems and at the same time provide more flexibility in locating new energy facility sites if they were used in the basin. Other countermeasures such as better reservoir regulation, more reservoir construction (an increasingly less feasible option), or more water conservation are also possible alternatives. We have begun preliminary analysis of the possibility of using groundwater for cooling, and preliminary indications are favorable.

Finally, our analysis of the potential water availability problems in the Ohio River region illustrates that one solution to environmental problems (the use of closed-cycle cooling to avoid thermal buildup in streams) may in the long run create other problems. Our analysis used water consumption figures characteristic of present technology. Even with a 20% error, water availability will become increasingly short in selected areas. This reinforces the argument that solutions to the energy problem will be complex because the problem is complex. Nevertheless, it would appear that the "free lunch," as far as water is concerned, is about over even in the humid eastern United States.

5.7 Recommendations for Further Research

This section has focused on water quantity issues associated with energy development, but there is an equal need for analysis of impacts on water quality. It is difficult to discuss critical levels of water

ORNL DWG 78;11846A

Fig. 5.7. 1985 proposed generating capacity, Ohio River basin and ECAR region. Base-load capacity planned by utilities.

Fig. 5.8. 1985 projected water consumption by energy facilities in Ohio River basin. By percentage of seven-day-ten-year low flow consumed by energy facilities.

ORNL DWG 78-11850A

Fig. 5.9. 2000 new capacity siting pattern. Base-load capacity sited to meet increase in electrical demand from 1985 to 2000. In megawatts electric.

ORNL DWG 78-1184/A

Fig. 5.10. 2000 total generating capacity, Ohio River basin and ECAR region. Base-load capacity needed to meet electrical demand for average week in August.

Fig. 5.11. 2000 projected water consumption by energy facilities in Ohio River basin. By percentage of seven-day-ten-year low flow consumed by energy facilities.

ORNL DWG 78-11849A

Fig. 5.12. 2020 new capacity siting pattern. Base-load capacity sited to meet increase in electrical demand from 2000 to 2020. In megawatts electric.

Fig. 5.13. 2020 total generating capacity, Ohio River basin and ECAR region. Base-load capacity needed to meet electrical demand for average week in August.

Fig. 5.14. 2020 projected water consumption by energy facilities in Ohio River basin. By percentage of seven-day-ten-year low flow consumed by energy facilities.

withdrawal without a thorough understanding of the heat loadings and temperature rises associated with the facilities on a given stream. Water consumption also has the potential of affecting water quality. Even if no additional pollutants are discharged, the evaporation of pure water can cause concentration of pollutants already in the stream and a concomitant deterioration of water quality. A thorough analysis of these quality issues might identify additional problem areas quite distinct from those identified on the basis of quantity alone.

We recognize the need for further analysis of these impacts as well as those caused by direct discharges from the facilities (e.g., acid mine drainage). These topics have not received adequate attention due to limited manpower and time, but they will be the focus of greater effort in the future. Our experience thus far indicates that the major obstacle to a thorough analysis will be the poor quality of data on background levels of pollutants already in the streams.

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6. IMPACTS ON SURFACE WATER QUALITY

6.1 Summary

Streams and rivers of the Southeast tend to be relatively acidic and low in dissolved solids compared with streams in other parts of the country. The most important coal-related impacts on surface water quality are likely to result from the erosion, sedimentation, and mine drainage associated with coal mining. Effluent control regulations should reduce discharges from other coal facilities to levels which will prevent deleterious effects on water quality, but at the possible cost of creating additional waste disposal problems.

6.2 Introduction

Point-source discharges associated with energy production will be subject to the effluent limitations of the Federal Water Pollution Control Act and Amendments. While the point-source effluents will presumably be controlled to avoid deleterious effects on water quality, as the magnitude of coal use increases, the amount of potentially harmful residuals, concentrated at specific locations, will also increase. Effluent control then becomes part of an integrated solid, liquid, and gaseous waste management problem, and should be studied as such.

Nonpoint sources of effluents are more difficult to control than those from point sources. Even when the provisions of the Surface Mining Control and Reclamation Act are met, storm flows in surface-mined watersheds could carry suspended sediment loads 100 times greater than similar flows in undisturbed basins. To a large extent, acid mine drainage reflects an area's geology and past mining history. Where pyritic materials occur in or near coal seams, special measures will be required to control acid discharges from active mines, while inactive or abandoned sites may continue to leak acids to streams.

In assessing water quality impacts from coal utilization associated with NCUA scenarios, it is useful to distinguish between the point sources and nonpoint sources of effluents. According to the Federal Water Pollution Control Act Amendments of 1972,¹ a point source is "... any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged" [Sect. 502(14)]. A nonpoint source is a generalized discharge of waste into a water body. It cannot be located as to specific source. We divide our discussion of water-quality impacts into sections that deal separately with point and nonpoint sources. We also include a brief synopsis of general water quality conditions in the southeastern United States as a background to our assessment.

6.3 General Water Quality Conditions in the South

Natural rivers and streams of the southern United States tend to be relatively acidic and low in dissolved solids and nutrients compared with streams in other parts of the country. This contrast is shown in maps taken from the 1976 Annual Report of the Council on Environmental Quality (Fig. 6.1).² Nitrogen concentrations (Map A) and phosphorus concentrations (Map B) are generally low in southern waters. These low levels reflect the high rainfall and high stream-flow rates and the relatively old, highly leached character of the landscape. The leached materials in this region tend to be naturally acidic (Map C). Total dissolved solids (Map D) show the most dramatic contrast between conditions in the South and those in other parts of the country (with the exception of the Pacific Northwest). The above patterns show the strong influence of erosion and the interactions between soil and water. The geologically mature, undisturbed landscape of the Southeast is less prone to erosion; it is largely forested, and has well-developed drainage patterns. However, because of the relatively low buffering capacity of many watersheds in the Southeast and the relatively low dissolved solids content of streams in undisturbed basins, the potential for impacts from land disturbance is great.

6.4 Point-Source Discharges

There are two broad subcategories of point sources associated with energy development: those connected with energy production, such as coal conversion, coal beneficiation, or coal combustion plants, and those associated with secondary effects, such as industrial or municipal effluents that result from the availability of energy. Assessment of the impacts of effluent loading associated with energy facilities is a complex problem that cannot yet be addressed in a fully satisfactory manner. It is possible to derive estimates of regional or statewide loadings of selected pollutants for a given NCUA scenario by taking the product of the effluent loading per unit of energy produced and the total energy production rate for a given area. However, it is not clear whether the resulting numbers are very useful, for several reasons. First, the amount of material actually released to waterways depends on processes and treatment levels. In some cases, the standards for releases have not been set or are expected to change; hence, loading levels will also be modified.

Second, and perhaps more important, the relationships between loading rates and expected concentrations in stream flow below the discharge point (spatial and temporal) are not known for most nonconservative or heavy-metal pollutants. Finally, and most significantly, the Federal Water Pollution Control Act and Amendments has adopted the policy of effluent limitation. This implies that the magnitude of point-source inputs is legislatively mandated to decrease, and that whatever is required (regardless of cost) to achieve that goal will be done. Therefore, the logical inference is that point-source effluents from energy production will be controlled so as not to have a deleterious effect on water quality.

A. Levels of total nitrogen: 1975. Annual mean values in parts per million.

B. Levels of total phosphorus: 1975. Annual mean values in parts per million.

Fig. 6.1. General Water quality conditions in the United States. Source: CEQ (1976). Note contrast between Southeast and other parts of the country.

Alaska, Hawaii, and Puerto Rico not drawn to scale

C. pH: 1975. Annual mean values
in standard pH units.

Alaska, Hawaii, and Puerto Rico not drawn to scale

D. Dissolved solids: 1975. Annual mean values
in parts per million.

Fig. 6.1 (continued)

It would be easy to end the discussion of point-source inputs here. However, it is an obvious fact that as the magnitude of coal utilization increases, the magnitude of potentially harmful residuals, concentrated at specific locations, will also increase. Thus, even if it is technically and economically feasible to remove wastes from point-source effluents before they are discharged, it can be done only at the cost of creating solid or gaseous wastes which must then be managed. In effect, residues removed from point sources become potential nonpoint-source pollutants. In order to confidently assess the integrated liquid, solid, and gaseous waste management problem associated with energy facilities, we need empirical data from representative sites throughout the Southeast. Ideally, the data would span the time period before and after installation of a facility and would be comprehensive enough to allow development of relationships between loading rates and the resulting spatial and temporal patterns of concentrations of selected pollutants. At present, such data apparently do not exist, at least for energy facilities. Although the STORET system contains instantaneous observations of some pollutants, it lacks a sufficient density of data to allow large-scale characterization of pollutant fluxes on a seasonal or annual basis. The development and summarization of such data should be a high-priority item.

6.5 Nonpoint Source Discharges

Effluents from nonpoint sources are inherently more difficult to control than those from point sources and present some risk to water quality even when regulated. These problem effluents occur where weather, especially precipitation, plays a major role in contaminant transport. In the coal fuel cycle, they will arise as leachates from coal handling facilities and waste disposal areas and as a result of drainage and erosion in mining areas. With higher coal production and increased coal use, leaching from waste disposal areas and coal handling facilities may cause effects observable at regional scales. At present, information about the future distribution and quantities of these effluents is insufficient to support a regional assessment. However, the Appalachian coal fields have a long, documented history of water quality problems related to coal mining, and the NCUA base case includes continued or expanded mining in large portions of this region. Our discussion will therefore focus on the potential impacts of the predicted mining.

6.6 Effects of Coal Mining

Coal mining affects water quality through the chemical changes caused by mine drainage and the physical changes of siltation and sedimentation resulting from erosion. Drainage has been associated with all types of coal mines. In its interim report on loading functions for assessment of water pollution from nonpoint sources, the EPA³ has designated four categories of mines, listed here in order of decreasing acid-drainage production per unit mine: active underground, inactive underground, active surface, inactive surface. The amount of drainage and its acid content from different mines of these types depends upon size of the mine,

acidity of associated rock material, neutralization capacity of the background alkalinity in the area, and other factors. The Appalachian Regional Commission⁴ found that the geographic extent of water quality problems associated with mine drainage corresponded closely to areas of present and historic mining, but that acid mine drainage, which most seriously affects water use, occurred over a more limited range determined by the presence of pyritic materials. The ARC concluded that the geographic extent of areas presently affected by acid mine drainage is essentially the same as that affected 40-50 years ago and that the future extent of acid mine drainage can, in general, be predicted from its present distribution, although all mining does have some potential for altering water chemistry through drainage.

The greatest single water quality problem associated with surface mining is siltation of streams. This problem was singled out by the Corps of Engineers in hearings before Congress in February 1977 and has been noted by many researchers (e.g., Minear and Tschantz⁵). The silt load carried by streams scours aquatic life from the surface of rocks, eliminates habitats of many organisms, destroys water appearance, and degrades the capacity of the stream to support life. Duration of the siltation problem is variable and cannot be generalized at present. Results reported by Minear and Tschantz⁵ indicate that sediment concentrations in surface-mined basins increased by a factor of 100 to 1000 or more over concentrations in undisturbed basins in similar settings in Appalachia. The highest sediment concentrations are associated with storm runoff, begin immediately after stripping commences, and may persist for many years following mining. Furthermore, although diversity of the aquatic community increases as silt load decreases following mining, the species composition of the community is not the same as in premining streams.

6.7 The NCUA Base Case 1974-1985

The southeastern counties in which the NCUA base case indicates coal mining through 1985 are outlined in Fig. 6.2. The coal-producing counties have been divided into four classes: those with low levels of mining predicted and no current mine drainage problems indicated by available information on water quality (LM, NOMD); those with high levels of mining predicted and no reported mine drainage problems (HM, NOMD); those with low mining predicted and current mine drainage problems (LM, MD); and those with high levels of mining predicted and current mine drainage problems (HM, MD). Low mining levels (LM) are defined as cumulative production totals of less than 0.1 quad of coal for the 1974-1985 period.

Within the currently affected counties, the proportion of streams receiving mine drainage varies, depending principally upon mine locations and mining practices. The occurrence of acid drainage in the mine dis-

Fig. 6.2. Water quality and mining levels, NCUA base case 1974-1985. Geographic distribution of existing mine drainage problems and projected levels of future mining. (LM: low levels of mining predicted; HM: high levels of mining predicted; MD: current mine drainage problems; NOMD: no current mine drainage problems.)

charges also varies, depending upon both mining practices and the distribution of pyritic materials. Table 6.1 illustrates these differences for eight river basins in the Southern Appalachian coal region, showing the percentage of stream miles within each basin receiving mine drainage and the percentage receiving acid mine drainage (AMD).

Table 6.1. Proportions of selected drainage basins affected by mine drainage, 1969 (from ARC⁴)

River basin	Stream miles receiving mine drainage (%)	Stream miles receiving acid mine drainage (%)
Monongahela	15.1	15.0
Little Kanawha	0.9	
Kanawha	7.6	0.8
Guyandotte	11.9	2.8
Big Sandy	7.8	
Kentucky	7.3	0.2
Cumberland	3.1	0.4
Tennessee-Black Warriors	0.4	0.2

Comparing Fig. 6.2 with Fig. 6.3 (erosion risk) reveals that almost all the counties in the low predicted mining, no current mine drainage problems (LM, NOMD) category are also counties which had very little or no coal production in 1974 ("NEW" mining classes in Fig. 6.3). The two largest clusters of such counties are in southern Alabama. To determine what effects might be observed under the NCUA base-case scenario, the projected mining levels for all Alabama counties with "old" and "new" mining in the four categories outlined in Fig. 6.2 have been summarized in Table 6.2. Mining levels at which mine drainage was detected in streams (HM, MD) are approximately ten times as high as the levels at which such drainage was not evident (LM, NMD). Projected levels of new mining are only one-tenth of the HM, NMD levels. This does not imply that no drainage occurs when mining levels are low. Rather, any mine discharges are quickly diluted or neutralized by the water bodies receiving them. Problem areas are thus confined to small streams and short stream reaches. Detectable mine drainage in the clusters of counties in southeastern and southwestern Alabama, for which new, low level mining has been projected, can be expected to be of this localized nature. Counties shown with high mining and no current mine drainage will continue to be mined at rates near their present levels. The potential for contamination is greater than in the new mining counties, but changes may still be quite local, and detection may depend on intensity of monitoring.

Fig. 6.3. Erosion risk, NCUA base case 1974-1985. Geographic distribution of the interaction of existing and projected new mining and the hydrologic potential for erosion and sediment yield. (OLD: old mining classes; NEW: new mining classes; LOW ER: low erosion risk; HIGH ER: high erosion risk.)

Table 6.2. Mining levels — Alabama 1974-1985

Category	No. of counties	Avg. prod. 1974 (quads)	Avg. prod. 1980 (quads)	Avg. prod. 1985 (quads)
OLD-HM, MD	2	0.1895	0.1842	0.1936
OLD-HM, NMD	8	0.0187	0.0182	0.0189
OLD-LM, NMD	1	0.0022	0.0022	0.0022
NEW-LM, NMD	10	0.000	0.000	0.0012

The other states with mining histories for which the NCUA projects additional mining are West Virginia, Kentucky, Tennessee, and Virginia. In all of these states except Virginia, the relationship between 1974 mining levels and observed mine drainage problems is not as direct as in Alabama. Table 6.3 lists, by state, the number of counties and their average 1974 production in each mining level and mine drainage class. "New" counties with no reported production in 1974 but with projected 1980 or 1985 production are included, because some do have mine drainage problems.

Table 6.3. Average 1974 coal production^a and number of counties (in parentheses)

Class	West Virginia	Kentucky	Tennessee	Virginia
OLD-HM, MD	0.1074 (22)	0.1307 (17)	0.0295 (6)	0.1753 (5)
OLD-HM, NMD	0.0434 (4)	0.1199 (12)	0.0112 (1)	0.0495 (1)
OLD-LM, MD	0.0016 (6)	0.0044 (4)	0.0015 (2)	(0)
OLD-LM, NMD	(0)	0.0037 (10)	0.0010 (6)	0.0002 (1)
NEW-LM, MD	0.00 (3)	0.0 (1)	0.0 (1)	(0)
NEW-LM, NMD	0.00 (6)	0.0 (4)	0.0 (3)	0.0 (2)

^aIn quads (1 quad = 10¹⁵ Btu).

Besides having counties with mine drainage and no active mines, these three states (West Virginia, Kentucky, and Tennessee) show high production counties with no reported drainage problems and low production counties with current problems. This distribution of problems occurs, in large part, because these states have a history of acid mine drainage problems. In areas where conditions favor the formation of acid mine drainage, such as the Guyandotte, Kanawha, and Monongahela river basins in West Virginia, the Cumberland River basin in Tennessee, and the Kentucky and Cumberland basins in Kentucky, inactive and abandoned mines can continue to leak acid for decades. Thus, in these areas, mine drainage problems are related to the past history of mining as well as to current levels of activity. Additional mining will pose additional risks, since 74% of the high mining counties are known to have had AMD

occurrences. Special treatment both during and after mining will be required to meet the pH range of 6.0 to 9.0 specified by the regulations of the Surface Mining Control and Reclamation Act.⁶ However, current problems can also be expected to continue unless successful efforts are made to eliminate or treat drainage at old and abandoned sites.

6.8 Sedimentation

It is a fact that most sediment transport is associated with storm runoff. Furthermore, it is the storm runoff rather than the dry weather flow that is more difficult to control in surface-mined areas. Therefore, in attempting to assess how sediment production patterns would be expected to change in response to mining associated with the NCUA scenario, we combined projected mining activities with the geographic distribution of expected storm runoff response in the southeastern United States. As an index to storm runoff potential, and hence to sediment production problems, we chose to use the ratio of annual quick-flow volume to rainfall amount as defined by Woodruff and Hewlett.⁷ Their hydrologic response index gives a quantitative measure of the tendency for rapid or flashy storm response for a given area. We believe that it is reasonable to assume that a high response index indicates a high potential for severe sediment production in a surface-mined area. Thus, the basis of our assessment is a combination of Woodruff and Hewlett's map of hydrologic response for the eastern United States and the geographic distribution of existing and projected mining activity levels, evaluated county by county. We recognize that this approach does not explicitly consider such factors as mining practices, soil erodibility, or basin slope. However, many of the factors are implicit in the index. Furthermore, there is strong evidence (mentioned earlier) that any major surface disturbance, such as that associated with mining, will increase sediment yield by factors of 100 to 1000 over undisturbed conditions; hence, we believe that our technique will show those areas where serious problems are most likely to occur.

We attempted to gather sufficient data on sediment concentrations or loads to present regional patterns of existing conditions in the study area. We believed such patterns would be a valuable test of the viability of our technique for characterizing erosion yield potential. In reviewing data gathered from the STORET system for hundreds of sites, we found that adequate sediment data simply do not exist to permit a regional summary. A review of special studies conducted in east Tennessee by Minear et al.⁸ clearly demonstrates that mined watersheds produce much more sediment than undisturbed basins which lie in the same hydrologic response category. Even though there are warnings from researchers about the dangers of extrapolating or generalizing special study results to a regional scale, it seems evident that in the case of sediment production, the trends are undeniable.

The results of the analysis are presented in Fig. 6.3. For the sake of clear presentation, some lumping of parameters into categories has occurred. Mining activity has been divided between counties where new mining will occur (no production known in 1974) and counties where mining

will continue. The mining identifier in the legend is thus either OLD or NEW. The erosion risk has been derived from the map of Woodruff and Hewlett.⁷ Those counties where more than 16% of the annual precipitation occurs as quick flow have been classified as high erosion risk (HIGH ER) counties. Those areas where the hydrologic response index is less than 16% are designated low erosion risk (LOW ER) for this analysis. Thus, a county with new mining after 1974 and high erosion risk would be identified with the shading denoted as NEW, HIGH ER in the legend at the top right of Fig. 6.3. Generally, the shading gets darker as the potential for high impact relative to existing conditions increases. Therefore, even though the sediment loads in category OLD, HIGH ER may exceed those in the NEW, LOW ER grouping, the relative potential impact is expected to be greater in the latter category. This is because past loads in an undisturbed basin would be very low compared with those in a basin which had already been disturbed.

When Fig. 6.3 is examined carefully, it appears that the brunt of the new erosion and sedimentation effects resulting from following the NCUA scenario to 1985 will occur in Alabama. In particular, the counties in the southeastern and southwestern part of the state show a potential for dramatic increases in sediment loading of streams. Even though the erosion risk index is low, we can expect significant potential increases in those streams that are impacted. In the north central part of the state, loads would be expected to remain relatively high because of high erosion risk. In those few water quality stations in Alabama which had accessible data, the expectations noted above were qualitatively supported. However, as noted earlier, data were not sufficient to establish quantitative relationships.

States other than Alabama will probably experience minor growth in the total number of impacted streams. One county in West Virginia (Doddridge) stands out as an area of projected new mining and high erosion risk. If our assumptions are valid, this county shows the highest potential for increases in sediment production of all of the areas examined.

6.9 Effect of the Surface Mining Control and Reclamation Act

It should be noted that the Surface Mining Control and Reclamation (SMCR) Act⁶ sets forth sediment discharge standards that should have a major effect in reducing the amount of potential erosion from a disturbed area. All surface and underground mining operations, including construction and maintenance of roads, surface work areas, and operating facilities, must not result in suspended solids concentrations greater than 70 ppm for single events or 35 ppm as a 30-day (consecutive flow days) average. McElroy et al.³ used data from USGS hydrologic benchmark basins to assess background suspended sediment concentrations in streams in undisturbed basins in the United States. In the southeastern region, concentrations range from 5 to 20 ppm for completely undisturbed basins. However, the U.S. Geological Survey has determined that most streams in the southeastern United States have mean annual suspended sediment concentrations that lie either in the range 0-280 ppm or 280-2000 ppm. Thus, for

situations covered by the SMCR Act, the resulting suspended solids concentrations from mined areas should lie well within the ranges expected in nonmined basins. There is a provision in the SMCR Act, however, that removes the allowed limits on suspended sediment concentrations in some situations. When a storm occurs that exceeds the 10-year, 24-hr precipitation event, there are no regulatory controls on suspended sediment concentrations in waters from mined areas. Data presented by Piest⁹ show that 10%-20% of the average annual sediment yield from small (less than 10 sq miles) basins results from large storms. Large storms are defined as those with a recurrence interval of two or more years. Since it is reasonable to assume that the 10-year, 24-hr precipitation event will usually result in stream-flow events with a recurrence interval greater than two years, it is also reasonable to assume that the exceptions to the SMCR Act will allow less than about 10% of the total potential sediment load to pass. If one assumes that the potential load for a disturbed area is 100 to 1000 times that of natural background,⁵ then the unregulated storms could result in up to a 100-fold increase in annual sediment yield for a disturbed basin, compared with pristine conditions. This would thus result in average concentrations of less than about 2000 ppm, which is in the range of sediment loading from basins with other types of land use.

6.10 Research needs

An extension of the hydrologic response index analysis to cover the entire southeastern part of the United States is needed. It should be coupled to sediment-yield studies to allow correlations to be established among the response index, mining practices, and sediment concentrations. Studies are also needed to provide an in-depth examination of the consequences of the Surface Mining Control and Reclamation Act on resulting water quality in stream flow from mined areas. In particular, the exemptions for the 10-year, 24-hour precipitation event deserve further consideration for specific situations.

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7. REGIONAL ECOLOGICAL IMPACTS

7.1 Summary

This analysis was performed (1) to evaluate the ecological impacts of increased coal utilization on the southern region as a complete system and (2) to key on some critical aspects of basic ecological processes and parameters within the region. The preliminary major findings are summarized below.

- Coal mining impacts will affect six of the twelve major ecological regions of the South. Some impacts related to coal use, such as waste disposal, will be localized near the point of use. Others, such as those caused by water consumption, will affect whole regions.
- Due to the increase in coal utilization by power generation facilities, a potential confrontation exists between resultant air pollution and fiber (softwood) and food (predominantly soybeans) production.

The counties containing strippable coal reserves occupy nearly 80 million acres of land. Of this, 13.2% is agricultural, 21.7% is in grazing systems, and 58.8% is forestland. Thus, again there is a potential conflict between food and fiber production and coal utilization.

Of the 219 counties in the southern United States which have strippable or deep mine coal reserves, 70% contain potential habitat for threatened or endangered mammal or bird species.

Preliminary studies of the effects of perturbations, such as an increase in the concentration of pollutants, on the long-term dynamics of forest growth and succession at the community level indicate a potential for change in the fundamental character of the growth and succession process and for alteration of the quasi-steady-state species composition.

7.2 Introduction

As discussed in the introduction to this report, this section is not intended to be a complete, integrated environmental assessment of increased coal utilization in the South. Rather, it is an attempt to identify and discuss a number of key ecological issues in the southern region. Consequently, this analysis of regional ecological impacts is divided into three main subsections. The first subsection is concerned with an ecosystem characterization of the predominant ecoregions of the southern United States. The discussion concludes with a description of the impacts that may be expected from the coal fuel cycle on the particular ecoregion. The next subsection is a regional overview of ecological problems and concentrates on possible impacts from sulfur dioxide and

strip mining-land use conflicts. The third subsection is concerned with two specific ecological disturbances arising from the increased use of coal: the impacts of coal extraction on sensitive animal species and the problem of assessing long-term pollutant impacts on forest dynamics. The increasing concentration of atmospheric CO₂ is discussed in Appendix F.

7.3 Ecosystem Characterization

The ORNL southern region extends from the topographically dissected Appalachian Mountains to the sandy flats and marshes of Florida and from the rich forests of the Smoky Mountains to the Chihuahuan Desert of western Texas. The area is one of great ecological variety, generally high (except for the western sections of Texas and Oklahoma) but varied productivity, and abundant resources. Bailey's¹ map, "Ecoregions of the United States," is a useful framework for organizing facts and judgments about terrain, ecosystems, and some of the more striking ways in which ecological impacts might differ from place to place. This map provides a preliminary stratification into provinces, with most provinces subdivided into sections of more or less homogeneous ecological character and potential.

Figure 7.1 shows Bailey's¹ ecoregions for the southern United States. The regions shown are all at the province level except for the mixed mesophytic, Appalachian oak forest, and oak-hickory forest categories, which are sectional divisions of Bailey's eastern deciduous forest province, and the southern forest and southern mixed floodplain classes, which are sections of the outer Coastal Plain forest province. The major characteristics of each of the ecoregions mapped in Fig. 7.1 are discussed below.

The Tropical (Everglades) Province comprises the southernmost portion of the Florida peninsula. The area is very flat and lies only a few feet above mean soil level. Soils of the province are primarily inceptisols, entisols, and histosols, all relatively poorly drained and often highly organic.

Vegetation is mostly Everglades swamp species, with mangrove along the Gulf Coast, some cypress savanna, southern Coastal Plain forest, and palmetto prairie species and, along the Atlantic Coast north of Miami, sand pine scrub.

Wildlife species abound in the Everglades National Park. Both the flora and fauna of this area contain many threatened and rare species, and conservation is a major requirement. Land development has taken place primarily along the southeastern Florida coast, where the entire coastline is either "strip development" or urban-suburban development. Dade and Broward counties average over 250 persons per square mile despite the fact that the majority of the land area of these counties is forestland or swampland. Truck farming (e.g., tomato farming) and other specialized uses also compete for land.

Fig. 7.1. County ecoregion classification (after Bailey¹).

The Chihuahuan Desert occupies the majority of western Texas. Most of the province was severely overgrazed in the last part of the 19th century. It has exhibited slow to little recovery (vegetational succession) and still suffers from widespread wind-blown erosion. The region is relatively sparsely settled (except around El Paso) and therefore does not receive much culturally derived pollution.

The Short Grass Prairie province covers most of the Texas and Oklahoma panhandles. This region has been severely overgrazed in the past and was the heart of the "Dustbowl" of the 1930s. Irrigation has converted a large percentage of the land to high-yield, industrialized agricultural use. Primary crops include cotton, corn, sorghum, and wheat.

The southern portion of the Tall Grass Prairie extends down into eastern Oklahoma. The majority of this province is either under cultivation, primarily for small grains, or in grazing systems such as pastureland or rangeland.

The Prairie Brushland province lies immediately east of the Chihuahuan Desert. Some dry-land wheat and irrigated wheat are grown in the northern and central sections, while both corn and sorghum are grown in the northern and southern sections. A significant proportion of the Texas citrus crop is grown in the southern section.

The Prairie Parkland province is important for rangeland and agricultural land. Two major coal deposits are found within this region: the Western Interior coal region, which enters from the north into eastern Oklahoma and western Arkansas, and the Texas Gulf coal region, which is primarily in Texas, but has some deposits in extreme western Louisiana. Most of the commercially important coal of the Western Interior region is in thin seams so that current mining is by the stripping of outcrop coal. Most of the coal is used for steam-electric generating plants where little preparation is required.

All of the identified coal reserves of the Texas Gulf region are lignite. All current production is strip-mined north of the Colorado River, where up to 180 ft of overburden is removed. This production is captive and includes coal for steam-electric plants and activated carbon. Because it is relatively uneconomical to transport bulky lignite considerable distances, use of the coal for conversion or combustion near its source can be expected.

The Southern Forest section occupies a comparatively narrow belt with long growing seasons. The mostly flat topography is underlaid by Tertiary and Quaternary sedimentary formations. Soils are highly varied and generally not very fertile, but when properly treated (fertilized, drained, and sometimes irrigated), they are capable of high rates of production. Climate is highly favorable throughout this area, and a variety of specialty crops is grown.

Large commercial forests of the area are primarily pine (locally termed "piney woods"). Because so much of the section is low or of poor local drainage, slash pine and other species tolerant of poor aeration are widespread. Longleaf pine ranges from moist to dry sandhill areas, where fire history has favored its regeneration.

Other forests consist of beech, sweetgum, and magnolia, in mixtures with pine and/or oak. In a narrow belt along the coast, the evergreen live oak adds to the distinctive appearance of both wild and cultivated vegetation. Laurel oak and the semievergreen water oak extend to or beyond the inland limits of the section, especially in the moist lowlands. In many areas, hardwood species are considered more a nuisance to be overcome through forest management practices (for pine) than an asset. In bottomlands, hardwood production is excellent. Wildlife management is an important consideration throughout the area.

The Southern Floodplain Forest section extends through the Mississippi embayment of the Coastal Plain from the Louisiana Delta to lowlands around Cairo, Illinois. Throughout this area, soils are mostly of recent origin and tend to be highly organic. For several centuries, this area has received the deposition of fine textured silts, clays, and organic matter from the upper Midwest. Consequently, soils are generally fertile and productive.

The native vegetation of southern floodplain forests consists mainly of lowland oaks, cypress, and gums. These are species-rich forests of high productivity. Although some of the area is covered by swampland, much of the land has been cleared and drained for cotton, soybeans, sugarcane, and feed grain production during the past two decades.

Swamp hardwood species of great economic value as well as bald cypress, Spanish moss, and a rich variety of animal life make these lowland forests famous as national assets. Wildlife reservations and many ecologically important areas, which are not formally designated for these purposes or legally protected in other ways, are of national significance as refuges for game birds and for an abundance of nongame wildlife.

The Southeastern Mixed Forest is a broad province, not yet divided into sections by Bailey.¹ A transitional or mosaic pattern combines some of the features noted above with others more typical of the central core of deciduous forest. This is the classical oak-hickory-pine forest region of the southeast and midsouth. The soils are mostly ultisols (red and yellow lateritics) of relatively low intrinsic fertility. Surface landforms range from high hills (bordering on low mountains) along the inland border of the province to flat plains nearer the coast.

The vegetation of the unit is typically a mixture of oak, hickory, and pine. Along the northern border, hardwood forests are more common, while toward the coast, pine predominates. Much of this region is especially valuable to commercial forest enterprises, which have large land holdings throughout this area. Loblolly and shortleaf pines are the principal species grown in the Oklahoma, Arkansas, Texas, and Louisiana portions of the province. Loblolly, shortleaf, longleaf, and slash pines are the major commercial species grown in the section from Alabama through Virginia.

The Mixed Mesophytic Forest section of the Eastern Deciduous Forest was formerly interpreted as an area in the Cumberland Mountains and Cumberland Plateau where numerous trees persisted in place despite the climatic changes that must have accompanied the glaciations. However,

new evidence for species migrations suggests that the famous floristic richness of this area (and of the higher Appalachians further east) instead reflects the highlands' diversity of habitats and their location as a crossroads for species invading from the Southeast and the Southwest within the last 10,000 years.

The Cumberland and, northward, Allegheny areas are the locations of most of the Appalachian coals, mostly in gently dipping beds layered between thick (locally pyritic) shales and more or less massive sandstones which hold up the bold cliffs and other topographic features of these regions. Soils of the area have weakly differentiated horizons showing alternation of parent materials. Generally these are only poor to fair for agricultural purposes. Forests are rich in species, including maples, buckeye, beech, tulip tree, oaks, hickories, and basswood. Prior to the chestnut blight, chestnut was important throughout the area. From the point of view of commercial timber, this area produces far below its potential. The forests have, for the most part, been repeatedly and severely highgraded, leaving genetically and commercially inferior trees over much of the area. Wildlife production is far below potential due to poaching and relatively little management.

The Appalachian Oak Forest section lies east of the Mixed Mesophytic section. The Appalachian range, containing the Blue Ridge and the Smoky Mountains, displays local topographic relief up to approximately 3280 ft, with elevations reaching nearly 6560 ft. This is an area of vast scenic beauty, with long vistas, beautifully sculpted valleys, clear mountain streams, waterfalls, and rich upland forests.

On the higher elevations, forests of spruce and fir occur. These grade with decreasing elevation into hemlock-hardwood forests and then into tulip poplar, oak-hickory, mixed, and pine forests. Finally, at lower elevations, forests of tulip poplar, sycamore (on floodplains), and many additional deciduous species predominate.

The soils of the area are generally shallow, rocky, and poor for agriculture. Rapid erosion of hill slope farms led to reduction in fertility and eventually to abandonment of the land or to a shift to small pastures. Second-growth (pine) forest became established over much of the area (this includes much white pine, especially on the Blue Ridge above 2625 ft). Only within the past two decades has the forest recovered from exploitive logging near the turn of the century. Extensive national forests offer prospects for a leading forest-products area in addition to intensive wilderness recreation use. Fish and wildlife are abundant and commercially important throughout the area.

Notable exceptions to the rugged mountainous terrain of the Blue Ridge Division are found in the "Valley and Ridge" physical division of the province lying along the section's northwestern belt. This area, from the valleys of the Clinch, Powell, Holston, and Tennessee rivers to Virginia's Shenandoah River, is characterized by thrust-fault-originated topography consisting of a series of washboard-like alternating ridges and valleys. The limestone valleys tend to be fertile, and those underlain by shale are used mostly for pasture and small fields (gardens).

The Oak-Hickory Forest section covers a wide area of the interior uplands west of the Cumberland Plateau. Soils are residual and generally only moderately fertile. Oak and hickory forest systems are typical of this area, especially on many of the drier sites. On the moister slopes and on valley soils, mesophytic communities are so important that Braun² used the term "Western Mesophytic" for the section east of the Mississippi. Commercially valuable hardwood timber is produced throughout the area. In the Cumberland River valley and other tributary valleys of the Mississippi bottomland, forests of gum, sycamore, silver maple, elm, and ash are highly productive. Wildlife is important in the area.

Some portions of the region (in western Kentucky) are underlaid by bituminous coal-bearing strata amenable to surface mining and also contain oil and gas deposits. Land reclamation following mining on such gently sloping topography is much more economical than on the steep slopes further east. The western Kentucky coal region is geologically and topographically akin to its counterparts in southern Illinois.

Table 7.1 enumerates, for the twelve regions just described, the ecological impacts which may result from coal development. This table is intended to provide, by ecological region, an overview of the spatial distributions and probable intensities of coal-related impacts. It does not represent a separate quantitative ecological assessment, but is rather a preliminary, qualitative synthesis of potential impacts on the ecological characteristics of the ecoregions (including natural resources, land use, and agricultural patterns). Much of the information on which it is based is presented in other sections of this report. Specific NCUA projections which were considered include coal mining locations and rates, siting of electrical generation facilities, water consumption rates, and air and surface water quality analyses. Many of the ecosystem characteristics with which the coal-related activities interact are presented in the preceding ecoregion characterizations. In areas where more complete NCUA analyses appear elsewhere in this report, Table 7.1 represents a summary. In other areas not treated elsewhere, Table 7.1 shows a qualitative analysis based on the linkages between known ecosystem characteristics and responses to stresses, coal fuel cycle effluents and requirements, and the NCUA coal utilization projections.

In Table 7.1, ecological impacts which would be expected to involve major cost, risk, or adjustment are rated A. Either broad extent or local severity can be expected for problems rated B. A rating of C implies that the potential impact requires continuing attention and should not be ignored in a picture of total ecological cost for coal. Some of the ratings might be upgraded to A or B if the impact were fully evaluated. The rating of D is applied to impacts of relatively limited occurrence, though not necessarily unimportant in the localities affected. Blank entries are not necessarily unimportant, but are given lower priority reflecting a focus on matters that seem more crucial for coal decisions.

The ecological impacts indicated in Table 7.1 do not include other synergistic effects of man's activities with the expanded use of coal. For example, the coastal zone is shared by 11 of the 16 states in this

Table 7.1. A preliminary analysis of ecological impacts associated with coal mining and use

[illegible]

study. This zone has long been identified by regional planners as one of the critical areas for future growth in the South. As the population of these areas expands, the stresses on the natural systems become more severe. Coal-related activities could include coastal siting as well as expanding barge transportation and docking for coal. The bulky nature of coal, with storage in open piles subject to rain and runoff, suggests that many coastal land and water areas of premium value for private and public use may be threatened physically or subjected to extreme competition among incompatible uses.

7.4 Energy Use and the Environment

As stated by Cook,³ "Ecological pollution may be the ultimate social cost of energy use, the cost that threatens the extinction of a society." In the United States, the direct social costs of energy use will outweigh the direct social costs of energy production, because more people are affected by the consequences of energy use than by the consequences of production. For example, most of the fossil fuel produced comes from unpopulated areas of the country; however, it is usually burned in or near cities and contributes significantly to air pollution. On the other hand, the production effects on the environment are more visible (e.g., hydroelectric dams, coal strip mining, or the Alaskan pipeline). The consequences of energy use on the environment are, normally, not immediately visible. There is, however, mounting evidence that the use of energy, especially coal-generated energy, has serious implications for the environment. These consequences vary widely and are dependent on the assimilative capacity of the environment or ecosystems in question.⁴ Commonly recognized problems stem largely from the emissions of gaseous pollutants such as SO₂ and NO_x which affect ecosystems in a subtle manner, causing a reduction in crop and forest productivity.^{5,6} These problems will be discussed later. The environmental as well as social efficiencies of using coal to generate electric power are questionable, if nuclear fuels, natural gas, or imported oil are available. The Council on Environmental Quality pointed out that coal causes the most harm to the environment (Table 7.2). Even so, coal may be able to compete with expensive oil and nuclear power if the effects of coal mining on the environment can be minimized at some reasonable economic costs and if the proposed coal conversion processes can be accomplished successfully (i.e., energetically and environmentally).

In order to place the energy-environmental conflict in a better perspective, we have portrayed the total energy use pattern in the South in Fig. 7.2. This figure depicts energy usage (Btu per square mile) for 1388 counties of the South.⁷ As would be expected, the urban areas use the most energy per square mile and, as a consequence, suffer the most environmental degradation. However, there are significant differences in energy use per square mile and per capita among the counties. Figure 7.3 depicts the energy consumption per capita. It is highest where the energy-intensive activities of mining, processing, and transportation of oil, gas, and coal form a substantial part of the county's economy. Typically,

Table 7.2. Comparative environmental impact of 1000-MWe energy systems operating at a 1.00^a load factor with low levels of environmental controls or with generally prevailing controls per year

System	Air emissions			Water discharges				Solid waste			Land use		Occupational health		Potential for large-scale disaster
	Tons (10 ³)	Curies (10 ³)	Severity ^b	Tons (10 ³)	Curies (10 ³)	Btu (10 ³)	Severity ^b	Tons (10 ³)	Curies (10 ³)	Severity ^b	Acres (10 ³)	Severity ^b	Deaths	Workdays lost (10 ³)	
Coal															
Deep-mined	498		5	9.53		3.96	5	783		3	38.2	3	5.20	8.77	Sudden subsidence in urban areas; mine accidents
Surface-mined	498		5	52.6		3.96	5	4247		5	44.6	5	3.43	3.09	Landslides, downstream flooding
Oil															
Onshore	206		3	7.19		3.96	3	n.a.		1	26.9	2	0.45	3.61	Massive spill on land from blowout or pipeline rupture
Offshore	206		3	7.89		3.96	4	n.a.		1	23.1	1	0.45	3.61	Massive spill on water from blowout or pipeline rupture
Imports	91.8		2	3.28		3.96	4	n.a.		1	22.6	1	0.08	0.69	Massive oil spill from tanker accident
Natural gas	31.3		1	1.05		3.96	2			0	27.0	2	0.26	1.99	Pipeline explosion
Nuclear		635	1	27.7	3.48	6.88	3	3408	1.8	4	24.8	2	0.20	0.27	Core meltdown, radiological health accidents

^aLoad factor in the original table was 0.75, a more realistic figure. However, for purposes of the NCUA, the load factor was set at 1.00 (see section on Technology Characterization); thus, all values in the original table (except for severity ratings) were multiplied by 1.3 to provide a general comparison.

^bSeverity rating key: 5 = serious, 4 = significant, 3 = moderate, 2 = small, 1 = negligible, 0 = none; n.a. = not available.

Source: The Council on Environmental Quality, *Energy and the Environment - Electric Power*, United States Government Printing Office, Washington, D.C., 1973, Table 3, p. 14.

Fig. 7.2. Energy consumption per year per square mile using all fuels (from Drysdale and Calef⁷). Interval limits expressed in millions of Btu per square mile as (1) <5, (2) 5-10, (3) 10-50, (4) 50-100, (5) >100. (Data from the Energy Sector, Geoecology Data Base.)

Fig. 7.3. Energy consumption per year per capita using all fuels (from Drysdale and Calef⁷). Interval limits expressed in millions of Btu per person as (1) <0.12, (2) 0.12-0.25, (3) 0.25-0.50, (4) 0.50-1.00, (5) >1.00. (Data from the Energy Sector, Geology Data Base.)

urbanized areas, such as Washington, D.C., are relatively low per capita energy consumptive areas.³ Practically all of Texas, Louisiana, and Oklahoma, states which will be most affected by a switch from gas and oil to coal-powered generating facilities, are relatively high in per capita energy consumption. Areas such as Houston, the most energy-intensive metropolitan region in the country, are high in both energy consumption per square mile and per capita.⁸ Rice^{9,10} gives detailed information on energy production-consumption statistics for the South and in Sect. 2 of this report.

7.5 Air Pollution

Coal-powered generating facilities (Fig. 7.4) have been identified as the leading contributors of sulfur dioxide (SO_2) to the atmosphere. Other facilities, such as refineries, also contribute a significant proportion of SO_2 and especially NO_x . Figure 7.5, from Drysdale and Calef,⁷ depicts the coal-powered generating facilities for 1985 based on estimates primarily from Federal Power Commission information. While Fig. 7.5 may not give the most accurate assessment of where coal-fired power plants will be located in 1985 (see Sect. 3 on siting analysis), it does show a significant increase over 1975 (Fig. 7.4). This increase in power production will affect air-quality levels by the years 1985 and 2000 when sulfur oxides in the atmosphere will increase to 12% and 20%, respectively, above the 1975 levels, with coal contributing to 80% of that increase. In the year 2000, NO_x will rise 70% above 1975 levels, with coal contributing 40% of the emissions.¹¹

From a regional perspective, it was determined that SO_2 was the key effluent to examine, in particular, its potential effects on vegetation. Plant species vary greatly in their response to SO_2 , due to their genetic composition, to their response to environmental factors, individually and in combination, and to the time-concentration relationship of SO_2 alone and in combination with other atmospheric pollutants.¹² Variation in any one of the complex of interacting factors will result in a variation in plant response. However, this discussion is not intended to focus attention on which species are most sensitive to SO_2 . This has been done before.^{13,14} Rather, we intend to discuss where potential impacts on forest and crop systems may occur from future levels of atmospheric SO_2 .

Before dealing with the affected systems, it is appropriate to discuss the input for levels of atmospheric SO_2 . Figures 7.6, 7.7, 7.8, and 7.9 represent different levels of atmospheric SO_2 . Figure 7.6 represents the total amount of SO_2 released per county per year, while Fig. 7.7 shows the emissions from only coal-fired generating plants. It is obvious that although electrical generating facilities furnish a significant proportion of the SO_2 emissions (approximately 60%¹⁵), there is a pressing need to be aware of the total atmospheric levels. Figure 7.8 is the average daily concentration of SO_2 for January 1974, based on EPA data from 233 counties having one or more monitoring stations. Although both rural and urban stations are included, the current distribution of monitoring stations is heavily weighted toward metropolitan areas and hence

Fig. 7.4. Electrical generating capacity of utilities >25 MW using coal for 1975 (from Drysdale and Calef⁷). Interval limits expressed in billions of BTU as (1) 0-1, (2) 1-10, (3) 10-100, (4) 100-1000. (Data from the Energy Sector, Geoecology Data Base.)

Fig. 7.5. Projected electrical generating capacity of utilities >25 MW using coal for 1985 (from Drysdale and Calef⁷). Interval limits expressed in billions of Btu as (1) 0-1, (2) 1-10, (3) 10-100, (4) 100-1000. (Data from the Energy Sector, Geocology Data Base.)

Fig. 7.6. Calculated sulfur dioxide emissions for the amount of fossil fuels consumed in a county (from Drysdale and Calef⁷). Interval limits expressed as 2200 lb per square mile are (1) <1.0, (2) 1.0-5.0, (3) 5.0-10.0, (4) 10.0-50.0, (5) >50.0. (Data from the Energy Sector, Geoecology Data Base.)

Fig. 7.7. Calculated sulfur dioxide emissions for the amount of coal consumed in a county (from Drysdale and Calef⁷). Interval limits expressed as 2200 lb per square mile are (1) <1.0, (2) 1.0-5.0, (3) 5.0-10.0, (4) 10.0-50.0, (5) >50.0. (Data from the Energy Sector, Geoecology Data Base.)

Fig. 7.8. Sulfur dioxide concentrations as monitored by EPA during January 1974, using the mean concentration from 233 counties having one or more monitoring stations. Interval limits expressed in micrograms per cubic meter as (1) <1.0, (2) 1.0-5.0, (3) 5.0-10.0, (4) 10.0-50.0, (5) >50.0. (Data from the Air Quality Sector, Geoecology Data Base.)

Fig. 7.9. Regional concentrations of sulfur dioxide calculated through use of a long-range trajectory model and based upon NCUA 1975 base-case scenario. Interval limits expressed in micrograms per cubic meter as (1) <0.1, (2) 0.1-1.0, (3) 1.0-3.0, (4) 3.0-10.0, (5) >10.0.

toward localized emission sources (see Shriner et al.¹⁶). Other drawbacks are that the data come from a variety of sampling methods and that there are unequal numbers of sampling sites per county. Thus, in counties with more than one sampling site, values were averaged. In many cases data did not exist for one or more pollutants within a county. Figure 7.9 depicts the concentrations of atmospheric SO₂ released by coal-fired generating plants. These data, obtained through the use of a long-range trajectory model (Sect. 4), are in micrograms per cubic meter, based on the daily average concentration for January 1975. This map leaves out background levels of SO₂ and other sources of emissions. The above figures indicate that (1) serious discrepancies among sources of pollutant data at the regional level continue to exist; (2) ambient levels of pollutants need to be considered in assessing future levels augmented by generating facilities; and (3) the problems of associating incomplete data on pollutant levels with the complex factors affecting interaction with the vegetation combine to make an evaluation of the impact of pollutants on regional level systems extremely difficult. It is important to be able to account for the synergistic effects of combinations of pollutants such as SO₂, NO_x, and ozone.

To estimate the potential impacts of increased levels of SO₂ on vegetation, we decided to use a map similar to Fig. 7.9, but projected for 1985 levels. Since it was almost impossible to ascertain what effects ambient SO₂ levels would have on macroscale systems, the best approach was to utilize the 1985 data (Fig. 7.10), overlaying this map with one of land-use systems. This was done for predominantly softwood forests (Fig. 7.11) and for soybean cropland (Fig. 7.12). These two categories were chosen because they are two of the South's systems most sensitive to SO₂ pollution. For both resultant maps (Figs. 7.13 and 7.14), the darkest configurations indicate the areas with the highest crop productivity (total average annual yield per county divided by the total county area) or highest softwood productivity (total growing stock volume per county divided by total county area) and the highest levels of atmospheric SO₂. While the role of emissions from coal-fired electric plants in the magnitude and occurrence of these levels may be debated, there is a high probability that the effluents from steam electric plants will interact with those from other industrial and urban sources. Thus, while the levels of SO₂ depicted here (and in Sect. 4) may not cause acute vegetational injury, they may, when combined with ambient SO₂ levels, cause severe chronic injury (an analysis of SO₂ impacts on forest ecosystems is found in Sect. 7.8). Furthermore, levels are averaged, so that there still may be periodic episodes which may cause acute injuries to the vegetation. The areas outlined on the computer-generated maps do indicate areas of justifiable concern. For example, if just those counties which are darkened on the SO₂-soybean map were to suffer a 10% drop in yield, the result would be a loss of 17 million bushels or \$102 million per year. Although the results are very general at this point, they indicate a substantial potential impact of SO₂ on pine forests and soybean yields. Careful evaluation is required to weigh the relative advantages of varying sizes and locations of coal-fired generating plants. They should not be so large as to overwhelm the local environment with gaseous effluents, fine and coarse particles, hot water, precipitated

Fig. 7.10. Regional concentrations of sulfur dioxide calculated through use of a long-range trajectory model and based upon NCUA 1985 base-case scenario. Interval limits expressed in micrograms per cubic meter as (1) <0.1 , (2) $0.1-1.0$, (3) $1.0-3.0$, (4) $3.0-10.0$, (5) >10.0 .

Fig. 7.11. Softwood stand volume from U.S. Forest Service Forest Survey State Reports published between 1963 and 1975. Growing-stock volumes are expressed as net volume of trees greater than 5.0 in. dbh (diameter at breast height) per total county area. Interval limits are expressed in cubic feet per acre as (1) <100, (2) 100-250, (3) 250-500, (4) 500-750, (5) >750. (Data from the Forestry Sector, Geoecology Data Base.)

Fig. 7.12. Soybean yield from the 1969 Census of Agriculture expressed as total production per total county area. Interval limits are expressed in bushels per acre as (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$, (6) >10.0 . (Data from the Agricultural Sector, Geoecology Data Base.)

Fig. 7.13. Potential SO_2 impacts on softwood forests. SO_2 levels (1985 long-range projections)² are expressed as micrograms per cubic meter, with low = <1.0 , medium = $1.0-10.0$, and high = >10.0 . Softwood productivity levels are defined as growing stock volume (cubic ft per acre per county), with low = <250 , medium = $250-500$, and high = >500 . Interval limits are expressed as: (1) no impact due to low softwood or SO_2 levels, (2) low potential impact due to medium softwood and medium SO_2 levels, (3) medium potential impacts due to medium (high) softwood and high (medium) SO_2 levels, (4) high potential impact due to high softwood and high SO_2 levels.

Fig. 7.14. Potential SO₂ impacts on soybeans. SO₂ levels (1985 long-range projections) are expressed as micrograms per cubic meter, with low = <1.0, medium = 1.0-10.0, and high = >10.0. Soybean productivity levels are defined as total yield per total county area, with low = <0.01, medium = 0.01-1.0, and high = >1.0. Interval limits are expressed as (1) no impact due to low soybean or SO₂ levels, (2) low impact due to medium soybean and SO₂ levels, (3) medium impact due to medium (high) soybean and high (medium) SO₂ levels, (4) high impact due to high soybean and SO₂ levels.

residues, and fly ash. At the same time, if too small, they will be inefficient.

7.6 Land Use and Coal Mining Conflicts

Decisions on land use development are usually made at the local level and are based on economic, political, and social considerations, not environmental ones (Cooper and Vlasin¹⁷). This is indeed unfortunate, because every regional environment has a limited capacity to assimilate waste material or to accept disturbance in a manner acceptable to man (in terms of health, aesthetics, recreation, resource production, and other values). As mentioned previously, an assessment of the ecological effects of coal mining in the South will be presented in a forthcoming report. However, at this time it is appropriate to discuss some of the potential conflicts.

The southern United States (1388 counties) is roughly composed of 20.8% agricultural land (Fig. 7.15), 28.1% grazing land (Figs. 7.16 and 7.17), 43.8% forestland (Fig. 7.18) (includes 4.1% federal land — see Appendix A), 3.7% urban land (Fig. 7.19), and 3.6% other land (including small lakes and water bodies). While the urban land (Fig. 7.19), for the most part, is not impacted by coal procurement, it is, of course, directly affected by coal use, since many of the coal-fired generating plants (Fig. 7.4) are located near the major users of electricity.

Land use for energy purposes in the United States will rise to over 10 million acres by the year 2000, 94% of which will be due to the mining of coal.¹¹ Table 7.3 shows the distribution of land-use types in the counties with coal reserves in the South, while Fig. 7.20 depicts a land-use map of the southern counties with strippable coal reserves. Table 7.4 gives statistics on the amount of reserves in each state. With nearly 80 million acres of land occurring within these counties, of which 13.2% is agricultural, 21.7% grazing, and 58.8% forest (including federal land), the potential confrontation with food and fiber production is obvious. The majority of forestland (Fig. 7.21) in the coal mining areas is in hardwoods (Fig. 7.22), especially in the northern and central Appalachian region, although southern Appalachia is predominantly in softwoods (Fig. 7.11). The majority of the western interior coal deposits in the southern region are under grazing systems — pastureland (Fig. 7.16) or rangelands (Fig. 7.17) — with a substantial amount of hardwood forests, predominantly oak-hickory. The Texas Gulf coal region is predominantly pastureland and softwood forests, with a considerable portion of rangeland in the western section. It is interesting to note the demarcation between eastern pastureland and western rangeland (except for the coastal areas and Florida). In fact, this transition is the area where scarcity of water becomes a limiting factor in terms of both natural and cultural systems (e.g., for cooling purposes).

The impacts of surface mining are, of course, far greater than just the initial consequences of disturbing or removing the initial land cover. Secondary effects range from severe modification of habitat (discussed

Fig. 7.15. Agricultural land based on 1967 Conservation Needs Inventory. Interval limits are expressed in percentage of a county in this classification: (1) 0-5.0, (2) 5.0-10.0, (3) 10.0-25.0, (4) 25.0-50.0, (5) 50.0-100.0. (Data from the Land Use Sector, Geoecology Data Base.)

Fig. 7.16. Pastureland based on 1967 Conservation Needs Inventory. Interval limits are expressed in percentage of a county in this classification: (1) 0-5.0, (2) 5.0-10.0, (3) 10.0-25.0, (4) 25.0-50.0, (5) 50.0-100.0. (Data from the Land Use Sector, Geoecology Data Base.)

Fig. 7.17. Rangeland based on 1967 Conservation Needs Inventory. Interval limits are expressed in percentage of a county in this classification: (1) 0-5.0, (2) 5.0-10.0, (3) 10.0-25.0, (4) 25.0-50.0, (5) 50.0-100.0. (Data from the Land Use Sector, Geocology Data Base.)

Fig. 7.18. Forestland and federally owned land based on 1967 Conservation Needs Inventory. These land-use classes were combined, based on the assumption that much of the large federally owned lands in the Southeast are forested. Interval limits are expressed in percentage of a county in this classification: (1) 0-10.0, (2) 10.0-25.0, (3) 25.0-50.0, (4) 50.0-75.0, (5) 75.0-100.0. (Data from the Land Use Sector, Geoecology Data Base.)

Fig. 7.19. Urban land based on 1967 Conservation Needs Inventory. Interval limits are expressed in percentage of a county in this classification: (1) 0-1.0, (2) 1.0-2.5, (3) 2.5-5.0, (4) 5.0-10.0, (5) 10.0-100.0. (Data from the Land Use Sector, Geoecology Data Base.)

Table 7.3. Distribution of land-use types in the counties with coal reserves in the southern United States

State	Number of counties	Agricultural		Grazing ^a		Forest		Urban		Federal		Other ^b		Total
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
Alabama	23	1,702,555	14.6	1,093,550	9.4	7,771,950	66.5	554,033	4.7	255,758	2.2	304,049	2.6	11,682,028
Arkansas	19	1,133,042	13.6	1,045,122	12.5	4,535,104	54.3	305,996	3.7	1,169,565	14.0	165,142	2.0	8,353,971
Georgia	2	28,075	9.0	31,378	10.0	167,102	53.3	22,739	7.3	45,309	14.4	19,325	6.1	313,600
Kentucky	47	2,262,075	9.6	1,299,274	11.1	6,844,374	58.7	272,478	2.3	523,533	4.5	444,353	3.8	11,665,760
Maryland	2	73,001	10.5	59,673	8.6	492,198	70.7	19,427	2.8	0	0	52,320	7.5	693,320
North Carolina	2	84,710	3.8	36,870	6.0	454,892	73.9	14,016	2.3	0	0	16,736	2.7	615,680
Oklahoma	16	1,084,228	3.8	3,282,329	41.8	2,577,355	32.8	322,822	4.1	470,658	6.0	108,603	1.4	7,845,995
Tennessee	19	793,699	5.7	305,371	6.1	3,446,613	68.4	234,585	4.7	107,753	2.1	152,459	3.0	5,040,480
Texas	38	2,327,322	11.7	8,381,178	42.3	7,410,163	37.4	739,137	3.7	550,876	2.8	410,144	2.1	19,818,820
Virginia	9	209,983	8.3	551,499	21.8	1,505,029	59.4	64,216	2.5	143,008	5.6	59,248	2.3	2,532,982
West Virginia	39	727,772	6.7	1,145,068	10.6	7,410,649	68.5	323,687	3.0	785,692	7.2	428,972	4.0	10,822,840
Total	216	10,446,470	13.2	17,243,132	21.7	42,614,429	53.7	2,873,136	3.6	4,052,152	5.1	2,160,451	2.7	79,385,476

^aIncludes pastureland and rangeland.^bLand not classified as agricultural, grazing, forest, urban or federal land: it includes small lakes and water bodies.

LANDUSE COUNTY CLASSIFICATION FROM CONS. NEEDS INVENTORY, 1967

Fig. 7.20. Predominant county land use (agriculture, pasture, range, and forest >50%, urban >10%) overlain by counties (outlined) with strippable coal reserves.

Table 7.4. Summary of estimated reserves of strippable bituminous and lignite coal^a
in the southern United States^b

Region and state	Remaining strippable reserves (10 ⁵ short tons)	Available strippable reserves (10 ⁵ short tons)	Minimum coal bed thickness (in.)	Maximum overburden thickness (ft)	Economic stripping ratio (ft:ft)
<i>Bituminous</i>					
Appalachia					
Alabama	607	134	14	120	24:1
Kentucky — east	4,609	781	28	120	14:1
Kentucky — west	4,746	977	24	150	18:1
Maryland	150	21	28	120	15:1
Oklahoma	434	111	12	120	15:1
Tennessee	483	74	28	120	19:1
Virginia	2,741	258	28	120	15:1
West Virginia	11,230	2,118	28	120	15:1
<i>Lignite</i>					
Arkansas	32	25	60	100	15:1
Texas	3,272	1,309	60	90	15:1

^aNo substantial amount of strippable subbituminous coal reserves exist in these states.

^bThe Bureau of Mines released an updated estimate of U.S. coal reserves by region and by recovery method in July 1974. These figures show a loss of some 30 billion tons in reserve estimates for West Virginia alone; from previous estimates other Eastern states lost smaller amounts (1 to 2 billion tons). Moreover, the new figures show a growing ratio of strip to deep minable reserves. Until such time as the Bureau of Mines can demonstrate the basis for these new figures, it was determined to use the older reserve figures for this report. It should be pointed out that, according to the Institute of Ecology, 72% of the nation's coal reserves lie in the East, if one calculated on a Btu, rather than a tonnage basis. Note: Both Georgia and North Carolina have insignificant quantities of coal and are not included in this table.

Source: U.S. Energy Outlook, Coal Availability, National Petroleum Council, 1973.

Fig. 7.21. Forest stand volume from U.S. Forest Service Forest Survey State Reports published between 1963 and 1975. Growing-stock volumes are expressed as net volume of trees greater than 5.0 in. dbh per total county area. Interval limits are expressed in cubic feet per acre as (1) <100, (2) 100-250, (3) 250-500, (4) 500-750, (5) >750. (Data from the Forestry Sector, Geoecology Data Base.)

Fig. 7.22. Hardwood stand volume from U.S. Forest Service Forest Survey State Reports published between 1963 and 1975. Growing-stock volumes are expressed as net volume of trees greater than 5.0 in. dbh per total county area. Interval limits are expressed in cubic feet per acre as (1) <100, (2) 100-250, (3) 250-500, (4) 500-750, (5) >750. (Data from the Forestry Sector, Geoecology Data Base.)

in the following section) to the impairment of water quality and the ecological impacts of major changes in land use patterns. Hopefully, recently enacted federal strip-mine legislation will temper major perturbations, but only time will tell. Subsidence from deep mines, as well as acid mine drainage, is also a serious problem. The ecological impacts from deep mines and strip mines will be discussed in more detail in a future publication.

7.7 Analysis of Coal Extraction Impacts on Sensitive Animal Species

7.7.1 Introduction

During the past 12 years, the U.S. Congress has passed three acts of legislation concerning the preservation and conservation of wildlife species. The Endangered Species Preservation Act of 1966, the Endangered Species Conservation Act of 1969 (which amended the 1966 Act), and the Endangered Species Act of 1973 were the results of public concern over the plight of the U.S. wildlife resources. Many species were found to be near extinction, and thus legislation to protect the remaining populations was widely supported. Although extinction is a natural phenomenon, human activities have accelerated the process by introducing additional stresses to populations with specialized habitat requirements. Land-use transitions associated with the extraction (predominantly strip mining) and utilization of coal resources potentially threaten the abundance and distribution of animals, both locally and regionally.

Five mammals, five birds, and three species of fish (Table 7.5) which are listed in the *Federal Register* as threatened and endangered species are known to occur in the southern U.S. where coal mining and coal utilization are projected by the NCUA to continue or to increase through 1985. All species will probably be affected by loss of habitat as mining continues to encroach on remaining territories. Effluents from mining operations will also contribute to the continued decline of endangered aquatic populations. Future research on the critical habitat needs of these animal species is required before predictive models can be used to identify the magnitude of the effects of perturbation on the populations. One of the goals of the NCUA is to document the regional distribution and abundance of animal populations, particularly species for which loss of habitat could mean extinction.

7.7.2 Analysis of Impacts on Sensitive Species

We have begun the development of a computerized data system by entering the distribution of animal species within the southeastern region. First consideration has been given to species which are nationally endangered or threatened. "Endangered" refers to any species which is in danger of extinction throughout all or a significant portion of its range, and which has been so designated under the provisions of the Federal Endangered Species Act of 1973 (PL 93-205). "Threatened" refers to species which are likely to become endangered in the immediate future

Table 7.5. Endangered mammal, bird, and fish species in the Southeast that are found in areas with potential for coal extraction

Common name	Scientific name
<i>Mammals</i>	
Gray bat	<i>Myotis grisescens</i>
Indiana bat	<i>Myotis sodalis</i>
Eastern cougar	<i>Felis concolor cougar</i>
Ozark big-eared bat	<i>Plecotus townsendii ingens</i>
Virginia big-eared bat	<i>Plecotus townsendii virginianus</i>
<i>Birds</i>	
Sandhill crane	<i>Grus canadensis</i>
Bald eagle	<i>Haliaeetus Leucocephalus</i>
Peregrine	<i>Falco peregrinus</i>
Red-cockaded woodpecker	<i>Dendrocopas borealis</i>
Bachman's warbler	<i>Vermivora bachmani</i>
<i>Fish</i>	
Slender chub	<i>Hybopsis cahnii</i>
Spotfin chub	<i>Hybopsis monacha</i>
Yellowfin madtom	<i>Noturus flavipinis</i>

due to a continued decline in population or habitat. Often, these are species which can successfully exploit an extreme or specialized habitat but which have lost the ability to compete in variable habitats. As habitat is destroyed, the only viable options open to such species are to adapt to changed conditions or to find new areas. When habitat loss is rapid, the time required for adaptation is not available, and the species are forced to move. Suitable unoccupied habitat is rarely available. The animals are forced to occupy marginal habitats where their existence is usually short lived. Five mammal and five bird species in the Southeast have already been designated by the U.S. Fish and Wildlife Service¹⁸ as severely threatened by loss of habitat (Table 7.5).

Many areas in the South which contain coal overlap the ranges of these endangered species. It is necessary to identify the areas where removal of coal could affect these endangered animals so that preventive measures can be undertaken to minimize adverse impacts on the population. Figure 7.23 shows the counties in the southeast which contain both strip-pable and deep mine coal reserves. Rather than produce maps with specific endangered species' ranges, Figs. 7.24 and 7.25 are composite maps outlining where 0, 1, 2, 3, or more species occur in a single county. This information was obtained from the Geoecology Data System (Appendix B). Data from Texas and Oklahoma were not available for the bird species and are not included in the maps of species distribution. By overlaying the species' distribution maps and the coal reserves maps, the areas of potential conflict can be highlighted (Fig. 7.26).

Fig. 7.23. Counties containing deep and strip mine coal (numbers in counties refer to millions of tons of coal reserves).

Fig. 7.24. Map of distribution of nationally endangered and threatened mammal species in the South.

Fig. 7.25. Patterns of nationally endangered and threatened bird species in the southern United States. Shading is indicative of those areas where endangered species would be expected to range (light shading represents areas of low numbers, while the darkest shading represents high numbers of species) (does not include central and western sections of Texas and Oklahoma).

Fig. 7.26. Overlay of threatened and endangered species distribution with those counties containing strippable or deep mine coal reserves. Numbers in counties refer to the number of species which might occur in that area.

Of the 219 counties shown in Fig. 7.26 to have strippable or deep mine coal reserves, 154 contain potential habitats for the endangered or threatened mammal and bird species listed in Table 7.5. Even though the distribution patterns of both the Indiana bat and the gray bat cover most of the area outlined in Fig. 7.26, their actual roosting caves are limited to a few scattered areas. Analysis of the impacts of coal extraction on these two species would necessarily have to deal with specific sites in order to determine if the animals actually occur within the mining area. This is generally true of all the species listed by the U.S. Fish and Wildlife Service. However, Fig. 7.24 shows that certain areas which contain strippable coal reserves (Fig. 7.23), such as northwestern Arkansas (Crawford and Franklin counties) and east-central Kentucky (Powell and Lee counties), have a high potential for harboring endangered species. In both of these cases, other bat species, the Ozark Big-eared and Virginia Big-eared, respectively, have been located. These counties warrant a more detailed study to determine if extraction operations would be detrimental to these species' continued existence.

The U.S. Fish and Wildlife Service also lists one endangered and five threatened fish species in the southeastern United States. Drainage from coal mines and related facilities is given as a reason for assigning the threatened ("likely to become endangered throughout all or a significant portion of their range") status to three of the five species.¹⁸ The NCUA base case indicates these counties where continued or expanded coal mining is expected. Our analysis indicates that some or all of the federally designated critical habitats for the three species occurs within these counties. Any mining effluents which reach critical streams could have serious adverse effects on the remaining populations of these animals. The counties (and the streams within them) which comprise the critical habitats for the three threatened fish species are listed in Table 7.6.

States have also designated as endangered or threatened those animal species which have a limited distribution in the state and are threatened with extinction on a localized basis. In most cases, these lists are designed to supplement the federal endangered list and to add state protection to specific animal resources. Many of the species (exclusive of those on the federal list) designated by states as endangered or threatened are at the edge of their geographical distribution, and may be more widely distributed than is indicated by these lists.

7.8 The Problem of Assessing Long-Term Pollutant (or Temperature) Impacts on Forest Dynamics

7.8.1 Introduction

Previous sections have demonstrated the potential impact of air pollutants on forest ecosystems in the South. The maps which overlay intensity of projected increases in SO₂ concentration on the distribution of forests indicate the geographical extent of the possible impact. In this section we report progress on the assessment of the

Table 7.6. Endangered fish species' habitats in the Southeast which are potential areas for conflicts due to coal extraction

Name	River	County, state
Slender chub (<i>Hybopsis caini</i>)	Powell, Clinch Powell Clinch	Claiborne, Tenn. Lee, Va. Scott, Va.
Spotfin chub (<i>Hybopsis monacha</i>)	Obed, Clear Creek, Daddys Creek Clear Creek Emory, Obed	Cumberland, Tenn. Fentress, Tenn. Morgan, Tenn.
Yellowfin madtom (<i>Noturus flavipinnis</i>)	Powell Powell Copper Creek Copper Creek	Claiborne, Tenn. Lee, Va. Scott, Va. Russell, Va.

effects of perturbations, such as an increase in pollutant concentration on forest community growth and on forest succession.

An obvious problem with forest succession studies is the slowness (by human standards) of change associated with the replacement sequence. For example, during the time elapsed since Clements¹⁹ first began publishing his work, only a small percent of the time required for a mature forest to develop (e.g., from an old field) has passed. To cope with this problem, forest ecologists examine a spatial sequence of similar communities that are in different stages of development. From this, inferences are made with the assumption that the spatial heterogeneity of sites can be arranged to represent a temporal continuum of the successional sequence. This technique has many positive attributes, and much has been learned about forest dynamics by using this approach. However, certain drawbacks are inherent in the classical methods of successional studies, such as the slowness of sequencing previously mentioned. The lack of accurate historical information concerning the community being studied adds to the uncertainty of making valid comments about the forest's future behavior. The most serious constraint associated with forest succession studies is using available information to make reliable predictions. The predictability of taxonomic sequence discussed by MacArthur and Connell²⁰ assumes relative constancy of the environment and that the growth and behavior of the individual taxa will adhere to some known set of characteristics.

The use of modeling techniques to examine community succession is creating significant interest among ecologists studying a variety of vegetation types. For example, Noble and Slatyer (personal communication) are applying stand growth models to describe "the individual by individual, or stand by stand replacement process" in the Tasmanian

sclerophyll-rain forest system. This work is based on the principle applied by Leak²¹ in the U.S. northern hardwood forest type and Botkin et al.²² in the Hubbard Brook Watershed studies. These techniques are also being applied by Reed et al.²³ in the Douglas fir-hemlock forest of the Northwest. The general feeling is that modeling procedures have become realistic enough that their predictive capability can be used to determine forest community behavior. Models, calibrated in conjunction with observations of forest communities in various stages of succession, can provide a more complete explanation of successional dynamics.

Credible projections of long-term successional sequences are further complicated by possible perturbations from pollutants in the atmosphere. Although seasonal or even yearly responses of arboreal species to pollution may be slight, the results of a constant exposure to an unnatural environment may result in significant changes in ecosystem behavior over a relatively long period of time. The same philosophy holds true for other environmental modifications. For example, a year's variation of a few degrees from the annual mean temperature may be relatively unnoticed. However, a long-term change of only a few degrees in the mean annual temperature could result in significant, or even drastic, changes in stand level productivity and regional forest behavior.

7.8.2 Available modeling techniques for long-term chronic effects on forests

Forest succession modeling has developed over the past five to ten years into a useful management tool. The modeling approach generally attempts to mimic the behavior of a natural (or near-natural) ecosystem. The models (implemented on a high-speed digital computer) usually simulate the ecological attributes of some relatively small (0.01 to 1 acre) area of land. To apply the models in a regional context, one must assume that the simulated forest stands are in some way representative of the elements that make up a landscape. This latter procedure may either be in the interpretation of the model behavior or may constitute an additional modeling exercise.

7.8.3 Description of the FORET model

FORET, the stand-level simulator developed by Shugart and West²⁴ and used in the NCUA assessment, simulates reproduction from seeds and vegetative growth and the death of trees larger than 0.5 in. on a 0.20-acre plot. The model does not consider seed source (although it does consider seedling establishment in great detail) nor does it keep track of the position of individual trees. The trees interact directly by shading one another and interact indirectly according to differences in reproductive strategies. The model is developed from a rationale presented by Botkin et al.²² The model is (as are most stand simulators) sensitive to the elimination of tree species, the elimination of individual trees, and altered tree growth rates. These sensitivities directly parallel the model characteristics needed to simulate blights, harvesting,

or pollutant effects. In an applied situation, the stand-simulator model can be of unique value to planners for the elucidation of how policy decisions or actions will have long-term effects on the region's forests. Examples include the consequences of additional timber harvesting or the effect of an increase in air pollution resulting from energy technology facilities.

The growth of each tree on the plot is a function of the climate (expressed in annual growing degree-days), the forest leaf-area index (which can be used to calculate shading), the crowding from other trees (to simulate competition), and the size of the tree. Under optimal conditions, each tree would grow to its maximum size (according to the species) in a period of time equal to the species' maximum age. Furthermore, the growth equation is written so that the species-specific growth rate can be estimated by assuming that each tree should attain 2/3 of its maximum size at half its maximum age (Fig. 7.27).

Species that might enter the plot as saplings are chosen on the basis of:

1. availability of bare mineral soil,
2. presence of leaf litter,
3. climatic conditions, and
4. deer or small mammal abundance.

The number of saplings which enter the plot is a random variable. New individuals can be initiated through seed germination or sprouting. When a tree dies, if it is of a proper size and of an appropriate species, the species represented by the tree is eligible to sprout that year. The model tallies all species eligible to germinate, randomly chooses from one to five of these eligible species, and then randomly plants one to three small saplings of each chosen species in the plot.

Two functions are used to model the death of trees on the simulated plot. One function assigns a probability of death to each tree based on the maximum age attainable by the species. The second function assigns a low probability of survival to trees whose annual growth increment is below a certain value. Shugart and West²⁴ give additional details on the model structure.

7.8.4 Preliminary results from SO_x and temperature perturbation experiments using the FORET model

FORET was used to simulate the long-term effects of two perturbations. Simulations were run for 1000 years with a time step of one year, beginning with a bare plot. In each case, growth and succession were simulated and averaged for 100 stands (Fig. 7.27).

The two perturbations are implemented by changes in the model data set. The *climate change perturbation* was incorporated in the model by increasing the mean number of growing degree-days. In this simulation,

Fig. 7.27. Generalized diagram of FORET model methodology.

the increase corresponds to 2°C increase in mean annual temperature. Researchers studying the potential climatic effects of atmospheric CO₂ produced by combustion of fossil fuels consider 2°C to be the approximate expected increase in average global annual temperature if atmospheric CO₂ is doubled.²⁵ The *pollutant effect perturbation* was implemented by decreasing the maximum growth rate of selected tree species by 10% or 20% as indicated in Table 7.7. The pollutant that was keyed on was SO₂ because of its expected release pattern (see Sect. 7.5) and its deleterious effects on vegetation.^{13,14} The choice of sensitive species and their degrees of sensitivity are based on literature review and are speculative. For additional information see Davis and Wilhour.¹⁴

We found a reduction of total stand biomass of as much as 20% under the perturbation conditions, and using spectral (harmonic) analysis techniques, found that the dynamics of forest biomass were changed (see Emanuel et al.²⁶ for details of this analysis). Considering the actual composition of the forests for each of the test cases (Figs. 7.28-7.30), the stressed systems show significant reductions in the number of important species. In each case, the systems would "look" different because the species composition would vary from case to case. We also believe the systems would "act" differently because the nature of the response of the systems (as evidenced by spectral analysis) seems to be altered.

Some preliminary evidence of individual species behavior can be seen in the 500-year simulations shown in Fig. 7.31. Yellow poplar, an early successional species with a rapid growth rate shows a rapid positive response to stress, with a maximum increase of approximately 50% above the control level. The enhancement of yellow poplar under a regime which inhibits its growth by 10% may be attributed to the relatively greater effect of the stress on other species competing at early stages of the developing forest stand. Thus, yellow poplar with its fast growth has an opportunistic potential favored by stress on other species with which it competes.

Black oak, on the other hand, with the same level of applied stress, shows greater-than-anticipated response. Biomass reductions ranging from about 45% at year 50 to 52% at year 200 occur throughout the development of this species. Reductions of this magnitude may be attributed primarily to the inability of black oak to compete with other species such as yellow poplar and white oak under the additional stress imposed by air pollution. White oak, a species not directly impacted by stress in the model, showed a positive response in the simulation. As a middle-to-late successional species, however, this response becomes evident only as the stand matures and begins to stabilize. The maximum biomass increment for white oak in the stressed forest was approximately +80% and occurred in the 350-year-old stand. The final species tested, black cherry, while less important compositionally, was included as an example of a sensitive but valuable sawtimber species. The effects of a 20% growth reduction on this species were quite dramatic (Fig. 7.31). Effects were most obvious on stands older than 100 years and resulted in almost total elimination of this species. The maximum reduction in biomass contributed by black cherry was approximately 95% and occurred

Table 7.7. List of species used in FORET model

Species	Common	Percent growth reduction ^a
<i>Acer rubrum</i>	Red maple	0
<i>Acer saccharum</i>	Sugar maple	0
<i>Aesculus octandra</i>	Buckeye	10
<i>Carya cordiformis</i>	Bitternut hickory	0
<i>Carya glabra</i>	Pignut hickory	0
<i>Carya ovata</i>	Shagbark hickory	0
<i>Carya tomentosa</i>	Mockernut hickory	0
<i>Cercis canadensis</i>	Redbud	10
<i>Cornus florida</i>	Dogwood	0
<i>Diospyros virginiana</i>	Persimmon	0
<i>Fagus grandifolia</i>	Beech	0
<i>Fraxinus americana</i>	Ash	0
<i>Juglans nigra</i>	Black walnut	20
<i>Juniperus virginiana</i>	Red cedar	0
<i>Liquidambar styraciflua</i>	Sweet gum	10
<i>Liriodendron tulipifera</i>	Yellow poplar	10
<i>Nyssa sylvatica</i>	Black gum	0
<i>Oxydendron arboreum</i>	Sourwood	0
<i>Pinus echinata</i>	Shortleaf pine	20
<i>Pinus strobus</i>	White pine	20
<i>Pinus virginiana</i>	Virginia pine	20
<i>Prunus serotina</i>	Black cherry	20
<i>Quercus alba</i>	White oak	0
<i>Quercus Coccinea</i>	Scarlet oak	10
<i>Quercus falcata</i>	Southern red oak	10
<i>Quercus prinus</i>	Chestnut oak	0
<i>Quercus rubra</i>	Red oak	10
<i>Quercus stellata</i>	Post oak	0
<i>Quercus velutina</i>	Black oak	10
<i>Robinia pseudoacacia</i>	Black locust	20
<i>Sassafras albidum</i>	Sassafras	10
<i>Tilia heterophylla</i>	Basswood	10

^aNumber indicates degree by which each species is theoretically affected by sulfur dioxide in the atmosphere.

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Fig. 7.28. Base-case species dynamics for important species during 1000 simulated years of succession. Vertical distance between lines represents the percent biomass contributed by each species listed at the right side of the figure.

Fig. 7.29. Biomass dynamics for 100 simulated stands for 1000 years with differential growth rate reduction associated with possible effects from sulfur dioxide. Compare with Fig. 7.28.

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Fig. 7.30. An example of forest stand simulations with a mean annual temperature increase of 2°C. Compare with Fig. 2.28.

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Fig. 7.31. Species and stand dynamics of a forest with and without continuous exposure to air pollution stress (___ unaffected; ---- affected).

at year 250. Responses of other species and of the whole stand indicate an overall growth suppression by the simulated stress. It is interesting to note that a maximum stand response of -20% was noted (at year 200), indicating a system level response which was greater than the additive response of its parts. When individual sensitivities were used to predict stand level response, the summed and biomass weighted response of the 7 species comprising 87% of the total biomass of the 200-year-old stand was only -7%.

The results of these simulations offer some interesting insights into responses which might be expected when forests are exposed to air pollution stress. They strongly suggest that the response of trees to air pollution may be quite different under the competitive conditions in a forest stand than would be expected from experiments conducted with single individuals or single species. Trees of intermediate sensitivity may experience either much greater or much less than expected impacts due to changes in their relative competitive potential within the forest stand. Both resistant trees and those of intermediate sensitivity may actually experience growth stimulation as a result of relative increases in competitive potential.

Conclusions derived from these simulations agree with those drawn by Botkin²⁷ in a study of species interactions under uniform stress. In a 13-species simulation of northern hardwood forest dynamics, he found that perturbations that reduced tree growth generally favored growth of shade-tolerant species. He also emphasized the importance of species interactions in understanding the response of forest systems under conditions which either increase or decrease growth of individual species. While it is a well-recognized fact that visible injury and growth reduction do not necessarily occur concurrently, the assumption that trees which are most sensitive to visible foliar injury are also most susceptible to growth reduction by chronic air pollution stress appears reasonable. The levels of growth inhibition which were selected also do not appear excessive based on documented growth responses of forest trees. Miller,²⁸ for example, reported a 37% reduction in growth of ponderosa pine in the oxidant-impacted San Bernadino Forest. Recent studies by Kress²⁹ indicate height growth reductions of up to 45% for sycamore exposed for 28 days to levels of O_3 , SO_2 , and NO_2 below the current ambient air quality standards and in the absence of visible foliar injury.

Documentation of the response of forest communities under chronic stress from air pollutants will not be easy. Miller³⁰ cites several lines of evidence supporting the importance of such changes in the San Bernadino Mountains. Studies under way at that site may add appreciably to our understanding of the nature and extent of such changes. While we would agree with the conclusion that quantitative field estimates of individual trees or species experiencing subtle and adverse effects due to reduced growth, reduced reproduction, or increased morbidity are perhaps not presently possible, we suggest that mathematical simulations such as those we have undertaken are both possible and fruitful mechanisms for projecting the potential influence of pollutant impacts on forest ecosystems.

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8. POPULATION EXPOSURES ASSOCIATED WITH SULFUR DIOXIDE RELEASES FROM COMBUSTION FACILITIES SITED IN THE NCUA BASE-CASE SCENARIO

8.1 Summary

The data presented in this section can be used to identify those areas within the southern region which are of greatest interest from the standpoint of population exposure to sulfur dioxide and sulfates. In general, the same areas have the highest estimated exposure levels in each of the three base-case scenarios. Jefferson County, Kentucky; Baltimore County, Maryland; Washington, D.C.; and Fulton County, Georgia, are assigned the highest sulfur dioxide exposure levels in each of three base-case scenarios. Population exposures estimated for these counties are compared with an average exposure level calculated for the region. As an example, the relative population exposures calculated for Jefferson County, Kentucky, in the 1975, 1985, and 2000 scenarios are 57, 58, and 48 times the average values for the region. Baltimore County, Maryland; Washington, D.C.; and Prince Georges County, Maryland, have the highest estimated sulfate exposure levels in the 1975, 1985, and 2000 scenarios. The relative population exposures to sulfates in the 1975, 1985, and 2000 base-case scenarios are 65, 58, and 52 times greater in Baltimore County, Maryland, than for the region as an average. Estimates of population exposure to sulfates may be converted into population risk through use of dose response values. An estimate of population risk is not presented in this section due to the high level of uncertainty associated with the linear dose response functions presently available.

8.2 Introduction

The combustion of coal produces many pollutants, generally classified into five major categories: hydrocarbons, carbon monoxide, oxides of nitrogen, sulfur dioxide, and particulates. Since it is not possible to address all of the major classes of pollutants within the limited scope of this study, assessment activities have been directed toward an examination of the impact of sulfur dioxide releases on human health.

8.3 Review of SO_x Information

The impact of pollutants on human health depends on a number of parameters which are very difficult to define. These include the physical and chemical properties of the pollutant; the duration, concentration, and route of exposure; and the uptake and metabolism of the pollutant. All of these factors must be understood before the impact of pollutant exposure on human health can be assessed.

Sulfur dioxide releases to the atmosphere from fossil fuel combustion generally exist in three forms: sulfur dioxide, sulfuric acid, and

inorganic sulfates. Although sulfur dioxide is most frequently used as the index of pollution, it alone is of relatively low toxicity.¹ Sulfur dioxide in concentrations typically found in current urban communities represents little, if any, hazard to the lungs. However, sulfur dioxide can adversely affect health when in the presence of other pollutants, such as particulates, or after conversion to sulfuric acid or sulfates.

Many epidemiological studies have shown that adverse health effects result from exposure to high levels of sulfur oxides and particulates. High levels have been associated with increased mortality during pollutant episodes, aggravation of symptoms among individuals with chronic respiratory disease, increased incidence of respiratory disease and illness, and depressed lung function in children. Sulfur dioxide and its products induce irritation of the membranes lining the respiratory tract. This irritant effect can cause reflex bronchoconstriction, slowing of mucus flow, depression of clearance of inert particles from the lung, and, in high concentrations, narrowing of airways due to inflammatory swelling of membranes.²

Evidence of the mortality and morbidity associated with high levels of SO_2 has been provided in situations where high pollutant levels have combined with some environmental factor, such as temperature, or with particular disease states which may themselves have dire consequences. Acute episodes of high SO_x pollution, such as those that occurred in the Meuse Valley,³ Donora,⁴ London,⁵ New York City,^{6,7} and Osaka,⁸ provide evidence of the impact that high SO_x pollutant levels can have on human health. It was shown that increases in mortality during these episodes occurred among those population groups already suffering from chronic illnesses, particularly of the heart and lung. Studies conducted in London,⁹ New York City,¹⁰ and Rotterdam¹¹ suggested an increased mortality in elderly persons at particulate levels of 500-715 $\mu\text{g}/\text{m}^3$ or at smoke concentrations of 750-1000 $\mu\text{g}/\text{m}^3$. Studies of bronchitic patients showed a close correlation between the ambient levels of SO_2 and smoke and the severity of the illness. Concentrations of SO_2 above 500 $\mu\text{g}/\text{m}^3$ and of smoke above 250 $\mu\text{g}/\text{m}^3$ aggravated their symptoms.¹²⁻¹⁷ Carnow et al.¹⁸ also found that the severity of symptoms among bronchitics increased with increasing exposure to SO_2 . These increases occurred at 710-858 $\mu\text{g}/\text{m}^3$. Particulate levels were not included in the analysis. Increases in illness severity at SO_2 levels of 120-250 $\mu\text{g}/\text{m}^3$ were observed among bronchitic patients aged 55 years or older.¹⁹ Cohen et al.²⁰ found a correlation between daily attack rates among asthmatics and SO_2 concentrations on days when SO_2 levels exceeded 200 $\mu\text{g}/\text{m}^3$ and there was a high concentration of suspended particulates. No evidence of a threshold concentration was seen.

A series of studies has been carried out on the relationship between elevated levels of SO_2 and particulates and the incidence of chronic respiratory disease. Ferris et al.²¹ reported an improvement in lung function and a lower incidence of respiratory disease with decreased levels of sulfur oxides and particulate matter. Studies conducted as part of the Community Health and Environmental Surveillance System (CHESS) have related levels of SO_2 and particulates to acute

respiratory illnesses and chronic respiratory symptoms in four different communities.²²⁻²⁹ A major aim of these studies was to determine which pollutant levels result in an impact on health. The CHES studies have subsequently been questioned, however, for making estimates of past exposures, for data inconsistencies, and for biases involved in self-administered questionnaires. References to CHES in this section are made with full realization of this criticism and the basis for this criticism. Data from CHES are presented only to provide some kind of relative perspective on the estimates of sulfate concentrations contained in this paper.

Many of the aforementioned studies carried out prior to 1970 were used to set the air-quality criteria for sulfur dioxides. These were developed to provide an air-quality standard for SO_2 below which no adverse health effects would occur. The SO_2 primary standard was set at $365 \mu\text{g}/\text{m}^3$ (24-hr average concentration) and $80 \mu\text{g}/\text{m}^3$ (annual average concentration). The findings of the CHES studies form the basis of the primary standard for annual average SO_2 exposures. An evaluation of data reviewed in this section suggests that health effects occur when annual levels of SO_2 or particulates exceed $100 \mu\text{g}/\text{m}^3$. The data presented in the CHES study suggest that elderly subjects with heart and lung disease and asthmatics experience adverse effects at levels below the 24-hr primary standard.³⁰ The conclusion that health effects are produced among vulnerable population groups at concentrations below the 24-hr standard is extremely difficult to evaluate, however.

There is not enough information to establish a primary standard for sulfates. However, in one series of CHES studies, concentrations of acid sulfates at levels of $8\text{-}10 \mu\text{g}/\text{m}^3$ for 24 hr were shown to produce aggravation of symptoms in asthmatics and in individuals with heart and lung disease.³¹ Strong evidence suggests that sulfates and other transformation products should be of the most concern. However, evaluation of the risks associated with these pollutants can only be a matter of judgment until better information is obtained.

8.4 Calculation of Population Exposures

8.4.1 Regional patterns of exposure

We have analyzed the potential SO_x pollutant loading for the entire 16-state southern region. A discussion of the long-range transport calculations used to establish these patterns is presented in Sect. 4. Figures 4.8 through 4.11 show the regional distribution patterns of sulfur dioxide released from the facilities sited in the 1975, 1985, and 2000 base-case scenarios. The regional distribution patterns of sulfates according to the same scenarios are presented in Figs. 4.12 through 4.15.

As stated in Sect. 4, the resolution of the wind data for the long-range transport calculations is somewhat larger than the dimension of a county typical of the region being studied. Calculations of

pollutant loadings obtained through use of these wind data will be subject to certain simplifying assumptions before subsequent population exposures can be predicted. Concentrations of SO_2 and sulfates are calculated for the county as a unit, using the approach described in Sect. 4. Values for sulfur dioxide or sulfate levels are then multiplied by the projected population of the particular county to obtain a measure of the population exposure. Data taken from the 1970 Census are used to calculate the 1975 exposure values. Population estimates for 1985 and 2000 are made through use of the MULTIREGION model described in Sect. 2. The sulfur dioxide and sulfate exposure levels for the 1975 base-case scenario are presented in Figs. 8.1 and 8.2. The 20 counties with the highest estimated levels of sulfur dioxide and sulfate exposure are listed in Tables 8.1 and 8.2. Estimated sulfur dioxide and sulfate exposure levels for 1985 are depicted in Figs. 8.3 and 8.4. Tables 8.3 and 8.4 list the 20 counties with the highest estimated sulfur dioxide and sulfate levels for the 1985 base-case scenario. Figures 8.5 and 8.6 show the sulfur dioxide and sulfate exposure patterns for the year 2000, and Tables 8.5 and 8.6 list the 20 counties which possess the highest estimated levels of population exposure for the 2000 base-case scenario.

8.4.2 Site-specific calculations of exposure

As mentioned in Sect. 4, a number of study areas were chosen from the 1985 siting projections because of a heavy concentration of generating capacity in the area or because the area constitutes a regional population center. Ground-level concentrations of SO_2 , NO_x , and total suspended particles (TSP) were calculated as annual averages for each study area based on the 1985 base-case scenario. A discussion of how these annual average concentrations were calculated may be found in Sect. 4. Figures 4.2 through 4.7 show the isopleths of annual average SO_2 , NO_x , and TSP ground-level concentrations for two of the eleven study areas. The figures depicting the annual average concentrations for the remaining nine study areas are in the appendixes to this report.

To calculate the population exposure for sulfur dioxide releases from facilities sited in an area, it is necessary to make some simplifying assumptions. For example, it is assumed that the population of the respective counties is evenly distributed throughout the county. This assumption is reasonable in light of the uncertainties associated with predictions of facility siting for the 1985 scenario (see Chapter 4). Isopleths of concentration for each of the eleven areas are examined to determine that fraction of each county encompassed by the various isopleths. The fractional value describing the portion of the county within an isopleth is multiplied by the total population of the county and the pollutant level assigned to the isopleth to obtain a measure of the population exposure. Table 8.7 gives the SO_2 population exposure levels for each of the counties which comprise the eleven study areas.

Fig. 8.1. Population exposure to sulfur dioxide based on 1970 census figures and 1975 sulfur dioxide concentrations. Interval limits expressed in micrograms per cubic meter $\times$ population density $\times 10^{-6}$: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$.

Fig. 8.2 Population exposure to sulfates based on 1970 census figures and 1975 sulfate concentrations. Interval limits expressed in micrograms per cubic meter $\times$ population density $\times 10^{-6}$: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$.

Table 8.1. County rank of SO₂ population exposures associated with
1975 base-case scenario

County	State	Annual SO ₂ level (µg/m ³)	Population	Annual exposure level (µg/m ³ per 10 ⁶ persons)
Jefferson	Kentucky	9.1	695,055	6.3
Baltimore	Maryland	2.9	1,526,836	4.5
Washington	D.C.	4.8	756,510	3.6
Fulton	Georgia	5.6	607,592	3.4
Prince Georges	Maryland	4.7	660,567	3.1
Davidson	Tennessee	5.7	448,003	2.6
Gaston	North Carolina	16.5	148,415	2.5
Mecklenburg	North Carolina	6.6	354,656	2.3
Cobb	Georgia	11.3	196,793	2.2
Guilford	North Carolina	7.5	288,590	2.2
Jefferson	Alabama	3.3	644,991	2.1
Mobile	Alabama	6.5	317,308	2.1
Montgomery	Maryland	3.9	522,809	2.0
Fairfax	Virginia	3.8	487,763	1.9
DeKalb	Georgia	4.3	415,387	1.8
Forsyth	North Carolina	8.3	214,348	1.8
Kenton	Kentucky	13.7	129,440	1.8
Shelby	Tennessee	2.4	722,014	1.7
Campbell	Kentucky	17.9	88,501	1.6
Kanawha	West Virginia	6.3	229,515	1.4

Table 8.2 County rank of sulfate population exposures associated with
1975 base-case scenario

County	State	Annual SO ₄ level (μg/m ³)	Population	Annual exposure level (μg/m ³ per 10 ⁶ persons)
Baltimore	Maryland	5.6	1,526,836	8.5
Washington	D.C.	6.8	756,510	5.2
Prince Georges	Maryland	6.7	660,567	4.4
Norfolk/ Chesapeake	Virginia	8.3	508,494	4.2
Montgomery	Maryland	6.7	522,809	3.5
Fairfax	Virginia	6.9	487,763	3.4
Fulton	Georgia	5.2	607,592	3.2
Henrico	Virginia	6.5	403,985	2.6
Harris	Texas	1.3	1,741,912	2.2
Jefferson	Kentucky	3.2	695,055	2.2
Kanawha	West Virginia	9.0	229,515	2.1
Jefferson	Alabama	3.1	644,991	2.0
Arlington	Virginia	6.9	285,222	2.0
New Castle	Delaware	5.0	385,856	1.9
Anne Arundel	Maryland	6.2	297,539	1.8
Davidson	Tennessee	4.1	448,003	1.8
DeKalb	Georgia	4.0	415,387	1.7
Guilford	North Carolina	5.6	288,590	1.6
Virginia Beach	Virginia	8.5	172,106	1.5

Fig. 8.3. Population exposure to sulfur dioxide based on 1985 population projections and sulfur dioxide concentrations. Interval limits expressed in micrograms per cubic meter $\times$ population density $\times 10^{-6}$: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$.

Fig. 8.4 Population exposure to sulfates based on 1985 population projections and sulfate concentrations. Interval limits expressed in micrograms per cubic meter $\times$ population density $\times 10^{-6}$: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$.

Table 8.3. County rank of SO₂ population exposures associated with
1985 base-case scenario

County	State	Annual SO ₂ level (µg/m ³)	Population	Annual exposure level (µg/m ³ per 10 ⁶ persons)
Jefferson	Kentucky	11.3	812,000	9.2
Fulton	Georgia	8.9	743,000	6.6
Baltimore	Maryland	3.6	1,758,000	6.3
Washington	D.C.	5.8	938,000	5.4
Harris	Texas	2.4	2,172,000	5.2
Prince Georges	Maryland	5.7	883,000	5.0
DeKalb	Georgia	7.6	528,000	4.0
Jefferson	Alabama	4.8	704,000	3.4
Guilford	North Carolina	10.1	332,000	3.4
Cobb	Georgia	13.1	252,000	3.3
Shelby	Tennessee	3.8	836,000	3.2
Montgomery	Maryland	4.7	666,000	3.1
Davidson	Tennessee	5.9	515,000	3.0
Fairfax	Virginia	4.6	648,000	3.0
Gaston	North Carolina	16.6	168,000	2.8
Mecklenburg	North Carolina	6.7	412,000	2.8
Mobile	Alabama	7.4	369,000	2.7
Kenton	Kentucky	19.3	142,000	2.7
Bexar	Texas	2.2	1,049,000	2.3
Campbell	Kentucky	23.3	97,000	2.3

Table 8.4. County rank of sulfate population exposures associated with 1985 base-case scenario

County	State	Annual SO ₄ level (µg/m ³)	Population	Annual exposure level (µg/m ³ per 10 ⁶ persons)
Baltimore	Maryland	6.9	1,758,000	12.1
Washington	D.C.	8.4	938,000	7.9
Prince Georges	Maryland	8.2	883,000	7.2
Harris	Texas	3.0	2,172,000	6.5
Norfolk/ Chesapeake	Virginia	10.5	601,000	6.3
Montgomery	Maryland	8.3	666,000	5.5
Fairfax	Virginia	8.5	648,000	5.5
Fulton	Georgia	6.3	743,000	4.7
Henrico	Virginia	8.1	467,000	3.8
Jefferson	Kentucky	4.4	812,000	3.6
Mecklenburg	North Carolina	8.4	412,000	3.5
Jefferson	Alabama	4.7	704,000	3.3
Arlington	Virginia	8.5	349,000	3.0
New Castle	Delaware	6.2	457,000	2.8
Davidson	Tennessee	5.4	515,000	2.8
DeKalb	Georgia	5.2	528,000	2.8
Anne Arundel	Maryland	7.6	356,000	2.7
Kanawha	West Virginia	11.6	222,000	2.6
Shelby	Tennessee	3.0	836,000	2.5
Guilford	North Carolina	7.1	332,000	2.4

Fig. 8.5. Population exposure to sulfur dioxide based on 2000 population projections and sulfur dioxide concentrations. Interval limits expressed in micrograms per cubic meter $\times$ population density $\times 10^{-6}$: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$.

Fig. 8.6. Population exposure to sulfates based on 2000 population projections and sulfate concentrations. Interval limits expressed in micrograms per cubic meter $\times$ population density $\times 10^{-6}$: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$.

Table 8.5. County rank of SO₂ population exposures associated with
2000 base-case scenario

County	State	Annual SO ₂ level (µg/m ³)	Population	Annual exposure level (µg/m ³ per 10 ⁶ persons)
Jefferson	Kentucky	11.6	912,000	10.6
Fulton	Georgia	8.9	866,000	7.7
Baltimore	Maryland	3.8	1,931,000	7.3
Washington	D.C.	5.9	1,111,000	6.6
Prince Georges	Maryland	5.8	1,097,000	6.4
Harris	Texas	2.4	2,599,000	6.2
DeKalb	Georgia	7.7	628,000	4.8
Guilford	North Carolina	12.7	353,000	4.5
Shelby	Tennessee	4.9	894,000	4.4
Cobb	Georgia	13.1	302,000	4.0
Montgomery	Maryland	4.8	795,000	3.8
Jefferson	Alabama	5.1	740,000	3.8
Fairfax	Virginia	4.7	789,000	3.7
Davidson	Tennessee	6.2	566,000	3.5
Mobile	Alabama	7.4	439,000	3.2
Mecklenburg	North Carolina	7.0	450,000	3.2
Gaston	North Carolina	17.0	181,000	3.1
Kenton	Kentucky	20.3	150,000	3.1
Bexar	Texas	2.2	1,228,000	2.7
Knox	Tennessee	7.6	346,000	2.6

Table 8.6. County rank of sulfate population exposures associated with 2000 base-case scenario

County	State	Annual SO ₄ level (μg/m ³)	Population	Annual exposure level (μg/m ³ per 10 ⁶ persons)
Baltimore	Maryland	7.5	1,931,000	14.5
Washington	D.C.	9.2	1,111,000	10.2
Prince Georges	Maryland	9.0	1,097,000	9.9
Harris	Texas	3.3	2,599,000	8.6
Norfolk/ Chesapeake	Virginia	12.4	634,000	7.9
Fairfax	Virginia	9.3	789,000	7.3
Montgomery	Maryland	9.1	795,000	7.2
Fulton	Georgia	6.8	866,000	5.9
Henrico	Virginia	9.2	520,000	4.8
Jefferson	Kentucky	4.9	912,000	4.5
Mecklenburg	North Carolina	9.5	450,000	4.3
Jefferson	Alabama	5.6	740,000	4.1
Arlington	Virginia	9.2	403,000	3.7
DeKalb	Georgia	5.6	628,000	3.5
New Castle	Delaware	7.0	493,000	3.5
Davidson	Tennessee	6.0	566,000	3.4
Anne Arundel	Maryland	8.4	399,000	3.4
Shelby	Tennessee	3.5	894,000	3.1
Virginia Beach	Virginia	12.7	233,000	3.0
Guilford	North Carolina	8.1	353,000	2.9

Table 8.7. SO₂ population exposures associated with 1985 base-case scenario for 11 study areas in 6 states in the South

State	County	Annual SO ₂ level (µg/m ³)	Population	Annual exposure level (µg/m ³ per 10 ⁶ persons)
Alabama	Jefferson	4-7	704,000	2.9
	Walker	4-7	60,000	0.3
	Shelby	2-4	43,000	0.1
Alabama	Mobile	0.6-5	369,000	0.6
	Washington	0.8-3	19,000	<0.1
Florida	Hillsborough	1-5	601,000	1.4
	Polk	0.5-5	273,000	0.3
Georgia	Bartow	2-15	40,000	0.2
	Cobb	3-5	252,000	1.1
	Floyd	2-7.5	89,000	0.4
Georgia	Carroll	1-10	56,000	0.2
	Coweta	1-7.5	39,000	0.2
Georgia	Bibb	1-3	177,000	0.3
	Monroe	2-6	14,000	<0.1
Mississippi	Harrison	0.6-3	156,000	0.2
	Jackson	0.4-3	106,000	0.1
North Carolina	Catawba	2-6	104,000	0.3
	Cleveland	1-4	82,000	0.2
	Gaston	3-5	168,000	0.6
North Carolina	Person	2-15	31,000	0.2
Texas	Franklin	1-5	6,000	<0.1
	Titus	1-30	21,000	0.1
Texas	Fort Bend	1-5	65,000	0.2

8.5 Discussion

8.5.1 Regional patterns of exposure

Examination of Table 8.1 reveals that the highest estimated levels of population exposure to sulfur dioxide in 1975 occurred in northern Kentucky and northern Maryland. The District of Columbia and counties in northern Georgia, central Tennessee, and southwestern North Carolina were also areas with high sulfur dioxide levels. For the 1975 base-case scenario, the highest estimated population exposure occurred in Jefferson County, Kentucky. The magnitude of the exposure value was influenced strongly by the relatively high population density of Jefferson County. Other counties, such as Campbell County, Kentucky, had much higher estimated levels of SO_2 , but had significantly lower levels of population exposure due to lower population densities. The county with the highest estimated SO_2 level in the 1975 base-case scenario, Marshall County, West Virginia, had a population of only 38,000, and thus had a much lower level of total population exposure.

The highest estimated sulfate exposure levels occurred in northern Maryland and the District of Columbia (Table 8.2). Estimated levels of sulfate concentration ranging to $9.0 \mu\text{g}/\text{m}^3$ also occurred in southern and central Virginia, northern Georgia, southwestern North Carolina, and southeastern Texas. Baltimore County, Maryland, had the highest estimated sulfate exposure level for 1975. As was the case with the sulfur dioxide exposure calculations, the population density of the county strongly affected the magnitude of the population exposure level. Kanawha County, West Virginia, had the highest estimated sulfate level but had an exposure level only 25% of that of Baltimore County, due to the significantly lower population.

It is important to realize that estimated levels of SO_2 and sulfates are calculated only for January, when meteorological conditions would tend to maximize the exposure from a particular level of pollutant release. Extrapolation of this single-month calculation to an entire year represents a "worse-case" situation and should be interpreted as such. Predicted January levels of SO_2 within the counties composing the southern region generally fall far below the $80 \mu\text{g}/\text{m}^3$ primary standard (annual average concentration) established for SO_2 .

Table 8.3 and 8.4 give the highest levels of population exposure to SO_2 and sulfates for the 1985 base-case scenario. The highest levels of SO_2 exposure generally occur in the same counties as in the 1975 base-case scenario. The only change in the overall listing occurs where two highly urban counties in eastern Texas, Harris and Bexar, replace Forsyth County, North Carolina, and Kanawha County, West Virginia. The highest estimated level of population exposure is found in Jefferson County, Kentucky. The 1985 estimated population exposure in Jefferson County shows an increase over the 1975 figure of 47% due to a 24% increase in SO_2 level and a 17% increase in population. The highest estimated SO_2 level occurs in Campbell County, Kentucky,

at $23.2 \mu\text{g}/\text{m}^3$, although the smaller population of Campbell County produces a much lower population exposure level than Jefferson County.

An examination of the regional sulfate loading pattern for 1985 reveals that the highest level population exposure occurs in generally the same counties as in the 1975 scenario. The only change in the listing of counties with the twenty highest levels of exposure is the replacement of Virginia Beach, Virginia, by Shelby County, Tennessee. As in the case of the 1975 scenario, Baltimore County, Maryland, has the highest exposure level to sulfates. Kanawha County, West Virginia, has the highest predicted sulfate level at $11.6 \mu\text{g}/\text{m}^3$. The estimated 1985 sulfate level in Kanawha County is 29% greater than the value for the 1975 base-case scenario. A total of 28 counties in the region have estimated sulfate levels for 1985 in excess of the $8\text{--}10 \mu\text{g}/\text{m}^3$ range associated by some investigators with the aggravation of symptoms in asthmatics and individuals with heart and lung disease.

A review of Tables 8.5 and 8.6 reveals where the highest levels of population exposure to SO_2 and sulfates occur in the 2000 base-case scenario. The highest estimated levels of SO_2 exposure occur in northern Kentucky, northern Georgia, northern Maryland, and the District of Columbia. In general, the 2000 population exposure pattern is not significantly different from that for 1985. Jefferson County, Kentucky, continues to have the highest estimated level of SO_2 exposure. Estimated SO_2 levels increase over 1985 levels by 3%, and the population increases by 12%. The projected SO_2 levels for the next highest county, Fulton County, Georgia, remain constant in the 1985 and 2000 base-case scenarios. Campbell County, Kentucky, again has the highest predicted SO_2 level at $24.3 \mu\text{g}/\text{m}^3$, a 5% increase over that predicted for 1985.

The distribution of sulfate exposure levels in the 2000 base-case scenario closely follows the pattern predicted for the 1985 scenario. Counties in north-central and central Maryland, eastern Texas, and southern Virginia have the highest levels of population exposure. Baltimore, Maryland, continues to have the highest level of population exposure to sulfates in the 2000 base-case scenario, and Virginia Beach, Virginia, has the highest estimated level of sulfates within the region at $12.7 \mu\text{g}/\text{m}^3$. This value is just slightly greater than the $12.6 \mu\text{g}/\text{m}^3$ value predicted for Kanawha County, West Virginia, in the 2000 base-case scenario. A total of 71 counties within the region have estimated sulfate levels above $10 \mu\text{g}/\text{m}^3$. This is an increase of 43 over the number of counties predicted for the 1985 base-case scenario.

8.5.2 Site-specific calculations of exposure for 1985

Table 8.7 shows the ranges of 1985 sulfur dioxide levels and populations for each of the eleven study areas. The highest estimated levels of SO_2 are found in Titus County, Texas; Bartow County, Georgia; and Person County, North Carolina. In no instance do any of the estimated levels of sulfur dioxide approach either the $80 \mu\text{g}/\text{m}^3$ annual standard or the $100 \mu\text{g}/\text{m}^3$ level considered by some investigators to be the threshold for impacts on human health.

8.6 Conclusions

The data presented in Tables 8.1 through 8.6 can be used to identify those areas within the southern region which are of greatest interest from the standpoint of population exposure to sulfur dioxide and sulfates. In general, the same areas have the highest estimated exposure levels in each of the three base-case scenarios. Jefferson County, Kentucky; Baltimore County, Maryland; Washington, D.C.; and Fulton County, Georgia, are assigned the highest sulfur dioxide exposure levels in each of the three scenarios. Baltimore County, Maryland; Washington, D.C.; and Prince Georges County, Maryland, have the highest estimated sulfate exposure levels in the 1975, 1985, and 2000 base-case scenarios.

It is possible to further examine these critical areas from the standpoint of relative population exposure. Table 8.8 lists the relative population exposures for counties with the highest estimates of sulfur dioxide and sulfate exposure. These values were obtained through comparison of estimated exposures for the individual county with an average exposure level calculated for all of the counties in the region. Four counties are shown in Table 8.8 which have relative population exposures to sulfur dioxide that range from 58 to 30 times the average exposure value for the region. These four counties are listed because the counties were assigned the highest estimated levels of sulfur dioxide exposure in Tables 8.1, 8.3, and 8.5. Jefferson County, Kentucky; Baltimore County, Maryland; and Washington, D.C., show a decreasing trend in relative exposure indices. Fulton County, Georgia, on the other hand, shows an increase in exposure index. With regard to relative population exposures to sulfates, indices listed in Table 8.8 range from 34 to 65 for the three counties listed in Tables 8.2, 8.4, and 8.6 as having the highest estimates of population exposure. Both Baltimore County, Maryland, and Washington, D.C., show a decreasing trend in relative population exposure. The remaining area, Prince Georges County, Maryland, shows a rather stable level of population exposure relative to the rest of the region.

In conclusion, it must be mentioned that the use of population exposure as an indicator of health impact has certain inherent limitations. It does not allow for consideration of dose rate effects or for consideration of small groups of individuals who may receive inordinately high levels of exposure. Nevertheless it does provide a means to screen those areas where population density and estimated pollutant concentrations combine to produce high levels of population exposure. In light of the limitations on population information, the resolution of our transport models, and the uncertainties associated with currently available dose response functions, this approach is probably most appropriate.

Table 8.8. Relative population exposures to sulfur dioxide and sulfates in high-exposure counties for 1975, 1985, and 2000 scenarios

County	State	Relative population exposures		
		1975	1985	2000
<i>Sulfur dioxide exposures</i>				
Jefferson	Kentucky	57	58	48
Baltimore	Maryland	41	39	34
Washington	D.C.	33	33	30
Fulton	Georgia	31	41	48
<i>Sulfate exposures</i>				
Baltimore	Maryland	65	58	52
Washington	D.C.	40	38	36
Prince Georges	Maryland	34	34	35

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9. REGIONAL SOCIOECONOMIC IMPACTS

9.1 Introduction and Major Findings

In socioeconomic impact assessment the unit of analysis may be the nation, a region, an impact area, or an individual site. In evaluating the impacts associated with a plausible siting pattern for the NCUA base-case scenario, a large number of sites is involved. There are at least two methodological approaches that have been used in such a situation.

One approach is the surrogate site analysis, in which typical sites are selected to evaluate social and economic impact. The results can be extrapolated to all sites in the scenario or siting pattern. There are at least three general errors that can be associated with this method: (1) specification error will occur if the impact model fails to reflect the conditions actually occurring at the site for a given length of time; (2) sampling error can arise when the distribution of impact model parameters over all possible sites is not known but is estimated with a sample; and (3) aggregation error will occur if there are differences between measures derived from a summation of impact calculations over all individual sites and those estimated from a smaller number of typical sites. These general errors are not unique to the surrogate site approach, but they can be a significant problem when typical site generalizations are applied to specific sites or when the results must be aggregated for scenario comparison.

A second methodological approach begins with a plausible siting pattern and evaluates one or more impact topics across all sites and regions. If necessary the results may be generalized by site classification. The disadvantage of this approach is that a comprehensive analysis of all sites is usually not feasible. Consequently, some important impacts may not be emphasized by this method. However, comparisons between sites and regions can be made and possibly more confidence can be placed in the aggregated assessments for comparing scenarios or siting patterns.

ORNL's socioeconomic assessment is of the second type. The assessment was designed to evaluate the potential impacts from development of new coal mines, electric generating facilities, and synthetic fuels plants under the NCUA base-case scenario. Socioeconomic comparisons were made in the assessment by using three impact indicators. Two indicators (material input expenditures and new retail business trade) measured potential economic benefits, while the third indicator (population growth rate) measured potential social costs. The assessment, based on the preliminary analysis, was not intended to be comprehensive or to develop a cost-benefit evaluation of the base-case scenario. (See Appendix D for an in-depth background review of social and economic costs associated with mining.) Such analysis was beyond the resources available for this assessment. Rather, this assessment was designed to point up key regions and site differences in order to identify the necessary research directions for future work.

An alternative approach could have conducted case studies of counties which might have been, on the surface, viewed as prototypical, rather than examining all counties in the southern NCUA region. Where full knowledge of a region exists on the basis of past studies, it is valid to select such prototypical counties; then in-depth studies of these counties can be appropriate as a first research task. However, in the case of the southern NCUA region, which covers a large number of states and where there is considerable variation among the counties, it would have been hazardous at the beginning of the assessment to have designated counties as prototypical for intensive studies for generalization purposes. Thus, the preliminary assessment gave considerable attention to developing key descriptors, background data, and general analysis for a large number of counties.

For example, the proportion of coal-generating plant construction materials that could be purchased within a given economic region [Bureau of Economic Analysis (BEA) area] was analyzed. These purchases, which generally represent a local economic benefit, varied from 5% to 78% for BEA areas nationwide, with the results being highly correlated with population size and the percent of urbanization. Thus, large urbanized BEA areas with highly developed and diversified economies would usually receive higher dollar amounts of material purchases. Smaller, less industrialized BEA areas may receive lower dollar amounts from internal purchases, but the construction of a plant may still provide an important economic stimulus.

As is shown in Sect. 9.2, the siting pattern is a significant determinant of the total internal supply potential. For example, using the 1985 base-case siting plan, about 31% of total material purchases would be supplied internally from within the same BEA area where the additional capacity is located. Internal supply potential was 20% for the 2000 siting plan and 18% for the 2020 siting plan. This pattern of total internal supply proportions occurs because the 1985 and 2000 siting plans locate new generating capacity in BEA areas that can supply the needed construction materials. If a BEA area has industries that can supply needed construction materials, its local economy will be stimulated by the expenditures for local purchases.

These findings suggest that it would be fruitful to conduct comparative cost analysis to identify whether or not the location of a new plant in one or more of the BEA areas examined can be justified on the basis of the new demands — especially for the major plant construction and operation inputs. (See ref. 1 for discussion of the comparative cost analysis approach and for citations of comparative cost studies. See ref. 2 for an estimate of the impact of the construction of a nuclear energy center on the increase in capacity in nearby counties to provide the basic *cement* input.) Such location of new plants would provide economic stimulus and should be investigated in future assessments.

A second indicator of potential economic benefit used in the assessment was the increase in local business trade forecast to result from wage expenditures by new work forces in counties with coal-related developments. Trade increases were defined to include new retail, service,

and wholesale receipts created by sales to new workers who move to a county site. Our analysis of trade increases, like our analysis of internal supply potentials, was intended to measure the economic stimulation expected from coal-related developments at different sites. Business trade multipliers were calculated for each county in the region expected to have new coal-related developments under the base-case scenario. County trade multipliers varied from 1.22 to 1.91, with densely populated counties having larger multipliers and consequently receiving the largest multiplier benefits from each dollar of wage expenditure. However, the benefits to small counties were still important. The multipliers were used to calculate examples of new-trade receipts for all sited counties.

Initial findings suggest that while it would be infeasible to conduct detailed input-output analysis for all counties in the southern NCUA region, in order to identify more precise multiplier effects covering all economic sectors in a county, it would be highly desirable in a future assessment effort to conduct such analysis for two or three prototypical counties in the following categories: (1) rural in rural BEA area, (2) rural in urban BEA area, (3) urban in rural BEA area, and (4) urban in urban BEA area. These classifications are discussed later in Sect. 9.5. (See ref. 2 for a relevant type of approach.) The findings also suggest that the traditional input-output study should be extended where possible to include public goods and services.

For the trade sector under the 1985 siting plan, business trade in host counties was forecast to range from \$0.6 million in South Carolina to \$94.8 million in Kentucky. In 2000, trade receipts ranged from \$0.6 million in Georgia to \$158.2 million in Kentucky. In 2020, receipts ranged from zero in Georgia to \$414.9 million in West Virginia. The total trade receipts forecast for the 12-state region were \$280, \$447, and \$1247 million for 1985, 2000, and 2020 respectively. These estimates represented new expenditures for the year when construction work forces were at their peak. They did not include expenditures for years before or after the peak of construction employment. Trade receipts will differ from year to year during the construction period. In future analysis, we will examine carefully the time pattern of economic impact and multiplier effect for a set of prototypical county types. (Such a time pattern has been examined in ref. 2.) The primary purpose of these peak-year estimates was to demonstrate the economic impact of the plausible siting patterns developed. Different siting patterns will produce significantly different new-trade receipts at both the county and state levels.

Social constraints or social costs can occur from new energy developments as well. One frequently observed negative impact of energy developments is the so-called boom-town phenomenon, where very rapid population growth occurs, resulting in a demand for public and private goods and services that exceeds the community's ability to provide these services. Services that are typically hard hit include housing, transportation, health care, and education. Conversely, a "bust" effect may occur if significant public and private investment in services occurs and is followed by an exit of the temporary work force, resulting in excess service capacity and unmanageable public indebtedness.

The probability of a boom-town-type impact was estimated by calculating expected rates of county population growth that would result directly from increased employment in coal-related facilities, including new synthetic fuels plants, generating plants, or mining employment. We assumed that counties with annual growth rates of less than 5% would not be adversely impacted, while those with rates from 5 to 15% would be moderately impacted and those above 15% would be severely impacted. Of the 186 counties in the 12-state region with new coal-related developments, 54 were expected to experience annual growth rates greater than 5% for some year between now and 2020. Thirty-seven of these were forecast to experience increases of 5 to 15%, and 17 to experience increases above 15%. Most of the counties with annual growth rates above 15% were in Kentucky, Texas, and West Virginia. The largest growth rates usually resulted from (1) the construction of large (4000 to 7000 MWe) generating complexes, (2) the construction of several types of facilities in the same county, or (3) large increases in mining employment.

In general, we believe that the influence of alternative siting patterns on socioeconomic effects is demonstrated by all three of the indicators examined. The distribution of internal material supply purchases, trade increases, and high population growth rates was different for each siting plan (1985, 2000, and 2020). While physical factors such as water availability or air quality usually dominate siting decisions, socioeconomic consequences follow whatever decisions are made. In general, material purchases and trade increases are lowest and population growth pressure highest for rural counties in rural regions.

It was recognized however, that future analysis should take into account more thoroughly the commuting patterns of the new labor force. Some of the work force will be in-migrants of a permanent character (largely associated with production operations and maintenance), and some will be in-migrants of a temporary character (associated with construction activity). An extension of the analysis for prototype counties would help to identify more precisely both site and nonsite counties for which coal mining, coal-fueled electric generation, and synthetic fuel production, either singly or in combination, might impose significant pressures and burdensome long-term effects from rapid growth. (It is also appreciated that in carrying through the extension, the procedures should be applied that will permit the injection into the analysis of specific situations of each county.)

9.2 Assessment of Internal Material Supply Potentials

This section presents an evaluation of the internal material supply potential of BEA areas forecast to host future coal-fired power plants. An 800-MWe coal electric plant was assumed for the analysis. A second purpose is to assess the potential internal material supply that may be associated with coal electric capacity additions across the 12-state southern region under the base-case scenario.

An 800-MWe coal electric plant requires a variety of regional material inputs that can be classified according to the Standard Industrial

Classification (SIC) directory.³ Since many of the materials supplied from local sources come from the economic area surrounding the site, BEA areas were chosen as the basic unit of analysis for this part of the socioeconomic section. There are 173 BEA areas that define the fundamental economic space around major population centers in the United States. In this analysis, purchases from within BEA areas forecast to host plants were considered local purchases that had local economic effects. Materials that would be imported from outside the site BEA area were assumed to produce very little direct or multiplier effects on local area jobs and income.

The steps in the procedure for calculating potential material input supply by BEA are enumerated below:

1. A list of material inputs for an 800-MWe coal plant was obtained from the Bechtel Corporation.^{4,5} These inputs are listed in the first column of Table 9.1 and Appendix G.2, Table G.1.
2. Each material input was identified by Standard Industrial Classification (SIC) code descriptions in the SIC directory.³ The SIC codes are given in columns 2 and 3 of Table 9.1 and Appendix G.2, Table G.1.
3. The Bechtel dollar estimates of expenditure by input category were converted to percentages of total material expenditure. These percentages are listed in the 5th column of Table 9.1.
4. By applying a location quotient (LQ), each BEA area was evaluated for its potential to supply each three-digit SIC material input. A BEA area was assumed to have the potential for supplying inputs from manufacturing industries with an LQ greater than 1.0.
5. The total proportion of all materials supplied from within each BEA area was obtained by adding the proportions supplied in each input category. All sand, gravel, and form lumber was assumed to be supplied by the site BEA area. Therefore, the expenditure proportions for these input categories were always included in the BEA area total. The expenditure proportions for all other three-digit SIC material inputs were included in the BEA area total if the industry LQ was greater than 1.00. If the LQ was less than 1.00, it was assumed that the input would be supplied by sources outside the BEA area, and the proportions were not included in the BEA area total.

The location quotient used in this study is based on three-digit Standard Industrial Classification (SIC) categories that were created for BEA areas from 1972 county business patterns data. The LQ equation is of the form

$$LQ_{ir} = \frac{SIC_{ir}/MANF_{ir}}{SIC_{in}/MANF_{in}},$$

Table 9.1. Materials and equipment list to construct an 800-MW coal electric plant

	Standard Industrial Classification Class		Cost (1977 dollars)	Percentage of total
	Two-digit	Three-digit		
Materials				
Wood products	24	242	2,722	2.04
Chemicals and allied products	28	282		
		285	597	.45
Rubber and miscellaneous plastics	30	304-6		
Petroleum and coal products	29	295	2,396	1.79
Stone, clay, and glass products	32	327	2,306	1.73 ^a
		329	1,160	.87 ^a
Primary metals	33	331	1,515	1.14
		335	2,406	1.80
Fabricated metal products	34	344	8,264	6.20
Other fabricated products		349	5,381	4.03
Total			26,747	20.05
Equipment				
Fabricated metal products	34	344	48,234	36.15
Machinery, except electrical	35	351	29,294	21.96
		353	10,928	8.19
		356	6,254	4.69
		358	1,287	.96
Electrical and electronic equipment	36	361	4,336	3.25 ^a
		362	1,073	.80 ^a
		364	719	.54 ^a
Instruments and related products	38	381		
		382	2,330	1.75
		384		
		387		
Total			104,456	78.29
Miscellaneous materials and equipment (unclassified)			2,222	1.66
Grand total			133,425	100.00

^aDetail estimated by Oak Ridge National Laboratory (ORNL).

Sources:

1. P. F. Paskert and J. M. Gallagher, *Escalation in the Costs and Manpower, Materials, and Equipment Needed for Energy Facilities*, Bechtel Corporation, San Francisco, Calif., October 1977, p. 3-3 and Table E54, p. 6-54.
2. J. R. Hogle et al., *Manpower, Materials, and Capital Costs for Energy-Related Facilities*, Bechtel Corporation, San Francisco, Calif., April 1976, pp. 102-111.
3. *Standard Industrial Manual 1972*, U.S. Government Printing Office, Washington, D.C., 1973.

where

LQ_{ir} = the location quotient for a three-digit SIC manufacturing industry designated i in a site BEA area designated r ,

SIC_{ir}, SIC_{in} = employment in a three-digit manufacturing SIC industry (i) in the BEA area (r) and nation (n) respectively,

$MANF_{ir}, MANF_{in}$ = total manufacturing employment in the region and nation respectively.

A location quotient exactly equal to 1.00 indicates the site BEA area has the same percentage employment in that industry as is observed at the U.S. level. This result is generally interpreted to reflect a self-sufficiency in that region with respect to the industry in question. LQ values less than 1.00 indicate areas that are likely importers of goods produced by that industry, and LQ values greater than 1.00 suggest probable export capability. (When it is not possible, because of limited research time and resources, to conduct input-output studies, or if it is not feasible to use shortcut input-output studies involving aggregate sectors, the location quotient becomes a very useful tool to identify the order of industrial magnitude in different regions.)

The assumption in this analysis was that materials that could be supplied locally would be supplied by the site BEA area. (This assumption has been suggested by Isard et al.¹ as a means of obtaining a base estimate of local material purchases. Adjustments could be made in specific cases to incorporate qualifying conditions such as contractual arrangements and input quality requirements.) This may not be true if one or more inputs are purchased through competitive bidding or by prior contract. Nevertheless, the estimates provide a measure of potential supply and therefore some indication of the effectiveness of a policy to maximize local purchases, should such a policy be encouraged as a mitigation strategy. Potential supply deficit areas can also be identified. Groups of such areas provide new markets that stimulate new growth in some regional industries. Consequently, a system of energy facilities developed over a long period of time may have significant impact on regional development.

As shown in Fig. 9.1, there were 66 BEA areas which could supply 0 to 25% of required materials (measured in 1977 dollar values) for an 800-MWe coal plant. There were 66 BEA areas in the 25.01 to 50.00% category, 33 in the 50.01 to 75% group, and 8 in the 75.01 to 100% category. The last two categories are potential suppliers of many of the material inputs that would be imported by members of the first two categories. Examples of expenditure proportions for selected BEA areas in the South are displayed in columns 5, 6, and 7 of Table 9.2.

0 - 25.00   25.01 - 50.00   50.01 - 75.00   75.01 - 100.00

Fig. 9.1. Estimated percent of material inputs purchased in site region; hypothetical 800-MWe coal electric plant in BEA economic areas.

Table 9.2. Additions to coal electric capacity and potential percent of material inputs supplied by site BEA area: 1985, 2000, and 2020

BEA area	Coal capacity addition (MWe)			Potential internal material supply fraction		
	1985	2000	2020	1985	2000	2020
19		1,134			0.0592	
20		3,597			0.3279	
21			4,000			0.0722
22			298			0.0768
23	3,670			0.0512		
27		1,644			0.1049	
30	280	5,955	3,568	0.0785	0.0785	0.0785
35			5,157			0.1067
36		2,622	10,000		0.3578	0.3578
37	1,442			0.3552		
38	518			0.0592		
40			2,406			0.0512
41	3,300	236		0.1052	0.1052	
44	896			0.3875		
45	2,732	2,481	1,467	0.4123	0.4123	0.4123
46	700	700		0.0973	0.0973	
47			315			0.1083
49		672	4,000		0.0745	0.0745
50		3,409	4,962		0.0745	0.0745
51			1,448			0.0691
52	1,300	1,073	9,165	0.2107	0.2107	0.2107
54	1,588	1,350		0.5158	0.5158	
55	400			0.5492		
62	4,330			0.4118		
64	1,252		6,502	0.4222		0.4222
66	17,930			0.7816		
115		211			0.0657	
122	951			0.0512		
123	950			0.0512		
124	43			0.4107		
129	1,200			0.3072		
130	5,250			0.4616		
131	2,334			0.3563		
133	266		530	0.1021		0.1021
134		1,621	3,977		0.0950	0.0950
136	720			0.1894		
137	1,456		2,000	0.1749		0.1749
138	1,620			0.3336		
139	540	540		0.3336	0.3336	
141	3,920		4,795	0.6140		0.6140
142	2,186			0.6620		
Total						
800-MWe plant				0.3143	0.1941	0.1824
Base-case scenario	61,774	27,245	64,590	0.4696	0.2024	0.2268

The extrapolation of the internal supply potential results to the base-case scenario involved (1) identifying the BEA areas with generating capacity additions at various points in time between 1980 and 2020, (2) converting planned additions to 800-MWe standard units, and (3) applying the relevant internal expenditure percentages that were estimated above. By summing over the BEA areas in ORNL's region, an estimate was obtained that measured the total potential expenditures that would be internal to the site regions.

The projected coal electric capacity additions under the base-case scenario that will be constructed by 1985, 2000, and 2020 are displayed in columns 2, 3, and 4 of Table 9.2. The subset of BEA areas in the South which have any capacity additions is different for each time period. That is, the list of BEA areas in column 1 overlaps with, but is not identical to, the lists of BEA areas in columns 3 and 4. Differences in the sets of BEA areas included by time period results in differences in the levels of total internal expenditures, even if variations in the size of additions are not considered. The next to last row in Table 9.2 displays the levels of regional internal expenditure that would result if capacity additions in the BEA areas in each siting pattern were single 800-MWe units. If a standard unit were sited in each county in the 1985 siting plan, the internal material purchases to build coal electric capacity in the South would be about 31% of total material purchases. With standard units in each county in the 2000 siting plan, internal purchases would be about 20% of the total; and in 2020, about 18% of the total.

The results in the next to last row of Table 9.2 show the effect of varying which BEA areas are included in a siting plan while holding the size of capacity additions constant. The results in the bottom row show the effect of varying both the BEA areas included and the size of capacity additions. To obtain the regional internal supply proportions in the last row, the fractions in columns 6, 7, and 8 were weighted by the size of the generating capacity additions in columns 2, 3, and 4. To accomplish the weighting, the planned capacity additions in columns 2, 3, and 4 were converted to multiples of 800 MWe, and then these multiples were used to weight the fractions in columns 6, 7, and 8. Internal expenditures under the 1985 pattern of additions are about 47%. Under the 2000 and 2020 patterns, the internal expenditures are about 20% and 23% respectively. By comparing the last two rows of Table 9.2, one can see the influence of unequal capacity allocations over the various BEA areas in the siting patterns.

In summary, the results presented in this section indicate that most of the list of three-digit SIC inputs could potentially be supplied by the site BEA area in only eight BEA areas. Seventy-six percent of the BEA areas have a potential for supplying material inputs amounting to less than 50% of total material expenditure. This indicates that very few BEA areas are self-sufficient in all the necessary materials for constructing a coal electric plant. Thus, in almost all cases, coal electric capacity additions in one BEA area will have income and employment impacts

in other BEA areas that supply inputs lacking in the site region. The analysis further suggests that, based on the NCUA base-case scenario, the counties forecast to host future coal power plants will experience significant leakage of economic benefits from the purchase of materials required to build these plants. Thus, the economic benefits may not be available to offset any negative social costs experienced by the local area. However, it should be kept in mind that additional research may uncover significant possibilities for the location of new production capacity in the BEA areas examined as well as larger multiplier effects in all the economic sectors involved.

Analysis of the NCUA base-case siting pattern indicates that BEA industry structure and the spatial distribution and size of generating capacity additions combined to produce significantly different patterns of estimated benefits from materials purchases. For the South as a whole, the pattern of generating capacity additions under the base-case scenario resulted in internal input supply levels of 47%, 20%, and 23% in 1985, 2000, and 2020 respectively.

Although this section has demonstrated that a strong link exists between siting and internal material purchase, ORNL is not recommending that plants be sited to maximize internal expenditure potential. Such a policy might quickly exceed the carrying capacity of those few regions in the highest internal percentage categories. Also, benefits from material purchases in some regions may be relatively small but very important to local economies. It is clear that certain highly industrialized BEA areas, particularly members of the largest percentage class in Fig. 9.1, will benefit from any siting pattern whether or not actual capacity is sited in them. These areas will supply some of the more specialized (and expensive) inputs (e.g., turbines and cooling system components) to many other BEA areas. Thus, there may be merit in a siting policy that distributes expenditures more equitably by increasing internal material purchases for less highly developed and diversified BEA areas.

9.3 Assessment of Local Trade Impacts

The second indicator of economic benefit used in ORNL's assessment was business trade generated by construction work forces. Business trade was defined to include economic activity in retail, wholesale, and service sectors.⁶⁻⁸ Increases in trade were calculated for the construction of coal generating plants, synthetic fuels plants, and coal mines. County-level business trade data were used to eliminate possible confounding of results which might occur by aggregation to the BEA region. BEA areas may be so large that effects of coal-related activity in one portion of the region may be disguised by other economic activity in the region. The analysis was centered on the site county in-migrating labor force because data were available to estimate the size of this group. (Data available from TVA suggest that about 30% of the construction work force will move to the site area, and that about 50% of these movers will

locate in the site county. Because data were not available to estimate the size of these groups, this analysis does not consider trade effects due to local residents of the site county, commuters from the site BEA area, or in-migrants to the BEA area in other than site counties.)

The analysis was composed of two steps. First, multipliers were calculated for retail, wholesale, and service sector trade and for total trade by county population size. These multipliers measure the total trade generated in each sector by an initial dollar of new expenditure from outside the local economy — in this case, new wage expenditures by in-migrant construction workers. (These trade multipliers are preliminary procedures and will be supplemented by input-output methods during future analysis.)

A sample of 268 counties in the ORNL region, grouped by nine population categories, was used for this analysis. Trade multipliers were calculated using the "minimum requirements" technique developed by Ullman and Dacey⁹ and Moore.^{10*} Results for each sector and for each population size group are presented in Table 9.3.

The second step in the analysis was the application of the multipliers to 186 southern counties in the base-case scenario for the years 1985, 2000, and 2020. These counties have one or more energy facilities sited in them for one or more of the years studied. The first step in applying the multipliers to the base case was to estimate the number of construction workers locating in each site county. After total construction force sizes were estimated, TVA's assumptions of 30% in-migrants to the area and 50% in-migrants to the site county (i.e., $0.30 \times 0.50 = 0.15$ of the total construction labor force) were applied to obtain the number of county in-migrants. Average employee wages were then calculated. Based on estimates of construction worker incomes from Isard, Reiner, and Van Zele¹¹ and real earnings growth rates derived from OBERs¹² projections, average before-tax earnings in 1977 dollars were projected to be \$18,000 per worker in 1985, \$23,000 in 2000, and \$37,000 in 2020. After-tax earnings were then obtained by multiplying the before-tax earnings by 0.75. Finally, it was assumed that 50% of after-tax income would be spent on

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*The model form is

$$A_{ij} = a_i + b_i \log P_j .$$

The estimated parameters are a_i and b_i , A_{ij} is the observed minimum trade level in industry i and population class j , and P_j is the median population in each population size class j . As suggested by Moore, the multiplier (M) can be defined as

$$M = \frac{1}{1 - kb} ,$$

where kb is the proportion of income spent to consume locally produced goods and services. Moore states that the minimum requirement estimated by the regression technique is a relatively fast and reasonably accurate method for obtaining the kb component.

Table 9.3. Trade multipliers by population class:
ORNL region

Population (thousands)	Median population (thousands)	Retail	Wholesale	Service	Total
<11	8	1.35	1.03	1.06	1.22
11-15	13	1.44	1.06	1.14	1.27
16-25	20	1.53	1.09	1.21	1.32
26-50	34	1.67	1.13	1.31	1.38
51-75	61	1.84	1.18	1.45	1.46
76-100	90	1.98	1.21	1.56	1.52
101-500	230	2.43	1.30	1.90	1.69
501-1000	645	3.23	1.42	2.51	1.91
>1000	1327	4.19	1.51	3.23	2.11

Notes: $MULT_j = \frac{1}{1 - EST_j}$

$$EST_{ij} = a_i + b_i \log P_i$$

i = population class

j = trade type.

total goods and services in the site county. These assumptions are consistent with those used in Isard's analysis.

Thus, to summarize, county-level total trade multipliers were applied according to the formula:

Total receipts = total trade multiplier (M) x number of
in-migrant construction employees x average income x after-
tax percentage (0.75) x local expenditure proportion (0.50) .

The examples of both direct and indirect new business trade occurring to each county from new in-migrants residing there are displayed in Figs. 9.2-9.4. Results aggregated to state levels are presented in Table 9.4 and show for 1985, 2000, and 2020 the state receipts before and after multiplier analysis. (Individual county results are presented in Appendix G.2, Table G.2.) The differences between the direct wage expenditures and the total expenditures in each state is the sum of the county-level indirect amounts which are generated by multiplier effects on wages spent.

Under the base-case siting pattern, total business trade stimulus (inside site counties) in 1985 ranges from a low of \$0.6 million in South Carolina to a high of \$94.8 million in Kentucky. In 2000, total expenditure ranges from \$0.6 million in Georgia to \$158.2 million in Kentucky. In 2020, the total business trade expenditure (in the site counties) ranges from zero in Georgia to \$515.9 million in West Virginia. These estimates represent the direct and secondary expenditures during

Fig. 9.2. Direct and indirect new retail business trade for counties from construction worker income expenditure, 1985; base-case scenario (millions of 1977 dollar equivalents).

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Fig. 9.3. Direct and indirect new retail business trade for counties from construction worker income expenditure, 2000; base-case scenario (millions of 1977 dollar equivalents).

Fig. 9.4. Direct and indirect new retail business trade for counties from construction worker income expenditure, 2020; base-case scenario (millions of 1977 dollar equivalents).

Table 9.4. A summary of direct and multiplier-augmented new business trade expenditure by in-migrants locating in site county under the base-case scenario
(Expenditures in millions of 1977 dollars)

State	1985		2000		2020	
	Direct	Total	Direct	Total	Direct	Total
Alabama	11.8	21.1	15.2	24.3	38.6	62.3
Florida	2.9	5.1	5.0	8.7	47.0	77.8
Georgia	6.3	8.3	0.46	0.6	0	0
Kentucky	69.6	94.8	117.4	158.2	239.9	331.1
Louisiana	4.1	5.9	5.6	8.3	14.6	24.6
Mississippi	3.7	5.4	4.5	6.5	13.3	20.0
North Carolina	5.6	7.6	5.0	7.7	1.1	1.3
South Carolina	0.4	0.6	11.5	16.7	11.0	18.7
Tennessee	2.7	3.6	5.2	6.9	39.6	54.7
Texas	27.4	37.7	17.5	26.6	49.1	69.3
Virginia	17.0	23.3	37.5	51.0	52.0	71.0
West Virginia	49.1	66.8	96.6	131.6	380.0	515.9
Total	200.6	280.2	321.5	447.1	886.2	1246.7

the peak year of the construction. They do not include lesser expenditure levels in each of the construction period years preceding and following the peak. The primary purpose of these estimates was to demonstrate the economic effect of the plausible siting patterns developed. As in the input supply analysis, the unequal siting pattern capacity across states and through time produces significantly different levels of new-trade benefits at county and state levels. Future study of the time pattern of impact during the entire construction period for prototypical counties will lead to more precise annual estimates of impact on total business trade.

9.4 Assessment of Regional Social Costs

This section presents an assessment of regional social costs. An increase in employment and population usually accompanies the development of energy facilities. Large and rapid increases in population often result in a demand for public and private goods and services that increases faster than a community's ability to provide them. A disequilibrium between supply and demand for services such as housing,

transportation, health care, and education may result in a lowered quality of life and various forms of social disruption. Thus, counties with high growth rates from coal development will frequently need assistance in meeting demands for local services.

9.4.1 Classification by growth rates

The strategy of using annual growth rates to identify likely levels of impacts on services is suggested by the boom-town research of Gilmore¹³ and Gilmore and Duff.¹⁴ Social impact analysts generally agree that migration in response to new employment opportunities is a prime determinant of social impact. For example, Gilmore and Duff¹⁴ observed that, in unmanaged growth situations, an annual population growth rate of more than 10% can be expected to strain local service capacities. Furthermore, rates of 15 to 20% annual growth seem to cause breakdowns in local and regional institutions such as housing or labor markets (ref. 12, p. 26). When growth rates exceed 15 to 20%, a severe disequilibrium between the demand for and the supply of local services often develops. The unavailability and severe inadequacy of local supplies of housing, schools, recreation, shopping facilities, water and sewer capacities, etc., results in a degraded quality of life and the associated problems of boom-town growth.¹³

The social impacts of energy developments are, to a large degree, determined by the amounts and rates of population growth created by them. By using population growth rate criteria as outlined above, one can relate the rate of population growth associated with an energy facility to the probability of social impact in the following way:

<u>Annual growth rate</u>	<u>Probability of social impacts</u>
Less than 5%	Low
5% to 15%	Moderate
More than 15%	High

The rate of population growth in the area around an energy facility is not, of course, the only determinant of social impact. It is only one guideline for this initial investigation. Many other factors, including amounts of excess service capacities, proximity to metropolitan areas, capital funding capacities, methods of tax revenue collection and allocation, and planning efforts, influence the effects of plant-related population growth on a community. For the preliminary assessment, projected population changes can provide a rough classification of probable degrees of social impact. There are very few communities that cannot handle growth of 1 or 2% per year. Conversely, there are very few communities that can handle growth of 20 or 30% per year.

9.4.2 Assumptions and procedures

In spite of the attractiveness of the idea of using population growth rates for projecting impact, there are a number of difficulties in predicting such rates. Three of the most significant are: (1) an impact area (base population) must be identified as a denominator for the rate; (2) in order to calculate the amount of population increase due to a facility's location in an impact area, a number of assumptions must be made about the number of in-moving workers, the proportion of workers that will locate in the impact area, the proportion of these workers that will bring families, and the average family size; and (3) assumptions must be made about the timing of construction and operation start-ups and scheduling for all facilities. All of these difficulties can be resolved if one is willing to accept enough assumptions. Some of the assumptions can be justified with evidence from previous energy projects. Other assumptions must be made somewhat arbitrarily.

The assumptions made about factors directly determining growth rates will, of course, determine the level of growth rates predicted. If, for example, states are defined as the impact areas, it is unlikely that any state would have population growth greater than 5% because of coal developments. On the other hand, if towns near a facility site are defined as impact areas, much higher growth rates would be predicted. Similarly, if one assumes that all employees of coal facilities will move into the impact area, much higher growth rates will be predicted than if one assumes that only 10% will move.

In choosing our assumptions for predicting growth rates, we generally have tried to make assumptions that either reflect what has usually happened in the past or are a middle-of-the-road choice in terms of influence on growth rates. We have, for example, defined the county as the impact region. A multicounty or a subcounty impact area would probably be more appropriate for some cases, but, on the average, a county is a reasonable compromise. Similarly, we assume that 30% of employees will move as a result of accepting employment at a coal facility. This is the average proportion of workers that have moved for employment on TVA projects. We chose this rate even though it is lower than the average in-mover rate at 14 western projects that were surveyed by the Old West Regional Commission.¹⁵ The average in-mover rate at those sites was 60% but varied from a low of 21.4% to a high of 96.8%.¹⁵ The lower average TVA experience (30% in-movers) probably results from the different development patterns in the eastern and western United States. In the Southeast, a construction project draws from a broad commuter labor shed. These commuter fields are generally absent at western sites, so that the in-mover rate is usually higher and the probability of boom-town growth is greater. However, these in-mover rates provide a reliable lower and upper bound for the expected rate of in-migration to projects sited for the base-case scenario.

Since ORNL's section of the NCUA report is concerned with a 12-state region in the Southeast, we believe that the TVA experience provides an approximate average for the sites under consideration. Nevertheless, to test the sensitivity of our results to the in-mover rate assumption,

the growth rates projected under a 30% in-mover rate were compared with those that would occur under the 60% rate.

In addition to the assumption of 30% movers, other assumptions based on TVA experience include that (1) the county share of the 30% in-movers will be 50%, (2) 65% of those moving into the county will bring their families, and (3) the average family size will be 3.7.

While typical past TVA experience on the percentage of movers, county share, and average family size could be defined, no identification of an average or typical pattern of peak employment levels in coal facilities by county was possible. Some counties may have one coal mine and no generating facilities, others two generating facilities and no mines, etc. Further, if several new mines and facilities are to be developed, the exact scheduling of the construction and operation phases of each is unpredictable. Because no typical scheduling pattern can be identified, a worst-case approach is used to define the peaking pattern (i.e., the relative overlapping of work forces for all facilities) for coal development by county. The worst case, in terms of producing the maximum population increase due to direct employment, would occur if all coal facilities reached peak employment levels in the same year. Thus, the worst-case peaking assumptions are that all facilities expected to be on line by 1985 in a given county will reach peak employment at the same time, that all facilities expected to be operational in 2000 will peak simultaneously, and that all facilities for 2020 will peak at the same time. As already indicated, the worst-case approach will be relaxed in future research.

Using the assumptions discussed above, examples of new population generated directly by employment in coal facilities were calculated as shown in Fig. 9.5 for each time period (present to 1985, 1985 to 2000, 2000 to 2020) and each county. The method of deriving peak employment figures by facility type is explained in Appendix G.3 for synthetic fuels and generating facilities and in Appendix G.6 for mining employment. Notice that peak employment is summed for all facilities expected to be sited in the county. This includes coal-electric generating, high-Btu synthetic fuels, low-Btu synthetic fuels, coal liquefaction, and coal mining facilities. Notice too that only population increase due to *direct* employment is considered. Secondary employment multipliers are not used in the calculation of the amount of total population increase.

One reason for not using multipliers in the calculation of population increases is that the generation of secondary employment is a several-year process. Secondary employment increases typically lag behind growth in the basic sector. Further, operations employment, which generates most local secondary employment, is significantly lower than construction employment in all coal facilities except mines. As a result, the highest annual growth rate will likely occur at the peak of construction employment. Estimates of the highest growth rate can, therefore, reasonably be based on peak levels of basic employment in construction.

Another reason for not using multipliers in the calculation of impact is that, in the absence of stimulated growth in basic industries,

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Fig. 9.5. Estimation of total new population due directly to coal development.

multiplier effects do not typically induce the in-migration of new population. Most secondary jobs, if they arise, are likely to be filled by local residents. In addition, in the eastern United States multiplier effects are not generally concentrated in a one-county area. The effects are dispersed over the whole economic region. If there are shortages of services due to rapid buildups of construction employment, local trade demands may be supplied by nearby centers where more services are already available. Consequently, the application of secondary multipliers at the county level may overestimate local secondary benefits. Future assessment research will develop methods to apply secondary employment multipliers such as those that can be derived from input-output and related location analysis.

After estimates of total population increase due directly to coal employment were obtained by the procedure described above, the expected change in population was calculated as a percentage of the county's projected population at about the midpoint of the intervals under consideration (i.e., population in 1980, 1990, and 2010). If the expected percentage change is less than 5%, we can conclude that there will be only a manageable level of growth in the county. If the growth is likely to be more than 5%, some shortages of goods and services will probably occur. When growth rates exceed 15%, severe shortages are likely.

9.4.3 Findings

Using the set of assumptions based on average TVA experience (30% movers, 50% county share, 35% single, 65% with families averaging 3.7 members), we found that the recent-trends siting pattern would result in peak growth rates greater than 15% in 17 of the 186 counties with new coal facilities. Two of these counties would grow by more than 15% between now and 1985, one between 1985 and 2000, and fourteen between 2000 and 2010. Of the counties with growth rates greater than 15%, ten are located in West Virginia, three in Kentucky, and two in Texas. Most of the high growth rates are due to the construction of several types of facilities in the same county, to the construction of large (4000 to 7000 MWe) generating complexes, or to increases in mining employment. Under the recent-trends scenario, only four counties have more than one generating or synthetic fuels facility scheduled for construction in a single time period (present to 1985, 1985 to 2000, or 2000 to 2020). The counties with more than one facility to be built in any time period are listed in Table 9.5. All of these counties are in the high-impact category. All other counties in the high-impact category are listed in Tables 9.6-9.8. Table 9.6 lists those counties that have high growth rates due to the construction of generating plants, and Table 9.7 lists those with high rates due to the construction of synthetic fuels plants. Table 9.8 lists counties with high growth rates expected to result from increases in mining employment. Figures 9.6-9.8 map counties with growth rates above 5% by time period (present to 1985, 1985 to 2000, and 2000 to 2020).

Table 9.5. Mix of facility types; peak growth rates by county and county population forecasts^a at the midpoint of the time period

State	County	Service base index ^b	Time period	Facility types	Growth rate (%)	Population at midpoint
Kentucky	Livingston	66	1985-2000	Liquefaction and generating	27.2	9,594
West Virginia	Marshall	137	2000-2020	High-Btu gasification, generating, and mining	22.4	33,307
	Tyler	87		Liquefaction, generating, and mining	48.9	8,964
	Wetzel	122		High-Btu gasification, generating, and mining	33.0	18,572

^aR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^bSee p. 9-35 for an explanation of the service base index.

Table 9.6. High growth rates due to construction of generating facilities;
peak growth rates greater than 15% by county and county population
forecasts^a at the midpoint of the time period

State	County	Service base index ^b	Growth rate (%)			Population		
			Present to 1985	1985-2000	2000-2020	1980	1990	2010
Georgia	Monroe	107	16.3			12,438		
Tennessee	Benton	89			17.7			13,944
Texas	Chambers	86			15.9			18,614
	Franklin ^c	68	17.3			5,348		
West Virginia	Mason ^c	94			18.7			19,599
	Pleasants	88			25.9			9,519

^aR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^bSee p. 9-35 for an explanation of the service base index.

^cThese counties also had some mining employment, but the growth was due almost entirely to the generating facility.

Table 9.7.. High growth rates due to construction of synthetic fuels facilities; peak growth rates greater than 15% by county and county population forecasts^a at the midpoint of the time period

State	County	Service base index ^b	Growth rate (%)			Population		
			Present to 1985	1985-2000	2000-2020	1980	1990	2010
Kentucky	Hancock ^c	87			25.8			11,238

^aR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^bSee p. 9-35 for an explanation of the service base index.

^cThis county had some mining employment, but the growth was due almost entirely to the synthetic fuels facility.

Table 9.8. High growth rates due to mining employment;^a peak growth rates greater than 15% by county and county population forecasts^b at the midpoint of the time period

State	County	Service base index ^c	Growth rate (%)			Population		
			Present to 1985	1985-2000	2000-2020	1980	1990	2010
Kentucky	Martin	38			15.49			8,389
West Virginia	Boone	67			23.65			20,148
	Logan	96			15.82			38,330
	Nicholas	85			17.76			18,228
	Webster	46			20.40			7,702
	Wyoming	89			15.03			26,277

^aOnly counties with mining employment of more than 500 were included in these calculations.

^bR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^cSee p. 9-35 for an explanation of the service base index.

Fig. 9.6. 1977-1985: counties with population increase greater than 5%.

Fig. 9.7. 1985-2000: counties with population increase greater than 5%.

Fig. 9.8. 2000-2020: counties with population increase greater than 5%.

The example results in Table 9.8 should be interpreted cautiously because the use of peak annual growth rates as indicators of probable local service shortages is less appropriate for mining employment than for construction employment in synthetic fuels or generating plants. Unlike synthetic fuels or generating employment, mining employment is as high or higher in the operations phase as in the construction phase. The rapid buildup to a large peak labor force followed by a rapid decline in employment will seldom occur for deep mines. As long as there is enough demand for coal, deep mining employment will generally remain at a fairly stable level for the 15- to 30-year lifetime of the mine. Surface mining employment at a given site is much shorter term (about one to five years) than deep mining employment, but it also tends to remain at a fairly stable level for the lifetime of the mine. Since employment fluctuates less for mines than for other types of coal facilities, the resources for building new towns, company towns, and permanent additions to service capacities are greater. Nevertheless, a temporary disequilibrium between supply and demand for services may occur at mining sites with large employment increases. Such imbalances are, however, more likely to occur, and to be more severe, at synthetic fuels or generating plant sites where there are equivalent amounts of population increase. If mining sites with high growth rates are excluded, 11 out of the 77 counties with additions to synthetic fuels or generating capacities will have growth rates greater than 15% (see Tables 9.5-9.7). Table 9.9 summarizes the distribution of high-growth-rate counties by state and by facility type. Note that most of the mining impacts, as well as many of the impacts due to other types of facilities, occur in West Virginia.

Counties with projected growth rates of 5 to 15% under the base-case scenarios are listed in Tables 9.10-9.12. Table 9.10 lists counties with moderate growth rates resulting from generating plant construction, Table 9.11 lists those from synthetic fuels plant construction, and Table 9.12 gives those from mining employment. Of the 186 counties with some type of new coal facility, 48 had expected growth rates of 5 to 15%. Twenty-four of these counties would grow 5 to 15% between now and 1985, 30 between 1985 and 2000, and 26 between 2000 and 2020. Of the counties with growth rates between 5 and 15%, 17 are located in Kentucky, 17 in West Virginia, 6 in Texas, and 4 in Virginia. If coal mines are excluded, 21 out of the 77 counties with synthetic fuels or generating facilities have growth rates between 5 and 15% (see Tables 9.10 and 9.11). Table 9.13 summarizes the distribution of all medium-impact counties by state and facility type. Notice that Kentucky and West Virginia have most of the medium-impact counties.

Of the 186 counties with a synthetic fuels plant, a generating plant, and/or coal mines, 54 had projected growth rates above 5%. The rest of these 186 counties had growth rates below 5% and were considered unlikely to experience any significant pressure on local services. Since the peak growth predicted for each county is the result of the interaction of the peak employment figure (resulting from the number and type of coal facilities sited in the county) and the population base in the county, the high-, medium-, and low-impact counties are not necessarily

Table 9.9. Counties with peak growth rates over 15%, classified by state and facility type

State	Generating	Synthetic fuels	Mining	Mix	Total
Kentucky	0	1 (2000-2020)	1 (2000-2020)	1 (1985-2000)	3
West Virginia	2 (2000-2020)	0	5 (2000-2020)	3 (2000-2020)	10
Georgia	1 (1985)	0	0	0	1
Tennessee	1 (2000-2020)	0	0	0	1
Texas	2 (1 in 1985) (1 in 2000-2020)	0	0	0	2
Total	6	1	6	4	17

Table 9.10. Peak growth rates of 5 to 15% due to new generating facility construction by county and county population forecasts^a at the midpoint of the growth period

State	County	Service base index ^b	Growth rate (%)			Population		
			Present to 1985	1985-2000	2000-2020	1980	1990	2010
Alabama	Greene	52		12.7	6.9		12,048	13,033
Florida	St. Lucie	126			5.1			84,610
Kentucky	Carroll	109	11.5			8,837		
	Trimble	70	10.5	13.0		5,818	6,403	
Louisiana	Grant	98		5.1			18,087	
North Carolina	Person	96	7.8			29,139		
Texas	Floyd	98	5.5			10,652		
	Goliad	54	6.4			5,321		
	Grimes ^c	81	5.6			13,447		
	Rusk ^c	103	5.3			35,638		
	Titus ^c	111	8.1			18,323		
Virginia	Caroline	75		14.0			17,551	
West Virginia	Brooke ^c	157			10.4			27,054
	Pleasants	88	9.8			7,889		
	Putman ^c	146			10.3			22,633

^aR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^bSee p. 9-35 for an explanation of the service base index.

^cThese counties also had some mining employment, but the growth was due almost entirely to the generating facility.

Table 9.11. Peak growth rates of 5 to 15% due to new synthetic fuels facility construction by county and county population forecasts^a at the midpoint of the growth period

State	County	Service base index ^b	Growth rate (%)			Population		
			Present to 1985	1985-2000	2000-2020	1980	1990	2010
Kentucky	Lewis	61		10.2			14,115	
	Livingston	65			8.7			14,328
	Meade	109		5.7	9.6		25,299	29,994
Texas	Shelby ^c	76		5.2	7.3		24,701	34,984
West Virginia	Mason ^c	94		6.6			23,179	
	Tyler ^c	87		12.8			9,945	

^aR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^bSee p. 9-35 for an explanation of the service base index.

^cThese counties also had some mining employment, but the growth was due almost entirely to the synthetic fuels facility.

Table 9.12. Peak growth rates of 5 to 15% due only to mining employment by county and county population forecasts² at the midpoint of the growth period

State	County	Service base index ^b	Growth rate (%)			Population		
			Present to 1985	1985-2000	2000-2020	1980	1990	2010
Kentucky	Breathitt	36	5.90	5.41		16,131	20,324	
	Floyd	68			6.51			29,307
	Harlan	71	5.44	5.91	6.55	38,377	42,770	48,614
	Hopkins	118		5.83	6.30		43,179	53,680
	Knott	38	6.05	6.66	6.47	16,617	20,820	30,249
	McLean	67			5.70			12,793
	Martin	38	11.61	12.40		9,269	9,401	
	Muhlenberg	96	12.3	12.3	11.3	28,270	31,372	39,372
	Ohio	77	6.06	6.20	5.83	19,026	21,063	26,345
	Pike	71	7.06	8.21	11.44	60,305	59,998	51,812
	Union	104	9.36	11.08	12.07	16,236	18,451	23,434
Virginia	Webster	89		6.06	8.31		14,294	17,602
	Buchanan	72	8.99	9.12	11.03	33,256	35,378	37,726
	Dickenson	57	7.57	8.09	10.64	16,181	17,150	17,181
West Virginia	Wise	85	5.89	6.36	8.37	35,618	37,175	36,502
	Barbour	74	5.84	5.87	5.42	15,019	20,103	36,298
	Boone	69	8.93	12.17		24,392	23,831	
	Braxton	89			6.64			9,405
	Clay	45			12.90			7,652
	Logan	96		7.17			44,892	
	Marshall	137		6.3			37,912	
	McDowell	79			6.44			53,792
	Mingo	75		5.49	12.74		31,995	27,819
	Nicholas	85	6.44	8.94		21,838	21,432	
	Raleigh	107			6.60			53,791
	Webster	46		6.71			9,039	
	Wyoming	89	6.25	8.13		30,163	30,276	

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^aR. J. Olsen et al., *MULTIREGION: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, October 1977.

^bSee p. 9-35 for an explanation of the service base index.

Table 9.13. Counties^a with growth rates of 5 to 15%,
classified by state and facility type

State	Total	Generating	Synthetic fuels	Mining
Alabama	1	1	0	0
Florida	1	1	0	0
Louisiana	1	1	0	0
North Carolina	1	1	0	0
Kentucky	17	2	3	12
Texas	6	5	1	0
Virginia	4	1	0	3
West Virginia	<u>17</u>	<u>3</u>	<u>2</u>	<u>12</u>
Total	48	15	6	27

^aA county may have 5 to 15% growth during more than one time period (see Tables 9.10-9.12).

homogeneous groups in terms of county characteristics. The same county might be placed in the low-impact category if one facility were sited in it and in the high category if two facilities were to be built. Similarly, the same county might easily adjust to increased employment in mining, but not to the development of synthetic fuels facilities. (See Appendix G.3 for an explanation of how the employment requirements for synthetic fuels and generating plants were obtained and Appendix G.6 for methods of estimating mining employment.)

In addition, two counties with the same population level may have different abilities to handle a certain rate of growth. As a general measure of development, a service base index was calculated for each southern county in the NCUA base-case scenario. The index is based on weighted levels of six variables: population, percent of the population in urban places, median family income, whether the county is a member of a Standard Metropolitan Statistical Area (SMSA), population density, and retail-wholesale-service trade. Although untested, it is expected that the service base capacity of counties will be directly correlated with levels of these six variables.

Each variable was given a weight with factor analysis, and the index was constructed with the following equation:

$$I_j = \left\{ \sum_{i=1}^6 \left[W_i \left(\frac{x_{ij} - \bar{x}_i}{Sd_i} \right) \right] + K \right\} 100 ,$$

where

- I_j = the index value for the county, $j = 1, \dots, 267$,
- W_i = the weight of the i th variable, where i ranges from 1 to 6,
- X_{ij} = the level of the i th variable in the j th county, where i ranges from 1 to 6, and j ranges from 1 to 267,
- $\bar{X}_i$ = the mean or average level of the i th variable,
- Sd_i = the standard deviation of the i th variable,
- K = a constant that is added to attach a certain level of the index to a desired point of comparison (e.g., if $K = 1$, then the index value will equal 100 for the case where all variable values take the mean level; if $K = 0$, the index will equal 0 for the mean values). The procedure for constructing the index is detailed in Appendix G.4.

An index for each NCUA county is displayed in the third column of Tables 9.5-9.8 and 9.10-9.12. The average values of the six variables produce an index value of 135. If the variable values are all zero, the index value will be zero. Consequently, county index values below 135 may be interpreted as below average, even though the county may be above average in one or more variables. Low index values are one indication that the county may have difficulty with moderate to high rates of growth. For example, in Table 9.12 Ohio and Pike counties in Kentucky have different population levels (19,000 and 60,000 respectively) but similar index values of 77 and 71. In the first time period, the two counties are projected to have 6% and 7% growth respectively. The index values are well below average and indicate that the two counties may be able to handle the growth rate equally well or poorly as the case may be. In contrast, a different situation is observed in Table 9.10. Carroll County, Kentucky, and Pleasants County, West Virginia, have similar population levels (8,000) but different index values of 109 and 88 respectively. Consequently, Carroll County may have a slight advantage in handling the 10% growth rate projected for the first time period. It is essential, however, not to attribute more to the index values than is justified. The index was constructed as a general indicator, and should not be interpreted as an absolute measure of level of development.

As was mentioned earlier, the assumptions one makes about the proportion of in-movers and the county share, as well as other factors determining growth, will naturally determine the level of growth rates predicted. In calculating the growth rates presented above, we assumed that the proportion of in-movers would be 30% and that the county share would be 50%. If these assumptions are changed, the distribution of counties in the high-, medium-, and low-impact categories will change as well. For example, if 100% of the workers moved and the county share were 100%, most counties would have growth rates over 5%. On the other hand, if the county share were 10% instead of 50%, many counties now classified as high- or medium-impact counties might shift to the low category.

An upper bound on the in-mover rate for southern construction sites is presumed to be the average value (60%) observed at 14 western

sites surveyed by the Old West Regional Commission.¹⁵ Under the 60% in-mover assumption, the growth rates displayed in Tables 9.5-9.8 and Tables 9.10-9.12 would be doubled. In addition, ten counties in those tables would have 5 to 10% growth rates in some years in which the growth rate was formerly less than 5%. Under a 60% in-mover rate, there are 27 additional counties that move into the 5 to 10% growth rate category. These counties, along with the ten from previous tables, are displayed in Table 9.14. Under the 30% rate all rates for counties in Table 9.14 would be less than 5%.

A summary of differences in the county distribution over the various growth rate categories is displayed in Table 9.15. Even with the higher 60% in-mover assumption, the majority of counties with new coal development fall in the 0 to 5% population growth category. There is, however, a significant change in the number of counties in the high-growth-rate categories. For example, in the first time period the number in the 10 to 15% category increases from 4 to 14, and the number in the 15% category increases from 2 to 12. Similar shifts occur in the other two time periods.

The last two columns of Table 9.15 display the county distributions under the lower- and upper-level in-mover assumptions. The percentages are based on the total number of observations in each category in all three time periods. At the 60% rate, the percent of county observations in the 0 to 5% growth rate category decreases from 83% to 75%. The most significant change occurs in the >15% category. The percent of county observations in that category increases from 3% to 9.5%. Over the sample most counties remain in the low-impact category (less than 5% growth) if a higher in-mover rate is applied, but there will be a high probability of encountering social and economic infrastructure constraints in some counties under either in-mover rate. As the rate of in-migration increases, the constraints become increasingly severe for the counties that are displayed in Tables 9.5-9.8.

To illustrate the general sensitivity of impact level to changes in assumptions about the proportion of in-movers and county share, a number of tables have been prepared. These tables allow one to examine the project work force that can be accommodated in a county of a given size under various sets of assumptions. These tables are presented in Appendix G.5, Tables G.5 and G.6.

Table 9.16 is a summary of some of the appendix tables for a construction project involving, at peak construction, 5000 employees and family members. In Table 9.16 the in-mover rate is varied from 10% to 100% and the county share of the in-migrants is varied from 25% to 100% in units of 25%. The table values display the minimum population required for this particular project under the various assumptions. For example, if the project is located in the southeastern United States, the appropriate in-mover percentages may be between 10% and 50%. For the South, the minimum community or county population sizes needed to limit growth to 5%, 10%, and 15%, respectively, are displayed in the quadrant labeled I. For a 5% growth limit under the assumption levels in the first quadrant, the minimum county size ranges from 2500 to 25,000 population.

Table 9.14. Additional counties with greater than 5% growth under a 60% in-mover assumption

State	County	Service base index	Growth rate (%)		
			Present to 1985	1985-2000	2000-2020
Alabama	Autauga	162			8.80
Kentucky	Boone	184	6.15		
	Boyd	213			7.49
	Breathitt	36	<i>a</i>	<i>a</i>	8.80
	Elliott	41			5.62
	Floyd	68	6.71	8.64	<i>a</i>
	Hopkins	118	9.93		
	Leslie	39	9.28	9.17	8.01
	Letcher	60	8.80	8.57	7.60
	McLean	67	5.14	8.65	<i>a</i>
	Mason	112	6.03		
	Perry	71	6.82	6.73	5.96
	Webster	89	7.21	<i>a</i>	<i>a</i>
Louisiana	Point Coupee	69	8.31		
Mississippi	Bolivar	86			6.05
	Lamar	64	5.54		
North Carolina	Caswell	75		5.13	
South Carolina	Gcorgetown	101		8.89	
Tennessee	Benton	89		6.36	
Texas	Bowie	187		5.12	
	Fayette	64	8.30		
	Fort Bend	176	5.79		
Virginia	Halifax	67		9.17	
West Virginia	Clay	45		8.14	
	Fayette	83			9.90
	Gilmer	48			7.53
	Lewis	96			5.22
	Lincoln	56			5.92
	Logan	96	9.40		
	McDowell	79	8.36	9.28	<i>a</i>
	Marshall	136	7.55	<i>a</i>	<i>a</i>
	Mason	94	8.82	<i>a</i>	<i>a</i>
	Mingo	85	6.65	<i>a</i>	<i>a</i>
	Pocahontas	54			6.43
	Raleigh	107		6.02	<i>a</i>
	Upshur	98			5.48
	Webster	46	5.20	<i>a</i>	<i>a</i>

^aPercentage reported in a previous table would be doubled.

Table 9.15. Summary of differences in county distributions for growth rate categories under 30% and 60% in-mover assumptions

Growth rate	Number of counties									
	Present to 1985		1985-2000		2000-2020		Total, present to 2020 ^a		Percent of all counties, present to 2020	
	30%	60%	30%	60%	30%	60%	30%	60%	30%	60%
0-5%	160	141	155	145	146	132	461	418	83	75
5-10%	20	19	21	13	17	15	58	47	10	8.5
10-15%	4	14	9	13	10	13	23	40	4	7
>15%	2	12	1	15	13	26	16	53	3	9.5
	<u>186</u>	<u>186</u>	<u>186</u>	<u>186</u>	<u>186</u>	<u>186</u>	<u>558</u>	<u>558</u>	<u>100</u>	<u>100</u>

^aThe "total" column triple-counts the counties. Each county occupies one growth rate category in each time period (present to 1985, 1985 to 2000, and 2000 to 2020).

Table 9.16. Population thresholds^a for energy developments with peak employment of 5000

In-mover rate (%)	County share of in-migrants											
	5% growth				10% growth				15% growth			
	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
	I		II		I		II		I		II	
10	2,500	5,000	7,500	10,000	1,250	2,500	3,750	5,000	833	1,667	2,500	3,333
20	5,000	10,000	15,000	20,000	2,500	5,000	7,500	10,000	1,667	3,333	5,000	6,667
30	7,500	15,000	22,500	30,000	3,750	7,500	11,250	15,000	2,500	5,000	7,500	10,000
40	10,000	20,000	30,000	40,000	5,000	10,000	15,000	20,000	3,333	6,667	10,000	13,333
50	12,500	25,000	37,500	50,000	6,250	12,500	18,750	25,000	4,167	8,333	12,500	16,667
	III		IV		III		IV		III		IV	
60	15,000	30,000	45,000	60,000	7,500	15,000	22,500	30,000	5,000	10,000	15,000	20,000
70	17,500	35,000	52,500	70,000	8,750	17,500	26,250	35,000	5,833	11,667	17,500	23,333
80	20,000	40,000	60,000	80,000	10,000	20,000	30,000	40,000	6,667	13,333	20,000	26,667
90	22,500	45,000	67,500	90,000	11,250	22,500	33,750	45,000	7,500	15,000	22,500	30,000
100	25,000	50,000	75,000	100,000	12,500	25,000	37,500	50,000	8,333	16,667	25,000	33,333

^aPopulation threshold is the minimum host community size necessary to limit population increase to some percentage level (5%, 10%, 15%) under the listed construction size (peak work force) for the various in-mover rates and county share percentages.

Threshold = [(construction population) x (mover percentage) x (county share)]/impact level.

The quadrant labeled IV in Table 9.16 may be the most appropriate for western projects such as those studied by the Old West Regional Commission. With in-movers ranging from 60 to 100% and a county share of 75 to 100%, the project of 5000 requires minimum host community sizes ranging from 45,000 to 100,000 (if growth is to be limited to 5%). Even at the 15% growth level, the threshold requirements in quadrant IV range from 15,000 to 33,000. Since many site counties or communities in the western United States do not meet these requirements, boom-town growth rates and serious socioeconomic constraints usually accompany major construction activity.

As is shown in Table G.5 of Appendix G.5, the population size threshold required to accommodate a facility increases rapidly as the peak employment level increases. Table G.6 in Appendix G.5 presents project size thresholds that can be accommodated by counties of a given size under various levels of in-migration and county shares. The project size thresholds reflect the same sensitivity to in-migration and county share levels as the population size thresholds in Table G.5 of Appendix G.5.

The above analysis applied a standard set of assumptions for new coal developments that include generating facilities, synthetic fuel plants, and coal mines. The 30% in-mover assumption may be inappropriate in the case of coal mine openings and operation. Frequently, as old mines close and new ones open, the labor force commutes from mine to mine without changing place of residence. Consequently, many of the counties in Tables 9.8, 9.12, and 9.14 can be dropped from the lists. In other words, if there are no in-movers to coal mine sites there would be no growth rates directly associated with in-movers. The decision was made to keep the 30% in-mover assumption for these counties so that development impacts, perhaps secondary social impacts, will not be underestimated. Even if all employees commute to the sites, some social and economic costs may be encountered and some local economic benefits may occur. Unfortunately, due to resource limitations this preliminary assessment could not account for economic benefits in nonsite counties or regions that send resources to site locations. Until methods can be employed to account for the spatial distribution of all benefits and costs, the 30% in-mover assumption has been applied to coal mining activity.

9.5 Summary and Conclusions

Some specific results of our analysis of the base case-scenario included the following:

1. The proportion of material inputs supplied internally by Bureau of Economic Analysis (BEA) area for an 800-MWe plant varied from 5% to 78%. These proportions were correlated with population size and proportion of the population in urban places. For the siting pattern through 1985, the total capacity-weighted proportion of internal purchases was 47%; for the 1985 to 2000 siting pattern, the proportion was 20%; and for 2000 to 2020, 23%.

2. County trade multipliers varied from 1.22 to 1.91. The estimated total trade expenditures associated with the base-case scenario varied by state to a maximum of \$515.9 million (in 1977 dollars). Urban counties typically had higher trade multipliers.

3. For the base-case scenario, a 30% in-mover rate assumption indicated that a total of 54 counties in the ORNL 12-state region would experience population growth rates (due directly to coal development) greater than 5% at some time between now and 2020. Of the 17 counties that would experience increases greater than 15%, five had populations of less than 10,000, eight had populations of 10,000 to 20,000, and four had populations above 20,000. Doubling the in-mover rate resulted in no significant change in the growth rate percentage for the majority of counties in the base-case example. However, for a few counties higher in-mover rates would result in higher probabilities of social and economic impacts.

In summary, the economic and social impact experienced by a site in the South will depend on both the characteristics of the site county and the characteristics of the surrounding region. In general, the results of our analysis of material input supply potentials, trade multiplier effects, and population growth rates suggested that, where possible, certain potential sites in rural counties of undeveloped regions should be avoided. Rural counties with small populations and no large towns are likely to experience the greatest population growth pressures and the smallest receipts of input supply or trade dollars (multiplier benefits). If such counties are close to metropolitan areas, however, growth pressures will be reduced along with trade increases. Thus, characteristics of the county as well as the surrounding region will influence the degree of impact.

The following tabulation displays the possible combinations of county and region by urban and rural categories.

County	Urban area (U)	Rural area (R)
Urban (U)	UU	UR
Rural (R)	RU	RR

For the categories tabulated, urban refers to areas with large populations, with large proportions living in urban places (>50%), and high levels of industrial development and diversification. Rural refers to areas with small populations, with low proportions living in urban areas (<50%), and little industrial development. Typically a large urban region will enjoy most of the direct and multiplier benefits from construction projects located within it and many benefits from projects external to the region. Absolute economic benefits (i.e., expenditures, income, and employment) received by urban counties in urban regions are greater than for any rural-urban combination ($UU > UR \geq RU > RR$). On the other hand, the infrastructure constraints (public and private amenity pressures) will vary in the opposite direction ($UU < UR \leq RU < RR$).

Even though absolute benefits to rural places are smaller than those for urban places, the benefits may seem significant when compared with existing employment and income sources. This is particularly true at the county level. Rural counties often have a great need for economic development even though they are likely to receive smaller absolute amounts of supply or trade dollars and to experience more adverse pressures from growth. But counties in the extreme RR category will usually receive fewer benefits and more costs than any other type of site. Thus, with all other siting factors equal, our preliminary assessment research suggests that such RR sites should be avoided.

In conclusion, the socioeconomic assessment has focused on a few examples of impact that may be associated with energy facility development under the base-case scenario. The analysis has demonstrated that siting plans, local and regional characteristics, and facility type all influence social and economic impact. There are more complex and perhaps more important issues that have not been addressed by this section. Time and resource constraints have not allowed an assessment of the deeper issues that concern industry structure, income distribution, regional development, and overall social welfare in the nation. However, we have been able to identify some of the points at which our approach and methods of analysis can be fruitfully extended during future research. Such research should then permit us to probe into some of these deeper issues and at the same time to arrive at more precise and more fully documented findings.

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APPENDIX A

STATE AND REGIONAL AGENCIES VISITED BY ORNL STAFF: TASK 1, NCUA

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APPENDIX B

ENERGY FACILITY SITING METHODOLOGIES

B.1 Overview of ORNL Siting Approach

The Oak Ridge National Laboratory (ORNL) has developed regional analysis procedures to transform estimates of future energy demand into siting patterns of energy production. For example, the National Coal Utilization Assessment (NCUA) scenarios developed by Brookhaven National Laboratory (BNL) and Argonne National Laboratory provide forecasts of energy demand by census regions for the United States, as well as possible technology mixes that may be used to meet the demand. "Technology mixes" refers to the proportion of each type of energy facility, such as coal, nuclear, oil, etc. In developing these siting patterns, we attempt to match the proportionate mixes when possible.

During the development of these procedures, a thorough review was made of the siting methodologies currently in use in the United States. This culminated in a report that presents conclusions based on experience at ORNL and the literature; recommendations are made for optimal combinations of techniques that should be used in regional and site-specific energy facility siting studies.¹

Past experience in regional modeling at ORNL has prompted the development of a computerized site-selection procedure capable of multiple resource analyses, using different constraints and scenarios. Because some decisions cannot be completely simulated by the computer, the design also accommodates manual operation whenever human judgment is required. Inputs to the siting analysis are provided via a computer-based information system known as the Oak Ridge Regional Modeling Information System (ORRMIS).² This system was developed in the Computer Sciences Division of ORNL through support from ORNL's Energy Division.

The siting procedure uses hierarchical scaling of analysis, stepping down spatially from large regional scales (e.g., census regions) to sub-regional scales (multiples of counties) and ultimately to site-specific levels. Specific sites are not recommended by ORNL because this function is the responsibility of utilities or state planning agencies, but the procedures can be used for site selection at that level if detailed resource data are available.

Figure B.1 is a flowchart summarizing the development of patterns and their use in impact analysis. National energy demand scenarios are provided exogenously (e.g., National Energy Plan) as a beginning point for our analysis. The Regional Economic Analysis Group at ORNL disaggregates these energy demand forecasts for the southern United States to subregional units [usually Bureau of Economic Analysis (BEA) areas for Water Resources Council regions]. Energy demands are then mapped by subregional units to determine the spatial distribution of demand and the future growth differential patterns that may be expected.

Fig. B.1. Siting analysis approach used at ORNL.

For each subregional unit, technology mixes to meet future demands are developed from knowledge of (1) energy technology characteristics, (2) proposed and existing facilities as provided by survey or from our corrected version of the Federal Energy Regulatory Commission (FERC) data on utilities, (3) time horizons for new technologies to be in use, and (4) technology mixes projected for each census region (usually provided exogenously). Information concerning utility plans for future plant type mixes and the general availability of suitable areas within each sub-region are also used to determine technology mixes.

Generated parallel to these analyses are technology characterizations according to resource requirements for each type of facility (water withdrawal and consumption rates, land requirements, and transportation needs). Siting criteria are developed for each technology in terms of these needs. Also, the potential environmental effects associated with the technology type (coal, nuclear, gas, etc.) and the social and legal limitations are considered along with the relative importance of each siting criterion. Knowledge of siting criteria and resource requirements also permits the determination of resource data and siting information that must be compiled in ORRMIS.

In the energy facility screening and siting process, the technology information is used to test the resource requirements of new energy development against the resources available and against current conditions of the region. This task requires the development of submodels that describe resource availability in terms of the siting requirements of various energy technologies and of the constraints toward siting. These site-characteristic models are collectively called the Oak Ridge Spatial Analysis Model (ORSAM). Each submodel is designed to spatially describe a specific siting criterion for the type of energy facility (e.g., nuclear, fossil-fueled, or other power plant or coal conversion plant) to be sited. For example, knowledge of stream-flow rate is not sufficient to determine adequate availability of cooling water without first determining potential low flows and maximum water consumption. In essence, the submodels replicate siting criteria considerations. Feedback loops in the system permit the varying of criteria, importance weights, or technology mixes based on results from the analyses. Ultimately, candidate energy facility siting and resource use patterns emerge from the site-screening process to provide input to the social, economic, and environmental impact analyses.

B.2 Geographic Specification of Energy Demand

The 1975 and 1985 energy facility siting patterns are based on existing and proposed generating capacity data provided by the FERC.³ The 1985 pattern is determined by the announced expansion plans of the utilities. Most of the existing and proposed facilities will be operating in 2000, but the location for unscheduled or replacement plants which must come on line to meet demands by 2000 and 2020 is uncertain. To site the capacity required to meet these increases in 2000 and 2020, it is essential to know where the deficits will occur.

The energy demand projections used in the NCUA analysis were made by BNL from the national growth projections provided by the Department of Energy (DOE). Energy demand projections are provided to ORNL at the census region level and are regionalized to either BEA areas or other regional units.

Demand is expressed in terms of required capacity so that existing and proposed capacity can be subtracted to show net deficits or surpluses of power production by subregion. Before beginning a siting analysis, surplus power is redistributed to the nearest deficit regions. Our

analysis determined that the planned electrical generating capacity in 1985 is adequate to meet base-case demands; therefore, it is unnecessary for ORNL to site additional plants.

The ORNL regional disaggregations of the BNL national energy scenarios provide basic information on the level of demand for which capacity must be sited and the relative amounts of generating or processing capacity in each technology and fuel type that must be sited in a given census region. The technology mixes serve as guidelines and control totals in the allocation of capacity within a given census region but do not necessarily determine the final mix sited in a given year. The capacity for 2000 and 2020 to be sited beyond the 1985 capacity is assumed to conform to the technology mixes provided by BNL.

B.3 Technology Characterization and Development of Siting Criteria

One of the first steps in developing a siting methodology is to identify the factors that must be considered by the utilities and state agencies in locating acceptable energy facility sites. To systematically accomplish this important step, we have adapted a group processing technique to the problem of factor identification. We have conducted two sessions of a particular technique — the nominal group process technique — to obtain expert opinion from power plant siting specialists.

The nominal group technique is a highly structured interactive approach which has been widely accepted in health and social services, education, industry, and government.⁴ The process consists of four basic steps: (1) nominal (silent and independent) generation of ideas in writing by a panel of participants, (2) round-robin listing of ideas generated by participants in a serial discussion, (3) discussion of each recorded idea for clarification and evaluation by the group, and (4) independent voting, with the group decision resulting in a mathematical ranking. The strengths of the technique lie in enhanced participation by group members, step-by-step movement toward a goal, and cross-education of participants.

Our sessions resulted in lists of weighted factors that have since become the basis for the factor models used in our siting methodology. The regional siting factors identified by one of our nominal group technique panels are shown in Table B.1. Our experience with nominal groups is described in detail in a published report.⁵ More group processing sessions are planned to identify factors pertinent to coal-fired power plants and other types of energy facilities. In a related project associated with identifying candidate siting regions for the state of Maryland, staff members of the Maryland Power Plant Siting Program provided us with weighted factors for both coal and nuclear plants. For the NCUA, we used these inputs to specify candidate siting regions for coal plants. Because no commercial coal conversion facilities have been built to date, we relied on information from industry and DOE personnel to define these siting criteria.

Table B.1. Factors and weights, second group, regional continuous

First vote	Second vote	Factor	Definition
92	98	Availability of water	Reflected in costs for acquiring water (example - reservoir), impact of getting and using water, and chance of future conflict with growing use by others
95	97	Minimize proximity to undesirable population distribution	NRC guidelines
93	94	Minimum adverse geological features	Geology and soils related to foundation cost and safety considerations of subsidence
95	89	Minimum adverse impact on regional aquatic biota	Rare and endangered species and loss of habitat
85	88	Minimum susceptibility to maximum hydrological/meteorological events	Includes such things as dam failures and floods
89	85	Minimum adverse impact on regional terrestrial biota	Rare and endangered species and loss of habitat
80	83	Minimum adverse impact on existing and potential land use	Incompatibility with perceived future or present use of site and surrounding area
75	72	Minimum <i>g</i> value for OBE	Calculation of potential acceleration caused by seismic activity. Tectonic province used at this scale. Determines if standard plant design can be used
71	70	Regional water quality	Impact on quality by plant and quality of input for plant
57	58	Presence of acceptable transportation systems	Could not be sufficiently defined
43	58	Land surface slope and relief	Rough terrain leads to excessive grading costs and poor accessibility
53	55	Minimum proximity to man-made hazards	Airports, military installations, etc.
46	46	Acceptable air diffusion	Poor diffusion leads to double containment and increased costs
53	43	Minimum adverse impact on historical/archaeological areas	Proximity to important sites or presence of unexplored sites as Indian mounds
45	41	Adverse impact on regional economy	Housing, services, etc.
43	38	Minimum impact on regional recreation	Affect patterns of recreation or type of recreation
31	35	Maximum proximity to load	Could not be sufficiently defined
36	29	Unfavorable attitude of regional population	Potential for local opposition
17	17	Maximum reliability of offsite power	Power to run plant, a safety concern

The minimum criteria to be considered in the county-level siting analysis for electric generating facilities were specified by the NCUA Siting Work Group. These criteria are:

1. Proximity to load centers. The factor to be considered is the distance to the load center or centers as an indication of the cost of transmission from each potential site.
2. Water availability. Water availability in terms of the flow available 95% of the time and the 7-day/10-year low is considered. The percentage of this flow actually available for energy use may vary from region to region — precise estimates cannot be obtained in most areas.
3. Coal availability. The relative availability of coal as indicated by the magnitude of the reserves and by the transport distance has been established at a subregional level using methods provided by the NCUA Scenario Work Group. This information relating to delivered price is considered in selecting the location of the plant relative to the producing mine.
4. Air-quality constraints. Air-Quality Maintenance Areas (AQMA's) as defined by the Environmental Protection Agency (EPA) have been considered as exclusionary areas for coal-fired plants except in the case where other overriding constraints make use of these areas mandatory. Regulations for the prevention of significant deterioration have not been used in the initial baseline siting patterns.
5. Seismic risk. Areas of high seismic risk [zone 3 as designated on the U.S. Geological Survey (USGS) seismic risk maps] are excluded as sites for nuclear facilities.
6. Population distribution. Population constraints exclude areas of 500 or more per square mile for siting of nuclear facilities. AQMA constraints often exclude coal-fired facilities as well.
7. Public lands. No facilities have been sited in state or federally owned lands.

B.4 Quantification of Siting Criteria

The siting analysis at ORNL uses a candidate site-screening procedure to locate potential counties suitable for energy facilities across the southern United States. Siting patterns derived from this analysis include nuclear and fossil-fueled power plants and coal conversion plants. Calculation of suitability depends on ORSAM, which replicates usual considerations by agencies making siting decisions for various criteria such as water availability, seismic risk, air quality, and coal availability.

B.4.1 Accessibility to load centers

We do not directly enter the accessibility-to-load-center calculations into the site suitability calculations. Rather, the accessibility

calculations are used at a later stage to guide the allocation process toward those highly suitable areas close to load centers. A simple gravity-potential model⁶ is being used to map the accessibility of any given county relative to the economic costs of transmitting power to surrounding load centers. Transmission is limited to 322 km (200 miles) and is based on present technology in transmitting power along ac lines.

B.4.2 Water availability

Water availability is considered a prime locational determinant in energy facility siting. Water requirements for a given facility may be calculated readily, but evaluating the availability of a dependable water supply to meet those requirements is much more difficult. Furthermore, a cumulative account must be made of the water requirements for all existing and planned facilities for a given river system. Water supplies are unevenly distributed among and within the several regions of the nation, and substantial annual and seasonal variation exists. We saw the need, therefore, to develop computerized tools to assess water availability from a regional perspective down to specific site evaluation. The Water Analysis System (WAS) developed at ORNL aids such availability analysis.⁷

The WAS enables the user to select, retrieve, and analyze historical stream-flow information from the USGS daily-value water tapes, which contain data for all USGS stream-gauging stations in the United States. The system is divided into distinct modules that presently enable the user to (1) delimit any region of the United States by state, county, size of drainage area, or latitude-longitude frame, (2) recall daily flow values from the USGS water tapes for all gauging stations within the study region, (3) compute low-flow recurrence frequencies and apply theoretical probability distributions, and (4) predict the reservoir drawdown capacity that would be necessary to maintain a given rate of stream flow at a specified rate of consumption.

The WAS is well suited to investigating a broad range of water resource questions, including evaluations of water availability to meet projected energy demands. To address this topic, procedures were developed at ORNL for assessing the quantity and distribution of surface water availability to meet projected demands. A computerized geographic data information system that includes water supply and demand data was constructed to facilitate analyses at various levels of resolution. For our NCUA analysis we used the county level. A method of downstream order accounting by bordering counties, which approximates the sequential order of the natural hydrology, was devised to measure the cumulative impacts of water use against available supply during a low- or any other flow level.

Description of low-flow availability uses flow estimates generated by WAS and information on the effects of reservoir regulation obtained from the U.S. Army Corps of Engineers.⁸ A detailed characterization of low flow at the county level is not yet complete for the entire study region. However, a baseline county approximation was constructed using

stream-reach data compiled in a study by the USGS. Figure B.2 is a display of ORNL's county interpolation of these data.

At the regional level, comparison of the projected water resource impacts of energy production focuses on the seasonal period when the total water demand will use the greatest proportion of estimated supply. Surface water supply estimates were based on the 95% monthly discharge for the critical supply month in each major river system. These figures represent the surface outflow that has a 95% chance of being exceeded for a given month.⁹ These monthly values were adjusted for the 1975 level of upstream surface water depletion to reflect the approximate total surface supply.

The estimated percentage contribution by groundwater sources to total water supply was included in the region-level analysis. If the groundwater portion of total water consumption exceeded 10%, a determination was made regarding the feasibility of increased groundwater withdrawals. The determination was based on the location of specific negative impacts of groundwater depletion, including

1. mining of groundwater that exhausts the water source
2. withdrawal that diminishes spring or stream flow
3. withdrawal that causes subsidence and fissures
4. withdrawal that causes intrusion of salt water into freshwater aquifers.

If increased groundwater withdrawals added to the already significant depletion problems, future groundwater use was held constant and not allowed to exceed the 1975 withdrawal total. Otherwise, groundwater sources were assumed to contribute the same proportional share of total water use. In all cases, interbasin water imports and exports and surface evaporation from reservoirs were assumed constant at 1975 levels.

At any level, the information system permits the structuring of water availability estimates and projected consumption into comparable formats. In downstream order, the water use per unit, cumulative total depletion, available remaining supply, and percentage depletion of the supply are computed, and the results are mapped.

B.4.3 Coal availability

As part of the NCUA, an inventory of coal reserves by county in the Appalachian region was compiled in terms of coal production potential. Coal production potential is assessed from a perspective that accounts for coal reserve totals, surface and deep coal seam thickness, coal quality, and past coal production. The ultimate result is a systematic quantification and mapping of the areas where coal is likely to be mined according to the production levels forecast in the scenario being considered. The feasibility of coal-fired generating plants in a given demand area then can be determined based on proximity to supply. To do

Fig. B.2. County proximity to water. Based on data supplied by the USGS concerning streams with 7-day/10-year low flow with greater than 300 ft³/sec flows or 300 ft³/sec possible with water storage and proximity to the Great Lakes or salt water.

this, coal availability at the mines is combined with a transportation model. By coupling this result with a transport model, the relative availability of coal at various points throughout the southeastern region can be determined. Figure B.3 illustrates county-level accessibility to high-sulfur coal, which is useful in locating potential sites for coal conversion facilities.

In addition to calculating the distribution and availability of coal reserves, certain environmental limitations for the use of coal from the Appalachian region are also determined. For example, significant coal reserves may lie in areas of high recreation potential, areas of critical wildlife habitat, and/or areas of poor or sensitive water quality; any one of these factors might be seriously diminished or destroyed by mining of coal resources. An accurate assessment of coal reserves should flag these environmentally sensitive areas, and any decisions regarding potential mining sites should necessarily recognize and respect the caveats.

B.4.4 Air resource limitations

Since air quality is an important consideration in siting coal-consuming energy facilities, we investigated the applicability of various air-quality models for measuring the spatial distribution of air pollutants. The usefulness of current models for very large regions such as the Southeast has not yet been demonstrated. Currently, AQMAS designated by the EPA are used in lieu of quantitative air-quality standards. AQMAS are regions defined by combinations of counties or portions of counties in which future air-quality degradation will be carefully monitored by regulatory agencies; therefore, AQMAS are less suitable for siting coal-using facilities. AQMAS for the entire United States have been identified and entered into our county-level information system (Fig. B.4).

B.4.5 Transportation limitations

At present, we have entered into our county-level information system data on rail and barge transport availability which are used in calculating suitability. Tentative agreement has been reached with the Federal Rail Administration to use its National Rail Network Model to calculate rail transport accessibility at the county level for the United States. Rail accessibility information will then be merged with existing data concerning water transportation to produce better transportation accessibility measures at the county level in terms of energy facility siting constraints.

B.4.6 Population distribution limitations

Population density in terms of constraints to the siting of energy facilities (particularly in the case of nuclear facilities) has been mapped for the United States (Fig. B.5). Several options in calculating

Fig. B.3. County-level accessibility to high-sulfur coal by county: southeast subregion.

Fig. B.4. Air-quality maintenance areas.

Fig. E.5. Areas of the United States with a population density of 500 or more per square mile.

site restrictions based on NRC siting regulations have been developed. Eventually, these options will be available in map form, depending on the technology being considered and the site constraint option desired. This analysis, however, used the percentage of a county with a population density greater than 500 per square mile as a constraint on siting power plants.

B.4.7 Social and institutional limitations

A generalized social impact assessment methodology developed by Pepper and Sorensen at the University of California, Santa Cruz, has been adopted by ORNL for quantification of siting factors related to the major social impacts stemming from energy facility siting. At present, both quantitative and verbal indicators of the four major social impact factors are in varying stages of development. The methodology identified four siting factors related to impact on social systems: (1) cultural characteristics, (2) governmental institutions, (3) local services, and (4) local economics. Using the social impact assessment in Pepper and Sorensen's methodology, sets of related issues were defined for each of these factors. Wherever feasible, quantifiable indicators were created. In other cases it was decided to rely on verbal descriptions or characterizations of potential impacts.

Several assumptions underlie our efforts to quantify impacts on the cultural characteristics of the county residents.

1. Consideration of the impact on cultural characteristics includes the effects of new people moving into the area in relation to the county population's life-style, socioeconomic status composition, racial composition, and values related to the land. A major factor in the impact on the cultural characteristics of the counties is the degree to which the in-moving workers and their families differ from the existing resident population.

2. Since general life-styles are associated with the demographic characteristics of a population, we have attempted to develop indexes measuring the differences between the composition of the in-moving worker and the indigenous populations on a number of life-style variables, such as marital status, life-cycle stage, and family size. Because socioeconomic status is closely related to a group's total set of values, introduction of a new population with widely different social status may create value conflicts. To anticipate the impact arising from these conflicts, an index was designed to measure the degree of dissimilarity between the socioeconomic status of the in-moving workers and the local county residents. Our thesis is that the more similar residents and workers are, the less likely it is that existing cultural systems will be significantly strained.

3. Factors affecting the ability of governmental institutions at the local level to manage change include growth rate, probability of land-use changes, and existing management infrastructure. Experience with boom-town developments indicates that the rate of population growth

is a key factor in the ability of local governmental institutions to manage change. Moore indicates that management capabilities begin to be outstripped as annual growth rates exceed 5%, and that severe problems emerge as 10% annual rates are exceeded in a community.¹⁰ The relationship between community growth rates and county growth rates was analyzed, and threshold levels were established for a growth index of potential impacts at the county level.

In addition to analyzing potential growth effects on institutional capacities, indicators of the presence of governmental management infrastructure, such as planning commissions, comprehensive plans, zoning and subdivision ordinances, and capital improvements programs, have been examined in conjunction with ongoing social impact assessment methodology development efforts by the Tennessee Valley Authority (TVA). It is anticipated that measures of this type will eventually be incorporated in the quantification of governmental and institutional impact indicators.

4. Indicators of local-service-level impacts are more easily definable and quantifiable. Several local-service impact measures are being developed in close cooperation with TVA. Indexes for water and sewer systems, fire and police protection, and health and education services are being constructed. ORNL intends to use the TVA experience as input for the development of service-level suitability indexes for the NCUA. Three types of impacts on the local economic systems have been identified: (1) fiscal impacts on the local governments, (2) monetary impacts on the private sector, and (3) employment effects. Some preliminary consideration has been given to the development of an overall fiscal capacity index for local governments at a county-wide level based on their relative tax efforts; however, to date, no site-screening indexes for the economic impact issues have been developed. Since the Social Impact Assessment Group, the Regional Economic Analysis Group, and the Regional and Urban Studies Section have focused some attention on the economic consequences of plant construction and operation, it is hoped that their knowledge will be useful in developing these indexes.

The combination of quantitative indexes and verbal characterizations of potential social impacts on candidate counties will be of limited value in their present form for constructing site-suitability profiles but will at least permit some consideration of the social and institutional limitations. When complete, however, these indexes should allow us to incorporate social impact considerations within the site-screening process in a more structured and systematic fashion. As with the physical constraints to siting, county socioeconomic impact profiles will permit evaluation of relative county suitabilities under varying policy alternatives.

B.5 Suitability Calculation

The siting criteria described above were used to specify the general suitability of counties for various types of energy facilities. The quantitative expressions of these criteria as captured by ORSAM were applied to the county-level information system (ORRMIS) through a screening algorithm of the form,⁹

$$S_i = \sum_{V=1}^N \frac{C_{Vi} I_V}{N},$$

where

S_i = suitability score for county i ,

V = variable (e.g., proximity to stream flow),

N = total number of variables,

C_{Vi} = compatibility index for value of variable V occurring in county i ,

I_V = importance weight of variable V .

The county-level data base presently in ORRMIS is pertinent to energy facility siting only at the regional scale. These are continuous variables which do not vary greatly over the area within a county. For example, seismic activity varies from one part of the nation to another, but variations within the relatively small area of a county (usually about 300 sq miles in the eastern United States) are negligible. In contrast, certain variables such as land surface slope and land use fluctuate so much within a small area that an aggregate figure for each county would not be useful in regional screening for energy facility sites.

As noted previously, regional siting factors have been defined through group processing techniques. Each variable has been assigned an importance weight to indicate its relative influence in the selection of suitable candidate counties for a facility, and each category within each variable has been given a compatibility index reflecting its positive or negative influence on the siting decision when it occurs in a county. The combined importance weights and compatibility indexes for a given facility type are referred to as a siting criteria matrix.

B.5.1 Calculation of site suitability for coal-fired generating facilities

Siting specialists invariably rank water availability among the most important factors in regional screening for coal-fired generating plant sites (Table B.2). Site suitability calculations based on Table B.2 for coal-fired plants are shown in Fig. B.6.

A 1000-MWe coal-fired plant with a wet-cooling tower requires a total water withdrawal of 17 million gallons per day (Mgd) and loses 10 Mgd through evaporation and drift. A similar plant with once-through cooling withdraws 826 Mgd and consumes 3 Mgd. In either case, the water withdrawal requirement is significant enough to require selection of a site near an ample water supply. Since current policies (enforced mainly by the EPA) favor cooling towers, we have assumed this to be the cooling

Table B.2. Regional siting criteria for a coal-fired generating plant

Variable	Importance weight	Category or value	Compatibility index
Water availability	10	Adjacent to stream with 7-day/10-year low flow ≥ 194 Mgd	10
		Adjacent to stream which could have 7-day/10-year low flow ≥ 194 Mgd if additional regulation were imposed	4
		Adjacent to Great Lakes	8
		Adjacent to Atlantic Ocean or Gulf of Mexico	5
		Other counties	<i>a</i>
Air-quality maintenance areas (AQMA)	10	Not an AQMA	10
		Partially an AQMA	5
		Entirely an AQMA	<i>a</i>
Accessibility of low-sulfur coal ($\leq 1.9\%$ S)	8	Values represent calculations from gravity model using tonnage of low-sulfur coal	
		Highest value	10
		Lowest value	1
		>300 miles from low-sulfur coal reserve	0
Barge accessibility	7	Adjacent to channel of ≥ 9 ft depth	<i>b</i>
Seismic activity	6	Activity level I (lowest risk)	10
		Activity level II	5
		Activity level III (highest risk)	0
Rail accessibility	6	Adjacent to medium- or heavy-duty railroad	10
		Not adjacent to medium- or heavy-duty railroad	0
Accessibility of high-sulfur coal ($> 1.9\%$ S)	4	Values represent calculations from gravity model using tonnage of high-sulfur coal	
		Highest value	10
		Lowest value	1
		>300 miles from high-sulfur coal reserve	0
Population density	3	90-100% of county has ≥ 500 inhabitants per square mile	0
		80-90%	2
		70-80%	3
		60-70%	4
		50-60%	5
		40-50%	6
		30-40%	7
		20-30%	8
		10-20%	9
		0-10%	10

^aScore equals number of miles of channel (maximum is 94.6).

^bExcluded from consideration as potential candidate counties.

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Fig. B.6. Suitability for coal-fired steam electric generating plants by county: southeast sub-region.

mode for all steam-electric facilities to be constructed in the future and have judged county suitability on the basis of a consumptive rate of 20 Mgd (sufficient to support a 2000-MWe coal-fired generating plant, a 1200-MWe nuclear plant, or a standard size commercial coal conversion facility).

A second major consideration for coal-fired plants is the status of air quality maintenance in the candidate counties. Although federal standards do not explicitly prohibit construction of new coal-fired plants in AQMAs, it was felt that the potential for environmental damage and the cost of pollutant abatement would justify exclusion of counties totally designated as AQMAs.

Concern for air quality also encourages the use of low-sulfur coal to reduce emissions of sulfur dioxide without the addition of costly scrubbers. Hence, proximity to large deposits of low-sulfur coal ($\leq 1.9\%$ S) has been judged a highly positive factor. Accessibility of high-sulfur coal ($> 1.9\%$ S) is a positive factor of somewhat less importance.

Barge and rail access are considered important because of the huge volumes of coal that must be moved to the plant daily. Shipment by barge is a cheaper form of transportation than movement by rail, and the cost of trucking would be prohibitive except in the case of mine-mouth plants.

B.5.2 Calculation of site suitability for nuclear generating facilities

It is apparent from the criteria matrix that siting specialists consider water availability to be of prime importance in choosing candidate sites for a nuclear generating facility (Table B.3). Population density is also considered to be important because of the safety hazard that might result from the accidental release of radiation in a highly populated area. A high level of seismic activity increases the risk of accidental release and is significant enough to exclude counties from consideration regardless of other characteristics.

For a nuclear facility, transportation accessibility is important primarily during the construction phase. Barge access contributes to site suitability because of the difficulty of transporting the huge reactor vessel over land. Railroads are a less desirable alternative for transport of the vessel but may be the mode for moving many other construction materials. Sites in counties without barge or rail access require expensive movement by highway and often involve costly measures such as raising of power lines and special routing to avoid narrow bridges or other restricted passages.

Calculations of site suitability at the county level based on the criteria matrix for nuclear facilities were made for the southern United States. Figure B.7 illustrates a mapping of nuclear suitability.

Table B.3. Regional siting criteria for a nuclear generating facility

Variable	Importance weight	Category or value	Compatibility index
Water availability	10	Adjacent to stream with 7-day/10-year low flow ≥ 194 Mgd	10
		Adjacent to stream which could have 7-day/10-year low flow ≥ 194 Mgd if additional regulation were imposed	4
		Adjacent to Great Lakes	8
		Adjacent to Atlantic Ocean or Gulf of Mexico	5
		Other counties	<i>a</i>
Population density	10	90-100% of county has ≥ 500 inhabitants per square mile	<i>a</i>
		80-90%	2
		70-80%	3
		60-70%	4
		50-60%	5
		40-50%	6
		30-40%	7
		20-30%	8
		10-20%	9
Seismic activity	7	0-10%	10
		Activity level I (lowest risk)	10
		Activity level II	5
Barge accessibility	4	Activity level III (highest risk)	<i>a</i>
		Adjacent to channel of >9 ft depth	<i>b</i>
Rail accessibility	2	Adjacent to medium- or heavy-duty railroad	10
		Not adjacent to medium- or heavy-duty railroad	0

^aScore equals number of miles of channel (maximum is 94.6).

^bExcluded from consideration as potential candidate counties.

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Fig. B.7. Suitability for nuclear electrical generating plants by county: southeast subregion.

B.5.3 Calculation of site suitability for coal conversion plants

Regional siting factors for coal liquefaction or gasification plants are similar to those for coal-fired generating facilities (Table B.4). The main difference is that high-sulfur coal is preferred over low-sulfur coal. Most conversion processes are specifically designed to use high-sulfur coal, which cannot be burned in many areas due to air-quality standards for sulfur dioxide emissions.

The ideal location for a high-Btu gas or synthetic crude facility would have barge or rail access for the coal input and commercial pipelines for the output. Also, conversion plants tend to be located near suitable coal reserves (whereas generating plants tend to be demand oriented). Consequently, counties more than 100 miles from a sizable coal reserve were excluded from the selection; but, proximities to barge channels and railroads were considered in the suitability calculation, and pipelines were considered in the site selection for possible shipment. Figure B.8 displays the mapping of site suitability for coal conversion facilities.

B.6 Allocation of Resources To Meet Demand

A basic assumption in allocating generating capacity to candidate counties is that the locational pattern of supply facilities should minimize transmission distance. Transmission line loss amounts to about 1% of the electricity for every 10 miles of transmission. Utilities are aware of this sizable loss, but in the past they have not considered transmission distance to be a major factor in site selection. In contrast, we have assumed that there will be increasing concern for minimization of transmission distances in future site selections because of the following.

1. Energy is becoming more valuable. There is increasing emphasis on improved efficiency in all generation and conversion processes. It would seem unwise to spend millions of dollars in research and development to improve the efficiency of a given plant by a few percent and then lose what was gained by unnecessarily placing the plant additional miles for its load center.
2. Many traditional supply areas in the East will be having trouble finding sufficient sites to meet their own demands by 2000. Indeed, a recent survey of state energy offices indicates that almost all states are emphasizing a goal of self-sufficiency by 2000, and exporting additional power to distant consumers is out of the question.
3. There is increasing emphasis on cogeneration to use the heat given off by generating plants. Most forms of cogeneration would require sites near load centers to use "waste" heat (e.g., steam for district heating can be piped about 40 miles).

Table B.4. Regional siting criteria for a coal conversion facility

Variable	Importance weight	Category or value	Compatibility index
Water availability	10	Adjacent to stream with 7-day/10-year low flow $\geq$ 194 Mgd	10
		Adjacent to stream which could have 7-day/10-year low flow $\geq$ 194 Mgd if additional regulation were imposed	4
		Adjacent to Great Lakes	8
		Adjacent to Atlantic Ocean or Gulf of Mexico	5
		Other counties	<i>a</i>
Air quality maintenance areas (AQMA)	10	Not an AQMA	10
		Partially an AQMA	5
		Entirely an AQMA	<i>a</i>
Accessibility of high-sulfur coal ($>1.9\%$ S)	4	Values represent calculations from gravity model using tonnage of high-sulfur coal	
		Highest value	10
		Lowest value	1
		>100 miles from high-sulfur coal reserve	<i>a</i>
Barge accessibility	7	Adjacent to channel of ≥ 9 ft depth	<i>b</i>
Seismic activity	6	Activity level I (lowest risk)	10
		Activity level II	5
		Activity level III (highest risk)	0
Rail accessibility	6	Adjacent to medium- or heavy-duty railroad	10
		Not adjacent to medium- or heavy-duty railroad	0
Accessibility of low-sulfur coal ($\geq 1.9\%$ S)	8	Values represent calculations from gravity model using tonnage of low-sulfur coal	
		Highest value	10
		Lowest value	1
		>100 miles from low-sulfur coal reserve	<i>a</i>
Population density	3	90-100% of county has ≥ 500 inhabitants per square mile	0
		80-90%	2
		70-80%	3
		60-70%	4
		50-60%	5
		40-50%	6
		30-40%	7
		20-30%	8
		10-20%	9
		0-10%	10

^aScore equals number of miles of channel (maximum is 94.6).

^bExcluded from consideration as potential candidate counties.

Fig. B.8. Suitability for coal conversion facilities by county: southeast subregion.

Energy facility allocation algorithms can vary from a simple siting-risk overlay method to a sophisticated modeling of spatial preferences considering distance and suitability simultaneously. The ORNL approach in this analysis involves calculation of site suitability interpreted in broad categories, with class intervals equal to one standard deviation and allocation of capacity based on highest suitability and accessibility to demand. For each BEA the allocation algorithm for siting net generating capacity in 2000 is as follows:

1. Locate the county with the highest population and assume this to be the load center for all demand in the BEA.
2. Describe a 100-mile-radius circle from the load center.
3. Locate all counties with suitability scores of one or more standard deviations above the mean for each technology within 100 miles of the load center.
4. Beginning with the high-suitability county nearest the load center, allocate demanded capacity up to 4000 MWe minus the existing and planned capacity for the year 2000. Repeat this step with successively greater distances until demanded capacity is allocated or all high-suitability counties are exhausted. The type of facility allocated is based on the magnitude of the site suitability score for each technology. If a site is highly suitable for both technologies, then an "either" characteristic is assigned and adjustments to match the census level technology mix are made later.
5. If there is any remaining demand, complete the 100-mile-radius allocation for all BEAs, then describe a second circle of 200-mile radius and repeat step 4.
6. If there is any remaining demanded capacity, redefine the candidate counties to include all scores above the mean, and repeat steps 4 and 5.

The procedure used to allocate the 2020 capacity is identical except that the maximum capacity is set at 8000 MWe. The 4000- and 8000-MWe limitations are used to avoid the simplistic solution of placing all capacity for a load center at one or two sites. If such concentrations are necessary, they appear as clusters of 4000- or 8000-MWe counties. The option of combining these into a single energy park is still available.

As was noted previously, the capacity sited to meet demand in each census region must be adjusted to match the proportions of each technology type required by the scenario provided by BNL for 2000 and 2020. To simulate the BNL scenario completely would require the phasing out of old plants as well as relatively new plants scheduled to come on line by 1990. In other words, some oil- and gas-fired plants, either existing or proposed, would have to be retired or canceled and a new coal, nuclear,

or other type plant sited (in most cases in different locations) to completely match the BNL scenario. Thus it was decided to rely upon the utilities' plans as far as they go and adjust only the unscheduled plants sited by ORNL to match the BNL scenarios.

In the case of conventional hydro generating facilities and new pumped-storage capacity, it was difficult to find sites with sufficient potential to meet the capacity levels required by the scenarios. Published data by the Water Information Center^{1,0} indicate that most of the gross theoretical hydroelectric potential in the South has already been developed, leaving little potential for expansion. Although pumped-storage capacity potential is not similarly constrained, the areas having the greatest potential (high local relief) are often remote from major load centers requiring this type of peaking capacity, particularly in the Coastal Plain region. Because of these difficulties, new pumped storage and hydro capacity were sited only to the BEA level until a more thorough analysis is completed next year. Scenario totals for hydro capacity were used, but the reader should be aware that they are extremely optimistic.

B.7 Assessment of Alternative Siting Strategies

As was noted previously, we have designed a resource analysis system capable of multiple analyses under varying constraints and maximization rules. Most of this capability depends on ORSAM and ORRMIS. Resource availability and siting constraint data are stored in several different types of data bases and are organized according to the most efficient method of information representation (e.g., by county or by state). Outputs are determined by the users and may be retrieved in a number of different forms (e.g., maps, tables, graphs, or three-dimensional displays). In addition, these data bases may be accessed for editing, updating, transformation, and simple display.

Each step — input, storage, retrieval, analysis, and display — represents complex processes. The software for performing these functions has been developed as individual generalized modules or packages to provide flexibility and allow the user to tailor the procedure to specific siting needs. Due to the complexity of the data structures and the analyses or models being built, no single software command system has been developed as yet to house and supervise all the individual modules. Instead, each user problem is solved by picking available modules "off the shelf" (or by developing new ones as required) and linking them in the most efficient manner to solve the user problem.

Many different types of information (e.g., water availability, site-population constraint, and land availability) are maintained in the data system and fed into ORSAM, which in turn provides output used to determine candidate areas for the siting of energy facilities.

Because we have taken this approach, each new scenario does not have to be assessed independently in an ad hoc manner. At present, the siting allocation procedure is being automated to permit users to more

readily interact with the information system to test multiple scenarios and various solution alternatives.

B.8 Siting Patterns Derived for Technologies Other than Coal

County-level siting patterns derived to date from our analyses include distributions for nuclear, oil, and gas generating plants. Peaking facilities such as gas turbine, oil combustion, and pumped storage as well as conventional hydro plants have been located at the BEA level but not at the county level. Solar and geothermal facilities also have been allocated to the BEA level but with less confidence than that assumed for other types of electric generating facilities.

A fundamental reference for information on existing and proposed electric generating facilities is available from the FERC.² Using this data base it is possible to construct a detailed image of the supply infrastructure as viewed by the utilities at any given year up to about 1990. Included is a description of the capacity, plant type, fuel type, cooling type, and location of generating units over 10 MWe in the United States. The file also indicates the year a facility came on line or is scheduled to come on line or the scheduled date of retirement of a unit.

ORNL has updated and corrected the FERC data set substantially through communication with utility companies and through published data on plant cancellations. The information is used in describing the siting patterns for generating facilities in 1975 and 1985 and to adjust NCUA scenarios to reflect utility plans.

The utilities' plans are judged to be more reliable projections than those derived from the theoretical models upon which the scenarios are based. Because total proposed capacity is more than adequate to meet the recent-trends demand scenario in 1985, the siting pattern and fuel-type mix for 1985 was obtained directly from the corrected FERC data. Other types of energy facilities, such as oil refineries and coal conversion facilities, have been located at the county level using plans proposed by industry and DOE, but have been forced to match BNL scenario projections.

Siting patterns for 2000 and 2020 include all existing or proposed generating plants not scheduled to be retired according to the corrected FERC data. Additional generating capacity is sited by ORNL to meet the generation demands projected in the recent-trends scenario technology mix. The scenario fuel mix totals, however, are adjusted according to the FERC data, again based on the assumption that the utilities' plans are more correct than the scenario.

The following maps (Figs. B.9 through B.20) present siting patterns derived for the modified base-case scenario for technologies other than coal. Hypothetical development of generating capacity is presented by state. Additional information may alter the siting pattern significantly, but the constraints and the alternatives discussed in this section provide the basis for these patterns.

Fig. B.9. Siting pattern for NCUA base case, 1975 nuclear steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.10. Siting pattern for NCUA base case, 1985 projected nuclear steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.11. Siting pattern for NCUA base case, 2000 projected nuclear steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.12. Siting pattern for NCUA base case, 2020 projected nuclear steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.13. Siting pattern for NCUA base case, 1975 oil steam capacity by county (in megawatts electric): southeast subregion.

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Fig. B.14. Siting pattern for NCUA base case, 1985 projected oil steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.15. Siting pattern for NCUA base case, 2000 projected oil steam capacity by county (in megawatts electric): southeast subregion.

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Fig. B.16. Siting pattern for NCUA base case, 2020 projected oil steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.17. Siting pattern for NCUA base case, 1975 gas steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.18. Siting pattern for NCUA base case, 1985 projected gas steam capacity by county (in megawatts electric): southeast subregion.

Fig. B.19. Siting pattern for NCUA base case, 2000 projected gas steam capacity by county (in megawatts electric); southeast subregion.

Fig. B.20. Siting pattern for NCUA base case, 2020 projected gas steam capacity by county (in megawatts electric): southeast subregion.

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APPENDIX C

SUPPLEMENTAL INFORMATION ON THE AIR-QUALITY ANALYSIS

Two models were used to describe the air concentrations of pollutants as discussed in Sect. 4. The first of these is the atmospheric transport model (ATM)¹ which is employed for the short-range studies (up to 100 km). For the long-range studies, a regional trajectory and diffusion-deposition model (RETADD)² was used. A brief description of each follows.

The ATM might best be described as a mathematical distillation of the relevant parts of *Meteorology and Atomic Energy* 1968.³ It is basically a straight line, Gaussian plume model, and can be applied to point, area, and line sources. Plume-rise parameters can be input, along with parameters necessary for calculation of wet-fall and dry-fall deposition. The model also incorporates a tilting of the plume for heavy particulates. The user can specify either the Pasquill-Gifford⁴ or the Briggs⁵-Smith⁶ dispersion parameters, the latter being more applicable for longer distances (i.e., 50 km). Calculations can be made for any time period for which meteorological data are available in the form of a frequency table (i.e., fractional occurrence of stability class type, wind direction, and wind-speed class).

For the short-range studies in Sect. 4, a stack height of 300 ft (91.4 m) was assumed. For taller stacks, the resulting air concentrations will be less. An example is given in Fig. C.1. The source term is the same as that for Person County, North Carolina (Fig. 4.5), namely, 5375 MWe. The meteorological data from Raleigh, North Carolina, used for this site results in the highest air concentrations directly south of the stack. Figure C.1 compares the resulting air concentrations in this direction for 300- and 600-ft stacks. The peak value for the 600-ft stack is about 60% of that for the shorter stack.

The RETADD model is the ORNL version of the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory's regional-continental scale transport, diffusion, and deposition model.⁷ The model uses observed upper-air winds⁸ to calculate forward or backward trajectories. For forward trajectories, deposition and ground-level concentrations can be calculated. In the trajectory analysis technique, the total diffusion process is partitioned into advective transport by the mean wind and into diffusive transport by the turbulence. These processes, usually called transport and diffusion, are assumed to be independent such that their individual effects can simply be added. If one is interested in time-integrated effects (e.g., monthly averages), the trajectories are identified as plume axes and the spread of material perpendicular to these axes is calculated using a plume spreading formula, such as that for a Gaussian plume. As the plumes move over a region the surface concentrations and depositions are accumulated, and at the end of the simulation, time-averaged surface concentration patterns are calculated.

Fig. C.1. Air concentrations as a function of stack height.

Figures C.2-C.28 show estimated annual average concentrations of SO_2 , NO_x , and TSP for the vicinity of the remainder of those locations shown in Fig. 4.1.

ORNL-DWG 77-20157

Fig. C.2. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Bartow, Cobb, and Floyd counties, Georgia. Locations of power plants and county outlines are shown.

ORNL-DWG 77-20156

Fig. C.3. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Bartow, Cobb, and Floyd counties, Georgia.

ORNL-DWG 77-20158

Fig. C.4. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Bartow, Cobb, and Floyd counties, Georgia.

ORNL-DWG 77-20164

Fig. C.5. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Carroll and Coweta counties, Georgia.

ORNL-DWG 77-20162

Fig. C.6. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Carroll and Coweta counties, Georgia.

ORNL-DWG 77-20163

Fig. C.7. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Carroll and Coweta counties, Georgia.

ORNL-DWG 77-20166

Fig. C.8. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Hillsborough and Polk counties, Florida.

ORNL-DWG 77-20167

Fig. C.9. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Hillsborough and Polk counties, Florida.

Fig. C.10. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Hillsborough and Polk counties, Florida.

ORNL-DWG 77-20143

Fig. C.11. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Fort Bend County, Texas.

ORNL-DWG 77-20142

Fig. C.12. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Fort Bend County, Texas.

ORNL-DWG 77-20141

Fig. C.13. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Fort Bend County, Texas.

ORNL-DWG 77-20145

Fig. C.14. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Jefferson, Shelby, and Walker counties, Alabama.

ORNL-DWG 77-20144

Fig. C.15. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Jefferson, Shelby, and Walker counties, Alabama.

ORNL-DWG 77-20148

Fig. C.16. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Jefferson, Shelby, and Walker counties, Alabama.

ORNL-DWG 77-20150

Fig. C.17. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Catawba, Cleveland, and Gaston counties, North Carolina.

ORNL-DWG 77-20152

Fig. C.18. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Catawba, Cleveland, and Gaston counties, North Carolina.

ORNL-DWG 77-20151

Fig. C.19. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Catawba, Cleveland, and Gaston counties, North Carolina.

Fig. C.20. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Bibb and Monroe counties, Georgia.

ORNL-DWG 77-20153

Fig. C.21. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Bibb and Monroe counties, Georgia.

ORNL-DWG 77-20155

Fig. C.22. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Bibb and Monroe counties, Georgia.

ORNL DWG 77 20173

Fig. C.23. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Mobile and Washington counties, Alabama.

ORNL-DWG 77-20172

Fig. C.24. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Mobile and Washington counties, Alabama.

ORNL-DWG 77-20171

Fig. C.25. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Mobile and Washington counties, Alabama.

Fig. C.26. Annual average calculated ground-level concentration of sulfur dioxide from coal-fired steam plants in Harrison and Jackson counties, Mississippi.

Fig. C.27. Annual average calculated ground-level concentration of nitrogen oxides from coal-fired steam plants in Harrison and Jackson counties, Mississippi.

ORNL-DWG 77-20148

Fig. C.28. Annual average calculated ground-level concentration of total suspended particulates from coal-fired steam plants in Harrison and Jackson counties, Mississippi.

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APPENDIX D

GEOECOLOGY DATA BASE

Environmental assessments within the NCUA report utilized the Geoecology Data Base¹ for data resources, analysis, and display. This appendix defines the sources of data used in the report and describes methods. The Geoecology Data Base was developed by the Spatial Data System for the Regional Ecological Impact Assessment project to provide quick response capability in order to quantitatively characterize environmental parameters for large geographic regions. By selecting variables from extant data and editing them into a common format, over 700 variables were made available for interactive computer analysis at the county-subcounty unit level of resolution for the 16 southern states (1388 county units). Many of the 30 thematic sectors cover the 37 eastern states or the entire nation. The data base uses the SAS data management and analysis system.² Shaded contour maps in this report were produced by linking output from the Geoecology Data Base to the Harvard SYMAP system.³ County outline shaded maps were produced by using mapping capabilities of the ORRMIS system developed by the Geographic Data Systems Group within the Computer Sciences Division at Oak Ridge National Laboratory.

D.1 Climate

County-level temperature and precipitation data were based on 30-year monthly norms (1941-1970) obtained from the National Climatic Center, NOAA. Temperature data from 1647 stations and precipitation data from 2081 stations in the eastern 37 states were analyzed with the mathematical interpolation routines of SYMAP to provide individual county estimates.⁴ Potential evapotranspiration and moisture indexes were calculated for each county, based on Thornthwaite formulas.⁵ Maps of the above parameters are found in Figs. D.1-D.6.

D.2 Energy

The Energetics of the United States: An Atlas, compiled by Brookhaven National Laboratory,⁶ was used for county-level measures of energy production and use. Various forms of energy use (e.g., gallons of gas, cubic feet of natural gas, tons of coal, kilowatts, etc.) were converted to Btu equivalents to allow summations. Total energy use per square mile and per capita were mapped (Figs. 7.2 and 7.3). Also, counties with electrical generation from coal-fired power plants were mapped for 1972 and 1985 projections (Figs. 7.4 and 7.5).

Fig. D.1. Maximum annual temperatures based on 30-year monthly norms for 1941-1970. Interval limits expressed as degrees Fahrenheit: (1) <72.5, (2) 72.5-77.0, (3) 77.0-79.2, (4) 79.2-81.5, (5) 81.5-83.7, (6) >83.7. (Data from the Climate Sector, Geoecology Data Base.)

Fig. D.2. Minimum annual temperatures based on 30-year monthly norms for 1941-1970. Interval limits expressed as degrees Fahrenheit: (1) <32.0, (2) 32.0-36.5, (3) 36.5-41.0, (4) 41.0-45.5, (5) 45.5-50.0, (6) 50.0-54.5, (7) >54.5. (Data from the Climate Sector, Geoecology Data Base.)

Fig. D.3. Average annual temperatures based on 30-year monthly norms for 1941-1970. Interval limits expressed as degrees Fahrenheit: (1) <54.5, (2) 54.5-59.0, (3) 59.0-63.5, (4) 63.5-68.0, (5) 68.0-72.5, (6) >72.5. (Data from the Climate Sector, Geoecology Data Base.)

Fig. D.4. Total annual rainfall based on 30-year monthly norms for 1941-1970. Interval limits expressed in inches: (1) <25.0, (2) 25.0-35.0, (3) 35.0-45.0, (4) 45.0-55.0, (5) >55.0. (Data from the Climate Sector, Geoecology Data Base.)

Fig. D.5. Annual potential evapotranspiration index calculated from 30-year monthly temperature and precipitation norms for 1941-1970 using the Thornthwaite formulas. Interval limits: (1) <30.0, (2) 30.0-35.0, (3) 35.0-40.0, (4) 40.0-45.0, (5) >45.0. (Data from the Climate Sector, Geoecology Data Base.)

Fig. D.6. Annual moisture index calculated from 30-year monthly temperature and precipitation norms for 1941-1970 using the Thornthwaite formulas. Interval limits: (1) $<(-40.0)$, (2) $(-40.0)-0.0$, (3) $0.0-20.0$, (4) $20.0-40.0$, (5) $40.0-60.0$, (6) >60.0 . (Data from the Climate Sector, Geoecology Data Base.)

D.3 Land Use

The 1967 Conservation Needs Inventory (CNI)⁷ was used to portray broad land-use categories which include urban, crop, pasture, range, and forest (Figs. 7.15-7.20). The original survey did not include data on federal land, urban land, or small lake acreages, but these data were obtained from Iowa State University, Department of Statistics, which had assisted in compiling the 1967 CNI. As used in this report, crop land represents areas being tilled, areas recently tilled, areas formerly tilled but not converted to other uses, land in conservation categories, and orchards/vineyards. Forestland is composed of commercial, noncommercial, and federal land. In the CNI, federal lands were not assigned to land-use categories. However, assigning them to forestland gives a more realistic map of forests by filling in the large areas of national forests and parks. But, it may give a false impression in the western part of the region by indicating the presence of forestland, which should, in fact, be classified as rangeland (e.g., Bureau of Land Management lands). Land-use maps were based on the percent of county area classified in each category. In Fig. 7.20, land-use classes were determined on the presence of $\geq 50\%$ occupancy of a county except for urban counties, which were based on $\geq 10\%$.

D.4 Agriculture

Agricultural production values for soybeans (Fig. 7.12), cotton, corn, sorghum, and wheat were obtained from the 1969 Census of Agriculture survey.⁸ These maps are presented in Figs. D.7-D.10. Statistics for 1975 yields of soybeans, corn, and wheat (Figs. D.11-D.13) were obtained from individual states. County-level productivity was expressed as the ratio of total production for a crop to the total acreage of the county.

This ratio incorporates both the yield per acre and the proportion of the county from which the crop was harvested and reflects the overall importance of the crop to the county. A crop with high yield but grown on a small portion of the county may have the same ratio as a crop with low yield but which is grown throughout the county. In either case, the crop would have the same importance relative to energy-related impacts.

D.5 Forestry

County-level statistics for forests were obtained from individual U.S. Forest Service state-level inventory publications. Growing stock volumes were mapped for softwoods, hardwoods, and all species (Figs. 7.11, 7.21, 7.22). Growing stock volume is defined as the net cubic foot volume of commercially acceptable trees at least 5.0 in. in diameter at breast height. Productivity was expressed as total stand volume divided by county acreage.

Fig. D.7. Cotton yield from the 1969 Census of Agriculture expressed as total production per total county area. Interval limits expressed as pounds per acre: (1) <0.01 , (2) $0.01-0.1$, (3) $0.1-1.0$, (4) $1.0-10.0$, (5) $10.0-100.0$, (6) >100.0 . (Data from the Agricultural Sector, Geoecology Data Base.)

Fig. D.8. Corn yield from the 1969 Census of Agriculture expressed as total production for grain per total county area. Interval limits expressed as bushels per acre: (1) <0.001, (2) 0.001-0.01, (3) 0.01-0.1, (4) 0.1-1.0, (5) 1.0-10.0, (6) >10.0. (Data from the Agricultural Sector, Geoecology Data Base.)

Fig. D.9. Sorghum yield from the 1969 Census of Agriculture expressed as total production per total county area. Interval limits expressed as bushels per acre: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$, (6) >10.0 . (Data from the Agricultural Sector, Geocology Data Base.)

Fig. D.10. Wheat yield from the 1969 Census of Agriculture expressed as total production per total county area. Interval limits expressed as bushels per acre: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.10$, (4) $0.10-1.00$, (5) $1.00-10.00$, (6) >10.0 . (Data from the Agricultural Sector, Geocology Data Base.)

Fig. D.11. Soybean yield from 1975 state summaries expressed as total production per total county area. Interval limits expressed as bushels per acre: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$, (6) >10.0 . (Data from the Agricultural Sector, Geoecology Data Base.)

Fig. D.12. Corn yield from 1975 state summaries expressed as total production for grain per total county area. Interval limits expressed as bushels per acre: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.1$, (4) $0.1-1.0$, (5) $1.0-10.0$, (6) >10.0 . (Data from the Agricultural Sector, Geocology Data Base.)

Fig. D.13. Wheat yield from 1975 state summaries expressed as total production per total county area. Interval limits expressed as bushels per acre: (1) <0.001 , (2) $0.001-0.01$, (3) $0.01-0.10$, (4) $0.10-1.00$, (5) $1.00-10.0$, (6) >10.0 . (Data from the Agricultural Sector, Geoecology Data Base.)

D.6 Air Quality

Air-quality patterns have been displayed using several sources of information for SO_2 , NO_x , and particulates. The measured patterns of SO_2 and particulates were mapped using January 1974 SAROAD⁹ monitoring data from EPA (Figs. 7.8, D.14). Unfortunately, the available data were limited, with only 233 counties having observations for SO_2 and 399 for particulates.

Annual SO_2 emissions from fossil fuel combustion were mapped, using data from ref. 6. Values were calculated from the amount of fuel burned in a county and the average percentage of sulfur in the fuels for the state. In addition to emissions from all fuels (coal, oil, and natural gas), a map was made based on coal combustion (Figs. 7.6, 7.7, D.15, D.16).

Data for a third set of maps were generated from use of a long-range trajectory model and the NCUA scenarios for 1975, 1985, and 2000. Estimates from a rectangular grid were mapped with SYMAP for both SO_2 and sulfates (Fig. 4.8-4.15). SYMAP was also used to estimate county-level values used in calculating population, crop, and forestry exposures (Figs. 7.13, 7.14, and 8.3-8.6).

Each of the three ways of displaying air-quality patterns used different data sources and units of measure; thus, the map levels are not directly comparable. However, the relative patterns should be comparable.

D.7 Population

Population densities for 1970, 1985, and 2000 were mapped, based on the 1970 census data included in ref. 6 and on projections made by the Energy Division at ORNL using the MULTIREGION program (Fig. D.17-D.19).

D.8 Health

County-level, age-adjusted mortality rates for 53 causes of death were obtained from the UPGRADE system operated by the Council on Environmental Quality.¹⁰ This data file was compiled from the National Center on Health Statistics for the period 1968 to 1972. Annual deaths per million people were calculated for whites and blacks, subdivided into males and females. Cause-of-death categories associated with SO_2 exposures were selected, and a combined mortality rate was calculated. Categories included in the combined mortality rate were rheumatic heart disease, hypertension, acute ischemic heart disease, chronic ischemic heart disease, other heart diseases, cerebrovascular disease, arteriosclerosis, aortic aneurism, diseases of other arteries, cancer of the lungs, influenza/pneumonia, and chronic respiratory diseases. Unfortunately, it was impossible to subset some classes (i.e., influenza/pneumonia) to limit the analysis to those more clearly associated with air pollutants.

Fig. D.14. Particulate concentrations as monitored by EPA during January 1974 using the mean concentration from 399 counties having one or more monitoring stations. Interval limits expressed as micrograms per cubic meter: (1) <20.0, (2) 20.0-40.0, (3) 40.0-60.0, (4) 60.0-80.0, (5) >80.0. (Data from the Air Quality Sector, Geoecology Data Base.)

Fig. D.15. Nitrogen oxide emissions (from Drysdale and Calef⁶) representing calculated emissions from the amount of fossil fuels consumed per county. Interval limits expressed as 2200 pounds per square mile: (1) <1.0, (2) 1.0-5.0, (3) 5.0-10.0, (4) 10.0-50.0, (5) >50.0. (Data from the Energy Sector, Geoecology Data Base.)

Fig. D.16. Particulate emissions (from Drysdale and Calef⁶) representing calculated emissions from the amount of fossil fuels consumed per county. Interval limits expressed as 2200 pounds per square mile: (1) <1.0, (2) 1.0-5.0, (3) 5.0-10.0, (4) 10.0-50.0, (5) >50.0. (Data from the Energy Sector, Geoecology Data Base.)

Fig. D.17. Population density for 1970 (from Drysdale and Calef⁶). Interval limits expressed as persons per square mile: (1) 1-25, (2) 25-50, (3) 50-100, (4) 100-250, (5) >250. (Data from the Energy Sector, Geoecology Data Base.)

Fig. D.18. Projected population density for 1985 obtained through use of ORNL MULTIREGION model. Interval limits expressed as persons per square mile: (1) 10-25, (2) 25-50, (3) 50-100, (4) 100-250, (5) >250. (Data from the Population Sector, Geoecology Data Base.)

Fig. D.19. Projected population density for 2000 obtained through use of ORNL MULTIREGION model. Interval limits expressed as persons per square mile: (1) 10-25, (2) 25-50, (3) 50-100, (4) 100-250, (5) >250.

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APPENDIX E

DATA-BASE SYSTEM FOR DISTRIBUTION OF ANIMAL SPECIES WITHIN THE SOUTHEASTERN UNITED STATES

The design and components of a data-base system for southeastern animal species are reflected in Fig. E.1. Initial focus is on the problem of describing and analyzing the geographical association of species and the environmental factors regulating their distribution. As pointed out by Schreiber et al.,¹

"The use of traditional range or distribution maps in resolving regional scale ecological problems has been limited in the past by the format of the data and inaccessibility of the data for convenient manipulation. The key to further development is the use of computer storage, retrieval, and analysis of the information. Having data in digital form permits multivariate statistical analysis to examine relationships between mapped variables or to test hypotheses about derived models of the system. Output from such analytical comparisons can be numerical, or, with the use of computer graphics, a map of any chosen variable or relationship between data sets can be produced, and spatially dependent processes can be examined and modeled."

We are utilizing counties as convenient and consistent spatial units in 16 southeast and southcentral states. This system lends itself to coupling with other types of quantitative data. We are using the programs STORER and RANGER¹ to store and manipulate species habitat and distribution data.

Table E.1 lists the 102 mammal species whose spatial distribution has been coded and cataloged in the geoecology data system. The distribution of these species was taken from various mammal guides and journal articles. The computer program STORER has been developed to aid in converting these diverse sources of information into a common, computer-readable form. The digitization procedure essentially consists of recording county codes in which species occur; however, several shortcuts have been incorporated into the sequence. Eight-character mnemonic names are utilized as codes for the latin binomial or trinomial names (Table E.1). Counties are numbered to reflect their geographic contiguity such that if a species occurs in the southern part of a state, the list of counties. The program also has capabilities to aid in checking and editing the digitized data. Once the data are stored, they can be retrieved by several methods according to the following needs:²

Fig. E.1. Components of a data-base system for animal species. The major focus of this system is on the geographical association of species and the environmental factors regulating their distribution.

Table E.1. Listing of mammal species and subspecies found within the southeastern United States

(The spatial distribution of these species has been coded and cataloged in the geocology data system)

Mnemonic code	Species	Common name
BASAST	BASSARISCUS ASTUTUS	Ringtail
BLABRE	BLARINA BREVICAUDA	Shorttail Shrew
CANLAT	CANIS LUTRANS	Coyote
CANRUF	CANIS RUFUS	Red Wolf
CASCAN	CASTOR CANADENSIS	Beaver
CERDAM	CERVUS DAMA	Fallow Deer
CLEGAP	CLETHRIONOMYS GAPPERI	Red-back Vole
CONCRI	CONDYLURA CRISTATA	Star-nosed Mole
CRYPAR	CRYPTOTIS PARVA	Least Shrew
DASNOV	DASYPUS NOVEMCINCTUS	None-banded Armadillo
DIDVIR	DIDELPHIS VIRGINIANA	Opossum
EPTFUS	EPTESICUS FUSCUS	Big Brown Bat
FECOCU	FELIS CONCOLOR COUGAR	Eastern Cougar
FECOCY	FELIS CONCOLOR CORYI	Florida Panther
GEOBUR	GEOMYS BURSARIUS	Plains Pocket Gopher
GEOCOL	GEOMYS COLONUS	Colonial Pocket Gopher
GEOCUM	GEOMYS CUMBERLANDIUS	Cumberland Island Pocket Gopher
GEOFON	GEOMYS FONTANELUS	Sherman's Pocket Gopher
GEOPIN	GEOMYS PINETIS	Southeastern Pocket Gopher
GEPIGO	GEOMYS PINETIS GOFFI	Goff's Pocket Gopher
GLAVOL	GLAUCOMYS VOLANS	Flying Squirrel
LASBOR	LASIURUS BOREALIS	Red Bat
LASCIN	LASIURUS CINEREUS	Hoary Bat
LASINT	LASIURUS INTERMEDIUS	Florida Yellow Bat
LASNOC	LASIONYCTERIS NOCTIVAGANS	Silver-haired Bat
LASSEM	LASIURUS SEMINOLUS	Seminole Bat
LUTCAN	LUTRA CANADENSIS	River Otter
LYNRUF	LYNX RUFUS	Bobcat
MARMON	MARMOTA MONAX	Woodchuck
MEPMEP	MEPHITIS MEPHITIS	Striped Skunk
MICHOY	MICROSOREX HOYI	Pygmy Shrew
MICLUD	MICROTUS LUDOVICIANUS	Louisiana Vole
MICOCH	MICROTUS OCHROGASTER	Prairie Vole
MICPEN	MICROTUS PENNSYLVANICUS	Meadow Vole
MICPIN	MICROTUS PINETORUM	Pine Mouse

Table E.1 (continued)

Mnemonic code	Species	Common name
MUSEVE	MUSTELA EVERGLADENSIS	Everglades Mink
MUSFRE	MUSTELA FRENATA	Longtail Weasel
MUSMUS	MUS MUSCULUS	House Mouse
MUSVIS	MUSTELA VISON	Mink
MYOAUS	MYOTIS AUSTRORIPARIUS	Southeastern Myotis
MYOCoy	MYOCASTER COYPUS	Nutria
MYOGRI	MYOTIS GRISESCENS	Gray Bat
MYOKEE	MYOTIS KEENI	Keen's Bat
MYOLEI	MYOTIS LEIBII	Leib's Bat
MYOLUC	MYOTIS LUCIFUGUS	Little Brown Bat
MYOSOL	MYOTIS SODALIS	Indiana Bat
NAPINS	NAPAEZAPUS INSIGNIS	Woodland Jumping Mouse
NEFLSM	NEOTOMA FLORIDANA SMALLI	Key Largo Woodrat
NEOALL	NEOFIBER ALLENI	Round-tail Muskrat
NEOFLA	NEOTOMA FLORIDANA	Wood-Rat
NYCHUM	NYCTICEIUS HUMERALIS	Evening Bat
OCHNUT	OCHROTOMYS NUTTALLI	Golden Mouse
ODOVIR	ODOCOILEUS VIRGINIANUS	White-tail Deer
ODVICL	ODOCOILEUS VIRGINIANUS CLAVIUM	Key Deer
ONDZIB	ONDATRA ZIBETHICUS	Muskrat
ORYPAL	ORYZOMYS PALUSTRIS	Rice Rat
OZYZCK	ORYZOMYS-UNDES, sp.	Cudjoe Key Rice Rat
PARBRE	PARASCALOPS BREWERI	Hairy Tail Mole
PEGOAL	PEROMYSCUS GOSSYPINUS ALLAPATICULA	Key Largo Cotton Mouse
PEMABA	PEROMYSCUS MANICULATUS BAIRDII	Prairie Deer Mouse
PEMANU	PEROMYSCUS MANICULATUS NUBITERRAE	Cloudland Deer Mouse
PEPODE	PEROMYSCUS POLIONOTUS DECOLORATUS	Pallid Beech Mouse
PERFLA	PEROMYSCUS FLORIDANUS	Florida Mouse
PERGOS	PEROMYSCUS GOSSYPINUS	Cotton Mouse
PERHIS	PEROGNATHUS HISPIDUS	Hispid Pocket Mouse
PERLEU	PEROMYSCUS LEUCOPUS	White-footed Mouse
PERPOL	PEROMYSCUS POLIONOTUS	Old-field Mouse
PIPSUB	PIPISTRELLUS SUBFLAVUS	Eastern Pipistrelle
PITPAR	PITYMYS PARVULUS	Florida Pine Mouse
PLERAF	PLECORUS RAFINESQUII	Rafinesque's Big-eared Bat
PLTOIN	PLECOTUS TOWNSENDII INGENS	Ozark Big-eared Bat
PLTOVI	PLECOTUS TOWNSENDII VIRGINIANUS	Virginia Big-eared Bat

Table E.1 (continued)

Mnemonic code	Species	Common name
PRI.OAU	PROCYON LOTOR AUSPICATUS	Key Vaca Raccoon
PRLOIN	PROCYON LOTOR INCAJTUS	Torch Key Raccoon
PROLOT	PROCYON LOTOR	Raccoon
RATNOR	RATTUS NORVEGICUS	Norway Rat
RATRAT	RATTUS RATTUS	Black Rat
REIFUL	REITHRODONTOMYS FULVESCENS	Fulvous Harvest Mouse
REIHUM	REITHRODONTOMYS HUMULIS	Eastern Harvest Mouse
SCAAQU	SCALOPUS AQUATICUS	Eastern Mole
SCCAMA	SCIURUS CAROLINENSIS MATECUMBEI	Key Largo Gray Squirrel
SCIAUR	SCIURUS AUREOGASTER	Red-bellied Gray Squirrel
SCICAR	SCIURUS CAROLINENSIS	Gray Squirrel
SCNIAV	SCIURUS NIGER AVICENNIA	Everglades Fox Squirrel
SCNISH	SCIURUS NIGER SHERMANI	Sherman's Fox Squirrel
SCNIVU	SCIURUS NIGER VULPINUS	Eastern Fox Squirrel
SIGHIS	SIGMODON HISPIDUS	Cotton Rat
SIHIEY	SIGMODON HISPIDUS EXSPUTUS	Lower Keys Cotton Rat
SORCIN	SOREX CINEREUS	Masked Shrew
SORDIS	SOREX DISPAR	Long-tail Shrew
SORFUM	SOREX FUMEUS	Smokey Shrew
SORLON	SOREX LONGIROSTRIS	Southeastern Shrew
SORPAL	SOREX PALUSTRIS	Water Shrew
SPIPUT	SPILOGALE PUTORIUS	Spotted Skunk
SYLAQU	SYLVILAGUS AQUATICUS	Swamp Rabbit
SYLFLO	SYLVILAGUS FLORIDANA	Eastern Cottontail
SYLPAL	SYLVILAGUS PALUSTRIS	Marsh Rabbit
SYLTRA	SYLVILAGUS TRANSITIONALIS	Wood Rabbit
SYNCOO	SYNAPTOMYS COOPERI	Southern Bog Lemming
TADBRA	TADARIDA BRASILIENSIS	Brazilian Free-tail Bat
TAMHUD	TAMIASCIURUS HUDSONICUS	Red Squirrel
TAMSTR	TAMIAS STRIATUS	Chipmunk
UROGIN	UROCYON CINEREOARGENTEUS	Gray Fox
URSAME	URSUS AMERICANUS	Black Bear
VULFUL	VULPES FULVA	Red Fox
ZAPHUD	ZAPUS HUDSONIUS	Meadow Jumping Mouse

- list of counties in which a species occurs,
- list of species that occur within a county,
- list of species that occur within a region of several counties (Table E.2): The mnemonic in the first grouping SYNC00 represents *Synaptomys cooperi* (southern bog lemming). The first through the sixth row are the data input. Row 1 reads 0, 3, 52, which signifies that SYNC00 occurs in all the counties of state 52. The second and third rows read that SYNC00 occurs in counties 20-26 and 47-54 in state 4 and occurs in every county in state 19 except 30-62 and 80-93. Following this grouping is a complete listing (in Federal Information Processing System code) of the counties where the particular species has been found. Finally, the number of counties occupied is the percentage of counties in the United States where the species occurs. Obviously, the smaller the value, the rarer the species.
- maps of counties in which a species occurs: Maps can be created for a single species (Fig. E.2) or for multiple species.
- data file to be utilized by other analysis programs (Fig. E.2): Figure E.2 is a computer map depicting potential habitat for endangered birds in Florida constructed from habitat information stored in the geoecology data file.

As indicated, abundance, derived relationships, and other quantitative information are being entered into the geoecology system. This is particularly true of those species listed in Table E.1. Since the populations of these species are already restricted, we have collected information concerning their habitat needs. This information has also been stored within the geoecology data system.

The geoecology system utilizes the Statistical Analysis System (SAS)³ for subsetting, merging, and analyzing county-level data. Data from the system can be input to cartographic display programs or simulation models according to the needs of the investigators.

(SYNCOD is the mnemonic listing for *Synaptomys cooperi* and TADBRA represents *Tadarida brasiliensis*)

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Fig. E.2. Computer map depicting potential habitat for endangered birds in Florida. The land (2) and water (6) patterns refer to areas adjacent to the study area. Cell count is the number of grid points under each legend pattern.

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APPENDIX F

DISCUSSION OF THE POSSIBLE IMPACTS CAUSED BY AN INCREASE IN ATMOSPHERIC CO₂

The increased input of carbon dioxide to the atmosphere is hypothesized to lead to climate modification. All ecoregions of the South would be impacted by a change in climate.

The concentration of carbon dioxide in the atmosphere has increased from about 315 ppm by volume in 1958 to about 330 ppm in 1974. This increase is attributed in large part to the production of CO₂ through fossil fuel utilization. Increases in the concentration of CO₂ in the atmosphere are expected to result in an increase in the absorption of infrared radiation from the earth, thereby increasing the temperature of air near the surface (the "greenhouse effect"). Other modifications in climate (e.g., changes in precipitation and evaporation rates) might also be expected. The possible impacts of such climate modification include melting of the polar ice caps, a shift in the geographical distribution of natural vegetation, a shift in the locations of best regions for various types of agriculture production, and increased frequency of drought in some regions. An intensive research program to clarify the carbon cycle problem and to develop policies to minimize impacts is called for.

The combustion of fossil fuels as a major contributor to the increased concentration of carbon dioxide in the earth's atmosphere will continue to be true for many decades, even with increases in rates of CO₂ production by nonfossil sources.¹ The "greenhouse effect" may lead to a significant warming of the air at the earth's surface even though temperature in the stratosphere decreases. The possibility of global climatic modification is now clearly of sufficient consequence to mark CO₂ and climate as a constraint on the expanded use of fossil fuels for electrical energy production.^{2,3} A general review of the CO₂-climate problem may be found in Baes et al.^{4,5} The increase in the production of atmospheric CO₂ since 1860 is clearly shown by the data compiled by Keeling⁶ and Rotty⁷ (Fig. F.1). The corresponding increase in the atmospheric concentration of CO₂ is evident in measurements taken at Mauna Loa, Hawaii, and at several other observatories (Fig. F.2; data from C. D. Keeling as given in Baes et al.⁵). The combustion of fossil fuels for electrical energy production accounts for a significant portion of the CO₂ production in Fig. F.1. A continuing increase in CO₂, such as that evident in Fig. F.2, may lead to climate modification.

Although the concept of climate modification by CO₂ is relatively simple, the physics of the situation is complicated by the uneven absorption of radiation by moisture in the atmosphere. The problem is further complicated by randomly occurring phenomena such as clouds and storms. Quantitative prediction of a temperature rise associated with a particular increase in CO₂ is difficult.

Fig. F.1. Annual CO₂ production from fossil fuels and cement. CO₂ production is expressed in terms of the amount of elemental carbon transferred to the atmosphere annually (data are from Keeling⁶ and Rotty⁷).

Fig. F.2. Atmospheric carbon dioxide concentration at Mauna Loa Observatory (data from C. D. Keeling as given in Baes et al.⁵).

Models used in analyzing the potential climatic impacts of an increase in CO_2 tend to be of two levels of sophistication. Several researchers (e.g., Mulholland⁸) have made use of a single global radiative heat balance equation to predict average increases in temperature. At the other end of the scale, high-resolution models such as those of Manabe and Wetherald⁹ incorporate a three-dimensional model for the general circulation of the atmosphere, including energy and moisture budgets. Recent extensions of such work deal more completely with phenomena such as variations in cloud cover and resulting climatic feedbacks. Changes in the oceans and the earth's surface albedo require continuing attention.¹⁰

Regardless of the limitations of present atmospheric models, meteorologists and climatologists seem to have reached a tentative consensus that a doubling of the concentration of CO_2 in the atmosphere will result in an increase of 2 to 4°C in the average surface temperature of the earth. It is generally accepted that raising the temperature increases potential evaporation. Further, an increase in global mean temperature would almost certainly be accompanied by unequal geographic changes in total precipitation. Recent model simulation results, particularly those of Manabe and Wetherald, indicate that the difference (precipitation minus evaporation) will decrease in the region between 35° and 48° north latitude, suggesting an increase in the frequency, spatial extent, duration, and intensity of drought.

An increase in the average temperature of the earth's surface will result in numerous impacts on life systems. The most significant are briefly summarized here.

Global temperature increases are expected to be most pronounced at high latitudes, partially because of a positive feedback of melting snow/ice cover and the associated decreases in reflected solar radiation. This melting of the polar ice caps implies an increase in the surface area of oceans. These feedback effects were not adequately treated in some of the earlier models — one reason why warming estimates based on these models may be too conservative. The implications of melting polar ice caps and resulting rises in sea levels are therefore more serious than would be indicated by considering only a globally averaged temperature increase.

The distribution of terrestrial vegetation is determined to a significant extent by temperature, moisture, and their interaction. When a modification of average precipitation rates is also assumed, shifts in the ranges of many species of plants are implied. Preliminary studies indicate that an increase in temperature may result in modifications of productivity, other ecological balances,^{4,11} and forest successional dynamics, in addition to changes in distribution.¹²

The disruption in the ecological and marketing geography of agriculture in an environment of increased temperature could be staggering. When the possibility of increased drought frequency is added to the uncertainty of weather changes for individual years and decades, the consequences may be catastrophic. Certainly, the regions over which particular crops are presently grown can be expected to shift in accordance with

temperature and moisture tolerance of the crops involved. The corn belt may move to the north, with wheat becoming prevalent in its previous location.⁵ Present agricultural areas which are marginal with respect to temperature or moisture may become unusable for agricultural purposes. Rangelands of the Great Plains may have many more years of extreme drought than what we have come to expect from the dustbowl cycle. Grazing capacity for livestock may become negligible over much of the West, except for a few tolerable months. If herds cannot be carried safely over the rest of the year in other accessible rangelands, they may have to be sacrificed at the very time when markets are least favorable for sale — as in the recent western droughts.

More irrigation and higher intensity of feedlot management may compensate when dry farming and open range become too risky to be continued. Yet, lowering levels of groundwater and surface water and increasing costs of pumping what remains will work together to narrow the regions where this option is realistic. Conflicts will be most acute in the very places where there is a competing desire to reallocate traditional agricultural water rights to energy facilities, fuel processing, or slurry transportation of coal.

Clearly, a good deal of research is required in every aspect of the global carbon cycle, the radiation balance of the atmosphere, and the effects of climate on the earth's life systems. Interdisciplinary research and assessments should be funded to study the CO₂/climate problem in a total system context. Only in this way will our understanding of the carbon cycle proceed fast enough to formulate policies to anticipate and mitigate some of the impacts outlined in this report.

Drawing from Baes et al.⁴ more specifically:

1. We must learn more about the carbon cycle.
2. We must predict more accurately the climatic effects of increasing atmospheric CO₂.
3. We must anticipate the consequences of climatic change.

In conclusion we quote a recent report by the National Research Council:¹³

"The climatic effects of carbon dioxide release may be the primary limiting factor on energy production from fossil fuels over the next few centuries. The prospect of damaging climatic changes may thus be the stimulus for greater efforts at conservation and a more rapid transition to alternate energy sources than is justified by economic considerations alone. The potential effect of carbon dioxide could be exacerbated by fluorocarbons, nitrous oxide, and other industrial gases. The natural variability of climate could increase or reduce the impact of such man-made effects.

"There are profound uncertainties regarding the carbon cycle, climate, and their interdependence. These uncertainties can be resolved only by a well-coordinated effort of extraordinarily interdisciplinary character. The focus for such an effort is not provided by any existing institutional mechanisms."

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APPENDIX G

SOCIOECONOMIC IMPACT ASSESSMENT

G.1 Socioeconomic Overview of Coal Mining

The major external costs considered in this section are the environmental effects and the health and safety problems of surface and deep coal mining. After these effects are summarized, past, present, and future employment in coal mining is discussed.

G.1.1 Technical processes and facilities in coal mining

Coal is extracted by two general types of processes: deep mining and surface mining. The room-and-pillar method of deep mining is typical in the United States, whereas the long-wall method predominates in most European countries. There are three main types of surface mining: strip or contour, auger, and area (see ref. 1 for a description of these three types and see ref. 2 for a discussion of new developments in mining technology). Most Appalachian surface mining is strip or auger mining.

Large-scale surface mining did not begin until the early 1960s, but once surface mining began, its share of coal production increased rapidly. In 1941, about 10% of U.S. coal was produced by surface methods; in 1967, about 34%; and in 1976, over 50%.³ The increased proportion of surface-mined coal is largely due to increased coal consumption for electricity production, which now consumes over 50% of total U.S. coal production. Surface-mined coal is generally of lower quality and has more waste material than deep-mined coal, but it is acceptable for electricity generation. Between 1940 and 1969, coal consumed for electricity generation increased from 51,474,000 to 310,312,000 tons. In the same time period, the amount of coal that was surface mined rose from 43,167,000 to 213,373,000 tons.⁴

The proportion of coal produced by surface methods probably will continue to increase. The principal advantage of surface mining is that more coal can be recovered at less cost to the producer. Other advantages of surface mining are greater productivity per man-day (about 30 tons vs an average of about 15 tons in deep mines) and recovery of greater proportions of the coal deposit (80% to 100% for surface mines vs 50% to 85% for deep mines).⁵⁻⁷

Despite these advantages, surface mining has greater environmental costs than deep mining. Some of these costs are discussed in more detail below. Like environmental effects, the health and safety effects of deep and surface mining also differ substantially. Because the effects of the two types of mining are so different, surface and deep mining are discussed separately in the following sections.

G.1.2 External costs of surface mining

Surface mining allows greater coal production at a lesser cost than deep mining. Surface mining is cheaper, not only in dollars, but also in human lives. Both fatal and nonfatal accident rates per ton produced are under one-half those of underground mines.⁸

The major disadvantage of surface mining is the potential for great environmental costs to land and water resources. Over 1,000,000 acres of land have been disturbed by surface mining.⁹ The most directly observable effects of surface mining are the destruction of the original land contours, vegetation, and wildlife habitats. Indirect effects include hydrologic changes, dispersion of toxic elements, acid mine drainage, siltation of streams, damage to wells, floods, and landslides. These environmental effects and the resulting damage to homes, property, and agricultural and recreational resources are the major social costs of surface mining.

A persistent problem in Appalachian surface mining has been the reluctance of mine operators to employ adequate reclamation practices and the inability or unwillingness of state governments to enforce reclamation standards. By 1970 all Appalachian states had surface mining regulations (see ref. 10 for a summary of each state's requirements). The enforcement of all Appalachian state surface mining laws has been by a permit and bond system. Permits were usually issued only after the following information was provided:

1. a listing of the owners of the surface and mineral rights,
2. a map of the area,
3. a reclamation plan,
4. a record of past and present permits held by the operator,
5. the posting of a performance bond.¹¹

Performance bonds were intended to guarantee that proposed reclamation work would be completed, but in many states forfeiture of bonds was less costly than reclamation. Therefore, many operators did not attempt to reclaim the land.

Because state laws have not been well enforced, federal control of strip mining often has been proposed. Federal strip mining laws were vetoed twice in the early 1970s. One of the main arguments of the administration of President Ford was that since the states had surface mining laws, a federal law was not needed. Some months after President Ford's 1975 veto, the state regulatory systems were examined by a Washington, D.C., research group (the Center for Science in the Public Interest) which found instances of corruption, lack of enforcement, poor training for mine inspectors, low fines, and sites that were never inspected.³ A federal strip mine bill was finally passed by the 1977 Congress and signed by President Carter, but the enforcement system for this bill is yet to be implemented.

There is no doubt that land reclamation at an acceptable cost is possible for some land areas. German coal operators have for years incorporated reclamation practices directly into their mining methods.^{12,13}

The cost of reclamation varies with factors such as the thickness of the seam, the depth of the overburden, and the slope of the surface. A study of the costs of reclamation in the Appalachian region, which tend to be higher than in the West, reported that the cost of minimally acceptable reclamation would range from \$0.49 to \$1.50 per ton.¹⁴

Adequate reclamation could not be accomplished in all coal-bearing areas of Appalachia. In a study of 56 strip mining sites in Appalachia, it was reported that successful reclamation had not been accomplished on slopes greater than 28°. Some researchers believe that strip mining on slopes greater than 18° should be prohibited.¹⁵ The technical question of exactly which kinds of land can and cannot be reclaimed has yet to be resolved. Nevertheless, it is clear that if strictly enforced reclamation standards were combined with a prohibition of surface mining on slopes of between 20° and 30°, much of the environmental damage could be avoided.

G.1.3 External costs of deep mining

Deep mining, like surface mining, has a number of adverse environmental effects. About 70% of acid mine drainage originates in deep mines.¹⁶ In 1970 the Federal Water Quality Administration estimated that four million tons of unneutralized sulfuric acid annually seeps from mines, degrades about 10,500 miles of Appalachian streams, and kills nearly one million fish. This mine drainage is estimated to cost Appalachia \$715 million yearly in recreation income alone.¹⁷ Surface subsidence, fires, and hydrologic changes are other common effects of deep mining. The Department of the Interior estimates that of the eight million acres that have been undermined, two million have subsided. This subsidence alters drainage patterns, damages crops, causes buildings to collapse, and depresses land values. In 1975, 500 refuse bank fires were burning in the United States, emitting carbon monoxide, hydrogen sulfide, and sulfur oxides. Sixty percent of these fires were within 1 mile of a community. There were also 292 fires burning in underground seams. One of these fires, located in New Straightsvilles, Ohio, has been burning since 1884.¹⁷

G.1.4 Mine safety

Even though there are large-scale environmental effects of deep mining, its total environmental costs are significantly less than those of surface mining. The rates of accidental deaths, injuries, and disease associated with deep mining are, on the other hand, much higher than for surface mining. Schmidt-Bleek and Moore estimated that the human capital costs of deep mining are five to six times those of surface mining.¹⁸ Franklin states that "In the 100 years that partial records of fatal mine accidents have been kept (the early figures are incomplete) more

than 120,000 men have died violently in coal mines, an average of 100 a month for a century."¹⁹ Deep mining continues to be the most hazardous occupation in the United States. In 1970, the frequency of deaths and injuries was four times the rate of all other industries and the severity of injuries was eight times the rate for all other industries.²⁰

Enforcement of safety rules in deep mines has often been a central issue in labor and management disputes.^{21,22} United Mine Workers' representatives demanded the right for workers to leave areas they consider unsafe in 1977 contract negotiations. Deep mines do not have to be dangerous work places. In certain cases, such as some underground mines operated by Bethlehem, U.S. Steel, and Armco, safety records are superior to those of some strip mines.²³ European countries that mine coal have substantially lower fatality rates than does the United States. As the Director of the U.S. Bureau of Mines told the Kentucky Coal Association on October 8, 1971, "the major cause of mines deaths is still the failure to observe safety laws."

The Coal Mine Health and Safety Act (CMHSA) of 1969 was intended to reduce the risks of death, disease, and injury among coal miners. The CMHSA is unusual among federal statutes in that the level of detail it provides to guide enforcement efforts is very high. Despite the detailed standards of CMHSA, enforcement practices have varied from district to district and even among inspectors. Varying interpretations of the regulations have led to confusion and disillusionment on the parts of miners and operators alike. Partly in response to the need to ensure uniform enforcement of CMHSA, two bills (HR 4287 and S 717) that would transfer the Mining Enforcement and Safety Administration to the Labor Department were passed out of committee in the 1977 Congress. The Senate version of the bill also would strengthen inspectors' rights to close mines, require inspection of gassy mines every five days, require safety programs for all miners, and accelerate penalty timetables.²⁴

An even broader reevaluation of CMHSA may be needed. According to a study by Davis Associates:

Many provisions of the Act and the resulting regulations have severely curtailed coal productions, multiplied cost, and are not effectively controlling the conditions for which they were intended.²⁵

The impact of CMHSA on productivity has been substantial. From 1940 to 1969, productivity increased steadily as mechanization and automation of the industry progressed. But, between 1969 and 1972, productivity declined sharply. Over that period, productivity in deep mines fell from 15.6 to 11.9 tons per man-day.²⁶ Most of this decline is attributed to CMHSA, although labor unrest and wildcat strikes also contributed to the decline. The CMHSA also has reduced production by forcing the closing of some mines. According to the *New York Times*, many small mines closed in 1973-1974 because of their inability to meet CMHSA requirements.²⁷ In addition to reducing production, CMHSA had the effect of increasing the price of coal by an estimated \$0.50 to \$2.00 per ton.²⁸ This increase translates into a cost of about \$0.02 to \$0.08 per million Btu.²⁹ If the declines in productivity and increases in costs had been accompanied

by significant reductions in the health and safety risks to miners, CMHSA would be less subject to criticism. But, during the first year after CMHSA's enactment, 254 miners died, as compared with 203 the year before. In more recent years, there has been some improvement (e.g., 132 deaths in 1974), but death and accident rates are still higher than those found in many European countries.

G.1.5 Black lung disease

The principal health hazard associated with deep mining is pneumoconiosis or black lung disease. The magnitude of the external costs of black lung disease is suggested by the fact that a black lung disability benefit program (created by CMHSA and administered by the Social Security Administration) paid over \$1 billion in benefits in 1975.³⁰ This money came entirely from federal funds, although plans now exist to shift the costs to the coal industry and to the states. Another indication of the extent of black lung disease is the fact that from January 1, 1970, to June 30, 1973, about 160,000 people received black lung benefits.³¹ In a prevalence study completed in 1964, it was estimated that about 100,000 active and retired coal miners suffered from the disease.³²

Exact figures on the incidence of black lung disease are difficult to obtain because its clinical symptoms are associated with diseases such as bronchitis and emphysema, which are not specific to coal mining. Comparisons of death rates due to respiratory diseases indicate, however, that coal miners die from respiratory diseases at 4.7 times the expected rate for the general population.³³ It also has been estimated that morbidity due to all major lung diseases among miners is 65% higher than among the general population.³⁴

It is generally assumed that inhalation of coal dust causes black lung disease. Costs of reducing dust to acceptable levels have been estimated by a U.S. Department of the Interior study at \$25.5 million per year.³⁵ The CMHSA of 1969 established standards for levels of dust in coal mines that, if vigorously enforced, would significantly reduce the incidence of black lung disease. Enforcement of the standards has, however, generally been lax.^{21,36}

The external costs of black lung disease in terms of federal disability payments, medical costs, and human suffering are enormous. Internalized costs for the coal industry, such as workman's compensation insurance, training programs to replace disabled workers, and declines in worker productivity, also are high. Cameron estimated that the costs of lowered worker productivity alone exceed the costs of dust abatement.³¹ There would seem, then, to be ample incentive for preventive measures. Yet, to date, adequate dust abatement has not been accomplished.

G.1.6 Employment

In 1920, the average number of miners employed daily was 639,547; in 1969, the average number was 124,532.³⁷ This decrease in employment

is explained not only by increased productivity in deep mines but also by shifts from deep to surface mining. In 1920, when total cost production was slightly higher than at present, about 4.5 tons per man-day were produced in underground mines. By 1969, productivity in deep mines was over 15 tons per man-day.³⁷ Mechanization of deep mining accounts for much of the increase in productivity. In the 1920s, less than 1% of deep-mined coal was mechanically loaded, whereas in 1973, over 99% was loaded by machine. Output per man-day in surface mining is almost twice that of deep mining.³⁸ The proportion of coal production accounted for by strip mining has risen from 1.5% in 1920 to over 50% in 1976.^{3,37} In the 1960s, the shift to surface mining and the mechanization and then automation of deep mining reduced the coal industry's labor requirements by over 50%.³⁹ In the 1970s, increased demand for coal has not resulted in major increases in mining employment. By the year 2000, the level of coal production is expected to double, and the number of miners is expected to increase by about 30%.⁴⁰

Even though the number of coal miners is, and will continue to be, smaller than in earlier decades, mining companies expect severe shortages of trained deep miners. Underground miners are, for the most part, the sons of previous generations of miners. A survey of three Appalachian deep mines found, for example, that 87% of the miners under 34 years of age had father who were miners.⁴¹ Because of this traditional pattern of recruitment to the occupation of deep mining, it is difficult to expand the labor force quickly. Surface miners are generally more mobile and are often employed as construction workers or heavy equipment operators before entering surface mining. As a result, recruitment of surface mining labor is not expected to be problematic.

At present, the age distribution among deep miners is bimodal. Most of the miners are either in their twenties or in their fifties. The intermediate generation, now in their thirties and forties, generally migrated to work outside the coal region. Forty percent of the present labor force will retire within the next ten years. If black lung benefit programs are liberalized, retirements may occur at a faster rate.⁴² Young and more highly trained replacements for the older generation of miners are not presently available, nor being trained, in sufficient numbers.⁴³ Bhutani et al. predicted that there will be a 20% shortfall in manpower with a goal of doubling production by 1985, and a 60% shortfall with a goal of tripling or quadrupling production.⁴⁴

Although new job opportunities will be available in coal mining, the impact on regional employment will be minor. In 1950, 10% of Appalachia's work force was in mining; in 1960, 3%; and in 1971, despite increased production, less than 3%.⁴⁵ If the number of miners increases 25% by 1990, as has been estimated by Warner, mining will then account for about 4% of regional employment.⁴⁶ Even when multiplier effects are considered, an incremental increase of only 1% or 2% in total employment for the region is predicted.⁴⁷

The relative significance of the Appalachian coal industry in terms of employment and investment is diminishing as the regional economy grows and diversifies. It does not seem likely that increased coal production

will provide a base for substantial expansions in employment or economic development in Appalachia as a whole.⁴⁸ Although demand for Appalachian coal is expected to increase through the 1980s, it will probably lose ground to cheaper low-sulfur Western coals in succeeding decades.

Even though the regional impact of increases in coal mining employment will be small, impacts on counties and local communities may be substantial. In such local areas, increased mining employment may revitalize the economy and lead to large, rapid population increases. Boom-bust cycles can be expected as coal production first rises rapidly and then ceases when reserves are depleted. Planning is needed for both the boom and bust stages. In the boom phase, shortages of goods and services such as housing, health care, and education may develop unless advance preparations are made. In the bust phase, high rates of unemployment and out-migration are likely to produce a stagnant local economy and increased poverty. Alternatives to mining employment need to be developed before the reserves are depleted.

G.1.7 Social costs of mining in Appalachia: colonial model

The social costs of coal mining to the people of Appalachia have been severe enough to stimulate the organization of a number of grass roots opposition movements. When the United Mine Workers, under John L. Lewis, was organizing the Appalachian coal fields in the 1930s and early 1940s, near warfare resulted. Miners organized in the face of wage cuts, discharges, labor spies and agents provocateurs, mass evictions of families, and company controlled sheriffs, judges, and armed strikebreakers. Violent labor struggles continued into the 1970s in some parts of Appalachia.²¹

Opposition to coal interests also has come from lone citizens who block bulldozers or sue operators for damages; from Congressman Ken Hechler (D-W. Va.), who has proposed bans on strip mining; from the Appalachian Catholic bishops and their recent statement on social justice; from the lawyers of the East Tennessee Research Corporation; and from local citizens' groups such as Save Our Cumberland Mountains.³

The journals and newsletters of opposition movements (e.g., *The Mountain Eagle*, *Mountain Call*, *Mountain Life and Work*, *People's Appalachia*) use the rhetoric of anticolonialism to describe the experience of coal-producing regions of Appalachia. Harry Caudill is a leading spokesman for the characterization of Appalachia as a colonial subnation. In his classic *Night Comes to the Cumberlands*⁴⁹ and in his more recent works (*My Land is Dying*,⁵⁰ *A Darkness at Dawn: Appalachian Kentucky and the Future*,⁵¹ and *The Watches of the Night*⁵²), Caudill argues that Appalachia's rich natural resources have been exploited by outsiders at the expense of the Appalachian people. In Caudill's view, Appalachia, like colonial nations, has supplied valuable raw materials to industrial areas without receiving any benefits in return.

Two types of evidence support the colonial model of Appalachia. One type of evidence is the poverty of the mining areas reflected in income, education, employment, health, and welfare statistics. There are, for

example, mining counties in Kentucky, West Virginia, and other parts of Appalachia that "simultaneously produce thousands of tons of coal worth millions of dollars while yielding infant mortality rates and other human welfare plights that we would expect to find in an underdeveloped country."⁵³ A second type of evidence is the domination that coal interests have exerted on state and local governments and on the courts. This domination was shown in the reluctance of state legislatures to enforce reclamation laws or to impose severance taxes. It was also shown by the failure of courts to hold mine owners liable for damages to the property of local landowners. Interpretations of the "broad form deed" by Kentucky courts were outstanding examples of a tendency to grant mine operators freedom from any responsibility for damages. Coal companies have often exerted control even more effectively at the local level than at the state level. In counties where most local people depended on coal companies for employment, the companies gained control of the economic, political, and legal systems. As recently as the 1930s, company towns where mine owners supplied "all community services including water, sanitation, police, postal, voting 'right,' medical, hospital, educational, religious, entertainment, and burial" were commonplace.⁵⁴ In such communities, company housing, stores, and a private monetary system known as scrip completed the system of control.

G.1.8 Culture of poverty

Some social scientists have argued that Appalachian poverty can be explained not by a colonial-exploitation model but by the attitudes, beliefs, traditions, and values of Appalachian people — in short, by a "culture of poverty." Ross presents a collection of quotations from the culture-of-poverty literature which are reproduced below:

1. The mine worker is filled with penetrating fears and apprehensions; the stoical mountain man is a victim of intense anxieties; lacking in confidence, worth, deep-seated feelings of inferiority; an unsurpassed sense of dependency and of inadequacy.
2. In "Yesterday's People," Jack E. Weller sees him as having a "regressive" outlook, being "existence-oriented", "not ready and eager for new ideas and experiences", "no rebellion, little questioning, little complaining."
3. A psychiatrist thinks that the miner "grew up dependent", lost "self-sufficiency and independence", and was "not attuned to group" activity.
4. Along like lines, a professor of social work views the coal mining region of Appalachia as "... a semi-primitive, socially unintegrated area where citizens are dominated by suspicion and fear, ..." with an "... overwhelming multitude of resigned, apathetic and willing victims." The rural Appalachian has "... an unrealistic notion of manhood, tough and sentimental,

prizing silence and masking feelings in an effort to dignify a fundamental inarticulateness. They prefer working with objects rather than with people. Many are conservative, bigoted, obsessed with the past and its preservation, trapped hopelessly ..."

5. A psychiatrist writing in the *Southern Medical Journal* in 1970 presents a social Darwinian thesis about rural Appalachians who sometime become coal miners: These "cultural primitives", descended from the non-industrial outcasts and beggars on the fringe of British society and from its debtor or criminal prisons, escaped bonded indenture to the isolated mountains in order to avoid work (which they dislike more than jail) and society; stealing, moonshining, producing illegitimate children, drinking, wasting "free food", lacking in love, affection and loyalty, they live together not by design but because they are excluded by others; in coal mine villages, they spend their money on "outrageous extravagances" and live in indolence, dirt, and "unattractive" communities; fundamentally uncivilized people," they are incapable of taking their place in modern America.⁵⁵

Ross criticizes such statements for tending "to focus on human defects as though they were genetic instead of economic and social."⁵⁴ Helen Lewis points out that such views assume that Appalachian subcultures

are not only distinct but pathogenic; there is no recognition that mainstream institutions might be pathogenic and responsible for Appalachian problems, rather, the difficulty must lie within the family or the non-institutional community. It becomes a way of blaming poverty on the poor.⁵⁶

Blaming poverty on the deficient character, values, or attitudes of the poor is, as Robert Coles has told us, a convenient way to avoid questions of social justice. If the people of Appalachia can be

portrayed convincingly as seriously retarded culturally, as not very smart, as provincial and even a little odd, then who is to worry about the way the rich and influential corporations treat them? Aren't they lucky just to have jobs? And aren't they, really, limited enough in mind and spirit to justify (for those always trying to come up with excuses) the way they live?⁵⁷

Setting aside arguments of colonial exploitation or cultures of poverty, there is reason to believe that economics based solely on the exploitation of natural resources will produce inherently unstable social systems. As Lynton Caldwell states:

There are almost always adverse social and ecological effects associated with the exploitation of an exhaustible resource. Mining communities everywhere have tended to be unstable or temporary. Capital and amenity investments are seldom made

to extend beyond the life-expectancy of the natural resource. But mining communities, like old soldiers, seldom die or disappear. They fade away into ghost towns that all too often continue to be occupied by people. The life-blood of the economy has been drained away, but the community and its institutions survive in a condition of economic and cultural impoverishment and environmental degradation.⁵⁸

In a similar vein, Richard Ball writes:

It is in the nature of mining that the economic base is slowly eaten away until the mine is abandoned, usually along with the community which had developed around it.⁵⁹

Even before the resources of a mine are exhausted, periodic boom and bust cycles in response to changing levels of demand for coal are typical. Reduced demand for coal in the 1950s led, for example, to the depopulation of entire communities as the unemployed headed for Indianapolis, Cleveland, Detroit, and Chicago. Between 1950 and 1960, the population of Leslie County, Kentucky, fell from 20,000 to 10,000. In Harlan County, Kentucky, the population dropped from 76,000 to 30,000.⁶⁰

G.1.9 Summary and conclusions

Historically, coal mining in Appalachia has imposed high costs on the people employed in or living near mining operations. As Colman McCarthy states, "the tragedy of Appalachia . . . has been so well documented that many outsiders believe the region should be written off as a national sacrifice area and determinations made that it won't happen elsewhere."⁶¹ Many Appalachians are, of course, not ready to be sacrificed, and local opposition to coal interests is increasing. But citizens' groups alone probably cannot stop mining abuses. Without major changes in the enforcement of environmental protection and health and safety measures, the social costs to Appalachia of future coal mining are likely to continue outweighing the benefits. At the same time, continued supplies of regional and national electric power and of metallurgical coal depend on Appalachian coal production. Dissociations of costs and benefits, in which those who benefit from an activity do not pay the full costs, are common in many types of energy developments.⁶² Some of the costs can be shifted to those who benefit from production if the costs of land reclamation, health and safety measures, and retraining programs are included in the price of coal.

Predicting the future social costs of Appalachian coal mining depends less on estimates of the rate and amount of production than on forecasts of how the production will take place. Will coal be mined with the safest and least environmentally damaging techniques available? Or will it be mined in the most profitable and expedient way? The answers to these questions will determine the future social costs of Appalachian coal mining.

G.2 Socioeconomic Impact Computations

Table G.1. 2-4 digit detail and description of materials and equipment
list: 800-MW coal electric plant

SIC Class	Title or description	Cost (1977 Dollars)
24	Wood products	
242	Products of sawmills and planning mills (i.e., construction lumber)	\$2,722,000
28	Chemicals and allied products	
282	Plastics and allied products	
285	Paints and allied products	
30	Rubber and miscellaneous plastics products	
304-6	Fabricated rubber products (e.g., hose and belting)	\$597,000
29	Petroleum and coal products	
295	Paving and roofing materials	\$2,396,000
32	Stone, clay, and glass products	
327	Concrete, gypsum, and plaster products	\$3,467,000
3271	Concrete block and brick	
3272	Concrete products not elsewhere included	
3273	Ready mixed concrete	
329	Miscellaneous nonmetallic mineral products	
3292	Asbestos products	
33	Primary metals industries	
331	Blast furnace and basic steel products	\$1,515,000
3315	Steel wire and related products	
3317	Steel pipes and tubes	
335	Nonferrous rolling and drawing	\$2,407,000
3351	Copper rolling and drawing	
3356	Nonferrous rolling and drawing not else- where included	

Table G.1 (continued)

SIC Class	Title or description	Cost (1977 Dollars)
34	Fabricated metal products 344	
344	Fabricated structural metal products	\$8,523,000
3441	Fabricated structural metal (HVAC ductwork and accessories)	
3444	Sheet-metal work	
3446	Architectural metal work	\$47,495,000
3443	Fabricated plate work (boiler shops)	
349	Other fabricated products	
3494	Valves and pipe fitting	\$5,381,000
3498	Fabricated pipe and fittings	
35	Machinery, except electrical	
351	Engines and turbines	\$29,294,000
3511	Turbines and turbine generator sets	
353	Construction and related machinery	
3531	Construction machinery	\$8,255,000
3532	Mining machinery	
3533	Oil-field machinery	
3534	Elevators and moving stairways	
3535	Conveyers and conveying equipment	
3536	Hoists, cranes, and monorails	\$2,673,000
3537	Industrial trucks and tractors	
356	General industrial machinery	
3561	Pumps and pumping equipment	\$6,254,000
3563	Oil and gas compressors	
3564	Blowers and fans	
358	Refrigerator and service machinery	
3585	Refrigerator and heating equipment (HVAC heating and cooling units)	\$1,287,000
36	Electric and electronic equipment	
361	Electric distributing equipment	\$5,775,000

Table G.1 (continued)

SIC Class	Title or description	Cost (1977 Dollars)
3612	Transformers	
3613	Switchgear and switchboard apparatus	
362	Electrical industrial apparatus	
3621	Motors and generators	
364	Electric lighting and wiring equipment	
3646	Commercial lighting fixtures	
3623	Welding apparatus, electric	\$353,000
38	Instruments and related products	
381	Engineering and scientific instruments	\$1,870,000
382	Measuring and controlling devices	
384	Medical instruments and supplies	
387	Watches, clocks, and watchcases	
xx	Unclassified miscellaneous material and equipment	\$1,800,000
xxx	Total above material and equipment	\$133,424,000

Source: *Standard Industrial Manual 1972*, U.S. Government Printing Office, Washington, D.C., 1973, and P. F. Paskert and J. M. Gallagher, *Escalation in the Costs and Manpower, Materials, and Equipment Needed for Energy Facilities*, Eechtel Corporation, San Francisco, Calif., October 1977.

Table G.2. Peak employment, trade multipliers, expenditure, and multiplier expenditure level associated with coal development in the ORNL region

County	Employment 1985	Employment 2000	Employment 2020	Multiplier 1985	Multiplier 2000	Multiplier 2020	Expenditures 1985 (\$)	Expenditures 2000 (\$)	Expenditures 2020 (\$)	Local Trade 1985 (\$)	Local Trade 2000 (\$)	Local Trade 2020 (\$)
ALAUTAUGA	0	0	447	1.38	1.38	1.38	0	0	6202125	0	0	8558932
ALBLOUNT	21	21	22	1.38	1.38	1.38	141750	181125	305250	195615	249952	421245
ALCHOCCTAW	2	7	14	1.32	1.32	1.38	13500	60375	194250	17820	79695	268065
ALCOFFEE	2	7	14	1.38	1.38	1.46	13500	60375	194250	18630	83317	283605
ALCRENSHAW	3	10	22	1.27	1.32	1.32	20250	86250	305250	25717	113850	402930
AICUILMAN	55	58	63	1.46	1.46	1.46	371250	500250	874125	542025	730365	1276222
ALLALLAS	0	0	538	1.46	1.46	1.69	0	0	7464750	0	0	12515427
ALFAYETTE	14	22	35	1.32	1.32	1.32	94500	189750	485625	124740	250470	541025
ALGREENE	0	554	328	1.27	1.27	1.27	0	4778250	4551000	0	6068377	5779770
ALJEFFERSON	G 1267	735	853	1.91	1.91	1.91	8552250	6339375	11835375	16334797	12108206	22605566
ALMARENGO	10	35	72	1.38	1.38	1.46	67500	301875	999000	93150	416587	1458540
ALMAFICN	29	41	61	1.32	1.32	1.38	195750	353625	846375	258390	466785	1167997
ALPIKE	2	6	13	1.38	1.38	1.38	13500	51750	180375	18630	71415	248917
ALSHELBY	30	30	31	1.38	1.38	1.38	202500	258750	430125	279450	357075	593572
ALTUSCALOOSA	168	183	206	1.69	1.69	1.69	1134000	1578375	2858250	1916460	2667454	4830442
ALWASHINGTON	G 94	0	0	1.32	1.32	1.38	634500	0	0	837540	0	0
ALWILCOX	2	5	11	1.32	1.32	1.38	13500	43125	152625	17820	56925	210622
ALWINSTON	50	51	52	1.32	1.32	1.32	337500	439875	721500	445500	580635	952380
FIRREVED	0	0	1153	1.69	1.69	1.69	0	0	15997875	0	0	27036409
FLEROWARD	0	350	671	1.91	1.91	1.91	0	3018750	9310125	0	5765812	17782339
FLHILLSBOURGH	G 270	0	0	1.91	1.91	1.91	1822500	0	0	3480975	0	0
FLPCIK	G 53	0	0	1.69	1.69	1.69	357750	0	0	604597	0	0
FLST LUCIE	0	235	1564	1.46	1.46	1.52	0	2035500	21700500	0	2971850	32984760
FLWASHINGTON	G 116	0	0	1.27	1.27	1.32	783000	0	0	994410	0	0
GACAHUN	0	53	0	1.22	1.22	1.27	0	457125	0	0	557652	0
GACARROLL	G 200	0	0	1.46	1.46	1.46	1350000	0	0	1971000	0	0
GAMONROE	G 738	0	0	1.27	1.27	1.32	4981500	0	0	6326505	0	0
KYBCCNE	G 402	0	0	1.38	1.38	1.38	2713500	0	0	3744630	0	0
KYBOYD	13	260	557	1.46	1.38	1.38	87750	2242500	7728375	128115	3094650	10665157
KYBREATHITT	346	399	479	1.32	1.32	1.38	2335500	3441375	6646125	3082860	4542615	9171652
KYBUTLER	16	29	49	1.22	1.27	1.27	108000	250125	679875	131760	317659	863441
KYCAFFCIL	G 369	0	0	1.22	1.22	1.22	2490750	0	0	3038715	0	0
KYCARTER	29	38	50	1.32	1.32	1.32	195750	327750	693750	258390	432630	915750
KYCHEISTIAN	10	12	14	1.46	1.46	1.46	67500	103500	194250	98550	15110	283605
KYCLAY	57	73	97	1.32	1.38	1.38	384750	629625	1345875	507870	868882	1857307
KYDAVISS	G 58	158	192	1.52	1.52	1.69	391500	1362750	2664000	595080	2071380	4502160
KYELICTT	40	45	51	1.22	1.22	1.22	270000	388125	707625	329400	473512	863302
KYPLCYD	426	533	693	1.38	1.38	1.38	2875500	4597125	9615375	3968190	6344032	13269217
KYGREENUP	11	15	22	1.38	1.38	1.38	74250	129375	305250	102465	178537	421245
KYHANCOCK	G 0	0	1054	1.22	1.22	1.27	0	0	14624250	0	0	1572797
KYHAFIAN	758	917	1155	1.38	1.38	1.38	5116500	7909125	16025625	7060770	10914592	22115362
KYHENDERSON	G 200	270	508	1.38	1.38	1.46	1350000	2328750	7048500	1863000	3213675	10290810
KYHOEKINS	763	914	1228	1.38	1.38	1.46	4745250	7883250	17038500	6548445	10878835	24876210
KYJACKSON	6	13	23	1.27	1.27	1.32	40500	112125	319125	51435	142339	421245
KYJEFFERSON	G 134	0	0	1.91	1.91	1.91	904500	0	0	1727595	0	0
KYJOHNSON	76	89	109	1.32	1.32	1.27	513000	767625	1512375	677160	1013255	1920716
KYKNCTT	365	504	711	1.32	1.32	1.38	2463750	4347000	9865125	3252150	5738040	13613872
KYKNCX	89	97	108	1.32	1.38	1.38	600750	836625	1498500	792990	1154542	2067930
KYLAUREL	49	51	54	1.38	1.38	1.38	330750	439875	749250	456435	607027	1033965
KYLEE	17	20	24	1.22	1.22	1.27	114750	172500	333000	139995	210450	422910
KYLESIE	219	283	378	1.27	1.32	1.38	1478250	2440875	5244750	1877377	3221955	7237755
KYLETCHER	415	498	621	1.38	1.38	1.38	2801250	4295250	8616375	3865725	5927445	11890597
KYLEWIS	0	525	0	1.27	1.27	1.27	0	4528125	0	0	5750719	0
KYLIVINGSTON	0	947	450	1.22	1.22	1.27	0	8167975	6243750	0	9964607	7929562

Table G.2 (continued)

County	Employment 1985	Employment 2000	Employment 2020	Multiplier- 1985	Multiplier 2000	Multiplier 2020	Expenditures 1985 (\$)	Expenditures 2000 (\$)	Expenditures 2020 (\$)	Local Trade 1985 (\$)	Local Trade 2000 (\$)	Local Trade 2020 (\$)
KYMCCREARY	68	84	109	1.27	1.27	1.32	459000	724500	1512375	582930	920115	1996335
KYMCLEAN	84	157	265	1.22	1.22	1.27	567000	1354125	3676875	691740	1652032	4669631
KYMAGCFFIN	86	111	148	1.27	1.27	1.32	580500	957375	2053500	737235	1215866	2710620
KYMAFTIN	391	423	472	1.22	1.22	1.22	2639250	3648375	6549000	3219885	4451017	7989780
KYMASON	G 197	0	0	1.32	1.32	1.32	1329750	0	0	1755270	0	0
KYMEADE	0	525	1050	1.32	1.32	1.38	0	4528125	14568750	0	5977125	20104875
KYMORGAN	40	44	49	1.27	1.27	1.32	270000	379500	679875	342900	481965	897435
KYMUHLBERG	G 1260	1401	1612	1.38	1.38	1.38	8505000	12083625	22366500	11736900	16675402	30865770
KYOHIO	418	474	558	1.32	1.32	1.38	2821500	4088250	7742250	3724380	5396490	10684305
KYOWSLEY	20	20	21	1.22	1.22	1.22	135000	172500	291375	164700	210450	355477
KYPERRY	359	440	562	1.38	1.38	1.46	2423250	3795000	7797750	3344085	5237100	11384715
KYPIKE	1545	1788	2152	1.46	1.46	1.46	10428750	15421500	29859000	15225975	22515390	43594140
KYTRIMBLE	G 221	301	0	1.22	1.22	1.22	1491750	2596125	0	1819935	3167272	0
KYUNION	552	742	1026	1.32	1.32	1.32	3726000	6399750	14235750	4918320	8447670	18791190
KYWEESTER	170	315	531	1.27	1.27	1.32	1147500	2716875	7367625	1457325	3450431	9725265
KYWHITLEY	91	95	101	1.32	1.38	1.38	614250	819375	1401375	810810	1130737	1933897
KYWOIPE	2	4	8	1.22	1.22	1.27	13500	34500	111000	16470	42090	140970
LACADEO	0	0	1050	1.69	1.69	1.69	0	0	14568750	0	0	24621187
LACALCASIEU	G 121	121	0	1.69	1.69	1.69	816750	1043625	0	1380307	1763726	0
LAGRANT	0	335	0	1.27	1.32	1.38	0	2889375	0	0	3813975	0
LAPOINT COUPEEG	362	0	0	1.32	1.38	1.38	2443500	0	0	3225420	0	0
LARAFIDES	G 118	118	0	1.69	1.69	1.69	796500	1017750	0	1346085	1719997	0
LAST MARY	0	77	0	1.46	1.52	1.69	0	664125	0	0	1009470	0
MSBOLIVAR	0	362	889	1.46	1.46	1.52	0	3122250	12334875	0	4558485	18749010
MEDE SOTO	G 156	156	0	1.38	1.38	1.38	1053000	1345500	0	1453140	1856790	0
MSJACKSON	G 232	0	0	1.52	1.69	1.69	1566000	0	0	2380320	0	0
MSLAMAR	G 161	0	0	1.46	1.52	1.69	1086750	0	0	1586655	0	0
MSISHCHINGO	0	0	70	1.32	1.32	1.32	0	0	971250	0	0	1282050
NCPUNCOMBE	G 0	367	0	1.69	1.69	1.69	0	3165375	0	0	5349484	0
NCCASWELL	0	205	0	1.32	1.32	1.32	0	1768125	0	0	2333925	0
NCGATES	0	0	67	1.22	1.22	1.22	0	0	929625	0	0	1134142
NCIEE	1	3	8	1.38	1.38	1.38	6750	25875	111000	9315	35707	153180
NCPERSON	G 820	0	0	1.38	1.38	1.38	5535000	0	0	7638300	0	0
SCGECFGETCWN	G 63	581	0	1.38	1.38	1.46	425250	5011125	0	586845	6915352	0
SCHORRY	G 0	750	797	1.46	1.52	1.69	0	6468750	11058375	0	9832500	18688654
TNANDERSON	117	128	145	1.46	1.46	1.52	789750	1104000	2011875	1153035	1611840	3058050
TNBENTON	0	150	894	1.27	1.27	1.27	0	1293750	12404250	0	1643062	15753397
TNCLAIENCE	106	110	116	1.32	1.32	1.32	715500	948750	1609500	944460	1252350	2124540
TNFENTRESS	2	7	14	1.27	1.27	1.32	13500	60375	194250	17145	76676	256410
TNHAMILTON	2	6	14	1.69	1.69	1.69	13500	51750	194250	22815	87457	328282
TNJEPFERSCH	0	0	555	1.38	1.38	1.38	0	0	7700625	0	0	10626862
TNMARION	28	32	37	1.32	1.32	1.38	189000	276000	513375	249480	364320	708457
TNMORGAN	33	40	51	1.27	1.32	1.32	222750	345000	707625	282892	455400	934065
TNPUTNAM	8	10	13	1.38	1.38	1.38	54000	86250	180375	74520	119025	248917
TNROANE	G 0	0	556	1.38	1.38	1.38	0	0	7714500	0	0	10646010
TNSCOTT	74	81	92	1.27	1.32	1.32	499500	698625	1276500	634365	922185	1684980
TNSEQUATCHIE	31	37	44	1.22	1.22	1.22	209250	319125	610500	255285	389332	744810
TNSULLIVAN	0	0	324	1.69	1.69	1.69	0	0	4495500	0	0	7597395
TXANDERSON	8	14	29	1.38	1.38	1.38	54000	120750	402375	74520	166635	555277
TXATASCOSA	G 179	0	0	1.32	1.32	1.38	1208250	0	0	1594890	0	0
TXBASTROP	17	32	64	1.32	1.32	1.38	114750	276000	888000	151470	364320	1225440
TXBEXAR	G 192	10	21	1.91	2.11	2.11	1296000	86250	291375	2475360	181987	614801
TXBOWIE	0	1060	545	1.52	1.69	1.69	0	9142500	7561875	0	15450825	12779569
TXCALDWELL	13	25	51	1.32	1.38	1.38	87750	215625	707625	115830	297562	976522

Table G.2 (continued)

County	Employment 1985	Employment 2000	Employment 2020	Multiplier 1985	Multiplier 2000	Multiplier 2020	Expenditures 1985 (\$)	Expenditures 2000 (\$)	Expenditures 2020 (\$)	Local Trade 1985 (\$)	Local Trade 2000 (\$)	Local Trade 2020 (\$)
TXCANE	2	5	9	1.22	1.27	1.38	13500	43125	124875	16470	54769	172327
TXCASS	6	12	24	1.38	1.38	1.52	40500	103500	333000	55890	142830	506160
TXCHAMBERS	0	0	1072	1.27	1.32	1.32	0	0	14874000	0	0	19633680
TXCHEROKEE	4	7	15	1.38	1.38	1.46	27000	60375	208125	37260	83317	303862
TXPAYETTE	G 255	18	37	1.32	1.32	1.32	1721250	155250	513375	2272050	204930	677655
TXFLOYD	G 212	0	0	1.27	1.27	1.27	1431000	0	0	1817370	0	0
TXFCET BEND	G 630	0	0	1.46	1.46	1.52	4252500	0	0	6208650	0	0
TXFRANKLIN	G 336	0	0	1.22	1.22	1.22	2268000	0	0	2766960	0	0
TXGOLIAD	G 123	0	0	1.22	1.22	1.22	830250	0	0	1012905	0	0
TXGRIMES	G 273	9	17	1.27	1.32	1.32	1842750	77625	235875	2340292	102465	311355
TXHARRISON	15	24	46	1.38	1.46	1.52	101250	207000	638250	139725	302220	970140
TXHENDERSON	G 181	25	51	1.38	1.38	1.38	1221750	215625	707625	1686015	297562	976522
TXHOPKINS	8	14	29	1.32	1.32	1.32	54000	120750	402375	71280	159390	531135
TXHOUSTON	6	11	23	1.32	1.32	1.38	40500	94875	319125	53460	125235	440392
TXLEE	2	4	8	1.22	1.22	1.27	13500	34500	111000	16470	42090	140970
TXLEON	9	16	33	1.22	1.27	1.32	60750	138000	457875	74115	175260	604395
TXMADISON	3	5	10	1.22	1.22	1.27	20250	43125	138750	24705	52612	176212
TXMARION	4	7	15	1.22	1.27	1.27	27000	60375	208125	32940	76676	264319
TXMILAM	59	89	155	1.32	1.38	1.38	398250	767625	2150625	525690	1059322	2967862
TXMORRIS	2	4	8	1.27	1.32	1.38	13500	34500	111000	17145	45540	153180
TXPANOLA	13	23	48	1.32	1.32	1.38	87750	198375	666000	115830	261855	919080
TXPOTTER	G 213	0	0	1.52	1.52	1.52	1437750	0	0	2185380	0	0
TXRCBERTSON	10	19	38	1.32	1.32	1.38	67500	163875	527250	89100	216315	727605
TXRUSK	685	28	56	1.38	1.38	1.46	4623750	241500	777000	6380775	333270	1134420
TXSHELBY	6	462	925	1.32	1.32	1.38	40500	3984750	12834375	53460	5259870	17711437
TXTITUS	G 539	28	53	1.32	1.38	1.46	3638250	241500	735375	4802490	333270	1073647
TXTRINITY	2	4	8	1.22	1.22	1.27	13500	34500	111000	16470	42090	140970
TXVAN ZANDT	25	46	94	1.32	1.32	1.38	168750	396750	1304250	222750	523710	1799865
TXWALKER	3	5	11	1.38	1.38	1.38	20250	43125	152625	27945	59512	210622
TXWARD	G 10	0	0	1.27	1.27	1.27	67500	0	0	85725	0	0
TXWOOD	12	22	45	1.32	1.32	1.38	81000	189750	624375	106920	250470	861637
VABUCHANAN	1086	1204	1511	1.38	1.38	1.38	7330500	10384500	20965125	10116090	14330610	28931872
VACARCIINE	0	894	0	1.27	1.32	1.32	0	7710750	0	0	10178190	0
VADICKENSON	442	503	663	1.32	1.32	1.32	2983500	4338375	9199125	3938220	5726655	12142845
VAHALIFAX	0	599	0	1.38	1.38	1.38	0	5166375	0	0	7129597	0
VALEE	75	98	159	1.32	1.32	1.32	506250	845250	2206125	668250	1115730	2912085
VAMONTGOMERY	4	11	31	1.46	1.46	1.46	27000	94875	430125	39420	138517	627982
VAPULASKI	3	10	27	1.38	1.38	1.38	20250	86250	374625	27945	119025	516982
VASCOTT	3	7	19	1.32	1.32	1.32	20250	60375	263625	26730	79695	347985
VATAZEKELL	146	169	227	1.38	1.38	1.38	985500	1457625	3149625	1359990	2011522	4346482
VAWISE	761	859	1109	1.38	1.38	1.38	5136750	7400250	15387375	7088715	10212345	21234577
WVBARECUR	318	429	714	1.27	1.32	1.38	2146500	3700125	9906750	2726055	4884165	13671315
WVBERKELEY	0	253	0	1.38	1.38	1.46	0	2182125	0	0	3011332	0
WVBOONZ	791	1053	1730	1.32	1.32	1.32	5339250	9082125	24003750	7047810	11988405	31684950
WVERAXTON	27	82	227	1.27	1.27	1.22	182250	707250	3149625	231457	898207	3842542
WVBROOKE	56	77	1023	1.38	1.38	1.38	378000	664125	14194125	521640	916492	19587892
WVCLAY	46	133	358	1.22	1.22	1.22	310500	1147125	4967250	378810	1399492	6060045
WVDODDRIDGE	12	38	105	1.22	1.22	1.22	81000	327750	1456875	98820	399855	1777387
WVPAYETTE	248	364	665	1.38	1.38	1.38	1674000	3139500	9226875	2310120	4332510	12733087
WVGILMER	14	33	82	1.22	1.22	1.22	94500	284625	1137750	115290	347242	1388055
WVGREENBRIER	61	97	190	1.38	1.38	1.32	411750	836625	2636250	568215	1154542	3479850
WVHANCOCK	7	21	287	1.38	1.38	1.38	47250	181125	3982125	65205	249952	5495332
WVLEWIS	83	171	398	1.32	1.32	1.38	560250	1474875	5522250	739530	1946835	7620705
WVLINCOLN	20	62	172	1.32	1.32	1.32	135000	534750	2386500	178200	705870	3150180

Table G.2 (continued)

County	Employment 1985	Employment 2000	Employment 2020	Multiplier 1985	Multiplier 2000	Multiplier 2020	Expenditures 1985 (\$)	Expenditures 2000 (\$)	Expenditures 2020 (\$)	Local Trade 1985 (\$)	Local Trade 2000 (\$)	Local Trade 2020 (\$)
WVLCGAN	768	1168	2201	1.38	1.38	1.38	5184000	10074000	30538875	7153920	13902120	42143647
WVMCDOWELL	774	909	1253	1.46	1.46	1.46	5224500	7840125	17454750	7627770	11446582	25483935
WVMARSHALL	G 521	864	2711	1.38	1.38	1.38	3516750	7452000	37615125	4853115	10263760	51908872
WVMASON	P 384	554	1331	1.32	1.32	1.32	2592000	4778250	18467625	3421440	6307290	24377265
WVMERCER	71	78	94	1.46	1.46	1.46	479250	672750	1304250	699705	982215	1904205
WVMINERAL	42	67	132	1.32	1.32	1.32	283500	577875	1831500	374220	762795	2417580
WVMINGO	386	637	1236	1.38	1.38	1.38	2605500	5494125	17843250	3595590	7581892	24623685
WVNICHOLAS	510	696	1175	1.32	1.32	1.32	3442500	6003000	16303125	4544100	7923960	21520125
WVOHIO	131	253	292	1.46	1.46	1.46	884250	2182125	4051500	1291005	3185902	5915190
WVPLEASANTS	G 280	0	894	1.22	1.22	1.22	1890000	0	12404250	2305800	0	15133185
WVPCCAHONTAS	8	25	70	1.22	1.22	1.22	54000	215625	971250	65880	263062	1184925
WVPUTNAM	8	24	846	1.38	1.38	1.32	54000	207000	11738250	74520	285660	15494490
WVRALIGH	488	711	1288	1.46	1.46	1.46	3294000	6132375	17871000	4809240	8953267	26091660
WVRANDOLPH	119	215	461	1.38	1.38	1.46	803250	1854375	6396375	1108435	2553037	9338707
WVROANE	1	3	9	1.27	1.27	1.22	6750	25375	124875	8572	32861	152347
WVTAYLOR	27	69	179	1.27	1.32	1.38	182250	595125	2483625	231457	785565	3427402
WVTUCKER	31	45	81	1.22	1.22	1.32	209250	388125	1151625	255285	473512	1520145
WVTYLER	4	462	1593	1.22	1.22	1.22	27000	3984750	22102875	32940	4861395	26965507
WVUPSHUR	172	271	525	1.32	1.38	1.46	1161000	2337375	7312125	1532520	3225577	10675702
WVWAYNE	51	98	219	1.38	1.38	1.38	344250	845250	3038625	475065	1166445	4193302
WVWESTER	85	220	570	1.22	1.22	1.22	573750	1897500	7908750	699975	2314950	9648675
WVWETZEL	41	129	2223	1.32	1.32	1.32	276750	1112625	30844125	365310	1463665	40714245
WVWCCD	0	0	559	1.52	1.69	1.69	0	0	7756125	0	0	13107851
WVWYCMING	684	893	1431	1.38	1.38	1.38	4617000	7702125	19882875	5371460	10628932	27438367

1. Employment 1985, Employment 2000, Employment 2020 = Peak work force in county in 1985, 2000, 2020.
2. Multiplier 1985, Multiplier 2000, Multiplier 2020 = County trade multiplier (retail+services+wholesale) 1985, 2000, 2020.
3. Expenditures 1985, Expenditures 2000, Expenditures 2020 = Income expenditure for trade by peak work force 1985, 2000, 2020.
4. Local Trade 1985, Local Trade 2000, Local Trade 2020 = Expenditures x Multiplier 1985, 2000, 2020.

G.3 Synfuels and Coal-Electric Generating Facility Employment Assumptions

Bechtel estimates of the total number of man-hours needed to construct a "nominal" facility were used as the basis for deriving the peak work-force size. The staff estimated the length of the construction period and then calculated a work-force profile which would satisfy the total man-hour needs of the project (see Table G.3). For simplicity, no consideration was given to economies of scale, staggered construction schedules for multiple-unit plants, variation of worker productivity within the region, absenteeism, escalation of work-force size, overtime, etc.

Table G.3. Peak work-force factors used to calculate growth rates

Type of facility	"Nominal" size ^a	Peak work force ^b	Peak work-force size factor
High-Btu coal-electric generating facility with sulfur removal equipment	800 MWe	1190	1.49 (people/MWe)
High-Btu gasification plant	250 MMcfd ^c	3500	14 (people/MMcfd)
Low- to medium-Btu gasification plant	1449 MMcfd ^c	2975	2.05 (people/MMcfd)
Coal liquefaction plant	21.7 Mbpd ^d	1300	0.06 (people/BLQ/d)

^aBechtel Corporation, *Manpower, Materials, and Capital Costs for Energy-Related Facilities*, April 1976, and *Manpower, Materials, Equipment, and Utilities Required to Operate and Maintain Energy Facilities*, March 1975.

^bDerived from staff estimates of manpower scheduling necessary to satisfy Bechtel estimates of man-hour requirements for each facility type.

^cMillion cubic feet per day.

^dThousand barrels per day.

G.4 Service Base Index

The service base index for each county was calculated using the factor analysis technique that is described in Nie et al.⁶³ A principal component factor analysis solution was calculated using a sample of 267 counties in the southern region. Six variables were selected to construct the service base index. The variables and respective factor score weights are displayed in Table G.4. The general form of the factor score index equation is

$$F = \sum_i \left[W_i \left(\frac{X_{ij} - \bar{X}_i}{S_d} \right) \right], \quad (1)$$

where

F = factor score index,

W_i = factor analysis weight for the i th variable,

X_{ij} = value of i th variable in county j ,

$\bar{X}_i$ = mean value of i th variable,

S_d = standard deviation of the i th variable.

Table G.4. Service base indicators and respective weights for estimating a service base index

Service base indicator	Factor score weight
Population, 1970 ($\times 10^3$)	0.2176
Percentage urban, 1970 (%)	0.2119
Median family income, 1970 \$	0.1892
SMSA county, 0-1	0.1865
Population density, 1970 (people per square mile)	0.2114
Retail-wholesale service trade, 1972 \$ $\times 10^6$	0.2131

The actual index equation in expanded form is

$$I = \{ [0.2176(\text{POP} - 91.26)/200.55] + [0.2119(\text{Urban} - 36.63)/29.43] + [0.1892(\text{INCOME} - 6730.30)/1854.49] + [0.1865(\text{SMSA} - 0.2958)1.4573] + [0.2114(\text{Density} - 161.01)/326.95] + [0.2131(\text{Trade} - 595062.94)/1616222.89] + 1.35263 \} 100 \quad (2)$$

The last factor inside the brackets in Eq. (2) is a constant that was added in order to set the value of the index equal to zero when all the indicators take the value of zero. If no constant factor is added, the index takes a value of zero in the case where all indicators are at the mean value ($\bar{X}$). The addition of 1.35263 results in an index value of 135 for the mean-values case. Consequently, index values less than 135 may be interpreted as indicating below-average service base capacity. Values above 135 indicate that the county is above average and can probably handle low to moderate growth rates. Nevertheless, it is essential not to rely completely on this index. Other variables not included in the analysis may be important in measuring service base capacity.

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G.5 Sensitivity of Population and Project Size Thresholds to
Varying Assumptions About Proportion In-movers and County Share

Table G.5. Population Thresholds for Energy Developments*

Immigrants = 0.10

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
ENERGY :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
PROJECT :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
SIZE :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
500	250.	500.	750.	1000.	125.	250.	375.	500.	83.	167.	250.	333.
1000	500.	1000.	1500.	2000.	250.	500.	750.	1000.	167.	333.	500.	667.
2000	1000.	2000.	3000.	4000.	500.	1000.	1500.	2000.	333.	667.	1000.	1333.
3000	1500.	3000.	4500.	6000.	750.	1500.	2250.	3000.	500.	1000.	1500.	2000.
4000	2000.	4000.	6000.	8000.	1000.	2000.	3000.	4000.	667.	1333.	2000.	2667.
5000	2500.	5000.	7500.	10000.	1250.	2500.	3750.	5000.	833.	1667.	2500.	3333.
6000	3000.	6000.	9000.	12000.	1500.	3000.	4500.	6000.	1000.	2000.	3000.	4000.
7000	3500.	7000.	10500.	14000.	1750.	3500.	5250.	7000.	1167.	2333.	3500.	4667.
8000	4000.	8000.	12000.	16000.	2000.	4000.	6000.	8000.	1333.	2667.	4000.	5333.
9000	4500.	9000.	13500.	18000.	2250.	4500.	6750.	9000.	1500.	3000.	4500.	6000.
10000	5000.	10000.	15000.	20000.	2500.	5000.	7500.	10000.	1667.	3333.	5000.	6667.
11000	5500.	11000.	16500.	22000.	2750.	5500.	8250.	11000.	1833.	3667.	5500.	7333.
12000	6000.	12000.	18000.	24000.	3000.	6000.	9000.	12000.	2000.	4000.	6000.	8000.
13000	6500.	13000.	19500.	26000.	3250.	6500.	9750.	13000.	2167.	4333.	6500.	8667.
14000	7000.	14000.	21000.	28000.	3500.	7000.	10500.	14000.	2333.	4667.	7000.	9333.
15000	7500.	15000.	22500.	30000.	3750.	7500.	11250.	15000.	2500.	5000.	7500.	10000.
16000	8000.	16000.	24000.	32000.	4000.	8000.	12000.	16000.	2667.	5333.	8000.	10667.
17000	8500.	17000.	25500.	34000.	4250.	8500.	12750.	17000.	2833.	5667.	8500.	11333.
18000	9000.	18000.	27000.	36000.	4500.	9000.	13500.	18000.	3000.	6000.	9000.	12000.
19000	9500.	19000.	28500.	38000.	4750.	9500.	14250.	19000.	3167.	6333.	9500.	12667.
20000	10000.	20000.	30000.	40000.	5000.	10000.	15000.	20000.	3333.	6667.	10000.	13333.

POPULATION THRESHOLD IS THE MINIMUM HOST COMMUNITY SIZE NECESSARY TO CONTROL POPULATION GROWTH TO SOME PERCENTAGE LEVEL (EG. 5%, 10%, 15%) UNDER THE LISTED CONSTRUCTION SIZES (PEAK WORKFORCE) GIVEN THE IMMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

THRESHOLD = (CONSTRUCTION POPULATION X MOVER FCT X COUNTY SHARE) / IMPACT LEVEL

Table G.5 (continued)

POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.20

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
ENERGY :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
PROJECT:	INMIGRANTS				INMIGRANTS				INMIGRANTS			
SIZE :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
500	500.	1000.	1500.	2000.	250.	500.	750.	1000.	167.	333.	500.	667.
1000	1000.	2000.	3000.	4000.	500.	1000.	1500.	2000.	333.	667.	1000.	1333.
2000	2000.	4000.	6000.	8000.	1000.	2000.	3000.	4000.	667.	1333.	2000.	2667.
3000	3000.	6000.	9000.	12000.	1500.	3000.	4500.	6000.	1000.	2000.	3000.	4000.
4000	4000.	8000.	12000.	16000.	2000.	4000.	6000.	8000.	1333.	2667.	4000.	5333.
5000	5000.	10000.	15000.	20000.	2500.	5000.	7500.	10000.	1667.	3333.	5000.	6667.
6000	6000.	12000.	18000.	24000.	3000.	6000.	9000.	12000.	2000.	4000.	6000.	8000.
7000	7000.	14000.	21000.	28000.	3500.	7000.	10500.	14000.	2333.	4667.	7000.	9333.
8000	8000.	16000.	24000.	32000.	4000.	8000.	12000.	16000.	2667.	5333.	8000.	10667.
9000	9000.	18000.	27000.	36000.	4500.	9000.	13500.	18000.	3000.	6000.	9000.	12000.
10000	10000.	20000.	30000.	40000.	5000.	10000.	15000.	20000.	3333.	6667.	10000.	13333.
11000	11000.	22000.	33000.	44000.	5500.	11000.	16500.	22000.	3667.	7333.	11000.	14667.
12000	12000.	24000.	36000.	48000.	6000.	12000.	18000.	24000.	4000.	8000.	12000.	16000.
13000	13000.	26000.	39000.	52000.	6500.	13000.	19500.	26000.	4333.	8667.	13000.	17333.
14000	14000.	28000.	42000.	56000.	7000.	14000.	21000.	28000.	4667.	9333.	14000.	18667.
15000	15000.	30000.	45000.	60000.	7500.	15000.	22500.	30000.	5000.	10000.	15000.	20000.
16000	16000.	32000.	48000.	64000.	8000.	16000.	24000.	32000.	5333.	10667.	16000.	21333.
17000	17000.	34000.	51000.	68000.	8500.	17000.	25500.	34000.	5667.	11333.	17000.	22667.
18000	18000.	36000.	54000.	72000.	9000.	18000.	27000.	36000.	6000.	12000.	18000.	24000.
19000	19000.	38000.	57000.	76000.	9500.	19000.	28500.	38000.	6333.	12667.	19000.	25333.
20000	20000.	40000.	60000.	80000.	10000.	20000.	30000.	40000.	6667.	13333.	20000.	26667.

*
POPULATION THRESHOLD IS THE MINIMUM HOST COMMUNITY SIZE NECESSARY
TO CONTROL POPULATION GROWTH TO SOME PERCENTAGE LEVEL (EG. 5%, 10%, 15%)
UNDER THE LISTED CONSTRUCTION SIZES (PEAK WORKFORCE) GIVEN THE INMIGRANT
RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

*
POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.30

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH					
ENERGY :	COUNTY SHARE OF				:	COUNTY SHARE OF				:	COUNTY SHARE OF			
PROJECT:	INMIGRANTS				:	INMIGRANTS				:	INMIGRANTS			
SIZE :	25%	50%	75%	100%:	:	25%	50%	75%	100%:	:	25%	50%	75%	100%
500	750.	1500.	2250.	3000.	:	375.	750.	1125.	1500.	:	250.	500.	750.	1000.
1000	1500.	3000.	4500.	6000.	:	750.	1500.	2250.	3000.	:	500.	1000.	1500.	2000.
2000	3000.	6000.	9000.	12000.	:	1500.	3000.	4500.	6000.	:	1000.	2000.	3000.	4000.
3000	4500.	9000.	13500.	18000.	:	2250.	4500.	6750.	9000.	:	1500.	3000.	4500.	6000.
4000	6000.	12000.	18000.	24000.	:	3000.	6000.	9000.	12000.	:	2000.	4000.	6000.	8000.
5000	7500.	15000.	22500.	30000.	:	3750.	7500.	11250.	15000.	:	2500.	5000.	7500.	10000.
6000	9000.	18000.	27000.	36000.	:	4500.	9000.	13500.	18000.	:	3000.	6000.	9000.	12000.
7000	10500.	21000.	31500.	42000.	:	5250.	10500.	15750.	21000.	:	3500.	7000.	10500.	14000.
8000	12000.	24000.	36000.	48000.	:	6000.	12000.	18000.	24000.	:	4000.	8000.	12000.	16000.
9000	13500.	27000.	40500.	54000.	:	6750.	13500.	20250.	27000.	:	4500.	9000.	13500.	18000.
10000	15000.	30000.	45000.	60000.	:	7500.	15000.	22500.	30000.	:	5000.	10000.	15000.	20000.
11000	16500.	33000.	49500.	66000.	:	8250.	16500.	24750.	33000.	:	5500.	11000.	16500.	22000.
12000	18000.	36000.	54000.	72000.	:	9000.	18000.	27000.	36000.	:	6000.	12000.	18000.	24000.
13000	19500.	39000.	58500.	78000.	:	9750.	19500.	29250.	39000.	:	6500.	13000.	19500.	26000.
14000	21000.	42000.	63000.	84000.	:	10500.	21000.	31500.	42000.	:	7000.	14000.	21000.	28000.
15000	22500.	45000.	67500.	90000.	:	11250.	22500.	33750.	45000.	:	7500.	15000.	22500.	30000.
16000	24000.	48000.	72000.	96000.	:	12000.	24000.	36000.	48000.	:	8000.	16000.	24000.	32000.
17000	25500.	51000.	76500.	102000.	:	12750.	25500.	38250.	51000.	:	8500.	17000.	25500.	34000.
18000	27000.	54000.	81000.	108000.	:	13500.	27000.	40500.	54000.	:	9000.	18000.	27000.	36000.
19000	28500.	57000.	85500.	114000.	:	14250.	28500.	42750.	57000.	:	9500.	19000.	28500.	38000.
20000	30000.	60000.	90000.	120000.	:	15000.	30000.	45000.	60000.	:	10000.	20000.	30000.	40000.

*
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RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.40

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH					: IMPACT LEVEL= 15% GROWTH				
ENERGY :	COUNTY SHARE OF				ENERGY :	COUNTY SHARE OF				ENERGY :	COUNTY SHARE OF			
PROJECT :	INMIGRANTS				PROJECT :	INMIGRANTS				PROJECT :	INMIGRANTS			
SIZE :	25%	50%	75%	100%	SIZE :	25%	50%	75%	100%	SIZE :	25%	50%	75%	100%
500	1000.	2000.	3000.	4000.	500	1000.	1500.	2000.	333.	667.	1000.	1333.		
1000	2000.	4000.	6000.	8000.	1000	2000.	3000.	4000.	667.	1333.	2000.	2667.		
2000	4000.	8000.	12000.	16000.	2000	4000.	6000.	8000.	1333.	2667.	4000.	5333.		
3000	6000.	12000.	18000.	24000.	3000	6000.	9000.	12000.	2000.	4000.	6000.	8000.		
4000	8000.	16000.	24000.	32000.	4000	8000.	12000.	16000.	2667.	5333.	8000.	10667.		
5000	10000.	20000.	30000.	40000.	5000	10000.	15000.	20000.	3333.	6667.	10000.	13333.		
6000	12000.	24000.	36000.	48000.	6000	12000.	18000.	24000.	4000.	8000.	12000.	16000.		
7000	14000.	28000.	42000.	56000.	7000	14000.	21000.	28000.	4667.	9333.	14000.	18667.		
8000	16000.	32000.	48000.	64000.	8000	16000.	24000.	32000.	5333.	10667.	16000.	21333.		
9000	18000.	36000.	54000.	72000.	9000	18000.	27000.	36000.	6000.	12000.	18000.	24000.		
10000	20000.	40000.	60000.	80000.	10000	20000.	30000.	40000.	6667.	13333.	20000.	26667.		
11000	22000.	44000.	66000.	88000.	11000	22000.	33000.	44000.	7333.	14667.	22000.	29333.		
12000	24000.	48000.	72000.	96000.	12000	24000.	36000.	48000.	8000.	16000.	24000.	32000.		
13000	26000.	52000.	78000.	104000.	13000	26000.	39000.	52000.	8667.	17333.	26000.	34667.		
14000	28000.	56000.	84000.	112000.	14000	28000.	42000.	56000.	9333.	18667.	28000.	37333.		
15000	30000.	60000.	90000.	120000.	15000	30000.	45000.	60000.	10000.	20000.	30000.	40000.		
16000	32000.	64000.	96000.	128000.	16000	32000.	48000.	64000.	10667.	21333.	32000.	42667.		
17000	34000.	68000.	102000.	136000.	17000	34000.	51000.	68000.	11333.	22667.	34000.	45333.		
18000	36000.	72000.	108000.	144000.	18000	36000.	54000.	72000.	12000.	24000.	36000.	48000.		
19000	38000.	76000.	114000.	152000.	19000	38000.	57000.	76000.	12667.	25333.	38000.	50667.		
20000	40000.	80000.	120000.	160000.	20000	40000.	60000.	80000.	13333.	26667.	40000.	53333.		

*
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RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

*
POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.50

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
ENERGY PROJECT SIZE	COUNTY SHARE OF INMIGRANTS				COUNTY SHARE OF INMIGRANTS				COUNTY SHARE OF INMIGRANTS			
	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
500	1250.	2500.	3750.	5000.	625.	1250.	1875.	2500.	417.	833.	1250.	1667.
1000	2500.	5000.	7500.	10000.	1250.	2500.	3750.	5000.	833.	1667.	2500.	3333.
2000	5000.	10000.	15000.	20000.	2500.	5000.	7500.	10000.	1667.	3333.	5000.	6667.
3000	7500.	15000.	22500.	30000.	3750.	7500.	11250.	15000.	2500.	5000.	7500.	10000.
4000	10000.	20000.	30000.	40000.	5000.	10000.	15000.	20000.	3333.	6667.	10000.	13333.
5000	12500.	25000.	37500.	50000.	6250.	12500.	18750.	25000.	4167.	8333.	12500.	16667.
6000	15000.	30000.	45000.	60000.	7500.	15000.	22500.	30000.	5000.	10000.	15000.	20000.
7000	17500.	35000.	52500.	70000.	8750.	17500.	26250.	35000.	5833.	11667.	17500.	23333.
8000	20000.	40000.	60000.	80000.	10000.	20000.	30000.	40000.	6667.	13333.	20000.	26667.
9000	22500.	45000.	67500.	90000.	11250.	22500.	33750.	45000.	7500.	15000.	22500.	30000.
10000	25000.	50000.	75000.	100000.	12500.	25000.	37500.	50000.	8333.	16667.	25000.	33333.
11000	27500.	55000.	82500.	110000.	13750.	27500.	41250.	55000.	9167.	18333.	27500.	36667.
12000	30000.	60000.	90000.	120000.	15000.	30000.	45000.	60000.	10000.	20000.	30000.	40000.
13000	32500.	65000.	97500.	130000.	16250.	32500.	48750.	65000.	10833.	21667.	32500.	43333.
14000	35000.	70000.	105000.	140000.	17500.	35000.	52500.	70000.	11667.	23333.	35000.	46667.
15000	37500.	75000.	112500.	150000.	18750.	37500.	56250.	75000.	12500.	25000.	37500.	50000.
16000	40000.	80000.	120000.	160000.	20000.	40000.	60000.	80000.	13333.	26667.	40000.	53333.
17000	42500.	85000.	127500.	170000.	21250.	42500.	63750.	85000.	14167.	28333.	42500.	56667.
18000	45000.	90000.	135000.	180000.	22500.	45000.	67500.	90000.	15000.	30000.	45000.	60000.
19000	47500.	95000.	142500.	190000.	23750.	47500.	71250.	95000.	15833.	31667.	47500.	63333.
20000	50000.	100000.	150000.	200000.	25000.	50000.	75000.	100000.	16667.	33333.	50000.	66667.

*
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RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

*
POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.60

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH					
ENERGY :	COUNTY SHARE OF				:	COUNTY SHARE OF				:	COUNTY SHARE OF			
PROJECT:	INMIGRANTS				:	INMIGRANTS				:	INMIGRANTS			
SIZE :	25%	50%	75%	100%:	:	25%	50%	75%	100%:	:	25%	50%	75%	100%
500	1500.	3000.	4500.	6000.	:	750.	1500.	2250.	3000.	:	500.	1000.	1500.	2000.
1000	3000.	6000.	9000.	12000.	:	1500.	3000.	4500.	6000.	:	1000.	2000.	3000.	4000.
2000	6000.	12000.	18000.	24000.	:	3000.	6000.	9000.	12000.	:	2000.	4000.	6000.	8000.
3000	9000.	18000.	27000.	36000.	:	4500.	9000.	13500.	18000.	:	3000.	6000.	9000.	12000.
4000	12000.	24000.	36000.	48000.	:	6000.	12000.	18000.	24000.	:	4000.	8000.	12000.	16000.
5000	15000.	30000.	45000.	60000.	:	7500.	15000.	22500.	30000.	:	5000.	10000.	15000.	20000.
6000	18000.	36000.	54000.	72000.	:	9000.	18000.	27000.	36000.	:	6000.	12000.	18000.	24000.
7000	21000.	42000.	63000.	84000.	:	10500.	21000.	31500.	42000.	:	7000.	14000.	21000.	28000.
8000	24000.	48000.	72000.	96000.	:	12000.	24000.	36000.	48000.	:	8000.	16000.	24000.	32000.
9000	27000.	54000.	81000.	108000.	:	13500.	27000.	40500.	54000.	:	9000.	18000.	27000.	36000.
10000	30000.	60000.	90000.	120000.	:	15000.	30000.	45000.	60000.	:	10000.	20000.	30000.	40000.
11000	33000.	66000.	99000.	132000.	:	16500.	33000.	49500.	66000.	:	11000.	22000.	33000.	44000.
12000	36000.	72000.	108000.	144000.	:	18000.	36000.	54000.	72000.	:	12000.	24000.	36000.	48000.
13000	39000.	78000.	117000.	156000.	:	19500.	39000.	58500.	78000.	:	13000.	26000.	39000.	52000.
14000	42000.	84000.	126000.	168000.	:	21000.	42000.	63000.	84000.	:	14000.	28000.	42000.	56000.
15000	45000.	90000.	135000.	180000.	:	22500.	45000.	67500.	90000.	:	15000.	30000.	45000.	60000.
16000	48000.	96000.	144000.	192000.	:	24000.	48000.	72000.	96000.	:	16000.	32000.	48000.	64000.
17000	51000.	102000.	153000.	204000.	:	25500.	51000.	76500.	102000.	:	17000.	34000.	51000.	68000.
18000	54000.	108000.	162000.	216000.	:	27000.	54000.	81000.	108000.	:	18000.	36000.	54000.	72000.
19000	57000.	114000.	171000.	228000.	:	28500.	57000.	85500.	114000.	:	19000.	38000.	57000.	76000.
20000	60000.	120000.	180000.	240000.	:	30000.	60000.	90000.	120000.	:	20000.	40000.	60000.	80000.

*
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RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

*
POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.70

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH					: IMPACT LEVEL= 15% GROWTH				
ENERGY :	COUNTY SHARE OF				ENERGY :	COUNTY SHARE OF				ENERGY :	COUNTY SHARE OF			
PROJECT:	INMIGRANTS				PROJECT:	INMIGRANTS				PROJECT:	INMIGRANTS			
SIZE :	25%	50%	75%	100%	SIZE :	25%	50%	75%	100%	SIZE :	25%	50%	75%	100%
500	1750.	3500.	5250.	7000.	875.	1750.	2625.	3500.	583.	1167.	1750.	2333.	3500.	4667.
1000	3500.	7000.	10500.	14000.	1750.	3500.	5250.	7000.	1167.	2333.	3500.	4667.	7000.	9333.
2000	7000.	14000.	21000.	28000.	3500.	7000.	10500.	14000.	2333.	4667.	7000.	9333.	14000.	18667.
3000	10500.	21000.	31500.	42000.	5250.	10500.	15750.	21000.	3500.	7000.	10500.	14000.	21000.	28000.
4000	14000.	28000.	42000.	56000.	7000.	14000.	21000.	28000.	4667.	9333.	14000.	18667.	21000.	28000.
5000	17500.	35000.	52500.	70000.	8750.	17500.	26250.	35000.	5833.	11667.	17500.	23333.	35000.	46667.
6000	21000.	42000.	63000.	84000.	10500.	21000.	31500.	42000.	7000.	14000.	21000.	28000.	35000.	46667.
7000	24500.	49000.	73500.	98000.	12250.	24500.	36750.	49000.	8167.	16333.	24500.	32667.	49000.	65333.
8000	28000.	56000.	84000.	112000.	14000.	28000.	42000.	56000.	9333.	18667.	28000.	37333.	56000.	74667.
9000	31500.	63000.	94500.	126000.	15750.	31500.	47250.	63000.	10500.	21000.	31500.	42000.	56000.	74667.
10000	35000.	70000.	105000.	140000.	17500.	35000.	52500.	70000.	11667.	23333.	35000.	46667.	70000.	93333.
11000	38500.	77000.	115500.	154000.	19250.	38500.	57750.	77000.	12833.	25667.	38500.	51333.	77000.	102667.
12000	42000.	84000.	126000.	168000.	21000.	42000.	63000.	84000.	14000.	28000.	42000.	56000.	84000.	112000.
13000	45500.	91000.	136500.	182000.	22750.	45500.	68250.	91000.	15167.	30333.	45500.	60667.	91000.	121333.
14000	49000.	98000.	147000.	196000.	24500.	49000.	73500.	98000.	16333.	32667.	49000.	65333.	98000.	130667.
15000	52500.	105000.	157500.	210000.	26250.	52500.	78750.	105000.	17500.	35000.	52500.	70000.	105000.	140000.
16000	56000.	112000.	168000.	224000.	28000.	56000.	84000.	112000.	18667.	37333.	56000.	74667.	112000.	149333.
17000	59500.	119000.	178500.	238000.	29750.	59500.	89250.	119000.	19833.	39667.	59500.	79333.	119000.	158000.
18000	63000.	126000.	189000.	252000.	31500.	63000.	94500.	126000.	21000.	42000.	63000.	84000.	126000.	168000.
19000	66500.	133000.	199500.	266000.	33250.	66500.	99750.	133000.	22167.	44333.	66500.	88667.	133000.	177000.
20000	70000.	140000.	210000.	280000.	35000.	70000.	105000.	140000.	23333.	46667.	70000.	93333.	140000.	186667.

*
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UNDER THE LISTED CONSTRUCTION SIZES (PEAK WORKFORCE) GIVEN THE INMIGRANT
RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

THRESHOLD = (CONSTRUCTION POPULATION X MOVER PCT X COUNTY SHARE) / IMPACT LEVEL

Table G.5 (continued)

*
POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.80

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
ENERGY PROJECT SIZE	COUNTY SHARE OF INMIGRANTS				COUNTY SHARE OF INMIGRANTS				COUNTY SHARE OF INMIGRANTS			
	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
500	2000.	4000.	6000.	8000.	1000.	2000.	3000.	4000.	667.	1333.	2000.	2667.
1000	4000.	8000.	12000.	16000.	2000.	4000.	6000.	8000.	1333.	2667.	4000.	5333.
2000	8000.	16000.	24000.	32000.	4000.	8000.	12000.	16000.	2667.	5333.	8000.	10667.
3000	12000.	24000.	36000.	48000.	6000.	12000.	18000.	24000.	4000.	8000.	12000.	16000.
4000	16000.	32000.	48000.	64000.	8000.	16000.	24000.	32000.	5333.	10667.	16000.	21333.
5000	20000.	40000.	60000.	80000.	10000.	20000.	30000.	40000.	6667.	13333.	20000.	26667.
6000	24000.	48000.	72000.	96000.	12000.	24000.	36000.	48000.	8000.	16000.	24000.	32000.
7000	28000.	56000.	84000.	112000.	14000.	28000.	42000.	56000.	9333.	18667.	28000.	37333.
8000	32000.	64000.	96000.	128000.	16000.	32000.	48000.	64000.	10667.	21333.	32000.	42667.
9000	36000.	72000.	108000.	144000.	18000.	36000.	54000.	72000.	12000.	24000.	36000.	48000.
10000	40000.	80000.	120000.	160000.	20000.	40000.	60000.	80000.	13333.	26667.	40000.	53333.
11000	44000.	88000.	132000.	176000.	22000.	44000.	66000.	88000.	14667.	29333.	44000.	58667.
12000	48000.	96000.	144000.	192000.	24000.	48000.	72000.	96000.	16000.	32000.	48000.	64000.
13000	52000.	104000.	156000.	208000.	26000.	52000.	78000.	104000.	17333.	34667.	52000.	69333.
14000	56000.	112000.	168000.	224000.	28000.	56000.	84000.	112000.	18667.	37333.	56000.	74667.
15000	60000.	120000.	180000.	240000.	30000.	60000.	90000.	120000.	20000.	40000.	60000.	80000.
16000	64000.	128000.	192000.	256000.	32000.	64000.	96000.	128000.	21333.	42667.	64000.	85333.
17000	68000.	136000.	204000.	272000.	34000.	68000.	102000.	136000.	22667.	45333.	68000.	90667.
18000	72000.	144000.	216000.	288000.	36000.	72000.	108000.	144000.	24000.	48000.	72000.	96000.
19000	76000.	152000.	228000.	304000.	38000.	76000.	114000.	152000.	25333.	50667.	76000.	101333.
20000	80000.	160000.	240000.	320000.	40000.	80000.	120000.	160000.	26667.	53333.	80000.	106667.

*
POPULATION THRESHOLD IS THE MINIMUM HOST COMMUNITY SIZE NECESSARY
TO CONTROL POPULATION GROWTH TO SOME PERCENTAGE LEVEL (EG. 5%, 10%, 15%)
UNDER THE LISTED CONSTRUCTION SIZES (PEAK WORKFORCE) GIVEN THE INMIGRANT
RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

*
POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.90

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH					: IMPACT LEVEL= 15% GROWTH				
ENERGY :	COUNTY SHARE OF				ENERGY :	COUNTY SHARE OF				ENERGY :	COUNTY SHARE OF			
PROJECT:	INMIGRANTS				PROJECT:	INMIGRANTS				PROJECT:	INMIGRANTS			
SIZE :	25%	50%	75%	100%	SIZE :	25%	50%	75%	100%	SIZE :	25%	50%	75%	100%
500	2250.	4500.	6750.	9000.	1125.	2250.	3375.	4500.	750.	1500.	2250.	3000.	4500.	6000.
1000	4500.	9000.	13500.	18000.	2250.	4500.	6750.	9000.	1500.	3000.	4500.	6000.	9000.	12000.
2000	9000.	18000.	27000.	36000.	4500.	9000.	13500.	18000.	3000.	6000.	9000.	12000.	18000.	24000.
3000	13500.	27000.	40500.	54000.	6750.	13500.	20250.	27000.	4500.	9000.	13500.	18000.	27000.	36000.
4000	18000.	36000.	54000.	72000.	9000.	18000.	27000.	36000.	6000.	12000.	18000.	24000.	36000.	48000.
5000	22500.	45000.	67500.	90000.	11250.	22500.	33750.	45000.	7500.	15000.	22500.	30000.	45000.	60000.
6000	27000.	54000.	81000.	108000.	13500.	27000.	40500.	54000.	9000.	18000.	27000.	36000.	54000.	72000.
7000	31500.	63000.	94500.	126000.	15750.	31500.	47250.	63000.	10500.	21000.	31500.	42000.	63000.	84000.
8000	36000.	72000.	108000.	144000.	18000.	36000.	54000.	72000.	12000.	24000.	36000.	48000.	72000.	96000.
9000	40500.	81000.	121500.	162000.	20250.	40500.	60750.	81000.	13500.	27000.	40500.	54000.	81000.	108000.
10000	45000.	90000.	135000.	180000.	22500.	45000.	67500.	90000.	15000.	30000.	45000.	60000.	90000.	120000.
11000	49500.	99000.	148500.	198000.	24750.	49500.	74250.	99000.	16500.	33000.	49500.	66000.	99000.	132000.
12000	54000.	108000.	162000.	216000.	27000.	54000.	81000.	108000.	18000.	36000.	54000.	72000.	108000.	144000.
13000	58500.	117000.	175500.	234000.	29250.	58500.	87750.	117000.	19500.	39000.	58500.	78000.	117000.	156000.
14000	63000.	126000.	189000.	252000.	31500.	63000.	94500.	126000.	21000.	42000.	63000.	84000.	126000.	168000.
15000	67500.	135000.	202500.	270000.	33750.	67500.	101250.	135000.	22500.	45000.	67500.	90000.	135000.	180000.
16000	72000.	144000.	216000.	288000.	36000.	72000.	108000.	144000.	24000.	48000.	72000.	96000.	144000.	192000.
17000	76500.	153000.	229500.	306000.	38250.	76500.	114750.	153000.	25500.	51000.	76500.	102000.	153000.	204000.
18000	81000.	162000.	243000.	324000.	40500.	81000.	121500.	162000.	27000.	54000.	81000.	108000.	162000.	216000.
19000	85500.	171000.	256500.	342000.	42750.	85500.	128250.	171000.	28500.	57000.	85500.	114000.	171000.	228000.
20000	90000.	180000.	270000.	360000.	45000.	90000.	135000.	180000.	30000.	60000.	90000.	120000.	180000.	240000.

*
POPULATION THRESHOLD IS THE MINIMUM HOST COMMUNITY SIZE NECESSARY
TO CONTROL POPULATION GROWTH TO SOME PERCENTAGE LEVEL (EG. 5%, 10%, 15%)
UNDER THE LISTED CONSTRUCTION SIZES (PEAK WORKFORCE) GIVEN THE INMIGRANT
RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{CONSTRUCTION POPULATION} \times \text{MOVER PCT} \times \text{COUNTY SHARE}) / \text{IMPACT LEVEL}$$

Table G.5 (continued)

POPULATION THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 1.00

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
ENERGY PROJECT: SIZE	COUNTY SHARE OF INMIGRANTS				COUNTY SHARE OF INMIGRANTS				COUNTY SHARE OF INMIGRANTS			
	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
500	2500.	5000.	7500.	10000.	1250.	2500.	3750.	5000.	833.	1667.	2500.	3333.
1000	5000.	10000.	15000.	20000.	2500.	5000.	7500.	10000.	1667.	3333.	5000.	6667.
2000	10000.	20000.	30000.	40000.	5000.	10000.	15000.	20000.	3333.	6667.	10000.	13333.
3000	15000.	30000.	45000.	60000.	7500.	15000.	22500.	30000.	5000.	10000.	15000.	20000.
4000	20000.	40000.	60000.	80000.	10000.	20000.	30000.	40000.	6667.	13333.	20000.	26667.
5000	25000.	50000.	75000.	100000.	12500.	25000.	37500.	50000.	8333.	16667.	25000.	33333.
6000	30000.	60000.	90000.	120000.	15000.	30000.	45000.	60000.	10000.	20000.	30000.	40000.
7000	35000.	70000.	105000.	140000.	17500.	35000.	52500.	70000.	11667.	23333.	35000.	46667.
8000	40000.	80000.	120000.	160000.	20000.	40000.	60000.	80000.	13333.	26667.	40000.	53333.
9000	45000.	90000.	135000.	180000.	22500.	45000.	67500.	90000.	15000.	30000.	45000.	60000.
10000	50000.	100000.	150000.	200000.	25000.	50000.	75000.	100000.	16667.	33333.	50000.	66667.
11000	55000.	110000.	165000.	220000.	27500.	55000.	82500.	110000.	18333.	36667.	55000.	73333.
12000	60000.	120000.	180000.	240000.	30000.	60000.	90000.	120000.	20000.	40000.	60000.	80000.
13000	65000.	130000.	195000.	260000.	32500.	65000.	97500.	130000.	21667.	43333.	65000.	86667.
14000	70000.	140000.	210000.	280000.	35000.	70000.	105000.	140000.	23333.	46667.	70000.	93333.
15000	75000.	150000.	225000.	300000.	37500.	75000.	112500.	150000.	25000.	50000.	75000.	100000.
16000	80000.	160000.	240000.	320000.	40000.	80000.	120000.	160000.	26667.	53333.	80000.	106667.
17000	85000.	170000.	255000.	340000.	42500.	85000.	127500.	170000.	28333.	56667.	85000.	113333.
18000	90000.	180000.	270000.	360000.	45000.	90000.	135000.	180000.	30000.	60000.	90000.	120000.
19000	95000.	190000.	285000.	380000.	47500.	95000.	142500.	190000.	31667.	63333.	95000.	126667.
20000	100000.	200000.	300000.	400000.	50000.	100000.	150000.	200000.	33333.	66667.	100000.	133333.

POPULATION THRESHOLD IS THE MINIMUM HOST COMMUNITY SIZE NECESSARY
TO CONTROL POPULATION GROWTH TO SOME PERCENTAGE LEVEL (EG. 5%, 10%, 15%)
UNDER THE LISTED CONSTRUCTION SIZES (PEAK WORKFORCE) GIVEN THE INMIGRANT
RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

THRESHOLD = (CONSTRUCTION POPULATION X MOVER PCT X COUNTY SHARE) / IMPACT LEVEL

Table G.6. Project Size Thresholds for Energy Developments*
Immigrants = 0.10

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
2000	4000.	2000.	1333.	1000.	8000.	4000.	2667.	2000.	12000.	6000.	4000.	3000.
3000	6000.	3000.	2000.	1500.	12000.	6000.	4000.	3000.	18000.	9000.	6000.	4500.
4000	8000.	4000.	2667.	2000.	16000.	8000.	5333.	4000.	24000.	12000.	8000.	6000.
5000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
6000	12000.	6000.	4000.	3000.	24000.	12000.	8000.	6000.	36000.	18000.	12000.	9000.
7000	14000.	7000.	4667.	3500.	28000.	14000.	9333.	7000.	42000.	21000.	14000.	10500.
8000	16000.	8000.	5333.	4000.	32000.	16000.	10667.	8000.	48000.	24000.	16000.	12000.
9000	18000.	9000.	6000.	4500.	36000.	18000.	12000.	9000.	54000.	27000.	18000.	13500.
10000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
15000	30000.	15000.	10000.	7500.	60000.	30000.	20000.	15000.	90000.	45000.	30000.	22500.
20000	40000.	20000.	13333.	10000.	80000.	40000.	26667.	20000.	120000.	60000.	40000.	30000.
25000	50000.	25000.	16667.	12500.	100000.	50000.	33333.	25000.	150000.	75000.	50000.	37500.
30000	60000.	30000.	20000.	15000.	120000.	60000.	40000.	30000.	180000.	90000.	60000.	45000.
35000	70000.	35000.	23333.	17500.	140000.	70000.	46667.	35000.	210000.	105000.	70000.	52500.
40000	80000.	40000.	26667.	20000.	160000.	80000.	53333.	40000.	240000.	120000.	80000.	60000.
45000	90000.	45000.	30000.	22500.	180000.	90000.	60000.	45000.	270000.	135000.	90000.	67500.
50000	100000.	50000.	33333.	25000.	200000.	100000.	66667.	50000.	300000.	150000.	100000.	75000.
70000	140000.	70000.	46667.	35000.	280000.	140000.	93333.	70000.	420000.	210000.	140000.	105000.
90000	180000.	90000.	60000.	45000.	360000.	180000.	120000.	90000.	540000.	270000.	180000.	135000.
100000	200000.	100000.	66667.	50000.	400000.	200000.	133333.	100000.	600000.	300000.	200000.	150000.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

*
PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.20

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	1000.	500.	333.	250.	2000.	1000.	667.	500.	3000.	1500.	1000.	750.
2000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
3000	3000.	1500.	1000.	750.	6000.	3000.	2000.	1500.	9000.	4500.	3000.	2250.
4000	4000.	2000.	1333.	1000.	8000.	4000.	2667.	2000.	12000.	6000.	4000.	3000.
5000	5000.	2500.	1667.	1250.	10000.	5000.	3333.	2500.	15000.	7500.	5000.	3750.
6000	6000.	3000.	2000.	1500.	12000.	6000.	4000.	3000.	18000.	9000.	6000.	4500.
7000	7000.	3500.	2333.	1750.	14000.	7000.	4667.	3500.	21000.	10500.	7000.	5250.
8000	8000.	4000.	2667.	2000.	16000.	8000.	5333.	4000.	24000.	12000.	8000.	6000.
9000	9000.	4500.	3000.	2250.	18000.	9000.	6000.	4500.	27000.	13500.	9000.	6750.
10000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
15000	15000.	7500.	5000.	3750.	30000.	15000.	10000.	7500.	45000.	22500.	15000.	11250.
20000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
25000	25000.	12500.	8333.	6250.	50000.	25000.	16667.	12500.	75000.	37500.	25000.	18750.
30000	30000.	15000.	10000.	7500.	60000.	30000.	20000.	15000.	90000.	45000.	30000.	22500.
35000	35000.	17500.	11667.	8750.	70000.	35000.	23333.	17500.	105000.	52500.	35000.	26250.
40000	40000.	20000.	13333.	10000.	80000.	40000.	26667.	20000.	120000.	60000.	40000.	30000.
45000	45000.	22500.	15000.	11250.	90000.	45000.	30000.	22500.	135000.	67500.	45000.	33750.
50000	50000.	25000.	16667.	12500.	100000.	50000.	33333.	25000.	150000.	75000.	50000.	37500.
70000	70000.	35000.	23333.	17500.	140000.	70000.	46667.	35000.	210000.	105000.	70000.	52500.
90000	90000.	45000.	30000.	22500.	180000.	90000.	60000.	45000.	270000.	135000.	90000.	67500.
100000	100000.	50000.	33333.	25000.	200000.	100000.	66667.	50000.	300000.	150000.	100000.	75000.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.30

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	667.	333.	222.	167.	1333.	667.	444.	333.	2000.	1000.	657.	500.
2000	1333.	667.	444.	333.	2667.	1333.	889.	667.	4000.	2000.	1333.	1000.
3000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
4000	2667.	1333.	889.	667.	5333.	2667.	1778.	1333.	8000.	4000.	2667.	2000.
5000	3333.	1667.	1111.	833.	6667.	3333.	2222.	1667.	10000.	5000.	3333.	2500.
6000	4000.	2000.	1333.	1000.	8000.	4000.	2667.	2000.	12000.	6000.	4000.	3000.
7000	4667.	2333.	1556.	1167.	9333.	4667.	3111.	2333.	14000.	7000.	4667.	3500.
8000	5333.	2667.	1778.	1333.	10667.	5333.	3556.	2667.	16000.	8000.	5333.	4000.
9000	6000.	3000.	2000.	1500.	12000.	6000.	4000.	3000.	18000.	9000.	6000.	4500.
10000	6667.	3333.	2222.	1667.	13333.	6667.	4444.	3333.	20000.	10000.	6667.	5000.
15000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
20000	13333.	6667.	4444.	3333.	26667.	13333.	8889.	6667.	40000.	20000.	13333.	10000.
25000	16667.	8333.	5556.	4167.	33333.	16667.	11111.	8333.	50000.	25000.	16667.	12500.
30000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
35000	23333.	11667.	7778.	5833.	46667.	23333.	15556.	11667.	70000.	35000.	23333.	17500.
40000	26667.	13333.	8889.	6667.	53333.	26667.	17778.	13333.	80000.	40000.	26667.	20000.
45000	30000.	15000.	10000.	7500.	60000.	30000.	20000.	15000.	90000.	45000.	30000.	22500.
50000	33333.	16667.	11111.	8333.	66667.	33333.	22222.	16667.	100000.	50000.	33333.	25000.
70000	46667.	23333.	15556.	11667.	93333.	46667.	31111.	23333.	140000.	70000.	46667.	35000.
90000	60000.	30000.	20000.	15000.	120000.	60000.	40000.	30000.	180000.	90000.	60000.	45000.
100000	66667.	33333.	22222.	16667.	133333.	66667.	44444.	33333.	200000.	100000.	66667.	50000.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.40

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	500.	250.	167.	125.	1000.	500.	333.	250.	1500.	750.	500.	375.
2000	1000.	500.	333.	250.	2000.	1000.	667.	500.	3000.	1500.	1000.	750.
3000	1500.	750.	500.	375.	3000.	1500.	1000.	750.	4500.	2250.	1500.	1125.
4000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
5000	2500.	1250.	833.	625.	5000.	2500.	1667.	1250.	7500.	3750.	2500.	1875.
6000	3000.	1500.	1000.	750.	6000.	3000.	2000.	1500.	9000.	4500.	3000.	2250.
7000	3500.	1750.	1167.	875.	7000.	3500.	2333.	1750.	10500.	5250.	3500.	2625.
8000	4000.	2000.	1333.	1000.	8000.	4000.	2667.	2000.	12000.	6000.	4000.	3000.
9000	4500.	2250.	1500.	1125.	9000.	4500.	3000.	2250.	13500.	6750.	4500.	3375.
10000	5000.	2500.	1667.	1250.	10000.	5000.	3333.	2500.	15000.	7500.	5000.	3750.
15000	7500.	3750.	2500.	1875.	15000.	7500.	5000.	3750.	22500.	11250.	7500.	5625.
20000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
25000	12500.	6250.	4167.	3125.	25000.	12500.	8333.	6250.	37500.	18750.	12500.	9375.
30000	15000.	7500.	5000.	3750.	30000.	15000.	10000.	7500.	45000.	22500.	15000.	11250.
35000	17500.	8750.	5833.	4375.	35000.	17500.	11667.	8750.	52500.	26250.	17500.	13125.
40000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
45000	22500.	11250.	7500.	5625.	45000.	22500.	15000.	11250.	67500.	33750.	22500.	16875.
50000	25000.	12500.	8333.	6250.	50000.	25000.	16667.	12500.	75000.	37500.	25000.	18750.
70000	35000.	17500.	11667.	8750.	70000.	35000.	23333.	17500.	105000.	52500.	35000.	26250.
90000	45000.	22500.	15000.	11250.	90000.	45000.	30000.	22500.	135000.	67500.	45000.	33750.
100000	50000.	25000.	16667.	12500.	100000.	50000.	33333.	25000.	150000.	75000.	50000.	37500.

PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

*
PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.50

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	400.	200.	133.	100.	800.	400.	267.	200.	1200.	600.	400.	300.
2000	800.	400.	267.	200.	1600.	800.	533.	400.	2400.	1200.	800.	600.
3000	1200.	600.	400.	300.	2400.	1200.	800.	600.	3600.	1800.	1200.	900.
4000	1600.	800.	533.	400.	3200.	1600.	1067.	800.	4800.	2400.	1600.	1200.
5000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
6000	2400.	1200.	800.	600.	4800.	2400.	1600.	1200.	7200.	3600.	2400.	1800.
7000	2800.	1400.	933.	700.	5600.	2800.	1867.	1400.	8400.	4200.	2800.	2100.
8000	3200.	1600.	1067.	800.	6400.	3200.	2133.	1600.	9600.	4800.	3200.	2400.
9000	3600.	1800.	1200.	900.	7200.	3600.	2400.	1800.	10800.	5400.	3600.	2700.
10000	4000.	2000.	1333.	1000.	8000.	4000.	2667.	2000.	12000.	6000.	4000.	3000.
15000	6000.	3000.	2000.	1500.	12000.	6000.	4000.	3000.	18000.	9000.	6000.	4500.
20000	8000.	4000.	2667.	2000.	16000.	8000.	5333.	4000.	24000.	12000.	8000.	6000.
25000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
30000	12000.	6000.	4000.	3000.	24000.	12000.	8000.	6000.	36000.	18000.	12000.	9000.
35000	14000.	7000.	4667.	3500.	28000.	14000.	9333.	7000.	42000.	21000.	14000.	10500.
40000	16000.	8000.	5333.	4000.	32000.	16000.	10667.	8000.	48000.	24000.	16000.	12000.
45000	18000.	9000.	6000.	4500.	36000.	18000.	12000.	9000.	54000.	27000.	18000.	13500.
50000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
70000	28000.	14000.	9333.	7000.	56000.	28000.	18667.	14000.	84000.	42000.	28000.	21000.
90000	36000.	18000.	12000.	9000.	72000.	36000.	24000.	18000.	108000.	54000.	36000.	27000.
100000	40000.	20000.	13333.	10000.	80000.	40000.	26667.	20000.	120000.	60000.	40000.	30000.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

*
PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.60

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	333.	167.	111.	83.	667.	333.	222.	167.	1000.	500.	333.	250.
2000	667.	333.	222.	167.	1333.	667.	444.	333.	2000.	1000.	667.	500.
3000	1000.	500.	333.	250.	2000.	1000.	667.	500.	3000.	1500.	1000.	750.
4000	1333.	667.	444.	333.	2667.	1333.	889.	667.	4000.	2000.	1333.	1000.
5000	1667.	833.	556.	417.	3333.	1667.	1111.	833.	5000.	2500.	1667.	1250.
6000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
7000	2333.	1167.	778.	583.	4667.	2333.	1556.	1167.	7000.	3500.	2333.	1750.
8000	2667.	1333.	889.	667.	5333.	2667.	1778.	1333.	8000.	4000.	2667.	2000.
9000	3000.	1500.	1000.	750.	6000.	3000.	2000.	1500.	9000.	4500.	3000.	2250.
10000	3333.	1667.	1111.	833.	6667.	3333.	2222.	1667.	10000.	5000.	3333.	2500.
15000	5000.	2500.	1667.	1250.	10000.	5000.	3333.	2500.	15000.	7500.	5000.	3750.
20000	6667.	3333.	2222.	1667.	13333.	6667.	4444.	3333.	20000.	10000.	6667.	5000.
25000	8333.	4167.	2778.	2083.	16667.	8333.	5556.	4167.	25000.	12500.	8333.	6250.
30000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
35000	11667.	5833.	3889.	2917.	23333.	11667.	7778.	5833.	35000.	17500.	11667.	8750.
40000	13333.	6667.	4444.	3333.	26667.	13333.	8889.	6667.	40000.	20000.	13333.	10000.
45000	15000.	7500.	5000.	3750.	30000.	15000.	10000.	7500.	45000.	22500.	15000.	11250.
50000	16667.	8333.	5556.	4167.	33333.	16667.	11111.	8333.	50000.	25000.	16667.	12500.
70000	23333.	11667.	7778.	5833.	46667.	23333.	15556.	11667.	70000.	35000.	23333.	17500.
90000	30000.	15000.	10000.	7500.	60000.	30000.	20000.	15000.	90000.	45000.	30000.	22500.
100000	33333.	16667.	11111.	8333.	66667.	33333.	22222.	16667.	100000.	50000.	33333.	25000.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

*
PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.70

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTRY	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	286.	143.	95.	71.	571.	286.	190.	143.	857.	429.	286.	214.
2000	571.	286.	190.	143.	1143.	571.	381.	286.	1714.	857.	571.	429.
3000	857.	429.	286.	214.	1714.	857.	571.	429.	2571.	1286.	857.	643.
4000	1143.	571.	381.	286.	2286.	1143.	762.	571.	3429.	1714.	1143.	857.
5000	1429.	714.	476.	357.	2857.	1429.	952.	714.	4286.	2143.	1429.	1071.
6000	1714.	857.	571.	429.	3429.	1714.	1143.	857.	5143.	2571.	1714.	1286.
7000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
8000	2286.	1143.	762.	571.	4571.	2286.	1524.	1143.	6857.	3429.	2286.	1714.
9000	2571.	1286.	857.	643.	5143.	2571.	1714.	1286.	7714.	3857.	2571.	1929.
10000	2857.	1429.	952.	714.	5714.	2857.	1905.	1429.	8571.	4286.	2857.	2143.
15000	4286.	2143.	1429.	1071.	8571.	4286.	2857.	2143.	12857.	6429.	4286.	3214.
20000	5714.	2857.	1905.	1429.	11429.	5714.	3810.	2857.	17143.	8571.	5714.	4286.
25000	7143.	3571.	2331.	1786.	14286.	7143.	4762.	3571.	21429.	10714.	7143.	5357.
30000	8571.	4286.	2857.	2143.	17143.	8571.	5714.	4286.	25714.	12857.	8571.	6429.
35000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
40000	11429.	5714.	3810.	2857.	22857.	11429.	7619.	5714.	34286.	17143.	11429.	8571.
45000	12857.	6429.	4286.	3214.	25714.	12857.	8571.	6429.	38571.	19286.	12857.	9643.
50000	14286.	7143.	4762.	3571.	28571.	14286.	9524.	7143.	42857.	21429.	14286.	10714.
70000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
90000	25714.	12857.	8571.	6429.	51429.	25714.	17143.	12857.	77143.	38571.	25714.	19286.
100000	28571.	14286.	9524.	7143.	57143.	28571.	19048.	14286.	85714.	42857.	28571.	21429.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE IMMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.80

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH					: IMPACT LEVEL= 15% GROWTH				
SITE	COUNTY SHARE OF				COUNTY SHARE OF					COUNTY SHARE OF				
COUNTY	INMIGRANTS				INMIGRANTS					INMIGRANTS				
POP	25%	50%	75%	100%	25%	50%	75%	100%		25%	50%	75%	100%	
1000	250.	125.	83.	62.	500.	250.	167.	125.		750.	375.	250.	187.	
2000	500.	250.	167.	125.	1000.	500.	333.	250.		1500.	750.	500.	375.	
3000	750.	375.	250.	187.	1500.	750.	500.	375.		2250.	1125.	750.	562.	
4000	1000.	500.	333.	250.	2000.	1000.	667.	500.		3000.	1500.	1000.	750.	
5000	1250.	625.	417.	312.	2500.	1250.	833.	625.		3750.	1875.	1250.	937.	
6000	1500.	750.	500.	375.	3000.	1500.	1000.	750.		4500.	2250.	1500.	1125.	
7000	1750.	875.	583.	437.	3500.	1750.	1167.	875.		5250.	2625.	1750.	1312.	
8000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.		6000.	3000.	2000.	1500.	
9000	2250.	1125.	750.	562.	4500.	2250.	1500.	1125.		6750.	3375.	2250.	1687.	
10000	2500.	1250.	833.	625.	5000.	2500.	1667.	1250.		7500.	3750.	2500.	1875.	
15000	3750.	1875.	1250.	937.	7500.	3750.	2500.	1875.		11250.	5625.	3750.	2812.	
20000	5000.	2500.	1667.	1250.	10000.	5000.	3333.	2500.		15000.	7500.	5000.	3750.	
25000	6250.	3125.	2083.	1562.	12500.	6250.	4167.	3125.		18750.	9375.	6250.	4687.	
30000	7500.	3750.	2500.	1875.	15000.	7500.	5000.	3750.		22500.	11250.	7500.	5625.	
35000	8750.	4375.	2917.	2187.	17500.	8750.	5833.	4375.		26250.	13125.	8750.	6562.	
40000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.		30000.	15000.	10000.	7500.	
45000	11250.	5625.	3750.	2812.	22500.	11250.	7500.	5625.		33750.	16875.	11250.	8437.	
50000	12500.	6250.	4167.	3125.	25000.	12500.	8333.	6250.		37500.	18750.	12500.	9375.	
70000	17500.	8750.	5833.	4375.	35000.	17500.	11667.	8750.		52500.	26250.	17500.	13125.	
90000	22500.	11250.	7500.	5625.	45000.	22500.	15000.	11250.		67500.	33750.	22500.	16875.	
100000	25000.	12500.	8333.	6250.	50000.	25000.	16667.	12500.		75000.	37500.	25000.	18750.	

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 0.90

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	222.	111.	74.	56.	444.	222.	148.	111.	667.	333.	222.	167.
2000	444.	222.	148.	111.	889.	444.	296.	222.	1333.	667.	444.	333.
3000	667.	333.	222.	167.	1333.	667.	444.	333.	2000.	1000.	667.	500.
4000	889.	444.	296.	222.	1778.	889.	593.	444.	2667.	1333.	889.	667.
5000	1111.	556.	370.	273.	2222.	1111.	741.	556.	3333.	1667.	1111.	833.
6000	1333.	667.	444.	333.	2667.	1333.	889.	667.	4000.	2000.	1333.	1000.
7000	1556.	778.	519.	389.	3111.	1556.	1037.	778.	4667.	2333.	1556.	1167.
8000	1778.	889.	593.	444.	3556.	1778.	1185.	889.	5333.	2667.	1778.	1333.
9000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
10000	2222.	1111.	741.	556.	4444.	2222.	1481.	1111.	6667.	3333.	2222.	1667.
15000	3333.	1667.	1111.	833.	6667.	3333.	2222.	1667.	10000.	5000.	3333.	2500.
20000	4444.	2222.	1481.	1111.	8889.	4444.	2963.	2222.	13333.	6667.	4444.	3333.
25000	5556.	2778.	1852.	1389.	11111.	5556.	3704.	2778.	16667.	8333.	5556.	4167.
30000	6667.	3333.	2222.	1667.	13333.	6667.	4444.	3333.	20000.	10000.	6667.	5000.
35000	7778.	3889.	2593.	1944.	15556.	7778.	5185.	3889.	23333.	11667.	7778.	5833.
40000	8889.	4444.	2963.	2222.	17778.	8889.	5926.	4444.	26667.	13333.	8889.	6667.
45000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
50000	11111.	5556.	3704.	2778.	22222.	11111.	7407.	5556.	33333.	16667.	11111.	8333.
70000	15556.	7778.	5185.	3889.	31111.	15556.	10370.	7778.	46667.	23333.	15556.	11667.
90000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.
100000	22222.	11111.	7407.	5556.	44444.	22222.	14815.	11111.	66667.	33333.	22222.	16667.

*
PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE)
THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION
INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%)
GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

Table G.6 (continued)

PROJECT SIZE THRESHOLDS FOR ENERGY DEVELOPMENTS
INMIGRANTS= 1.00

: IMPACT LEVEL= 5% GROWTH					: IMPACT LEVEL= 10% GROWTH				: IMPACT LEVEL= 15% GROWTH			
SITE :	COUNTY SHARE OF				COUNTY SHARE OF				COUNTY SHARE OF			
COUNTY :	INMIGRANTS				INMIGRANTS				INMIGRANTS			
POP :	25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%
1000	200.	100.	67.	50.	400.	200.	133.	100.	600.	300.	200.	150.
2000	400.	200.	133.	100.	800.	400.	267.	200.	1200.	600.	400.	300.
3000	600.	300.	200.	150.	1200.	600.	400.	300.	1800.	900.	600.	450.
4000	800.	400.	267.	200.	1600.	800.	533.	400.	2400.	1200.	800.	600.
5000	1000.	500.	333.	250.	2000.	1000.	667.	500.	3000.	1500.	1000.	750.
6000	1200.	600.	400.	300.	2400.	1200.	800.	600.	3600.	1800.	1200.	900.
7000	1400.	700.	467.	350.	2800.	1400.	933.	700.	4200.	2100.	1400.	1050.
8000	1600.	800.	533.	400.	3200.	1600.	1067.	800.	4800.	2400.	1600.	1200.
9000	1800.	900.	600.	450.	3600.	1800.	1200.	900.	5400.	2700.	1800.	1350.
10000	2000.	1000.	667.	500.	4000.	2000.	1333.	1000.	6000.	3000.	2000.	1500.
15000	3000.	1500.	1000.	750.	6000.	3000.	2000.	1500.	9000.	4500.	3000.	2250.
20000	4000.	2000.	1333.	1000.	8000.	4000.	2667.	2000.	12000.	6000.	4000.	3000.
25000	5000.	2500.	1667.	1250.	10000.	5000.	3333.	2500.	15000.	7500.	5000.	3750.
30000	6000.	3000.	2000.	1500.	12000.	6000.	4000.	3000.	18000.	9000.	6000.	4500.
35000	7000.	3500.	2333.	1750.	14000.	7000.	4667.	3500.	21000.	10500.	7000.	5250.
40000	8000.	4000.	2667.	2000.	16000.	8000.	5333.	4000.	24000.	12000.	8000.	6000.
45000	9000.	4500.	3000.	2250.	18000.	9000.	6000.	4500.	27000.	13500.	9000.	6750.
50000	10000.	5000.	3333.	2500.	20000.	10000.	6667.	5000.	30000.	15000.	10000.	7500.
70000	14000.	7000.	4667.	3500.	28000.	14000.	9333.	7000.	42000.	21000.	14000.	10500.
90000	18000.	9000.	6000.	4500.	36000.	18000.	12000.	9000.	54000.	27000.	18000.	13500.
100000	20000.	10000.	6667.	5000.	40000.	20000.	13333.	10000.	60000.	30000.	20000.	15000.

PROJECT SIZE THRESHOLD IS THE MAXIMUM PEAK WORKFORCE (IE. PROJECT SIZE) THAT CAN BE SITED AT EACH POPULATION LEVEL IF POPULATION INCREASE IS TO BE LIMITED TO A CERTAIN LEVEL (EG. 5%, 10%, 15%) GIVEN THE INMIGRANT RATE AND THE VARIOUS COUNTY SHARE PERCENTAGES

$$\text{THRESHOLD} = (\text{POPULATION} \times \text{IMPACT LEVEL}) / (\text{MOVER PCT} \times \text{COUNTY SHARE})$$

G.6 Mining Employment

The county estimates of mining employment are based on estimates of county coal production. Estimates of both production and mining employment are derived from a computer algorithm that combines the following information:

1. large region control totals from the base-case scenario,
2. historic levels of production,
3. reserve base,
4. employment by type of extraction.

The algorithm operates in five-year steps from 1975 to 2020. Control totals (census region) from the scenario were interpolated to provide boundary conditions for each interval.

The calculations first assumed that production for each county in any given period is equal to last period's production. This level is tested against the county's reserve base, and if reserves are sufficient, it is summed for all counties in the control region. If the control total exceeds the lagged values, the difference is allocated to all counties in the region according to the individual county's share of reserves. If the control total is less, the difference is allocated according to last period's production. This series of calculations results in two values for each county which are added together and which for all counties are equal to the control total. This process is repeated for each time period.

To calculate employment, it is necessary to divide production into strip mining and deep mining. This is done by assuming that production is divided between the two in proportions equal to the reserve fraction for each county that is strippable or deep-minable. This level is then multiplied by the following employment rate for each type of extraction and summed, yielding an employment level for each county:

1. 11,660 man-years per quad underground coal production
2. 4060 man-years per quad strip mined coal production

Productivity improvements may occur in coal production in the future, but sufficient uncertainty regarding the character of new mines brought into production and environmental restrictions exists to preclude simple analysis. Hence, it is assumed that productivity remains constant over the study period for this report.

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APPENDIX H
TECHNOLOGY CHARACTERIZATION

H.1 Introduction

The preliminary analyses summarized in this section were performed to provide information on the basic resource requirements and effluent releases of coal combustion and coal conversion facilities typical of those which might be sited in the southern United States. A thorough review of the technical literature was carried out as a first step in the analysis. Data were obtained for each representative process outlined in this section. The data were then compiled into tables and normalized to the level of commercial plant size agreed upon in the NCUA Technology Characterization Work Group. The unit coal combustion facility is 1000 MWe with a load factor of 100%. The plant operates at an overall efficiency of 35%. Capacity of the unit coal gasification plant is 250 MMscfd with a load factor of 90% and an overall plant efficiency of approximately 50%. The unit coal liquefaction plant produces 50,000 bblsd with a load factor of 90% and a process efficiency of approximately 70%.

In order to carry out the various elements of the technology characterization, it was necessary to assume parameters to represent the various coals used in the region. Much of the coal resource used in the region is mined in Appalachia. The majority of the coal mined in Appalachia is bituminous and ranges from high to low volatility. Sulfur may vary from a minimum of 2% to as high as 50%.^{1,2} The representative numbers selected to characterize Appalachian coals utilized by facilities sited in the region are listed in Table H.1.

Table H.1. Typical Appalachian coal characteristics^a

Ash	16%	Carbon	64%
Fixed carbon	47%	Hydrogen	5%
Heat value	12000 Btu/lb	Nitrogen	2%
Moisture	6%	Oxygen	8%
Volatile matter	37%	Sulfur	3%

^aData from *Preparation of Coal Conversion Systems Technical Data Handbook*, Institute of Gas Technology, Chicago, Ill., 1976.

H.2 Coal Combustion

This analysis considers a coal combustion unit based upon a pulverized-coal, tangentially-fired boiler. This unit is of nominal size (1000 MWe) and is fitted with an electrostatic precipitator. A flue gas desulfurization (FGD) unit is assumed to be part of the system and cooling is provided by wet towers. The resource requirements for the plant are presented in Table H.2. Coal input was calculated on the basis of plant size, plant efficiency, and load factor. The 1000 MWe plant in this study is assumed to have a load factor of 100% and a plant efficiency of 38%. This efficiency was calculated on the basis of an overall heat rate of 9600 Btu/kW-hr.³ The ratio of Btu/kW-hr or heat rate yields the overall plant efficiency and consideration of efficiency and load factor will yield the Btu required by the plant per year. The number of tons of coal required can then be calculated based upon the assumed heat value for coal of 12,000 Btu/lb (Table H.1). Addition of a flue gas desulfurization system serves to raise the overall heat rate by 2-3% and reduce the efficiency of the plant by approximately 3%.³ The analysis of water requirements focuses upon the use of a wet cooling tower. Limestone requirements of the FGD unit are also listed in Table H.2. Land-use requirements for the plant reflect the area required for disposal of FGD sludge.

Table H.2 also provides a characterization of this technology from the standpoint of gaseous emissions, solid wastes, and liquid effluents. The gaseous emissions addressed in this table include the criteria pollutants of sulfur oxides, particulates, and nitrogen oxides.⁴⁻¹² Sulfur oxide release values have been calculated assuming that 99% of the sulfur in the coal goes to flue gas and that the flue gas desulfurization unit operates at 85% efficiency. Particulate releases were based on the assumption that 80% of the coal ash is fly ash and that the electrostatic precipitator operates at 99% efficiency. Releases of nitrogen oxides were approximated at 10% of the sulfur oxide releases before consideration of the FGD unit removal rates. Solid wastes have been categorized into bottom ash, fly ash, and sludge.^{3,4,8} The bottom ash represents 20% of the total ash output calculated from the ash content of the coal. The fly ash component of the solid waste is that portion of the fly ash which is removed by the electrostatic precipitator. The sludge results from the throwaway process assumed for flue gas desulfurization. This nonregenerable method of flue gas desulfurization produces a combination of limestone and sulfur. Liquid effluents have also been addressed in Table H.2. Values for total suspended solids (TSS) and total dissolved solids (TDS) are presented under the category of liquid effluents.⁸

H.3 Coal Gasification

For the purpose of this analysis, a generalized coal gasification plant has been examined. Much of the data presented here has been drawn from published information on the Lurgi gasification process.^{2,13,14} The standard plant will produce 250 MMscfd of substitute natural gas with

Table H.2. Characteristics of a 1000-MWe coal-fired electric generating plant

Plant inputs		Plant releases	
Coal	3.4×10^6 tons/year	Gaseous emissions	
		SO _x	1.5×10^4 tons/year
Water		Particulates	4.4×10^3 tons/year
Process and cooling		NO _x	1.0×10^4 tons/year
Nonconsumptive	3.0×10^{11} gal/year		
Consumptive	4.2×10^9 gal/year	Solid waste	
Scrubber	8.4×10^8 gal/year	Bottom ash	1.1×10^5 tons/year
		Fly ash	4.4×10^5 tons/year
Limestone	3.5×10^5 tons/year	Sludge	7.9×10^5 tons/year
Land	1000 acres	Liquid effluents	
		TSS	6.0×10^2 tons/year
		TDS	5.1×10^3 tons/year

a heat value of 1000 Btu/scf. A utility plant is associated with the gasification unit to provide process steam and electricity. The utility plant is assumed to be a 500-MWe plant fitted with an electrostatic precipitator and a flue gas desulfurization unit. Cooling is provided by a wet tower. The resource requirements for the plant are presented in Table H.3. Coal input to the gasification process was calculated on the basis of process efficiency and annual capacity factor.³ The gasification process operates at a load factor of 90% and an efficiency of approximately 66%. This efficiency was calculated on the basis of a heat value for substitute natural gas of 1000 Btu/scf and a heat value for coal of 12,000 Btu/lb. The ratio of gasifier output to coal input yields the process efficiency. Process boilers and utility power generation operate at an efficiency of 35% and the addition of this element serves to reduce the overall plant efficiency to approximately 50%.

The analysis of water requirements shown in Table H.3 provides a single value for the entire gasification plant. Water consumption values assigned to the gasification process have been extracted from the literature and standardized for a 250-MMscfd plant.^{2,13,14} The water requirements for the 500-MWe utility plant have been incorporated in the overall figure. In general, the resource requirements for the 500-MWe utility plant are scaled down from the figures presented in Table H.2 for the 1000-MWe plant.

The plant effluent releases are summarized in Table H.3.^{3,13} This analysis has been carried out on the assumption that both the gasification process and the utility plant will serve as a source of environmental pollutants. Estimates of sulfur oxide releases from the gasification process are a factor of seven less than releases from the utility plant. Particulate releases from the gasification process are assumed to be negligible and nitrogen oxides are not a major consideration in the gasification process considered. Solid wastes have been categorized into bottom ash, fly ash, and sludge. These wastes result from the operation of the utility plant and not the gasification plant. No indication of the types and volumes of solid waste generated by the gasification plant itself could be derived from the technical literature. Most technical sources assume that solid wastes are generated from ash and sulfated lime and this assumption was accepted for the purpose of this characterization. Little data are available on the nature and amount of liquid effluents from the gasification process. For the purpose of this analysis, it will be assumed that this plant will not discharge any wastewater except to evaporation ponds.

H.4 Coal Liquefaction

The coal liquefaction plant considered in this analysis has been generalized. The process detailed in this analysis is based to a great extent upon catalytic hydrogenation and is similar to the H-Coal process.¹³ This standard plant will produce 50,000 bbl/d of low-sulfur syncrude with a heat value of 5.8×10^6 Btu/bbl. A utility plant is associated with the liquefaction plant to provide steam and electric power.

Table H.3. Characteristics of a 250-MMscfd coal gasification plant

Plant inputs		Plant releases	
Coal		Gaseous emissions	
Gasification process	5.0×10^6 tons/year	Gasification process	
Utility plant	1.6×10^6 tons/year	SO _x	1.0×10^3 tons/year
		Utility plant	
Water		SO _x	7.1×10^3 tons/year
Consumption	6.0×10^9 gal/year	Particulates	2.0×10^3 tons/year
		NO _x	4.8×10^3 tons/year
Limestone	1.6×10^5 tons/year	Solid waste	
Land	1000 acres	Utility plant	
		Bottom ash	5.1×10^4 tons/year
		Fly ash	2.0×10^5 tons/year
		Sludge	3.7×10^5 tons/year

The utility plant is assumed to be a 300-MWe plant fitted with an electrostatic precipitator and a flue gas desulfurization unit. Cooling is provided by a wet tower. Table H.4 lists the resource requirements of the plant. All auxiliary facilities except for the utility plant have been grouped under the heading "liquefaction process." Coal input to the liquefaction process was calculated on the basis of overall plant efficiency and annual capacity factor. The liquefaction process operates on a load factor of 90% and an efficiency of approximately 70%. This value was calculated on the basis of a heat value for syncrude of 5.8×10^6 Btu/bbl and a heat value for coal of 12,000 Btu/lb. The ratio of liquefier output to coal input yields the process efficiency. The operation of the utility plant at an efficiency of 35% reduces the overall plant efficiency to 70%.

The water requirements of the plant are defined in terms of consumptive water use. These water requirement values have been derived from information taken out of the technical literature.¹³ In many cases, technical estimates had to be scaled down to the requirements of a 50,000-bbld plant. The water requirements of the 300-MWe utility plant have been incorporated into the figure of 4.0×10^9 gal/year. The limestone resource requirement provides for the operation of the flue gas desulfurization unit in the utility plant. This value was scaled down from the figure given in Table H.2 for the 1000-MWe power plant.

Effluent releases from the liquefaction plant are also given in Table H.4. Gaseous emissions from the liquefaction plant have been distributed between the liquefaction process and the utility plant. Sulfur oxide releases from the liquefaction process result from the amount of coal sent to the gasifier and reactor minus the amount of sulfur which subsequently ends up in the syncrude. A sulfur recovery factor of 98% efficiency is applied to the resulting value. The releases of sulfur oxides from the utility plant are estimated from the sulfur input in tons per year and the 85% efficiency of the FGD unit. Oxides of nitrogen are produced by both the liquefaction process and the utility plant. Emissions from the liquefaction process originate from the process boilers while emissions from the utility plant were calculated in the same manner as for the 1000-MWe electric generating plant. Particulate releases from the liquefaction process are assumed to be zero, while particulate releases from the utility plant are calculated on the assumption that 80% of coal ash is fly ash and that the electrostatic precipitator operates at 99% efficiency. Solid wastes from the liquefaction process have not been characterized either in nature or volume. The solid wastes listed in Table H.4 are generated by the utility plant. Contributions of bottom ash account for 20% of the total coal ash. The fly ash component is that trapped by the electrostatic precipitator. Sludge is produced by the nonregenerable FGD unit. All solid waste calculations for the utility plant were based on scaled-down versions of the figures given in Table H.2 for the 1000-MWe plant. There are no liquid effluents shown in Table H.4. It is assumed that there will be no discharge of wastewater from the coal liquefaction plant.

Table H.4. Characteristics of a 50,000-bbld coal liquefaction plant

Plant inputs		Plant releases	
Coal		Gaseous emissions	
Liquefaction process	5.4×10^6 tons/year	Liquefaction process	
Utility plant	1.5×10^5 tons/year	SO _x	3.0×10^3 tons/year
		NO _x	1.3×10^3 tons/year
Water		Utility plant	
Consumptive	4.0×10^9 gal/year	SO _x	6.7×10^2 tons/year
		Particulates	1.9×10^2 tons/year
		NO _x	6.8×10^3 tons/year
Limestone	1.6×10^4 tons/year	Solid waste	
Land		Utility plant	
	1000 acres	Bottom ash	4.8×10^3 tons/year
		Fly ash	1.9×10^4 tons/year
		Sludge	3.5×10^4 tons/year

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