IRC. 1055

U.S. GEOLOGICAL SURVEY CIRCULAR 1055

Coal Resources Available for Development—A Methodology and Pilot Study

AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that are listed in various U.S. Geological Survey catalogs (**see back inside cover**) but not listed in the most recent annual "Price and Availability List" are no longer available.

Prices of reports released to the open files are given in the listing "U.S. Geological Survey Open-File Reports," updated monthly, which is for sale in microfiche from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices given below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

U.S. Geological Survey, Books and Open-File Reports
Federal Center, Box 25425
Denver, CO 80225

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained ONLY from the

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

U.S. Geological Survey, Map Distribution
Federal Center, Box 25286
Denver, CO 80225

Residents of Alaska may order maps from

Alaska Distribution Section, U.S. Geological Survey
New Federal Building - Box 12
101 Twelfth Ave., Fairbanks, AK 99701

OVER THE COUNTER

Books

Books of the U.S. Geological Survey are available over the counter at the following U.S. Geological Survey Public Inquiries Offices, all of which are authorized agents of the Superintendent of Documents:

- **WASHINGTON, D.C.**—Main Interior Bldg., 2600 corridor, 18th and C Sts., NW.
- **DENVER, Colorado**—Federal Bldg., Rm. 169, 1961 Stout St.
- **LOS ANGELES, California**—Federal Bldg., Rm. 7638,300 N. Los Angeles St.
- **MENLO PARK, California**—Bldg. 3 (Stop 533), Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**—503 National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**—Federal Bldg., Rm. 8105, 125 South State St.
- **SAN FRANCISCO, California**—Customhouse, Rm. 504, 555 Battery St.
- **SPOKANE, Washington**—U.S. Courthouse, Rm. 678, West 920 Riverside Ave.
- **ANCHORAGE, Alaska**—Rm. 101, 4230 UniversityDr.
- **ANCHORAGE, Alaska**—Federal Bldg, Rm. E-146, 701 C St.

Maps

Maps may be purchased over the counter at the U.S. Geological Survey offices where books are sold (all addresses in above list) and at the following U.S. Geological Survey offices:

- **ROLLA, Missouri**—1400 Independence Rd.
- **DENVER, Colorado**—Map Distribution, Bldg. 810, Federal Center
- **FAIRBANKS, Alaska**—New Federal Bldg., 101 Twelfth Ave.

Coal Resources Available for Development—A Methodology and Pilot Study

By JANE R. EGGLESTON, M. DEVEREUX CARTER, and JAMES C. COBB

A methodology for assessing available coal resources was developed and tested in a pilot study conducted on the Matewan 7.5-minute quadrangle, Kentucky

U.S. GEOLOGICAL SURVEY CIRCULAR 1055

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1990

Free on application to the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging in Publication Data

Eggleston, Jane R.
Coal resources available for development : A methodology and pilot study / by Jane R. Eggleston, M. Devereux Carter, and James C. Cobb. p. cm.—(U.S. Geological Survey circular ; 1055)
Includes bibliographical references.
Supt. of Docs. no. : I 19.4/2 : 1055
1. Prospecting. 2. Coal. I. Carter, M. Devereux. II. Cobb, James C. III. Title. IV. Series.
TN271.C58E34 1990 553.2'4'0973—dc20 89-600390

CONTENTS

FIGURES

TABLES

Coal Resources Available for Development—A Methodology and Pilot Study

By Jane R. Eggleston,[1] M. Devereux Carter,[1] *and* James C. Cobb[2]

Abstract

Coal accounts for a major portion of our Nation's energy supply in projections for the future. A demonstrated reserve base of more than 475 billion short tons, as the Department of Energy currently estimates, indicates that, on the basis of today's rate of consumption, the United States has enough coal to meet projected energy needs for almost 200 years. However, the traditional procedures used for estimating the demonstrated reserve base do not account for many environmental and technological restrictions placed on coal mining. A new methodology has been developed to determine the quantity of coal that might actually be available for mining under current and foreseeable conditions. This methodology is unique in its approach, because it applies restrictions to the coal resource *before* it is mined. Previous methodologies incorporated restrictions into the recovery factor (a percentage), which was then globally applied to the reserve (minable coal) tonnage to derive a recoverable coal tonnage. None of the previous methodologies define the restrictions and their area and amount of impact specifically. Because these restrictions and their impacts are defined in this new methodology, it is possible to achieve more accurate and specific assessments of available resources.

This methodology has been tested in a cooperative project between the U.S. Geological Survey and the Kentucky Geological Survey on the Matewan 7.5-minute quadrangle in eastern Kentucky. Pertinent geologic, mining, land-use, and technological data were collected, assimilated, and plotted. The National Coal Resources Data System was used as the repository for data, and its geographic information system software was applied to these data to eliminate restricted coal and quantify that which is available for mining. This methodology does not consider recovery factors or the economic factors that would be considered by a company before mining.

Results of the pilot study indicate that, of the estimated original 986.5 million short tons of coal resources in Kentucky's Matewan quadrangle, 13 percent has been mined, 2 percent is restricted by land-use considerations, and 23 percent is restricted by technological considerations. This leaves an estimated 62 percent of the original resource, or approximately 612 million short tons available for mining. However, only 44 percent of this available coal (266 million short tons) will meet current Environmental Protection Agency new-source performance standards for sulfur emissions from electric generating plants in the United States. In addition, coal tonnage lost during mining and cleaning would further reduce the amount of coal actually arriving at the market.

Manuscript approved for publication November 2, 1989.
[1]U.S. Geological Survey, Reston, VA 22092.
[2]Kentucky Geological Survey, Lexington, Ky.

INTRODUCTION

In the spring of 1986, a research project (pilot study) was undertaken by the U.S. Geological Survey (USGS), in cooperation with the Kentucky Geological Survey (KGS), to develop and test a methodology for determining the quantity of coal resources actually available for mining under current conditions. Impetus for the study came from the numerous energy forecasts projecting an increasing domestic dependency on coal in future years and from the lack of specificity in the current literature regarding the availability of coal for development. Conoco, in its 1986 "World Energy Outlook," predicted that about 25 percent of the U.S. energy supply will come from coal by the year 2000 (fig. 1). The Department of Energy's Energy Information Administration (EIA, 1988a) forecast that coal consumption would increase from 26.9 percent today to 37 percent of our domestic energy supply by the year 2000 (fig. 2). Without an adequate reserve base, these forecasts for coal consumption cannot be substantiated (fig. 3).

The reserve base, indicated by the shaded area on figure 3, is defined as that portion of demonstrated coal resources that can be mined economically at the time of determination. Assessing the reserve base is currently an activity of the EIA. Using coal resource data from the State geological surveys and the USGS, the EIA applies minable depth and thickness limits to determine the demonstrated

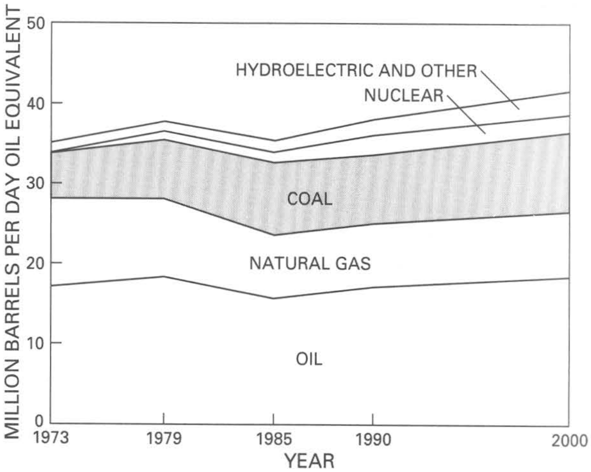

Figure 1. U.S. energy supply forecast to the year 2000 (Conoco, Inc., 1986).

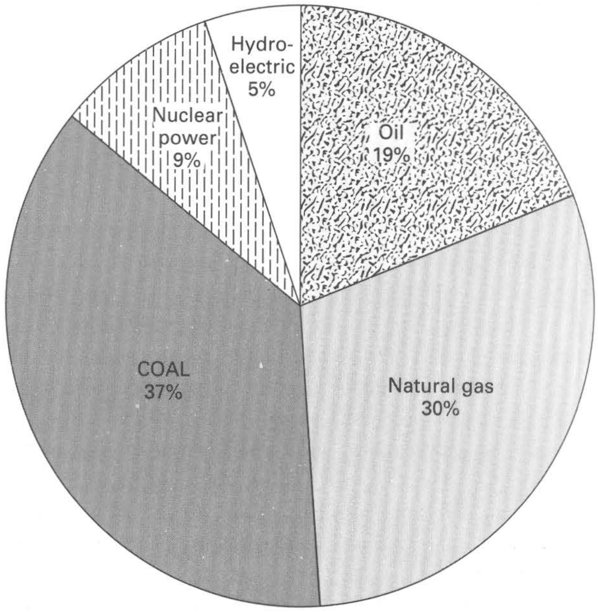

Figure 2. Domestic energy supply in the year 2000 (modified from EIA, 1988a).

reserve base (DRB), which is currently estimated to be about 475 billion short tons (EIA, 1988b). This is the figure upon which many energy forecasts have been based. Even if coal production increases markedly from its current level of a little over 900 million short tons per year, we should still have several hundred years of coal supply according to this current DRB figure. But how much of this coal *really* is available?

To determine the actual availability of coal for development, the USGS and KGS developed and tested a methodology that would provide greatly increased specificity to coal resource assessments. In addition to depth and thickness limitations to coal mining, other restrictions that effectively limit mining of coal were applied. In this study, we defined available coal as follows:

ORIGINAL COAL RESOURCES
minus
COAL MINED AND COAL LOST IN MINING
equals
REMAINING COAL RESOURCES
minus
COAL RESTRICTED BY LAND-USE CONSIDERATIONS
minus
COAL RESTRICTED BY TECHNOLOGICAL CONSIDERATIONS

Original coal resources are defined as the amount of coal, containing 33 percent or less ash, in the ground prior to production and under less than 6,000 ft of overburden. The coal beds are either 14 in or thicker for anthracite and bituminous coal or 30 in or thicker for subbituminous coal and lignite, in such form and amount that extraction is currently or potentially feasible (Wood and others, 1983). Coal mined and coal lost in mining is the quantity of coal that has been removed or "sterilized" by surface or underground mining. Remaining coal resources are defined as original resources less coal mined and coal lost in mining. Land-use restricted coal most likely will not be mined because surface features or structures would be disrupted by mining, and the integrity of the natural environment would be threatened, or the rights of the individual or community would be impacted. Technologically restricted coal most likely will not be mined because geologic or mining-related factors would negatively impact the economics or safety of a mine.

Land-use and technological restrictions vary regionally because of types of mining, regulatory variations, land-use differences, and geologic conditions. In addition, available coal can be designated as compliance or noncompliance coal, depending on whether or not it meets the Environmental Protection Agency's (EPA) new-source performance standards for sulfur emissions. According to EPA's requirements (CFR, 1987), compliance coal must release no more than 1.2 lb of sulfur dioxide per 1 million Btu when burned in powerplants.

In the development of the methodology, an optimal size for a study area was determined. This study area had to be small enough to allow for detailed delineation of coal geology, mined areas, and a variety of restrictions in a timely fashion but had to be large enough to be representative of a wider area. If the methodology proved successful, the USGS, in cooperation with Geological Surveys in other coal-bearing States, would propose to apply the methodology to additional study areas.

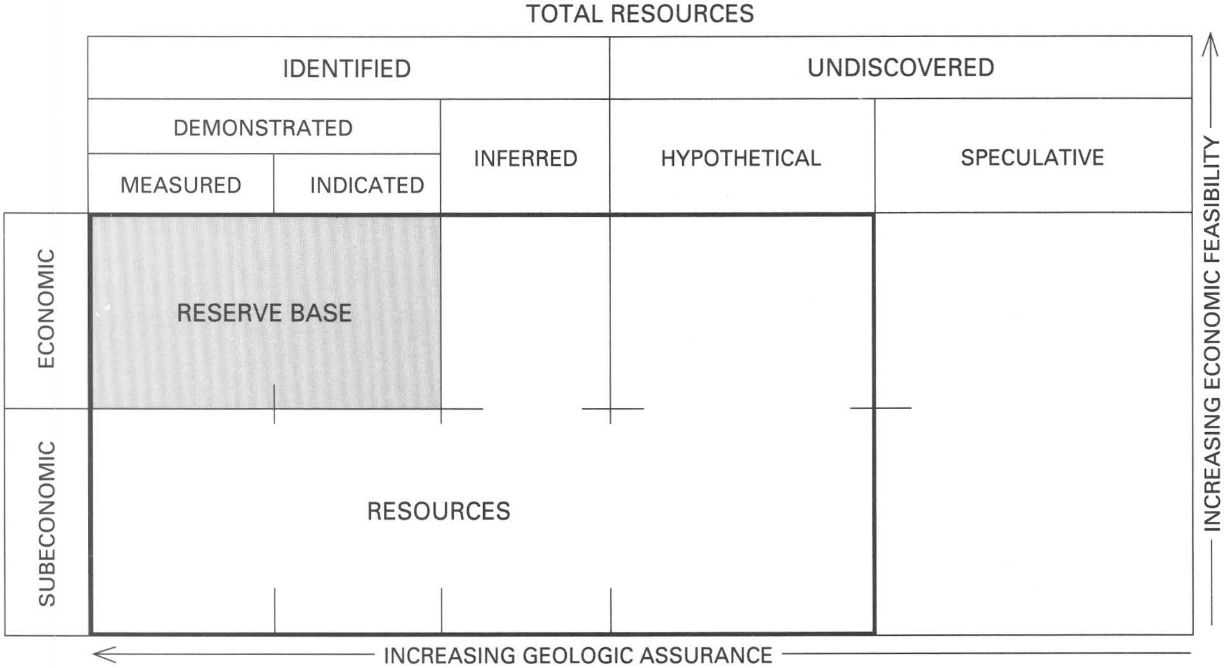

Figure 3. Resource classification system (modified from Averitt, 1975).

ACKNOWLEDGMENTS

The authors wish to thank the Kentucky Department of Mines and Minerals, the U.S. Office of Surface Mining Reclamation and Enforcement (Lexington, Ky., office), and the Kentucky Department of Natural Resources for help in defining and gathering the geologic, regulatory, and mining information used in this study. O.B. Davidson, N.K. Gardner, R.E. Sergeant, and S.J. Tewalt were valuable members of the project team in conducting the pilot study. We wish to thank K.J. Englund, N.K. Gardner, H.J. Gluskoter, S.P. Schweinfurth, and R.E. Sergeant for their thorough reviews of this manuscript.

GENERAL APPROACH

In developing a methodology for determining available coal resources, several steps were defined. These are (1) study area selection, (2) data collection and assimilation, and (3) resource estimation. The following sections detail the methodology that was developed for testing in a pilot study.

Area Selection

It might be preferable to study an entire region in the detailed fashion developed in this methodology. However, since we arbitrarily define a region in this study as containing multiple counties and usually several States or parts of States, the time, manpower, and costs required to conduct such a comprehensive study make this approach impractical. It is therefore crucial that the study areas selected be representative of larger areas, so that results can be extrapolated. If a region is divided into segments based on similarity of characteristics such as geology, mining practices, mining history, production patterns, and previous coal resource assessments, areas having similar characteristics can be defined for subsequent purposes of extrapolation.

Geologic conditions may vary throughout a region, and these conditions can be categorized. The stratigraphic position of coal beds in the area is significant, because coals represent a variety of depositional environments through geologic time. These different environments dictate the coal's physical and chemical characteristics, including lateral continuity, thickness, quality, and roof and floor rock types. Regions also vary with respect to the degree of folding and faulting. It is therefore necessary to categorize a region by its stratigraphic and structural features so that no significant geologic characteristics will be ignored in the course of the regional study. At least one study area should be located in each major geologic type area.

Mining practices also may vary within a region, often because of geologic characteristics. Because these variations will influence the restrictions required, mining practices should be categorized. For example, in areas that have gentle topography, strip mining is more prevalent, whereas in areas that have steep topography, contour mining and mountaintop removal are common. In some areas, longwall underground mining is common, whereas in others room-and-pillar is the norm. At least one study area should be located in each different mining area. In many instances, the mining areas and geologic type areas could be the same.

The extent of past and present mining within a region varies and should be categorized in a general manner. Likewise, the reserve base and production of the region should be categorized. Areas that have a larger reserve base and production must be given greater emphasis, although areas that have lesser reserves and production should be represented by study, too. The reserve base has been developed in a number of previous studies, and these published data will provide a relative idea of resource distribution throughout the region. Production figures are published also, usually annually.

Several possible methods of extrapolating the study results from smaller to larger areas that have similar characteristics exist. But it is probably most logical to take advantage of previous resource studies to accomplish this. Once the study is completed for one area, the results can be evaluated and compared to previous resource estimates to obtain percentages higher or lower than previous estimates. These percentages can then be applied to previous resource estimates for the surrounding area to develop an estimate for current available coal for the larger area. In this methodology, however, it is assumed that the previous resource estimates for both the study area and the larger area were conducted in the same fashion, with the same assumptions, level of detail, and geologic knowledge. In addition, of course, the previously discussed geologic and restrictive features must be similar in both the study area and the larger surrounding area. Geological features include lateral continuity of the coal beds, structure (folding, faulting, and dip), and mine-roof stability. Restrictive features include the land-use and technological parameters (as described in the "Introduction") that most impact coal availability. While this extrapolation process is less thorough than performing an intensive study throughout the entire region, it is a workable method that will provide valuable results in a reasonable period of time for a large area.

The size of the study area selected should be a workable size but should have enough variability and information to represent, together with other study areas in the region, a realistic cross section of the region. For the purposes of this study, a 7.5-minute quadrangle was deemed the optimum size for a study area, because it would allow us to apply the necessary detail to accomplish the task in a reasonable period of time. In addition, much of the geologic mapping in the Eastern United States has been done at this scale.

Data Collection and Assimilation

After a study area is selected, data needs must be defined, and the necessary data must be gathered and assimilated. Data needs are categorized in the following way: geologic considerations, past and present mining, land-use restrictions, and technological restrictions. Possible sources of data are shown in table 1. A good data base is the key to development of an assessment of available coal. Time spent talking with local specialists familiar with the area and reviewing appropriate literature is well spent. Supplementary data can be collected in the field when other sources are deemed to be inadequate.

Geologic considerations include coal-related information such as coal thicknesses and intervals, lateral extent of coal, outcrops and structure (folding, faulting, and dip), and coal quality. Because this information is the foundation upon which all subsequent restrictions are applied in this methodology, adequate time and effort are required to develop this comprehensive geologic data base.

For each coal bed in the study area, accurate locations of past and present underground and surface mines must be identified and plotted. In some cases, locations already have been plotted by State mining agencies or geological surveys. Even then, however, updating is often necessary. The U.S. Bureau of Mines maintains a microfilm library consisting of maps of abandoned undergound mines. In addition, State mining regulatory agencies have maps of recent surface and underground mines, because such maps are required for the mine permitting process. Topographic maps and air photographs also can be used to determine the location and extent of surface mines. Adits of underground mines often are shown on topographic maps, but in localities that have multiple closely spaced coal beds, mines cannot be assigned to a specific coal bed unless additional information is obtained. Also, the lateral extent of the underground mine cannot be determined from locations alone.

Land-use restrictions primarily impact surface mining, although a few may restrict underground mining also. The Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95–87) defined certain land uses that are protected from surface mining and (or) deep mining. These Federal requirements have now been incorporated into State regulations. State regulations vary but generally maintain the Federal requirements as a minimum. However, variances are given to many of the regulations. It is therefore vital to consider local practices when determining the impact of various land uses on mining in the study area.

The following land-use factors can restrict the mining of coal:

1. *Cemeteries.*—Surface mining cannot be conducted through a cemetery; the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) requests mine

Table 1. Sources of data for assessing coal availability

Types of data	State Geological Survey	U.S. Geological Survey	State mine regulatory agency	U.S. Office of Surface Mining	Air photographs	Topographic maps	Mining companies or engineers	U.S. Bureau of Mines	Mining associations	Historical societies	Field reconnaissance	U.S. Bureau of Land Management	U.S. and State Forest Services
Geology													
Coal bed thicknesses and intervals	×	×	×				×	×			×	×	
Coal outcrops	×	×			×		×				×	×	
Coal quality	×	×	×				×	×			×	×	
Structural features	×	×			×		×				×	×	
Past and present mining													
Surface	×		×		×	×	×				×	×	×
Underground	×		×		×	×	×	×			×	×	×
Land-use restrictions													
Oil and gas wells	×	×	×		×	×	×				×	×	×
Cemeteries			×		×	×	×				×	×	×
Streams		×	×	×	×	×	×				×	×	×
Residential public buildings			×	×	×	×	×				×		
Historic sites, public lands			×	×			×			×	×	×	×
Highways and railroads			×	×		×	×				×	×	×
Powerlines and pipelines					×	×	×				×	×	×
Federal lands			×	×	×	×	×				×	×	×
Endangered species habitats			×	×			×				×	×	×
Technological restrictions													
Surface mining:													
coal depth and thickness	×		×				×	×	×		×	×	
Underground mining:													
coal depth and thickness	×		×				×	×	×			×	
Proximity to mines			×				×	×	×			×	
Barrier pillars			×	×			×	×				×	
Roof of floor problems			×				×	×	×			×	
Structural problems	×	×			×		×	×				×	

operators to leave a 100-ft buffer around cemeteries. The locations of most cemeteries are shown on topographic maps.

2. *Streams, Lakes, and Reservoirs.*—Surface mining through small streams can be accomplished by rechanneling the streams. Streams that have a mean average flow of more than 5 ft^3/s are under the control of the U.S. Army Corps of Engineers, however, and should be considered a restriction on mining. Variances to mine across these streams are difficult to obtain. Streamflow records for streams in the study area can be obtained from the local USGS Water Resources Division offices or by direct measurements of the streams. Although more commonly impacting surface mining, streams and other water bodies restrict shallow underground mining because of the potential for subsidence hazards, which can cause flooding of the mine.
3. *Residences, Towns, and Public Buildings.*—Federal law prohibits surface mining within 300 ft of a private residence or public building. But individual homeowners may sign a waiver allowing the mining company to mine up to, or through, their house. Often a house is moved to a new location. Groups of houses and public buildings such as schools, town halls, and hospitals do, however, pose a restriction to surface mining. Only shallow underground mining would be restricted by the presence of towns and buildings, and this restriction is because of the possibility of subsidence.
4. *Historic Sites and Non-Federal Public Parks.*—Coal in public parks and historic sites cannot be mined, except in the extremely rare case in which all agencies responsible for managing these parks and sites

approve. Locations of parks and historical sites are usually shown on topographic maps, or they can be obtained from local public agencies.

5. *Highways and Railroads.*—Roads and railroads can be moved during surface mining, provided such action is cost effective and approved by the responsible agencies or companies. The one exception is federally funded highways, which cannot be mined through or moved for mining. A barrier of 100 ft must be left between the mine and highway.
6. *Powerlines and Pipelines.*—No specific laws prohibit mining through these features. Sometimes a 100-ft buffer is left, especially for major line networks, but other times operators move the lines or mine under powerlines and leave islands of coal at the posts. Therefore, some coal may be restricted, depending on local mining procedures and economics.
7. *Federal Lands.*—Surface mining is prohibited on lands within the boundaries of the National Park System, the National Wildlife Refuge System, the National System of Trails, the National Wilderness Preservation System, the Wild and Scenic Rivers System (including study rivers), National Recreation Areas, and areas designated as endangered species habitats. Mining is allowed on National Forest land but only if the mining will not interfere with the original purpose for which the land was set aside.
8. *Oil and Gas Wells.*—Oil and gas wells restrict both surface and underground mining. In this study, we consider the wells as land-use restrictions when they restrict surface mining and as technological restrictions when they restrict underground mining. A 200-ft buffer is commonly left around the wells, but this buffer zone is sometimes less if the exact location of the well is known. Oil and gas well locations are usually available from State geological surveys.

As herein defined, technological restrictions primarily impact underground mining. However, depth and thickness of a coal bed may be considered as technological restrictions to surface as well as underground mining. Technological restrictions are based on the limitations of mining safety, costs, and equipment. The following are some technological factors that can restrict mining.

1. *Coal-Bed Depth and Thickness.*—Technological factors can limit the minimum surface-minable coal-bed thickness because certain equipment does not have the flexibility to separate thin (generally 14 in or less) coal beds from the surrounding rock. Surface-mining depth is limited because certain equipment or combinations of equipment are not designed for deep pits. Most underground mining is limited to coal beds greater than 28 in thick because of equipment and manpower requirements; mines are generally within 1,000 ft of the surface because production costs increase with an increase in depth.
2. *Coal Beds too Close to Another Bed or Mine.*—Beds that are close (usually 40 ft or less vertically) to an abandoned underground mine or another coal bed that is more likely to be mined are restricted from mining (sterilized) because of safety concerns. In mining close to an abandoned or active mine in the same coal bed, a barrier of at least 100 ft is generally required for safety purposes.
3. *Geologic Conditions that Impact Mining.*—Unstable roof or floor rock can be a restriction if safety and cost factors adversely impact mining. If a coal bed is known to split, pinch out, or be faulted, it could be considered a restriction on mining, depending on local practices. Steep dip of the coal bed sometimes limits mining because the equipment is designed for relatively flat-lying beds. An exception is in areas such as the Anthracite region, where the mining technique is especially designed for steeply dipping beds.

In summary, technological factors can limit the minability of coal in a variety of ways. Because local mining practices and geologic conditions vary regionally, regional differences must be taken into account in quantifying available coal. Mining engineers working for local companies and regulatory inspectors, who regularly visit the mines and are familiar with local conditions, are a good source of additional information.

Coal quality can influence the marketability of coal and therefore the likelihood of mining particular coal beds. Because of EPA's sulfur emission standards for coal-burning powerplants, high-sulfur coal is not as marketable as low-sulfur coal. Other coal-quality factors, such as ash, moisture, and sodium and chlorine content, also have important effects on coal marketability. In southern West Virginia a few coal beds have high levels of inertinite macerals, which inhibit complete and rapid burning of the coal in power generation boilers. This coal-quality parameter restricts the coal as a competitive fuel source. Mine operators and coal marketing representatives usually have the best information on problems associated with coal quality, unique to the area, that impact marketability. State geological surveys have files of coal-quality data, and, if data are limited, they can be supplemented by collection and analysis of channel samples of coal beds in the study area.

Resource Estimation

Introduction

The three basic elements essential to coal resource calculations are (1) coal-bed thickness, (2) specific gravity of the coal, and (3) the size of the area to be included in the tonnage estimate. Thickness is determined by measurements from coal-bed exposures at the surface (outcrops), from boreholes, and in coal mines. The number and spacing of the thickness measurements are major determinants of the degree of reliability of the estimate. Specific gravity is a measure of the weight factor of a coal and may be determined from individual coal analyses in the area involved. This measurement is employed mainly for mine development studies. However, a table of the average specific gravity for each coal rank in the United States has been established and is generally used for large-area coal resource estimation in this country. For bituminous coal, the average specific gravity is 1.32, or 1,800 tons per acre-foot; this figure is used for coal availability studies in the central Appalachian region. Areal measurements in this study were accomplished by computer calculation of the digitized areas.

The methodology for coal resource calculations developed in this study follows the Coal Resource Classification System of USGS Circular 891 (Wood and others, 1983). The basic criteria set forth by Circular 891 were modified slightly for timeliness in this study and are as follows.

1. Only coal in beds greater than or equal to 14 in thick is included as a resource. Coal in a bed less than 14 in thick is excluded.
2. Coal resource tonnages are reported in thickness increments of either 14 to 28 in or greater than 28 in.
3. Three overburden categories are reported: 0 ft to surface-minable limit, surface-minable limit to 1,000 ft, and greater than 1,000 ft. Surface-minable limits may be 0 to 100, 0 to 200, or 0 to 300 ft, whichever would most closely follow local practice. The remainder are considered potential underground-minable coals.
4. Coal resource estimates are reported in the following categories of assurance or reliability: measured (including coal 0 to 0.25 mi from point of thickness measurement), indicated (0.25 to 0.75 mi), inferred (0.75 to 3 mi), and hypothetical (greater than 3 mi).

Computer Resource Calculations

The initial steps required in calculating resources for this study include collection of data points for coal thickness, elevation, and quality parameters (where available); correlation of beds; determination of the approximate specific gravity; selection and delineation of the land-use and technological restrictions; and preparation of outcrop maps. Once these initial steps are completed, data entry begins. Data entry is by far the most time-consuming aspect of the study, but it is essential that data be entered correctly and stored in clearly documented fields. All subsequent work by a variety of users derives from this basic data base.

The point source data, including coal-bed thickness, elevation, location, lithology, and chemistry, are digitally recorded and stored in their appropriate stratigraphic and geochemical data bases. The coal-bed outcrop, the mined areas, and most of the land-use and technological restrictions are drawn on base maps, and each is digitized, labeled, and stored in its individual data base. Once the data have been entered, checked for errors made during entry, and corrected, the user may begin to generate derivative maps. Data-point maps are plotted to display the number of points and spread of the basic information. Gridded files of coal thickness, structure, and quality are generated, and the isopachs, structure contours, and isopleths of chemical values are plotted. The computer-drawn lines may then be modified, if necessary, to follow the user's interpretation of the thickness, elevation, and chemical character of the coal.

The depth of coal from the surface may be generated from a file of digital surface elevations. The National Mapping Division of the USGS has produced Digital Elevation Models (DEM's) covering about one-third of the United States. Fortunately, DEM's are available for most of the Appalachian basin. When the DEM is used, computer grid-to-grid subtraction of the elevation at the top of the bed from the surface elevation creates a grid of the overburden, which can be contoured to derive the depth-of-burial (overburden) lines.

Once coal thickness and overburden maps have been generated, individual lines (14- and 28-in coal-bed thickness, 200- and 1,000-ft overburden) can be selected and stored for future use.

As previously stated, the areas covered by land-use restrictions and some of the technological restrictions may be plotted on base maps and digitized. Most of the areas affected by technological restrictions, however, are readily generated by the computer. Barrier pillars of coal, left for safety purposes around active or abandoned coal mines, may be created as buffers at the required distances from the digitized boundaries of the mine. For underground mining, the interburden between beds is determined through grid-to-grid subtraction of the top of the lower bed from the base of the upper bed. Where the two beds occur within less than the restrictive distance, a determination is made as to which of the two coals would most likely be mined, largely based on coal thickness. These restriction lines are saved and stored with the other computer-derived restrictions for coal-bed depth and thickness.

At this point, the user has all of the line files necessary for coal resource calculation: outcrop, coal-bed thickness, overburden thickness, surface and deep mines, land-use and technological restrictions, and parameters for quality. Given the weight factor, the computer will then calculate the amount of original, mined and lost in mining, restricted, and available coal resources for each coal bed in the prescribed thickness and overburden categories.

First, the original coal resource is calculated by thickness and overburden categories to quantify all of the coal in the ground prior to mining and prior to application of restrictions. Next, the resources are calculated for the surface and deep mines and subtracted from the original resource to determine the amount of coal left in the ground after mining—the remaining resource. Each of the land-use and technological restrictions is then combined individually with the remaining coal resource to ascertain the amount of coal that will be restricted from future mining by each type of constraint.

Many of the restrictions overlap one another, as is the case with towns/streams, thin interburden, and previous mining above or below a coal bed. Therefore, to avoid duplication of restrictions before the available resource is calculated, all of the land-use restrictions must be combined into one land-use restrictions file, and, likewise, all of the technological restrictions must be combined into one technological restrictions file for each coal bed. Care must be taken also not to overlap or duplicate land-use and technological restrictions, especially in the surface-minable area. The resultant restriction files are finally excluded from the remaining coal resource to derive the amount of coal resource available for development in each of the prescribed thickness and overburden categories.

While noncompliance with respect to sulfur dioxide potential is not considered a restriction to mining for the coal availability studies, an estimate of compliance coal was included in this study because it is a factor in determining marketability for most of the power-generating coals in the central Appalachian region.

When the original, remaining, available, and available compliance coal tonnages have been determined for the study area, these results can be related to previous estimates and extrapolated to the larger, similar area defined earlier in the study when the study area was selected.

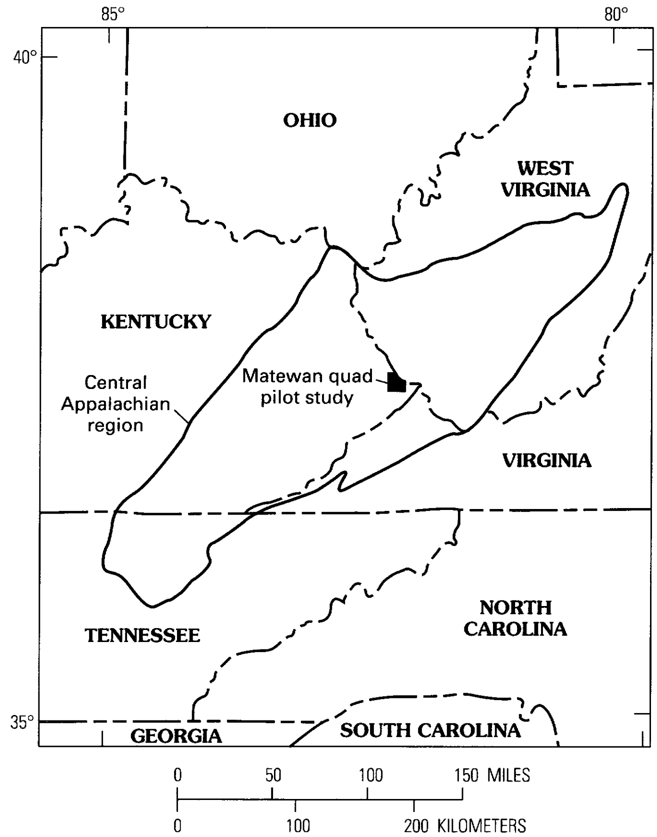

Figure 4. Location map of the pilot study area, Matewan quadrangle, central Appalachian region.

MATEWAN QUADRANGLE PILOT STUDY

Once a methodology had been developed for assessing available coal resources, a pilot study was conducted to apply and test this methodology. The study was a cooperative effort between the USGS and the KGS. The central Appalachian region, which includes eastern Kentucky, was chosen as a focal point because coal production has been historically high for this region and industry has a great deal of interest in this area. The 7.5-minute quadrangle was determined to be the optimum size for study, and the Matewan quadrangle (fig. 4) was selected for several reasons. Located on the eastern edge of Pike County, Ky., this quadrangle is fairly representative of its surrounding area, having low population density, many coal beds, and intensive mining. The quadrangle was selected also because most of its surface and underground mine maps already had been compiled.

Data Sources

The geology of the Matewan quadrangle has been studied by a number of researchers. Key reports used in developing the coal geology for this pilot study included the 1:24,000-scale geologic quadrangle map by Trent (1965), KGS's Energy Resources Series (Brant and others, 1983), and coal thickness (Kentucky Geological Survey, 1986) and coal quality (Currens, 1986; Currens and others, 1987) reports. KGS geologists identified 21 coal beds as being potentially minable. Of the 21 beds, some had more data available than others. The amount of data available is usually related to the degree to which coals have been economically important. Eight of the coal beds have been mined underground to some extent, and eight have been surface mined. All of the coal beds considered in this study are from the Pennsylvanian Breathitt Formation (fig. 5). The topography of the area is rugged and steep, typical of the central Appalachian region. Consequently, most of the coal beds are exposed at the surface and thus are accessible for surface and underground mining.

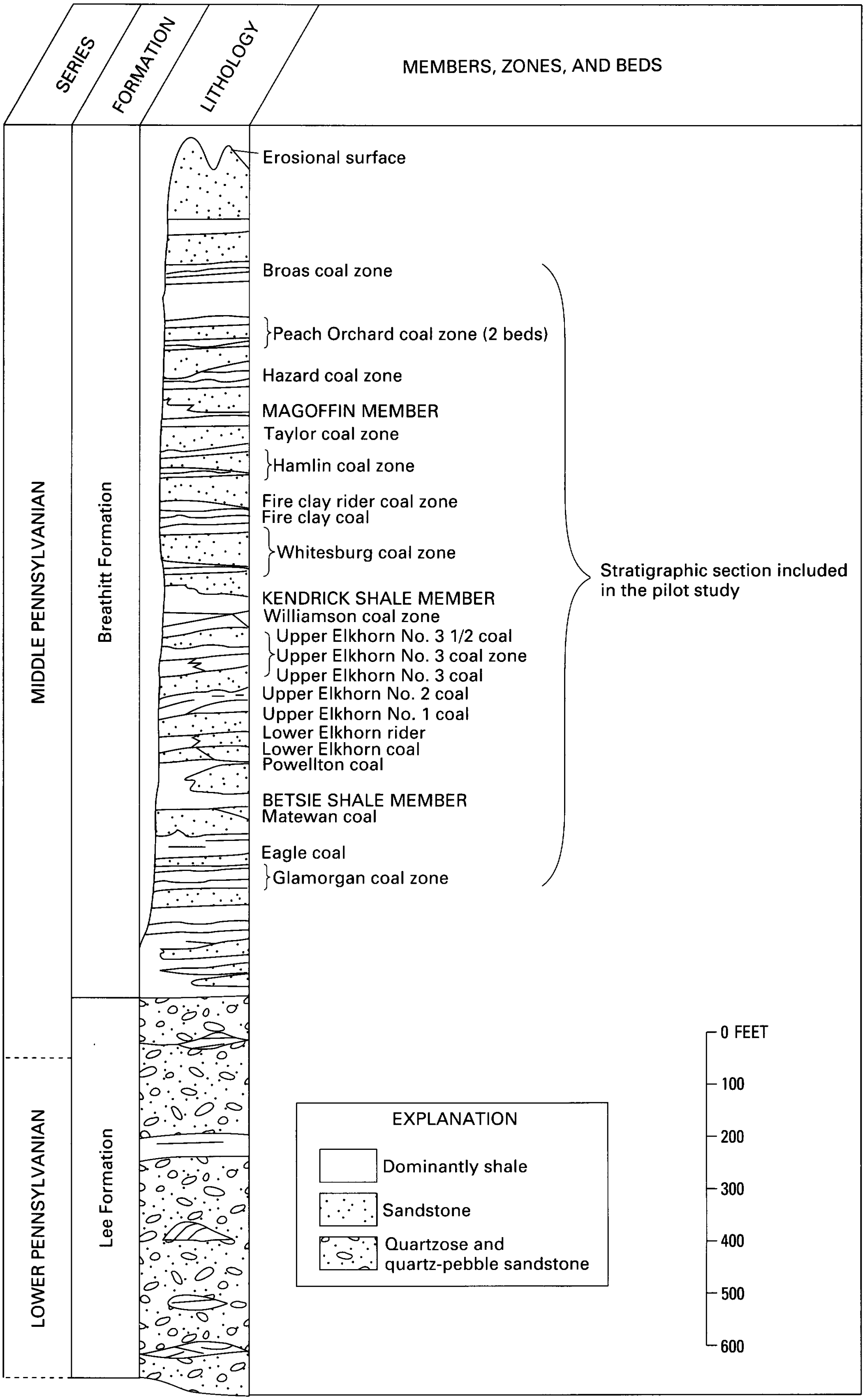

Figure 5. Stratigraphic column for the Matewan quadrangle pilot study (modified from D.R. Chesnut, Jr., Kentucky Geological Survey, written commun., 1987).

Abandoned and active underground mines were located and plotted in a cooperative effort between the Kentucky Department of Mines and Minerals (KDMM) and the KGS. Mined areas were located and plotted on the Matewan quadrangle, with mined coal beds being noted. In some cases, the mining companies had given coal beds names that were different from the accepted KGS bed nomenclature; therefore, an effort was made to properly correlate the mined beds with the KGS nomenclature. The mines were located with the help of records from the KDMM and the Kentucky Division of Surface Mining, aerial photography, and verbal communications with mine operators and regulatory officials. These mines were also identified as to the coal bed mined.

KGS and USGS geologists met with many local regulators, mining engineers, and consultants to determine the restrictive parameters that should be applied to the Matewan quadrangle. Some of the land-use restrictions were outlined under the Kentucky Natural Resources and Environmental Protection Cabinet Document 405 KAR 24:040, entitled "Permit Application Review," and the Kentucky Revised Statutes 350.465 and 350.610, which define Kentucky's surface mining regulatory program. Also, the Lexington regional office of the OSM was helpful in describing potential variances to regulations and their likelihood of being granted. If the granting of a particular variance is commonplace, the restriction was not considered in this study. In addition, information pertaining to potential nonregulatory restrictions (for example, powerlines or pipelines) and depth and thickness limits of a coal bed was obtained from State agencies including the Kentucky Natural Resources and Environmental Protection Cabinet, the Kentucky Department for Surface Mining Reclamation and Enforcement, and the KDMM.

Methodology

Computer methods were used to enter, store, generate, and manipulate the information concerning thousands of minute locations and to perform the repetitive combinations and calculations involved in the project. The USGS has developed the National Coal Resources Data System (NCRDS) as the master data base for coal resource information. NCRDS maintains a data base manager (PACER) (Cargill and others, 1976) and graphics programs (GARNET) (Olson, 1977) to access and manipulate the data for coal resources assessment. GARNET programs calculate and tabulate coal resources according to the specifications of USGS Circular 891. Therefore, the NCRDS formats and software were selected for the coal availability studies.

Data for the Matewan quadrangle were compiled during a recent coal resource assessment study (Brant and others, 1983) and were transferred to the NCRDS format and data base with ease. KGS geologists digitized coal outcrops of the 21 beds identified for study and digitized the mine map data acquired from the KDMM.

Four of the land-use restrictions (powerlines, pipelines, streams, and towns) were plotted on scale-stable base maps and digitized by the KGS. Cemeteries and oil and gas wells were digitized as points, and GARNET created the buffers around them. All of the boundary lines for technological restrictions were generated by GARNET. The restrictions applied to the Matewan quadrangle are as follows:

Restrictions	Criteria
	Land-use
Surface mining:	
Powerlines	100-ft buffer.
Pipelines	100-ft buffer.
Cemeteries	100-ft buffer (a GARNET-generated 300-ft by 300-ft square around center of cemetery was used).
Oil and gas wells	a 200-ft by 200-ft square around well site was used.
Major streams	100-ft buffer if flow greater than 5 ft^3/s.
Towns	300-ft buffer.
Underground mining:	
None	
	Technological
Surface mining:	
Too thin	less than 14 in is resource cutoff.
Too deep	greater than 200 ft.
Underground mining:	
Too thin	less than 28 in.
Too deep	greater than 1,000 ft.
Deep mine barrier pillars (between mines, for safety)	50-ft buffer zone around active or abandoned mines.
Deep mining too close above or below	less than 40 ft of separation.
Thicker beds too close above or below	less than 40 ft of separation.
Oil and gas wells	200-ft by 200-ft square around well site.

A conflict appeared in reporting potential overlapping land-use and technological restrictions in the 0- to 200-ft overburden category. For this study, the decision was made that future mining at less than 200 ft of overburden was most likely to be surface mining, so that only those restrictions applicable to surface mining were applied to the 0- to 200-ft category.

After all of the Matewan data were transmitted to the USGS and entered into NCRDS, all computer searches, manipulations, combinations, resource calculations, and tabulations were performed by the USGS in close communication with the KGS. USGS personnel ran computer programs to test and develop the methodology and applicability of NCRDS software to parameters for a coal availability study. In fact, methodologies were modified and GARNET and other NCRDS programs were enhanced frequently as the project progressed.

PACER searches of the stratigraphic data base extracted only the coal within each coal bed, excluding partings and other noncoal lithologies. Coal thickness and elevation files were created for each of the 21 coal beds. The data points were displayed and gridded, and isopach and structure contour lines were plotted. Where necessary, interpretive points were added and incomplete coal thickness data deleted to derive reasonable coal thickness and structure depictions. The 14- and 28-in isopach lines were stored as boundary lines for coal thickness. The bed elevation grids were stored for subsequent combination with a grid file of the surface topography to derive overburden and for grid-to-grid operations to calculate interburden intervals between the coal beds.

The DEM for the Matewan 7.5-minute quadrangle was acquired from the National Mapping Division of the USGS. This model provided a grid with 60-m spacing of the surface elevations that, when combined with the top-of-coal elevation grid for each coal bed, supplied the overburden categories (200 and 1,000 ft) required as overburden criteria for each coal bed.

A grid interval of 0.03728 mi (approximately 43,000 grid nodes in the Matewan quadrangle) was selected for use in resource calculation and is recommended for future coal availability studies. This interval corresponds to the 60-m (approximately 200-ft) grids of the DEM's as utilized in GARNET. The GARNET resource program subdivides each grid cell into 16 segments. A 200-ft grid interval is thereby subdivided into 50-ft squares to ensure that the smallest boundaries (the 50-ft barrier pillars) would not be excluded from the resource computations.

GARNET programs generated the combinations of coal thickness lines (isopachs), overburden and interburden lines, outcrops, surface and underground mines, and each of the land-use and technological restrictions. Several thousand different combined areas were created, and more than 1,000 were used in coal resource calculations.

Original coal resources, coal mined and lost in mining, remaining coal resources, individual restrictions, and available coal resources were all calculated as a check on the methodology. However, only two of the first three and one of the last two must be calculated, so we recommend that coal mined and lost in mining, coal remaining, and individual restrictions should be calculated. The original resource may be derived from the sum of the two categories "coal mined and lost in mining" and "remaining coal resources." Available coal resources is the result when the restricted coal is subtracted from the remaining coal resources.

Enough chemical data were available in the KGS computer files to generate sulfur isopleth lines for most of the 21 beds. The amount of available coal meeting current compliance standards was then calculated for the Matewan quadrangle.

Results

The methodology was repeated for each of the 21 coal beds. Figures 6–10 are a series of maps depicting the areas affected by restrictions on one bed, the Upper Elkhorn No. 2. Figure 6 shows the original, posterosional extent (shaded) of the Upper Elkhorn No. 2 coal bed in the Matewan quadrangle, Ky. The white area indicates an absence of this coal bed. As additional restrictions were applied to the Upper Elkhorn No. 2, more and more of the coal bed was eliminated from consideration. On figure 7, portions of the coal bed that have been removed by underground and surface mining are shown. Land-use restrictions have been added on figure 8. These include powerlines, pipelines, gas and oil wells, cemeteries, towns, and large streams, all with buffer zones around them. All of these land-use restrictions, except for oil and gas wells, apply only to surface mining. Technological restrictions affect a large portion of the Upper Elkhorn No. 2 coal, as shown on figure 9. These restrictions apply only to underground-minable coal and include (1) portions of the coal bed that lie less than 40 ft above or below an abandoned mine or a coal that we judged would be more desirable to mine, (2) deep-mine barrier pillars, (3) buffer zones around oil and gas wells, (4) areas where the coal lies more than 1,000 ft below the surface, and (5) areas where the coal is too thin (less than 28 in thick). Figures 10*A* and 10*B* illustrate the results, after all mined and restricted coal was eliminated. Coal available for surface mining was limited to that which is less than 200 ft deep and 14 in or more thick; this available coal is shown as the shaded area in figure 10*A*. Coal available for underground mining is shown as the shaded area in figure 10*B*. Figure 11 summarizes the results of the Upper Elkhorn No. 2 resource analysis. Of the 92 million short tons of coal remaining today in the Upper Elkhorn No. 2 coal bed, 28 million short tons (30 percent) are estimated to be available for mining, most of which is considered to be surface minable.

A similar methodology was applied to the other 20 coal beds included in the Matewan quadrangle pilot study. Results for all 21 coal beds in the quadrangle are presented in table 2. Figure 12 summarizes the results in pie-chart format, showing resource results by percentage of the original 986.5 million short tons of coal. Most of the mined coal was removed by underground mining (92 percent).

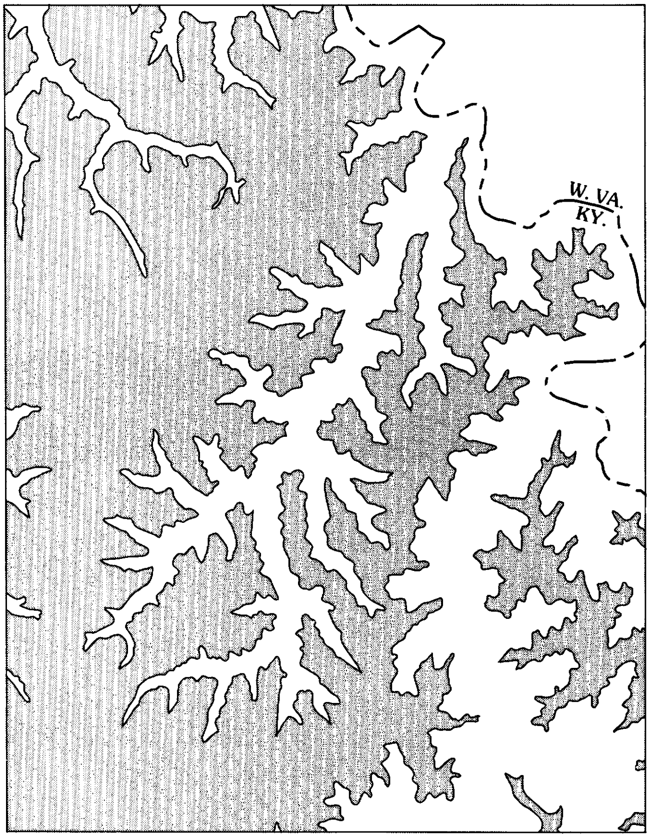

Figure 6. Original occurrence of the Upper Elkhorn No. 2 coal bed (shaded) in the Matewan quadrangle study area.

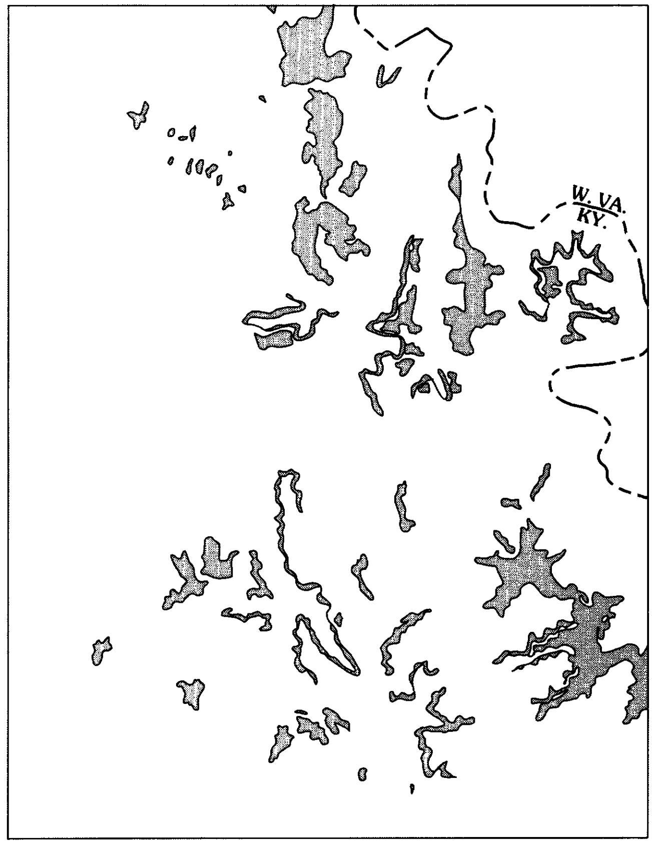

Figure 7. Mined areas (shaded) of the Upper Elkhorn No. 2 coal bed, Matewan quadrangle study area.

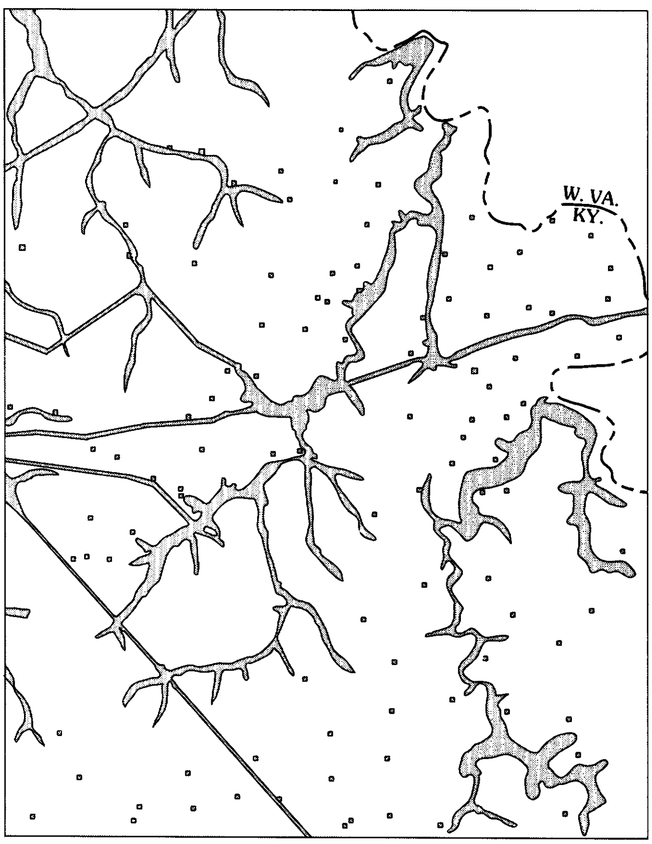

Figure 8. Land-use restrictions (shaded) to mining the Upper Elkhorn No. 2 coal bed, Matewan quadrangle study area.

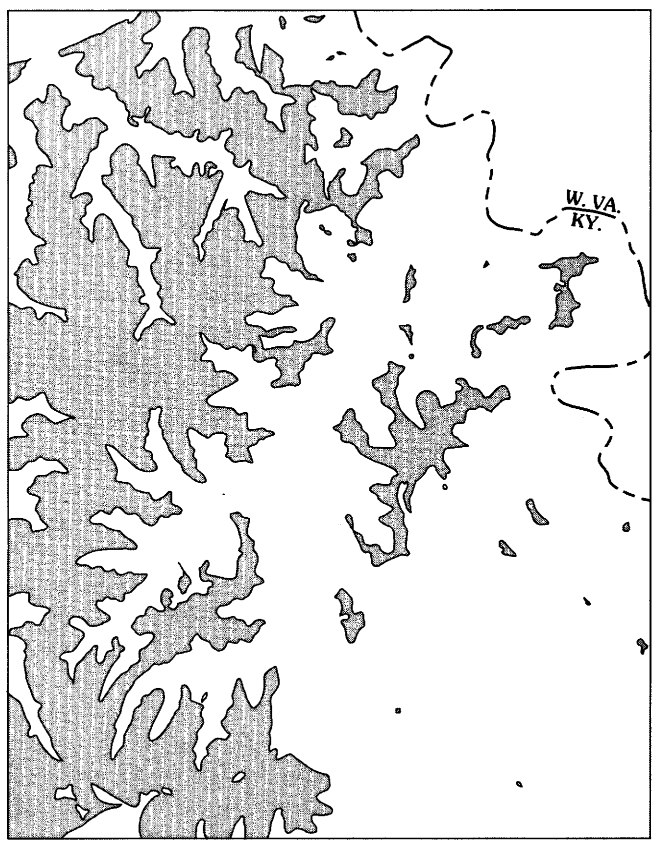

Figure 9. Technological restrictions (shaded) to mining the Upper Elkhorn No. 2 coal bed, Matewan quadrangle study area.

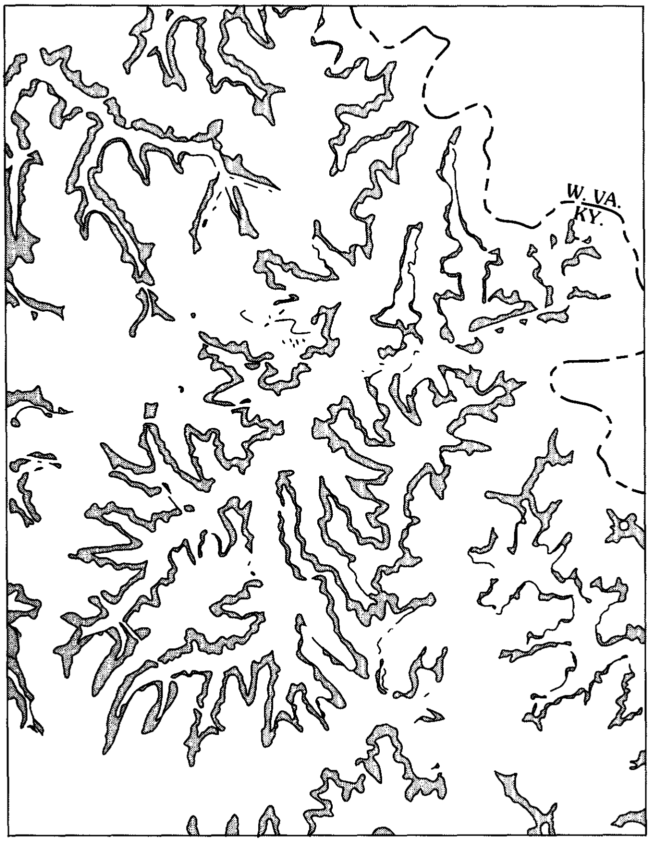

Figure 10*A*. Available surface-minable resources (shaded) of the Upper Elkhorn No. 2 coal bed, Matewan quadrangle study area.

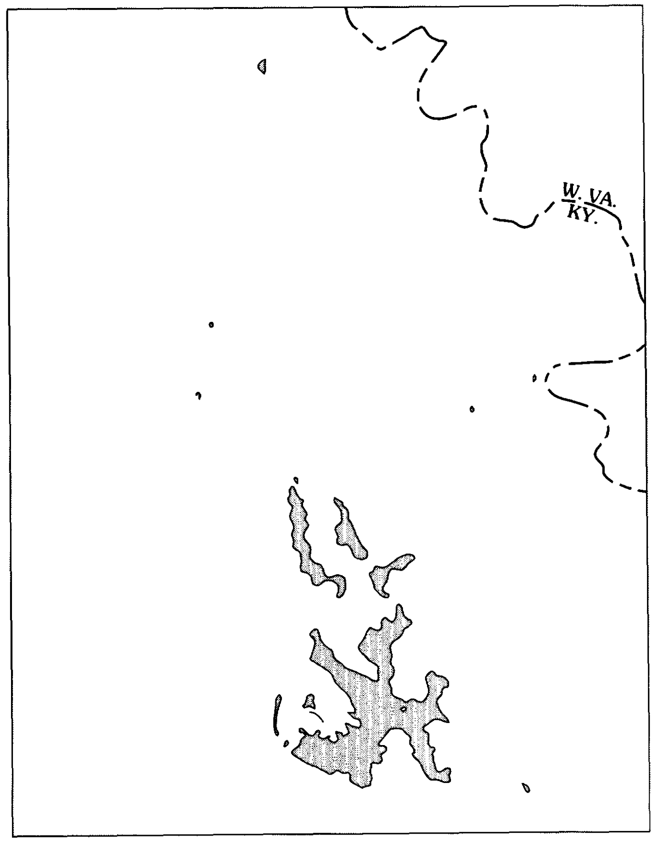

Figure 10*B*. Available underground-minable resources (shaded) of the Upper Elkhorn No. 2 coal bed, Matewan quadrangle study area.

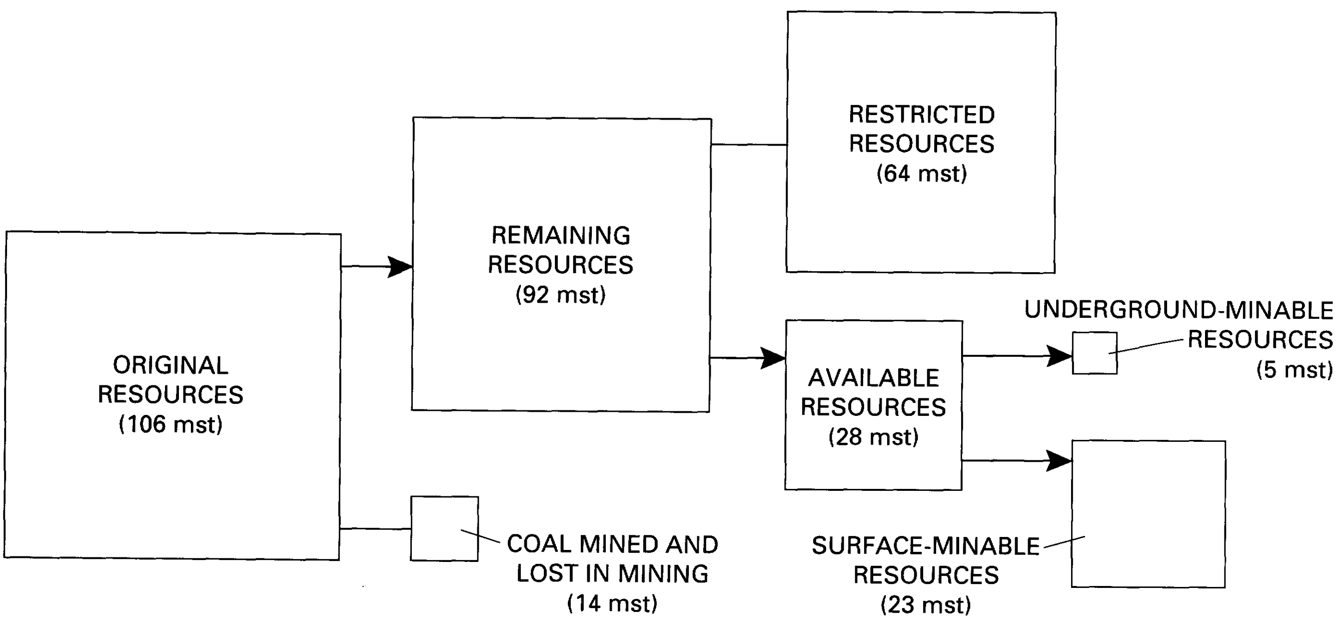

Figure 11. Resource summary of the Upper Elkhorn No. 2 coal bed, Matewan quadrangle study area. mst, millions of short tons.

Table 2. Coal resource study summary, Matewan quadrangle
[Million short tons]

ORIGINAL COAL	986.5
Coal mined and lost in mining:	
Mined underground	117.6
Surface mined	10.7
Total mined	128.3
REMAINING COAL	858.2
Coal restricted by land use:	
Streams	6.6
Powerlines	4.4
Pipelines	3.5
Towns	1.9
Oil and gas wells	.7
Cemeteries	.5
Total restricted by land use	17.1*
Coal restricted by technology:	
Bed is less than 28 in thick	123.4
More minable coal bed is within 40 ft above or below	86.2
Active or abandoned mine is within 40 ft above or below	21.8
Barrier pillars adjacent to previous mines	3.9
Bed is deeper than 1,000 ft	1.9
Oil and gas wells	.5
Total restricted by technology	228.0*
AVAILABLE COAL	613.0
AVAILABLE COMPLIANCE COAL	267.0

*Not necessarily a sum. Calculated separately to avoid double counting of overlapping restrictions.

Table 3. Land-use restrictions to surface mining, Matewan quadrangle
[Expressed as percentages of total]

Streams	38
Powerlines	25
Pipelines	19
Towns	11
Oil and gas wells	4
Cemeteries	3
Total: 17.1 million short tons (2% of original coal)	

Land-use restrictions play a very minor role in limiting surface mining, restricting only 2 percent of original coal. Of the land-use restrictions considered, major streams (flow greater than 5 ft^3/s) restrict the most coal (38 percent) (table 3). Of the 23 percent of original coal restricted by technological parameters, coal beds that are too thin (less than 28 in) contribute the most to restricting coal from being mined underground (table 4). Finally, 613 short tons of coal (62

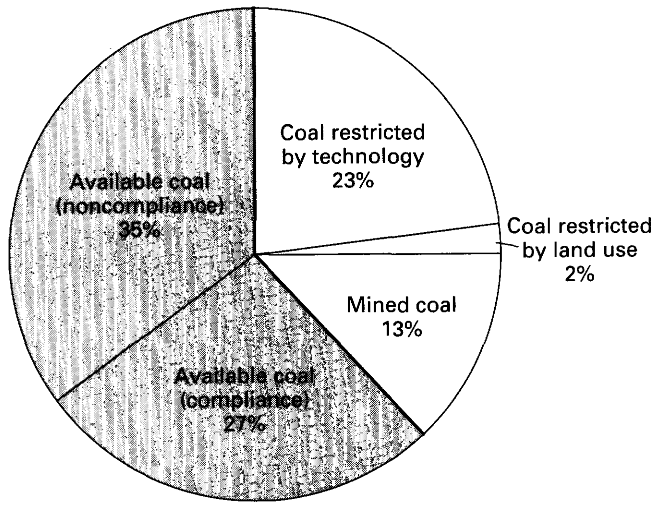

Figure 12. Results of the pilot study of the coal resources in the Matewan quadrangle. Restricted, mined, and available coal are shown as a percentage of the original coal resources

Table 4. Technological restrictions to underground mining, Matewan quadrangle
[Expressed as percentages of total]

Bed is less than 28 in thick	51.9
More minable coal bed is within 40 ft above or below	36.3
Active or abandoned mine is within 40 ft above or below	9.2
Deep mine barrier pillars adjacent to previous mines	1.6
Beds deeper than 1,000 ft	.8
Oil and gas wells	.2
Total: 228 million short tons (23% of original coal)	

percent of original coal) in the Matewan study area are available for mining, 53 percent of which is available for underground mining and 47 percent for surface mining. If coal quality factors are considered, only 27 percent of the original coal is available for mining and meets EPA compliance standards.

Other Limiting Factors

Other factors may limit the availability of coal even further. For example, in many situations mining could be inhibited or totally restricted by localized geologic problems such as coal-bed discontinuities or mine roof problems. Economic factors may further limit coal availability. Many mine costing models incorporate financial factors to determine the amount of coal that could be mined at various costs. Agencies such as the Electric Power Research Institute (EPRI, 1981) and the U.S. Department of Energy

(EIA, 1982) have developed mine costing models, as have many mining companies. These models could be applied to the results of this study to determine the impact of the economics of mining coal on the quantity of available coal that might actually be currently minable or minable at a given price.

In this study, available coal is still coal "in the ground," not the quantity of coal that actually reaches the market. Prior to shipment, coal is lost in mining and in cleaning. In general, approximately 50 percent of available coal may be lost during underground mining (depending on the mining method used), 10 percent during surface mining, and 10 percent or more during coal cleaning (when required). When these recovery factors are applied to the estimated 613 million short tons of available coal in the Matewan quadrangle, it becomes evident that a significantly smaller amount of coal will actually arrive at the market.

SUMMARY

The methodology developed to determine available coal resources was applied to the Matewan 7.5-minute quadrangle, Pike County, Ky. During the pilot study, some plans and expectations were revised after mining engineers and regulatory officials were consulted. After a number of difficulties were worked out in the computer programs and in the project in general, some "streamlining" of the original methodology was accomplished, and the methodology is now available for additional studies. While results from the Matewan quadrangle are useful, it is estimated that the methodology must be applied to approximately 15 to 20 additional 7.5-minute quadrangles in the central Appalachian region before meaningful results for the entire region (fig. 4) can be obtained. However, on the basis of these initial studies, it appears that the quantity of coal available for mining is considerably less than the total remaining resource. For the Matewan quadrangle, technological restrictions appear to be the most critical limiting factor on coal availability.

To quantify the Nation's available coal resources—particularly the amount of available low-sulfur (compliance) coal resources—investigations must be conducted in coal regions throughout the United States. Results of this continuing research could have far-reaching implications for U.S. coal policy and energy planning.

REFERENCES CITED

Averitt, P., 1975, Coal resources of the United States, January 1, 1974: U.S. Geological Survey Bulletin 1412, 131 p.

Brant, R.A., Chesnut, D.R., Frankie, W.T., and Portig, E.R., 1983, Coal resources of the Big Sandy District, Kentucky: University of Kentucky Institute for Mining and Minerals Research, Energy Resource Series, 47 p.

Cargill, S.M., Olson, A.C., Medlin, A.L., and Carter, M.D., 1976, PACER; data entry, retrieval, and update for the National Coal Resources Data System (Phase I): U.S. Geological Survey Professional Paper 978, 107 p.

Code of Federal Regulations (CFR), 1987, Parts 53–60: Washington, D.C., U.S. Government Printing Office, v. 40, p. 255–257.

Conoco, Inc., 1986, World energy outlook through 2000: Wilmington, Del., Coordinating and Planning Department, 11 p.

Currens, J.C. , 1986, Coal-quality data for the Eastern Kentucky Coal Field: Kentucky Geological Survey, Open-File Report, 104 p.

Currens, J.C., Bragg, L.J., and Hower, J.C., 1987, Analysis of coal samples from the Big Sandy District, Kentucky: Kentucky Geological Survey, Ser. 11, Information Circular 20, 421 p.

Electric Power Research Institute (EPRI), 1981, Coal mining cost model: Palo Alto, Calif., EPRI EA–1273, 4 v.

Energy Information Administration (EIA), 1982, Documentation of the Resource Allocation and Mine Costing (RAMC) model: Washington, D.C., U.S. Department of Energy, Energy Information Administration Report DOE/NBB–0020, 160 p.

———1988a, Annual energy outlook 1987 with projections to 2000: Washington, D.C., U.S. Department of Energy, Energy Information Administration Report DOE/EIA–0383(87), 66 p.

———1988b, Coal production—1987: Washington, D.C., U.S. Department of Energy, Energy Information Administration Report DOE/EIA–0118(87), 176 p.

Kentucky Geologic Survey, 1986, Coal-thickness data for the Big Sandy District, Kentucky: Kentucky Geological Survey, Open-File Report, 212 p.

Office of Surface Mining Reclamation and Enforcement, 1988, Public Law 95–87 (includes all revisions through June 1, 1988): 175 p.

Olson, A.C., 1977, Graphic analysis of resources by numerical evaluation techniques (GARNET): Computers & Geosciences, v. 1, p. 539–545.

Trent, V.A., 1965, Geology of the Matewan quadrangle in Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–373, 1:24,000 scale.

Wood, G.H., Jr., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations, as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7.5- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7.5-minute quadrangle photogeologic maps on planimetric bases that show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

"Publications of the Geological Survey, 1879–1961" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the Geological Survey, 1962–1970" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the U.S. Geological Survey, 1971-1981" may be purchased by mail and over the counter in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only.

"Price and Availability List of U.S. Geological Survey Publications," issued annually, is available free of charge in paperback booklet form only.

Selected copies of a monthly catalog "New Publications of the U.S. Geological Survey" are available free of charge by mail or may be obtained over the counter in paperback booklet form only. Those wishing a free subscription to the monthly catalog "New Publications of the U.S. Geological Survey" should write to the U.S. Geological Survey, 582 National Center, Reston, VA 22092.

Note.—Prices of Government publications listed in older catalogs, announcements, and publications may be incorrect. Therefore, the prices charged may differ from the prices in catalogs, announcements, and publications.