COAL RESOURCE ASSESSMENTS: CALCULATING RESOURCES BY GIS AT THE USGS

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INTRODUCTION

Coal production in the United States during 1997 was greater than in any prior year (EIA, 1998a). This increase of 2.4 percent over the previous year continued a fairly regular rate of average annual increase in coal production of 2.7 percent that began in 1961 (figure 1). The trend is continuing, and through the first 11 months of 1998 the coal production was 2.5 percent greater than during the equivalent period in 1997 (EIA, 1998b).

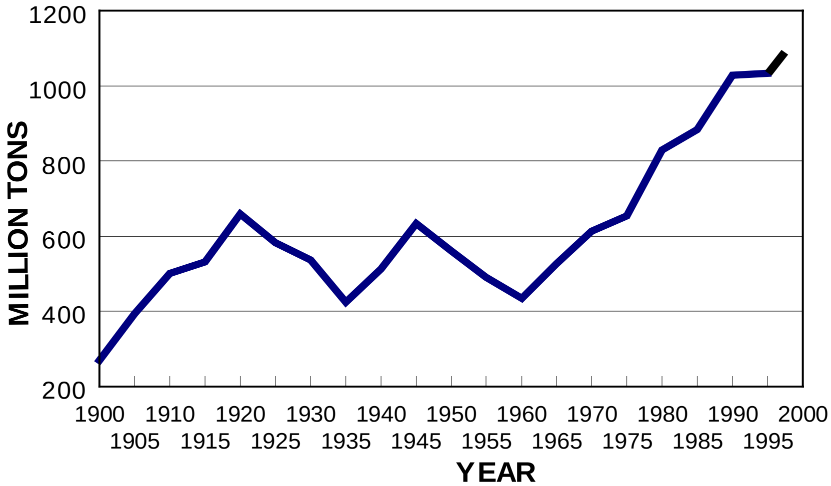

Figure 1. U. S. Coal production, 1990-1997. Data from Energy Information Administration

Of all the sources of energy produced in the United States, coal is the largest, accounting for 23.2 percent of the total (EIA, 1998c). Natural gas is next in importance with 19.5 percent. The majority of the electricity in this country is produced from burning coal; the amount increased in 1998 to a total of 57 percent. Energy from coal combustion will necessarily be the dominant source of electricity for many years to come. Ninety percent of all the coal consumed in the United States is used to produce electricity and the cost of that coal continues to decline. The average mine price in 1997 decreased by two percent from 1996, continuing a 15 year period of decreasing price. The average rate of decrease during the ten years from 1988 through 1997 was two percent per year (EIA, 1998a).

The data presented in the previous two paragraphs suggest that the coal industry is alive, well, and thriving. Recent projections as to the future of coal are, for the most part, in general agreement that the production will continue to increase at approximately the current rate for the next 16 to 21 years (figure 2, EIA, 1997).

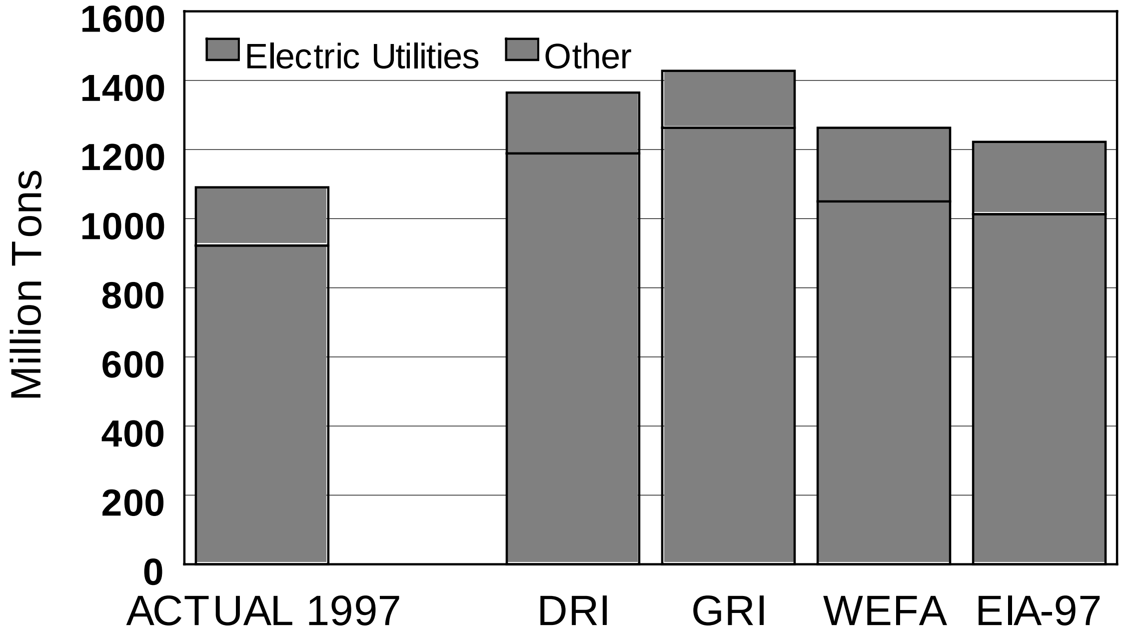

Figure 2. Coal consumption forecasts for 2015. Coal for generating electricity and for all other uses are shown. Forecast comparisons were compiled by Energy Information Administration and presented in tabular form (EIA, 1997). In this figure EIA-97 is the reference case from EIA, 1997 and comparisons are made with WEFA - the WEFA Group; GRI - Gas Research Institute; and DRI - DRI/McGraw-Hill.

A very different view of the future resulted from recent analyses done by the EIA for the U.S. House of Representatives Committee on Science (EIA, 1998d). In these analyses the impacts of the Kyoto Protocol on U.S. energy markets were modeled using six scenarios that reduced the carbon emissions to varying levels below the reference case (carbon emissions in the reference case are 33 percent above the 1990 levels in 2020). The six scenarios resulted in projections that coal consumption in the U.S. in 2010 would be reduced by between 18 and 77 percent with further significant decreases by 2020.

Results of the “Kyoto scenarios” that model the future of the coal industry in the EIA report to Congress would require rapid changes in the energy markets and would cause significant economic impacts on a national scale. It is difficult to envision the energy mix changing that rapidly. The future is always uncertain, but, understanding the nature of our major indigenous resource, coal, is vital to the economic and environmental well being of the nation, in times of increasing use as well as in times of decreasing consumption.

NATIONAL COAL RESOURCE ASSESSMENTS: THEN AND NOW

The U.S. Geological Survey (USGS) has published estimates of the total coal resources in the Nation on at least six occasions during the past 90 years. The first such estimate was by Campbell and Parker, 1909, and the most recent estimate was by Averitt, 1975. It is interesting to note that the amount of total original coal resources estimated in the first publication in 1909 and that in the 1975 report differ by only one percent of the total. The method used in the prior assessments was to gather all published information on coal resources wherever they could be found, principally in publications of state geological surveys and the U.S. Geological Survey, and then to summarize the data by state and sum the total. Careful attempts at standardizing results from the different studies were done, but the large number of investigations that were summed and the lack of standard techniques for use in those studies made it difficult to do so. Much valuable information concerning the Nation's endowment of coal is to be found in the earlier reports and the 1975 publication by Averitt continues to stand out as an exceptionally informative, well written, and thoughtful publication. However, because of the disparate nature of the parts that made up the whole of the assessment, estimates of uncertainty were not done.

The current assessments of coal resources at the USGS differ from previous assessments in several significant ways. First, not all of the coal resources (coal endowment) of the Nation are being assessed. The USGS National study (National Coal Resource Assessment or NCRA), as well as local and regional investigations, are measuring the quantity, characterizing the quality, and evaluating the availability and recoverability of those coal resources and reserves that will supply much of the needs for fossil fuel in the U.S. during the twenty-first century, primarily the first third of that century. The scales on which the studies are conducted vary widely, from areas as small as a single 7 ½ minute quadrangle (approximately 60 square miles) to regional studies that include basins extending over several states.

A second, and most significant attribute of the modern assessments, is that all of the information is stored, manipulated and analyzed in digital form. All current USGS assessments, regardless of scale, make use of geographically referenced data; that is, their position on or in the earth is precisely known. The digital data are then manipulated and analyzed by means of a Geographic Information System (GIS). The term, GIS, refers to a computer system used to collect, store, update, manipulate, analyze, and present the results of information concerning, in this case, coal deposits that are geographically located on the earth's surface and within the earth's crust.

The basic, underlying concepts of calculating volume and tonnages are the same as those that mining engineers and geologists have used for many years, but the ability to manipulate, evaluate, and then re-evaluate the data, to customize the assessments, and thereby to respond to a large range of questions concerning the nature of the resources and reserves, is new . This is the result of the GIS and its ability to process large amounts of data in a relatively short time.

COAL RESOURCE DATA HANDLING AND ANALYSES BY GIS

Inasmuch as the total coal endowment (all of the coal in the ground) of the United States is large and the locations of all of the major coal basins are known, it is not necessary to predict the location of additional, undiscovered resources in order to identify those that will be important in generating the Nation's electric energy for the twenty-first century. Coal resource assessments are the results of the analyses based on measurements that have been made directly on the coals of interest. The most important and time-consuming aspect of the coal resource assessment process is acquiring, validating, organizing, interpreting and entering the data into a digital database so that the GIS can function properly. The National Coal Resources Data System (NCRDS) of the U.S. Geological Survey is one major source of the geographically referenced data, as are data sets obtained from other Federal agencies, state geological surveys, and coal companies. Coal location and thickness are obtained from measurements taken from rock exposures in the field, in coal mines, and from holes drilled during exploration for coal in advance of mining. Direct measurements of drill core and interpretation of geophysical logs, that represent some physical property of the rocks, are often used to determine thickness and extent of the coal bed. Some of the drill holes, measured sections, and coal mine data are used to produce cross sections and to provide a three dimensional view of the distribution of the coal deposit. Ultimately, a data base is developed and it forms the foundation for resource analyses.

The USGS has assessed coal resources using a computerized database since the 1970's. In-house software replaced manual calculations after careful comparisons of results between the two methods, both of which followed the basic methodology described in Wood and others, 1983. In the late1980's the USGS software evolved to a public-domain raster-based GIS; the current resource assessment utilizes commercial gridding and GIS packages.

The current GIS software generate digital files (generally called coverages) that can be plotted as maps showing the spatial distribution of the data. Coverages represent a wide range of features, such as areal extent of the coal bed , the thickness of the coal over the area, the depth to the coal from the surface, areas that were previously mined, and the land ownership - whether Federal, State, or private. The amount of the coal resource is calculated from these coverages. A volume of coal is obtained by combining the areal extent of the bed with the thickness of the coal. The volume is multiplied by the specific gravity of the coal, and the result is expressed in tons. There are several ways to execute this calculation and derive short tons using a GIS (or a combination of GIS and other software) with the aforementioned coverages as input. The three basic types of information that can be stored digitally in a GIS are point, vector (line), and raster (grid). Proceeding from the database's point-source information on coal thickness to a gridded model is perhaps the most critical and subjective step. Various software packages use different algorithms to interpolate a surface between points. The geologist, based on his/her knowledge of available coal data and understanding of the study area, must set parameters, such as grid cell size. To achieve a realistic thickness model, the gridding step is often repeated, as the geologist fine-tunes the parameters or selects alternative algorithms.

Once the thickness is modeled, two different avenues can be taken. The thickness can remain a grid or be contoured and converted to lines/polygons, which approximate the grid. In other words, the resource calculation can be performed using all vector data or both grid and vectors. Comparisons of tonnage from these two approaches have been documented (Tewalt, 1998; Roberts and Biewick, 1999). When tonnage is aggregated at a relatively small scale (e.g., county), the differences between results are usually less than one percent. As a final step, the GIS can store the tonnage as an attribute of a coverage and the procedures used to derive those values are documented in the metadata for that digital information.

The GIS can also be queried and new coverages can be made from the existing ones. For example, one can ask where there is coal that is more than 20 feet thick, at a depth of less than 200 feet, all under Federal ownership and the GIS will produce a new coverage (figure 3). The quantity of coal in the newly defined category is then readily determined.

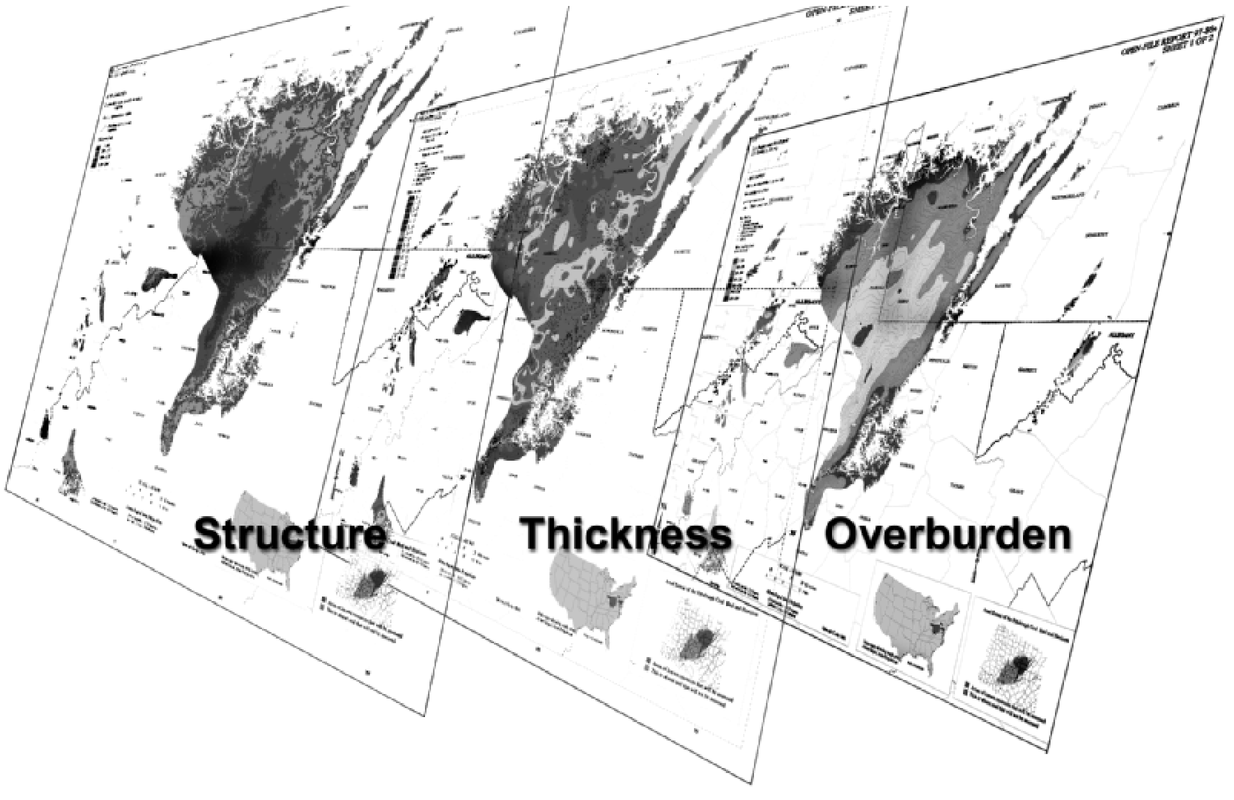

Figure 3. GIS coverages displaying structure (elevation relative to sea level), thickness, and overburden (depth from the surface of the earth to the coal) for the Pittsburgh coal bed in northern West Virginia, Pennsylvania, Maryland, and Ohio. Modified from Tewalt and others, 1997a, and Tewalt and others, 1997b.

It is this ability to query the data sets and not be bound by the limits set by others that is one of the major strengths of the GIS. Potential users of the coal resource assessments will ask quite different questions of the system, depending on their specific interests; and geologists, mining engineers, county and state planners, Federal land managers, and policy makers will certainly have differing needs and interests.

High quality databases that are required in order to perform coal resource analyses by GIS lend themselves to other mathematical calculations. The coal resource assessment data bases are large enough and sufficiently well defined so that statistical methods can be employed in determining the confidence of the results. Experience gained in conducting the assessments has demonstrated that thickness variation in the coal bed or coal zone and the density of the data points are the primary sources of uncertainty of the final resource numbers. It is now possible to state confidence limits on many of the categories of resources reported.

COAL ASSESSMENTS: FROM RESOURCES TO RESERVES

The National Coal Resource Assessment (NCRA), a current study that is nearing completion, is identifying those resources that will provide the greater portion of the Nation's coal during the next several decades. For the purposes of this study, the country has been divided into five principal coal producing regions, as shown in figure 4.

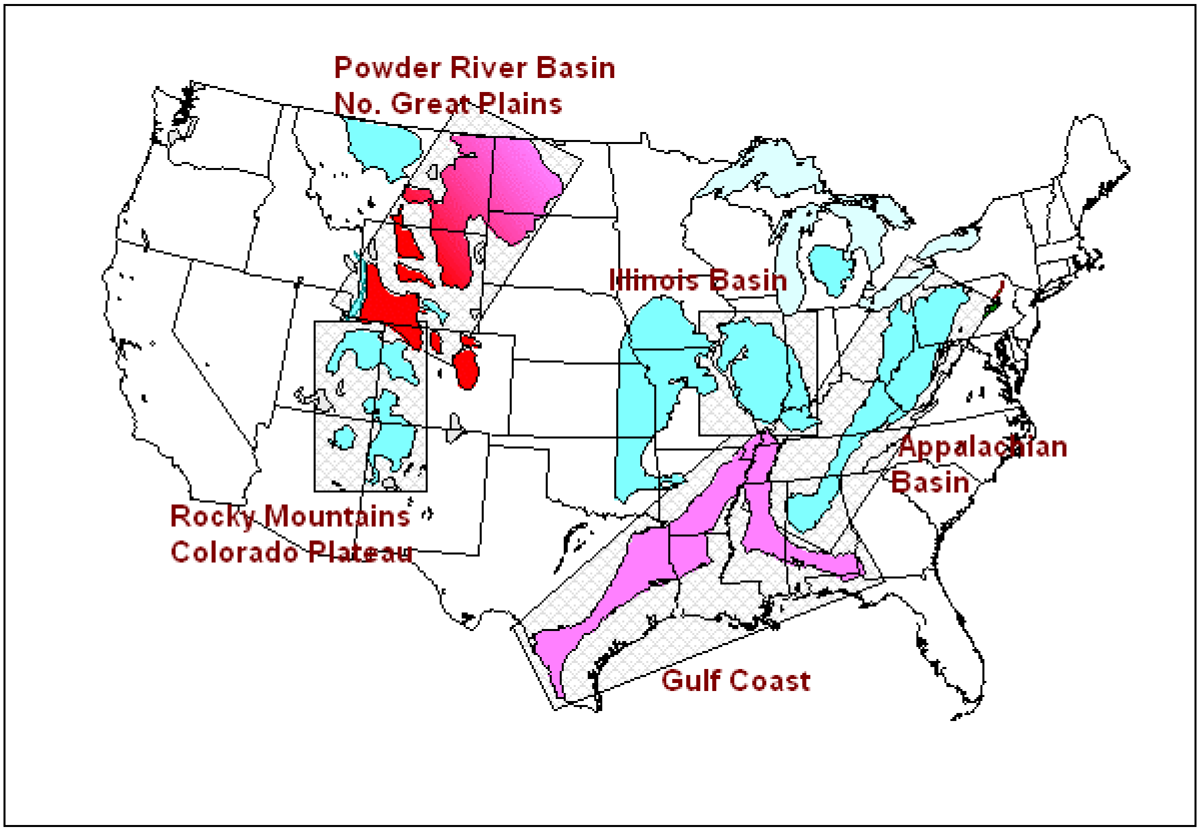

Figure 4. National Coal Resource Assessment Regions

A team composed of geologists, geochemists, and GIS experts from the USGS, in parnership with counterparts from state geological agencies, is investigating the resources of each region; one team for each region. The scientists working in each region have specific knowledge and expertise in those areas and are therefore capable of evaluating the accuracy of the data being collected and validity of the products of the assessment in their region. At the conclusion of the National Coal Resource Assessment study, each regional project will publish a detailed report on CD-ROM.

However, publication of the information that is being generated has not been deferred until the completion of the study. Maps, reports, assessments of resources, and databases have been published in a variety of modes, including digital publications available on the USGS website (http://www.usgs.gov/themes/energy.html), hard copy USGS publications, and publications in Journals and at National meetings of energy, mining, and geologic organizations.

The quantities of coal reported in the regional studies as part of the National Coal Resource Assessment are **coal resources**; coal that has some potential for future production, but additional studies must be done in order to determine the economic feasibility of producing those resources. **Coal reserves,** a subset of the resource that can be produced at a profit under current market conditions, are identified as a result of the USGS Coal Availability and Coal Recoverability studies (Eggelston, and others, 1990, and Rohrbacher and others, 1993). Until recent years, the estimates of coal reserves in the United States did not address the amount of coal made unavailable for production because of environmental, land use, technological, and geologic constraints. The Coal Availability and Coal Recoverability projects at the USGS were initiated in response to the need for this information. The USGS, in cooperation with geological agencies in the principal coal producing states, (1) identify and delineate the current major restrictions on the availability of coal resources; (2) estimate the amount of remaining coal resources that may be available for development under those constraints; (3) estimate the amount of coal that can be economically extracted and marketed, and (4) identify possible social and economic disruptions that occur within local and regional economies as coal resources are exhausted.

Because of the data intensive nature of Coal Availability/Coal Recoverability, these studies can only be done in relatively small areas (tens to hundreds of square miles) and where abundant data are available. The results of the detailed analyses can then be extrapolated to entire coal basins or coal producing regions. Coal Availability studies have generally been designed to sample approximately three to four percent of the total area of a coal producing region. An example of the density of the distribution of quadrangles on which Coal Availability studies have been completed is shown in figure 5. The region is the central and northern Appalachians and includes parts of Kentucky, West Virginia, and Virginia, Pennsylvania, Maryland and Ohio.

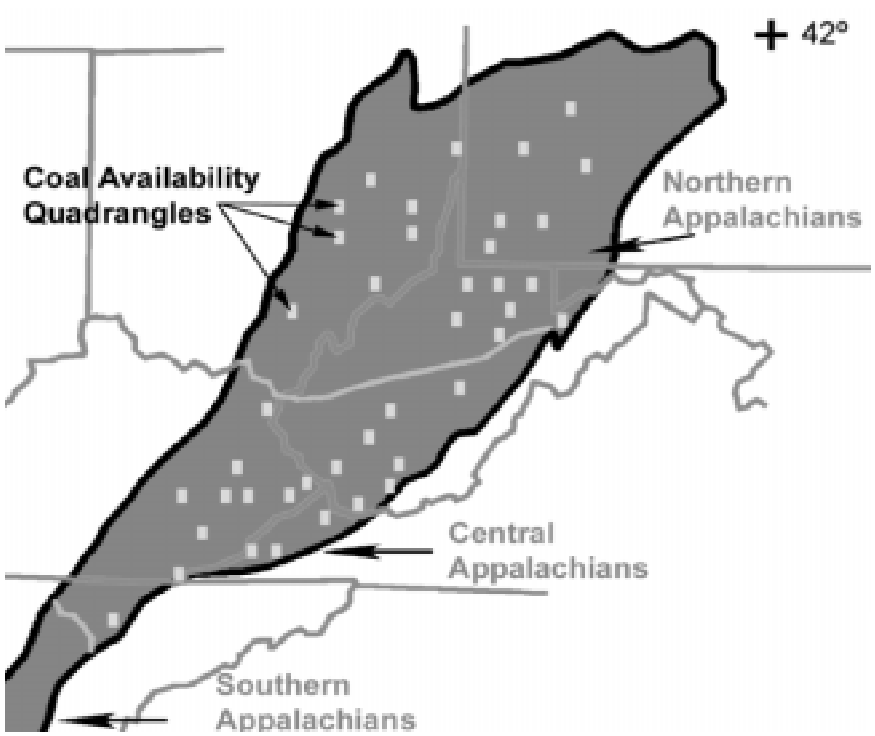

Figure 5. Coal Availability Quadrangles in Central and Northern Appalachia

COAL RESOURCE INFORMATION DELIVERY

Results of the five regional coal resource assessment projects will be published in a variety of forms; hard copy, digital files, CD-ROM, and a summary of the National assessment will also appear on CD-ROM. In addition, the data will be incorporated into an Internet information delivery system which is currently under development at the USGS. This is an information delivery system that will enable the user, by means of the Internet, to access the information developed in the National Coal Resource Assessment and, at the same time, integrate that information with other databases. It will provide access to nationwide spatial data, display basic maps, and allow for the manipulation of the data by means of an Internet browser. The user will be able to query the data and create and download the newly defined databases and maps. Much of the data available in the system are from USGS sources (oil and gas resources; coal quality; oil, gas, and coal chemistry) but are not restricted to those originating from the USGS. Data originating from other sources include government land ownership, land use coverages, biological data (such as endangered species habitat) and major transportation systems (railroads, pipelines, and major highways). The system will support Federal, State, and local agencies, as well as the private sector in analyzing and making decisions regarding land-management and environmental issues related to energy resources.

REFERENCES

Averritt, Paul, 1975, Coal Resources of the United States, January 1, 1974: U.S. Geological Survey Bulletin 1412, 131p.

Campbell, M. R., and Parker, E. W., 1909, Coal fields of the United States, *in* Papers on the conservation of mineral resources: U.S. Geological Survey Bulletin 394, p. 7-26.

Eggleston, J. R., Carter, M. D., and Cobb, J. C., 1990, Coal resources available for development - A methodology and pilot study: U.S. Geological Survey Circular 1055, 15p.

EIA, 1997, Annual Energy Outlook, 1998: Energy Information Administration, DOE/EIA-0383(98), 228p.

EIA, 1998a, Coal Industry Annual 1997: DOE/EIA-0584(97), 256p.

EIA, 1998b, Weekly U.S. Coal production Overview, Week Ended 11/28/98, Released December 3, 1998.

EIA, 1998c, Annual Energy Review, 1997, Energy Information Administration, DOE/EIA-0384(97), 358p.

EIA, 1998d, Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity, Energy Information Administration, Prepared for the U.S. House of Representatives Committee on Science, SR/OIAF/98-03, 227p.
Roberts, L. N. R. and Biewick, L. R. H., 1999, National Coal Resource Assessment Methodology: Comparison of resource calculations using ARC/INFO and EarthVision, USGS Open-File Report 99-5, 9 p.

Rohrbacher, T. J., Teeters, D. D., Sullivan, G. L., and Osmonson, L. M., 1993, Coal resource recoverability - A methodology: U.S. Bureau of mines Information Circular 9368, 48 p.

Tewalt, S. J., 1998, National Coal Resource Assessment Methodology: Comparison of resource calculation methods by two Geographic Information Systems (GIS), USGS Open-File Report 98-365, 6 p.

Tewalt, S., Ruppert, L., Bragg, L., Carlton, R., Brezinski. D., and Wallack, R., 1997a, Map showing generalized thickness contours of the Pittsburgh coal bed in Pennsylvania, West Virginia, and Maryland, digitally compiled by Tewalt, S., Ruppert, L., Wallack, R., and Weiss, E.: U.S. Geological Survey Open-File Report 97-748.

Tewalt, S., Ruppert, L., Bragg, L., Carlton, R., Brezinski. D., Yarnell, J., and Wallack, R., 1997b, Map showing structure contours and overburden thickness isopleths of the Pittsburgh coal bed in Pennsylvania, Ohio, West Virginia, and Maryland, digitally compiled by Tewalt, S., and Wallack, R.: U.S. Geological Survey Open-File Report 97-864.

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