

**A Characterization and Determination of the
Coal Reserves and Resources of Southwest Virginia**

Erik C. Westman

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
In
Mining and Minerals Engineering

Dr. Christopher Haycocks
Dr. Stanley Suboleski
Dr. Michael Karmis
Dr. Ertugrul Topuz
Dr. Gerald Luttrell
Dr. John Wilson

April 1999

Blacksburg, Virginia

Keywords: Coal Reserves, Coal Resources, Virginia, Economic Model

A Characterization and Determination of the Coal Reserves and Resources of Southwest Virginia

Erik C. Westman

(ABSTRACT)

Coal mining has been the primary industry of Southwest Virginia for more than 100 years. Coal production increased steadily until it reached a peak in 1990. Since then it has begun a decline, accompanied by decreasing coal revenues to the region. In order to more effectively plan the future economy of the area a study was conducted to characterize and estimate remaining coal resources. Seam thickness was found to be the parameter which most influenced resource levels. An economic model was developed to determine which portion of the reserves could economically be extracted. It was found that 3.95 billion tons, or 14% of the remaining resource, are economic under current mining conditions. Many of these reserves, however, occur in seams at depths which require costly development prior to initiation of mining. The database used for the study was found to be accurate, but imprecise. Based on the quantitative measurements of accuracy and precision, a reserve quantity of 1.6 billion tons should be used for planning purposes. The precision of the database can be improved with additional data. A program encouraging the mining industry to submit their data to the state, while ensuring confidentiality, would allow more precise estimates to be made, ultimately benefiting all members of the Southwest Virginia community.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Christopher Haycocks, for his continuing support and encouragement during the course of my research.

Sincere thanks are also extended to Dr. Stanley Suboleski, Dr. Michael Karmis, Dr. Ertugrul Topuz, Dr. Gerald Luttrell and, Dr. John Wilson for their helpful support during this research.

Funding for this project was provided by the Powell River Project, whom the author sincerely thanks.

This research would not have been possible without the invaluable assistance of members of the Central Appalachian coal mining community including Red Robertson, Mike Brown, John Bullock, Alan Dennis, John Feddock, Mark Goth, Ben Hatfield, Marshall Hunt, Scott Keim, Doug Mullins, Ken Nicewonder, Burton Perry, Horace VanMeter, David Wampler and many others.

Finally, I wish to thank my extended family for their support during this time, and especially my immediate family – Krista, Elizabeth, Anna, Emily, and Samuel – for their support and encouragement.

TABLE OF CONTENTS

Abstract	ii
Acknowledgements.....	iii
Table of Contents.....	iv
List of Figures.....	vii
List of Tables	xi
Chapter 1 Introduction.....	1
1.1 Background and Problem Statement.....	1
1.2 Justification and Objectives	1
1.3 Methodology	4
Chapter 2 Literature Review	5
2.1 Current Coal Industry.....	5
2.1.1 U.S. Coal Industry.....	5
2.1.2 Virginia Coal Industry	7
2.2 Previous Coal Resource Estimates.....	8
2.2.1 United States Coal Resource Estimates	8
2.2.2 Virginia Coal Resource Estimates	10
2.3 Interpolation.....	11
2.3.1 USGS Technique	11
2.3.2 Area of Influence Methods	12
2.3.3 Inverse Distance Weighting.....	16
2.3.4 Spline Fitting.....	16
2.3.5 Kriging.....	16
2.4 Coal Models.....	18
2.4.1 Regional Production Model	18
2.4.2 Regional Resource Restriction Models	19
2.4.2.1 Restrictions	20
2.4.2.1.1 Land-Use Restrictions.....	20
2.4.2.1.2 Technologic Restrictions	21
2.4.2.1.3 Legislative Restrictions.....	23
2.4.2.2 Resource Restriction Studies	23
2.4.2.1.1 USGS Coal Availability Studies.....	23
2.4.2.1.2 USBM Coal Recoverability Studies	25
2.4.3 Economically-Based National Policy Analysis Models	26
2.4.3.1 Resource Allocation and Mine Costing Model (RAMC)	26
2.4.3.2 Coal and Electric Utilities Model (CEUM)	26
2.4.3.3 Data Resources Inc.(DRI)/Zimmerman Model.....	26
2.4.3.4 Energy Information Administration Coal Market Module	28
Chapter 3 Database For GIS Evaluation Of Southwest Virginia Coal Seams	30
3.1 Southwest Virginia Coal Geology	30
3.2 Description of Geographic Information System.....	31
3.3 Data Sources	32

3.3.1	Outcrops and Previous Mining	33
3.3.2	Thickness and In-Seam Reject.....	33
3.3.3	Land-Use Restrictions.....	34
3.3.4	Coal Quality and Washability.....	34
3.3.5	Seam Elevations.....	34
3.4	Database Development	34
3.4.1	Interpolation.....	35
3.4.2	Multiple-Seam Interaction	36
3.4.3	Land-Use Restrictions.....	36
3.4.4	Property Size.....	40
3.4.5	Washability	40
Chapter 4	Analysis Of Database Accuracy	41
4.1	Database Verification Methods.....	41
4.2	Comparison to Other Studies	43
4.3	Quantitative Accuracy Assessment Technique.....	44
4.4	Discussion of Database Accuracy and Precision.....	50
Chapter 5	Parametric Analysis	51
5.1	Resource Calculation	51
5.2	Resource Definitions.....	52
5.2.1	Inclusive, Moderate, and Exclusive Resource Definitions	52
5.2.2	Remaining, Available, and Recoverable Resources	52
5.2.3	Industry Minimum Reserve Definitions	56
5.3	Parametric Analysis	57
5.3.1	Influence of Restrictions	57
5.3.2	Correlation Between Resources and Parameters	57
5.3.3	Regression Analysis of Resources and Parameters	61
5.4	Discussion.....	64
Chapter 6	Economic Model.....	67
6.1	Model Development.....	67
6.1.1	Sales Price.....	67
6.1.2	Mining Cost	69
6.1.2.1	Underground Mining	69
6.1.2.2	Surface Mining.....	71
6.1.3	Additional Costs	72
6.1.4	Economic Models for Surface and Underground Mining	72
6.2	Model Validation	73
6.2.1	Property One	73
6.2.2	Property Two	76
6.3	Application of Economic Model	76
6.4	Discussion of Results.....	84
Chapter 7	Application And Summary	85
7.1	Planning Considerations for Southwest Virginia	85

7.2 Comparison to Eastern Kentucky and West Virginia	87
7.3 Summary	89
Chapter 8 Conclusions and Recommendations	92
8.1 Conclusions.....	92
8.2 Recommendations.....	93
References	94
Appendix A Raw Data Used in Database	100
Appendix B Plots of Data Locations, Seam Thickness, Raw Ash Content, Raw Sulfur Content, In-Seam Reject, Underground Mining Profitability, Surface Mining Profitability, Property Size, Access, and Mining Method for 26 Seams Studied.....	142
Vita	403

LIST OF FIGURES

Figure 1.1	Virginia coalfields (Brown et al., 1952)	2
Figure 1.2	Generalized columnar section of southwest Virginia coalfield lithology (Nolde et al., 1994)	3
Figure 2.1	United States coalfields (Wood et al., 1983)	6
Figure 2.2	Projected fuel demand for electricity generation (DOE/EIA, 1997)	6
Figure 2.3	Recent Virginia coal production, by county (VCCER, 1998)	8
Figure 2.4	Terminology used in USGS coal resource classification system.....	9
Figure 2.5	Schematic of terminology and measurement specifications used in USGS coal resource classification system (Wood et al., 1983)	10
Figure 2.6	Schematic diagram showing discretization of an area using the triangular interpolation method for reserve estimation	12
Figure 2.7	Schematic diagram showing discretization of an area using the polygonal interpolation method for reserve estimation	13
Figure 2.8	Schematic diagram showing discretization of an area using the cross- section interpolation method for reserve estimation; A) using gradual changes, B) using linear reserves per square unit, and C) using the rule of nearest points	14
Figure 2.9	Schematic diagram showing discretization of an area using the isoline interpolation method for reserve estimation; A) cross section of a mineral body along exploration line 10-10, B) isopach plan of the same mineral body along the exploration line 10-10, C) cross section along exploration line 10-10 made from isopach plan B) (Popoff, 1966)	15
Figure 2.10	Sample semivariogram.....	17
Figure 2.11	Proposed production cycle of coal in Southwest Virginia (Milici and Campbell, 1991b).....	18
Figure 2.12	Relationships and terminology used in Resource Restriction models (Rohrbacher et al., 1993)	20
Figure 2.13	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 (Eggleston et al., 1990).....	24
Figure 2.14	USGS/USBM coal resource programs – Matewan quadrangle results chart (Rohrbacher et al., 1993)	25
Figure 3.1	Average thickness for each of three seams using four different interpolation methods.....	35
Figure 3.2	Land-use restrictions for surface mining	38
Figure 3.3	Land-use restrictions for underground mining	39
Figure 3.4	Relationship between raw ash content (%) and heating capacity (Btu/lb) for Southwest Virginia coal	40
Figure 4.1	Two plots show the same area for the features, however one does not accurately represent the other because the features are not in the same locations	42
Figure 4.2	Accuracy plot for All Seams and Seam 2 in Property 1	46
Figure 4.3	Accuracy plot for All Seams in Property 2.....	48
Figure 4.4	Accuracy plot for All Seams from Lee County study.....	50

Figure 5.1	Relationship between seam thickness and unrestricted resources	58
Figure 5.2	Relationship between raw sulfur content and unrestricted resources	58
Figure 5.3	Relationship between raw ash content and unrestricted resources	59
Figure 5.4	Relationship between in-seam reject and unrestricted resources.....	59
Figure 5.5	Relationship between property size and unrestricted resources	60
Figure 5.6	Relationship between database and estimated surface-mineable tonnage using polynomial fit, with trend line (all values in million tons).....	62
Figure 5.7	Relationship between database and estimated surface-mineable tonnage using linear fit, with trend line (all values in million tons).....	63
Figure 5.8	Relationship between database and estimated underground-mineable tonnage using linear fit, with trend line (all values in million tons).....	63
Figure 6.1	Relationship between raw ash content and sales-price penalty	68
Figure 6.2	Relationship between raw sulfur content and sales-price penalty	69
Figure 6.3	Relationship between actual and model underground mining costs.....	70
Figure 6.4	Profitability of original resources and location of previous mining of Seam A at Property 1 (north arrow and scale intentionally left off for confidentiality).....	74
Figure 6.5	Profitability of remaining resources and location of current mining of Seam A at Property 1 (north arrow and scale intentionally left off for confidentiality).....	75
Figure 6.6	Profitability of original resources and location of previous mining of Seam X at Property 2 (north arrow and scale intentionally left off for confidentiality).....	77
Figure 6.7	Profitability of remaining surface resources and location of current surface mining of Seam X at Property 2 (north arrow and scale intentionally left off for confidentiality).....	78
Figure 6.8	Profitability of remaining underground resources and location of current underground mining of Seam X at Property 2 (north arrow and scale intentionally left off for confidentiality).....	79
Figure 6.9	Relationship between Profitability and Reserves for underground, surface, and all mineable properties	80
Figure 6.10	Approximated relationship between Profitability and Reserves for surface resources	81
Figure 6.11	Approximated relationship between Profitability and Reserves for underground resources	81
Figure 6.12	Past and predicted average mine mouth price of coal for Eastern U.S., Western U.S., and U.S. average, dollars per ton (DOE/EIA, 1999b).....	82
Figure 6.13	Relationship between Profitability and Reserves for surface mining based on predicted sales prices in 5 and 20 years	83
Figure 6.14	Relationship between Profitability and Reserves for underground mining based on predicted sales prices in 5 and 20 years	83
Figure 7.1	Relationship between Profitability and Reserves for underground mining showing effect of \$2 per ton tax credit for seams 30 inches thick or less	86
Figure 7.2	Relationship between Profitability and Reserves for underground mining showing effect of \$1 per ton penalty for seams with more than 3 inches in- seam reject	86

Figure 7.3	Relationship between Profitability and Reserves for underground mining showing effect of \$1 per ton tax credit for seams with 1% raw sulfur or less.....	87
Figure 7.4	Virginia coal production forecasts with optimistic, pessimistic, and most likely predictions (after Crabtree, 1995).....	88
Figure B1	Data Locations for Aily Seam.....	B1
Figure B2	Seam Thickness for Aily Seam.....	B2
Figure B3	Raw Ash Content of Aily Seam.....	B3
Figure B4	Raw Sulfur Content of Aily Seam.....	B4
Figure B5	In-Seam Reject of Aily Seam.....	B5
Figure B6	Underground Mining Profitability of Aily Seam.....	B6
Figure B7	Surface Mining Profitability of Aily Seam.....	B7
Figure B8	Property Size of Aily Seam.....	B8
Figure B9	Access for Aily Seam.....	B9
Figure B10	Mining Method for Aily Seam.....	B10
Figures B11 – B20	for Blair Seam.....	B11
Figures B21 – B30	for Clintwood Seam.....	B21
Figures B31 – B40	for Dorchester Seam.....	B31
Figures B41 – B50	for Hagy Seam.....	B41
Figures B51 – B60	for High Splint Seam.....	B51
Figures B61 – B70	for Imboden Seam.....	B61
Figures B71 – B80	for Imboden Marker Seam.....	B71
Figures B81 – B90	for Jawbone Seam.....	B81
Figures B91 – B100	for Kelly Seam.....	B91
Figures B101 – B110	for Kennedy Seam.....	B101
Figures B111 – B120	for Lower Banner Seam.....	B111
Figures B121 – B130	for Low Splint Seam.....	B121
Figures B131 – B140	for Lyons Seam.....	B131
Figures B141 – B150	for Morris Seam.....	B141
Figures B151 – B160	for Norton Seam.....	B151
Figures B161 – B170	for Pocahontas #3 Seam.....	B161
Figures B171 – B180	for Pardee Seam.....	B171
Figures B181 – B190	for Phillips Seam.....	B181
Figures B191 – B200	for Raven Seam.....	B191
Figures B201 – B210	for Splash Dam Seam.....	B201
Figures B211 – B220	for Taggart Seam.....	B211
Figures B221 – B230	for Taggart Marker Seam.....	B221
Figures B231 – B240	for Tiller Seam.....	B231
Figures B241 – B250	for Upper Banner Seam.....	B241
Figures B251 – B260	for Wilson Seam.....	B251

LIST OF TABLES

Table 2.1	Energy Prices to Electricity Generators by Source (1996 Dollars per Million Btu). Source – DOE/EIA, 1998a.....	7
Table 2.2	Estimates of Original Coal Resource in Virginia (from Brown et al., 1952; DOE/EIA 1981)	11
Table 3.1.	Seams studied in this estimate	30
Table 3.2	Average Thickness and interaction potential for seams analyzed	37
Table 4.1	Comparison of resource estimates for Brown et al. (1951) and current study, all figures in millions of tons.....	43
Table 4.2	Comparison between resource estimates for Lee County from Campbell et al. (1991) and the current study, all figures in million tons.....	44
Table 4.3	Borehole and database thicknesses for five seams from first property, borehole and database values in inches. Accuracy calculated as borehole divided by database thickness.....	45
Table 4.4	Borehole and database thicknesses for seven seams from second property, borehole and database values in inches. Accuracy calculated as borehole divided by database thickness.....	47
Table 4.5	Measured thicknesses, database thicknesses, and accuracy of the database for the seams evaluated in Lee County	49
Table 5.1	Parameters and values used in Parametric Analysis	51
Table 5.2	Three definitions of resources unrestricted by land-use or multiple-seam interaction	52
Table 5.3	Results of USBM preparation characteristic studies	53
Table 5.4	Remaining, available, and recoverable coal resources of Southwest Virginia, all figures in millions of tons.....	53
Table 5.5a	“Available” Underground Resources by Seam and County (2% max. sulfur, 30 in. min. thickness, 25% max. ash, 50% max. in-seam reject, 10,000 tons min. property size; all figures in 1000’s of tons.....	54
Table 5.5b	“Available” Surface Resources by Seam and County (2% max. sulfur, 12 in. min. thickness, 25% max. ash, 10,000 tons min. property size; all figures in 1000’s of tons.	55
Table 5.6	Composite of results from industry interviews.....	56
Table 5.7	Surface and deep steam and metallurgical resources using industry’s <i>minimum</i> definition of reserves; all figures in millions of tons	57
Table 5.8	Resources restricted by multiple-seam interaction and land-use; all figures in millions of tons	57
Table 5.9	Pearson correlations for Surface Resources.....	61
Table 5.10	Pearson correlations for Underground Resources.....	61
Table 5.11	Results of Best Subsets Regression for surface resources	64
Table 5.12	Results of Best Subsets Regression for underground resources	64
Table 5.13	DOE/EIA sulfur content categories for coal, Approximate percent sulfur calculated assuming 13,000 Btu/lb. coal.....	65
Table 5.14	Comparison of current results to previous studies.....	66
Table 6.1	Effect of Ash Content on Sales Price.....	67

Table 6.2	Effect of Sulfur Content on Sales Price	67
Table 6.3	Access methods and costs	71
Table 6.4	Cost related to mining different stripping ratios	71
Table 6.5	Additional costs to mining	72
Table 6.6	Results of Reserve Study and comparison to Matewan study by Rohrbacher et al.	84
Table 7.1	Pearson correlation between profitability and parameters	85
Table 7.2	1996 Remaining Resource, Estimated Economic Reserves, and 1995 production for states in Central Appalachia coal basin; all figures in million short tons	89
Table A1	Raw data for Aily Seam	A1
Table A2	Raw data for Blair Seam	A2
Table A3	Raw data for Clintwood Seam	A3
Table A4	Raw data for Dorchester Seam	A5
Table A5	Raw data for Hagy Seam	A7
Table A6	Raw data for High Splint Seam	A9
Table A7	Raw data for Imboden Seam	A10
Table A8	Raw data for Imboden Marker Seam	A11
Table A9	Raw data for Jawbone Seam	A12
Table A10	Raw data for Kelly Seam	A15
Table A11	Raw data for Kennedy Seam	A16
Table A12	Raw data for Lower Banner Seam	A19
Table A13	Raw data for Low Splint Seam	A21
Table A14	Raw data for Lyons Seam	A22
Table A15	Raw data for Morris Seam	A24
Table A16	Raw data for Norton Seam	A25
Table A17	Raw data for Pocahontas #3 Seam	A27
Table A18	Raw data for Pardee Seam	A29
Table A19	Raw data for Phillips Seam	A30
Table A20	Raw data for Raven Seam	A31
Table A21	Raw data for Splash Dam Seam	A33
Table A22	Raw data for Taggart Seam	A35
Table A23	Raw data for Taggart Marker Seam	A36
Table A24	Raw data for Tiller Seam	A37
Table A25	Raw data for Upper Banner Seam	A39
Table A26	Raw data for Wilson Seam	A41

CHAPTER 1 – INTRODUCTION

1.1 Background and Problem Statement

Without economically recoverable energy sources a nation typically cannot maintain healthy economic growth. Currently, coal provides more electricity in the United States than all other energy sources combined and at a cost of approximately one-half that of other sources (DOE/EIA, 1999b). In addition to providing electricity, coal is also used in the production of steel, which is vital for maintaining a healthy manufacturing industry. Coal is a natural resource, available for improving quality of living; but also finitely distributed, requiring prudent exploitation.

Coal mining has taken place in Virginia since 1748, when mining in the Richmond basin was the first recorded production in the United States (Henderson, 1985). Since that time, more than 2.1 billion tons of coal have been extracted from three primary areas within the state: the Richmond basin, the Valley coal fields, and the Southwest Virginia coal field (Brown et al., 1952; VCCER, 1998).

The Southwest Virginia field (Figure 1.1) is by far the largest in Virginia and is currently the only active field. Coal in this region exists in 57 principle seams in 7 different geologic formations (Figure 1.2) (Nolde et al., 1994). In 1997, the mining of coal in this area generated over \$200 million in payroll to more than 6,500 employees (VCCER, 1998), resulting in a continued major socio-economic impact not only on the approximately 100,000 people of southwestern Virginia, but also on the entire Commonwealth. Between 1990 and 1995, production declined from a record level of 46.5 million tons to 35.9 million tons. Since 1995, production has stabilized – a result which may be attributable to a tax credit subsidizing mining in thinner seams.

The continued decline of coal mining in Virginia will result in major challenges to the people of this state. By more accurately determining the remaining economically mineable coal reserves in southwestern Virginia, appropriate planning can be completed to assist in the transfer from a mining-based culture.

1.2 Justification and Objectives

Prior to this research, a comprehensive study of the Southwest Virginia coal field had not been completed in nearly 50 years. Brown et al. (1952) published a resource study identifying known coal resources from seams of greater than 14 inches in thickness. Since that time, annual coal production figures were subtracted from this resource study to determine the remaining resources. In recent years the Powell River Project, the funding agency the research discussed in this dissertation, realized that a current analysis

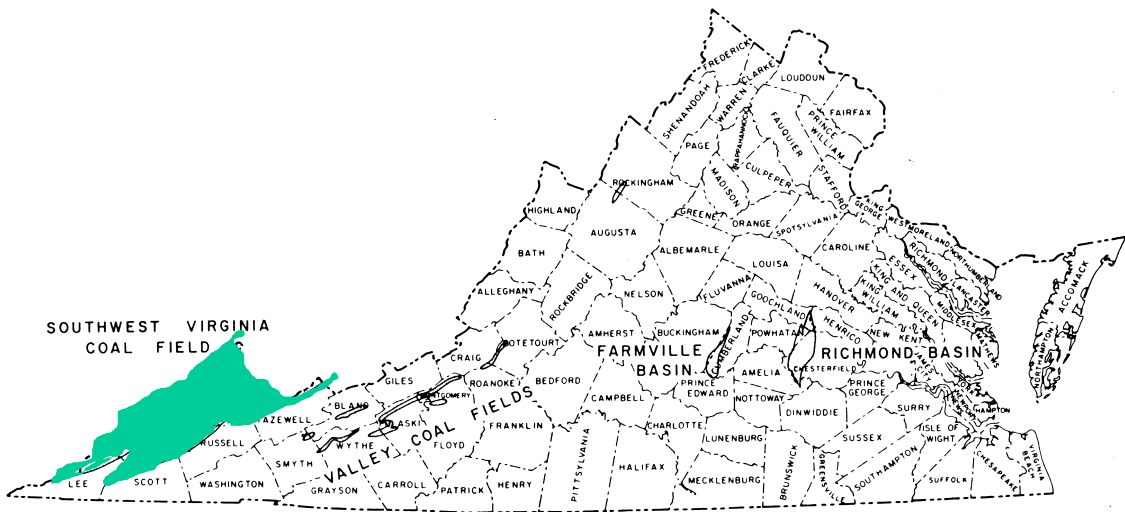


Figure 1.1 Virginia coalfields (Brown et al., 1952)

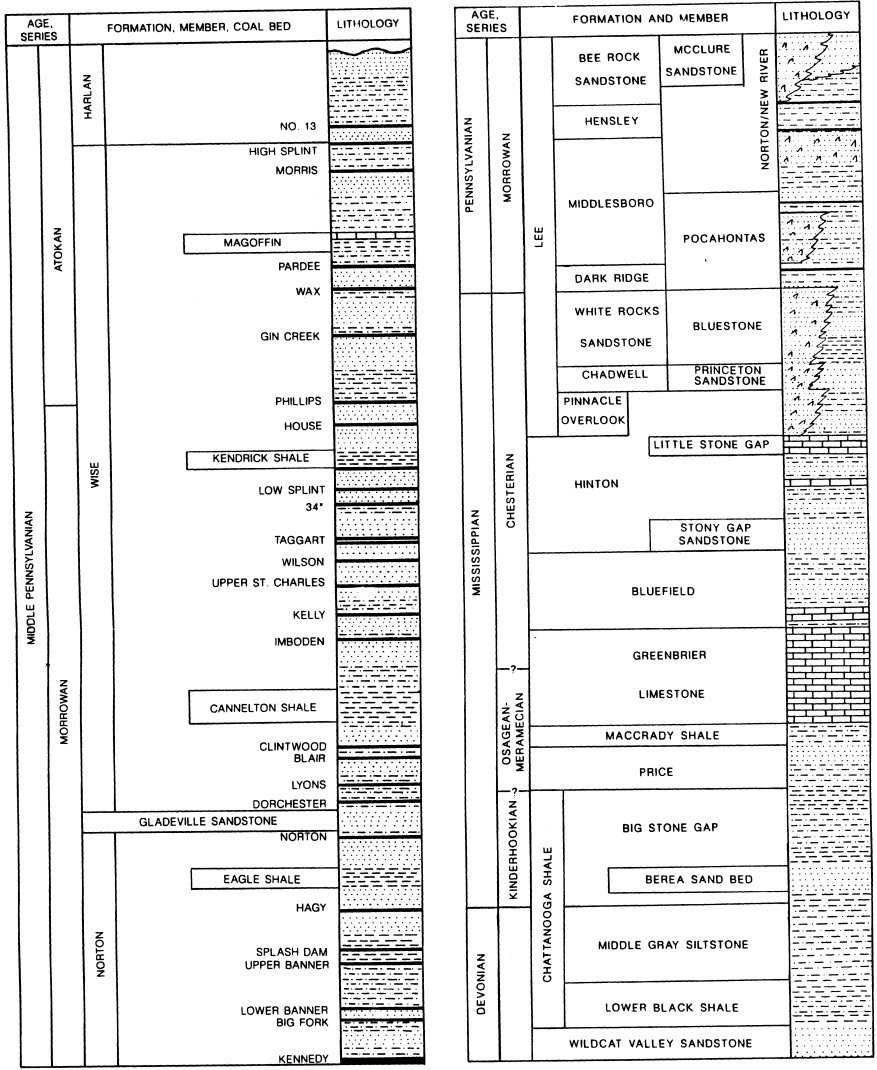


Figure 1.2 Generalized columnar section of southwest Virginia coalfield lithology (Nolde et al., 1994)

of reserves is vital for the determination of the long-term economic potential of Southwest Virginia and, also, the entire Commonwealth.

The difference between resources and reserves must be clearly understood. The commonly held distinction, which is used in this dissertation, is that a coal resource is coal existing in the earth, whereas a coal reserve is that portion which can be economically mined.

The research described in this dissertation provides a more accurate estimation of coal reserves by:

- 1) determining reserves based on current mining technology, legislative restrictions, and economic conditions;
- 2) developing an economic model to define the role of coal sales price on coal reserves;
- 3) establishing the relative influence of various land-use, legislative, and technologic restrictions on reserves; and
- 4) determining the accuracy of the reserve estimate by comparing the results to local studies.

1.3 Methodology

The input of active mining companies was critical to the completion of a meaningful study and was used extensively in the project. The definition of a coal reserve, as well as common parameters used in economic models, was determined by interviewing representatives from small contract miners, land companies, consultants, and large operating companies.

The coal reserve estimate was completed using a geographic information system (GIS) to analyze a database of publicly available data. The database of coal seam outcrops, thickness, and qualities was developed from state and federal government data sources, and was analyzed with ArcView GIS software. A GIS allows spatial data to be not only analyzed as with a database program, but also plotted as with a mapping program. These capabilities permit large quantities of spatial data to be manipulated and analyzed in an accurate and efficient manner. Supporting programs were also written to automate repeated tasks involved in conducting the parametric analysis.

Simple statistical tools, such as multiple linear regression, were used to develop equations for various relationships. By developing an equation which relates factors such as sulfur content, seam height, and property tonnage to reserve tonnage, the relative degree of influence between the various parameters can be readily discerned. This allows a clearer understanding of the role played by changes to legislative, technologic, or land-use restrictions may have on coal production, and hence the socio-economic fabric of Southwest Virginia.

CHAPTER 2 – LITERATURE REVIEW

Accurate coal reserve estimates are guided by several underlying principles. A clear understanding of both national and local coal industries provides the contextual basis for reserve estimate interpretation. Prior coal reserve estimates, along with the strengths and limitations of the methodologies applied, direct current efforts. Next, a firm grasp of interpolation methods used to estimate the distribution of values between measurement points is required. Finally, an in-depth knowledge of the various models which have been proposed for describing coal extraction guides the development of a new model.

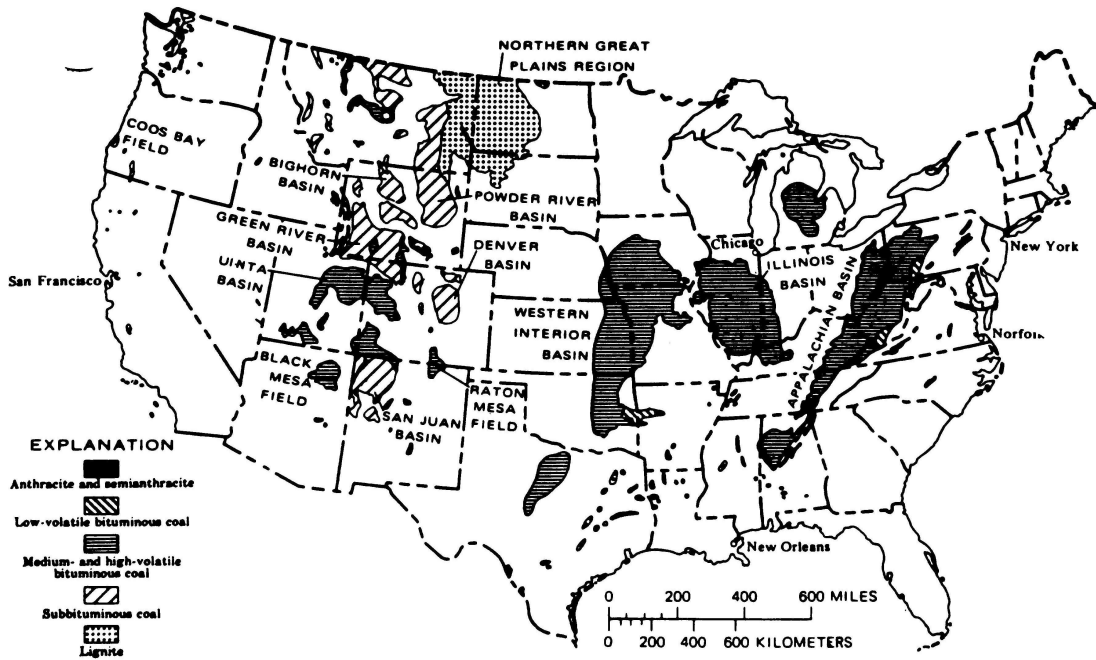
2.1 Current Coal Industry

2.1.1 U.S. Coal Industry

There are three primary coal basins in the U.S., each with its own characteristics (Figure 2.1) (USGS, 1996). Hong (1998) provided a review of U.S. coal production in each of these basins. The Appalachian basin, accounting for 43% of the coal production in 1997, contains the best quality coals, but has a more limited reserve base than the other two regions. The Illinois basin produced 16% of the U.S. coal in 1997 and has substantial reserves, however the reserves are typically higher in sulfur content, resulting in a lower demand. The remaining 41% of the nation's coal production in 1997 came from the Western Basin. This basin boasts large coal reserves at shallow depths, however, its coal is of a lower quality than eastern coals, usually possessing only two-thirds of the heating capacity.

National coal production has grown steadily at approximately 1% per year for the past 20 years, and continued growth is predicted for the next 20 years (Figure 2.2) (DOE/EIA, 1997). Continued demand for coal is tied to projected increasing electricity demand, as coal remains the least-expensive source of electrical power generation (Table 2.1) (DOE/EIA, 1998a).

Transportation and legislative restrictions have had a significant influence on the production history of the three primary coal basins. Proximity of the Appalachian coalfield to barge transportation, serving the major industrial centers of the eastern U.S., has resulted in more rapid development of that field than of the Illinois or Western fields. As railroad and barge capacity extended westward, the Illinois basin grew. As a result of the Clean Air Amendment of 1990 requiring reduced sulfur emissions, improved rail capacity allowed dramatic expansion of the Western coal basin, as it typically contains vast supplies of low sulfur coal (DOE/EIA, 1995a).



Prepared by Paul Averitt, 1975

Figure 2.1 United States coalfields (Wood et al., 1983)

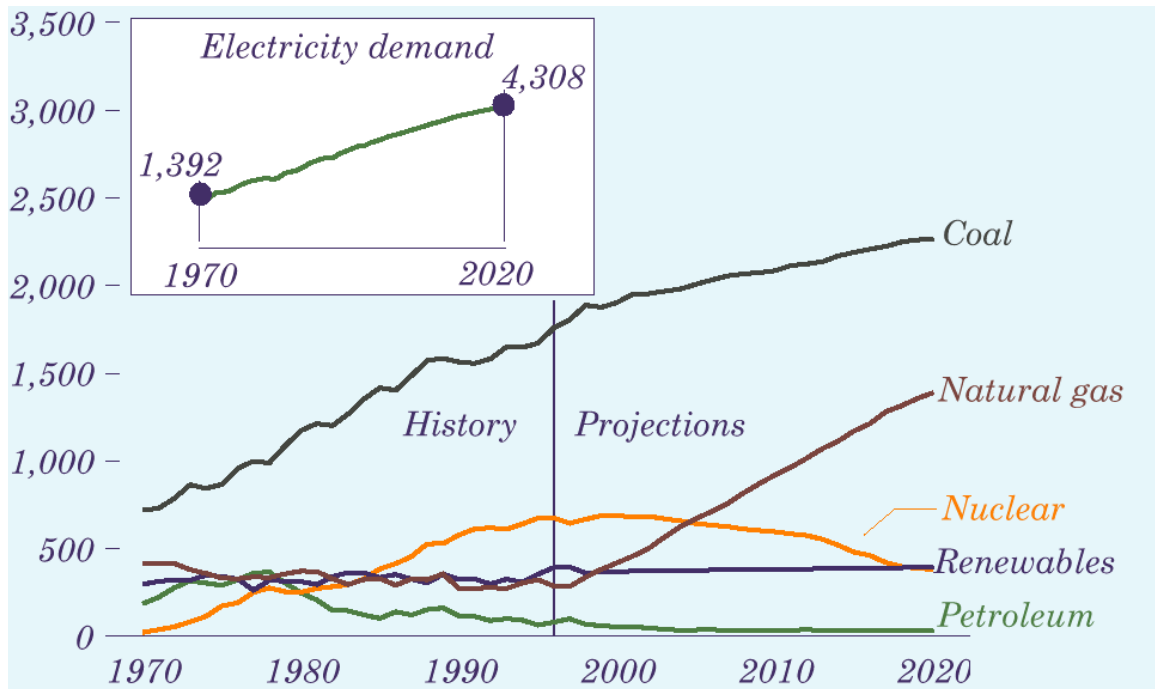


Figure 2.2 Projected fuel demand for electricity generation (DOE/EIA, 1997)

Table 2.1 Energy Prices to Electricity Generators by Source (1996 Dollars per Million Btu). Source – DOE/EIA, 1998a.

Energy Source	\$ / million Btu (1996 Dollars)
Petroleum Products	3.27
Distillate Fuel	4.90
Residual Fuel	3.07
Natural Gas	2.64
Steam Coal	1.29

A significant event in the near future of the coal industry is the deregulation of electrical power generation. A DOE/EIA report (1998a) states that this deregulation will have a major impact on the coal mining industry, including increased price volatility and the continuation of the restructuring and consolidation currently occurring in the coal industry.

2.1.2 Virginia Coal Industry

An understanding of the Southwest Virginia coal industry is important as a background to a resource estimate. Figure 2.3 shows the annual coal production for the individual counties and the cumulative production for the field since 1975. Buchanan and Wise counties produce the most coal while the production from Dickenson county, once a more productive county, has fallen over the last several years (VCCER, 1998). Coal from the Southwest Virginia field was sold to 24 states in 1992 (DOE/EIA, 1994a), and underground mine production accounts for approximately three-quarters of the state's tonnage (VCCER, 1998). While total production has remained relatively constant, the number of mine workers has decreased from over 9000 in 1993 to about 6500 in 1997 (VCCER, 1998), indicating increased efficiency in the mining process. During this time, there were approximately 250 producing mines in the field, commonly employing about 25 mine workers and with an average production of only about 150,000 tons of coal (VCCER, 1998). Since 1975, the Virginia mine price of coal has consistently been in the range of \$25 to \$35 per ton (current dollars), but when adjusted by the Consumer Price Index, the mine price has fallen from nearly \$80 per ton to about \$25 per ton in 1996 (1992 dollars) (VCCER, 1998).

The landscape of U.S. and Virginia coal mining has changed throughout its history. While demand, transportation, and legislation are critically important, a reliable knowledge of the existing coal reserves is foundational for continued health of the coal industry.

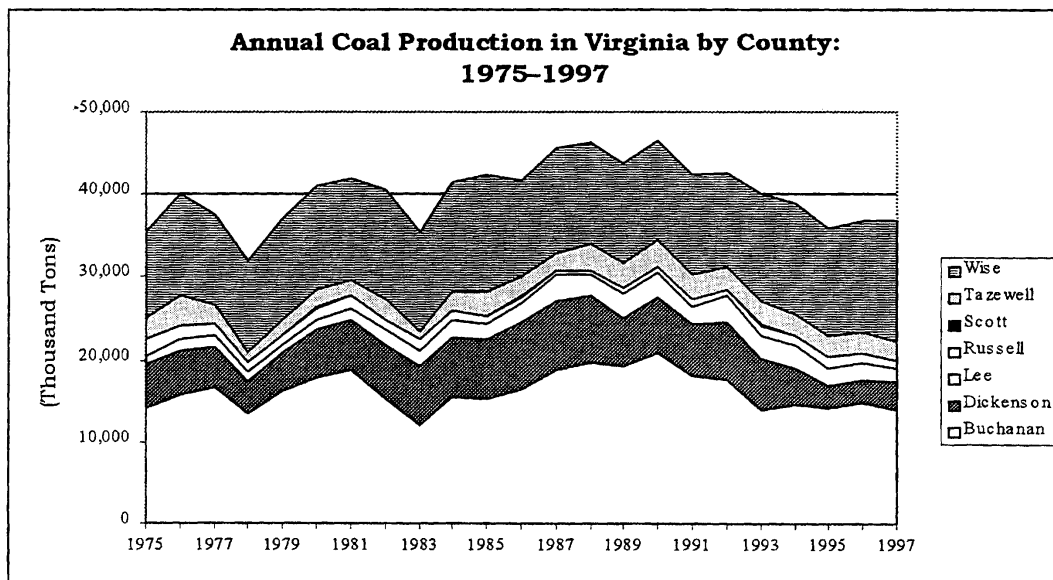


Figure 2.3 Recent Virginia coal production, by county (VCCER, 1998)

2.2 Previous Coal Resource Estimates

In examining coal resources of the United States and Virginia, it is first necessary to start with a clear grasp of terminology. Confusion exists between the terms ‘resource’ and ‘reserve.’ It is commonly understood both within the coal mining industry and from government definitions that the term ‘resource’ refers to coal existing in the ground while the term ‘reserve’ indicates coal which can be extracted economically under certain economic conditions, legislative guidelines, and technologic practices. This terminology will be followed in this dissertation.

2.2.1 United States Coal Resource Estimates

The United States Geological Survey (USGS) has been the primary federal agency to define a coal resource classification system and to fund studies of national coal resources. The currently accepted standard for coal resource classification in the United States is USGS Circular 891 (Wood et al., 1983) in which a coal resource is defined as any coal existing in the earth less than 6000 ft deep and more than 14 inches thick, if anthracite or bituminous, or more than 30 inches thick, if subbituminous or lignite.

Various resource divisions are based on seam thickness, depth, rank, and distance from the measurement point. Coal resources are sub-divided into measured, indicated,

inferred, hypothetical, and speculative, with larger groupings under the titles of identified and undiscovered. *Measured* coal resources are within 0.25 miles of the data sampling points. If the coal is more than 0.25 miles but less than 0.75 miles from the measurement locations, they are termed *indicated* resources. Measured plus indicated resources are collectively called *demonstrated* resources. *Inferred* resources are between 0.75 and 3 miles from the measurement location. Coal that is suspected to be present but with no data points within three miles is termed *undiscovered*. A simplified version of this segregation is shown in Figure 2.4.

The total coal resource is estimated by adding the various categories described above. Measurement locations are plotted on a map with the different categories delineated (Figure 2.5). The volume of each of these categories is then determined by measuring the area in the plane of the coal seams and multiplying by the thickness of the coal at the measurement points. These volumes are then summed for each seam.

Several studies have been conducted to estimate coal resources in the United States. One study, the National Coal Resource Database, was a compilation on the basis of seam thickness (Carter et al., 1981). More recently, the USGS initiated a National Coal

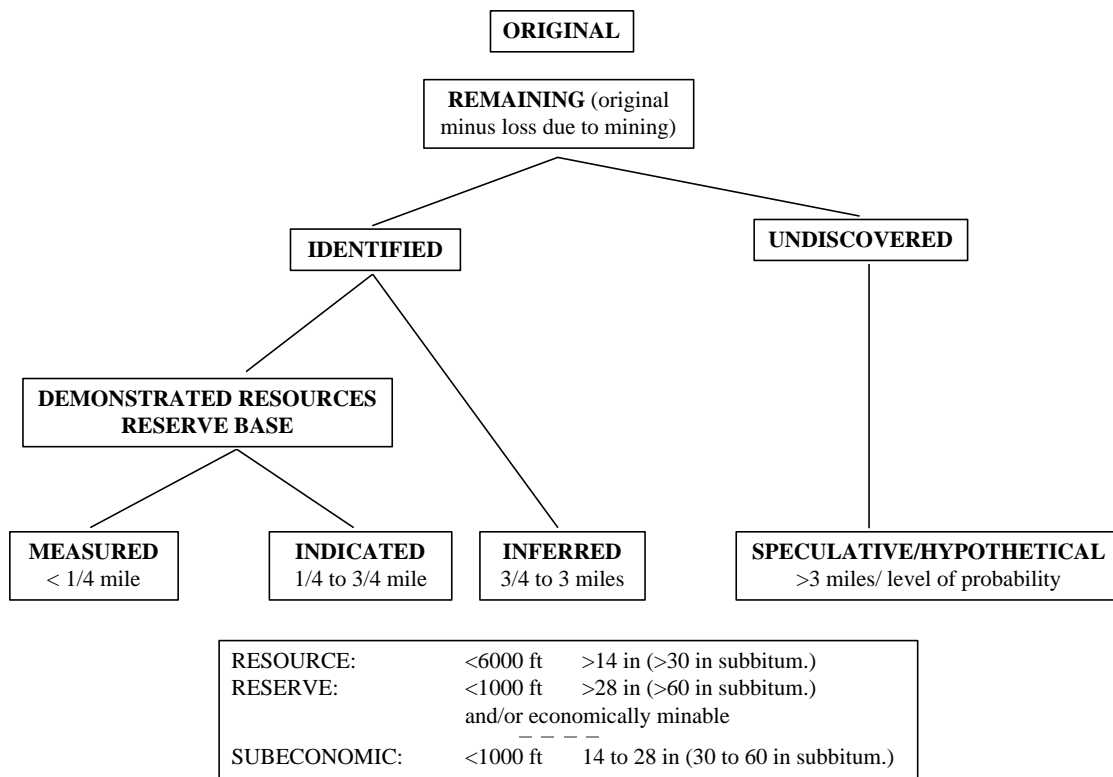


Figure 2.4 Terminology used in USGS coal resource classification system

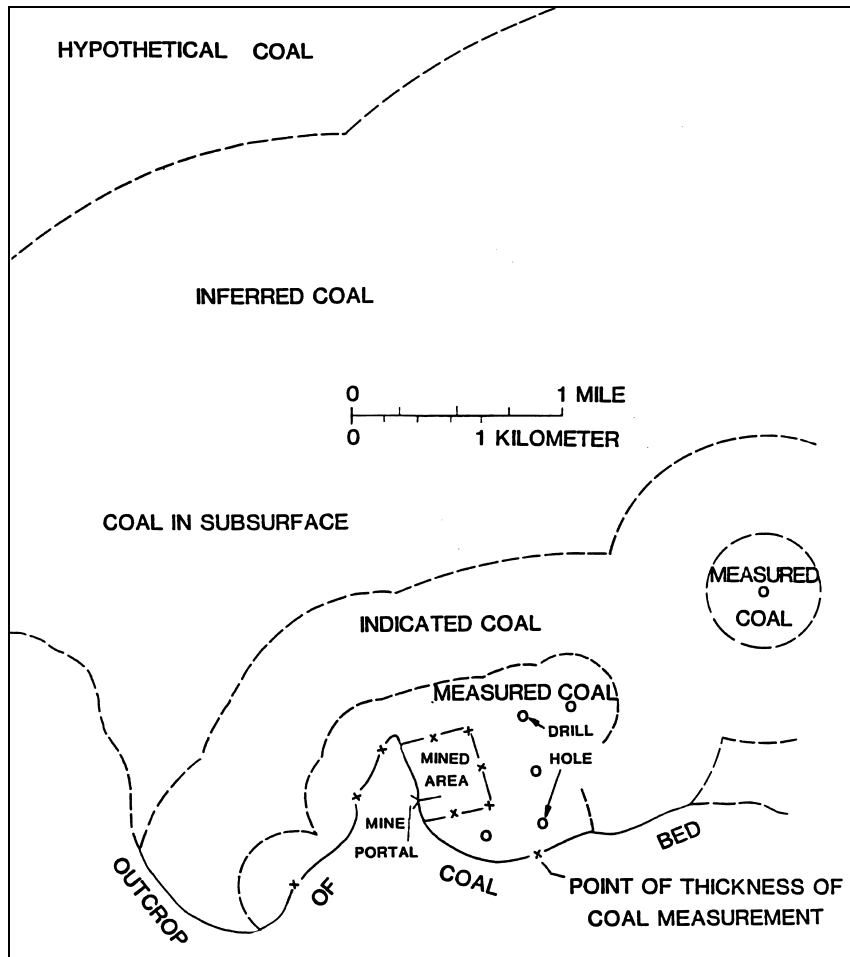


Figure 2.5 Schematic of terminology and measurement specifications used in USGS coal resource classification system (Wood et al., 1983)

Assessment, an on-going reassessment focusing on identifying and characterizing the *primary* coal producing beds in the United States. Results of this assessment are scheduled to be available in 1999 (USGS, 1996).

2.2.2 Virginia Coal Resource Estimates

Several estimates of the coal resources in Virginia have been completed. Averitt and Berryhill (1950) document the estimation arrived at by M.R. Campbell between 1913 and 1928 as a portion of a national study. Also, during the early 1920s a series of studies conducted jointly by the USGS and Virginia Geological Survey estimated coal resources (Hinds, 1918; Harnsberger, 1919; Giles, 1921, 1925; Wentworth, 1922; Eby, 1923). Hinkle (1969) estimated the strippable coal reserves of Southwest Virginia. The currently accepted study was completed by the USGS (Brown et al., 1952), and subsequently adjusted for the Pocahontas #3 bed (DOE/EIA, 1981). The results of these

Table 2.2 Estimates of Original Coal Resources in Virginia
(from Brown et al., 1952; DOE/EIA 1981)

Study	Original Coal Resource Estimate
Campbell (1913-1928)	21,149 million in Eastern and Southwest fields
USGS/VGS (1918-1925)	27,200 million in Southwest field
Brown et al., USGS (1952)	11,696 million in Southwest field
DOE/EIA (1981)	12,296 million in Southwest field

studies are shown in Table 2.2. It is important to note that the study techniques, quality, and quantity of data were different for each of the studies.

While the results from Brown et al. are a useful starting point, many additional coal resources have been identified in the nearly 50 years since the completion of that study. These data come primarily from deeper seams which had been poorly explored earlier. One study showed that in Lee County the original coal resource estimate was about twice that of Brown et al. (Campbell et al., 1991). The study, funded by the USGS, was based on a careful correlation of coalbeds, use of published data from mine maps and drill holes, and the use of computer programs to calculate the volume of remaining coal. Results from 475 surface sample points and 111 drill holes showed 871 million tons of remaining coal, compared to 432, 442, and 466 data sources, respectively, for studies by VDM, DOE/EIA, and Brown et al. (Campbell et al., 1991).

Current studies place emphasis on continuity of coalbeds between measurement locations in an effort to increase the accuracy of the estimate. State studies for southwest Virginia have correlated 57 coalbeds in southwest Virginia, giving lateral extent, thickness ranges, relative location to other geologic beds, and other names given to the beds (Nolde et al., 1994).

2.3 Interpolation

Incomplete knowledge of the distribution of quality and thickness of a coal seam results in the necessity of estimating, as opposed to calculating, reserves. Several different approaches have been used for interpolating between data points. This discussion will include a description of several of the more common techniques used for interpolation, and thus for reserve estimation, along with their advantages and disadvantages.

2.3.1 USGS Technique

The USGS technique uses the classification system described in Section 2.2.1 and separates the coal bed into each of the different categories (Figures 2.4 and 2.5) (Wood et al., 1983). Areas for each category are determined with a planimeter, grid block counting, or some other technique. By assuming constant thickness within each

designated area, volumes are calculated. The volumes are then summed for each designation and totals are then estimated. Reliability is assumed with the different categories within the classification system. This is a commonly accepted technique for the coal mining industry, but does not accurately reflect the impact of geologic variations.

2.3.2 Area of Influence Methods

Several simple techniques assume equal thickness or quality within an area of influence (Popoff, 1966). Included in these methods are the triangular, polygonal, cross-section, and isopach techniques. The triangular method divides the area under consideration into discrete triangular units with a sampling site at each corner, as shown in Figure 2.6. The quality and thickness of the coal seams is then calculated assuming linear change between the sampling points. The disadvantages of the triangular method include: it cannot be easily extended to the boundary of the coal resource outside of the sampling points, it is difficult to computerize the formation of the triangles, and it is tedious when done manually. The advantages include that the technique is simple and conservative.

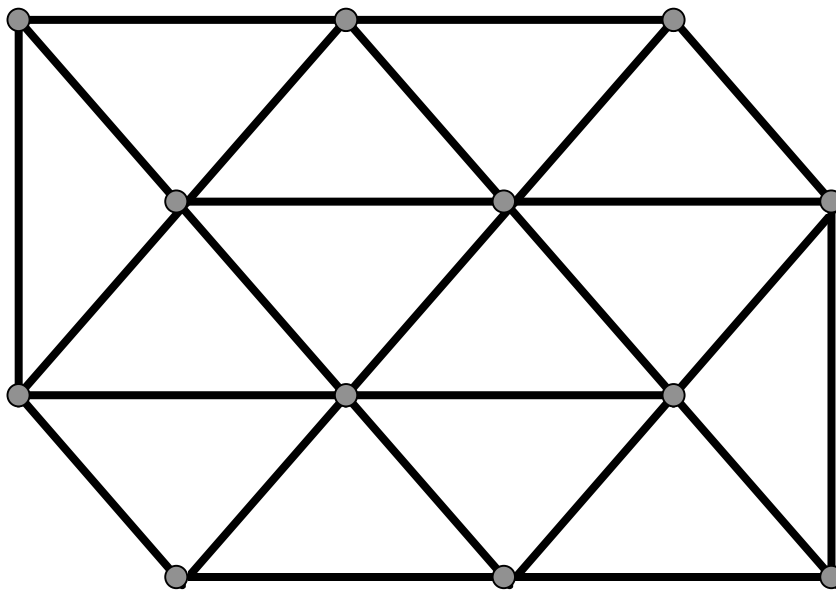


Figure 2.6 Schematic diagram showing discretization of an area using the triangular interpolation method for reserve estimation

The polygonal method is similar to the triangular method except that discretization of the area is with polygons instead of triangles and the sampling points are in the middle of the discrete area instead of at the corner (Figure 2.7). This allows the discrete areas to be extended to the boundaries of the coal resource. However, the generation of the polygons and the calculation of areas are still not simple, and uneven sampling densities result in a poorer estimate of the area.

The cross-section technique connects sampling points, creating cross-sections throughout the coal bed (Figure 2.8). Areas and volumes are then calculated by assuming linear change along and between the cross-sections. While the generation of the cross-sections is still tedious, the cross-sections are useful for other purposes in mine planning.

The isopach technique uses data from sampling points to create contour maps of constant thickness or quality (Figure 2.9), and areas can be determined from the contours. Given the areas and thickness data, volumes are calculated. The determination of the amounts of different qualities is very difficult to do manually as iso-thickness and iso-quality templates must be overlain. This method is now used primarily with the aid of computers.

The only error analysis for the Area of Influence techniques is obtained by the comparison of two or more independent estimations.

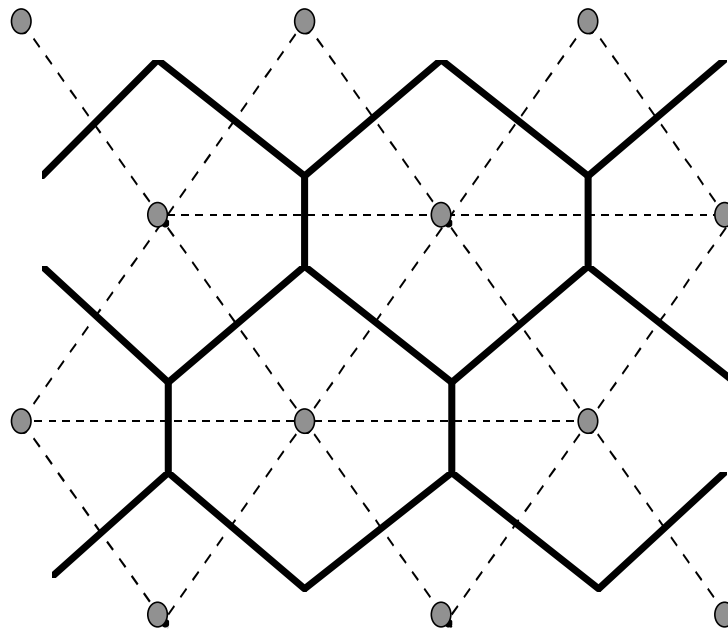


Figure 2.7 Schematic diagram showing discretization of an area using the polygonal interpolation method for reserve estimation

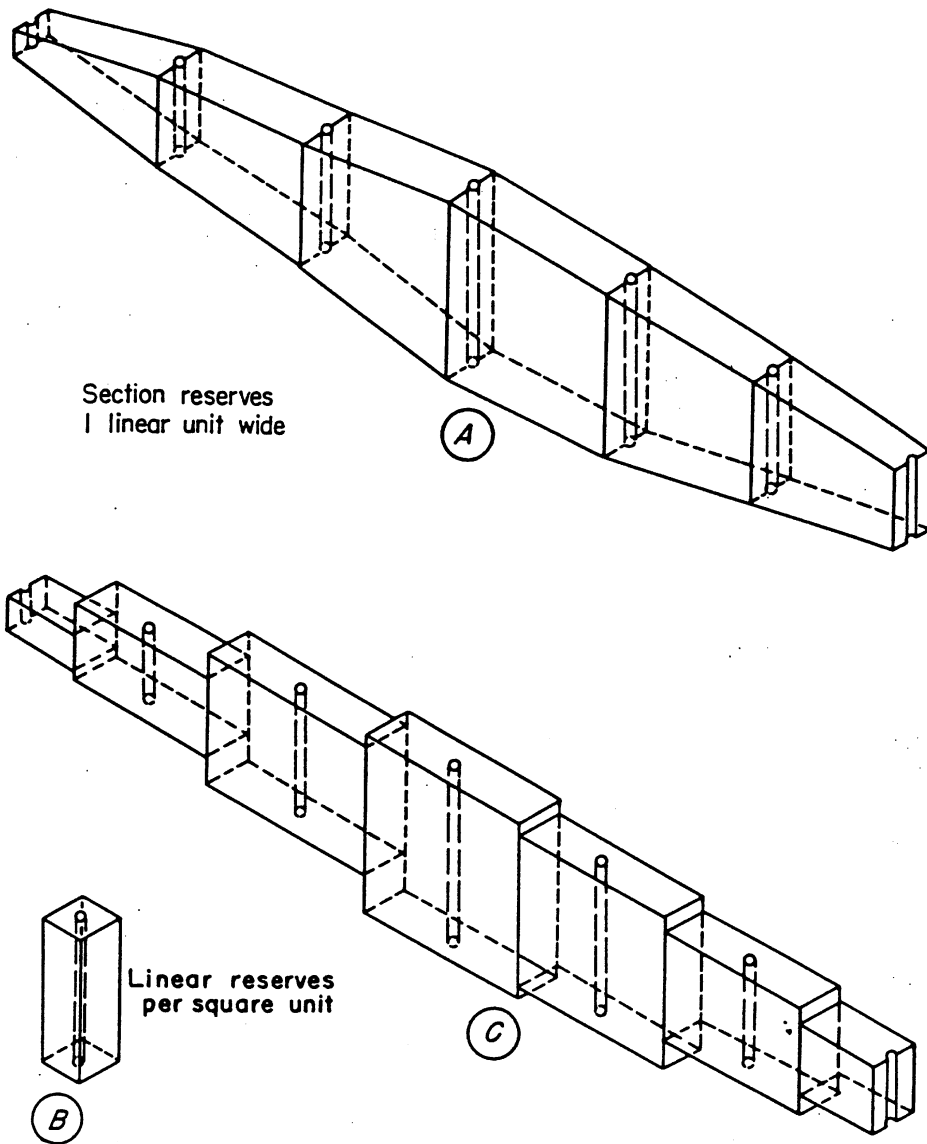


Figure 2.8 Schematic diagram showing discretization of an area using the cross-section interpolation method for reserve estimation; A) using gradual changes, B) using linear reserves per square unit, and C) using the rule of nearest points (Popoff, 1966)

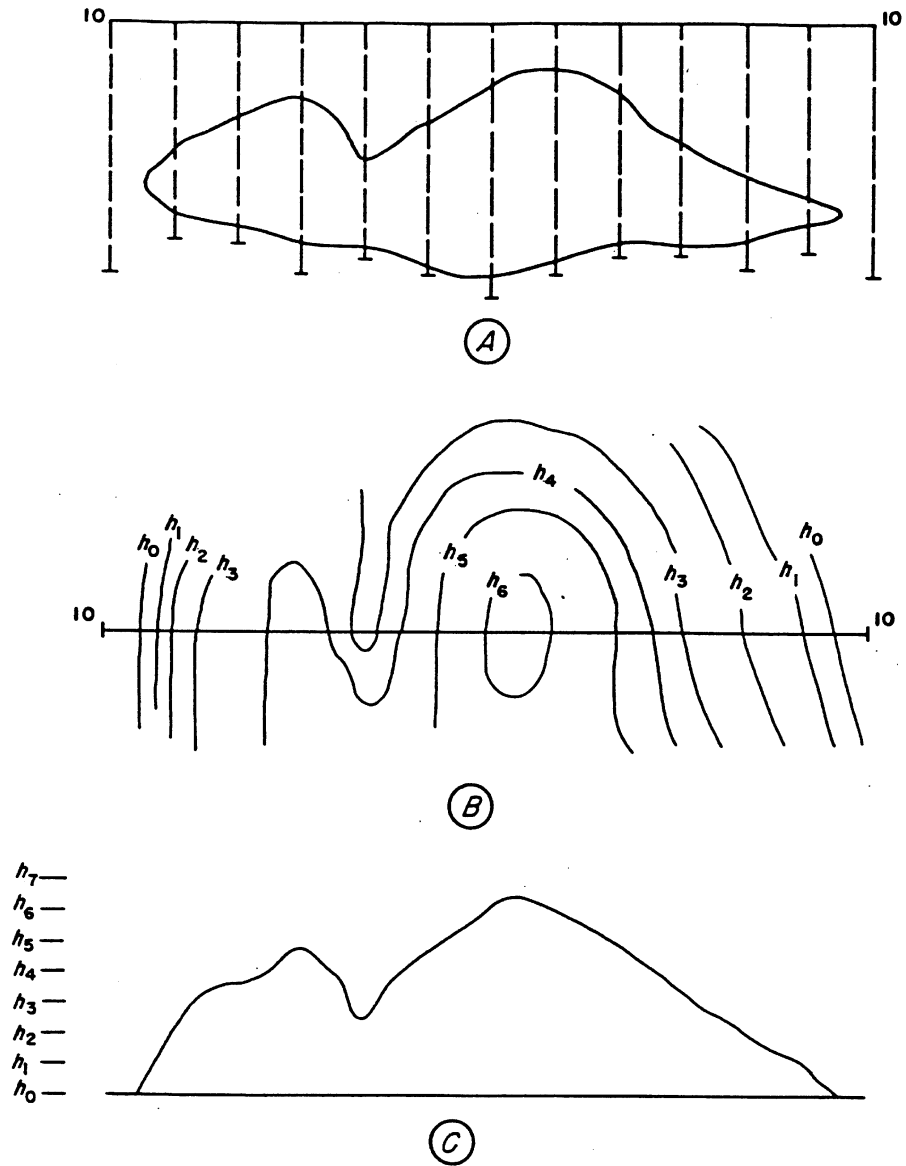


Figure 2.9 Schematic diagram showing discretization of an area using the isoline interpolation method for reserve estimation; A) cross section of a mineral body along exploration line 10-10, B) isopach plan of the same mineral body along the exploration line 10-10, C) cross section along exploration line 10-10 made from isopach plan B) (Popoff, 1966)

2.3.3 Inverse-Distance Weighting

The Inverse-Distance Weighting interpolation technique allows the calculation of a thickness at a point by averaging the measured thickness at nearby points and assuming that the thickness to be calculated is most similar to the closest measurement points. As the distance from the measurement points increases, the influence of the point on the interpolation decreases. The amount of influence can be altered by changing the weight, with the inverse-distance and inverse-distance squared methods being the most common forms used. To calculate the interpolated value, the following equation is used:

$$g_i = \frac{\sum_{i=1}^n \left(\frac{x_i}{d_i^p} \right)}{\sum_{i=1}^n \left(\frac{1}{d_i^p} \right)}$$

where g = interpolated value at point i ,
 d = distance from point i to measured data point,
 x = value at measured data point, and
 p = power or weighting function.

A major problem with the Inverse-Distance Weighting method is that when many data points are used the interpolated surface may not always honor (match) the input data points because it is forced to an average (Wingle, 1992).

2.3.4 Spline Fitting

Interpolation between data points can be done by fitting a spline curve to the data points. A spline curve can be thought of as a rubber sheet that is bent to fit each of the data points while maintaining the minimum possible curvature for the entire sheet. This technique is best used for gently varying surfaces as abrupt changes close together can cause the interpolated surface to dramatically overshoot realistic values.

2.3.5 Kriging

The origin of the specialized field of geostatistics stems from the observation that geologic processes can be included in the traditional field of statistics to improve estimations. Work by Krige and Matheron in the 1960s resulted in a weighted moving average technique which minimizes the variance of the estimation errors (Krige, 1978). The technique is based on the concept that the *difference* between sampling points is a

function of the *distance* between the sampling points. This technique is known as kriging.

The fundamental tool used in kriging is the semivariogram, which is a plot of the distance between sample points versus the semivariance. The semivariance is defined as half of the average squared difference between sample points. Kriging is, therefore, a function of the average squared difference between sample points. A typical semivariogram is shown in Figure 2.10 along with the data from which it was generated. The point on the x-axis at which the semivariance becomes constant is termed the range, and is the distance between sample points at which variation is no longer spatially correlated. The corresponding point on the y-axis is termed the sill. The relationship shown by the semivariogram plot of Figure 2.10 is called a spherical model. Additional shapes and models are also available. After a semivariogram model which best matches the data is selected, the interpolation is performed using the semivariogram as a weighting function. Errors associated with kriging can be analyzed by plotting a variance surface which shows the calculated variance at all points. The disadvantage of kriging is that it requires many input points to obtain accurate results (Lam, 1983).

The value of describing the distribution of quality and thickness between measurement points has resulted in many different techniques being used. As computational power has grown, the complexity of the techniques has expanded. The interpolation technique used in a coal reserve estimate can dramatically influence the results obtained and should, therefore, be chosen carefully.

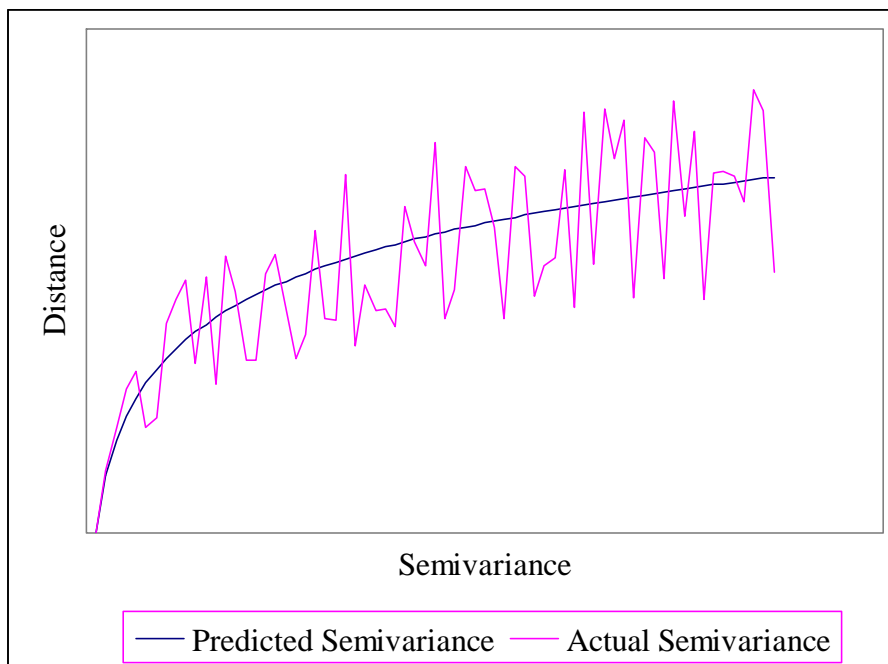


Figure 2.10 Sample semivariogram

2.4 Coal Models

While many different models have been proposed for estimating which portion of the remaining coal resource is a reserve, the goal of all coal analysis models is to predict future production based on current conditions. The three predominant types of models – production-based, restricted resource, and regionalized policy analysis – will be described and discussed below.

2.4.1 Regional Production Model

A model proposed by Milici, based on prior work by Hubbert (1962, 1972, 1973), states that the production history of a natural resource follows a bell-shaped curve (Figure 2.12). Since a natural resource, especially a fossil fuel, goes through the cycle of discovery, development, exploitation, and depletion, production generally increases to reach a maximum at the point at which one-half of the original reserves are depleted. Production then decreases as the coal resource depletion continues. The production curve is not smooth because of changing economic conditions and geologic variations within the resource.

Milici outlined this model for Central Appalachia and Southwest Virginia in several publications (Milici and Campbell, 1991a; Milici and Campbell, 1991b; Milici, 1997). For Southwest Virginia, he stated that the maximum production would occur between

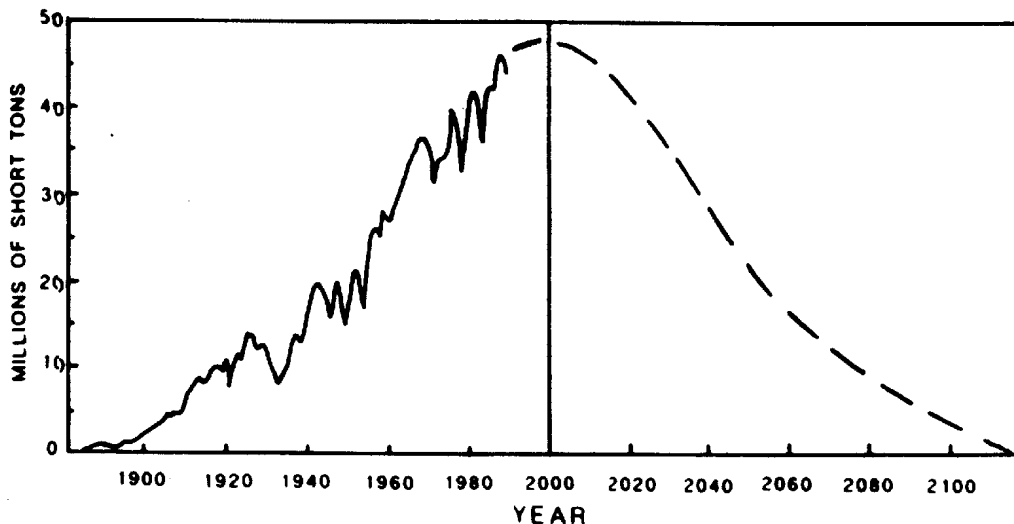


Figure 2.11 Proposed production cycle of coal in Southwest Virginia (Milici and Campbell, 1991b)

1989 and 2011 and would decrease to a production level of 20- to 30-million tons per year between 2020 and 2080 (Milici and Campbell, 1991a), or that production level would peak shortly before 2000, at a value of less than 50 million tons per year. As shown earlier, production has dropped substantially since a peak of 46.5 million tons in 1990.

Similar work was completed by Crabtree (1995) who forecast Southwest Virginia coal production by fitting a multiple linear regression model to six independent variables. The variables used included: 1) Virginia coal price times Virginia coal mining productivity, 2) Virginia mining company production levels, 3) Virginia coal reserves, 4) U.S. domestic electricity consumption, 5) U.S. coal exports, and 6) U.S. domestic industrial coal consumption. Values from 1979 to 1993 were used to generate multiple linear regression coordinates, and the model accounted for nearly 87% of the variation in Virginia coal production during these years. The model was then used to project future coal production in Virginia under optimistic, moderate, and pessimistic views.

The primary limitation to Milici's model is that conditions of development and shut-down in a mining region are not similar. In the state of Virginia, for example, railroads were slowly introduced to the region, with Buchanan County being the final county to receive this form of transportation. As mining production drops in the state of Virginia, the effect of transportation does not follow the same trend as during its development. Another concern with this model is the dependence on the definition of original *reserves*. Original resources are generally defined, as previously stated, but by definition the reserve level changes as technologic, economic, and legislative restrictions change.

2.4.2 Regional Resource Restriction Models

The systematic restriction of resources is another approach for estimating reserves based on a resource estimate. This approach is typically used for a localized scale (county or smaller), and can provide a valid reserve estimation if reasonable parameters and values are incorporated for the appropriate restrictions.

Resources may be restricted for various reasons, including: already mined out or sterilized by previous mining, limited by land-use or technological restrictions, lost during the mining process, or restricted by limits on mine operating costs. The relationship between resource definitions, along with terminology, is shown in Figure 2.13 (Eggleston et al., 1990, Rohrbacher et al., 1993).

The one true restriction used when evaluating coal resources, however, is that a satisfactory profit must result from the sale of the coal. Many of the restrictions do not prohibit the mining of coal, but they do reduce the profit made on it. For example, the

Original Resources minus:	Equals:
Mined and Abandoned Restricted by Technology or Land-Use Lost due to Mining and Washing Restricted by Operating Costs	Remaining Resources Available Resources Recoverable Resources Reserves

Figure 2.12 Relationships and terminology used in Resource Restriction models (Rohrbacher et al., 1993)

land-use restriction of a residence is not a restriction if the coal beneath the residence will pay for the relocation of the residence.

Because this technique was used in the reserve estimate described in this dissertation, the restrictions and previous studies will be described in detail.

2.4.2.1 Restrictions

2.4.2.1.1 Land-Use Restrictions

Many different natural and cultural land-based features restrict the availability of coal. The Federal Surface Mining Control and Reclamation Act of 1977 (OSMRE, 1988) designates certain features which must be protected from surface and/or underground mining. Included in this list of restricted features are water bodies, residences and public buildings, highways, railroads, federal lands, powerlines, pipelines, cemeteries, and oil and gas wells. Each type of feature will be briefly discussed.

Restrictions related to streams, lakes, and reservoirs differ for surface and underground mining methods. Small streams (less than 5 ft³/sec, mean average flow) can be diverted during surface mining. Larger bodies of water typically must be mined around with an adequate barrier between mining and the water body to prevent drainage from the body of water. Subsidence of water bodies that lie over underground mine workings can result in flooding of the underground workings. Adequate thickness must exist between the underground mine and the water body.

The impact of mining on dwelling structures is also regulated. Given adequate economic conditions, surface mining operations may choose to relocate individual residences, otherwise a 300 ft barrier is required by federal law between surface operations and residences. Groups of residences along with public buildings, such as hospitals, schools, and town or county facilities, cannot be moved. Adequate distance and overburden thickness are required by underground operations to ensure that surface subsidence does not structurally damage the buildings.

Transportation routes, such as highways and railroads, can be relocated to allow surface mining to take place. However, the relocation requires appropriate authorization and must be economically feasible for the mining company. Federally funded highways cannot be moved and require a 100 ft barrier between mining and the highway. As with dwelling structures, an adequate distance and overburden thickness is required so that underground operations do not damage the surface structures due to subsidence caused by mining.

Surface mining is not allowed in National Parks, National Wildlife Refuge Areas, the National System of Trails, National Wilderness Preservation Areas, the Wild and Scenic Rivers System, National Recreation Areas, and areas with endangered species. Surface and underground mining is permissible in National Forest lands, but must be authorized.

Areas of unmined coal (buffers) are typically left around powerlines, pipelines, cemeteries, existing underground mines, and oil and gas wells at both surface and underground mines (Eggleston et al., 1990). A typical buffer width is 200 ft. In the case of oil wells, if the wells are abandoned, they can be plugged to allow a smaller barrier to be left in underground mines.

2.4.2.1.2 Technologic Restrictions

While land-use restrictions are fairly straightforward, technological restrictions are much more complicated. Seam depth and thickness, geology, and multiple-seam interaction all establish whether a bed is economically mineable. Seam depth and thickness limitations differ for surface and underground mines. For coal to be economically surface mined, the ratio of overburden volume to coal volume must typically be less than approximately 15 to 20. Thus, seam depth and thickness are inter-related for surface mining. Underground mining equipment has not been developed to remove seams of less than 25-30 in. without also removing large amounts of roof or floor rock, which is generally costly to separate. Seams which are located below drainage level require a box cut, slope, or shaft, which adds substantially to the start-up costs of the mine, making many coal resources uneconomic. If the seam is more than 1,500-2,000 ft deep, ground control in an underground mine becomes an increasing problem, often resulting in the abandonment of coal properties.

Faults, folds, sand channels, and severe seam dip are geologic features which can restrict mining. Seam disruptions, including faults, folds, pinchouts, and sand channels, require mining through additional rock, which increases the cost to produce coal. These geologic features can also result in safety hazards. Seam dips exceeding 5-10 degrees dramatically increase operating costs, especially in room and pillar mining.

Sterilization of reserves due to the interaction of overlying or underlying seams continues to be a major problem for many U.S. coal seams. Because of its significance in Southwest Virginia, interaction will be discussed more thoroughly than the other technologic restrictions. In Appalachia, coal recovery from longwalls above or below mined-out seams may be impossible or significantly restricted because of multiple-seam conditions. Determining which areas have not been sterilized is an essential precursor to long-range planning and resource conservation. Current techniques used in reserve calculation underestimate and oversimplify the sterilization caused by seam interaction. By understanding the mechanisms involved in multiple-seam interaction and the tools available for assessing and mitigating the effects of interaction, the most efficient use of remaining resources can be achieved.

Interaction between workings in overlying or underlying seams has been demonstrated to have a major effect on reserve estimation (Sellami et al., 1994). Current standards for estimating reserves assume complete sterilization if the seams are within 40 ft of each other and no interaction effects if the innerburden is more than 40 ft thick (Wood et al., 1983, Rohrbacher et al., 1993). Prior work has produced computerized evaluation methods to determine coal reserves influenced by multiple-seam mining (Zhou et al., 1990). To evaluate multiple-seam effects, hazard maps have also been used with significant success, and they permit the user to determine the degree of damage that is acceptable during the mining process (Fraher et al., 1992). In evaluating a property, the cost of mining through areas adversely impacted by interaction must be determined. Based on the severity of the interaction, costs can vary from increased support needs to abandonment of the property.

The primary interactions associated with overmining are due to subsidence or pressure arching (Holland, 1951). Zones of horizontal compression and tension are created by trough subsidence of the upper seam. A tensile zone results in fractured, reduced strength coal, floor, and roof, causing an increased potential for roof falls. The zone of horizontal tension can also be influenced by increased vertical stresses due to bending of the overlying beds, resulting in potential entry convergence. Stiffer geologic strata (such as sandstones or limestones) tend to bridge the voids of the lower mine, reducing the effect of subsidence in the upper seam. Additionally, a greater lower seam mining height and a higher extraction ratio yield more subsidence. Results of case studies show that as time increases between the mining of two seams, conditions generally improve (Webster et al., 1984). Interseam shearing, a massive block subsidence resulting in a roof fall extending from the lower seam to the upper seam, can also be a problem with overmining if the seams are within approximately 50 ft of each other.

The transfer of stresses beneath remnant structures (such as coal pillars), results in concentrated areas of increased vertical stress, and is the primary interaction encountered in undermining. The effects of workings in overlying seams can extend to depths of 110 ft for room and pillar mining, and up to 700 ft for an active longwall (Scurfield, 1970). Stiffer materials, such as sandstone and limestone, tend to reduce the distance of stress

transfer, while softer materials, such as shales, tend to transfer stress over greater distances.

The stresses created by undermining result from the abutment stresses developed in the upper seam. Development, forward, side, and rear abutment stresses all transfer to the lower strata. Room and pillar mining only results in development stresses. In longwall mining and pillaring, forward, side, and rear abutment stresses are also produced, resulting in the transfer of much higher stresses than normally encountered in room and pillar mining. High vertical stresses can cause face weighting, floor heave, and excessive rib spalling.

2.4.2.1.3 Legislative Restrictions

Legislative decisions dramatically impact the coal mining industry. As an example, requirements of the Environmental Protection Agency affect coal reserve estimation by reducing the value of coal which produces more than 1.2 lbs. of sulfur dioxide per million Btu, thus reducing overall coal resources (CFR, 1987). Restrictions are also enforced for chlorine content and may soon exist for carbon dioxide and nitrogen oxides (DOE/EIA, 1999b). Because of these restrictions, not only is the chemical content of the coal important, but the capability of removing the offending chemical from it is also critical.

2.4.2.2 Resource Restriction Studies

2.4.2.2.1 USGS Coal Availability Studies

Coal availability studies have been completed by the USGS for estimating reserves that are unaffected by the above types of restrictions. The USGS procedure for calculating coal availability is defined as original coal resources minus coal mined and lost in mining and coal restricted by technological and land-use considerations (Eggleston et al., 1990). A pilot study was performed in Matewan quadrangle in extreme eastern Kentucky. Results of the study found that of the original coal resource, 13% had been mined, 2% was restricted by land use, 23% was restricted by technology, and 35% was available but did not meet the EPA compliance standards, leaving 27% available and low sulfur (Figure 2.14).

Several of the coal availability studies document results from southwest Virginia. Given data from 297 coalbed locations and 174 drill hole summaries, available coal resources in the Appalachia quadrangle were estimated as well as the effect of technologic and land-use restrictions. Approximately 30% of the remaining coal resources are restricted, with 97% of the restriction being technologic (Sites and Hostettler, 1991a).

A coal availability study was completed for the Wise quadrangle using 234 coalbed measurement locations and 87 drill hole summaries. The study found that 31% of original resources were restricted by technologic or land-use restrictions, with 90% of the restrictions being technologic and only 4% of the original resources being previously mined (Sites and Hostettler, 1991b).

Sites et al. (1991) have reported the results of a coal availability study in the Vansant Quadrangle. They found that, as with the Appalachia and Wise studies, approximately 30% of the remaining resources were restricted, primarily due to technologic conditions.

ORIGINAL COAL = 986.5 MILLION SHORT TONS

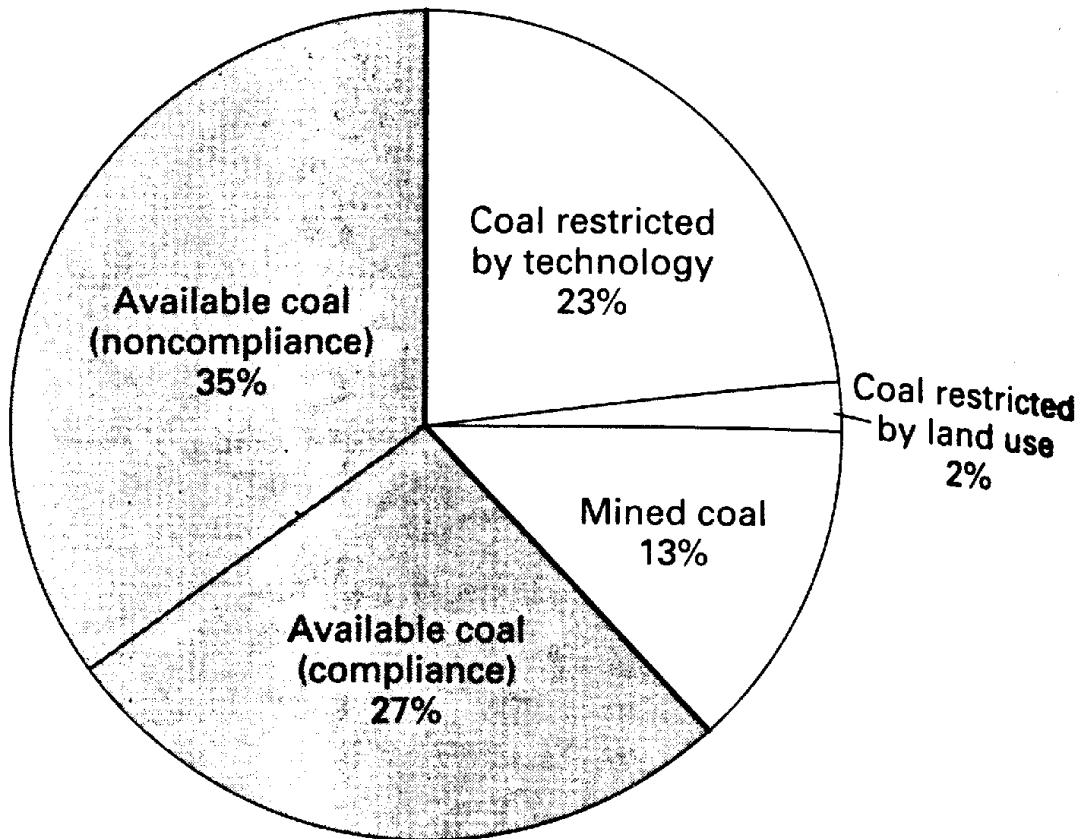


Figure 2.13 Results of the pilot study of the coal resources in the Matewan quadrangle. Restricted, mined, and available coal are shown as a percentage of the original coal resources (Eggleston et al., 1990)

2.4.2.2.2 USBM Coal Recoverability Studies

Following the USGS coal availability studies, the United States Bureau of Mines (USBM) conducted coal recoverability studies which added economic factors to the USGS estimations. The procedure adopted by the Bureau for estimating economically mineable coal goes beyond the USGS coal availability studies by evaluating mining losses, washing losses, mine operating costs, and sulfur content. For the Matewan Quadrangle in Eastern Kentucky, the pilot study found that 59% of the coal resource was available, but nearly half of that was lost in mining and washing, and at a sales price of \$25 per ton (relative to 1990 market), only 7.5% of the original coal resource could be economically mined (Figure 2.16) (Rohrbacher et al., 1992). A software package was developed by the USBM to evaluate prefeasibility-level mining costs for a given coal property, using this method. It allows an analysis of up to 25 seams with up to 5 different mining methods at a property (Plis et al., 1993, Suffrendi et al., 1994).

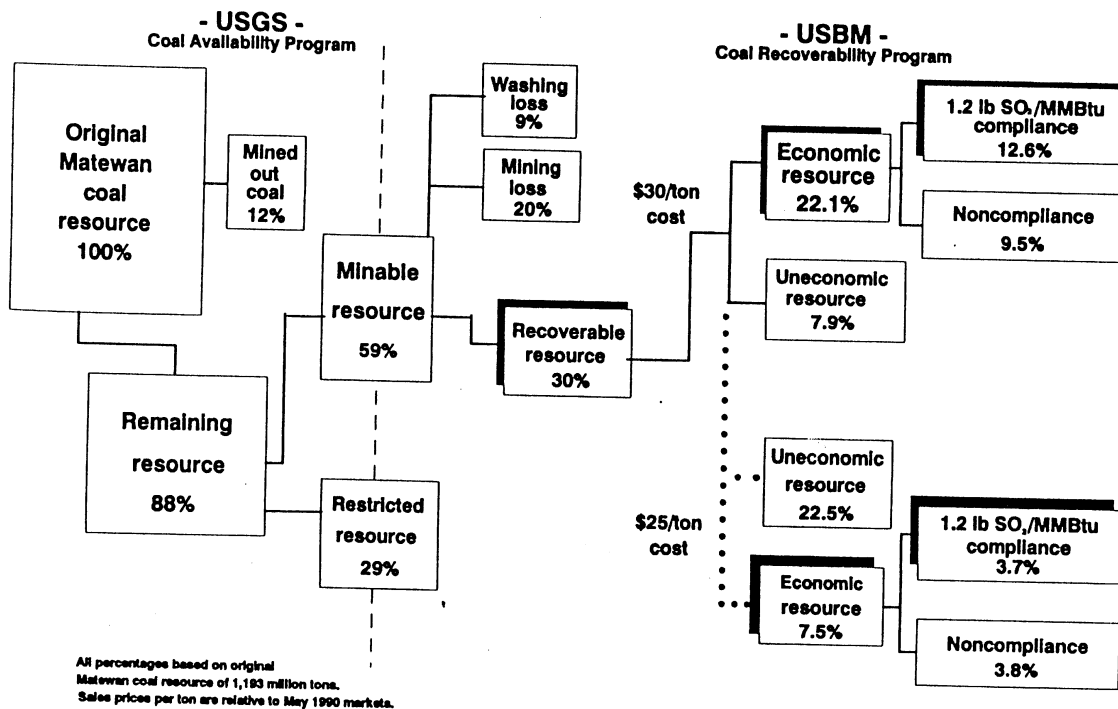


Figure 2.14 USGS/USBM coal resource programs – Matewan quadrangle results chart (Rohrbacher et al., 1992)

2.4.3 Economically-Based National Policy Analysis Models

Several models have been developed which simulate nation-wide coal production, transportation, and demand. These models are based on costs and are used to analyze the impact of various policy decisions, such as decreased sulfur emissions or increased productivity, on the production and consumption of coal. The models typically segregate the country into individual production, transportation, and/or demand regions, resulting in better performance for national evaluation than for local estimations. A total of four models will be reviewed. The first two will be reviewed briefly, while the second two, which are more common, will be treated in greater depth.

2.4.3.1 Resource Allocation and Mine Costing Model (RAMC)

The Resource Allocation and Mine Costing Model (RAMC) was developed by the United States Department of Energy / Energy Information Administration (DOE/EIA, 1992). The model divides the country into 32 supply regions and separates coal into 5 heat contents and 6 sulfur contents. Mining costs are calculated based on capital, labor, and power/supply costs, each with escalation factors. The model assumes all mines operate at full capacity and that demand equals production over the long term.

2.4.3.2 Coal and Electric Utilities Model (CEUM)

The Coal and Electric Utilities Model (CEUM), by ICF, is similar to the RAMC model but it includes development costs, production decreases near mine shut-down, and accommodates short-term price fluctuations through rents (ICF, 1989). The CEUM model divides the country into 40 supply regions and separates coal into 7 heat/volatile matter levels and 7 sulfur content groups, plus an additional anthracite group. Production is estimated as a function of depletion, labor productivity, and costs.

2.4.3.3 Data Resources Inc.(DRI)/Zimmerman Model

Data Resources Inc. has developed a coal production and demand forecasting service for steam coals (Zimmerman, 1981). The forecasts were based on a model which divided the country into 6 production regions and 12 demand regions. Coal was separated into eight sulfur categories. A production tonnage was output for each region and sulfur group, along with transportation tonnage along routes and delivered price to each region.

A six-step process was used to develop the forecast. An initial electricity price was assumed which then determined an initial demand for coal in each region. If the price was higher than other energy sources, the initial demand would be lower. With the initial demand determined, the supply module would estimate the cost to mine the coal as a

function of the region and sulfur content. The transportation module then estimated the cost to transport the coal from the supply region to the demand region. In its fourth step the program would minimize the cost of production and transportation for each demand region determined by allowable sulfur emissions in the region. The program would then determine electricity prices from the production and transportation costs, which would set the electricity prices and subsequent demand. These parameters could then be re-entered to the model, replacing the initial assumptions, and the process iterated.

In the DRI/Zimmerman model the cost to mine a unit of coal depended on the amount of production at the mine, a disturbance factor, and either seam thickness, for a deep mine, or stripping ratio, for a surface mine. The seam thickness and stripping ratio for a given production region are assumed to follow a log-normal distribution.

The production of the mine is calculated from the number of working sections, the seam thickness, and the number of openings to the seam (drifts, slopes, and/or shafts). For a deep mine this relationship is:

$$Q/S = A Th^\gamma S^\beta Op^\alpha \varepsilon$$

where: Q = output mine production,
 S = number of sections at mine,
 A, γ , β , α = constants,
 Th = seam thickness,
 Op = number of openings to the seam, and
 ε = disturbance factor.

The relationship is similar for a surface mine:

$$\log(\text{MUF}) = -0.447 + 0.612(\log RQ) + 0.507(\log N)$$

where: MUF = maximum usefulness factor
 (bucket capacity multiplied by machine radius),
 R = stripping ratio (ft of overburden to ft of coal),
 Q = total mine output (overburden and coal),
 N = number of machines in use.

The cost to mine is then calculated as:

$$E = \alpha + \beta S + \xi$$

where E = expenditures
 α , β = constants
 S = number of sections at mine, and

ξ = disturbance factor.

Transportation costs for the DRI/Zimmerman model are based on the use of unit trains.

A primary limitation of the model is that it assumes that all the coal of lowest price is mined before any more expensive coal is extracted. Additionally, there is some question about whether the assumed log-normal distribution of coal seam and stripping ratio is an accurate description of these parameters.

2.4.3.4 Energy Information Administration Coal Market Module

The Coal Market Module of the National Energy Modeling System by the Department of Energy, Energy Information Administration is a regional model similar to the DRI/Zimmerman model (DOE/EIA, 1998b). Two additional submodules, one for distribution and the other for production, are used in conjunction with the demand module. Coal from 11 supply regions is divided into 4 thermal and 3 sulfur ranges. Distinction is made between underground and surface mines. Output from the Coal Market Module is compared to results from the Petroleum Market Module and used in the Coal Distribution Module.

Input parameters are used to determine mining costs, which include coal production, mine mouth coal prices, miner wages, labor productivity, cost of mining equipment, and price of diesel fuel. Additionally, annual growth rates for equipment costs, labor productivity and wages are also factored in. Outputs from the model include price/production curves for each supply region, mine type, and coal type.

The coal distribution submodule is used to determine transportation parameters for domestic and international shipment. The 11 supply regions contain 34 supply sources which feed 13 demand regions. The coal demands are estimated with the Electric Power submodule while the coal supply is estimated from the Coal Production submodule of the National Energy Modeling System. Five major coal supply sectors are included: utilities, industrial (private electricity generation), metallurgical, residential, and export.

Each coal supply curve has a heat, sulfur, and ash value connected to it. Coal distribution is constrained environmentally and technologically because coals with certain characteristics cannot be used economically in particular areas. Transportation constraints occur from a lack of local competition and reliability constraints are determined for transportation zones. The Coal Market Module was developed as a national coal model, and as such performs well, however, because the nation is regionalized by the model, it cannot be used for regional or local reserve estimates.

Many different variables influence the results of a regional coal reserve estimate. Understanding the current local and national coal industry, prior resource studies, and the methods and models used, is essential for estimating Southwest Virginia coal reserves.

CHAPTER 3 – DATABASE FOR GIS EVALUATION OF SOUTHWEST VIRGINIA COAL SEAMS

A comprehensive database was established for use with a geographic information system to allow the evaluation of the coal resources of Southwest Virginia. This chapter describes the Southwest Virginia coal geology, discusses geographic information systems, then describes the data sources used to develop the database.

3.1 Southwest Virginia Coal Geology

The coalfields of Southwest Virginia, home to approximately 130,000 people, are in hilly ground covered by deciduous forests. Coal has been deposited under an area of more than 1,000 square miles. A generalized stratigraphic section of the Southwest Virginia coal field shows approximately 30 primary coal seams deposited in the Pennsylvanian era which have been mined (Figure 1.2). However, over the last 50 years, production has come from more than 80 seams (VCCER, 1998). Several of these seams may be the same seam, however with different local names.

The seams analyzed in this study are shown in Table 3.1. The production from these seams accounts for 1459.5 million tons of the 1613.2 million tons (90.5%) produced between 1951 and 1997, and 31.6 of the 36.9 million tons (85.7%) produced in 1997 (VCCER, 1998). These seams were chosen primarily because of the abundance of data available for them. It is recognized that some deeper seams (such as Greasy Creek, Lower Seaboard, Upper Horsepen, and Squire Jim) contain significant quantities of coal, but the small amount of data available, combined with the high economic cost of sinking the necessary shafts to develop these seams, makes them less attractive for a meaningful reserve estimate.

Table 3.1. Seams studied in this estimate

Seam	Seam	Seam	Seam
High Splint	Kelly	Hagy	Tiller
Morris	Imboden	Splashdam	Pocahontas No. 3
Pardee (Parsons)	Imboden Marker	Upper Banner	
Phillips	Clintwood	Lower Banner	
Low Splint	Blair	Kennedy	
Taggart	Lyons (Eagle)	Aily	
Taggart Marker	Dorchester	Raven (Red Ash)	
Wilson (Standiford, Harlan, Upper Standiford)	Norton	Jawbone	

3.2 Description of Geographic Information System

A geographic information system (GIS) is a computer program which combines the functions of a database with mapping. This combination allows spatial data to be queried and analyzed, as with a database program, and also plotted, as with a mapping program. These capabilities permit large quantities of spatial data to be manipulated and analyzed in an efficient manner. A GIS differs from Computer Assisted Drawing (CAD) in that new data can be created by analyzing the available data. The GIS used in this project was ArcView by Environmental Systems Research Institute, Incorporated. This GIS was selected because of its ease of use, general acceptance, and ability to readily accept data of common formats. Because of the importance of the GIS to this project, a detailed description will be given of the tasks performed by a GIS and steps involved in using a GIS to solve a problem. Data format and components, and the locations of geographic features, will also be described. Finally, sources of error in a GIS study will be listed.

A functional GIS must perform several tasks, including data input, management, display and storage. The program must allow data input and must display data to allow verification. The data must then be stored and the database managed. Several different techniques exist for database management including the hierarchical, network, relational, and object oriented approaches. The GIS must then allow the database to be analyzed, typically in the form of queries. As an example of the data analysis function of a GIS, a coal property database could be queried to display all coal with thickness greater than 36 inches, sulfur content less than 1.5 percent, and ash content less than 15 percent. The final component of a GIS is a user interface, typically a graphical user interface, which allows the spatial data to be displayed with accurate relative location.

In solving a problem with a GIS, a series of steps must be followed. The problem to be solved must initially be clearly defined so that both the question and the criteria needed to answer it, are clear. The database must then be built by initially finding data sources, then by considering the scale at which the data were collected. The resolution required to solve the problem determines the required spacing of data points. The map projection of the data sources must also be known so that the data can all be converted to the same projection. After the database is established, the analysis is completed by querying the spatial data. The results of the analysis are then interpreted and evaluated to determine if the initial problem is being solved. The results are then calibrated or verified. The database and/or queries are then refined, if needed. The final results are analyzed and presented so that the impact on the problem can be evaluated.

Spatial data can be represented in a GIS in either vector or raster format. The vector format identifies features by their characteristics and locations while the raster format is a series of squares or cells which are either filled or left empty. A vector format would represent a line as a beginning point connected to an ending point. The same line in raster format would be represented as a series of adjacent filled squares. Examples of data which are well represented by vector format include coal seam outcrops, outlines of previous mining, and physical features such as water bodies or roads. The distribution of

a variable, such as ash or sulfur content, is more readily described with the raster data format.

Any geographic feature represented in a GIS has four major components: geographic location, attributes, spatial relationships, and time. As an example, the *location* of a portion of the Pocahontas #3 seam can be described with a latitude and longitude or a northing and easting from a State Plane Coordinate system. The *attributes* of the seam at that location could include thickness, in-seam reject, and ash content. The *spatial relationships* could include the fact that it is above or below other seams and whether it is outcropping at the surface. *Time* features would include whether it had been mined and was still in existence at that location at the time desired.

Geographic data are referenced to locations on the earth's surface by using a standard system of coordinates. Local coordinates typically follow a state plane coordinate system, established for all or a portion of an individual state. International coordinates follow the Universal Transverse Mercator system. Geographic, geodetic, or astronomic latitude and longitude coordinates may also be used at a larger scale.

Errors can occur in a GIS-based analysis for a number of reasons. The age of the data acquired for the database must be determined to ensure that conditions have not changed. As an example, if working with seam descriptions more than five years old it must be verified that the seam hasn't been mined in that area in the interim. Errors can also occur if the coverage does not accurately match the real-world distribution – for example, if no data were collected for certain areas of the analysis. The scale of the original map must also be considered. To analyze a five-acre parcel with any level of precision requires that the input data must be sufficiently densely spaced. The purpose of the original data collection must also be taken into account when using that data for the database. If the data were collected for a purpose unrelated to the analysis, the measurements may not be reliable. Finally, errors can be introduced when converting between data formats. If the program only accepts comma-delimited data and the input data are in spreadsheet form, the conversion must be made properly.

3.3 Data Sources

Data sources were considered carefully for the reserve estimation because of accuracy concerns. Thickness data are reported by the mines to the state and federal governments. However, these data were not used because they would bias the database toward thicknesses which have been, or are currently being, mined. This situation would result in a database which shows thicker-than-true seams. Additionally, if two seams have similar quality characteristics, but coal from one seam sells for more than that from the other, a mine will, on occasion, inaccurately report which seam is being mined.

Publicly available data were used in building the database. By using these data, it was assumed that they were of good quality and of reasonable accuracy. While private data were considered for the database, they were very difficult to obtain due to confidentiality

concerns of the mining companies. The raw data used for constructing the database are given in Appendix A for each seam.

3.3.1 Outcrops and Previous Mining

The Virginia Division of Mines, Mineral and Energy (VDMME) published AutoCad drawing exchange (DXF) files of previously mined areas and the seam outcrops associated with that mining. These files were available from the VDMME at an internet file transfer protocol (ftp) site (pulaski.mme1.state.va.us). In their supplied form, the files provide data for an individual seam in an individual quadrangle. These files were combined into seam-wide extents for each seam. It is important to note that outcrop delineations were only available for quadrangles in which mining had been conducted in the past. More complete outcrop descriptions were obtained by augmenting the files with published outcrop descriptions in VDMME Publication 131 (Nolde, 1994). Thus, the outcrops for the reserve study were based first on the digital files made available by the VDMME, then augmented by Publication 131 to extend the outcrops into quadrangles in which no mining had occurred for the particular seam.

3.3.2 Thickness and In-Seam Reject

Thickness and in-seam reject data were taken primarily from VDMME Publication 131 (Nolde, 1994). This publication reports seam descriptions generally on a quadrangle-by-quadrangle basis and includes seam and parting (reject) thicknesses, innerburden content and thickness between adjacent seams, other names by which the seams are known, and, as stated previously, maps of formation outcrops.

This publication is the most recent of its type by the VDMME and represents the most up to date correlation efforts. Seam correlation is very important since a seam may be known in several localized areas by several different names. Similarly, a particular seam name may be used in several areas for what was initially thought to be the same seam, but has since been determined to be different seams.

Using thickness data from Publication 131 results in uniformly spaced data points, typically one or two thicknesses per quadrangle. While this data spacing is not as dense as would be desired for a localized reserve estimate, it is acceptable for a regional reserve estimate. Typically, each thickness point in Publication 131 represents the average thickness derived from multiple borehole measurements. In the cases where additional seam thicknesses were given for the quadrangle, these were included in the database. Frequently, a thickness range was given for a quadrangle, and in such cases both the minimum and the maximum were used and the data points were separated by 3000 feet. This practice resulted in a normal distribution of thickness within the quadrangle, i.e. both the minimum and maximum were used, but the majority of the areas in the quadrangle were defined as average thickness. A total of 521 thickness points and 408 in-seam reject points were obtained for the 26 seams.

3.3.3 Land-Use Restrictions

Digital 7.5-minute topographic quadrangles for the Southwest Virginia coalfield in AutoCad drawing file format (DWG) have been published by the VDMME. Data regarding land-use restrictions were extracted from these files. As an example, the delineation of railroad routes for each quadrangle were extracted and compiled together, resulting in a coalfield-wide plot of railroad routes.

United States Department of Agriculture, National Forest Service-owned land boundaries were obtained from the George Washington – Jefferson National Forest website (www.fs.fed.us/gwjnf/ftp/) as ArcInfo export files (e00). Both the proclamation boundaries (within which the Forest Service may purchase land) and the individual boundaries of currently owned lands were obtained.

3.3.4 Coal Quality and Washability

Quality characteristics, including sulfur, ash, and Btu/lb, were obtained from the USGS CoalQual database (<http://energy.er.usgs.gov/products/databases/CoalQual/index.htm>). A total of 332 points were obtained for the 26 seams, each point providing a sulfur and an ash content.

Washability data for the coal seams were available from USBM and DOE reports (Miller, 1957; Gray and Boley, 1958a; Gray and Boley, 1958b; Deurbrouck, 1963a; Deurbrouck, 1963b; Deurbrouck, 1966; Cavallaro et al., 1990). Weight, sulfur, and ash washability were obtained based on a specific gravity of 1.60. A total of 161 data points were obtained for ash and weight washability and 51 data points were obtained for sulfur washability.

3.3.5 Seam Elevations

Seam elevations are important for calculating overburden and innerburden thickness and were obtained from Bulletin 84 (Miller 1974). Seam elevations were also obtained by establishing the elevation of the outcrops based on the ground-surface elevations from the digital topographic quadrangles.

3.4 Database Development

To compile the database, many data points had to be reformatted or new parameters calculated from existing data. Point location measurements, such as seam thickness and quality parameters were transcribed from the published data sources into spreadsheet files, which could be read by ArcView. AutoCad files, i.e. the outcrop, prior mining files, and land-use restriction files were combined for all quadrangles on a seam-by-seam basis, so that the outcrops of each seam were contained in a single file. These files were

then brought into ArcView. All features were projected onto the North American Datum 1927 Virginia South of the State Plane Coordinate system.

3.4.1 Interpolation

Several different interpolation techniques were evaluated for generating parameter distributions between sample locations. Linear kriging, inverse-distance squared, spline, and triangular interpolation were evaluated to compare results relative to each other. The thickness distribution for three different seams (Splashdam, Clintwood, and Upper Banner) was calculated using each of the four techniques. Figure 3.1 shows the average of these distributions for each seam and interpolation method. The results showed that the spline technique calculated the lowest average thickness for the Splashdam and Upper Banner seams, but the highest average thickness for the Clintwood. The triangular and linear kriging methods consistently calculated the thickness near the average of the four techniques. However, the triangular method does not allow extrapolation beyond the data points and the linear kriging produced unrealistic artifacts away from the data points. The inverse-distance squared method was selected for interpolation.

Individual grids were generated for the seam thickness and each of the quality parameters (sulfur, ash, in-seam reject) using the inverse-distance squared interpolation method. The inverse-distance squared method was used because of its ease of use within the GIS and its reasonable results, described in the previous paragraph. The cell size of the grids was

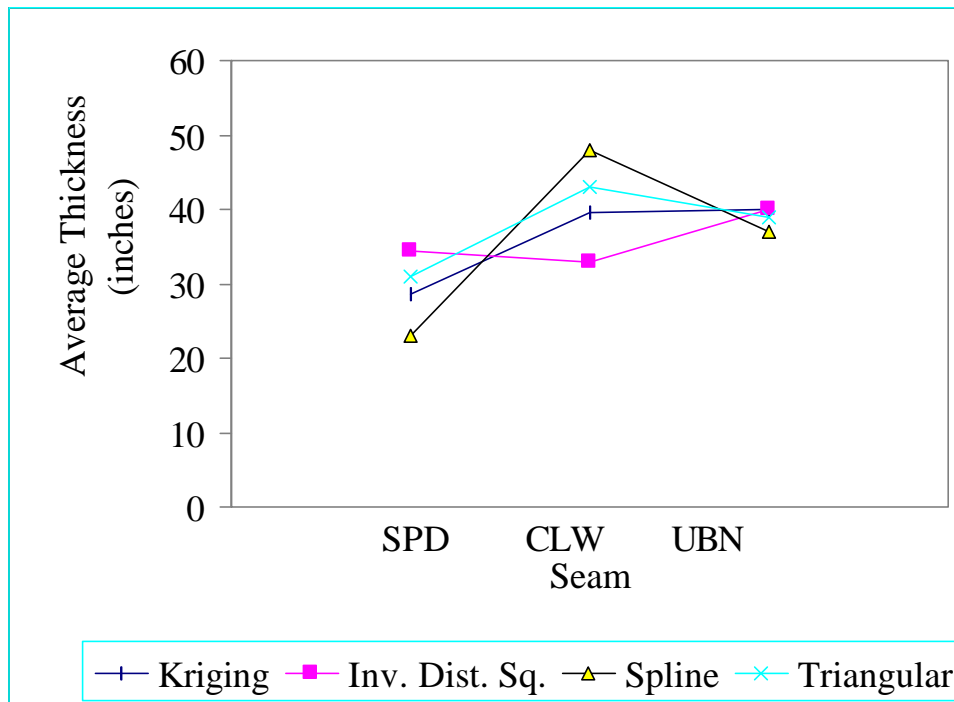


Figure 3.1 Average thickness for each of three seams using four different interpolation methods

209 ft by 209 ft, or approximately 1 acre. This cell size was chosen because it allowed small features, such as small contour mines, to be accounted for. However, the cell size was not so small that the processing of data files would be too slow with current computational power. The data grids are shown in Appendix B.

3.4.2 Multiple-Seam Interaction

The effect of multiple-seam interaction had to be determined for the seams. Multiple seam interaction occurs when mining in a seam above or below the seam of interest sterilizes coal reserves in the seam of interest. The assumption was made that the thicker of two adjacent seams would be mined, causing potential reserve sterilization in the thinner of the two seams. The average thickness of the seams was used to determine which seams would be potentially sterilized. Table 3.2 shows the seams along with their average thickness and the interaction potential for adjacent seams. If seam A is thicker than seam B and located above it, it was assumed that seam A would be mined and, therefore, seam B would be potentially subject to undermining restrictions. A limitation was that only adjacent seams were considered, when in fact super-adjacent seams may perhaps be sterilized or cause sterilization. Determination of interaction for undermining (lower seam mining) was based on work by Haycocks and Karmis (1983), which stated that the minimum stable innerburden (D) is:

$$D = 110 - 0.65S$$

where: S = the percent hard rock (i.e. sandstone) in the innerburden.

Innerburden material types and thicknesses were obtained from VDMME Publication 131 (Nolde et al., 1994). Overmining (upper seam mining) interaction was determined by Luo et al. (1997) who state that damage rating (DR) is:

$$DR = 1.69 (L_t^3 P_h O_t I_t^{-1})^{0.05} E_l^{1.16} T^{-0.07}$$

where: L_t = lower seam thickness (inches),
P_h = percent hard rock in the innerburden,
O_t = overburden thickness (feet),
I_t = innerburden thickness (feet),
E_l = lower seam extraction ratio (assumed to be 70%), and
T = time delay between mining (assumed to be 5 years).

If the damage rating exceeded 2.5, it was assumed that the seam was sterilized.

3.4.3 Land-Use Restrictions

Land-use restrictions were calculated differently for surface and underground resources. Restrictions for underground mining were more lenient as certain features (e.g. bodies of

Table 3.2 Average Thickness and interaction potential for seams analyzed

Seam	Average Thickness	Potential Interaction
High Splint	55	None
Morris	50	Undermining
Pardee	46	Undermining
Phillips	16	Undermining and Overmining
Low Splint	30	Overmining
Taggart	44	None
Taggart Marker	30	Undermining
Wilson	25	Undermining and Overmining
Kelley	28	Overmining
Imboden	49	None
Imboden Marker	24	Undermining and Overmining
Clintwood	32	None
Blair	28	Undermining
Lyons	24	Undermining and Overmining
Dorchester	36	None
Norton	32	Undermining
Hagy	17	Undermining and Overmining
Splashdam	24	Overmining
Upper Banner	28	None
Lower Banner	27	Undermining and Overmining
Kennedy	29	None
Aily	10	Undermining and Overmining
Raven	27	Overmining
Jawbone	36	None
Tiller	36	Undermining
Pocahontas #3	32	None

water, dwellings) can be mined under, without subsiding, but not mined through using surface mining. Forest Service currently-owned lands, airports, and cemeteries were considered to be completely restricted for both surface and underground mining. Utilities (pipelines, powerline poles, gas wells, gage stations), lakes and perennial streams, high-duty roads, railroads, and building concentrations of greater than 1.5 buildings per acre were allowed to have 50% of the coal mined in underground mines beneath them, as this would not cause the features to subside. This was accomplished by restricting half of the acres with these features. A 100-ft radius buffer was placed around utilities, streams, high-duty roads, and railroads for surface mining, while a 300-ft radius buffer was used for buildings. The land-use restrictions for surface and underground mining are shown in Figures 3.2 and 3.3. These restrictions resulted in approximately 104,000 acres being

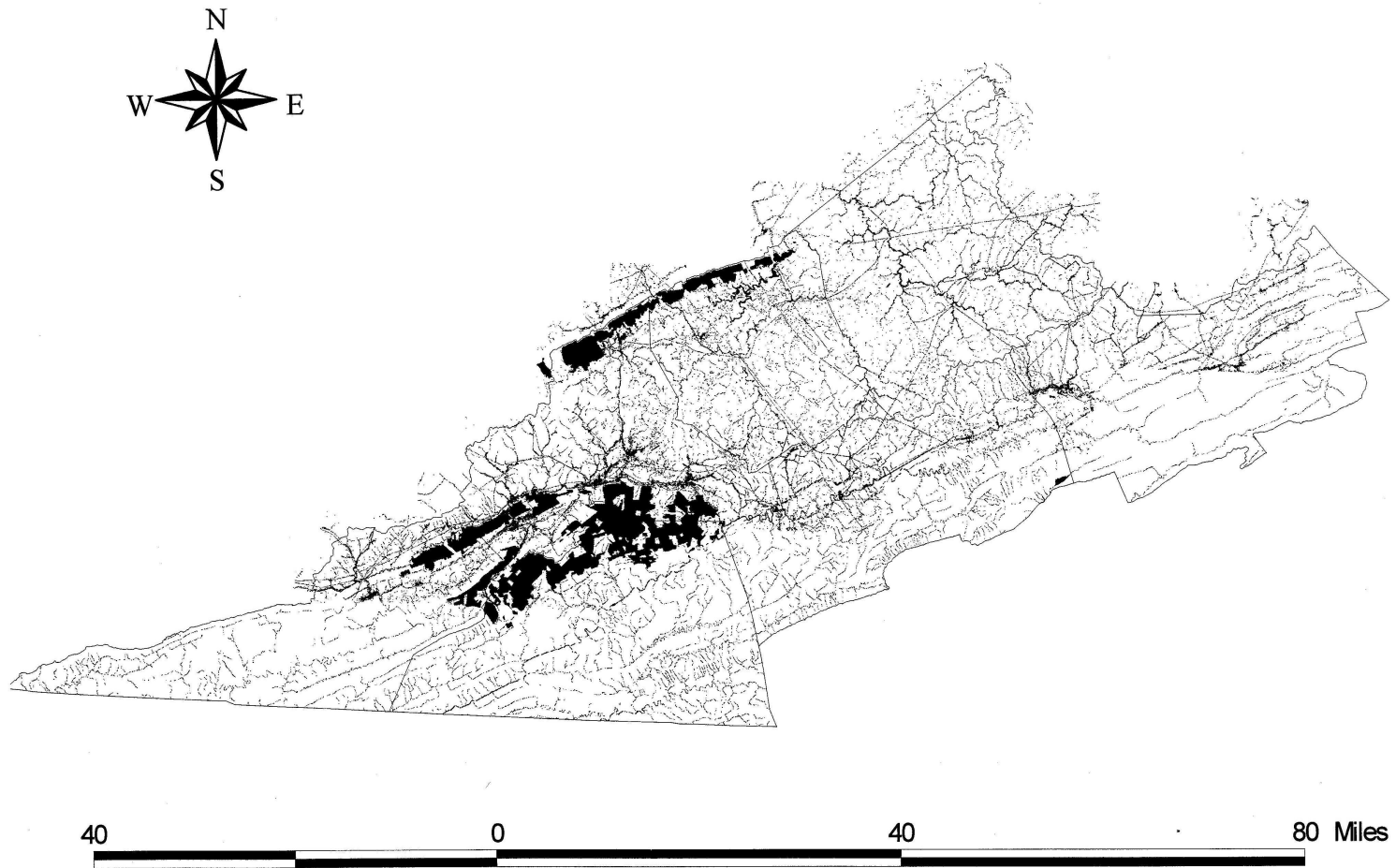


Figure 3.2 Land-use restrictions for surface mining in seven counties of Southwest Virginia

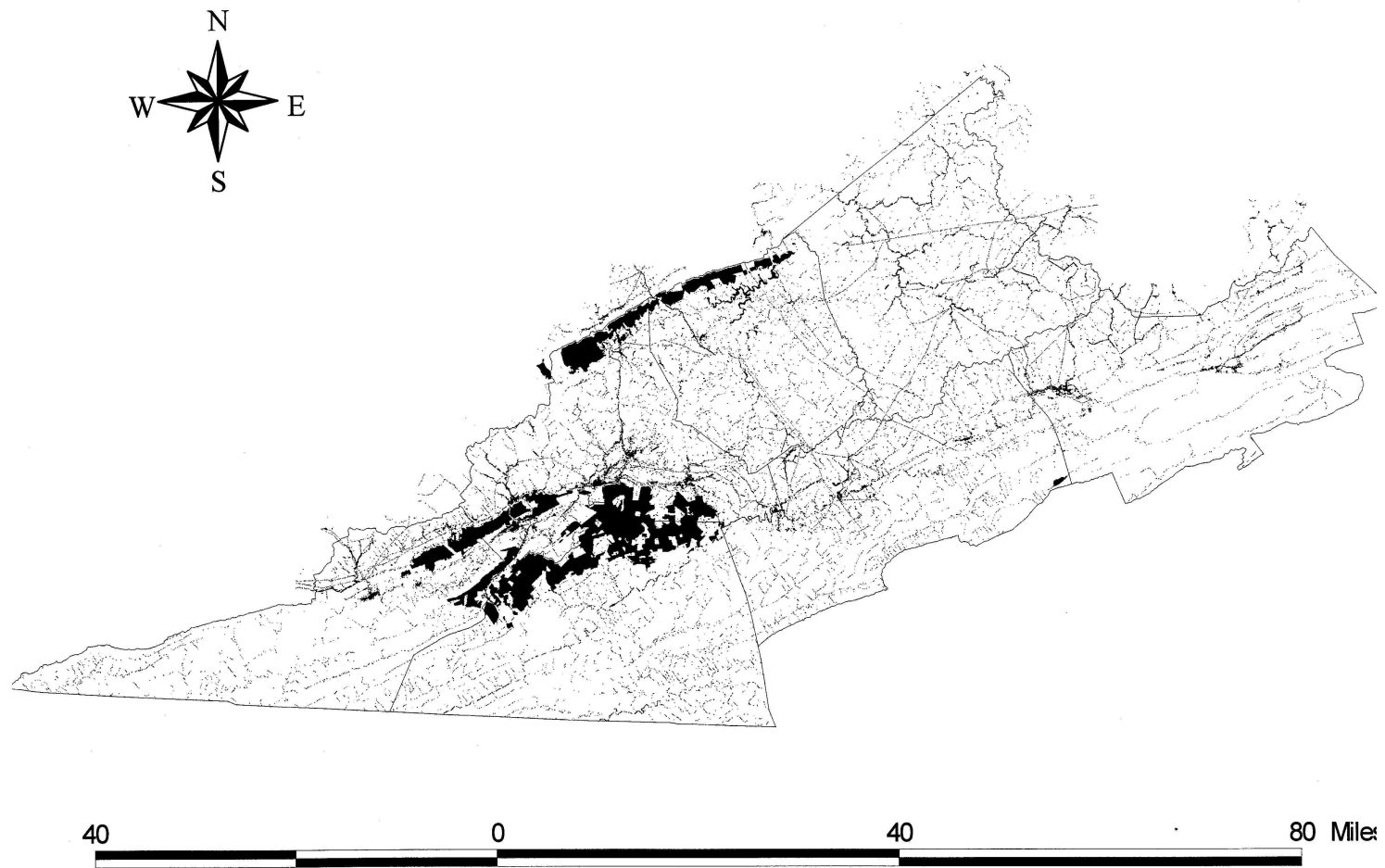


Figure 3.3 Land-use restrictions for underground mining in seven counties of Southwest Virginia

restricted from underground mining and 126,000 acres being restricted from surface mining. Of these totals, approximately 74,000 acres were restricted because they were Forest Service lands. The percentage of acres restricted by the other factors agrees well with previous studies (Sites and Hostettler, 1991a,b).

3.4.4 Property Size

An important parameter in evaluating the viability of a coal property is the size of the mineable area containing coal. A property with excellent coal qualities may not be profitable if the reserve size is too small. A grid which described the various property sizes was generated for each seam. This grid was based on the coal still existing (not yet mined), the thickness of the coal, and the coal outcrop locations. Each one-acre cell within this grid contained a value equal to the tonnage of the contiguous property of which it was a part.

3.4.5 Washability

Grids were made of both raw and washed percentages of ash and sulfur content, however, due to very limited washability data, the raw content grids were used in all analyses. This choice was discussed with an industry representative who assisted with the decision. Grids were not made of the heating capability of the coal (BTU content) as it is closely tied to the ash content (Figure 3.4) and the analysis would have been redundant.

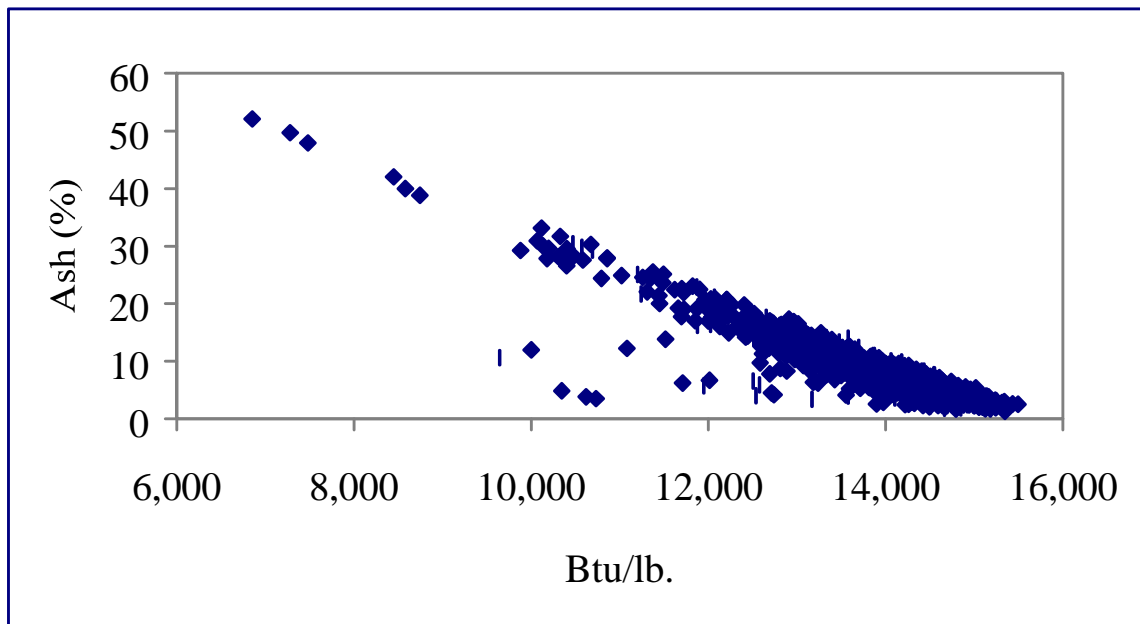


Figure 3.4 Relationship between raw ash content (%) and heating capacity (Btu/lb) for Southwest Virginia coal

CHAPTER 4 – ANALYSIS OF DATABASE ACCURACY

The validity of a reserve estimate is determined by the accuracy and precision of its results. Two techniques were employed to establish the accuracy of this reserve estimation. Initially, the results of this estimate were compared to previous estimates. Following this comparison, a new technique was used to quantitatively determine the accuracy and precision of the database. This technique, and the results obtained using it, will be described.

4.1 Database Verification Methods

Two techniques which may be used to check the accuracy and precision of the established database are a comparison with other databases and the Accuracy Assessment technique. When comparing two or more databases it must be ensured that the databases have the same or similar characteristics. For the Southwest Virginia coal database, consideration must be given to which seams were studied, the extent of the seams, and what seam thicknesses were included in the study. Adjustments must also be made if mining has removed resources between the time frame of the two studies. After consideration of these conditions, the comparison between the two databases is straightforward, and the accuracy and precision can be obtained for one relative to the other, as a measure of the similarity between the two databases.

A new technique for analyzing the accuracy of a GIS-based coal reserve estimate was developed as a part of this research. A spatial data analysis method was developed by geographers to determine the accuracy of digital maps compared to existing drawn maps (Campbell, 1997). A problem which confronted the geographic community in the 1970's was how best to quantitatively compare the data from trusted, manually-drafted maps to that of computer-drawn plots. One method proposed was to compare the relative areas of different terrain shown on the two types of maps. As shown in Figure 4.1, though, this can lead to erroneous results because while the areas may be similar, their locations are not.

The technique which was originally developed was named "Accuracy Assessment" or "Analysis of Contingency Tables." In the technique, two images are compared, one of which displays data in multiple locations which have been verified. The two images are broken into cells of the same size and relative location, and the results in the images are compared on a cell-by-cell basis. A table, called the contingency table, confusion matrix, or error matrix, is generated which summarizes the observations by pairs. The pairs represent the number of observations of each class that were correctly classified or incorrectly classified as another class. The percentage of correct observations is then calculated as the number of correct observations divided by the total number of observations. This percentage can be compared to the percentage which may have been correct by chance. Analysis can also be made of the distribution of incorrect

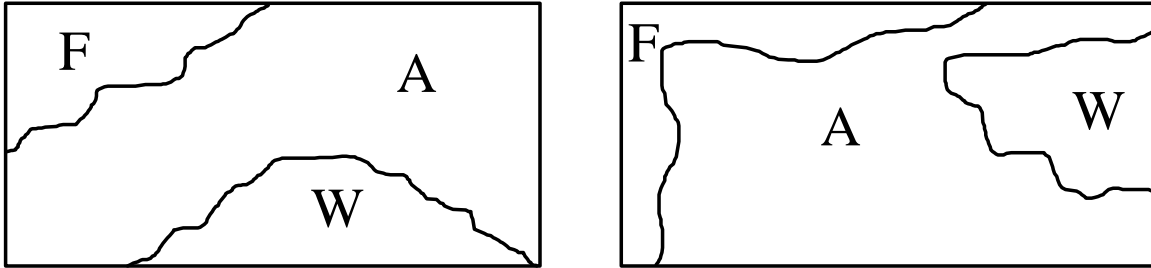


Figure 4.1 Two plots show the same area for the features, however one does not accurately represent the other because the features are not in the same locations

observations. The concept behind this technique can be adapted to coal resource estimation.

Although the technique cannot be applied directly to resource estimation, the general concept can be adapted. The original method was developed to determine if a particular land feature was actually in the location specified on the map. Coal resource estimation, on the other hand, must not only assess if the coal is present in the location specified by the estimate, but also how closely the estimate agrees with the actual resources at the specified location. It is not enough to say that the seam's presence is accurately located in the resource estimate; the accuracy of its thickness and quality must also be determined.

The proposed method for assessing the accuracy of a resource estimate is straightforward. The estimate is completed using uniformly spaced data and distributions of seam thickness are interpolated based on these. Localized data points, not used in the resource estimate, are then used to determine the accuracy. The localized data points are assumed to be "true," or 100% accurate, at the given scale of the study. Ideally, the accuracy assessment should use 5 to 10 localized study areas, including in the range of 5-20 data points spaced at approximately one-tenth the spacing of the uniformly spaced data used for the resource estimate. The accuracy of the resource estimate is the ratio of the true measurement to the interpolated value, so that an accurate value would have an accuracy value of 1.0. The log of the accuracy value is plotted versus the number of measurements within a given range. By plotting the log of the accuracy value, values which are off by one-half are shown equidistant from the true value as those which are double the true value.

The standard deviation (σ) of the difference describes the amount of variation, which is related to the precision of the study. Given the accuracy value, the standard deviation, and using elementary statistical estimation theory, a confidence level can be assigned to the accuracy. A confidence level of 50% is achieved within 0.6745σ . Similarly, confidence levels of 80 and 90% are associated with 1.28σ and 1.645σ , respectively.

4.2 Comparison to Other Studies

Several studies have been made of Southwest Virginia coal resources. The most recent comprehensive study was by Brown et al. (1951), while Campbell et al. (1991) studied Lee County.

Brown et al. completed a comprehensive study of known coal resources using a technique similar to the current USGS standard (measured, indicated, inferred, etc.). Fifty-nine seams were studied and all seven counties were included. At the time of the survey, very little mining was conducted below drainage, and so very little exploratory data were available for below-drainage seams. For this reason, the cumulative resource estimate made by Brown cannot be compared to the current database with the expectation of meaningful results. However, the resource estimates from above-drainage seams were compared.

Table 4.2 shows the comparison of resource estimates from both the Brown study and the current study. Production from the seams since 1950, based on VCCER, 1998, was subtracted from Brown's results. The results of the upper seams (High Splint through Taggart) agree well, while the results of the current study are significantly higher for the lower seams (Taggart Marker through Hagy). This is not surprising since less data for the lower seams were available for Brown's survey, reducing the level of resources estimated by that study.

A subset of the results of the current study, those data within Lee County, were compared to results of a resource estimate for the county (Campbell et al., 1991). Campbell et al.

Table 4.1 Comparison of resource estimates for Brown et al. (1951) and current study, all figures in millions of tons.

Seam	Brown Estimate	Current Estimate
High Splint	13	31
Morris	26	22
Pardee	52	44
Phillips	15	28
Low Splint	103	105
Taggart	<u>95</u>	<u>967</u>
Taggart Marker	104	141
Kelly	127	285
Imboden	231	413
Clintwood	325	627
Blair	172	734
Lyons	135	516
Dorchester	317	914
Norton	153	1,424
Hagy	<u>313</u>	<u>794</u>
Sum High Splint through Taggart	304	327
Sum Taggart Marker through Hagy	1875	5847

Table 4.2 Comparison between resource estimates for Lee County from Campbell et al. (1991) and the current study, all figures in million tons.

Seam	Campbell Estimate	Current Estimate
High Splint	2	2
Morris	2	2
Pardee	7	8
Phillips	11	5
Taggart	22	39
Taggart Marker	40	35
Wilson	36	0
Kelly	103	79
Imboden	122	147
Imboden Marker	134	50
Clintwood	115	128
Blair	81	117
Lyons	1	24
Dorchester	<u>85</u>	<u>169</u>
Sum	762	804

only estimated resources for the above drainage seams (which, in Lee County, are the High Splint through Dorchester). Table 4.3 shows a comparison between the resource estimates obtained by Campbell et al. and the current study. The resource estimates for Campbell et al. are as of January, 1988, and production from the intervening years was not subtracted. Because the study is much more recent than the Brown study, it has more data for the lower seams, and therefore compares more closely with the current estimate.

4.3 Quantitative Accuracy Assessment Technique

The Accuracy Assessment technique was used to quantitatively determine the accuracy of the Southwest Virginia coal database. Accuracy was determined by comparing data at three different properties to data within the database. Ideally, all parameters would be assessed for accuracy, however, because only thickness data were available for the properties it was the only parameter evaluated. The thickness data for the first two properties are from private companies, so, for confidentiality reasons, the seam names and property locations will not be disclosed.

The first property contains five seams (herein signified as ‘1,’ through ‘5’). Table 4.4 shows the borehole thicknesses for the seams and the corresponding database thickness at the same locations. As would be expected, the values from the borehole measurements show much greater variation than the values, at the same locations, from the regional database. The borehole measurements are assumed to be “true” and the accuracy shown in Table 4.4 is, therefore, relative to those measurements. The standard deviation of the accuracy measurements indicates the precision of the database.

Table 4.3 Borehole and database thicknesses for five seams from the first property, borehole and database values in inches. Accuracy calculated as borehole divided by database thickness.

Seam	Borehole	Database	Accuracy	Seam	Borehole	Database	Accuracy
1	36	40	0.90	4	32	30	1.07
1	27	43	0.63	4	30	31	0.97
1	38	45	0.84	4	32	30	1.07
1	35	44	0.80	4	48	31	1.55
1	13	42	0.31	4	35	32	1.09
1	18	40	0.45	4	19	34	0.56
1	31.5	39	0.81	4	39.5	32	1.23
1	10.5	42	0.25	4	25	32	0.78
1	58	41	1.41	4	20.5	29	0.71
1	29.5	46	0.64	4	30	30	1.00
1	38.5	49	0.79	4	66	30	2.20
1	53.5	48	1.11	4	30	31	0.97
1	54	49	1.10	4	21	30	0.70
1	28	41	0.68	4	37.5	31	1.21
1	68	39	1.74	4	54.5	33	1.65
	Seam 1	Accuracy	0.83		Seam 4	Accuracy	1.12
2	13	12	1.08	5	36	40	0.90
2	12	12	1.00	5	27	43	0.63
2	5	13	0.38	5	38	45	0.84
2	12	13	0.92	5	35	44	0.80
2	24	13	1.85	5	13	42	0.31
2	6.5	13	0.50	5	18	40	0.45
2	15.5	13	1.19	5	31.5	39	0.81
2	13	13	1.00	5	10.5	42	0.25
2	12.5	12	1.04	5	58	41	1.41
2	8.5	12	0.71	5	29.5	46	0.64
2	8.5	13	0.65	5	38.5	49	0.79
2	9.5	13	0.73	5	53.5	48	1.11
2	9.5	12	0.79	5	54	49	1.10
2	5.5	12	0.46	5	28	41	0.68
2	31	13	2.38	5	68	39	1.74
	Seam 2	Accuracy	0.98		Seam 5	Accuracy	0.83
3	25	39	0.64				
3	44	36	1.22				
3	29	33	0.88				
3	35.5	38	0.93				
3	28	32	0.88				
3	32	34	0.94				
3	39	42	0.93		Seams 1-5	Accuracy	0.94
3	30	34	0.88			Std. Dev.	0.42
	Seam 3	Accuracy	0.91				

The distributions of the accuracy of the database for seam 2 and for the combination of all the seams are shown in Figure 4.2. If the database were perfectly accurate, the majority of the accuracy values would have a value of 1.0, but the standard deviation would be nonzero. If the database were perfectly precise, all the accuracy values would have the same value (hence, the standard deviation would be zero), but that value would be greater than or less than 1.0. If the database were perfectly accurate and precise, all accuracy values would have a value of 1.0, with a standard deviation of 0. The accuracy of the database is 0.94 and the standard deviation is 0.42. Based on these values, it can be stated that, with a 50% confidence level, the values are between 66 and 122% of the correct values; or, with a 80% confidence level, the values are between 40 and 148% of the correct values. These values indicate that the database is reasonably accurate, but not precise. Precision would likely be improved by adding more data points to the database.

The second property provided a total of 65 seam thickness measurements for 7 beds. Three of the beds have only one or two thickness measurements. As with the first property, for confidentiality reasons, the seams are not labeled with their true names and the location of the property has not been given. Table 4.5 shows the borehole and database thicknesses for the 65 points, along with the accuracy for each bed and all beds combined.

As with the first property, the accuracy analysis with the data from the second property indicates that the database is accurate (accuracy of 0.88, standard deviation of 0.41, or

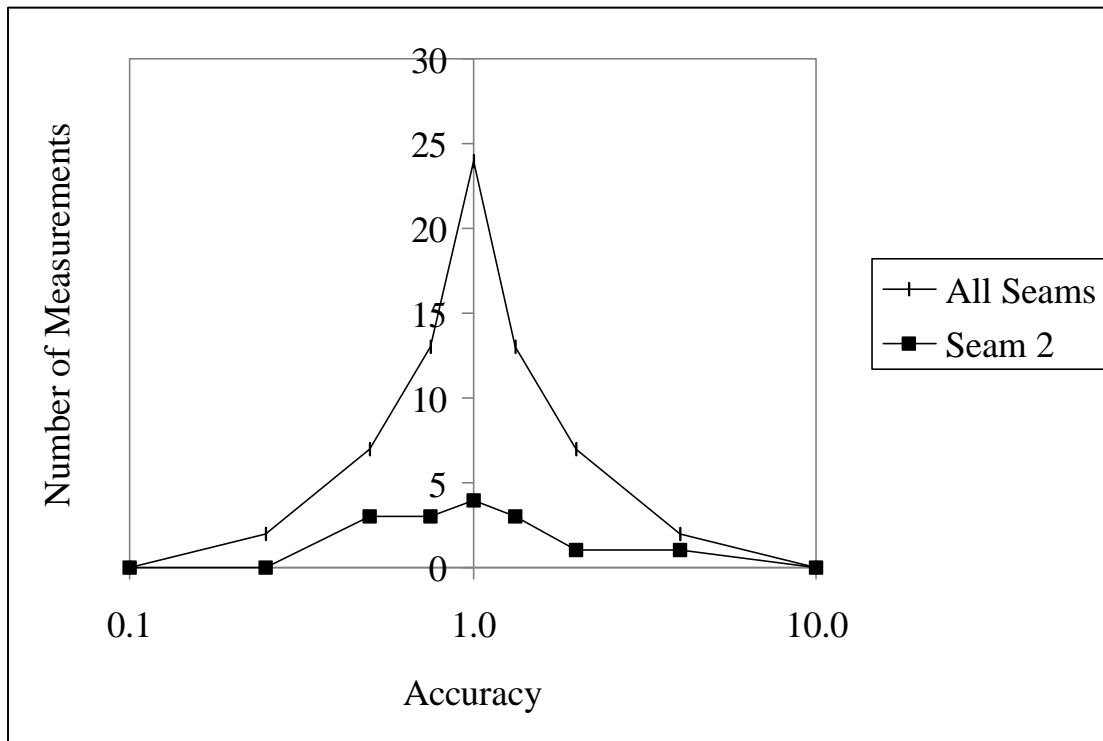


Figure 4.2 Accuracy plot for All Seams and Seam 2 in Property 1

Table 4.4 Borehole and database thicknesses for seven seams from the second property, borehole and database values in inches. Accuracy calculated as borehole divided by database thickness.

Seam	Borehole	Database	Accuracy	Seam	Borehole	Database	Accuracy
1	29	56	0.52	4	23	25	0.92
1	37	48	0.78				
1	36	51	0.70	5	43	38	1.13
1	17	52	0.33				
1	29	54	0.54	6	50	55	0.91
1	35	49	0.71	6	30	55	0.55
1	42	48	0.88	6	30	55	0.54
1	26	55	0.47	6	30	55	0.54
1	31	51	0.61	6	30	55	0.54
1	25	55	0.45	6	41	55	0.74
	Seam 1	Accuracy	0.60	6	29	55	0.52
				6	30	56	0.54
2	26	30	0.87	6	61	56	1.10
2	32	30	1.07	6	43	56	0.77
2	32	30	1.07	6	29	56	0.52
2	22	30	0.73	6	30	56	0.54
2	42	30	1.40	6	40	56	0.71
2	48	30	1.60	6	33	56	0.59
2	41	30	1.37	6	22	56	0.39
2	32	30	1.07		Seam 6	Accuracy	0.63
2	49	30	1.64				
2	43	30	1.44	7	23	30	0.77
2	65	30	2.17	7	32	30	1.07
2	19	30	0.64	7	17	30	0.57
2	49	30	1.64	7	32	30	1.07
2	19	30	0.63	7	23	30	0.77
2	19	30	0.64	7	34	30	1.13
2	30	30	1.00	7	26	30	0.86
2	24	30	0.80	7	30	30	1.00
2	46	30	1.54	7	48	30	1.59
2	23	30	0.77	7	18	30	0.60
2	10	30	0.33	7	18	30	0.60
2	34	30	1.14	7	24	30	0.80
2	17	30	0.57		Seam 7	Accuracy	0.90
2	44	30	1.47				
2	19	30	0.63				
	Seam 2	Accuracy	1.09				
3	19	32	0.60		Seams 1-7	Accuracy	0.88
3	49	25	1.98			Std. Dev.	0.41
	Seam 3	Accuracy	1.29				

within 36 and 140% of the correct value at a 80% confidence level), but the database does not have a high level of precision. Figure 4.3 shows the distribution of the number of measurements versus their accuracy.

Individual measurements from the Campbell study of Lee County (Campbell et al., 1991) were used with the Accuracy Analysis technique to evaluate the accuracy of the database. The individual measurements were obtained from the Campbell study by examining borehole measurements which were located on isopach lines plotted in the report. Isopach thickness increments (typically 14, 28, and 42 inches) of many seams were plotted. Also displayed on these plots were the locations of the measurement points used to develop the isopachs. Where the measurement point fell on an isopach line, it was assumed that the measurement was the value of the isopach line. Because these results are published, the seam names are given. A total of 63 measurements from 10 different seams were evaluated and are given in Table 4.6.

The database is again shown to be accurate, but with limited precision. Based on the values for accuracy and standard deviation, it can be stated that, with a 50% confidence level, the values are between 60 and 140% of the correct values, or with a 80% confidence level, the values are between 24 and 176% of the correct values. Figure 4.4 shows the distribution of accuracy measurements for all ten seams.

A comparison of the results from all three properties shows that, while it lacks precision, the database is accurate, especially when considering all seams together. For properties one and two, the database overestimates the thickness by five to ten percent. The

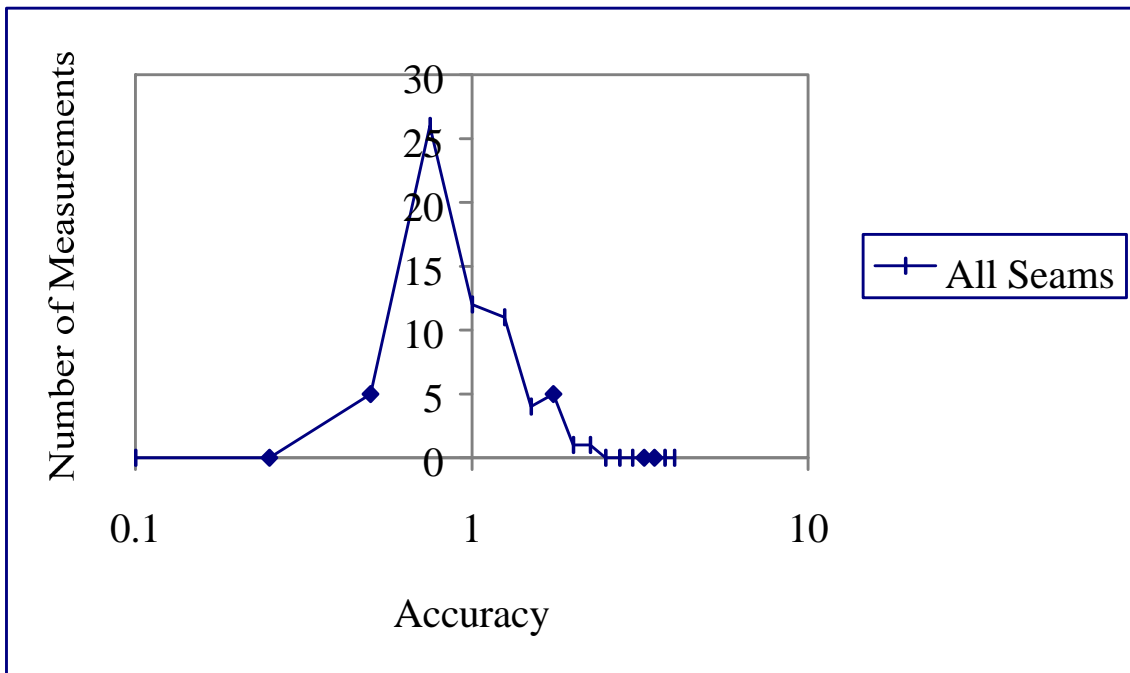


Figure 4.3 Accuracy plot for All Seams in Property 2

Table 4.5 Measured thicknesses, database thicknesses, and accuracy of the database for the seams evaluated in Lee County.

Seam	Measured	Database	Accuracy	Seam	Measured	Database	Accuracy
Pardee	42	54	0.77	Clintwood	14	30	0.47
				Clintwood	42	30	1.41
				Clintwood	14	30	0.47
Low Splint C	14	27	0.53	Clintwood	28	30	0.94
Low Splint C	28	18	1.55	Clintwood	28	30	0.95
		Accuracy	1.04	Clintwood	42	29	1.43
				Clintwood	28	29	0.97
Wilson	28	13	2.22	Clintwood	14	29	0.49
Wilson	42	12	3.62	Clintwood	14	28	0.49
Wilson	14	11	1.26	Clintwood	28	28	0.99
Wilson	28	9	3.18	Clintwood	28	28	1.01
Wilson	28	35	0.80			Accuracy	0.87
Wilson	28	38	0.73				
Wilson	42	33	1.27	Blair	28	28	1.00
		Accuracy	1.87	Blair	14	28	0.50
				Blair	14	28	0.51
Kelly	42	29	1.44	Blair	42	28	1.53
Kelly	42	29	1.44	Blair	28	28	1.01
Kelly	28	29	0.96	Blair	14	25	0.55
Kelly	42	30	1.41	Blair	14	24	0.58
Kelly	28	30	0.93	Blair	14	24	0.57
Kelly	28	30	0.93	Blair	28	24	1.16
Kelly	14	30	0.46	Blair	28	23	1.21
		Accuracy	1.08			Accuracy	0.86
Imboden	28	51	0.55	Lyons	14	15	0.97
Imboden	28	51	0.55	Lyons	14	15	0.96
Imboden	42	54	0.77			Accuracy	0.96
Imboden	28	55	0.51				
Imboden	28	56	0.50	Dorchester	14	37	0.37
Imboden	42	56	0.75	Dorchester	42	38	1.11
Imboden	42	56	0.75	Dorchester	42	38	1.09
Imboden	42	56	0.75	Dorchester	28	39	0.73
Imboden	42	56	0.75	Dorchester	14	39	0.36
		Accuracy	0.66	Dorchester	42	38	1.11
				Dorchester	42	39	1.07
Imboden Marker	28	24	1.16	Dorchester	14	40	0.35
Imboden Marker	28	24	1.16			Accuracy	0.77
Imboden Marker	42	24	1.74				
Imboden Marker	14	24	0.58				
Imboden Marker	28	24	1.16				
Imboden Marker	42	24	1.74	All Seams	Accuracy	1.00	
		Accuracy	1.25		Std. Dev.	0.59	

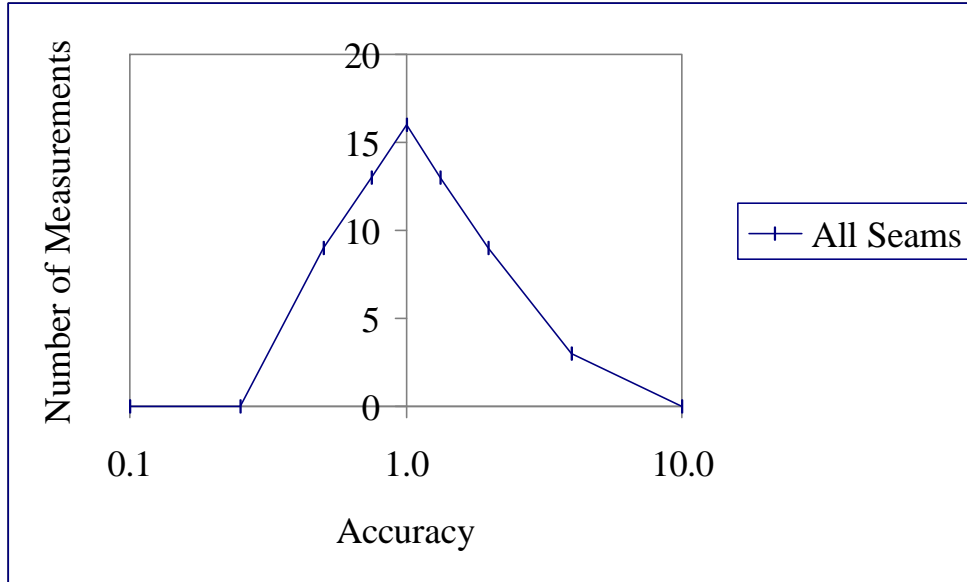


Figure 4.4 Accuracy plot for All Seams from Lee County study

cumulative accuracy of all three properties was found to be between 62 and 126% of the correct value at a 50% confidence level, and between 33 and 155% of the correct value at an 80% confidence level.

4.4 Discussion of Database Accuracy and Precision

The precision of the database can likely be improved by increasing the density of the data points. Because coal seam thickness and quality can vary over relatively small distances (less than 50 ft), precision would be greatly improved if each coal seam could be sampled at such small intervals. Unfortunately, this is impractical even at a local (mine property) level, much less at a regional level.

It is important to understand the database accuracy prior to any parametric or economic analysis. Results obtained from such analysis are only as trustworthy as the input data on which they are based. For this database, it has been shown that the results can be considered reliable to within approximately 60% at an 80% confidence level.

CHAPTER 5 – PARAMETRIC ANALYSIS

A parametric analysis was completed to show the impact of various parameters on resource quantities. Because this analysis did not include profitability, the results are termed “resources” instead of “reserves.”

5.1 Resource Calculation

Various combinations of parameters were analyzed. The database grids interpolated in ArcView were used to calculate the tonnage in a seam which fell within each set of parameters. Table 5.1 shows the values used for the parameters analyzed. For each of the 26 different seams evaluated, 27,216 different descriptions of resource were determined. The process could have been done within ArcView, but because of the number of descriptions considered, it was more time effective to write a stand-alone computer program to perform the estimations (Luxbacher, 1999).

The structure of the program was simple. Grids of each of the parameters to be analyzed, as well as stripping ratio, were read. If the stripping ratio was less than, or equal to, 15, then the acre was assumed to be mineable by surface methods. If the stripping ratio was greater than 15 it was assumed that the coal in that seam for that acre would be mined using underground methods. Reject and multiple-seam interaction were not considered for surface-mineable resources, and only the appropriate land-use restrictions were applied for surface and underground mining.

The values of the various grids were then compared to the values listed in Table 5.1. The thickness and property tonnage values were evaluated as minimums, while the ash content, sulfur content, and reject were evaluated as maximums. In other words, tonnages were calculated for resources greater than 12,30, or 48 inches in thickness, but containing less than 5, 15, or 25% ash content, as examples.

Table 5.1 Parameters and values used in Parametric Analysis

Parameter	Values Used
Minimum Thickness (inches)	12, 30,48
Maximum Ash Content (% , raw)	5,15,25
Maximum Sulfur Content (% ,raw)	0.5, 1.0, 2.0
Maximum In-Seam Reject (% by weight)	10,50,90
Mining Method	Surface, Underground
Multiple-Seam Interaction	Yes, No
Minimum Property Tonnage	10,000; 1,000,000; 100,000,000
Land-Use Restriction	None, Surface Mining, Underground Mining
County	All, Lee, Scott, Wise, Russell, Dickenson, Tazewell, Buchanan

5.2 Resource Definitions

The results of the parametric analysis program were compiled so that the influence of the various parameters could be determined on a seam-by-seam basis for each mining method and in each county. Results obtained from the resource calculation can be described using several existing definitions. Simple distinctions between inclusive, moderate, and exclusive definitions were first explored. The USGS definitions for remaining, available, and recoverable resources were then used. Next, minimum requirements for a reserve, as defined by the coal mining industry, were used as a definition. The industry definitions included requirements for metallurgical use and steam generation. Each of these definitions provides additional insight into the coal resources of Southwest Virginia.

5.2.1 Inclusive, Moderate, and Exclusive Resource Definitions

The coal resources of Southwest Virginia were separated into different relative qualities. Table 5.2 shows the resources calculated for three different resource definitions, each unrestricted by land-use or multiple-seam interaction. The first definition is very inclusive, the second is moderate, and the third is very exclusive. While these definitions are simplistic, they provide a measure of the relative quantities of different grades of coal remaining in Southwest Virginia.

Table 5.2 Three definitions of resources unrestricted by land-use or multiple-seam interaction.

Max. Sulfur (raw, %)	Min. Thickness (inches)	Max. Ash (raw, %)	Min. Prop. Size (tons)	Max. In-Seam Reject (wt %)	Resources (million tons)		
					Underground	Surface	Total
2	12	25	10,000	50	19,900	3,950	23,850
1	30	15	1,000,000	33	8,460	1,980	10,440
0.5	48	5	100,000,000	10	1	20	21

5.2.2 Remaining, Available, and Recoverable Resources

A more rigorous approach to resource definition is to use the definitions of remaining, available, and recoverable resources developed by the USGS and listed in Figure 2.13. Remaining resources are those resources which have not been previously mined or sterilized within an abandoned mine. With this database, the remaining resources will be approximated by using the most inclusive definition above, but additionally including resources restricted by land-use or multiple-seam interaction.

Available resources are defined by the USGS as remaining resources minus resources restricted by technology or land-use. The tonnage associated with land-use and multiple-seam interaction restrictions was easily removed from the resource calculations. Additionally, seam thickness less than 28 inches was considered to be technologically

restricted by the USGS. For this database, thicknesses below 30 inches were removed as this was one of the values used in the resource calculation (Table 5.1).

By subtracting mining and washing losses from the available resources, recoverable resources were estimated. Based on input from the coal industry, mining losses were assumed to be 40% for underground mining and 15% for surface mining. Washing losses were more difficult to determine as only raw sulfur and ash contents were used in the database. To determine washing losses, the average yield of clean coal floating at a specific gravity of 1.60 was used. The average weight recovered, ash, and sulfur contents achieved from the 151 data points of the USBM studies (Miller, 1957; Gray and Boley, 1958a; Gray and Boley, 1958b; Deurbrouck, 1963a; Deurbrouck, 1963b; Deurbrouck, 1966; Cavallaro et al., 1990) are shown as Table 5.3. Based on these results, a figure of 12% loss of the coal due to washing was used in determining recoverable resources. This figure was only applied to underground resources as surface mining is more selective and surface resources are, therefore, less frequently washed.

Remaining, available, and recoverable resources are shown in Table 5.4 for each county and the total field. Available resources are shown in Table 5.5 for each seam, separated by county and mining method.

Table 5.3 Results of USBM preparation characteristic studies

Specific Gravity					
> 1.60			1.55-1.60		
Weight (%)	Ash (%)	Sulfur (%)	Weight (%)	Ash (%)	Sulfur (%)
100.0	13.1	1.5	88.3	5.3	1.2

Table 5.4 Remaining, available, and recoverable coal resources of Southwest Virginia, all figures in millions of tons.

	Remaining	Available	Recoverable
Buchanan	8,411	3,446	2,114
Tazewell	532	246	137
Dickenson	7,234	4,783	2,937
Russell	1,569	1,032	583
Wise	8,583	4,849	2,912
Scott	482	201	139
Lee	924	604	454
Total	27,735	15,160	9,276

Table 5.5a “Available” Underground Resources by Seam and County (2% max. sulfur, 30 in. min. thickness, 25% max. ash, 50% max. in-seam reject, 10,000 tons min. property size; all figures in 1000’s of tons.

County	Underground							Total
	Buchanan	Dickenson	Lee	Russell	Scott	Tazewell	Wise	
Aily	0	0	0	0	0	0	0	0
Blair	0	0	0	0	0	0	0	0
Clintwood	69,300	23,854	0	0	0	0	105,955	199,110
Dorchester	209,125	15,708	51,904	0	0	0	359,601	636,337
Hagy	75,549	0	0	9	0	0	0	75,558
High Splint	0	0	1,927	0	0	0	15,535	17,463
Imboden	29,681	874	86,846	0	0	0	174,033	291,433
Imboden Marker	0	0	0	0	0	0	0	0
Jawbone	202,522	913,365	6,085	69,744	0	72,069	1,346,198	2,609,985
Kelly	0	0	6,800	0	0	0	77,739	84,540
Kennedy	334,331	400,052	0	96,212	0	9,928	125,274	965,798
Lower Banner	166,469	125,402	0	74,808	0	6,347	27,731	400,756
Low Splint	0	0	0	0	0	0	44,773	44,773
Lyons	0	0	0	0	0	0	0	0
Morris	0	0	0	0	0	0	1,995	1,995
Norton	77,573	0	0	0	0	0	530	78,103
Pocahontas #3	171,378	133,959	4,112	92,171	97,476	9,312	353,175	861,582
Pardee	0	0	6,087	0	0	0	32,272	38,359
Phillips	0	0	0	0	0	0	0	0
Raven	152,500	259,940	0	144,212	0	41,246	272,084	869,981
Splash Dam	216,395	29,093	0	5	0	0	4,299	249,791
Taggart	2,391	0	15,112	0	0	0	51,781	69,284
Taggart Marker	0	0	0	0	0	0	0	0
Tiller	815,963	1,087,128	5,384	398,224	0	85,268	515,893	2,907,861
Upper Banner	4,779	514,299	0	39,028	0	0	234,433	792,539
Wilson	3,463	0	0	0	0	0	12,238	15,701
Total	2,531,418	3,503,675	184,258	914,413	97,476	224,169	3,755,541	11,210,949

Table 5.5b “Available” Surface Resources by Seam and County (2% max. sulfur, 12 in. min. thickness, 25% max. ash, 10,000 tons min. property size; all figures in 1000’s of tons.

County	Surface							Total
	Buchanan	Dickenson	Lee	Russell	Scott	Tazewell	Wise	
Aily	16,154	34,219	0	1,137	0	569	1,219	53,299
Blair	29,058	9,610	81,681	0	0	0	106,025	226,374
Clintwood	13,398	8,439	87,613	0	0	0	52,018	161,469
Dorchester	31,757	19,575	102,317	0	0	0	33,691	187,340
Hagy	95,842	41,999	0	19,721	0	292	84,705	242,560
High Splint	0	0	65	0	0	0	13,719	13,784
Imboden	15,169	4,165	51,382	0	0	0	32,756	103,472
Imboden Marker	0	655	6,900	0	0	0	5,143	12,698
Jawbone	835	134	0	507	0	1,827	138	3,441
Kelly	5,791	1,968	17,455	0	0	0	19,889	45,103
Kennedy	122,512	374,463	0	53,859	0	10,902	139,966	701,701
Lower Banner	258,685	288,828	4,489	17,809	0	3,586	199,912	773,309
Low Splint	0	0	2,498	0	0	0	6,644	9,142
Lyons	46,336	31,411	221	0	0	0	22,885	100,853
Morris	0	0	986	0	0	0	7,858	8,844
Norton	118,298	163,285	34,545	8,973	0	288	147,820	473,209
Pocahontas #3	121	39	0	3,660	103,103	1,662	0	108,586
Pardee	0	0	2,237	0	0	0	3,142	5,378
Phillips	0	0	210	0	0	0	573	783
Raven	817	121	0	107	0	47	1,949	3,042
Splash Dam	136,361	76,801	0	920	0	747	86,120	300,950
Taggart	1,644	0	23,313	0	0	0	563	25,521
Taggart Marker	1,694	0	3,624	0	0	0	2,525	7,842
Tiller	290	27	0	4,238	0	2,128	3	6,687
Upper Banner	17,291	223,705	0	6,354	0	3	120,961	368,313
Wilson	2,144	0	0	0	0	0	3,102	5,246
Total	914,199	1,279,447	419,536	117,286	103,103	22,051	1,093,326	3,948,947

5.2.3 Industry Minimum Reserve Definitions

Formal interviews were held with individuals from eight companies representing the broad spectrum of the mining industry in Southwest Virginia. The purpose of the interviews was to determine the minimum requirements for a coal reserve. It is important to note that even if a coal property meets the definitions given in the interviews, it is not necessarily a reserve. The coal on the property must also be economic to mine.

A limited number of interviews was held because it was felt that the answers of these companies would be representative of the industry as a whole. Five individuals were with mining companies, from the largest companies to relatively small, but successful, contractors. Two individuals who were employed by land companies were interviewed, and one consulting company representative was interviewed. The interviews were conducted on an individual basis.

Questions were asked regarding reserve layout, land use and ownership, mining conditions, coal quality, operating costs and sales profit. Companies were questioned to determine minimum allowable values for some of these parameters. Using seam thickness as an example, it was understood that under certain conditions a 36" seam might be more attractive than a 60" seam, but a 20" seam would probably never be mined by underground methods.

The results of the interviews, shown as a composite in Table 5.6, suggest that the requirements for opening a new surface or underground steam coal operation are similar. A new metallurgical grade coal mine can be much smaller in size; however, coal of acceptable quality is more rare. Requirements for opening a new longwall mine are much more stringent because a very large reserve is required in a nearly square layout.

Table 5.7 shows the resource values which meet industry's minimum definition of a reserve. Again, it is important to realize that not all of these are necessarily economic reserves, and therefore are not truly reserves.

Table 5.6 Composite of results from industry interviews

	Surface Steam	Deep Steam	Deep Metallurgical	Longwall*
Minimum total tonnage	0.5	0.5	0.15	75
Minimum annual tonnage	0.5	0.5	0.2	4
Maximum stripping ratio	15:1	---	---	---
Minimum seam thickness (ft)	---	3	2.3	5
Maximum reject (wt. %)	50	50	55	50
Maximum sulfur (% , washed)	1.5	1.5	1	1.5
Maximum ash (% , washed)	20	15	6.5	15

* A property layout of approximately square shape is an additional requirement for longwall mines

Table 5.7 Surface and deep steam and metallurgical resources using industry's *minimum* definition of reserves; all figures in millions of tons.

	Surface Steam	Deep Steam	Surface Metallurgical	Deep Metallurgical	Total
Buchanan	859	2,425	76	897	4,257
Tazewell	21	219	11	45	296
Dickenson	1,235	2,837	81	1,156	5,309
Russell	115	831	24	298	1,268
Wise	1,068	3,525	127	578	5,298
Scott	103	97	31	12	243
Lee	416	180	22	16	634
Total	3,817	10,114	372	3,002	17,305

5.3 Parametric Analysis

5.3.1 Influence of Restrictions

An analysis of the parameters included in the database shows the relative impact of each parameter on the resource totals. A better understanding of the influence of each parameter on Southwest Virginia coal resources provides a firm basis for decisions which impact the economy of the region. Initially, resources restricted by multiple-seam interaction and land use were separated (Table 5.8).

Table 5.8 Resources restricted by multiple-seam interaction and land-use; all figures in millions of tons.

	Total	Multiple-Seam	Land-Use	Unrestricted
Buchanan	8,411	819	135	7,453
Tazewell	532	2	22	508
Dickenson	7,234	243	324	6,662
Russell	1,569	21	47	1,500
Wise	8,583	1,021	676	6,865
Scott	482	0	281	201
Lee	924	156	68	695
Total	27,735	2,262	1,553	23,884

5.3.2 Correlation Between Resources and Parameters

The influence of seam thickness, sulfur content, ash content, in-seam reject, and property tonnage on unrestricted resources can be seen in Figures 5.1 through 5.5, respectively. The values for these plots were obtained by altering the variable of interest but keeping the other factors held at the values of the most inclusive definition from Table 5.2.

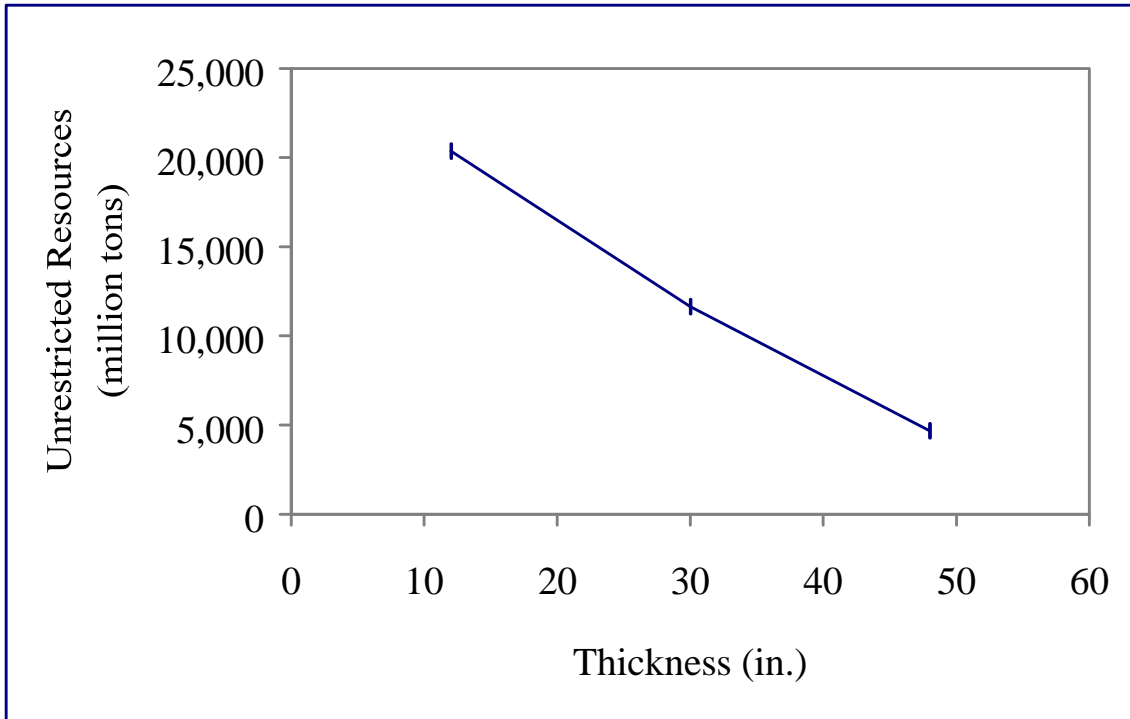


Figure 5.1 Relationship between minimum seam thickness and unrestricted resources

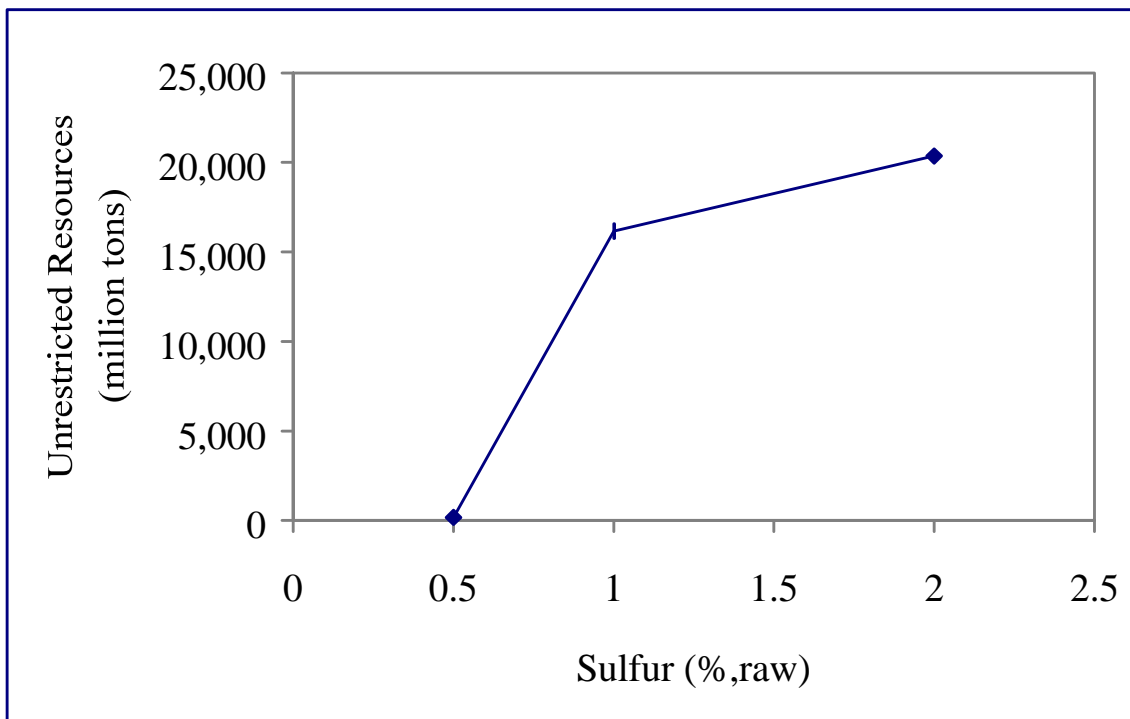


Figure 5.2 Relationship between maximum raw sulfur content and unrestricted resources

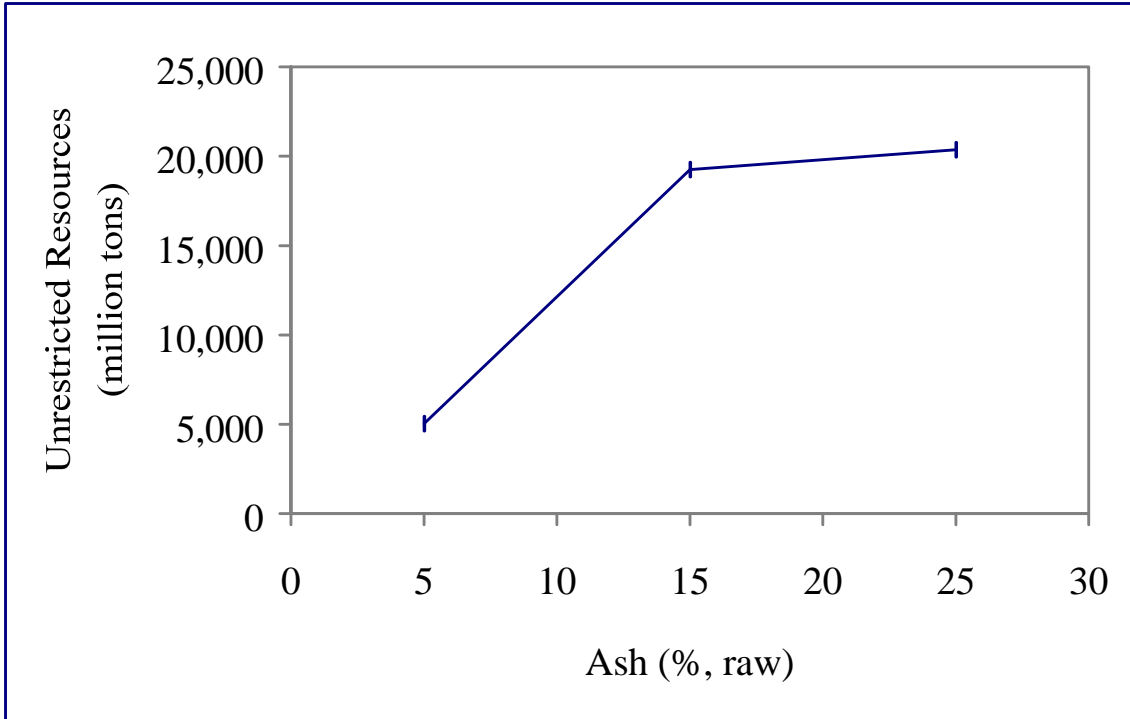


Figure 5.3 Relationship between maximum raw ash content and unrestricted resources

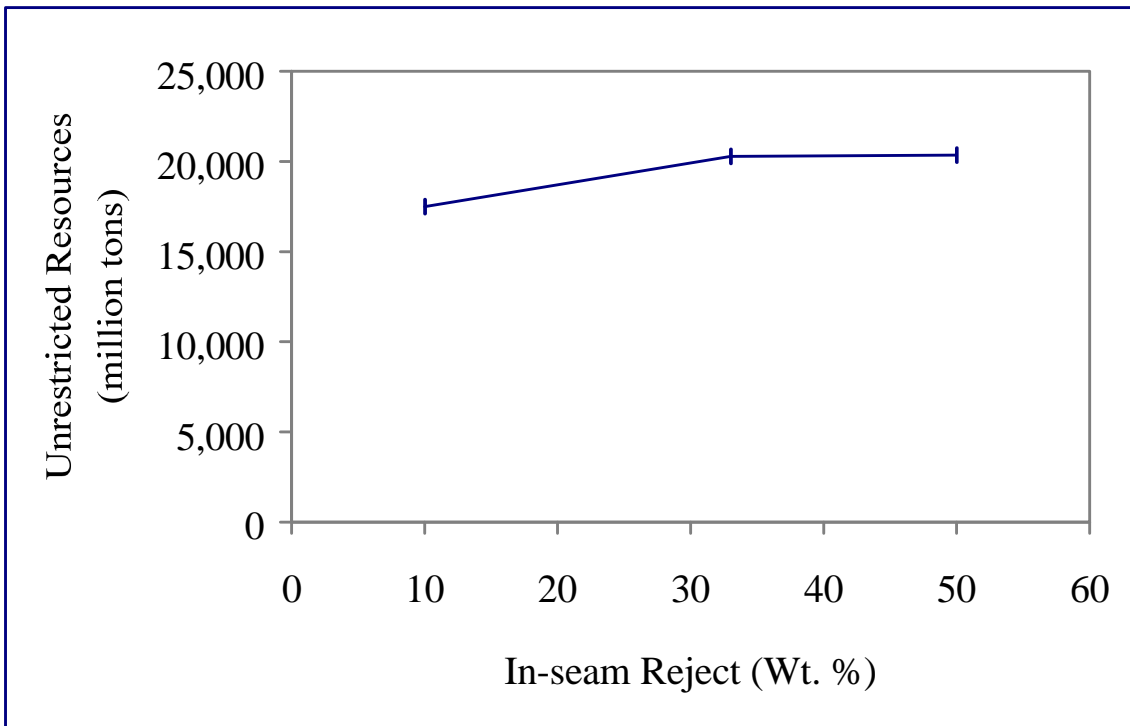


Figure 5.4 Relationship between maximum in-seam reject and unrestricted resources

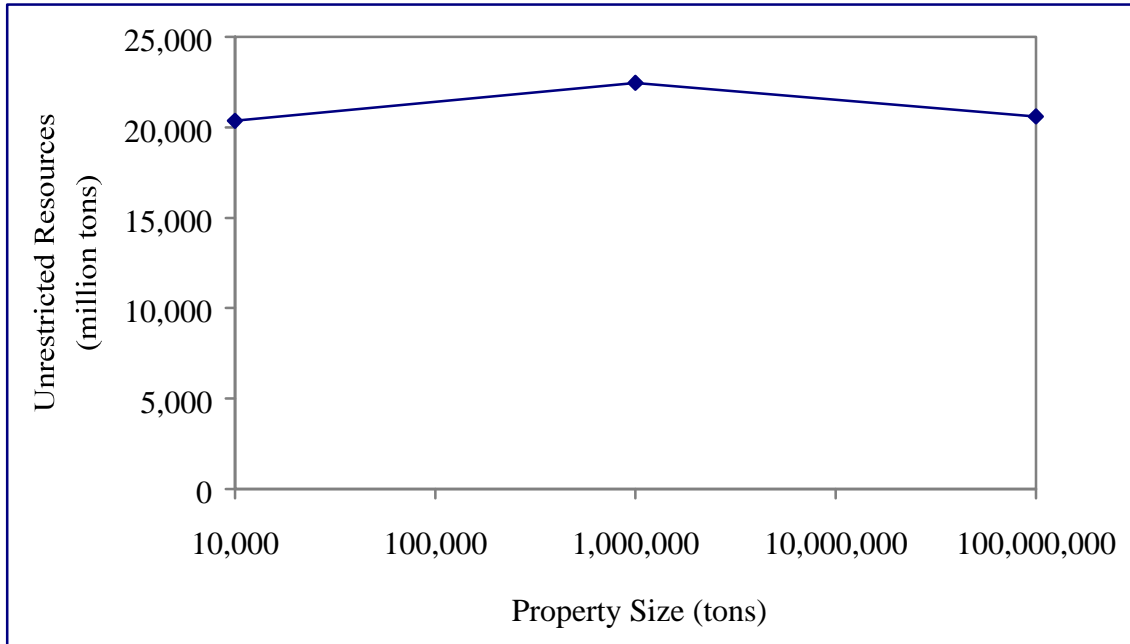


Figure 5.5 Relationship between minimum property size and unrestricted resources

A statistical analysis of the parameters can show which parameters have the most influence on resource totals and how to estimate resource levels by assuming values for the various parameters. A Pearson correlation was performed initially on unrestricted underground and surface resources to determine the correlation between parameters and resources. Minitab 11.21 was used to perform the correlation. The Pearson correlation coefficient provides a measurement of the relationship between two variables. If the variables are directly related the value will be positive, while indirect relationships result in negative correlation. The values are between -1 and 1 .

In determining the Pearson correlation coefficient, the logarithm of the property tonnage was used so that it would not vary by orders of magnitude while the other parameters stayed within an order of magnitude. Tables 5.9 and 5.10 show the results of the Pearson correlation for surface and underground resources. As expected, it can be seen that the various parameters are not correlated to each other. As an example, seam thickness is not influenced by sulfur content, and it should not be influenced by sulfur content. Seam thickness is probably not correlated to surface resources because thinner seams can be mined if the stripping ratio is acceptable.

The correlation between resources and the parameters considered can also be seen from the results. For underground resources, the resource level is most sensitive to sulfur content, then thickness, then ash content. The fact that thickness has a negative correlation to resources means that as the minimum thickness increases, resource levels decrease. The resource level is relatively insensitive to property tonnage and in-seam reject. Resource level is most influenced by sulfur content and ash content for surface resources. A relationship was not found to exist between surface resources and seam thickness.

Table 5.9 Pearson correlation coefficients for Surface Resources

	Sulfur Content	Thickness	Property Size	Ash Content
Thickness	0			
Property Size	0	0		
Ash Content	0	0	0	
Resources	0.720	0	-0.121	0.451

Table 5.10 Pearson correlations for Underground Resources

	Sulfur Content	Thickness	Property Size	Reject	Ash Content
Thickness	0				
Property Size	0	0			
Reject	0	0	0		
Ash Content	0	0	0	0	
Resources	0.528	-0.438	-0.033	0.036	0.348

5.3.3 Regression Analysis of Resources and Parameters

Equations were fit so that unrestricted resource tonnage could be estimated as a function of the parameters considered and so that the most influential parameters could be determined. Equations for unrestricted surface-mineable resources as a function of the parameters studied were obtained using the Microsoft Excel solver tool to obtain a polynomial equation, and Minitab 11.21 to obtain a multi-variable linear regression solution. As with the correlation analysis, the property tonnage parameter was input as the logarithm to the base ten of the property tonnage. Surface-mineable resources were found to fit the following polynomial and linear equations:

$$R = (16.3S^{32.1}) (11.7Th^{3.8}) (6.5A^{6.0}) (175 \log_{10}Tn^{-1.1})$$

and

$$R = -1.10e9 + 1.60e9 S - 0 Th - 1.02e8 \log_{10}Tn + 7.6e7 A$$

where

R = Resource (tons)
 S = Maximum allowable Sulfur content (%),
 Th = Minimum allowable Thickness (inches),
 A = Maximum allowable Ash content (%), and
 Tn = Minimum Property Tonnage (tons).

The coefficient of determination (r^2) for the polynomial and linear equations was 0.469 and 0.736, respectively. Plots of the tonnage obtained from the program and from the two equations are shown in Figures 5.6 and 5.7.

Because the equation developed with multi-variable linear regression had the better coefficient of correlation, only a linear equation was developed for underground resources. Unrestricted resources were found to be described as:

$$R = 1.28e9 + 4.67e9 S - 1.64e8 Th - 1.11e8 \log_{10} Tn + 6.11e6 I + 2.35e8 A$$

where I is the in-seam reject and the remaining parameters used are the same as in the surface mineable equation. The r^2 was 0.594 and the plot of tonnage estimated by the program versus tonnage estimated by the equation is shown as Figure 5.8.

Following the regression analysis, Best Subsets Regressions were run for surface and underground resources to determine how accurately resources could be determined with the equations generated, but using fewer of the variables. As with the multivariable linear regression, Minitab 11.21 was used. Tables 5.11 and 5.12 show the results of the Best Subsets Regressions. For surface resources, resource tonnage can be estimated with a coefficient of determination of 0.721 using only sulfur and ash content values. This compares favorably to the coefficient of determination obtained using all of the variables, which was 0.736. A coefficient of determination of 0.591 was obtained for underground resources using only ash and sulfur contents and seam thickness. This is almost as good as that obtained using all the variables (0.594).

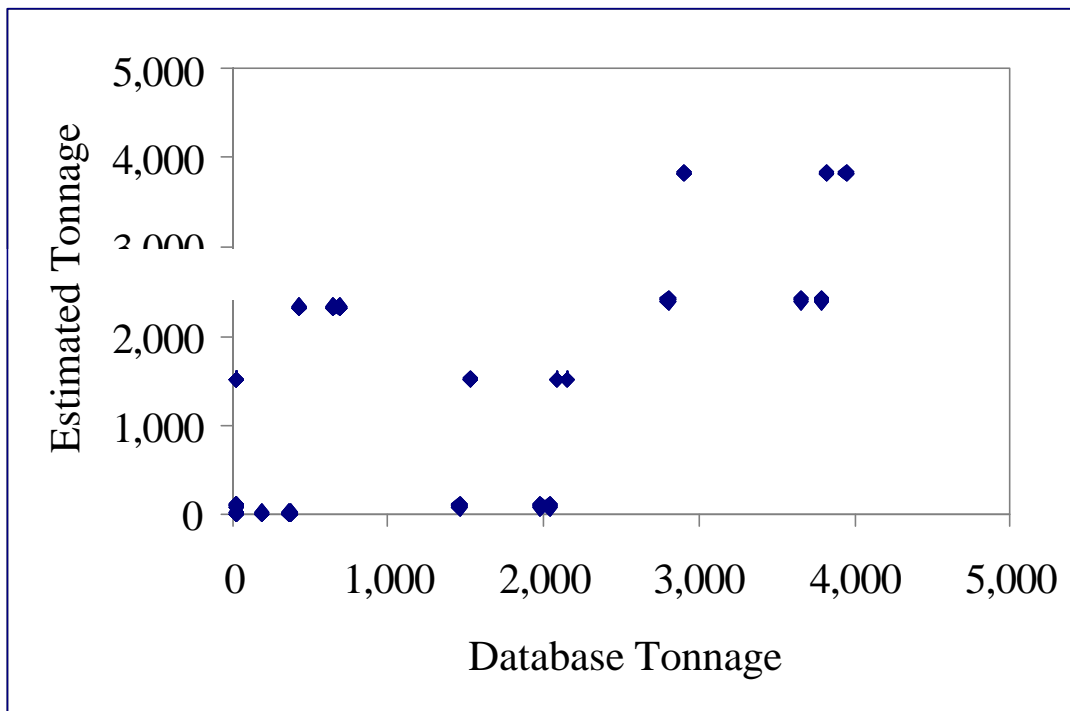


Figure 5.6 Relationship between database and estimated surface-mineable tonnage using polynomial fit, with trend line (all values in million tons)

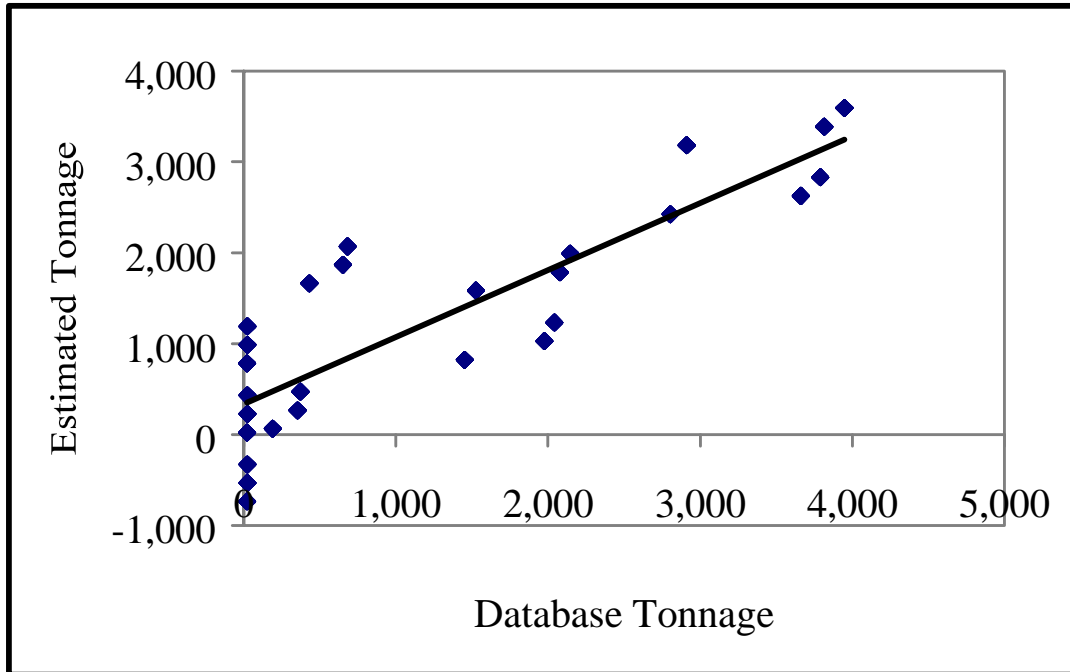


Figure 5.7 Relationship between database and estimated surface-mineable tonnage using linear fit, with trend line (all values in million tons)

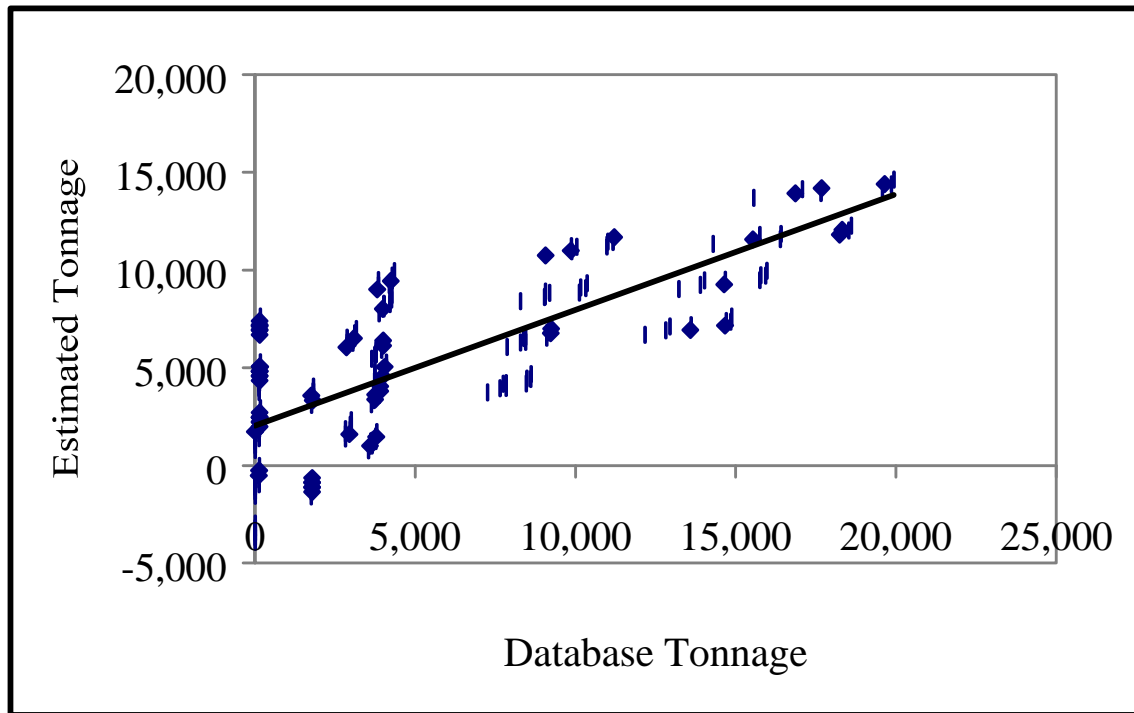


Figure 5.8 Relationship between database and estimated underground-mineable tonnage using linear fit, with trend line (all values in million tons)

Table 5.11 Results of Best Subsets Regression for surface resources

R ²	Sulfur Content	Thickness	Property Size	Ash Content
0.518	X			
0.203				X
0.721	X			X
0.532	X		X	
0.736	X		X	X
0.721	X	X		X
0.736	X	X	X	X

Table 5.12 Results of Best Subsets Regression for underground resources

R ²	Sulfur Content	Thickness	Property Size	Inseam Reject	Ash Content
0.278	X				
0.192		X			
0.470	X	X			
0.400	X				X
0.591	X	X			X
0.472	X	X		X	
0.593	X	X		X	X
0.593	X	X	X		X
0.594	X	X	X	X	X

5.4 Discussion

Results of the parametric analysis show the influence of various parameters on coal resource levels. Figures 5.1 through 5.5 clearly show that thickness, ash content, and sulfur content affect resources more significantly than in-seam reject or property size. This analysis is confirmed by the Pearson correlation results. It is also noticeable that, as expected, resource levels are directly related to maximum ash content, maximum sulfur content and maximum in-seam reject, but indirectly related to minimum seam thickness and minimum property size. The Pearson correlation results show that sulfur content has the greatest influence on resource levels for both surface and underground resources.

Sulfur levels of coal resources are of special interest due to regulations enforced by the Environmental Regulation Agency for the Clean Air Act Amendment of 1990 (DOE/EIA, 1994b). The DOE/EIA defines low-, medium-, and high-sulfur coals as shown in Table 5.13 (DOE/EIA, 1999a). Although sulfur is the most influential parameter in determining resource levels, it is not necessarily the most important parameter to consider when assessing Southwest Virginia coals. As the results shown in Figure 5.2 indicate, very little (< 15%) of the unrestricted coal in Southwest Virginia coal is high-sulfur, while more than 50% is low sulfur. Two-thirds of the unrestricted coal is

Table 5.13 DOE/EIA sulfur content categories for coal, Approximate percent sulfur calculated assuming 13,000 Btu/lb. coal

Quality	Pounds of Sulfur per Million Btu	Approximate % Sulfur
Low Sulfur	≤ 0.60	≤ 0.78
Medium Sulfur	$0.60 < S \leq 1.67$	≤ 2.17
High Sulfur	> 1.67	> 2.17

less than 1%, meaning that it can easily be blended with slightly lower sulfur coal to obtain compliance coal. The coals of Southwest Virginia are shown to possess generally favorable sulfur contents.

Access to the coal seam is a primary concern in evaluating coal properties for development. Seams which can be mined by punching in from an outcrop require much less initial capital investment, and are therefore lower risk, than seams which require expensive shafts to be sunk for access. If the six deepest seams (Kennedy, Aily, Raven, Jawbone, Tiller, and Pocahontas #3) are considered to be primarily below drainage and requiring shafts for access, it can be seen that 60% of the “available” resources exist in these seams. Resources defined as “available” are either surface-mineable with less than 2% sulfur, more than 12 inches thick, and less than 25% ash, or underground-mineable with less than 2% sulfur, more than 30 inches thick, less than 25% ash, and less than 50 weight percent in-seam reject. If the 13 highest seams (50% of seams) are considered, it can be seen that 1.3 billion tons (less than 10%) are available. Additionally, significant resources are tied up in portions of other seams which would require shafts for access.

The definition obtained from industry of the minimum requirements for installing a longwall mine (shown in Table 5.6) was used to determine the existing resources which are potentially mineable by the longwall method. Resources fitting the requirements for a longwall mine were found in the Imboden, Upper Banner, Jawbone, Tiller, and Pocahontas #3 seams. However, these resources were very limited.

The estimates obtained for the USGS definitions of remaining, available, and recoverable resources can be compared to other studies. As discussed in Section 2.4.2.1.1, the USGS performed “Coal Availability” studies on selected quadrangles in the Central Appalachian coal basin. Results of these studies are published for the Vansant, Wise, and Appalachia quadrangles in Southwest Virginia and the Matewan quadrangle of Eastern Kentucky (Sites et al., 1991; Sites and Hostettler, 1991b, Sites and Hostettler, 1991a, Eggleston et al., 1990). Table 5.14 shows the comparison, in terms of percentages, for this study and the USGS studies. Although slightly different definitions for available and recoverable resources were used, it can be seen that the results of this study show similar or more conservative resource levels than the USGS studies. The land-use restrictions for this study included large National Forest areas, which did not exist in the quadrangles studied by the USGS. However, the mining and washing losses were found to be less substantial for Southwest Virginia coals than assumed by the USGS.

Table 5.14 Comparison of current results to previous studies

Study	Remaining Resources (million tons)	% Available	% Restricted by Land-Use	% Restricted by Multiple-Seam Interaction
Current – Southwest VA	27,735	55	5.6	8.2
USGS – Vansant Quad	875	67	0.4	6.9
USGS – Wise Quad	771	67	4.0	7.1
USGS – Appalachia Quad	1010	70	1.0	15
USGS – Matewan Quad	986	62	2.0	13

CHAPTER 6 – ECONOMIC MODEL

6.1 Model Development

An economic model was developed so that the effect of sales price on the coal reserves in Southwest Virginia could be determined. The model was based on input provided by industry representatives and was designed so that it could be used in conjunction with the GIS database to develop quantity and spatial distribution of economic coal reserves. The model was developed so that profitability could be determined as a function of sales price, mining costs, mining productivity, and additional costs.

6.1.1 Sales Price

The initial component of the model was the sales price which was established as a function of sulfur and ash content in the coal. As with the parametric analysis, BTU's were not considered because they are directly related to ash content (Figure 3.4). A penalty was assessed to sales price for ash and sulfur content. By assessing a penalty, instead of establishing a sales price, both steam and metallurgical coals could be evaluated together. Sales price penalties based on ash and sulfur content for both metallurgical and steam coals were taken from Coal Outlook and industry input (Coal Outlook, 2/17/97 and 3/17/97) and are shown in Table 6.1 and Table 6.2.

The sulfur and ash contents were found to be linearly related to sales price penalties, and can be expressed as:

$$\text{Ash Penalty} = (1.1 * \text{Ash Content}) - 5.75$$

$$\text{Sulfur Penalty} = (3.1 * \text{Sulfur Content}) - 2.25$$

where *Penalty* has units of dollars per ton and *ash* and *sulfur contents* have units of percent, as sold. The coefficient of determination (R^2) for the relationships were 0.996

Table 6.1 Effect of Ash Content on Sales Price

Ash Content (as sold, %)	Penalty (\$/ton)
5	0
10	5
15	10
20	16.5

Table 6.2 Effect of Sulfur Content on Sales Price

Sulfur Content (as sold, %)	Penalty (\$/ton)
0.75	0
1.0	1
2.0	4

and 0.997 for ash and sulfur, respectively. These relationships are plotted in Figures 6.1 and 6.2.

Based on the reported sales price for metallurgical and steam coals (Coal Outlook, 2/17/97; Coal Outlook, 3/17/97) the sales price for coal was found to be expressed as a function of sulfur and ash content by:

$$\text{Sales Price} = 35 - \{(1.1 * \text{Ash Content}) - 5.75\} - \{(3.1 * \text{Sulfur Content}) - 2.25\}$$

or,

$$\text{Sales Price} = 43 - (1.1 * \text{Ash Content}) - (3.1 * \text{Sulfur Content})$$

where *Sales Price* has units of dollars per ton.

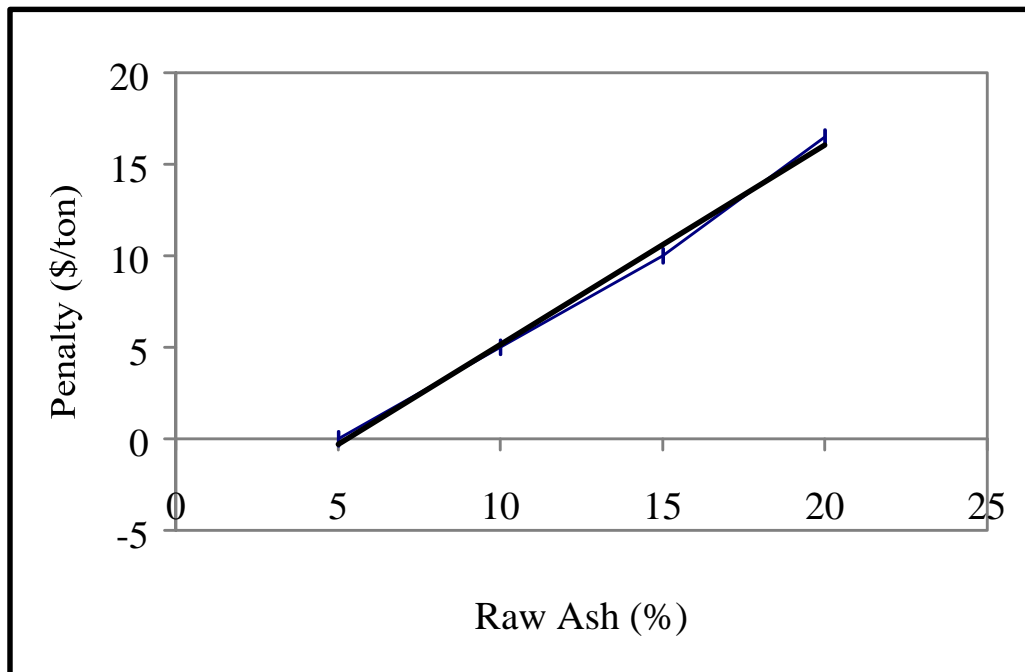


Figure 6.1 Relationship between raw ash content and sales-price penalty

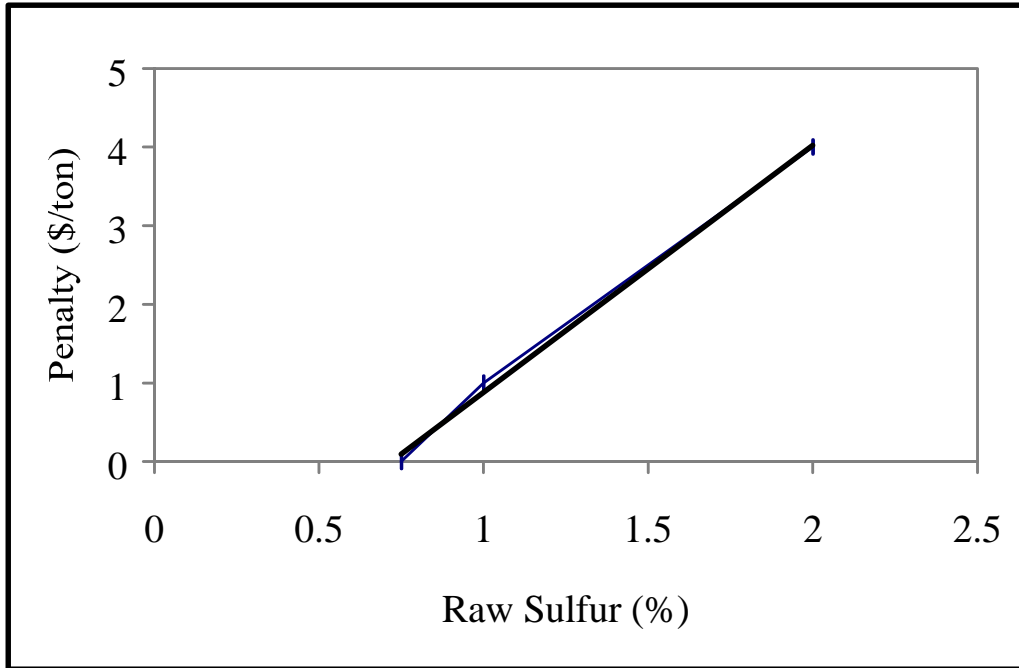


Figure 6.2 Relationship between raw sulfur content and sales-price penalty

6.1.2 Mining Cost

6.1.2.1 Underground Mining

The next component of the model was mining cost. Since mining costs differ for surface and underground mining, two relationships were developed. For underground mining, the mining cost was calculated as a function of seam thickness, labor cost, mining productivity, in-seam reject, access costs, and property size. Analysis of the database showed very limited resources which matched industry's definition of property size which could support a longwall mine (more than 48 to 60 inches thick, more than 50 millions tons which could be mined from the property). Hence the economic model was developed assuming that underground mining would be conducted with continuous miners only.

Mining costs as a function of labor costs and coal thickness were developed on the basis of input from industry. A matrix of labor costs (20, 25, and 30 \$/hour) and seam thickness (28, 36, 48, 60 inches) was developed with associated mining costs. This matrix was reduced, with an R^2 of 0.951, to the following equation:

$$\text{Mining Cost} = 19.6 - (0.28\text{Thickness}) + (0.28\text{Labor})$$

where *Mining Cost* has units of dollars per ton, *Thickness* is in inches and *Labor* is in dollars per hour. The relationship obtained is shown as Figure 6.3. The cost to mine one inch of reject is the same as that to mine one inch of coal, but no profit is made from it. The above figure was modified for in-seam and out-of-seam reject as a direct proportion

of mining cost with reject reported in inches, therefore, the mining cost as a function of coal thickness, labor costs, and inches of reject is expressed as:

$$MiningCost = \frac{R + Thickness(19.6 - 0.28Thickness + 0.28Labor)}{Thickness}$$

where reject (R) is in inches. This figure is then modified for access costs.

Access costs, based on industry input, were assumed to be as listed in Table 6.3. Access costs are development costs which occur prior to any coal being mined; they include capital costs for belts, ventilation, etc.. These costs are recovered as coal is mined, and are therefore offset by the amount of coal mined through the access portal. It follows that the larger the reserve block mined through the portal, the lower the access cost on each ton mined within the property. The access costs are added to the mining costs but divided by the clean tonnage sold from the property:

$$MiningCost = \frac{R + Thickness(19.6 - 0.28Thickness + 0.28Labor)}{Thickness} + \frac{Access}{Tonnage}$$

where $Access$ is in dollars and $Tonnage$ is in tons.

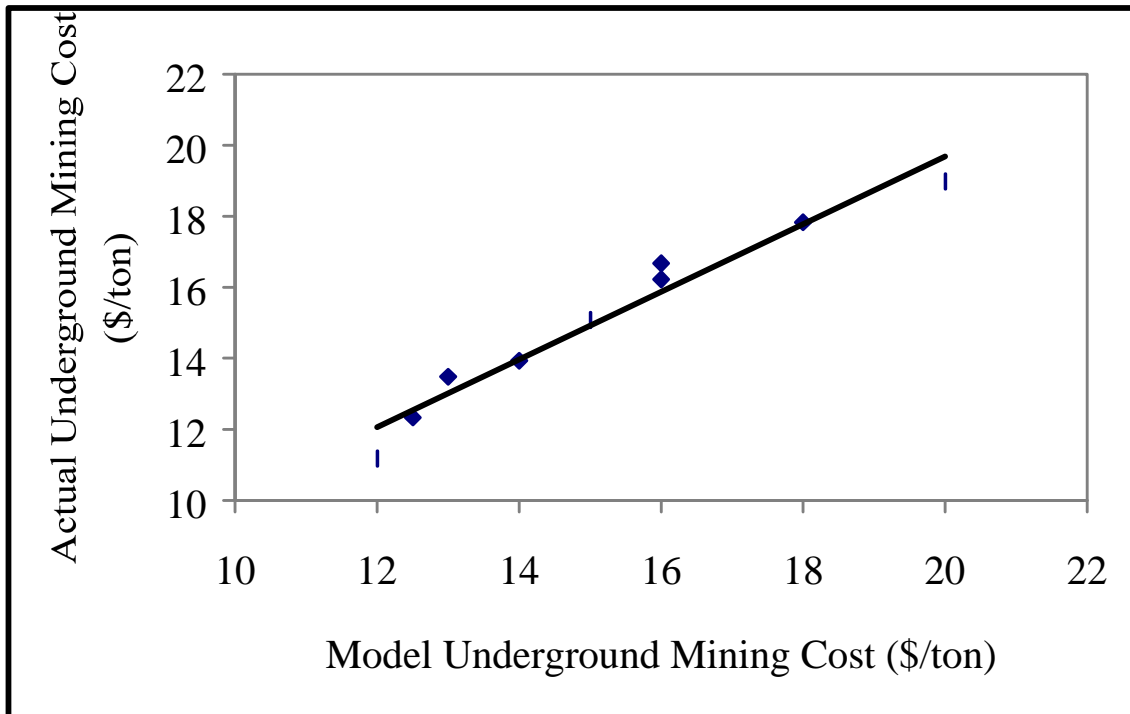


Figure 6.3 Relationship between actual and model underground mining costs

Table 6.3 Access methods and costs

Access Method	Cost (millions of dollars)
Punch, Drift	1
Boxcut	2
Slope	4
Shaft	10

This relationship for underground mining costs can be multiplied by a productivity constant, P, which is assumed to be 1.0 for current mining practices:

$$MiningCost = \left(\frac{1}{P} \right) \frac{R + Thickness(19.6 - 0.28Thickness + 0.28Labor)}{Thickness} + \frac{Access}{Tonnage}$$

6.1.2.2 Surface Mining

Stripping ratio, labor cost, and productivity were found to influence mining costs for surface mining. The stripping ratio is the ratio of the thickness of overburden which must be removed, to the coal thickness. Reject was not considered as it can be removed in the mining process. Likewise, access costs and property size were not included, as they are less significant in surface mining.

Based on industry input, the costs related to the stripping ratio shown in Table 6.4 were established. These costs were related to labor costs and reduced to a linear equation:

$$Mining\ Cost = 1 + (0.55 * Stripping\ Ratio) + (0.23 * Labor\ Cost)$$

which had a coefficient of determination (R^2) of 0.956, shown in Figure 6.3. This relationship can be multiplied by a productivity constant, P, which is assumed to be 1.0 for current mining practices:

$$Mining\ Cost = \{1 + (0.55 * Stripping\ Ratio) + (0.23 * Labor\ Cost)\} / P$$

Table 6.4 Cost related to mining at different stripping ratios

Stripping Ratio	Labor Cost (\$/hour)	Mining Cost (\$/ton)
10:1	20.00	12.00
15:1	20.00	14.00
20:1	20.00	16.00
10:1	25.00	12.50
15:1	25.00	15.00
20:1	25.00	18.00
10:1	30.00	13.00
15:1	30.00	16.00
20:1	30.00	20.00

6.1.3 Additional Costs

The final component of the economic model was additional costs. Interviews with members of the Southwest Virginia coal industry took place, as described in Chapter V, and published in Westman et al. (1998). Based on responses made during these interviews, costs for transportation, taxes, and royalties were established, and are shown in Table 6.5. These costs are assumed to be the same for both surface and underground mining, except no preparation costs are associated with surface mining. While costs vary at different mining operations, the costs used are intended to generally reflect conditions in Southwest Virginia, although it is understood that some operations will have lower costs while others will have higher costs.

Table 6.5 Additional costs to mining

Item	Cost (\$/ton)
Preparation	5.00
Transportation	2.50
Taxes	2.00
Royalties	2.00
Office Overhead	1.50

6.1.4 Economic Models for Surface and Underground Mining

By subtracting the mining costs and the additional costs from the sales price, the complete relationship for surface mining (no preparation costs) can then be expressed as a profit, in dollars per ton, as:

$$Pf = 35 - 1.1 \text{ Ash} - 3.1 \text{ Sulfur} - P^{-1} \{1 + (0.55 * \text{Stripping Ratio}) + (0.23 * \text{Labor Cost})\}$$

and for underground mining, including preparation costs as:

$$Pf = 30 - 1.1A - 3.1S - \left(\frac{1}{P}\right) \frac{R + \text{Thick}(19.6 - 0.28\text{Thick} + 0.28L)}{\text{Thick}} + \frac{X}{\text{Tonnage}}$$

where

- Pf = Profit (\$/ton),
- A = Ash content (as sold, %),
- S = Sulfur content (as sold, %),
- Ratio = Stripping Ratio,
- L = Labor Costs (\$/hour),
- P = Productivity Factor (1.0 in 1998 mining conditions),
- Thick = Coal thickness (inches),
- R = Reject (inches),
- X = Access Costs (\$), and
- Tonnage = Clean tons sold from property.

6.2 Model Validation

The economic model was applied to two properties to determine the validity of the model. As with the accuracy analysis of the database, some data from the two properties were from private sources so the location, seam names, scale, and direction will not be used and seam properties will not be stated.

Two scenarios were evaluated: comparing the profitability of the original resources to what has been mined to date, and comparing the profitability of the remaining resources to the location of current mining. Ideally, the more profitable original resources should correlate to previous mining and current mining should be in areas of the most profitable remaining resources.

The distribution of profitability within the seams was calculated using the economic model within the GIS. Private thickness data existed for the two properties, and was used instead of the thickness data from the database. Surface mining was assumed wherever the stripping ratio was less than 15. Where the stripping ratio exceeded 15, underground mining was assumed. Access methods for underground mining were determined as a function of stripping ratio, as shown in Table 6.3. For both surface and underground mining, labor costs were assumed to be \$25 per hour and the remaining parameters existed within the database.

In evaluating the correlation between profitability and mining, it should be remembered that profitability should typically exceed \$5/ton to justify the risk involved in mining.

6.2.1 Property One

Seam A has been extensively mined in the first property, and was chosen for evaluation because of the presence of past and current mining, indicating that it had, and still has, economic reserves. Current mining exists at two locations on the property; one is a surface mine and the other is an underground mine.

The current profitability of the original resources is shown in Figure 6.4. While some prior mining has occurred in what are now unprofitable resources, the resources likely were profitable at the time they were mined. Profitability is generally higher to the right side of the plot, and mining has occurred more consistently in that area.

Profitability of the remaining underground resources is shown in Figure 6.5, along with the location of the portal of the currently active underground mine. Very little reserves exist in this seam at this location. The active mine is extracting resources which are shown as marginally uneconomic. This could be for two reasons. Either the reserves are, in fact, economic and the production of the mine (less than 150,000 tons in 1996) is too small for the precision of the database, or the mine is using lower cost labor and potentially operating at a current loss. The fact that there is only one underground mine



Figure 6.4 Profitability of original resources and location of previous mining of Seam A at Property 1
(north arrow and scale intentionally left off for confidentiality)

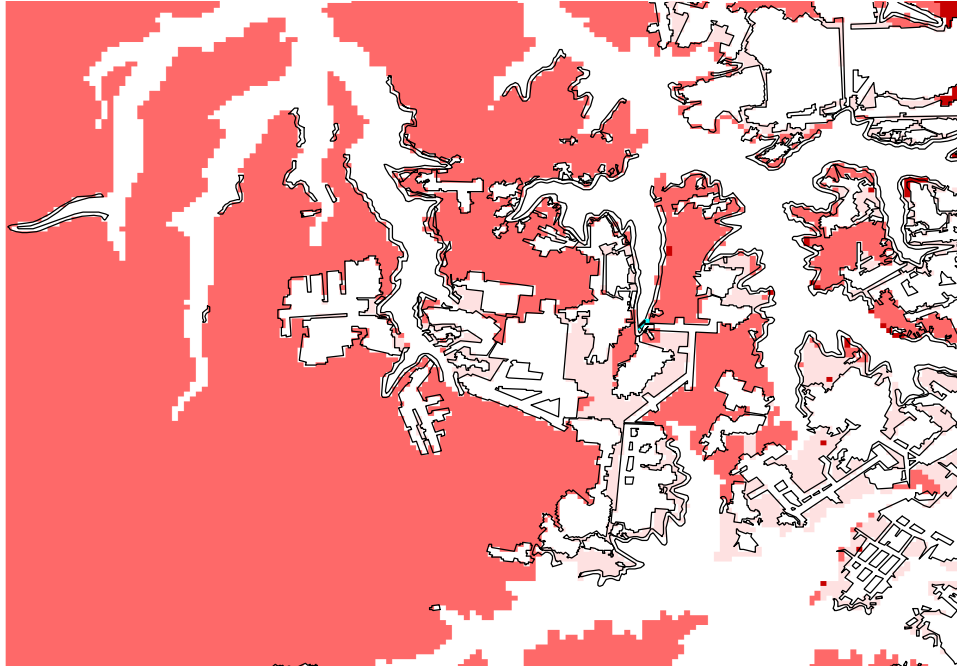


Figure 6.5 Profitability of remaining resources and location of current mining of Seam A at Property 1
(north arrow and scale intentionally left off for confidentiality)

currently operating in the seam at this location tends to indicate that the coal is unprofitable.

6.2.2 Property Two

A more localized study was completed for the second property. Figure 6.6 shows the current profitability of the original resources. As with the first property, mining has occurred in areas which are shown to be the most profitable. Additionally, no mining has occurred in the unprofitable areas.

Figures 6.7 and 6.8 show the current profitability of remaining surface and underground resources, respectively. One current surface mine is operating in the area and is located near the small areas of profitable surface reserves shown in Figure 6.7, but off the plot. Because there are limited surface resources remaining, limited conclusions can be drawn from examining surface resources. The remaining underground resources are marginally profitable, and no mining is currently occurring in this seam at the location.

The results for the two seams at the properties described are comparable to results obtained in other seams at the properties. While no model will show precise correlation with imprecise data as the input, the results of the model used on these two properties show that previous mining occurred where the most economic reserves were located and that the limited current mining is in marginally economic property.

6.3 Application of Economic Model

The economic model was applied to the Southwest Virginia coal database by assuming values for some parameters and using database values for others. Assumed values for labor costs, coal preparation, etc. are shown in Table 6.5. Values for sulfur content, thickness, ash content, in-seam reject, property tonnage, and stripping ratio were drawn from the database for each acre. A labor cost of \$25 per hour was assumed. Thus for each seam a profit was attached to the coal on an acre-by-acre basis using the GIS. Acres which were restricted by land-use or multiple-seam interaction were excluded from the analysis. Because the economic model was used with the remaining resources unaffected by land-use or interaction, the mining losses described in Section 5.2.2 were re-applied. Based on industry input, ash contents above 15% resulted in reduced yield according to the equation:

$$Yield = 100 - (Ash + 6)$$

where *yield* and *ash* are expressed as a percent. This relationship was found to agree with results from USBM studies, shown in Table 5.3. The stripping ratio was used to

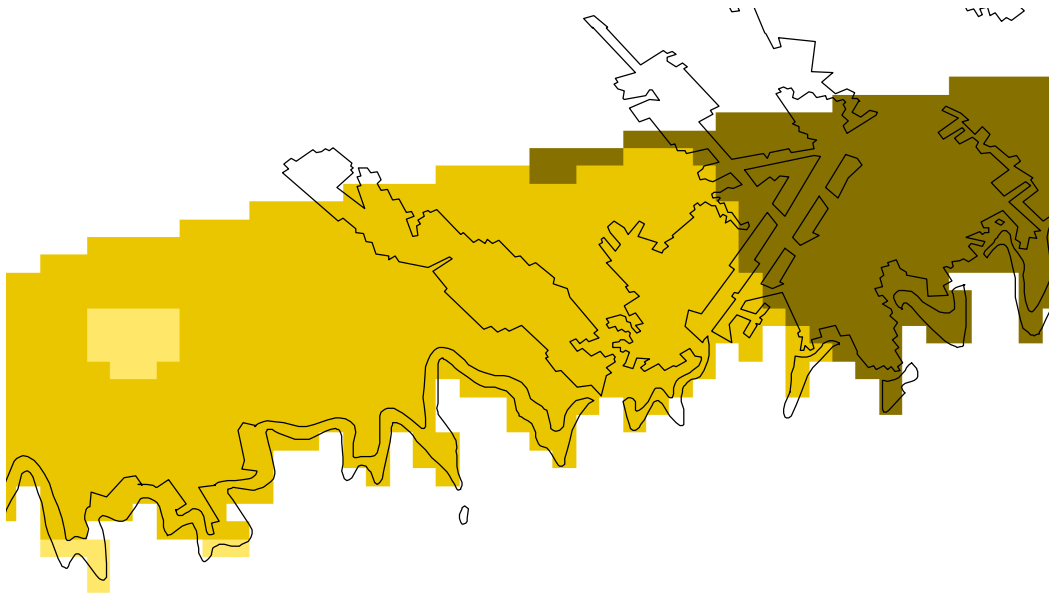


Figure 6.6 Profitability of original resources and location of previous mining of Seam X at Property 2
(north arrow and scale intentionally left off for confidentiality)



Figure 6.7 Profitability of remaining surface resources and location of current surface mining of Seam X at Property 2
(north arrow and scale intentionally left off for confidentiality)

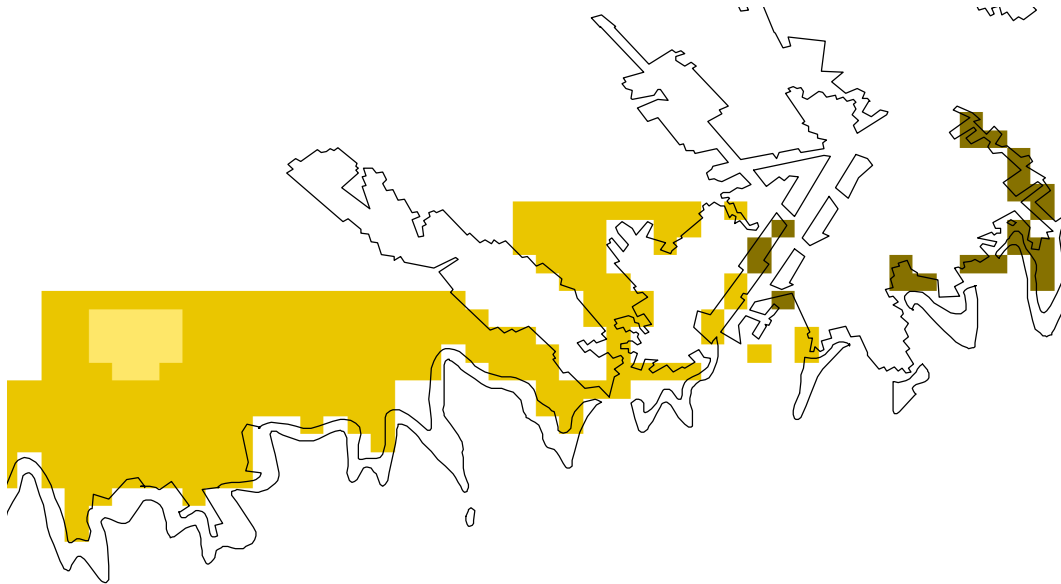


Figure 6.8 Profitability of remaining underground resources and location of current underground mining of Seam X at Property 2
(north arrow and scale intentionally left off for confidentiality)

determine if an acre was mined by surface or underground methods. If the stripping ratio was less than 15, it was assumed that the location would be surface mined. The stripping ratio was not used in calculating surface reserves because imprecision in the overburden thickness data resulted in occasional negative stripping ratios, dramatically influencing the profitability. A stripping ratio of 10 was assumed to be an average value and was therefore used for all surface-mineable tracts.

Results show the level of resources which are truly reserves, i.e., are economic to extract and sell. Figure 6.9 displays the relationship between profitability and reserve tonnage for surface, underground, and the two combined. High risks are inherent to coal mining, and therefore a high rate of return is required. For this reason, a profit of five dollars per ton was used to determine reserve level, which represents approximately 15 to 20 percent of sales price.

To simplify further sets of analyses, the curves shown in Figure 6.9 were approximated by calculating profitability for each resource definition obtained in Section 5.1. The approximated curves for surface and underground mining are shown as Figures 6.10 and 6.11.

Projections of future sales price and productivity can be incorporated into the model to estimate reserves at future times. Figure 6.12 shows projected average mine-mouth coal prices through the year 2020 (DOE/EIA, 1999b). The figure shows a drop for eastern coals of approximately \$1.50 per ton by the year 2004, and approximately \$4.50 per ton by the year 2019. Although this is a mine-mouth price, not including transportation costs, it indicates a continued tightening of profit margins. This change in profitability

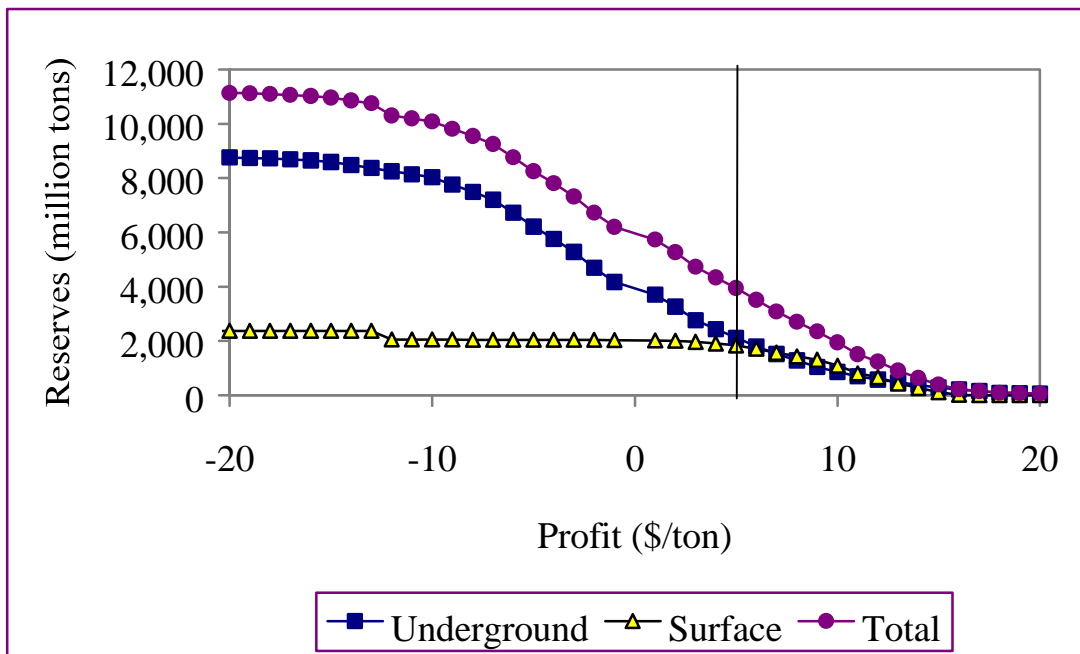


Figure 6.9 Relationship between Profitability and Reserves for underground, surface, and all mineable properties

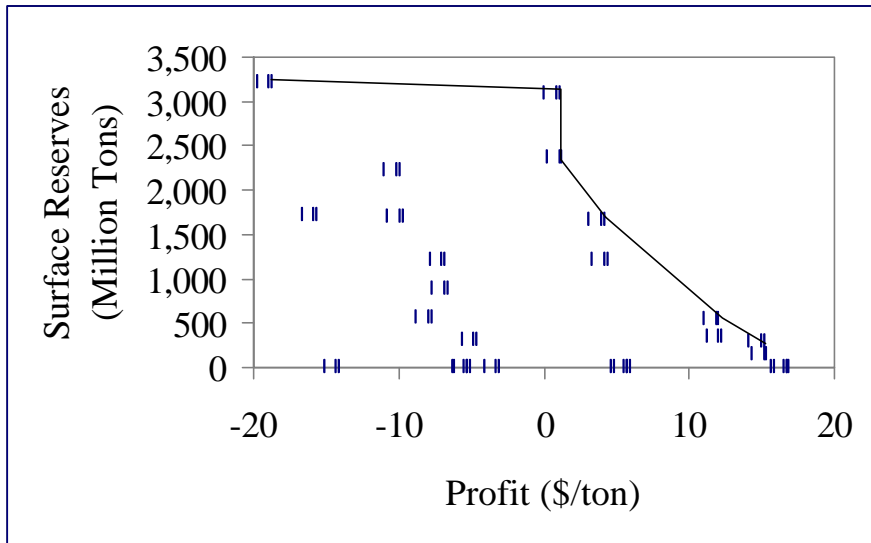


Figure 6.10 Approximated relationship between Profitability and Reserves for surface resources

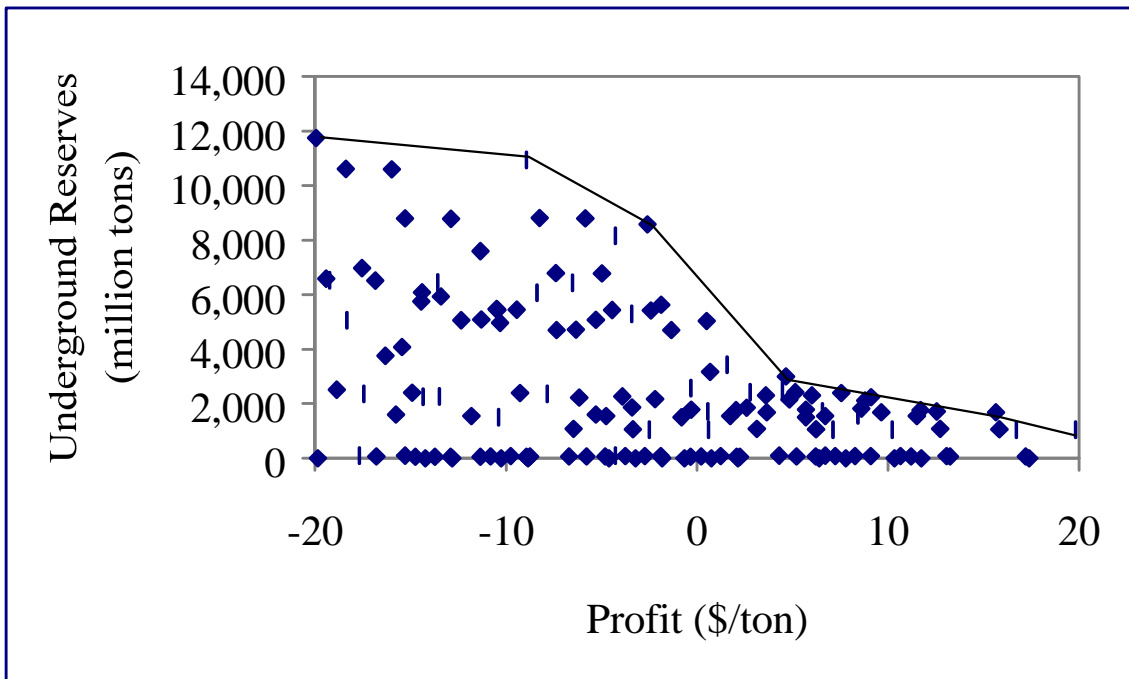


Figure 6.11 Approximated relationship between Profitability and Reserves for underground resources

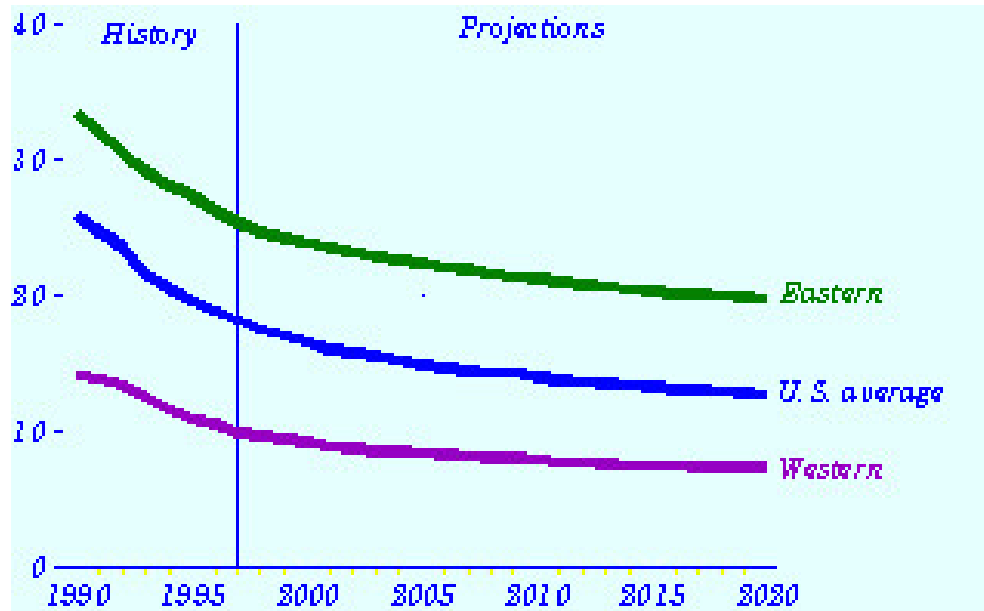


Figure 6.12 Past and predicted average mine mouth price of coal for Eastern U.S., Western U.S., and U.S. average, dollars per ton (DOE/EIA, 1999b)

was applied to the curves shown in Figures 6.10 and 11, with the result shown in Figure 6.14 and 6.15. While productivity for Eastern mines is projected to increase by 30 percent over the next 20 years, labor costs are projected to drop by 15 percent. The combined effect, along with projected decreases in transportation costs, will result in slightly increased profitability.

Several weaknesses exist in the model and must be understood when evaluating the results. Stripping ratio was used to determine whether given acres were surface mineable or underground mineable, and was based on surface and seam elevations. Due to imprecision in the elevation data, it is likely that some reserves are included as surface mineable which should be underground mineable, and vice versa. Another difficulty in implementing the economic model with the database was that the sales price relationships were developed for ash and sulfur contents as sold, which could be raw (if from a surface mine) or washed, whereas the database contained raw ash and sulfur contents. This is a weakness in the economic model, but was accepted as the coals of Southwest Virginia are generally lower in ash and sulfur content than other coals in the Central Appalachian coalfield.

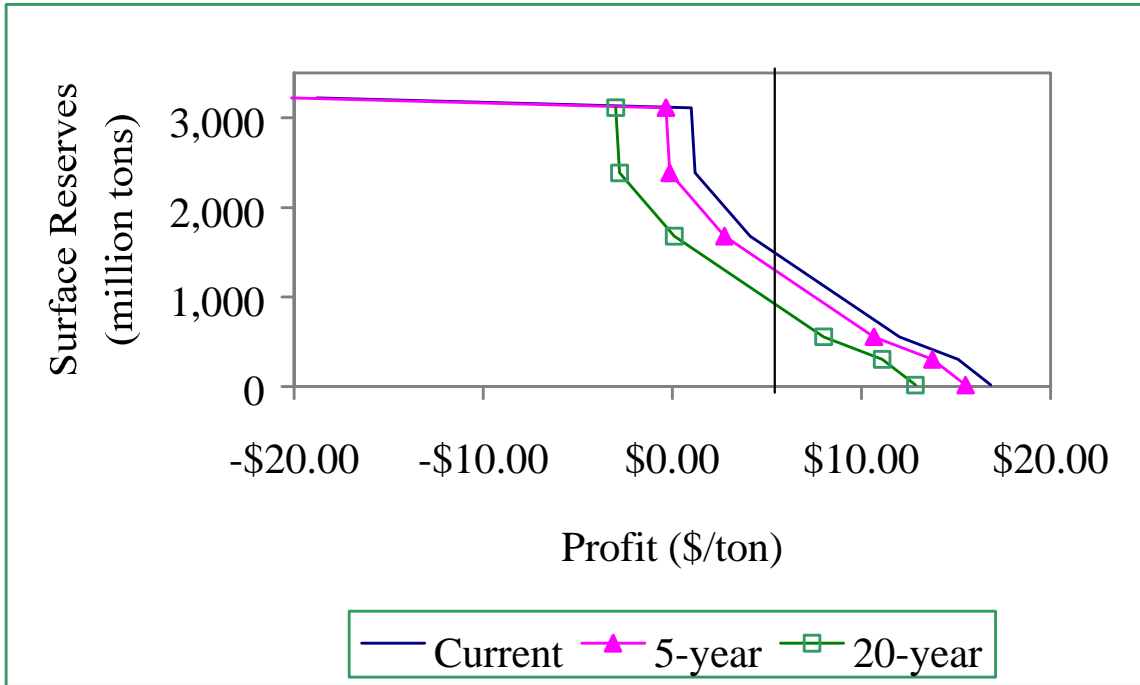


Figure 6.13 Relationship between Profitability and Reserves for surface mining based on predicted sales prices in 5 and 20 years

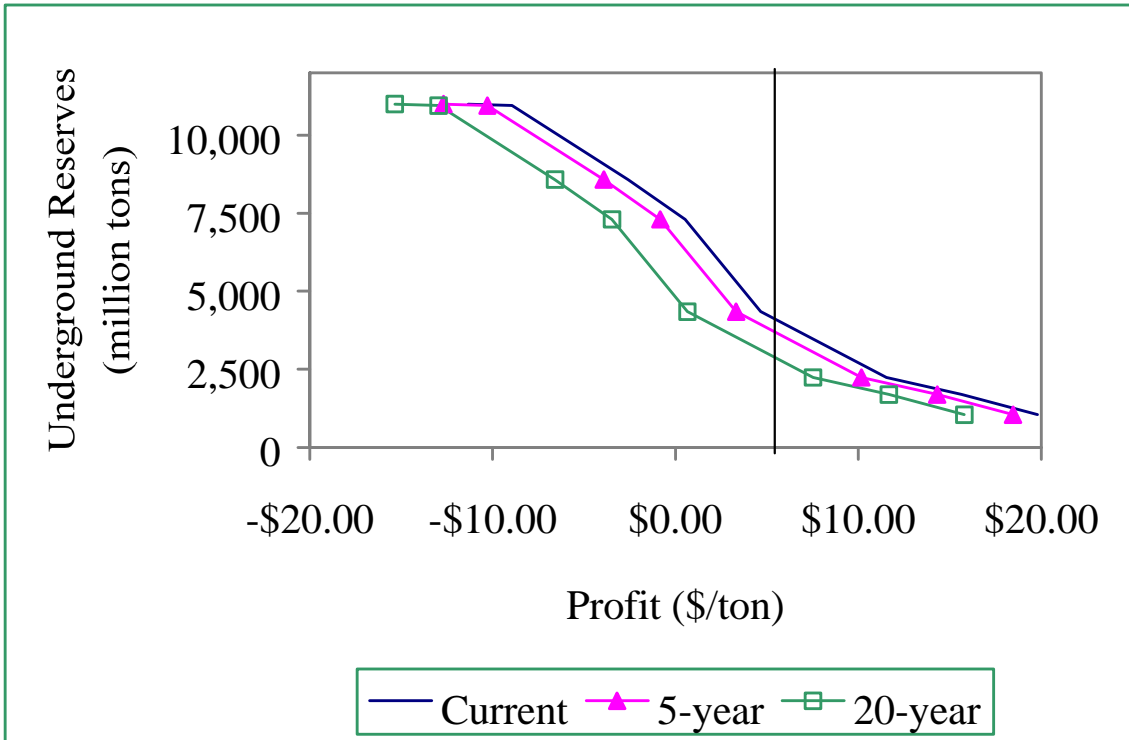


Figure 6.14 Relationship between Profitability and Reserves for underground mining based on predicted sales prices in 5 and 20 years

6.4 Discussion of Results

The results of the reserve study show what measures are most important to the economic health of the Southwest Virginia community. Reserve levels are most influenced by seam thickness.

The results of the reserve study can be combined with the results of the resource study and compared to a similar study. Table 6.6 shows remaining resources along with reserves. Values are also shown as a percent of the remaining resource. These values can be compared to USBM findings for the Matewan quadrangle of eastern Kentucky (Rohrbacher et al., 1992). Table 6.6 shows the comparison assuming a \$25 per ton sales price for the Matewan study. Although differences exist between the two studies – primarily in size of study area, but also in definitions – the results of the two studies agree reasonably well.

Table 6.6 Results of Reserve Study and comparison to Matewan study by Rohrbacher et al.

Remaining Resource (million tons)	Reserves (million tons)	Reserve percentage of Remaining (%)	Matewan Reserve percentage of Remaining (%)
27,735	3,947	14.2	8.5

CHAPTER 7 – APPLICATION AND SUMMARY

7.1 Planning Considerations for Southwest Virginia

It is important too many different parties that wise planning occur to ensure the continued socio-economic health of Southwest Virginia. Results of the reserve study indicate that, without appropriate action, coal production will decrease in the coming years. While the future can never be clearly predicted, and there will always be *some* coal mined in Southwest Virginia, the current level of employment is not likely to be maintained.

Two approaches can be taken to optimize long-term prosperity of Southwest Virginia: manage current investments wisely and subsidize mining operations. Potential growth industries and their required infrastructure should be targeted for present investment in Southwest Virginia. These industries may be tied to the proposed Coalfields Expressway interstate highway, cultural heritage of the area, or manufacturing industries.

The potential influence of subsidizing mining operations through tax credits for various parameters can be seen in two different ways. A Pearson correlation was run on results of the economic model, resulting in the correlations given as Table 7.1. As was expected (discussed in Section 5.4), the influence of sulfur is much less significant to reserve levels than to resource levels. Seam thickness and in-seam reject are the most influential parameters to reserve levels.

These relationships can also be seen by their effects on the curves shown as Figures 6.10 and 6.11. These curves were obtained using the database and approximation described in Section 6.3. The influence of a \$2 per ton credit on seam thickness less than, or equal to, 30 inches is shown as Figure 7.1. The influence of a \$1 per ton penalty on seams with 3” or more of in-seam reject, potentially applicable to reduce surface reject piles, is shown on the underground reserves as Figure 7.2. Finally, the effect of a \$1 per ton credit on tons mined with 1% or less sulfur is shown as Figure 7.3. The goal of any credit should be to increase the tonnage of marginally profitable coal reserves (\$0 to \$5 per ton) as the highly profitable and unprofitable reserves will not significantly influence reserve quantities.

As stated in Chapter 6, 3.9 billion tons of economically mineable coal were found to remain in Southwest Virginia. The known imprecision of the study was used to obtain a reserve quantity for planning purposes. The database was shown to be within

Table 7.1 Pearson correlation between profitability and parameters

Parameter	Correlation to Profitability
Thickness	0.696
In-Seam Reject	0.591
Ash	0.250
Sulfur	0.176

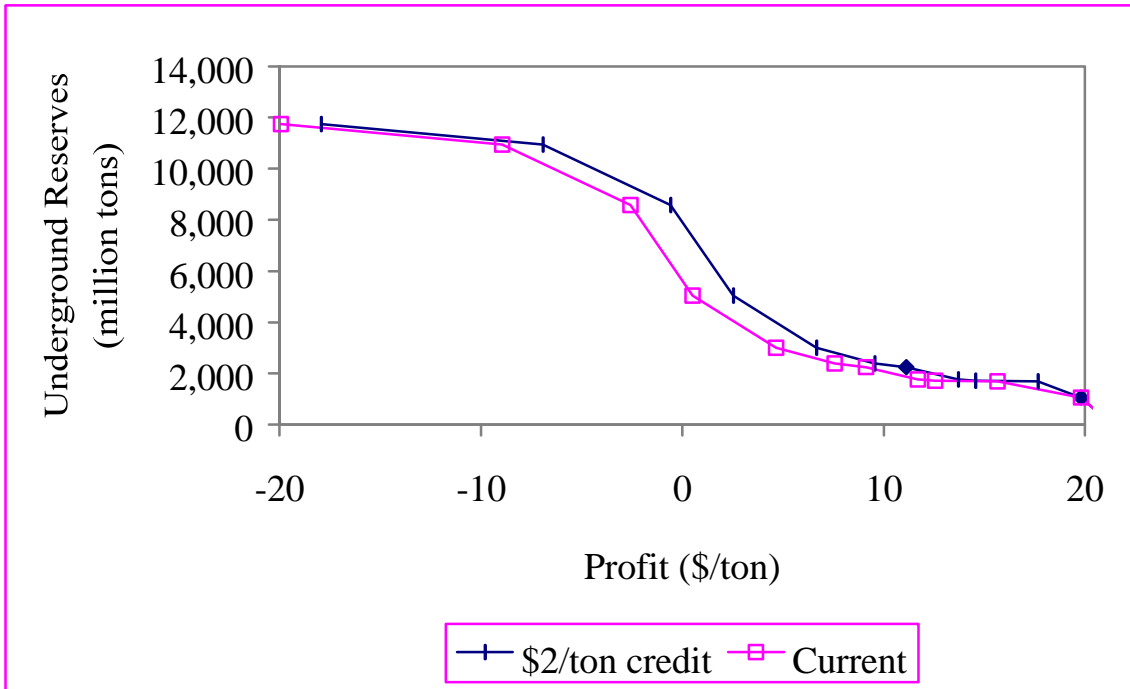


Figure 7.1 Relationship between Profitability and Reserves for underground mining showing effect of \$2 per ton tax credit for seams 30 inches thick or less

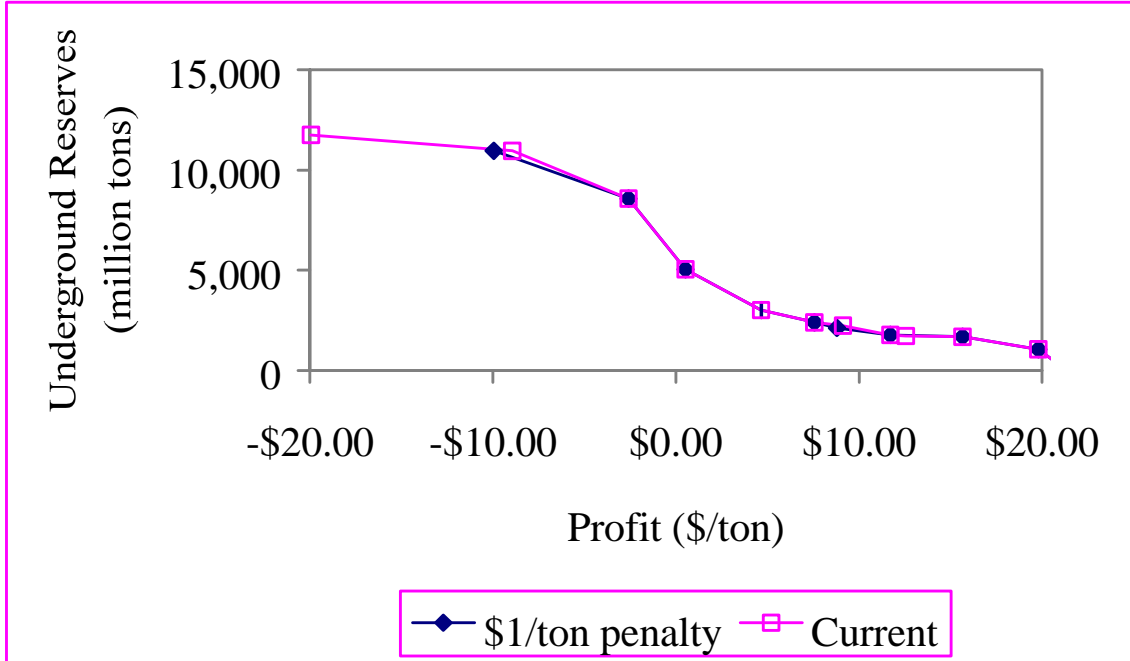


Figure 7.2 Relationship between Profitability and Reserves for underground mining showing effect of \$1 per ton penalty for seams with more than 3 inches in-seam reject

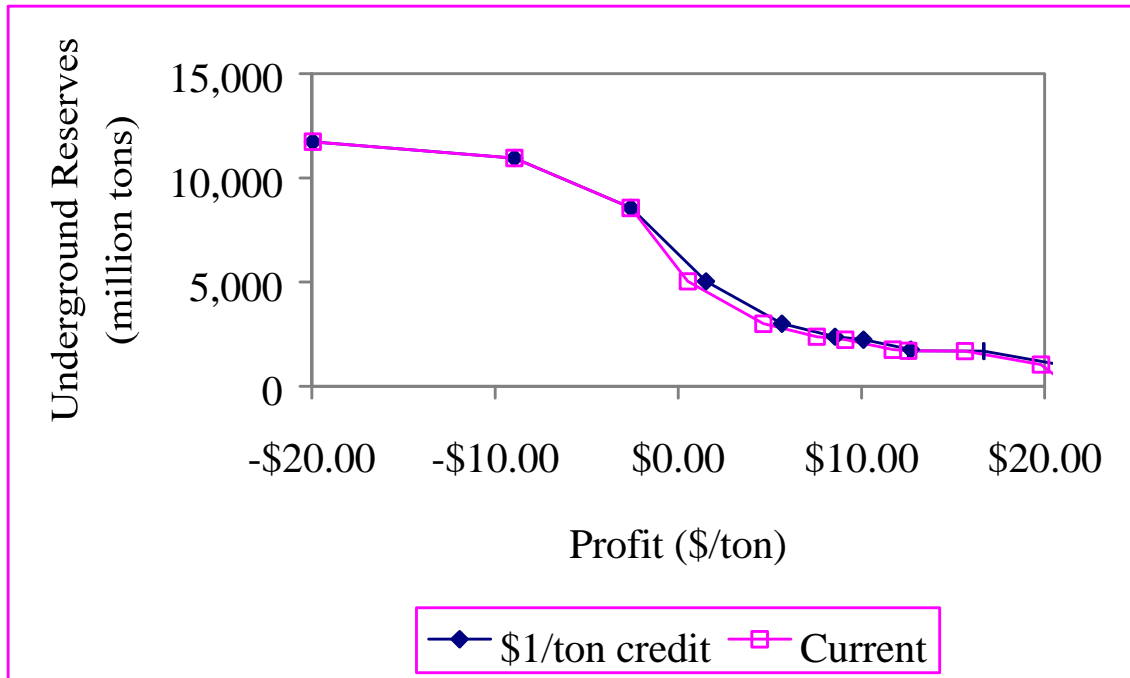


Figure 7.3 Relationship between Profitability and Reserves for underground mining showing effect of \$1 per ton tax credit for seams with 1% raw sulfur or less

approximately 60% at an 80% confidence level. It can be stated for planning purposes, therefore, that at an 80% confidence level there are at least 1.6 billion tons (40% of 3.9 billion tons) of economically mineable coal remaining in Southwest Virginia with current mining conditions.

While it is important to have a figure for remaining reserves, it is also important to estimate annual production in the short term. Such estimation is beyond the scope of this project, however, was completed by Crabtree (1995) based on a multiple linear regression model. Crabtree's results, shown as Figure 7.4, show past production from 1979 through 1993 as well as the projected production assuming pessimistic, most likely, and optimistic prediction. The actual production for 1994 through 1997 has been included and falls between the most likely and pessimistic predictions.

7.2 Comparison to Eastern Kentucky and West Virginia

The results of the resource studies can be used to establish the potential for future Southwest Virginia mining, compared to Eastern Kentucky and Southern West Virginia. An approximate estimate of coal reserves in each of these states was completed. The coal availability studies conducted by the USGS, described in Section 2.4.2, provided restriction estimates typically for one quadrangle or county. It should be noted that inaccuracy is introduced, therefore, in extrapolating to an entire state. It should also be noted that this analysis was completed using results of the study by Brown et al. (1952)

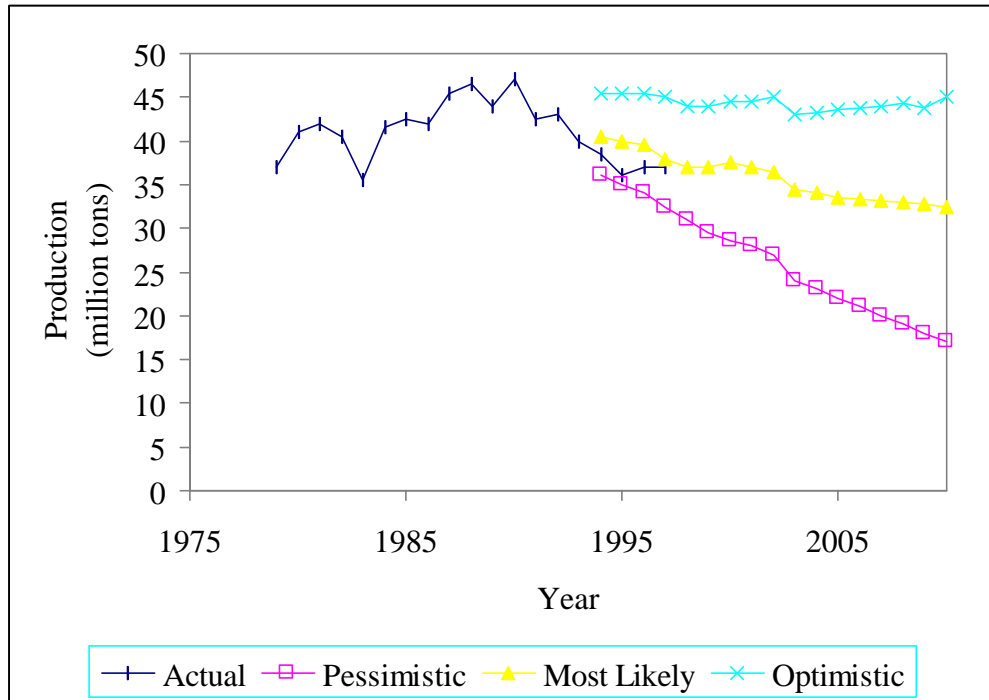


Figure 7.4 Virginia coal production forecasts with optimistic, pessimistic, and most likely predictions (after Crabtree, 1995).

for Southwest Virginia coal reserves. The reserve levels found in this dissertation are higher than those reported in this comparison to West Virginia and Kentucky.

Approximate reserve estimates for Eastern Kentucky and West Virginia were obtained by subtracting restricted coal, mining and washing losses, economic constraints, and noncompliance coal from the remaining resource. Based on results of the coal availability studies, 33% of the tonnage was subtracted from the remaining resource to account for technical and land-use restrictions. A 50% loss was then assumed for recovery loss due to mining and washing. Economic constraints are difficult to estimate, but sales prices have not risen substantially since the studies were completed, so an assumption that 50% of the coal is uneconomic was used. Because the amount of compliant coal which is restricted may be reduced by blending with high and low sulfur coals, a figure of 20% was used. By combining restrictions due to technical and land-use constraints, mining and washing losses, marketability, and compliance, an assumption of approximately 13% of the remaining resource was estimated as the level of true economically mineable reserves. This compares well to a figure of 14.2% of remaining resources being reserves found by the current study of Southwest Virginia coals.

The results of these assumptions, as well as 1995 production figures, for Virginia, West Virginia, Tennessee, and Kentucky are shown in Table 7.2. While eastern Kentucky and West Virginia have substantially higher estimated economic reserves, they also have significantly higher annual production rates. Future adjustments for newly developed reserves are also likely. For example, between 1993 and 1995 the Demonstrated Reserve

Table 7.2 1996 Remaining Resource, Estimated Economic Reserves, and 1995 production for states in Central Appalachia coal basin; all figures in million short tons.

	1996 Remaining Resource ¹	Estimated Economic Reserves ²	1995 Production ³
Eastern Kentucky	53,900	7,000	119
Virginia	8,000	1,040	34
West Virginia	55,400	7,200	163

¹ from Brown et al., 1952, Cobb et al., 1996, McColloch, 1996, US DOE, 1995b, and VCCER, 1998.

² based on assumptions discussed in the text (13% of Remaining Resource)

³ from U.S. Dept. of Energy, 1995b

Base for eastern Kentucky rose from 8,600 to 12,485 million short tons (DOE/EIA, 1996).

7.3 Summary

A database was established for 26 Southwest Virginia coal seams. The database includes coal thickness, ash, sulfur, in-seam reject, multiple-seam interaction, land-use restrictions, property tonnage, and county data, as well as seam outcrops and previous mining locations. Data for the database were obtained from publicly available sources. A total of 521 thickness points and 408 in-seam reject points were used, most of these describing the average thickness within a quadrangle. Additionally, 332 data points, each describing both sulfur and ash content, were included. The ArcView geographic information system was used as the primary data viewing and manipulation tool. The inverse-distance squared method was found to be the best suited of several methods evaluated for interpolating between measurement locations. Grids composed of one acre cells were generated for each of the parameters and each of the seams.

Interpolated thickness grids were evaluated for accuracy by comparison to other databases and by using a quantitative accuracy assessment method developed as a part of the project. Resource estimates based on the project database compared well with resource estimates by Brown et al. (1952) and Campbell et al. (1991) for Southwest Virginia and Lee County, respectively. The quantitative accuracy assessment method showed that the thickness data *accurately* represent true thickness but do not *precisely* represent true thicknesses. Due to the scale of the study, precise representation was not expected.

The factors which most influence resource levels were determined by completing a parametric analysis. Multiple-seam interaction and land-use limitations restrict 8% and 6% of the remaining resource, respectively. Of the thickness and quality parameters, sulfur content, thickness, and ash content have the most influence on resource levels, while in-seam reject and property size have much less effect. Regression analysis found that surface resources were described by:

$$R = -1.10e9 + 1.60e9 S - 0 Th - 1.02e8 \log_{10} Tn + 7.6e7 A$$

while underground resources were described by:

$$R = 1.28e9 + 4.67e9 S - 1.64e8 Th - 1.11e8 \log_{10} Tn + 6.11e6 I + 2.35e8 A$$

where
 R = Resource (tons)
 S = Maximum allowable Sulfur content (%),
 Th = Minimum allowable Thickness (inches),
 Tn = Minimum Property Tonnage (tons),
 I = In-Seam Reject, and
 A = Maximum allowable Ash content (%).

To separate reserves, or economic resources, from uneconomic resources, an economic model simulating Central Appalachian coal production profitability was developed. Extensive industry input was foundational to the model. Coal sales price was established as a function of ash and sulfur content. Mining costs were related to stripping ratio, labor cost, and productivity for surface mining and to thickness, in-seam reject, labor costs, access costs, property tonnage and productivity for underground mining. Additional costs, including transportation, preparation, taxes, royalties, and office overhead were determined. Surface mining profitability was found as:

$$Pf = 33 - 1.1 Ash - 3.1 Sulfur - P^{-1} \{1 + (0.55 * Ratio) + (0.23 * L)\}$$

While underground profitability was described as:

$$Pf = 30 - 1.1A - 3.1S - \left(\frac{1}{P}\right) \frac{R + Thick(19.6 - 0.28Thick + 0.28L)}{Thick} + \frac{X}{Tonnage}$$

where
 Pf = Profit (\$/ton),
 A = Ash content (as sold, %),
 S = Sulfur content (as sold, %),
 Ratio = Stripping Ratio,
 L = Labor Costs (\$/hour),
 P = Productivity Factor (1.0 in 1998 mining conditions),
 Thick = Coal thickness (inches),
 R = Reject (weight percent),
 X = Access Costs (\$), and
 Tonnage = Clean tons sold from property.

The model was validated by applying it to two properties and: 1) comparing original profitability to previously mined areas and 2) current mining locations to the profitability of remaining resources. The model showed good correlation and was then applied to the database.

Communication of project results and identification of areas of needed future research allow appropriate planning strategies to be developed for Southwest Virginia. A computer program was written to allow resource levels to be determined as a function of the various parameters. Results of the study can be used to increase the effectiveness of strategic decision making for Southwest Virginia. Estimated reserves of eastern Kentucky and West Virginia were compared to those of Virginia to determine the potential influence of neighboring states on future Southwest Virginia coal production. Several steps were identified to increase the precision of the database and the relevancy of the study.

CHAPTER 8 – CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

A database of the characteristics of 26 Southwest Virginia coal seams was established. The database was analyzed to characterize and estimate remaining coal resources. An economic model was developed and validated to determine the portion of the resources which are economically mineable reserves.

Approximately 27.7 billion tons of coal remain in Southwest Virginia. Of this resource, approximately 15.2 billion tons are unrestricted by land-use (or multiple-seam interaction if underground), less than 2% sulfur, less than 25% ash, greater than 12 inches thick if surface and greater than 30 inches thick if underground. These “available” resources are split into 11.2 billion tons of underground resources and 4.0 billion tons of surface resources. Using current industry-based definitions, approximately 14% of the remaining resource, or 3.95 billion tons, was found as an economically mineable reserve which is estimated to be sold if current conditions continue.

The resource quantities found in this study are approximately double those found by Brown et al. (1952) in the previous comprehensive resource study for Southwest Virginia. This difference was expected, however, as much more data exists currently for deeper seams than existed at the time of Brown’s study. A resource study for Lee County (Campbell et al., 1991) also found approximately double the resources as the Brown study, so the current findings are considered reasonable.

While the database was found to accurately reflect resource levels in Southwest Virginia, a lack of publicly available data limited the precision of the study. The database thicknesses were evaluated using a quantitative accuracy assessment technique and found to be between 62 and 126% of the correct value at a 50% confidence level, and between 33 and 155% of the correct value at an 80% confidence level.

Because Southwest Virginia coals contain low sulfur levels compared to other Eastern U.S. production areas, sulfur content has much less influence on reserve level than it did on resource level. Thickness was found to be the most influential parameter on reserve level.

Predicted decreases in sales price will reduce the level of reserves. The resources which may be mined with the longwall method are very limited. Much of Southwest Virginia coal resources (> 60%) are in seams with little outcrop, meaning that expensive development is required to access the resources. These development costs significantly increase the risk involved with these seams, making them less attractive in the currently volatile coal market.

Further production is likely to come from the existing large base of small operations, which may pay below the industry average. The continuation of current conditions will

likely result in reduced production with few large operations (> 1million tons per year) starting. The most effective enhancements to reserve base are credits for thickness and development costs.

8.2 Recommendations

Results of this study are important to state and county decision-makers as well as coal companies, land management companies, consulting engineers, utilities, and railroad companies. It is hoped that the results of this study will assist in strategic developments aimed at ensuring the long-term socio-economic health of the Southwest Virginia community.

Results of the resource and reserve studies can be improved with further research in several areas. The accuracy and precision of parameters other than thickness could be evaluated. Instead of removing areas restricted by land-use or multiple-seam interaction from the reserve study, a cost could be associated with the restriction so that the resource could still be mined if it could be extracted economically. Additional parameters, including seam dip, could be added to the study to make the results more accurate. The analyzed property size was determined by summing all adjacent acres. This practice did not always lead to well-laid out properties. Faults may also reduce true property sizes.

Multiple-seam interaction was based on seam averages – i.e. the seam with the higher average thickness was assumed to be mined, sterilizing an adjacent seam. The averages used were seam-wide. The results of the study could be improved by analyzing seam interaction on a more local scale. In some areas Seam A may be mined in favor of Seam B, but the opposite may occur in other areas. Further, only adjacent seams were assumed to be influenced by interaction, while in actuality, super-adjacent seams may be impacted.

Stripping ratios were only calculated for individual seams. In some cases, several seams may be economically surface mined when the lower seams have stripping ratios much greater than 15:1 or 20:1, but are economical when considered with overlying seams. Mountain top removal was not considered, and may make some properties more profitable for surface mining.

As stated in Section 3.1, only 26 of the more than 80 seams were analyzed. Many resources exist in deeper seams, but little data were available for them to be analyzed.

Additional data will improve the precision, and perhaps the accuracy of the study. Borehole thickness measurements, washability data, and quality characteristics obtained by members of the coal mining industry should be relayed to the state government so that a comprehensive, precise database could be established. This database would allow an accurate *and* precise resource estimate to be maintained, ultimately benefiting both members of the Commonwealth and the coal industry.

REFERENCES

- Averitt, P. and L.R. Berryhill, 1950, "Coal Resources of the United States, A Progress Report," U.S.G.S. Circular 94.
- Brown, A., H.L. Berryhill, D.A. Taylor, and J.V.A. Trumbull, 1952, "Coal Resources of Virginia," U.S. Geological Survey Circular 171, 57 pp.
- Campbell, E.V.M., J.A. Henderson Jr., and L.L. Myers, 1991, "Coal Resource Estimate for Lee County, Virginia," Virginia Division of Mineral Resources, Publication 111, Charlottesville, VA, 61 pp.
- Campbell, J.B., 1997, "Introduction to Remote Sensing," Guilford Press, New York, pp. 375-398.
- Carter, M.D., A.L. Medlin, M.A. Carey, and K.K. Krohn, 1981, "Stratigraphic Sequence Form Manual; Guide for Entering Stratigraphic Data into the National Coal Resource Data System (NCRDS)," Open-File Report 81-0562, 12 pp.
- Cavallaro, J.A., A.W. Deurbrouck, R.P. Killmeyer, W. Fuchs and P.S. Jacobsen, 1990, "Sulfur and Ash Reduction Potential, and Selected Chemical and Physical Properties of United States Coals," DOE/PETC/TR-90/7, Volume 1, pp. 934-949.
- Coal Outlook, 1997, Pasha Publications, Arlington, Virginia
- Cobb, J.C., R.E. Andrews, and G.A. Weisenfluh, 1996, "Coal Geology of Kentucky," 1996 Keystone Industry Coal Manual, Intertec Publishing, Chicago, pp. G73-G94.
- Code of Federal Regulations (CFR), 1987, Parts 53-60, U.S. Government Printing Office, Washington, D.C., v. 40, pp. 255-257.
- Crabtree, W.A., 1995, "Forecast of Virginia Coal Production," M.Sc. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 166 pp.
- Department of Energy, Energy Information Administration, 1981, "Demonstrated Reserve Base of Coal in the United States on January 1, 1979," U.S. Department of Energy Report DOE/EIA-0280(79), Washington D.C., 121 pp.
- Department of Energy, Energy Information Administration, 1992, "Documentation of the Resource Allocation and Mine Costing (RAMC) Model," DOE/EIA-M021(92), pp. 1-10.
- Department of Energy, Energy Information Administration, 1994a, "State Coal Profiles," DOE/EIA-0576, pp. 95-102.

Department of Energy, Energy Information Administration, 1994b, "Acid Rain Compliance Strategies for the Clean Air Act Amendments of 1990," DOE/EIA-0582, pp. ix-3.

Department of Energy, Energy Information Administration, 1995a, "Energy Policy Act Transportation Rate Study: Interim Report on Coal Transportation," DOE/EIA-0597, 136 pp.

Department of Energy, Energy Information Administration, 1995b, "1995 Coal Industry Annual," DOE/EIA-0584(95), 258 pp.

Department of Energy, Energy Information Administration, 1996, "U.S. Coal Reserves: A Review and Update," DOE/EIA-0529(95), p. 32.

Department of Energy, Energy Information Administration, 1997, "Annual Energy Outlook, 1998," DOE/EIA 0383(98), 223 pp.

Department of Energy, Energy Information Administration, 1998a, "Challenges of Electric Power Industry Restructuring for Fuel Suppliers," DOE/EIA 0623, 138 pp.

Department of Energy, Energy Information Administration, 1998b, "Model Documentation Coal Market Module of the National Energy Modeling System," DOE/EIA M060(98), 153 pp.

Department of Energy, Energy Information Administration, 1999a, "U.S. Coal Reserves: 1997 Update," DOE/EIA-0529(97), 60 pp.

Department of Energy, Energy Information Administration, 1999b, "Annual Energy Outlook, 1999," DOE/EIA 0383(99), 223 pp.

Deurbrouck, A.W., 1963a, "Preparation Characteristics of Coal from Tazewell County, VA," U.S. Bureau of Mines Report of Investigations 6297, 31 pp.

Deurbrouck, A.W., 1963b, "Preparation Characteristics of Coal from Russell County, VA," U.S. Bureau of Mines Report of Investigations 6342, 32 pp.

Deurbrouck, A.W., 1966, "Preparation Characteristics of Coal from Buchanan County, VA," U.S. Bureau of Mines Report of Investigations 6740, 49 pp.

Eby, J.B., 1923, "Geology and Mineral Resources of Wise County and the Coal-Bearing Portion of Scott County, Virginia," Virginia Division of Mineral Resources, Bulletin 24, Charlottesville, VA, 617 pp.

Eggleston, J.R., M.D. Carter, and J. C. Cobb, 1990, "Coal Resources Available for Development – A Methodology and Pilot Study," U.S. Geological Survey Circular 1055, 15 pp.

Fraher, R., C. Haycocks, M. Karmis, and Y. Zhou, 1992, "Ground Control Hazard Analysis in Multi-Seam Mining," Proc., 11th Int'l. Conf. on Ground Control in Mining, Univ. of Wollongong, N.S.W., pp. 302-307.

Giles, A. W., 1921, "Geology and Coal Resources of Dickenson County, Virginia," Virginia Division of Mineral Resources, Bulletin 21, Charlottesville, VA, 224 pp.

Giles, A. W., 1925, "Geology and Coal Resources of Lee County, Virginia," Virginia Division of Mineral Resources, Bulletin 26, Charlottesville, VA, 216 pp.

Gray, T.E. and C.C. Boley, 1958a, "Preparation Characteristics of Coal from Wise County, VA," U.S. Bureau of Mines Report of Investigations 5391, 50 pp.

Gray, T.E. and C.C. Boley, 1958b, "Preparation Characteristics of Coal from Dickenson County, VA," U.S. Bureau of Mines Report of Investigations 5405, 31 pp.

Haycocks, C. and M. Karmis, 1983, "Ground Control Mechanisms in Multi-Seam Mining," Final Report prepared for the Office of Mineral Institutes, Bureau of Mines, U.S. Department of the Interior, 328 pp.

Harnsberger, T.K., 1919, "Geology and Coal Resources of the Coal-Bearing Portion of Tazewell County, Virginia," Virginia Division of Mineral Resources, Bulletin 19, Charlottesville, VA, 195 pp.

Henderson, J. A., 1985, "Summary of Coal Resources in Virginia," Keystone Coal Industry Manual, McGraw-Hill, New York, pp. 581-585.

Hinds, H., 1918, "Geology and Coal Resources of Buchanan County, Virginia," Virginia Division of Mineral Resources, Bulletin 18, Charlottesville, VA, 278 pp.

Hinkle, M.E., 1969, "The Strippable Coal Reserves of Virginia," unpublished Information Circular, U.S. Bureau of Mines, pp. 1-13.

Hong, B.D., 1998, "Annual Review 1997: Coal," Mining Engineering, Vol. 50, No. 5, May, pp. 60-68

Holland, C.T., 1951, "Multiple-Seam Mining," Coal Age, August, pp. 89-93.

Hubbert, M.K., 1962, "Energy Resources," National Academy of Sciences – National Research Council, Publication 1000-D, 141 pp.

Hubbert, M.K., 1972, "Man's Conquest of Energy: Its Ecological and Human Consequences," The Environmental and Economic Forum 1979-1981, U.S. Atomic Energy Commission TID 25857.

Hubbert, M.K., 1973, "Survey Of World Energy Resources," Canadian Mining and Metallurgical Bulletin, Vol. 66, no.735, p. 37-53.

ICF, Inc., 1989, "Documentation of the ICF Coal and Electric Utilities Model: Coal Supply Curves Used in the 1987 EPA Interim Base Case," prepared for the U.S. Environmental Protection Agency.

Krige, D.G., 1978, "Lognormal-de Wijsian Geostatistics for Ore Evaluation," South African Institute of Mining and Metallurgy, Johannesburg, 50 pp.

Lam, N.S., 1983, "Spatial Interpolation Methods: A Review," The American Cartographer, Vol. 10, No. 2, pp. 129-149.

Luo, J., C. Haycocks, and M. Karmis, 1997, "Gate Road Design in Overlying Multiple Seam Mines," Preprint 97-107, SME Annual Meeting, Denver, CO, 4 pp.

Luxbacher, M., 1999, Personal Communication

McColloch, G.H., 1996, "Coal Geology of West Virginia," 1996 Keystone Industry Coal Manual, Intertec Publishing, Chicago, pp. G183-G193.

Milici, R.C. and E.V.M. Campbell, 1991a, "Virginia Coal Resources – A Long-Term View," Virginia Coal and Energy Journal, Number 3 (Summer 1991), Virginia Center for Coal and Energy Research, Blacksburg, VA, 22 pp.

Milici, R.C. and E.V.M. Campbell, 1991b, "The Long Term Outlook for Coal Production in Virginia," Virginia Mining Journal, Volume 4, Number 3, Virginia Mining Association, Norton, VA, pp. 17-21.

Milici, R.C., 1997, "A Life Cycle Approach to Coal Resource Analysis: Examples from the Appalachian and Illinois Basins," Soc. of Mining, Met. and Expl., Preprint 97-25, 6 pp.

Miller, J.W., 1957, "Preparation Characteristics of Coal from Lee County, VA," U.S. Bureau of Mines Report of Investigations 5358, 14 pp.

Nolde, J.E., W.W. Whitlock, J.A. Lovett, and W.S. Henika, 1994, "Geology and Mineral Resources of the Southwest Virginia Coalfield," Virginia Division of Mineral Resources Publication 131, 142 pp.

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

Plis, M.N., T.J. Rohrbacher, and D.D. Teeters, 1993, "COALVAL 2.0, A Prefeasibility Software Package for Evaluating Coal Properties Using Lotus 1-2-3, Release 2.2," USBM Information Circular 9348, 93 pp.

- Popoff, C.C., 1966, "Computing Reserves of Mineral Deposits: Principles and Conventional Methods," USBM Information Circular 8283, 113 pp.
- Rohrbacher, T.J., D.D. Teeters, G.L. Sullivan, and L.M. Osmonson, 1992, "Coal Reserves of the Matewan Quadrangle, Kentucky," USBM Information Circular 9355, 36 pp.
- Rohrbacher, T.J., D.D. Teeters, G.L. Sullivan, and L.M. Osmonson, 1993, "Coal Resource Recoverability – A Methodology," USBM Information Circular 9368, 48 pp.
- Scurfield, R.W., 1970, "Staffordshire Mining Layout for the Mid-1970's," *Mining Engineer*, Vol. 130, pp. 73-84.
- Sellami, M., J. Tissaoui, C. Haycocks, and M. Karmis, 1994, "Computer Evaluation of Reserve Losses due to Multi-Seam Interaction," Proc., 8th International Conf. of the Assoc. for Computer Methods and Advances in Geomechanics, West Virginia Univ., Morgantown, WV., pp.
- Sites, R.S., E.V.M. Campbell, K.K. Hostettler, N.K. Gardner, and S.J. Trewalt, 1991, "Restrictions to Mining: Their Effect on Available Coal Resources," *Geology in Coal Resource Utilization*, Energy Minerals Division, American Association of Petroleum Geologists, edited by D.C. Peters, published by Tech Books, Fairfax, VA, pp. 81-94.
- Sites, R.S. and K.K. Hostettler, 1991a, "Available Coal Resources Study of Appalachia 7.5-Minute Quadrangle, Virginia-Kentucky," Virginia Division of Mineral Resources, Publication 118, Charlottesville, VA, 51 pp.
- Sites, R.S. and K.K. Hostettler, 1991b, "Available Coal Resources Study of the Wise 7.5-Minute Quadrangle, Virginia," *Virginia Minerals*, Charlottesville, VA, Vol. 37, No. 3, pp. 17-23
- Suffrendi, C.D., M.N. Plis, T.J. Rohrbacher, and D.D. Teeters, 1994, "COALVAL 2.0, A Prefeasibility Software Package for Evaluating Coal Properties Using Lotus 1-2-3, Release 3.1," USBM Open File Report 35-94, 198 pp.
- USGS, 1996, "Assessing the Coal Resources of the United States," Fact Sheet FS-157-96, <http://energy.usgs.gov/factsheets/nca/nca.html>
- Virginia Center for Coal and Energy Research, 1998, "Virginia Coal," Virginia Polytechnic Institute and State University, Blacksburg, VA, 100 pp.
- Webster, S.L., C. Haycocks, and M. Karmis, 1984, "Subsidence Interaction Effects in Multi-Seam Mining," *Proceedings, 2nd International Conference on Stability in Underground Mining*, Lexington, KY, pp. 589-604.

Wentworth, C.K., 1922, "Geology and Coal Resources of Russell County, Virginia," Virginia Division of Mineral Resources, Bulletin 22, Charlottesville, VA, 179 pp.

Westman, E.C., C. Haycocks, and M. Karmis, 1998, "Resources vs. Reserves: the Future of Central Appalachian Coal," Mining Engineering, Vol. 50, No. 12, Dec., pp. 33-37.

Wingle, W.L., 1992, "Examining Common Problems Associated with Various Contouring Methods, Particularly Inverse-Distance Methods, Using Shaded Relief Surfaces," Geotech '92 Conference Proceedings, Lakewood, CO, 13 pp.

Wood, G.H., T.M. Kehn, M.D. Carter, and W.C. Culbertson, 1983, "Coal Resource Classification System of the U.S. Geological Survey," U.S. Geological Survey Circular 891, 65 pp.

Zhou, Y., R. Milici, and E. Campbell, 1990, "Computer-Aided Evaluation of Coal Reserves Influenced by Multiple-Seam Mining," Proc., 4th Conf. on Use of Computers in the Coal Industry, West Virginia Univ., Morgantown, WV., pp.

Zimmerman, M.B., 1981, "The U.S. Coal Industry: The Economics of Policy Choice," The MIT Press, Cambridge, Mass., 205 pp.

APPENDIX A

RAW DATA USED IN DATABASE

Table A.1 Raw Data for Aily Seam

East	North	Name	Location	Quadrangle	Thickness	AddInfo	OtherName	elevation	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
998855	330700	Aily	100-150 ft above Raven No. 1	Keen Mountain	0	very thin, locally 23"									
998855	327700	Aily	100-150 ft above Raven No. 2	Keen Mountain	23	very thin, locally 23"									
962466	332000	Aily	40-110 ft below Kennedy	Vansant	0										
962466	329000	Aily	40-110 ft below Kennedy	Vansant	20										
926080	333500	Aily	40-110 ft below Kennedy	Prater	0										
926080	330500	Aily	40-110 ft below Kennedy	Prater	20										
964615	389000	Aily	60-105 ft above Raven No. 1, & 165-230 ft above Jawbone	Grundy	0										
964615	386000	Aily	60-105 ft above Raven No. 1, & 165-230 ft above Jawbone	Grundy	24										
973225	375702	Aily	2-4ft below the McClure Sandstone Member	Grundy	20										
960750	285085	Aily	85-140 ft above Raven No. 3	Big A Mountain	5	very thin									
917058	298207	Aily	40-50 ft above Raven No. 3 & 85-100ft below Kennedy	Duty	18										
849518	245500	Aily	120-160 ft above Raven No. 1 & 120-150ft below Kennedy	Coeburn	3										
849518	242500	Aily	120-160 ft above Raven No. 1 & 120-150ft below Kennedy	Coeburn	24										
840352	244345	Aily	crops out along northside of Guest River	Coeburn	25										
957000	358000	Aily		Grundy	0										
965000	368000	Aily		Grundy	5										
898500	337000	Aily		NE Buch, Dickens	0										
890000	331000	Aily		Haysi	10										
813000	245000	Aily		Wise	0										
974350	417634	Aily						885							
986108	412173	Aily						970							
968592	384922	Aily						1086							
973496	382138	Aily						1185							
965409	381440	Aily						1165							
957578	384139	Aily						1110							
952396	381170	Aily						1061							
942233	382786	Aily						974							
901222	370545	Aily						1171							
959228	371562	Aily						1140							
961918	326576	Aily						1633							
954516	326349	Aily						1592							
964740	321287	Aily						1687							
871341	333222	Aily						1094.5							
870372	323345	Aily						1221.3							
851223	319375	Aily						1255.4							
826579	307056	Aily						836.7							
876892	293066	Aily						1492.5							
981123	305576	Aily						2174							
796549	295512	Aily						866.3							
844992	253592	Aily						1730.23							
844992	253592	Aily						1705.23							
850324	261230	Aily						1689.44							
854675	252062	Aily						1787.55							
854675	252062	Aily						1765.55							
996392	401522	ALLY						1167							
955825	387089	ALLY						1023							
937831	273411	Aily							4.6	27.3	59.6	8.5	0.7	13140	W192607
873907	238298	Aily							3	31.7	55.4	9.9	0.8	13127	W200126

Table A.2 Raw Data for Blair Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin;AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
740021	248748	Blair	125 ft above Dorchester	Appalachia	10		0	8	2' between								
787800	256700	Blair	40-60 ft above Lyons	Norton (sou	26		0	17	55" coal w/in 30' sequence								
811000	267800	Blair	25-55 ft above Lyons	Wise	20		0	10									
811000	264800	Blair	25-55 ft above Lyons	Wise	36		0	20									
795500	254300	Blair		Wise (W of	76		6	0									
887858	286400	Blair	70-80 ft above Lyons	Nora	2		0	0	mostly shale								
887858	289400	Blair	70-80 ft above Lyons	Nora	30		22	0	mostly shale								
849000	297500	Blair	100 ft above Dorchester	Caney Ridg	14		0	0	Lower Clintwood								
849000	294500	Blair	101 ft above Dorchester	Caney Ridg	54		0	0	Lower Clintwood								
814975	292500	Blair	100 ft above Dorchester	Pound	14		0	0	Lower Clintwood								
814975	289500	Blair	101 ft above Dorchester	Pound	54		0	0	Lower Clintwood								
778536	294100	Blair	40-70 ft above Lyons	Flat Gap	16		0	6	Rider 10-40' above								
778536	291100	Blair		Flat Gap	30		0	12	Rider 10-40' above								
826579	307056	BLAIR								1752.7							
796549	295512	BLAIR								1799.3							
787883	269564	BLAIR								2083							
749089	262701	BLAIR								1607.54							
974855	384911	BLAIR								1989.8							
805449	269624	Blair									6.4	31.2	59.6	2.8	0.7	13970	W191136
829347	264549	Blair									3.9	35	55	6.1	3	13770	W191332
806603	268157	Blair									2.9	29.9	58.2	9	0.8	13510	W192602
815317	272538	Blair									3.9	30.3	60.7	5.1	0.9	14064	W192703
815504	265545	Blair									5.5	31	58	5.5	0.6	13813	W194412
815473	264838	Blair									1.7	33.8	53.3	11.2	5.2	13325	W196287
820461	258045	Blair									2.9	33.2	55.7	8.2	0.6	13596	W196288
811149	279399	Blair									2.3	30.4	61.1	6.2	0.8	14161	W197300
802852	256577	Blair									2.9	35.1	59.2	2.8	0.9	14490	W199467
805436	269321	Blair									11	28.2	54.1	6.7	0.9	12010	W200123
805725	279735	Blair									4.9	32.3	57.5	5.3	1.6	13710	W200132
788212	274629	Blair									1.88	33.15	61.49	3.48	0.82	14618	W223356
797248	293770	Blair									1.84	31.95	57.39	8.82	0.85	13719	W226977
819107	275716	Blair									6.93	30.45	59.07	3.55	0.55	13878	W229075
812842	284792	Blair									3.26	31.4	60.33	5.01	2.41	14284	W235315
823147	294270	Blair									2.33	31.73	63.54	2.4	0.61	14872	W238482
802360	291927	Blair									1.75	30.11	57.63	10.51	1.01	13469	W246902

Table A.3 Raw Data for Clintwood Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
740021	248748	Clintwood	145 ft above Dorchester, 25	Appalachia	25		0	0										
776518	248600	Clintwood	30-60 ft above Blair	Norton	20		0	20	18-120" between splits (siltstone)									
776518	245600	Clintwood		Norton	40		0	40	18-120" between splits (siltstone)									
804000	260700	Clintwood	35-55 ft above Blair	Wise	20		0	20	5-30 ft above lower bed (siltstone, sandstone)									
804000	263700	Clintwood		Wise	30		0	30	5-30 ft above lower bed (siltstone, sandstone)									
785300	276200	Clintwood		Flat Gap (S	12		0	12	10-15 ft siltstone between									
776800	277000	Clintwood		Flat Gap (N	44		4	0										
853313	336400	Clintwood	40-70 ft above Lyons	Clintwood	36		0	18	12-18" Marker									
853313	333400	Clintwood	40-70 ft above Lyons	Clintwood	48		0	30	12-18" Marker									
816933	317000	Clintwood	40-70 ft above Lyons	Jenkins Eas	36		0	18	12-18" Marker									
816933	320000	Clintwood	40-70 ft above Lyons	Jenkins Eas	48		0	30	12-18" Marker									
897500	341800	Clintwood	40-60 ft above Upper Lyons	Haysi (soutl	50		0	0										
889696	351100	Clintwood	40-60 ft above Upper Lyons	Haysi (othe	13		0	0										
917100	353500	Clintwood	140-180 ft above Eagle	Prater	28		0	0										
917100	350500	Clintwood	140-180 ft above Eagle	Prater	48		0	0										
927858	377438	Clintwood	500 ft above Splash Dam	Harman	55		3	0										
939700	410900	Clintwood	500 ft above Splash Dam	Jamboree	55		3	0										
990800	380500	Clintwood	20-90 ft above Lyons	Patterson (E	0		0	0										
1000700	374695	Clintwood	20-90 ft above Lyons	Patterson (s	39		0	0										
999400	374695	Clintwood	20-90 ft above Lyons	Patterson (n	93		24	0										
964184	395300	Clintwood	10-95 ft above Lower Lyons	Grundy (no	63		0	10	19" shale between									
968000	394900	Clintwood	10-95 ft above Lower Lyons	Grundy (sou	60		0	0										
965901	423000	Clintwood	120- ft above Dorchester, 20	Hurley	0		0	0										
965901	420000	Clintwood	120- ft above Dorchester, 20	Hurley	43		0	0										
1002169	421700	Clintwood	120- ft above Dorchester, 20	Panther	0		0	0										
1002169	418700	Clintwood	120- ft above Dorchester, 20	Panther	43		0	0										
796549	295512	CLINTWOOD									1852.3							
787883	269564	CLINTWOOD									2160							
806603	268157	Clintwood										2.9	32.2	53.5	11.4	2.8	13030	W191135
818915	269347	Clintwood										1.5	33.5	54.6	10.4	4.4	13290	W191334
785978	260757	Clintwood										4.3	32.3	58.5	4.9	1.1	13890	W192604
806890	280393	Clintwood										4.1	30.2	58.1	7.6	0.9	13590	W192605
806809	280396	Clintwood										3.1	30.1	63	3.8	0.6	14430	W192608
829821	306233	Clintwood										2.3	33.4	59.6	4.7	2.8	14270	W192611
815723	272521	Clintwood										6	28.2	57.1	8.7	3.3	12810	W192613
781956	259821	Clintwood										1.5	33.5	53.3	11.7	1.2	13279	W193663
815563	265037	Clintwood										2.3	33	58.5	6.2	2.5	14120	W194852
778436	253701	Clintwood										3.9	37.1	53	6	2.6	13755	W196283
825865	262875	Clintwood										3	31.5	59.9	5.6	1.1	14024	W199468
843459	314361	Clintwood										3.9	33.7	57.7	4.7	0.8	14138	W203392
843459	314361	Clintwood										2.2	30.8	55.9	11.1	0.9	13396	W204162
841203	328122	Clintwood										4	34.6	57.8	3.6	0.9	14262	W204617
839424	328197	Clintwood										3.7	34.5	55.4	6.4	1.6	13738	W206886
855349	331274	Clintwood										4	33.2	56.5	6.3	1.3	13800	W206887
855200	331584	Clintwood										3.4	33.7	59	3.9	1.6	14327	W206888
821701	322979	Clintwood										8.9	34.1	49.2	7.8	2.6	12690	W209961
835016	317856	Clintwood										3.9	30.8	52.1	13.2	1.1	12755	W210397
835008	319577	Clintwood										2.14	30.89	61.8	5.17	0.72	14075	W212486
820067	324567	Clintwood										1.85	31.65	52.6	13.9	0.71	12767	W212490
916957	375740	Clintwood										1.55	33.65	58.81	5.99	1.31	14217	W217685

Table A.3 Raw Data for Clintwood Seam

971467	393479	Clintwood	2.22	30.17	61.19	6.42	1	14071	W218978
710918	217292	Clintwood	2.67	36.22	56.07	5.04	1.34	13922	W219360
963991	379490	Clintwood	1.57	31.27	64.09	3.07	0.68	14799	W223355
784707	272455	Clintwood	1.18	34.21	60.17	4.44	0.78	14566	W225108
784992	267887	Clintwood	1.53	33.69	60.92	3.86	0.74	14531	W225109
789239	307180	Clintwood	2.09	35.47	55.14	7.3	1.17	13776	W226974
790692	307015	Clintwood	2.08	34.8	56.12	7	3.34	13827	W226975
796929	293885	Clintwood	17.74	27.56	49.87	4.83	0.54	10342	W226976
798036	309932	Clintwood	2.7	34.09	55.79	7.42	0.84	13723	W229073
798036	309932	Clintwood	2.37	36.01	52.61	9.01	3.57	13517	W229074
813908	275636	Clintwood	3.18	33.04	60.59	3.19	0.82	14453	W229076
789693	308273	Clintwood	2.02	34.17	54.17	9.64	1.22	13481	W229081
790404	307837	Clintwood	1.84	34.83	51.69	11.64	1.32	13216	W229082
843684	323563	Clintwood	4.48	32.55	56.06	6.91	1.48	13635	W229083
843978	322842	Clintwood	9.41	28.6	56.3	5.69	0.68	11942	W229084
814938	267493	Clintwood	4.24	30.88	58.45	6.43	0.89	13802	W229550
814938	267493	Clintwood	4.41	31.26	52.97	11.36	6.61	12795	W229551
814938	267493	Clintwood	5.23	30.88	53.03	10.86	4.41	12875	W229552
807867	302924	Clintwood	3.38	32	62.05	2.57	0.66	14575	W231835
814423	283813	Clintwood	3.81	30.39	58.06	7.74	2.25	13641	W231836
808026	300994	Clintwood	4.09	31.36	61.09	3.46	0.69	14409	W231838
789222	264360	Clintwood	3.3	34.18	57.07	5.45	0.69	14088	W236237
851042	330948	Clintwood	1.96	35.09	59.29	3.66	1	14558	W238479
907642	369227	Clintwood	2.02	35.56	55.5	6.92	2.69	14110	W238483
856180	327899	Clintwood	3.34	32.76	60.18	3.72	1.04	14409	W238942
821989	295635	Clintwood	2.88	33.18	60.76	3.18	0.62	14606	W238944
821989	295635	Clintwood	2.96	32.5	60.8	3.74	0.94	14505	W238945
908421	370705	Clintwood	3.2	34.65	56.24	5.91	1.95	14131	W238946
962742	404829	Clintwood	2.28	35.89	54.88	6.95	3.41	13853	W246909
962742	404829	Clintwood	1.82	31.72	61.7	4.76	0.79	14370	W246910

Table A.4 Raw Data for Dorchester Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin; AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
732200	238200	Dorchester	100 ft above Norton	Appalachia		40	0	0									
776518	247104	Dorchester	100 ft above Norton	Norton (possible 2 beds			0	0									
787900	262300	Dorchester	100 ft above Norton	Norton (sou		14	0	0									
782500	251500	Dorchester	100 ft above Norton	Norton (nor		60	0	0									
807700	268300	Dorchester	80-115 ft above Norton	Wise (north		30	0	22									
807700	265300	Dorchester	80-115 ft above Norton	Wise (north		40	0	28									
848500	296700	Dorchester	70-100 ft above Norton	Caney Ridg		12	0	0	Blair								
848500	293700	Dorchester	70-100 ft above Norton	Caney Ridg		61	30	0									
814975	292500	Dorchester	70-100 ft above Norton	Pound		12	0	0	Blair								
814975	289500	Dorchester	70-100 ft above Norton	Pound		61	30	0									
778536	294100	Dorchester	80-100 ft above Norton	Flat Gap		30	0	0									
778536	291100	Dorchester	80-100 ft above Norton	Flat Gap		44	0	0	Glamorgan								
853313	334902	Dorchester	40-70 ft above Norton	Clintwood (		9	0	9	5-15' btwn	Lyons							
816933	320000	Dorchester	40-70 ft above Norton	Jenkins Eas		9	0	9	5-15' btwn	Lyons							
925100	333900	Dorchester		Prater		19	0	0	Lyons								
925100	330900	Dorchester		Prater		60	0	0									
897000	345500	Dorchester	40-100 ft above upper Nor	Haysi		28	0	0									
990200	391600	Dorchester	120 ft above Norton	Patterson 1		3	0	0	Blair								
990200	394600	Dorchester	121 ft above Norton	Patterson 1		50	0	0									
964184	377500	Dorchester	45-100 ft above Norton, 57Grundy			3	0	0	Blair, Glamorgan, Eagle								
964184	374500	Dorchester	45-100 ft above Norton, 57Grundy			70	2	0									
936900	365000	Dorchester		Harmon (SI		72	0	0									
926600	377300	Dorchester		Harmon		46	0	0									
979340	440625	DORCHESTER								1292.65							
792183	269252	DORCHESTER								2269.9							
787883	269564	DORCHESTER								2015							
749089	262701	DORCHESTER								1468.54							
817482	251595	Dorchester									2.3	33	56.3	8.4	0.9	13600	W191066
817482	251595	Dorchester									1.3	31.1	53.1	14.5	0.6	12820	W191067
779555	258672	Dorchester									1.9	36.5	56.1	5.5	3.1	14120	W191068
817070	251460	Dorchester									3.4	35	59.1	2.5	1.1	14260	W191335
817070	251460	Dorchester									2.5	36.1	59.2	2.2	1.2	14500	W191336
827564	265344	Dorchester									3.5	34.4	58.5	3.6	1.1	14100	W191337
805421	279593	Dorchester									4.4	27.5	59.5	8.6	1	13400	W192592
817151	251715	Dorchester									3.7	34.9	56.4	5	2.1	13860	W192603
909191	372271	Dorchester									1.9	35.2	50.6	12.3	3.9	13116	W193673
939469	334885	Dorchester									4.5	28.5	59.1	7.9	1	13777	W194293
939469	334885	Dorchester									2.4	29.2	63.4	5	0.9	14572	W194294
946671	357719	Dorchester									2.5	27.6	67	2.9	0.9	14720	W194297
941735	347098	Dorchester									2.5	25.3	52.9	19.3	0.7	12095	W194300
800592	250000	Dorchester									3.8	33.7	60.2	2.3	0.9	14418	W194411
744777	234908	Dorchester									2	32.3	49.6	16.1	0.8	12326	W205190
737367	240360	Dorchester									1.5	33.1	53	12.4	1.2	13126	W205191
807714	300014	Dorchester									1.82	30.24	53.5	14.44	3.38	12705	W212494
935672	352047	Dorchester									3.13	31.08	63.52	2.27	1.36	14689	W214769
935672	352047	Dorchester									7.65	27.53	62.23	2.59	1.13	13895	W214770
940335	347414	Dorchester									1.35	30.82	62.11	5.72	1.47	14426	W217399
940335	347414	Dorchester									1.44	29.04	62.41	7.11	0.83	14394	W217400
941869	357062	Dorchester									2.58	29.22	59.76	8.44	1.15	13741	W217401
941869	357062	Dorchester									2.03	30.59	63.26	4.12	0.72	14661	W217402

Table A.4 Raw Data for Dorchester Seam

923029	383209	Dorchester	2.86	33.05	62.05	2.04	1.02	14809	W218770
952226	383674	Dorchester	2.36	28.96	50.86	17.82	0.78	12220	W218774
952927	384653	Dorchester	2.54	32.22	59.94	5.3	1.67	14278	W218775
954484	384061	Dorchester	3.55	28.61	53.5	14.34	0.69	12442	W218973
710920	217292	Dorchester	1.92	37	54.49	6.59	0.86	13778	W219361
957505	401075	Dorchester	1.41	29.24	52.03	17.32	0.77	12375	W223352
985871	427344	Dorchester	2.1	32.43	62.16	3.31	0.83	14523	W223353
926650	401085	Dorchester	2.38	34.22	57.51	5.89	4	13831	W223358
956085	396006	Dorchester	1.12	33.07	58.09	7.72	0.83	14059	W225107
819527	287949	Dorchester	3.39	31.62	59.59	5.4	1.59	14123	W231834
820256	287921	Dorchester	2.61	31.67	60.41	5.31	1.4	14268	W235313
886165	350640	Dorchester	1.79	33.09	62.28	2.84	0.8	14729	W236241
807714	300014	Dorchester	5.8	33.43	56.83	3.94	1.67	13572	W236244
936093	351703	Dorchester	2.19	31.27	64.61	1.93	1.24	14844	W236245
937778	350082	Dorchester	2.36	28.4	58.49	10.75	1	13530	W238474
938275	350135	Dorchester	8.22	27.48	60.93	3.37	0.94	13162	W238475
933233	351872	Dorchester	13.17	22.67	52.21	11.95	0.5	9999	W238476
933233	351872	Dorchester	3.41	36.3	57.04	3.25	1.29	14544	W238477
829067	328756	Dorchester	2.13	38.01	54.94	4.92	1.32	14266	W238481

Table A.5 Raw Data for Hagy Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
820000	258600	Hagy	150 ft above Splash Dam	Wise		3	0			Edwards								
820000	255600	Hagy	151 ft above Splash Dam	Wise		16	0			Edwards								
809700	248700	Hagy	150 ft above Splash Dam	Wise (south		24	0		excluding shale partings									
849518	261700	Hagy	150-170 ft above Splash Dam	Coeburn		0	0		probably di	Edwards								
849518	258700	Hagy	150-170 ft above Splash Dam	Coeburn		24	0											
960746	302300	Hagy	120 ft above Splash Dam	Big A Moun		37	8											
923000	283200	Hagy	120-160 ft above Splash Dam	Duty (along		0	0			Splash Dam coal of Meissner								
923000	280200	Hagy	120-160 ft above Splash Dam	Duty (along		16	0											
887858	289400	Hagy	80-150 ft above Splash Dam	Nora		0	0											
887858	286400	Hagy	80-150 ft above Splash Dam	Nora		30	0											
851416	290500	Hagy	90-140 ft above Spash Dam	Caney Ridg		0	0			Edwards								
851416	288000	Hagy	90-140 ft above Spash Dam	Caney Ridg		28	0											
826000	292500	Hagy	90-140 ft above Spash Dam	Pound		0	0			Edwards								
826000	289500	Hagy	90-140 ft above Spash Dam	Pound		28	0											
857100	346600	Hagy	100-110 ft above Splash Dam	Clintwood (		29	0											
853400	343100	Hagy	100-110 ft above Splash Dam	Clintwood (		21	0											
852100	333900	Hagy	100-110 ft above Splash Dam	Clintwood		3	0											
830000	318500	Hagy	100-110 ft above Splash Dam	Jenkins Eas		3	0											
889696	333408	Hagy	80-110 ft above Splash Dam	Haysi		21	0											
926080	333500	Hagy	80-130 ft above Splash Dam	Prater		12	0											
926080	330500	Hagy	80-130 ft above Splash Dam	Prater		42	0											
962467	332100	Hagy	80-130 ft above Splash Dam	Vansant		12	0											
962467	329100	Hagy	80-130 ft above Splash Dam	Vansant		42	0											
944000	330000	Hagy	80-130 ft above Splash Dam	Vansant		31	0											
998855	345700	Hagy	110-140 ft above Splash Dam	Keen Moun		6	0											
998855	342700	Hagy	110-140 ft above Splash Dam	Keen Moun		27	0											
999000	361200	Hagy	avg 133 ft above Splash Dam	Patterson		34	0											
1000512	374695	Hagy	avg 133 ft above Splash Dam	Patterson		20	0											
964300	370900	Hagy	105-170 ft above Splash Dam	Grundy (lov		40	8											
968900	370800	Hagy	105-170 ft above Splash Dam	Grundy (mc		33	0		2 beds									
955900	385900	Hagy	105-170 ft above Splash Dam	Grundy (he		8	0											
955900	382900	Hagy	105-170 ft above Splash Dam	Grundy (he		18	0											
978800	378100	Hagy	105-170 ft above Splash Dam	Grundy (Ri		14	0		2 beds									
957800	360500	Hagy	105-170 ft above Splash Dam	Grundy (so		5	0											
957800	360500	Hagy	105-170 ft above Splash Dam	Grundy (so		0	0											
965901	423000	Hagy	80-130 ft above Splash Dam	Hurley		0	0											
965901	420000	Hagy	80-130 ft above Splash Dam	Hurley		20	0											
994000	415300	Hagy	80-130 ft above Splash Dam	Panther		0	0											
994000	412300	Hagy	80-130 ft above Splash Dam	Panther		20	0											
927858	377438	Hagy	80-110 ft above Splash Dam	Harman (V		36	0											
927300	391600	Hagy	80-110 ft above Splash Dam	Harman (Le		50	0											
968592	384922	HAGY									1616							
974855	384911	HAGY									1679.8							
906333	372853	HAGY									1527.39							
912541	363732	HAGY									1508							
904757	369424	HAGY									1546.77							
904237	354195	HAGY									1443							
902821	350415	HAGY									1471							
899956	343012	HAGY									1485.34							
908677	268584	HAGY									2347							

Table A.5 Raw Data for Hagy Seam

787883	269564	HAGY	1665								
948789	331408	Hagy	2.87	24.06	62.58	10.49	1.39	13430	W214768		
937339	351771	Hagy	2.84	27.28	60.12	9.76	2.06	13449	W214771		
938705	353733	Hagy	1.61	27.03	65.7	5.66	1.2	14180	W215413		
943338	325113	Hagy	1.33	24.98	59.91	13.78	2.94	13392	W215447		
943367	322153	Hagy	2.61	25.9	64.27	7.22	0.92	14065	W215875		
886536	349747	Hagy	1.65	31.66	54.88	11.81	3.6	13183	W236240		
896511	332794	Hagy	2.64	30.29	58.11	8.96	1.24	13631	W240452		
957821	408233	Hagy	2.06	31.26	56.55	10.13	1.43	13444	W246907		
914824	377127	Hagy	1.82	28.69	59.64	9.85	0.78	13543	W246911		

Table A.6 Raw Data for High Splint Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN	
662900	222000	High Splint	50-100 ft above Morris	Wise Count		12													
662900	219000	High Splint	50-100 ft above Morris	Wise Count		54													
740021	268700	High Splint	40-80 ft above Morris	Appalachia		48													
740021	267200	High Splint	40-80 ft above Morris	Appalachia		60													
740021	265700	High Splint	40-80 ft above Morris	Appalachia		84													
762600	285400	High Splint	100 ft above Morris	Flat Gap		10				No. 12									
762600	285500	High Splint	101 ft above Morris	Flat Gap		55													
762600	285600	High Splint	102 ft above Morris	Flat Gap		85													
765705	282868	High Splint										3.6	30.8	48.6	17	0.8	11853	W195442	

Table A.7 Raw Data for Imboden Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin;AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
740021	248748	Imboden	420-500 ft above Dorchester	Appalachia	60												
717300	229500	Imboden	420-500 ft above Dorchester	Benham	60												
816933	320500	Imboden	15-20 ft above Imboden Marker	Jenkins Eas	24				Upper Bolling								
816933	317500	Imboden	15-20 ft above Imboden Marker	Jenkins Eas	59												
853313	336400	Imboden	15-20 ft above Imboden Marker	Clintwood	24												
853313	333400	Imboden	15-20 ft above Imboden Marker	Clintwood	59												
797400	266700	Imboden	300 ft above Clintwood	Wise	11												
797400	263700	Imboden	300 ft above Clintwood	Wise	34												
768508	273184	IMBODEN								1761.6							
769619	245454	Imboden									3.3	31.8	48.9	16	0.8		12129 W203385
769619	245454	Imboden									2.7	36.9	57.4	3	1		14388 W203386
771573	253859	Imboden									3.3	35	57.2	4.5	1		14125 W208049
798032	288092	Imboden									2.2	28.51	53.55	15.74	0.66		12430 W212491
742252	254751	Imboden									1.21	35.14	59.33	4.32	0.68		14515 W214246
732331	254710	Imboden									1.59	32.66	57.75	8	0.77		13682 W214247
737711	249029	Imboden									1.4	33.73	59.21	5.66	0.62		14212 W214248
776640	294199	Imboden									1.7	37.62	54.78	5.9	2.49		14147 W229080

Table A.8 Raw Data for Imboden Marker Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo	
819000	320300	Imboden Marker		Jenkins East		11													
819000	317300	Imboden Marker		Jenkins East		35													
812900	290400	Imboden Marker		Pound		26													
798749	302248	Imboden Marker										2.6	33.8	57.2	6.4	2.7		13850	W192609
816893	320962	Imboden Marker										2.51	36.22	56.19	5.08	1.96		13995	W212489
803108	301854	Imboden Marker										2.09	32.72	58.94	6.25	0.97		14030	W246903

Table A.9 Raw Data for Jawbone Seam

East	North	Name	Coal	Parting	Rider	RiderParting	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
1057000	341000		10		4	0	0							
1057000	340800	Jawbone	61		4	0	0							
1035240	329410		10		4	0	0							
1035240	326410		61		4	0	0							
998850	330710		10		0		0							
998850	327710		60		0		0							
998850	330710	Rider				6	0							
998850	327710					21	0							
962460	330560		18		0	0	0							
926080	331960		18		0	0	0							
944270	331250	Rider				9	0							
1036440	363570		20		8		0							
1036440	360570		42		8		0							
1009140	364540		20		8		0							
1009140	361540		42		8		0							
1036440	363570	Rider				0	0							
1036440	360570					21	0							
1009140	364540	Rider				0	0							
1009140	361540					21	0							
964180	377540		5		4	0	0							
964180	374540		35		4	0	0							
964180	374540	Rider				0	5							
964180	377540					17	5							
950000	300000		27		0	0	0							
963000	284980		15		0	0	0							
925760	287920		0		0	0	0							
925760	284920		48		0	0	0							
851410	290930		42		0	0	0							
851410	287930		76		0	0	0							
814970	292470		42		0	0	0							
814970	289470		76		0	0	0							
849510	243960		50		0		0							
849510	243960	Rider				20	0							
964500	283000		3		0	0	0							
991883	442351	JAWBONE						654						
981048	431415	JAWBONE						630						
974350	417634	JAWBONE						713						
986108	412173	JAWBONE						803						
977055	398745	JAWBONE						810						
988411	385092	JAWBONE						1098						
955825	387089	JAWBONE						855						
968592	384922	JAWBONE						907						
973496	382138	JAWBONE						1003						
965409	381440	JAWBONE						952						
957578	384139	JAWBONE						881						
952396	381170	JAWBONE						834						
881927	386749	JAWBONE						706.22						
959228	371562	JAWBONE						900						
973300	369298	JAWBONE						1103						
1040749	375666	JAWBONE						1644.7						

Table A.9 Raw Data for Jawbone Seam

917478	257248	Jawbone		1.6	28.1	54.2	16.1	0.6	12502	W192706
930209	269689	Jawbone		2.6	22.6	45.2	29.6	0.5	10194	W192707
905986	250403	Jawbone		1.2	31.3	53.7	13.8	0.6	12846	W192708
1018129	308886	Jawbone		0.9	28.4	58.1	12.6	0.5	13356	W195133
915424	295331	Jawbone		2.5	18.7	47.9	30.9	0.8	10069	W195440
933420	282043	Jawbone		4	25.6	57	13.4	0.6	12739	W204159
913536	293712	Jawbone		1.54	19.75	53.63	25.08	0.55	11197	W211171
725005	220989	Jawbone		1.52	39.18	56.18	3.12	0.9	14650	W219357
710920	217292	Jawbone		1.25	39.41	49.42	9.92	4.22	13569	W219364
803423	323768	Jawbone		2.95	34.3	58.12	4.63	0.57	14117	W219405
860002	351630	Jawbone		2.65	35.46	59.79	2.1	0.58	14671	W219788
822107	336222	Jawbone		3.34	34.52	59.7	2.44	0.51	14218	W219790
861971	236390	Jawbone		2.37	30.95	49.08	17.6	1.93	12034	W238940
901222	370545	JAWBONE (SPLITS)	974							
956423	328688	JAWBONE (SPLITS)	1337							
961918	326576	JAWBONE (SPLITS)	1427							
954516	326349	JAWBONE (SPLITS)	1275							

Table A.10 Raw Data for Kelly Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin; AddInfo	OtherName Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
740021	248748	Kelly	70-120 ft above Imboden	Appalachia	30		0									
773600	257400	Kelly	5-75 ft above Imboden	Norton (N &	40		0									
777200	291700	Kelly	30-90 ft above Imboden	Flat Gap	4		0									
767700	295500	Kelly	30-90 ft above Imboden	Flat Gap (sc	51		6									
817800	319700	Kelly	60-80 ft above Imboden	Jenkins Eas	12		0									
817800	316700	Kelly	60-80 ft above Imboden	Jenkins Eas	30		0									
853313	336400	Kelly	60-80 ft above Imboden	Clintwood	12		0									
853313	333400	Kelly	60-80 ft above Imboden	Clintwood	30		0									
768508	273184	KELLY							1820.6							
736553	229303	Kelly								3.6	33.3	53.8	9.3	0.8		13089 W194854
775782	294211	Kelly								4.49	32	53.88	9.63	0.96		13163 W231830

Table A.11 Raw Data for Kennedy Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin; AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
1063000	331900	Kennedy	250 ft above Raven No.1 & Jewell Ridg		12		0										
1063000	328900	Kennedy	250 ft above Raven No.1 & Jewell Ridg		30		0										
1068200	309300	Kennedy	250 ft above Raven No.1 & Jewell Ridg		30		5										
1068200	306300	Kennedy	250 ft above Raven No.1 & Jewell Ridg		36		6										
998855.2	330700	Kennedy	230-260 ft above Raven No.Keen Moun		30		0										
998855.2	327700	Kennedy	230-260 ft above Raven No.Keen Moun		38		0										
964184	376042.1	Kennedy	200 ft above Raven No. 1 & Grundy				0										
962467	332000	Kennedy		Vansant		14	0										
962467	329000	Kennedy		Vansant		72	0										
926080.5	333500	Kennedy		Prater		14	0										
926080.5	330500	Kennedy		Prater		72	0										
962467	330563.6	rider	12-25 ft above Kennedy	Vansant			0	10	3								
926080.5	331961.5	rider	12-25 ft above Kennedy	Prater			0	10	3								
1027000	361500	Kennedy		Bradshaw		0	0										
983000	378700	Kennedy	200-240 ft above Raven No.Patterson (S		21		0										
984500	388500	Kennedy	200-240 ft above Raven No.Patterson (C		14		0										
964184	377500		165-205 ft above Raven	Grundy		8	0										
964184	374500		165-205 ft above Raven	Grundy		35	2		Widow Kennedy								
976700	359600		165-205 ft above Raven	Grundy (Gr		29	0		Grundy								
976700	370100		165-205 ft above Raven	Grundy (Lic		34	0										
955300	365600		165-205 ft above Raven	Grundy		12	0										
955300	362600		165-205 ft above Raven	Grundy		26	0										
964100	391000		165-205 ft above Raven	Grundy		24	0										
927857.7	378900		5-15 ft above McClure or B-Harman			12	0										
927857.7	375900		5-15 ft above McClure or B-Harman			35	4										
940100	408100		5-15 ft above McClure or B-Jamboree			12	0										
940100	405100		5-15 ft above McClure or B-Jamboree			35	4										
974503.9	409862.6		180 ft above Raven No. 1 & Hurley				0										
967600	425300		181 ft above Raven No. 1 & Hurley (Kn			13	0										
990000	424100		182 ft above Raven No. 1 & Panther (La			40	0										
997198.5	285200		135 ft above Raven No. 3	Honaker		6	0										
997198.5	282200		136 ft above Raven No. 3	Honaker		70	0										
968900	291200		60-140 ft above Aily	Big A Mou		34	0		Widow Kennedy								
960746.1	284984.7	rider	15-30" ft above Kennedy	Big A Mountain			0										
924303.3	288000		160-215 ft above Raven No.Duty			0	0										
924303.3	285000		160-215 ft above Raven No.Duty			56	0										
887858.5	289400		139 ft above Aily	Nora		0	0										
887858.5	286400		140 ft above Aily	Nora		52	0										
851415.6	291000		2-5 ft above McClure Sands Caney Ridg			0	0										
851415.6	288000		2-5 ft above McClure Sands Caney Ridg			70	0										
814974.8	292500		2-5 ft above McClure Sands Pound			0	0										
814974.8	289500		2-5 ft above McClure Sands Pound			70	0										
878000	326300			Haysi		10	0										
878000	323300			Haysi		60	0										
896000	321700			Haysi (Lick		24	0										
896000	318700			Haysi (Lick		36	0										
896000	321700	thick rider	5-10 ft above the main bed	Haysi (Lick Creek)			0	6	60 innerbrdn								
896000	318700	thick rider	5-10 ft above the main bed	Haysi (Lick Creek)			0	9	120 innerbrdn								
898700	313500			Haysi (Left		41	0										
817883	333100		Just above Bee Rock Sandst	Jenkins Eas		47	16										

Table A.11 Raw Data for Kennedy Seam

886021.1	242461.7	165 ft above Aily	St. Paul	29	0						
849518	243960.9	165 ft above Aily	Coeburn	29	0						
825400	245800	140 ft above Aily	Wise (E of l	26	0						
819800	248100	141 ft above Aily	Wise (Whit	17	0						
813500	247800	142 ft above Aily	Wise (W of	0	0						
783100	240700	29 ft above Bee Rock sands	Norton	31	4						
986108	412173	KENNEDY									1045
996392	401522	KENNEDY									1240
974990	400906	KENNEDY									1124
977055	398745	KENNEDY									1082
988411	385092	KENNEDY									1387
955825	387089	KENNEDY									1128
968592	384922	KENNEDY									1190
973496	382138	KENNEDY									1285
965409	381440	KENNEDY									1249
957578	384139	KENNEDY									1185
952396	381170	KENNEDY									1170
942233	382786	KENNEDY									1077
881927	386749	KENNEDY									996.22
913992	387341	KENNEDY									1073.2
908331	375187	KENNEDY									1243.67
906333	372853	KENNEDY									1144.39
904757	369424	KENNEDY									1191.77
901222	370545	KENNEDY									1261
959228	371562	KENNEDY									1233
967561	358807	KENNEDY									1469.25
1010631	378947	KENNEDY									1715
1040749	375666	KENNEDY									1994.7
1001904	352604	KENNEDY									1879.62
964740	321287	KENNEDY									1797
988736	345113	KENNEDY									1727.4
904237	354195	KENNEDY									1026
902821	350415	KENNEDY									1120
871341	333222	KENNEDY									1255.5
851223	319375	KENNEDY									1342.4
837462	297477	KENNEDY									1285
879278	288440	KENNEDY									1638.4
882935	273030	KENNEDY									1709.2
768508	273184	KENNEDY									701.6
792183	269252	KENNEDY									1512.9
787883	269564	KENNEDY									1228
782728	247082	KENNEDY									1493
819571	250281	KENNEDY									1861
819571	250281	KENNEDY									1840
844992	253592	KENNEDY									1835.23
850324	261230	KENNEDY									1799.44
854675	252062	KENNEDY									1916.55
1026915	323652	Kennedy									
1006900	291882	Kennedy				2.6	30.2	64	3.2	0.9	14690 D170129
989447	293530	Kennedy				2.8	34	54.9	8.3	0.6	13620 D170134
985915	301048	Kennedy				1.6	33.5	58.3	6.6	0.9	14080 D170135
						1.6	32.4	59.2	6.8	1.7	14080 D170136

Table A.11 Raw Data for Kennedy Seam

1004527	293487	Kennedy	2.5	34.5	54.9	8.1	0.5	13560	D170137
994092	287490	Kennedy	2.2	36.4	56.4	5	0.8	14260	D170138
1015428	323959	Kennedy	1.9	28	67.1	3	0.8	14790	D170147
924029	261957	Kennedy	2.4	27.9	50.4	19.3	0.8	11970	W192606
1018318	330515	Kennedy	2.7	25	69	3.3	0.6	14755	W193932
1016032	313718	Kennedy	1.1	28.6	59.9	10.4	0.6	13671	W195134
872472	285893	Kennedy	1.8	25.8	55.8	16.6	0.6	12730	W196290
907909	311686	Kennedy	1.38	20.76	55.29	22.57	0.74	11698	W211168
912889	308676	Kennedy	2.51	19.1	48.84	29.55	1.45	10403	W211172
969238	292163	Kennedy	2.35	33.28	60.39	3.98	0.94	14459	W213993
982702	340358	Kennedy	1.19	23.46	72.6	2.75	0.68	15156	W215412
975575	326866	Kennedy	1.66	24.79	70.47	3.08	0.94	14884	W215448
975575	326866	Kennedy	1.65	23.6	69.47	5.28	0.61	14769	W215449
978113	321477	Kennedy	3.1	25.23	66.99	4.68	0.74	14422	W215876
978248	322678	Kennedy	3.41	25.28	66.97	4.34	0.8	14466	W215877
947735	343300	Kennedy	1.27	24.12	69.07	5.54	0.74	14593	W217397
980789	312339	Kennedy	1.71	28.44	65.21	4.64	0.69	14540	W217592
939571	273338	Kennedy	1.8	31.73	57.65	8.82	0.83	13674	W217597
884483	350625	Kennedy	3.48	35.51	56.58	4.43	1.62	13934	W219359
710920	217292	Kennedy	1.39	39.12	52.08	7.41	2.93	13813	W219363
724907	218869	Kennedy	1.75	35.21	55.11	7.93	1.32	13675	W219400

Table A.12 Raw Data for Lower Banner Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
819700	248000	Lower Banner	270 ft above Kennedy	Wise		6	0											
824200	246600			Wise		38	0											
849518	261400		200-260 ft above Kennedy	Coeburn		24	0											
849518	258400		200-260 ft above Kennedy	Coeburn		36	0											
886021	255400		200-260 ft above Kennedy	St. Paul		24	0											
886021	252400		200-260 ft above Kennedy	St. Paul		36	0											
851416	290900		560 ft above Jawbone	Caney Ridg		10	0											
851416	287900		560 ft above Jawbone	Caney Ridg		53	0											
879172	299724		200-240 ft above Kennedy	Nora		18	0											
887401	278100		200-240 ft above Kennedy	Nora		26	0											
887401	275100		200-240 ft above Kennedy	Nora		49	0											
924303	288000			Duty		10	0			Puncheon Camp No.2								
924303	285000			Duty		50	0											
816933	330100		150-200 ft above Kennedy	Jenkins Eas		21	5											
853313	334902		150-200 ft above Kennedy	Clintwood		21	5											
833500	335700		150-200 ft above Kennedy	Jenkins Eas		36	0											
896000	339300		150-200 ft above Kennedy	Haysi		68	0											
889696	333408		150-200 ft above Kennedy	Haysi		6	0											
889696	333408		150-200 ft above Kennedy	Haysi		24	7		avg. resource 17"									
965700	330000		120-210 ft above Kennedy	Vansant		44	0			Cary								
926080	331961		120-210 ft above Kennedy	Prater		0	0											
998855	330700		180-210 ft above Kennedy	Keen Moun		30	0			Cary								
998855	327700		180-210 ft above Kennedy	Keen Moun		54	0											
1035245	345200		80-120 ft above Big Fork	Jewell Ridg		0	0		discontinuous									
1035245	342200		80-120 ft above Big Fork	Jewell Ridg		50	0											
1036842	360900		30-60 ft above Big Fork	Bradshaw		0	0			Cary								
996500	360100		30-60 ft above Big Fork	Patterson (v		47	0											
964184	377500		145-215 ft above Kennedy	Grundy		0	0											
964184	374500		145-215 ft above Kennedy	Grundy		47	0			Cary								
976800	360200		145-215 ft above Kennedy	Grundy (Gr		48	0											
973400	357800		145-215 ft above Kennedy	Grundy (Ri		36	0											
969600	357800		145-215 ft above Kennedy	Grundy (Le		18	0											
972000	356100		145-215 ft above Kennedy	Grundy (Ri		29	0											
963100	377500		145-215 ft above Kennedy	Grundy (Lo		2	0											
963100	374500		145-215 ft above Kennedy	Grundy (Lo		24	0											
965901	423000		100-170 ft above Kennedy	Hurley		0	0											
965901	420000		100-170 ft above Kennedy	Hurley		40	0											
997198	285200		60 ft above Big Fork	Honaker		18	0											
997198	282200		60 ft above Big Fork	Honaker		77	0											
981048	431415	LOWER BANNER									993							
988895	424254	LOWER BANNER									982							
986108	412173	LOWER BANNER									1206							
968592	384922	LOWER BANNER									1315							
965409	381440	LOWER BANNER									1387							
957578	384139	LOWER BANNER									1360							
913992	387341	LOWER BANNER									1179.2							
959228	371562	LOWER BANNER									1363							
1001904	352604	LOWER BANNER									2052.62							
918570	340115	LOWER BANNER									1349.9							
902821	350415	LOWER BANNER									1246							

Table A.12 Raw Data for Lower Banner Seam

899956	343012 LOWER BANNER	1249.34							
826579	307056 LOWER BANNER	1175.7							
908677	268584 LOWER BANNER	2148							
866151	263107 LOWER BANNER	2036							
866151	263107 LOWER BANNER	1983							
782728	247082 LOWER BANNER	1670							
922596	271876 Lower Banner		2	30.5	55	12.5	0.6	12840	D161636
1007286	293591 Lower Banner		1.5	36.3	55	7.2	0.6	13910	W187057
1007800	340071 Lower Banner		4.6	23.1	66.1	6.2	0.7	13932	W193947
992540	334910 Lower Banner		3.4	25	64.8	6.8	1.6	14076	W193948
992540	334910 Lower Banner		3.6	23.5	63.5	9.4	0.6	13666	W193949
992254	334720 Lower Banner		7	23.3	58.4	11.3	1.2	12606	W193950
888392	279299 Lower Banner		2.5	28.2	56.4	12.9	1.1	12993	W209962
894083	278877 Lower Banner		2.2	28.4	58.2	11.2	1.1	13284	W210396
879564	267680 Lower Banner		1.6	30	53.1	15.3	0.8	12852	W210398
899669	275184 Lower Banner		2.4	30.5	60	7.1	0.8	14077	W210400
916917	273695 Lower Banner		3.8	32.2	57.5	6.5	0.8	13924	W210402
920780	281894 Lower Banner		1.59	31.93	61.8	4.68	0.8	14555	W217596
724907	218869 Lower Banner		1.66	39.31	52.68	6.35	2.19	14039	W219351
711085	217386 Lower Banner		1.69	37.89	56.4	4.02	1.02	14452	W219797
879564	267680 Lower Banner		1.34	27.06	51.97	19.63	0.58	12129	W236246
992540	334910 Lower Banner		2.02	23.15	64	10.83	0.56	13526	W240450

Table A.13 Raw Data for Low Splint Seam

East	North	Name	Location	Quadrangle Parting	LSP A	LSP B	LSP C	LSP D	RiderPart	AddInfo	OtherName	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
682200	222200	Low Splint		Lee County	0				8	10' between 2 benches								
682200	219200	Low Splint		Lee County	0			52										
682200	220700	Low Splint	24-45 ft above	Lee County	0		26											
682200	222200	Low Splint	directly below Kendrick St	Lee County	0	1												
682200	219200	Low Splint	directly below Kendrick St	Lee County	0	39												
723900	238500	Low Splint	180-220 ft above Taggart	Appalachia	0		10	24		6-30' shale and sandstone between C and D)								
723900	235500	Low Splint	180-220 ft above Taggart	Appalachia	0		20	36										
740021	259100	Low Splint	180-220 ft above Taggart	Appalachia	7		18			Amburgy?								
740021	256100	Low Splint	180-220 ft above Taggart	Appalachia	7		36											
740021	259100	Low Splint		Appalachia	0	0												
740021	256100	Low Splint		Appalachia	0	24												
740021	259100	Low Splint	directly below Kendrick St	Appalachia	0	4												
740021	256100	Low Splint	directly below Kendrick St	Appalachia	0	31												
767000	268200	Low Splint	130 ft above Taggart	Norton (Lo	6		30			w/ 6" parting								
767000	265200	Low Splint	131 ft above Taggart	Norton (Lo	6		60											
768300	262000	Low Splint	60 ft above Low Splint C	Norton (Lo	0	18												
775200	279100	Low Splint	60-80 ft above 34 Inch	Flat Gap (sc	0		56			No. 6								
768300	286700	Low Splint	60-80 ft above 34 Inch	Flat Gap (sc	0		25											
778536	294100	Low Splint	40-60 ft above 34 Inch	Flat Gap (L	0		20											
778536	291100	Low Splint	40-60 ft above 34 Inch	Flat Gap (L	0		39											
778536	294100	Low Splint	40-60 ft above 34 Inch	Flat Gap (L	0			9										
778536	291100	Low Splint	40-60 ft above 34 Inch	Flat Gap (L	0			14										
778536	292569	Low Splint	70 ft above the Low Splint	Flat Gap (L	0	5												
791754	290273	Low Splint										3.1	32.6	53.6	10.7	2	13197	W203389
722418	233125	Low Splint										2.3	37.9	55.3	4.5	0.6	14192	W205193
722418	233125	Low Splint										2.3	36.3	51.4	10	0.8	13184	W205194

Table A.14 Raw Data for Lyons Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
738000	248700	Lyons		Appalachia		3	0	0										
776518	248600	Lyons	50 ft above Dorchester	Norton		24	0	0										
776518	245600	Lyons	50 ft above Dorchester	Norton		30	0	0										
813017	265800	Lyons	30-65 ft above Dorchester	Wise		22	0	0										
796700	253500	Lyons	30-65 ft above Dorchester	Wise (west		3	0	0										
814975	290976	Lyons	45-60 ft above Dorchester	Pound		25	0	0		Eagle								
778536	294100	Lyons	40-60 ft above Dorchester	Flat Gap		0	0	0										
778536	291100	Lyons	40-60 ft above Dorchester	Flat Gap		25	0	0										
853313	336400	Lyons	30-50 ft above Dorchester	Clintwood		26	0	0		Eagle, Blair								
853313	333400	Lyons	30-50 ft above Dorchester	Clintwood		32	0	0										
890700	352300	Lyons	30-60 ft above Dorchester	Haysi (2 be		50	0	28		Eagle, Blair								
926080	352100	Lyons	45-80 ft above Dorchester	Prater		24	0	0		Eagle								
926080	349100	Lyons	45-80 ft above Dorchester	Prater		95	0	0										
999600	366500	Lyons	40-70 ft above Dorchester	Patterson (s		14	0	0		Eagle								
997200	388800	Lyons	40-70 ft above Dorchester	Patterson (n		79	30	0										
997200	385800	Lyons	40-70 ft above Dorchester	Patterson (n		71	11	0										
964184	377500	Lyons	10-85 ft above Dorchester	Grundy		35	0	0		Eagle, Blair								
964184	374500	Lyons	10-85 ft above Dorchester	Grundy		50	0	0		Eagle, Blair								
926700	393600	Lyons		Harman (no		82	15	0										
925500	358000	Lyons		Harman (so		62	28	0										
927858	377438	Lyons		Harman		43	0	0										
939600	406600	Lyons		Jamboree		43	0	0										
964300	423500	Lyons		Hurley		5	0	0										
964300	420500	LYONS		Hurley		30	0	0										
826579	307056	LYONS								1723.7								
749089	262701	LYONS								1525.54								
785899	261216	Lyons									2.6	34.8	56.3	6.3	3.1		13770	W191063
819935	258746	Lyons									2	32.6	58.7	6.7	1.5		13900	W191064
784651	259642	Lyons									1.3	35.2	57.2	6.3	0.6		14230	W191065
784651	259642	Lyons									3.6	32.9	58	5.5	2.9		13810	W191069
829311	264570	Lyons									2.6	31.5	62.1	3.8	1.2		14370	W192588
818092	263708	Lyons									3.9	32.2	61.9	2.1	0.5		14490	W192601
945486	347806	Lyons									5.1	25.6	49.3	20	1.2		11449	W194302
938485	334689	Lyons									5.9	27.7	51.5	14.9	1.5		12229	W194305
791188	302597	Lyons									3.1	34.7	55.8	6.4	2.4		13924	W197299
776915	243792	Lyons									1.9	37.6	54.8	5.7	1.6		13973	W198542
782206	250704	Lyons									3	34.2	53.9	8.9	2.8		13389	W202130
932371	356376	Lyons									3.6	23.3	44.9	28.2	0.6		10302	W204620
903605	336770	Lyons									2.7	30.35	55.94	11.01	2.85		13122	W211174
903539	336193	Lyons									2.7	29.46	55.83	12.01	2.2		13032	W211675
807680	299345	Lyons									2.57	31.38	53.51	12.54	2.47		12887	W212493
817598	260577	Lyons									3.8	32.77	59.77	3.66	0.65		14210	W215874
931900	394019	Lyons									2.67	31.98	60.92	4.43	1.07		14290	W218768
954375	374173	Lyons									2.73	30.93	59.87	6.47	1.2		14103	W218771
970960	394055	Lyons									1.9	32.74	60.31	5.05	1.1		14353	W223361
972149	384257	Lyons									1.55	29.54	60.49	8.42	0.68		13823	W225106
816478	258588	Lyons									16.46	26.16	53.59	3.79	0.61		10620	W231828
816588	258897	Lyons									15.74	27.28	53.45	3.53	0.46		10733	W231829
816227	258114	Lyons									2.18	33.51	62.65	1.66	0.96		14793	W235317
816227	258114	Lyons									2.87	35.79	57.47	3.87	1.28		14412	W235318

Table A.14 Raw Data for Lyons Seam

961780	404549 Lyons	1.73	30.1	57.21	10.96	1.19	13412 W246908
--------	--------------	------	------	-------	-------	------	---------------

Table A.15 Raw Data for Morris Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN	
662400	220900	Morris	270-280 ft above Pardee	Keokee (2 t	24		5		2 beds										
665400	220900	Morris	270-280 ft above Pardee	Keokee (2 t	38		10												
740021	267500	Morris	300-350 ft above Pardee	Appalachia	30		10												
740021	266000	Morris	300-350 ft above Pardee	Appalachia	72		10												
740021	264500	Morris	300-350 ft above Pardee	Appalachia	60		10												
768900	281300	Morris		Flat Gap	12		0		w/ shale	No. 11									
768900	284300	Morris		Flat Gap	24		0												
748055	273380	Morris										2.2	34.5	56.5	6.8	0.7		13687	W204164
734430	266951	Morris										2.9	34.6	57.5	5	0.6		13972	W205196
742497	267161	Morris										1.82	36.73	57.3	4.15	0.66		14191	W214255

Table A.16 Raw Data for Norton Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
776518	247104	Norton	40 ft below base of Gladeville Sa	Norton	26		0	0										
776518	247104	Norton	40 ft below base of Gladeville Sa	Norton	30		0	0										
785500	254000	Norton	40 ft below base of Gladeville Sa	Norton (nor	54		13	0										
813017	245508	Norton	390 ft above Splash Dam	Wise	30		0	0										
801600	255900	Norton	391 ft above Splash Dam	Wise	14		0	0										
849518	260000	Norton	330 above Hagy	Coeburn	12		2	0										
849518	257000	Norton	330 above Hagy	Coeburn	34		4	0										
913400	277700	Norton	90 ft above Eagle Shale Member	Duty - lowe	13		0	0										
913400	274700	Norton	90 ft above Eagle Shale Member	Duty - lowe	20		0	0										
878200	278600	Norton	140-180 ft above Hagy No. 2	Nora (Brust	41		12	0										
887858	301800	Norton	140-180 ft above Hagy No. 2	Nora (north	27		6	0										
887858	298800	Norton	140-180 ft above Hagy No. 3	Nora (north	31		7	0										
851416	290900	Norton	220-260 ft above Hagy	Caney Ridg	12		0	0										
851416	287900	Norton	220-260 ft above Hagy	Caney Ridg	40		0	0										
814975	292500	Norton	220-260 ft above Hagy	Pound	12		0	0										
814975	289500	Norton	220-260 ft above Hagy	Pound	40		0	0										
778536	292569	Norton	80-100 ft below Dorchester	Flat Gap (n	30		0	0										
847800	334900	Norton	110-120 ft above Hagy No. 2	Clintwood	35		0	0										
847800	331900	Norton	110-120 ft above Hagy No. 3	Clintwood	40		0	0										
816933	323000	Norton	110-120 ft above Hagy No. 2	Jenkins Eas	35		0	0										
816933	320000	Norton	110-120 ft above Hagy No. 3	Jenkins Eas	40		0	0										
884300	345100	Norton	180-220 ft above Hagy	Haysi 2 - t	44		6	29	9									
889696	333408	Norton	180-220 ft above Hagy	Haysi 2 - t	25		0	20										
926080	331961	Norton	200-240 ft above Hagy	Prater	18		0	0										
926080	344200	Norton	200-240 ft above Hagy	Prater	31		0	0										
948700	333800	Norton	200-240 ft above Hagy	Vansant	18		0	0										
948700	330800	Norton	200-240 ft above Hagy	Vansant	36		0	0										
986800	342400	Norton	110-140 ft above Hagy No. 2	Keen Moun	3		0	0		Glamorgan								
1000512	374695	Norton	160-200 ft above Hagy	Patterson	20		0	0										
1012400	374695	Norton	160-200 ft above Hagy	Patterson (e	4		0	0										
994200	364500	Norton	160-200 ft above Hagy	Patterson (s	36		0	0										
964184	368900	Norton	245-340 ft above Splash Dam	Grundy (soi	12		0	0		Glamorgan								
964184	365900	Norton	245-340 ft above Splash Dam	Grundy (soi	80		0	0										
964184	377500	Norton	245-340 ft above Splash Dam	Grundy (no	12		0	0										
964184	374500	Norton	245-340 ft above Splash Dam	Grundy (no	80		27	0										
927858	377438	Norton	15-200 ft above Hagy	Harman	25		10	0		Glamorgan, Blair								
935000	381700	Norton	15-200 ft above Hagy	Harman (Ne	96		36	0										
940800	407600	Norton	15-200 ft above Hagy	Jamboree	25		10	0		Glamorgan, Blair								
965901	423000	Norton	120-160 ft above Hagy	Hurley 1-3	18		0	0										
991800	419500	Norton	120-160 ft above Hagy	Panther 1-3	18		0	0										
965901	420000	Norton	6-20 ft above middle	Hurley 1-3	39		0	0										
991800	416500	Norton	6-20 ft above middle	Panther 1-3	39		0	0										
792183	269252	NORTON									2172.9							
787883	269564	NORTON									1921							
749089	262701	NORTON									1407.54							
945761	347978	Norton										2.3	25.8	55.8	16.1	1	12712	W194292
951578	325872	Norton										1.7	25.1	56.2	17	1	12687	W194301
800816	251587	Norton										2.4	34.2	58.5	4.9	0.7	14350	W196289
826841	263549	Norton										2.8	31.6	63.4	2.2	1.3	14645	W199466
801286	251307	Norton										4	32.1	58.5	5.4	0.8	13820	W200484

Table A.16 Raw Data for Norton Seam

859010	255832	Norton	3.9	34.4	55.4	6.3	0.9	13733	W202129
832937	267357	Norton	2.7	31.3	61.3	4.7	0.8	14284	W204157
832937	267357	Norton	2.2	31.8	60.3	5.7	0.9	14199	W204158
854791	297489	Norton	3.9	29.9	61.6	4.6	0.9	14203	W206889
818174	289632	Norton	2.36	30.26	63.06	4.32	0.72	14390	W212492
824761	294798	Norton	2.17	30.23	61.78	5.82	0.78	14135	W213994
824737	295196	Norton	1.99	31.08	61.36	5.57	0.92	14208	W213995
948188	332225	Norton	1.32	24.56	53.69	20.43	0.63	12043	W217398
724907	218869	Norton	2.77	38.38	54.59	4.26	1.46	14069	W219354
711085	217386	Norton	1.53	37.36	57.07	4.04	0.93	14300	W219796

Table A.19 Raw Data for Pocahontas No. 3 Seam

Eastings	Northing	Seam	Thickness	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
1182177	370179	Pocahontas No. 3		97							
1182177	367179			132							
1071637	326659	Pocahontas No. 3		30							
964184	377542	Pocahontas No. 3		49							
964184	374542			0							
979817	307143	Pocahontas No. 3		48							
978131	286100	Pocahontas No. 3		20							
941653	264542	Pocahontas No. 3		0							
941653	261542			14							
1015423	283076	Pocahontas No. 3		28							
919767	263891	Pocahontas No. 3		30							
861408	266242	Pocahontas No. 3		30							
812038	224275	Pocahontas No. 3		36							
812038	221275			84							
1100000	320000	Pocahontas No. 3		97							
1030000	285000	Pocahontas No. 3		30							
988411	385092	POCAHONTAS No. 3			63						
965409	381440	POCAHONTAS No. 3			-102						
957578	384139	POCAHONTAS No. 3			-121						
952396	381170	POCAHONTAS No. 3			-142						
901222	370545	POCAHONTAS No. 3			-98						
959228	371562	POCAHONTAS No. 3			-122						
973300	369298	POCAHONTAS No. 3			11						
967561	358807	POCAHONTAS No. 3			134.25						
945974	360356	POCAHONTAS No. 3			-100.5						
1010631	378947	POCAHONTAS No. 3			188						
1040749	375666	POCAHONTAS No. 3			357.7						
1021532	354255	POCAHONTAS No. 3			501						
1037773	350649	POCAHONTAS No. 3			364.28						
1001904	352604	POCAHONTAS No. 3			222.62						
994596	351443	POCAHONTAS No. 3			107						
972716	350887	POCAHONTAS No. 3			49						
965440	349464	POCAHONTAS No. 3			101						
915546	333129	POCAHONTAS No. 3			-235.9						
918570	340115	POCAHONTAS No. 3			-204.1						
956423	328688	POCAHONTAS No. 3			83						
961918	326576	POCAHONTAS No. 3			146						
954516	326349	POCAHONTAS No. 3			98						
959881	322630	POCAHONTAS No. 3			171						
964740	321287	POCAHONTAS No. 3			57						
970176	322449	POCAHONTAS No. 3			51						
984440	382105	POCAHONTAS No. 3			19						
988736	345113	POCAHONTAS No. 3			59.4						
993613	332982	POCAHONTAS No. 3			151						
988980	319077	POCAHONTAS No. 3			391.14						
999399	318640	POCAHONTAS No. 3			478						
1023033	332067	POCAHONTAS No. 3			485						
1036988	342985	POCAHONTAS No. 3			358						
1041280	334949	POCAHONTAS No. 3			796						
1042415	324407	POCAHONTAS No. 3			752						

Table A.17 Raw Data for Pardee Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin;AddInfo	OtherName	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
663600	220700	Pardee	220-270 ft above Phillips	Lee Cty		21	0									
666600	220400	Pardee	220-270 ft above Phillips	Lee Cty		92	0									
740600	264400	Pardee	250 ft above Phillips	Appalachia		48	6		Parson							
763600	283800	Pardee	325 ft above Phillips	Flat Gap (hea		40	0		No. 10, Parsons							
769971	274816	Pardee								3.6	36.8	53.9	5.7	0.8		13877 W195441
770231	275989	Pardee								3.4	32.7	49.9	14	1.2		12508 W195443
737229	269723	Pardee								3.5	33.5	56.2	6.8	0.6		13425 W204163
727635	257467	Pardee								2.2	35.9	53.2	8.7	0.9		13529 W205195

Table A.18 Raw Data for Phillip Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderParting	AddInfo	OtherName	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
738100	260600	Phillips	300 ft above Kendrick S	Appalachia		20				Lower Philips, No. 7							
767000	281000	Phillips	325 above Low Splint	Flat Gap (P		11			4 splits, 11" No. 7								
779200	289100	Phillips		Flat Gap (s		20	12		40" coal in 59" seam								
772584	284776	Phillips									5.5	33.7	54.6	6.2	1.2	13235	W200485

Table A.20 Raw Data for Raven Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin;AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
1059400	339200	Raven	205 ft above Jawbone	Amonate (e		36			Raven #1, Garden Hole, Jaeger, Jewell, Lower Douglas, Middle Raven, Raven Red Ash, Red Ash, Tunnel								
1000500	340100	Raven	140 ft above Jawbone	Keen Mtn. (		24											
1000500	337100	Raven	140 ft above Jawbone	Keen Mtn. (		48											
961300	331800	Raven	80 ft above Jawbone	Vansant		10											
961300	328800	Raven	80 ft above Jawbone	Vansant		32											
924600	332500	Raven	80 ft above Jawbone	Prater		10											
924600	329500	Raven	80 ft above Jawbone	Prater		32											
951200	344900	Raven		Vansant (S		30											
915700	313900	Raven		Prater (Fryi		31											
927800	313200	Raven		Prater (Mur		10											
1029700	360700	Raven	140-200 ft above Jawbone	Bradshaw		24											
999300	374000	Raven	140-200 ft above Jawbone	Patterson		24											
962600	377400	Raven	100-170 ft above Jawbone	Grundy		6											
962600	374400	Raven	100-170 ft above Jawbone	Grundy		29											
996100	286300	Raven		Honaker		14											
996100	283300	Raven		Honaker		44											
935400	274000	Raven	150-230 ft above Jawbone	Duty (SE)		47											
887300	287900	Raven	170 ft above Jawbone	Nora		28											
851200	289200	Raven	170 ft above Jawbone	Caney Ridg		28											
880900	323600	Raven	130 ft above Jawbone	Haysi (SW)		12											
880900	320600	Raven	130 ft above Jawbone	Haysi (SW)		60											
894200	343900	Raven		Haysi (Russ		9											
894200	340900	Raven		Haysi (Russ		25											
849300	243000	Raven	120-160 ft above Jawbone	Coeburn		36											
886000	241100	Raven	120-160 ft above Jawbone	St. Paul		36											
820900	249300	Raven		Wise (W of		36											
986108	412173	RAVEN (splits)								919							
996392	401522	RAVEN (splits)								1090							
981048	431415	RAVEN								697							
988895	424254	RAVEN								722							
974990	400906	RAVEN								957							
977055	398745	RAVEN								916							
988411	385092	RAVEN								1224							
955825	387089	RAVEN								962							
968592	384922	RAVEN								1026							
974855	384911	RAVEN								999.8							
973496	382138	RAVEN								1110							
957578	384139	RAVEN								1022							
952396	381170	RAVEN								998							
919519	384742	RAVEN								850.33							
959228	371562	RAVEN								1057							
1021532	354255	RAVEN								1999							
915546	333129	RAVEN								934.1							
961918	326576	RAVEN								1570							
954516	326349	RAVEN								1526							
964740	321287	RAVEN								1570							
926946	327134	RAVEN								1220.2							
871341	333222	RAVEN								1021.5							
870372	323345	RAVEN								1123.3							
851223	319375	RAVEN								1161.4							

Table A.20 Raw Data for Raven Seam

837462	297477 RAVEN	1074						
876545	294635 RAVEN	1335.3						
876892	293066 RAVEN	1344.5						
879716	291042 RAVEN	1327.4						
879278	288440 RAVEN	1380.4						
981123	305576 RAVEN	2069						
813600	246196 RAVEN	1349.7						
819571	250281 RAVEN	1564						
844992	253592 RAVEN	1574.23						
850324	261230 RAVEN	1560.44						
854675	252062 RAVEN	1651.55						
881339	237904 RAVEN	1673.32						
871176	230739 Raven		1.5	32.9	50.6	15	1.2	12535 W193664
875244	236053 Raven		3.6	21.4	64.2	10.8	0.9	12966 W203384
914297	286143 Raven		2.02	22.9	50.49	24.59	0.5	11261 W211170
875097	237192 Raven		1.65	31.86	52.5	13.99	1.1	12789 W215446
1025230	328568 Jewell		3.4	26.5	66.5	3.6	0.7	14630 D170131
1021469	318483 Jewell		3.6	28.7	63.9	3.8	0.5	14450 D170140
1053705	351355 Jewell		3	21.6	72.4	3	0.6	14790 D170141
1019058	325855 Jewell		2.2	26.1	69.2	2.5	0.5	14920 D170146
1025168	324625 Jewell		2	26.6	67.3	4.1	0.7	14690 D170148
1016874	341719 Jewell		1.9	22.7	71.3	4.1	0.5	14790 D170149
1039268	350337 Jewell		2.4	20.7	74.5	2.4	0.6	14940 D170159
1049737	330242 Jewell		2.9	26.8	64.8	5.5	0.9	14290 D170164
936405	274276 Raven No 1		1.1	30.9	62.1	5.9	0.8	14390 D161626

Table A.21 Raw Data for Splash Dam Seam

East	North	Name	coal	reject	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
813700	258600	SPLASH DAM		16	0							
849518	261500	SPLASH DAM		20	0							
849518	258500	SPLASH DAM		36	0							
960747	300500	SPLASH DAM		5	0							
924303	287986	SPLASH DAM		0	0							
924303	284986	SPLASH DAM		26	0							
880000	281500	SPLASH DAM		40	2							
880000	278500	SPLASH DAM		68	28							
887858	286400	SPLASH DAM		6	0							
887858	289400	SPLASH DAM		34	0							
851416	287931	SPLASH DAM		6	0							
851416	290931	SPLASH DAM		24	0							
814975	289476	SPLASH DAM		6	0							
814975	292476	SPLASH DAM		24	0							
820000	325000	SPLASH DAM		10	0							
853313	334902	SPLASH DAM		10	0							
816933	331100	SPLASH DAM		26	0							
853313	345600	SPLASH DAM		27	0							
889696	333408	SPLASH DAM		30	5							
935000	320000	SPLASH DAM		37	0							
935617	346500	SPLASH DAM		7	0							
935617	349500	SPLASH DAM		35	0							
986500	343500	SPLASH DAM		10	0							
986500	340500	SPLASH DAM		23	0							
983000	379000	SPLASH DAM		33	4							
999000	387000	SPLASH DAM		28	7							
997000	375000	SPLASH DAM		31	13							
978000	370000	SPLASH DAM		38	0							
986000	388500	SPLASH DAM		19	0							
986000	391500	SPLASH DAM		30	0							
948000	358500	SPLASH DAM		12	0							
948000	361500	SPLASH DAM		39	0							
964184	378000	SPLASH DAM		55	0							
981048	431415	SPLASH DAM			1123							
988895	424254	SPLASH DAM			1080							
955825	387089	SPLASH DAM			1405							
968592	384922	SPLASH DAM			1481							
974855	384911	SPLASH DAM			1560.8							
973496	382138	SPLASH DAM			1593							
957578	384139	SPLASH DAM			1461							
906333	372853	SPLASH DAM			1415.39							
912541	363732	SPLASH DAM			1390							
904757	369424	SPLASH DAM			1505.77							
913305	357623	SPLASH DAM			1322.33							
959228	371562	SPLASH DAM			1475							
1010631	378947	SPLASH DAM			2072							
904237	354195	SPLASH DAM			1313							
902821	350415	SPLASH DAM			1404							
908677	268584	SPLASH DAM			2262							
787883	269564	SPLASH DAM			1562							

Table A.21 Raw Data for Splash Dam Seam

782728	247082 SPLASH DAM	1878							
813600	246196 SPLASH DAM	2155.7							
880672	276442 Splashdam	2	29.6	59.3	9.1	1	13822	W210393	
882714	265846 Splashdam	1.9	33.5	55	9.6	1.8	13599	W210394	
880658	267121 Splashdam	3	34.8	55.1	7.1	4.1	13751	W210395	
878788	275666 Splashdam	3.3	42.9	32.1	21.7	0.7	11236	W210399	
881377	353196 Splashdam	2.84	31.06	55.96	10.14	0.63	13207	W211676	
882416	353544 Splashdam	2.32	28.88	52.78	16.02	0.75	12627	W211677	
926653	363453 Splashdam	1.63	27.46	65.98	4.93	0.6	14364	W217688	
914985	391859 Splashdam	3.26	29.31	58.48	8.95	2.34	13610	W218767	
931217	390446 Splashdam	2.68	28.68	61.91	6.73	0.7	14011	W218769	
949942	385266 Splashdam	2.18	30.81	60.72	6.29	1.17	14269	W218772	
949149	385227 Splashdam	2.4	31.07	62.22	4.31	0.82	14541	W218773	
724907	218869 Splashdam	2.49	37.66	56.8	3.05	0.67	14485	W219348	
952477	395280 Splashdam	1.86	29.69	63.09	5.36	0.65	14351	W223357	
940266	393356 Splashdam	1.41	29.15	62.06	7.38	0.67	14125	W223359	
941077	393641 Splashdam	3.2	27.93	62.38	6.49	0.65	13976	W223360	
896470	333299 Splashdam	2.82	29.51	62.36	5.31	0.77	14337	W238941	

Table A.22 Raw Data for Taggart Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin;AddInfo	OtherName	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
680000	218600	Taggart	10-55 ft above Taggart Marker	Lee County	16		0	100 ft above Taggart Marker in Keokee								
680000	215600	Taggart		Lee County	116		0									
740021	248748	Taggart	20-60 ft above Taggart Marker	Appalachia	36		15	Rider 20-60 Taggart A, Rider = B								
714700	235200	Taggart	20-60 ft above Taggart Marker	Benham	36		15									
772200	266900	Taggart	30-40 ft above Taggart Marker	Norton	48		0									
770200	281600	Taggart		Flat Gap (sc	28		20	<18' shale/s No. 5 in KY								
774600	289200	Taggart		Flat Gap (sc	58		30									
794173	288170	Taggart Marker								4.3	35.8	57	2.9	0.9		14290 W191333
768622	263418	Taggart Marker								2.1	34.5	52.9	10.5	0.7		13437 W194853
733333	237615	Taggart Marker								3.79	34.83	56.45	4.93	0.74		13870 W218776

Table A.23 Raw Data for Taggart Marker Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartin; AddInfo	OtherName	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
680200	220100	Taggart Marker	80-120 ft above Wilson	Lee Cty	12			2								
680200	217100	Taggart Marker	0-20 ft above lower	Lee Cty	27			22	typ. 10 ft between							
740021	250200	Taggart Marker	65-90 ft above Wilson	Appalachia	12			0								
740021	247200	Taggart Marker	65-90 ft above Wilson	Appalachia	60			0								
772300	267900	Taggart Marker	260 ft above Imboden	Norton	36			0								
772300	264900	Taggart Marker	261 ft above Imboden	Norton	48			0								
778536	292569	Taggart Marker	60-90 ft above Wilson	Flat Gap	25			0								
794173	288170	Taggart Marker								4.3	35.8	57	2.9	0.9		14290 W191333
768622	263418	Taggart Marker								2.1	34.5	52.9	10.5	0.7		13437 W194853
733333	237615	Taggart Marker								3.79	34.83	56.45	4.93	0.74		13870 W218776

Table A.24 Raw Data for Tiller Seam

East	North	Name	Location	Quadrangle	Thickness	AddInfo	OtherName	Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleNo
1020300	309700	Tiller	300-325 ft above Upper Seaboard & 2	Carbo	35										
996000	284400	Tiller			35										
1030000	307400	Tiller			42										
960746.1	283484	Tiller	300-325 ft above Upper Seaboard & 2	Big A Mountain	0										
960746.1	286484	Tiller	300-325 ft above Upper Seaboard & 2	Big A Mountain	82										
950400	287200	Tiller		Indian Creek	55										
944700	268500	Tiller		Alvy Creek	78										
962467	332060	Tiller		Vansant	18										
962467	329060	Tiller		Vansant	36										
926080.5	333460	Tiller		Prater	18										
926080.5	330460	Tiller		Prater	36										
1000512	376200	Tiller		Patterson	26										
1000512	373200	Tiller		Patterson	40										
1020700	370100	Tiller		Bradshaw	26										
1020700	367100	Tiller		Bradshaw	40										
967500	361600	Tiller			0										
967500	358600	Tiller		Grundy	12										
943600	288300	Tiller	Tiller & overlying Jawbone coalesce		84										
943600	287700	Tiller	Tiller & overlying Jawbone coalesce		216										
925761.1	287900	Tiller	Merges with Jawbone	Duty	0										
925761.1	284900	Tiller	Merges with Jawbone	Duty	144										
917900	388600	Tiller		Harman	0										
917900	385600	Tiller		Harman	6										
815500	290000	Tiller		Pound	0										
835300	333500	Tiller			0										
981048	431415	TILLER						575							
974350	417634	TILLER						652							
986108	412173	TILLER						726							
974990	400906	TILLER						797							
977055	398745	TILLER						753							
988411	385092	TILLER						1042							
955825	387089	TILLER						772							
957578	384139	TILLER						815							
952396	381170	TILLER						797							
942233	382786	TILLER						722							
959228	371562	TILLER						846							
973300	369298	TILLER						1038							
1040749	375666	TILLER						1614.7							
1021532	354255	TILLER						1800							
1037773	350649	TILLER						1760.28							
994596	351443	TILLER						1372							
915546	333129	TILLER						700.1							
961918	326576	TILLER						1289							
959881	322630	TILLER						1402							
964740	321287	TILLER						1326							
970176	322449	TILLER						1267							
988736	345113	TILLER						1319.4							
993613	332982	TILLER						1484							
1036988	342985	TILLER						1794							
1042415	324407	TILLER						2282							

Table A.24 Raw Data for Tiller Seam

1030094	300025 TILLER	2295							
871341	333222 TILLER	850.5							
851223	319375 TILLER	1012.4							
876892	293066 TILLER	1170.5							
879716	291042 TILLER	1163.4							
866151	263107 TILLER	1342							
981123	305576 TILLER	1741							
937098	269020 TILLER	2001							
918480	264246 TILLER	1613.7							
782728	247082 TILLER	1120							
854675	252062 TILLER	1410.55							
881339	237904 TILLER	1485.32							
881339	237904 TILLER	1455.32							
1039148	321400 Tiller		2.3	26.7	63.8	7.2	0.7	14000	D170161
923946	263873 Tiller		1.8	29.2	56.8	12.2	0.6	13263	W192709
908093	259513 Tiller		1.6	31.5	60.8	6.1	0.5	14346	W197303
908092	259476 Tiller		1.8	32.9	60.9	4.4	0.6	14560	W197304
908091	259447 Tiller		1.2	33.6	62.3	2.9	0.6	15026	W197305
908088	259531 Tiller		1.3	32	60.7	6	0.5	14396	W197306
942437	287037 Tiller		1.94	28.48	65.9	3.68	0.56	14795	W215450
724907	218869 Tiller		1.41	37.56	50.01	11.02	1.59	13334	W219401

Table A.25 Raw Data for Upper Banner Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPartingAddInfo	OtherName Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
824900	244700	Upper Banr	100-150 ft above Lower Ban	Wise (E of White	36		0									
831600	264900	Upper Banr	100-150 ft above Lower Ban	Wise (Steel Fork)	36		0									
813017	245508	Upper Banr	100-150 ft above Lower Ban	Wise (W of White	5		0									
849518	260000		140 ft above Lower Banner	Coeburn	24		1									
851416	289431		120-160 ft above Lower Ban	Caney Ridge (Ste	28		1									
860017	277737		120-160 ft above Lower Ban	Caney Ridge	60		1									
888600	276500		160 ft above Lower Banner	Nora	49		3	in 3 splits								
888600	273500		160 ft above Lower Banner	Nora	107		27									
896200	300600		160 ft above Lower Banner	Nora	49		3									
896200	297600		160 ft above Lower Banner	Nora	107		27									
888300	289600		80 ft above Lower Banner	Nora	17		0	in 3 splits								
888300	286600		80 ft above Lower Banner	Nora	40		0									
924303	288000			Duty	9		1									
924303	285000			Duty	74		1									
960746	305700		50-100 ft above Lower Bann	Big A Mountain	0		0									
997198	285200		115 ft above Lower Banner	Honaker	28		3									
997198	282200		116 ft above Lower Banner	Honaker	48		3									
816933	328600		80-90 ft above Lower Banne	Jenkins East	0		0									
860500	326000		80-90 ft above Lower Banne	Clintwood	63		1									
880099	324000		85 ft above Lower Banner	Haysi	48		1									
880099	321000		85 ft above Lower Banner	Haysi	60		1									
889600	333400		86 ft above Lower Banner	Haysi	46		1									
883700	347200		85 ft above Lower Banner	Haysi	12		1									
962467	332100		70-120 ft above Lower Bann	Vansant (Youngs	0		0									
962467	329100			Vansant (other)	20		1									
926080	331961		70-120 ft above Lower Bann	Prater	11		1									
928300	340400		70-120 ft above Lower Bann	Prater (War Fork	26		1									
1003300	343800		70-100 ft above Lower Bann	Keen Mountain (I	15		1									
991700	377300			Patterson	2		1									
991700	389600			Patterson	2		1									
1015600	368400			Patterson (head of	28		1									
954700	368400		70 ft above Lower Banner	Grundy	0		1									
954700	365400		71 ft above Lower Banner	Grundy	17		1									
964184	376042			Grundy (other)	0		0									
993900	416400		80 ft above Lower Banner	Panther	19		1									
974600	421800		80 ft above Lower Banner	Hurley	17		3									
981048	431415	UPPER BANNER								1077						
968592	384922	UPPER BANNER								1426						
974855	384911	UPPER BANNER								1510.8						
973496	382138	UPPER BANNER								1535						
965409	381440	UPPER BANNER								1427						
957578	384139	UPPER BANNER								1422						
913992	387341	UPPER BANNER								1215.2						
959228	371562	UPPER BANNER								1411						
915546	333129	UPPER BANNER								1370.1						
918570	340115	UPPER BANNER								1418.9						
902821	350415	UPPER BANNER								1297						
908677	268584	UPPER BANNER								2226						
866151	263107	UPPER BANNER								2148						
866151	263107	UPPER BANNER								2134						

Table A.25 Raw Data for Upper Banner Seam

923433	278726	Upper Banner	1.4	31.8	58.5	8.3	0.5	13810	D161629
925530	274294	Upper Banner	1.4	32.6	56.5	9.5	0.5	13530	D161634
1008372	316926	Upper Banner	2.9	30.4	60.2	6.5	0.6	13950	D170139
999450	289925	Upper Banner	11.5	33.5	51	4	0.4	12530	W187056
841075	277315	Upper Banner	4.3	30.4	60.9	4.4	1	14261	W195444
845601	288738	Upper Banner	4.1	29.2	59.8	6.9	0.7	13829	W198543
848684	250828	Upper Banner	1.3	38.2	56.4	4.1	0.5	14520	W200486
837929	283824	Upper Banner	2.8	28.8	58.1	10.3	0.9	13535	W203390
889731	272027	Upper Banner	3.3	32.6	60.5	3.6	0.6	14470	W204160
889731	272027	Upper Banner	3.4	28.8	52	15.8	0.6	12383	W204161
852364	271686	Upper Banner	2	31.7	60	6.3	0.6	14235	W209959
886836	268048	Upper Banner	2	31.8	57.2	9	0.7	13619	W209963
915812	273527	Upper Banner	1.5	33.1	50.5	14.9	2.2	12830	W210401
883888	318310	Upper Banner	0.95	22.81	55.57	20.67	0.61	11960	W215414
883888	318310	Upper Banner	0.76	27.79	67.8	3.65	1.08	14974	W215415
724907	218869	Upper Banner	1.89	36.48	55.29	6.34	1.32	13965	W219793
845601	288738	Upper Banner	2.79	28.38	61.92	6.91	0.71	13943	W236247
850517	300903	Upper Banner	13.39	24.84	55.56	6.21	0.51	11707	W238943
887774	318917	Upper Banner	1.54	24.89	59.76	13.81	0.73	13003	W246906

Table A.26 Raw Data for Wilson Seam

East	North	Name	Location	Quadrangle	Thickness	Parting	Rider	RiderPar	AddInfo	OtherName Elev	moisture	volatiles	fixedc	stdash	sulfur	btu	CSampleN
664836	206725	Wilson	50-70 ft above Upper St. Charles, 23'	Pennington G		3		0		Harlan							
701388	223000	Wilson	50-70 ft above Upper St. Charles, 23'	Keokee		63		0		Upper Standiford							
740021	250200	Wilson	180-280 ft above Kelly	Appalachia		12		0									
740021	247200	Wilson	180-280 ft above Kelly	Appalachia		48		0									
767000	267200	Wilson	220 ft above Kelly	Norton (Roar		14		0									
767000	263200	Wilson	221 ft above Kelly	Norton (Roar		26		0									
778536	292569	Wilson	20-40 ft above Upper St. Charles	Flat Gap		30		0									
774158	254155	Wilson									3.8	33.4	51.8	11	0.8		12987 W203387
789646	288981	Wilson									1.7	33.75	55.38	9.17	1.12		13622 W212488
782339	292372	Wilson									1.91	33.57	58.21	6.31	1.1		14026 W223354
650072	195207	Wilson									2.23	38.33	50.22	9.22	4.07		13072 W226970
695007	214016	Wilson									4.69	38.65	46.98	9.68	3.69		12585 W226971

APPENDIX B

**PLOTS OF DATA LOCATIONS, SEAM THICKNESS, RAW
ASH CONTENT, RAW SULFUR CONTENT, IN-SEAM
REJECT, UNDERGROUND MINING PROFITABILITY,
SURFACE MINING PROFITABILITY, PROPERTY SIZE,
ACCESS, AND MINING METHOD FOR 26 SEAMS
STUDIED**

VITA

Erik C. Westman

Erik C. Westman was born to Roger and Diane Westman on July 22, 1964 in Wheat Ridge Colorado. Following completion of a B.Sc. in Geophysical Engineering from the Colorado School of Mines in May, 1986, Erik Westman worked as a Land Surveyor and Seismic Data Processor. He returned to school for a M.Sc. in Civil Engineering (Geotechnical) from the University of Colorado. After working as a Geotechnical Engineer, he accepted a position as Geophysical Engineer with the Denver Research Center of the U.S. Bureau of Mines. After three years he became the Principal Investigator for a project to use seismic tomography to map stress concentrations in longwall panels. Following closure of the Bureau, he worked as a Mining Engineer for NSA Engineering, Inc. until moving with his wife and children to Blacksburg to start his Ph.D. program at Virginia Tech. He expects to complete the requirements for the Ph.D. degree in April, 1999.