Chapter F

National Coal Resource Assessment: Estimates of Uncertainty

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National Coal Resource Assessment: Estimates of Uncertainty

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Abstract

As part of the U.S. Geological Survey's National Coal Resource Assessment, uncertainty estimates on coal resources were computed for more than 60 coal beds and zones in the Appalachian Basin, Colorado Plateau region, Gulf Coast region, Illinois Basin, and the Northern Rocky Mountains and Great Plains region. We developed a technique that incorporates spatial correlation of coal-bed/zone thicknesses obtained from drill and outcrop data. For each assessed coal unit, we fitted a statistical model to a semivariogram computed from coal thickness. We used the model, together with drill density data, to obtain an estimate of uncertainty that also accounted for the influence of preferential sampling.

We report uncertainty estimates by historical categories of coal resource assessment: measured, indicated, inferred, and hypothetical. These categories represent coal tonnage within increasing radii from a data point. In general, uncertainty estimates are larger for western coals than eastern coals due to greater variability in coal thickness in the western regions. For example, in the measured category, the median percent error (defined as the half-width of the 90-percent confidence interval divided by the total assessed resource) is 10.7 for 21 beds/zones in the Northern Rocky Mountains and Great Plains region. For the same category, the median percent error for five beds/zones in the Appalachian and Illinois Basins is only 1.6. This paper illustrates our ability to relate measures of uncertainty and spatial correlation to geologic phenomena and the volume of remaining resources. Specifically, we can now make meaningful comparisons of uncertainty in coal volumes between beds/zones and across regions.

Introduction

The U.S. Geological Survey (USGS) recently completed a National Coal Resource Assessment (NCRA) of the coal beds and zones that will most likely provide the bulk of the Nation's fuel for power generation for the next 20 to 30 years. Five priority assessment regions were studied: the Appalachian Basin, the Colorado Plateau, the Gulf Coast, the Illinois Basin, and the Northern Rocky Mountains and Great Plains (fig. 1). Within each of these regions, the most important coal beds or zones were assessed. These beds or zones fell into one of three categories—the top-producing coals in the region, coals containing large resources or development potential, or areas with significant Federal land or mineral ownership. Most resource assessments in the NCRA project were made on coal zones, but beds, fields, and mines also were assessed as appropriate for the area or data set. Coal resources were assessed by categories of geological assurance that reflect the volume of coal within a known distance from a data point, usually a drill hole or outcrop location. Most of the estimates on the volume (tonnage) of coal within assessed coal zones or other units are based on the historical USGS categories of geological assurance, namely measured, indicated, inferred, and hypothetical (Wood and others, 1983).

For the study presented in this paper, uncertainty estimates were calculated on the remaining resources, specifically the presently unmined coal, in four of the five regions. The exception is the Colorado Plateau. The Colorado Plateau reported original coal resources in those areas of negligible mining and remaining resources in areas of relatively intense mining such as the Yampa coal field. This methodology incorporated variability and spatial relations among coal-unit thicknesses by the historical USGS categories of assurance. It contrasts with the approach used in the past where, within each reliability category, the same degree of geological assurance was assumed regardless of the variability and spatial correlation in the coal-unit-thickness measurements. This new approach was possible because of the quantity and quality of available drilling data and enhanced GIS techniques.

Data

Data used in computing the uncertainty estimates for this study included coal thickness in the reporting unit. Most often this unit was a bed or zone, but sometimes it was a mine or coal field. For example, in the Wyodak-Anderson coal zone of the Powder River Basin, the Decker, Gillette, and Sheridan coal fields were assessed. Available drill-hole

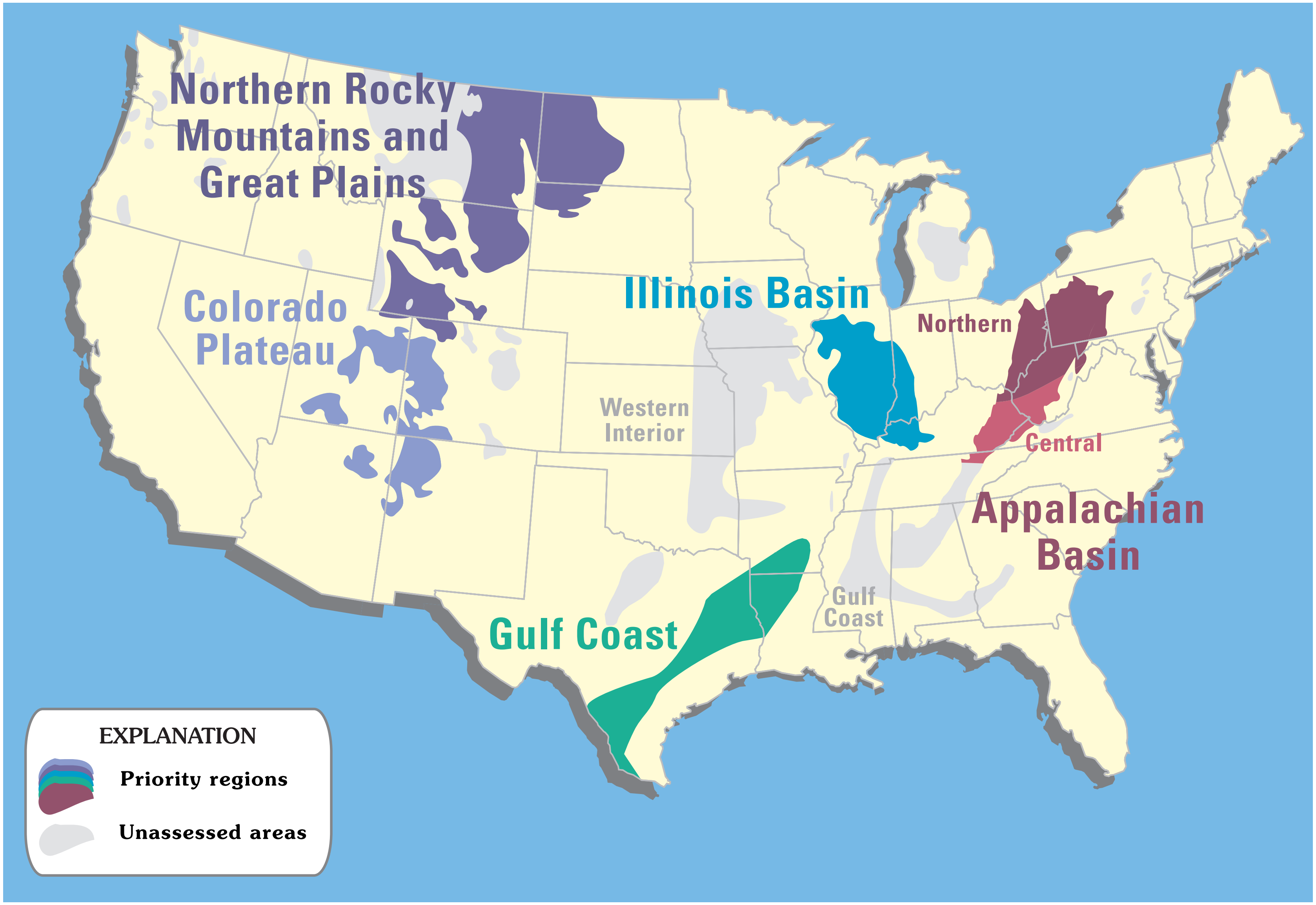

Figure 1. Priority assessment regions.

data and outcrop measurements were used to estimate initial coal resources; however, only coal thickness measurements greater than a specified minimum were used to compute final estimates. Partings in coal zones were removed, and only total coal thickness was used. For coal in the Appalachian and the Illinois Basins, the minimum coal thickness reported in resource computations was 14 inches (0.35 m). For the Colorado Plateau region, the minimum bed thickness used was 1.2 ft (0.37 m). For the Gulf Coast, it was 1.5 ft (0.46 m), and for the Northern Rocky Mountains and Great Plains region, it was 2.5 ft (0.76 m). These differences reflect mining practices. Geologists familiar with the region estimated coal resources for various assurance, thickness, and overburden categories using a combination of publicly available and confidential data. Uncertainty estimates were calculated using these same drill-hole data, except in the Illinois Basin where only publicly available data were used. Drilling density (number of drill holes per unit area) was higher in surface-mined areas and lower in areas of deeper or unmined coal. Spatial coverage by drill holes varied considerably from zone to zone and region to region. In some zones and regions, data were highly clustered, whereas, in others, drilling patterns were more uniformly distributed. Procedures were implemented in the methodology, especially the estimation of a pseudo sample size, to partially alleviate the influence of preferential sampling.

Methodology

The method used to estimate uncertainty on the remaining volume of coal unit is described in Schuenemeyer and Power (2000) and is reproduced in Appendix B of this report with permission of the publisher. Briefly, the method involves the computation of a semivariogram for each coal unit. A model is then fit to the semivariogram. Standard deviations corresponding to the measured, indicated, inferred, and hypothetical categories are derived from the semivariogram model. For each category, a standard error (a measure of variability of the mean estimate of the coal resource) is computed using the spatial area of the unit and drilling density. Finally, an estimate of uncertainty on coal resources is computed. Isaaks and Srivastava (1989) provide additional details about the semivariogram and spatial modeling.

A step-by-step narrative of the methodology is given here using the Wyodak-Anderson coal zone of the Powder River Basin (PRB). For details of the assessment of the PRB, see the Fort Union Coal Assessment Team (1999) report.

For each coal unit, the uncertainty-estimation procedure began with an investigation of a possible large-scale spatial trend in coal thickness. We estimated this possible trend using a LOWESS (nonparametric) regression model with a span of at least 0.5. When this trend accounted for at least 50 percent of the variability in thickness, residual thicknesses obtained after removing the trend were used in subsequent analyses. The fitted coal thickness for the Wyodak-Anderson coal zone is shown in figure 2. It shows that the coal zone becomes thicker toward the central part of the basin. A residual thickness is an observed thickness minus the estimated value obtained from the regression model at a given drill-hole location. Residual thicknesses no longer include this systematic large-scale trend. Failure to account for large-scale systematic change in thickness can bias estimates of variability by inflating the spatial correlation. In the subsequent methodology discussion, we use the term thickness, but this implies residual thickness when a large-scale trend is present.

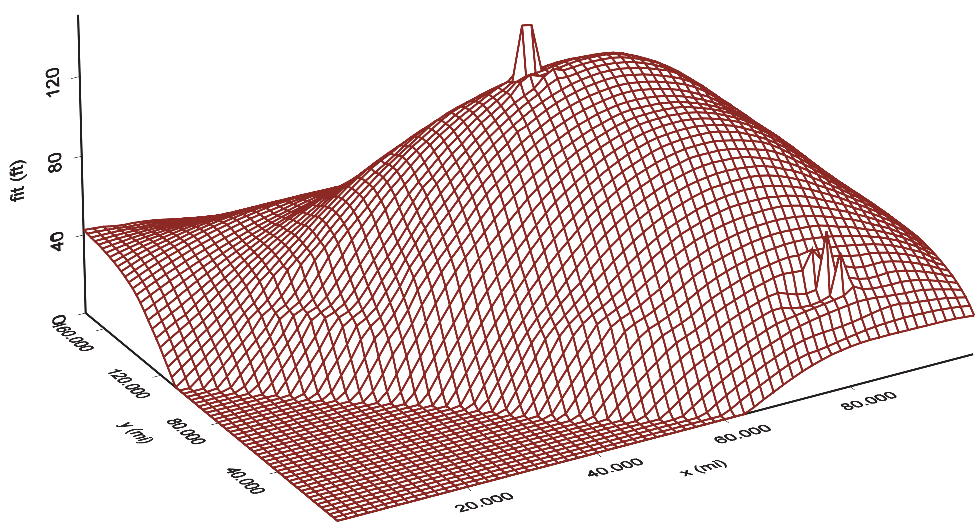

Figure 2. Contour of fitted coal-zone thickness in Wyodak-Anderson coal zone using a LOWESS regression model.

A semivariogram—a measure of spatial variability—was computed on coal thickness. Here we illustrate the semivariogram using the Wyodak-Anderson coal-zone data set (fig. 3). The dots denote the computed semivariogram. The gamma axis (in units of squared feet) is a measure of dissimilarity between all pairs of coal unit thicknesses *h* units (miles or kilometers) apart. Next, a model was fit to the semivariogram. Among models commonly used to fit the semivariogram are the exponential, spherical, Gaussian, linear, and nugget (Isaaks and Srivastava, 1989). For this data set, we judged an exponential model (the solid line) to fit best. Figure 3 shows that pairs of drill holes that are close together are more likely to have similar thicknesses (less dissimilarity) than those farther apart. At $h = 0$, where points (drill holes) are coincident, we expect gamma to be zero, that is, no dissimilarity. However, we see for the exponential model this is not the case, as the exponential curve would intersect the gamma axis at 212.04 ft^2 (19.7 m^2). This value is called the nugget and represents microscale variation. This variation may be due to measurement errors in bed or zone thicknesses of closely spaced drill holes and (or) some spatial variation that cannot be detected due to a lack of closely spaced holes. Clearly, we cannot make direct estimates of variability where data fail to exist.

The range for this example, 2.36 mi (3.80 km), reflects the approximate limit of spatial correlation. Beyond the range, there is little, if any, correlation between pairs of coal thickness observations. The sill reflects the variability in the data at the range exclusive of the nugget effect. In this example, the sill is 529.75 ft^2 (49.22 m^2). The nugget plus sill, in this example 741.79 ft^2 (68.91 m^2), is an estimate of the variance of the thickness data. It is approximately the asymptotic value of the exponential model. For most of the data sets, the range is in the neighborhood of 2 to 4 mi (3.2 to 6.4 km), although there are exceptions. Had there been no spatial correlation, the nugget model would have been appropriate because the nugget model represents an absence of spatial correlation.

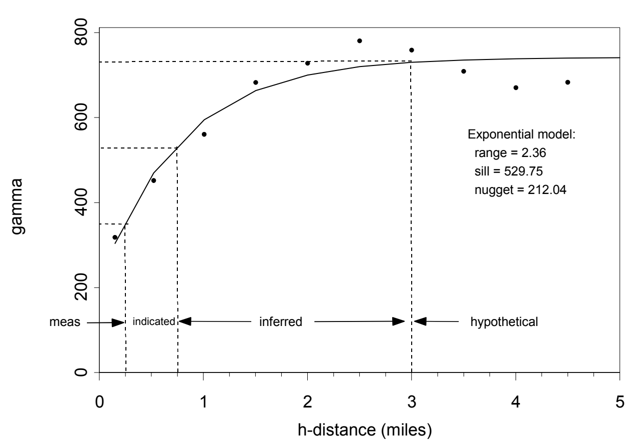

Figure 3. Semivariogram and model for the Wyodak-Anderson coal zone. Vertical dashed lines indicate historical geologic assurance categories; the horizontal axis indicates dissimilarity of zone thicknesses in square feet.

We estimated the variance of coal-unit thicknesses at the upper boundaries (radii of circles) of the resource reporting categories. For most of the regions in this NCRA study, these are 0.25, 0.75, and 3.0 mi (0.40, 1.21, and 4.83 km) corresponding to the measured, indicated, and inferred categories, respectively (the vertical dashed lines in fig. 3). Exceptions will be discussed as appropriate. The estimated variance for the measured category was 356 ft^2 (33.1 m^2), computed from the semivariogram model at 0.25 mi (0.40 km) and is indicated by the lowest horizontal dashed line. Estimates for the indicated and inferred categories were computed in a similar manner.

Details of the computation of uncertainty estimates for the Wyodak-Anderson coal zone are shown in table A-NR14 of Appendix A. The areas of each category (row 2 of table A-NR14) and volume of coal in each category (row 7 of table A-NR14) were furnished by the regional resource assessment teams. The pseudo *n* (labeled n^*, row 8 of table A-NR14) is less than or equal to the number of drill holes in the data set. It was derived to mitigate the effect of preferential sampling and to compensate for the absence of data in the indicated, inferred, and hypothetical categories. We estimate n^* for the measured category by dividing the area of the measured category by the size of a circle of radius 0.25 mi (the definition of this category). Although no data points exist in the other reliability categories, we choose to “estimate” the number of points in the indicated and inferred categories by dividing their areas by areas of circles of 0.75 and 3 mi radius, respectively. For the hypothetical category, we let $n^* = 1$ because this is the most conservative choice that we can make and there is no basis by which to choose a larger n^*. Again, details are given in Schuenemeyer and Power (2000) (Appendix B).

Estimates of uncertainty were made that both excluded and included measurement error. Measurement error refers primarily to errors associated with differences in measuring and (or) reporting identical coal thicknesses. The nugget effect sometimes provides a reasonable estimate of this component of measurement error. However, measurement error may also include errors in estimating zone boundaries and mined areas. Because of the difficulty of isolating the measurement error component, we report only the uncertainty estimates that include measurement error in the main body of this paper. Estimates of measurement error are given for each coal unit in Appendix A. Uncertainty estimates on the volume of coal in each unit are computed at the 90-percent confidence level. Since many of the assumptions associated with this procedure cannot be verified, and some certainly introduce biases, results should be interpreted cautiously. However, we believe that they do provide a basis for making comparisons of the volume of remaining coal within and across zones and beds.

Uncertainty Results

Uncertainty results are presented for assessment units within each of the five regions. For each of the five regions, the first table consists of a data set ID, the assessment unit, its area, and the number of data points. To illustrate, see table x1 where "x" is replaced by the identifier of the region (for example, AB for the Appalachian Basin). Table x2 shows the spatial models and estimated standard deviations for each assessment unit. The following tables present uncertainty estimates on total resources and subcategories of geological assurance. For most assessment units, resources were reported for the measured, indicated, inferred, and hypothetical categories (Wood and others, 1983). In the Colorado Plateau region, results were reported by identified (the volume within 3 mi of a data point) and hypothetical categories due to concerns that data quality would not support more detailed estimates. In the Illinois Basin, the States of Illinois and Indiana reported resources by categories of 0 to 0.5 mi (0 to 0.8 km), 0.5 to 2 mi (0.8 to 3.2 km), and 2 to 4 mi (3.2 to 6.4 km) to be consistent with internal precedence. The base or point estimate of remaining resources in millions of short tons (MST) was estimated by regional assessment geologists and is taken to be an estimate of the mean coal in the unit. The *n** is the pseudo sample size described previously. The percent error (the last column in these tables) is the half-width of the confidence interval divided by the base (MST) times 100. Figures 4 through 7 show the percent error for coal units by region of measured, indicated, inferred, and hypothetical resources, respectively. In Appendix A, we present additional tables that show detailed computations and results for each assessment unit. Estimates prepared by the regional assessment teams include resources subdivided into coal thickness and overburden thickness categories (Wood and others, 1983) in addition to the geological assurance categories. We only estimated uncertainty on coal resources by geological assurance categories. Note that table 1 provides a cross reference between data set IDs within a region, coal unit name, and computational table.

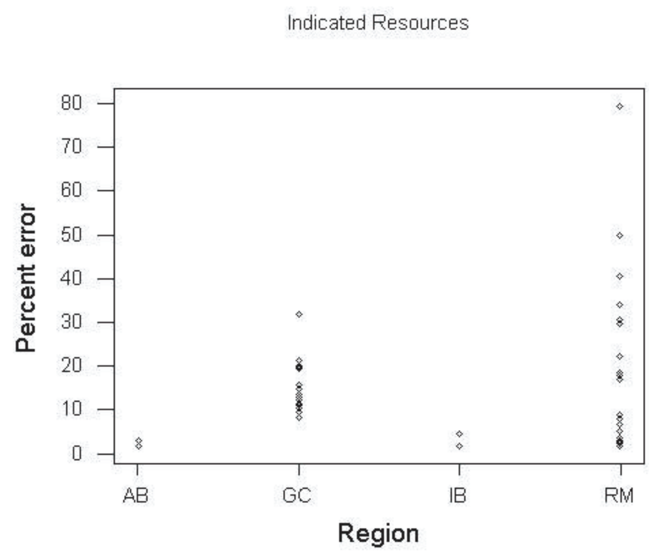

Figure 5. Percent error for indicated resources in the Appalachian Basin (AB), Gulf Coast region (GC), Illinois Basin (IB), and Northern Rocky Mountains and Great Plains region (RM).

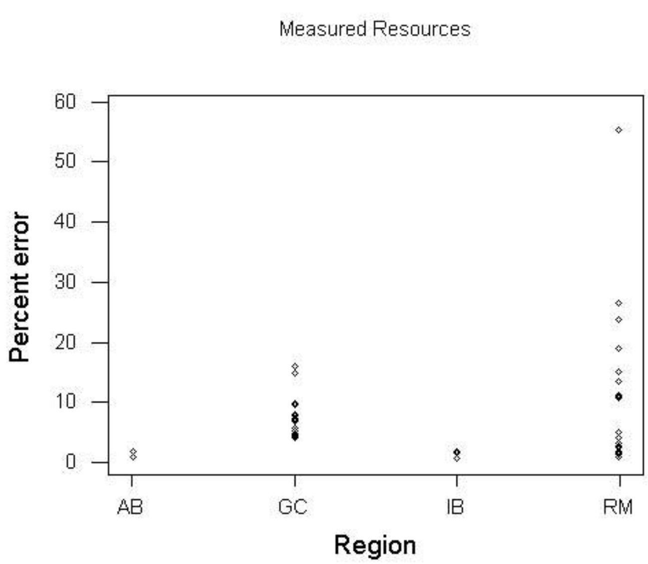

Figure 4. Percent error for measured resources in the Appalachian Basin (AB), Gulf Coast region (GC), Illinois Basin (IB), and Northern Rocky Mountains and Great Plains region (RM).

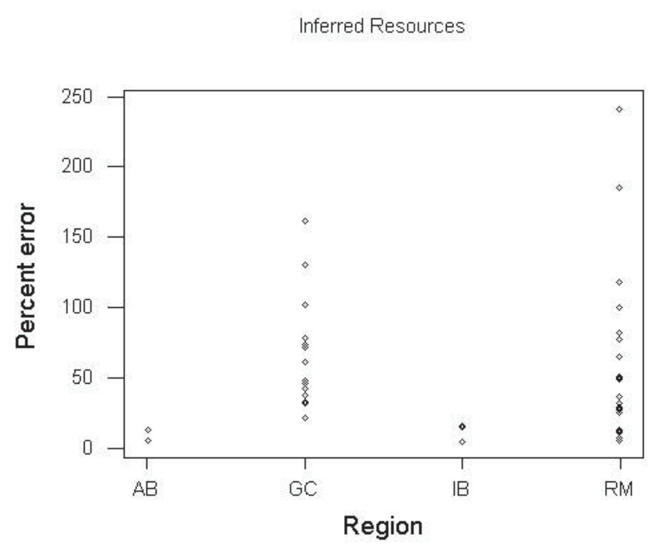

Figure 6. Percent error for inferred resources in the Appalachian Basin (AB), Gulf Coast region (GC), Illinois Basin (IB), and Northern Rocky Mountains and Great Plains region (RM).

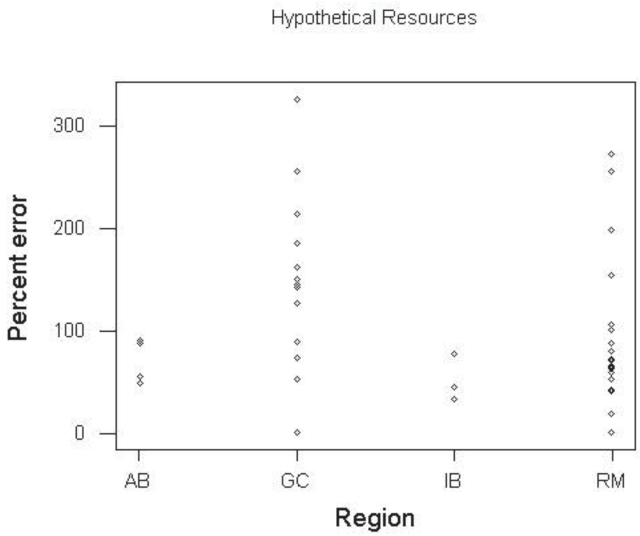

Figure 7. Percent error for hypothetical resources in the Appalachian Basin (AB), Gulf Coast region (GC), Illinois Basin (IB), and Northern Rocky Mountains and Great Plains region (RM).

The confidence intervals for coal units assessed by the categories of measured, indicated, inferred, and hypothetical are given for the Appalachian Basin in figures 8 through 11, for the Gulf Coast region in figures 12 through 15, for the Illinois Basin in figures 16 through 19, and for the Northern Rocky Mountains and Great Plains region in figures 20 through 23. The vertical axis in these figures is in log base e units. The coal units are presented in ascending order by mean volume (indicated by a solid black dot on the figures). The upper 90-percent confidence limit is indicated by a triangle pointing downward and the lower limit by an upward-pointing triangle. The purpose of these figures is to permit a visual comparison of uncertainty intervals across coal units within categories of geological assurance. The numerical results are presented in tables, which will be described in the results for each region.

Appalachian Basin (AB)

Five primary units were assessed in the Northern and Central Appalachian Basins (table AB1). The resource units varied in areal extent from 9,149 mi^2 (23,696 km^2) for the Upper Freeport bed to 1,403 mi^2 (3,634 km^2) for the Pocahontas No. 3 unit. The number of drill holes is generally proportional to areal extent. We summarize the spatial (semivariogram) models in table AB2. All coal beds exhibited some significant spatial correlation except for the Pittsburgh coal bed where the spatial correlation was less than 0.25 mi (0.40 km) so we assigned it a nugget model. For the Upper Freeport, Fire Clay, and Pond Creek beds, only two categories

Table 1. Assessment units by region and data set ID.

[AB, Appalachian Basin; CP, Colorado Plateau region; GC, Gulf Coast region; IB, Illinois Basin; RM, Northern Rocky Mountains and Great Plains region]

Region	Data set ID	Assessment unit	Computation table in Appendix A
AB	FC	Fire Clay zone	A-AB4
AB	PC	Pond Creek zone	A-AB5
AB	PIT	Pittsburgh bed	A-AB1
AB	POC	Pocahontas No. 3	A-AB2
AB	UF	Upper Freeport bed	A-AB3
CP	CAM	S. Piceance—Cameo Wheeler	A-CP11
CP	COALR	S. Piceance—Coal Ridge	A-CP12
CP	DANa	Danforth a	A-CP1
CP	DANb	Danforth b	A-CP2
CP	DANc	Danforth c	A-CP3
CP	DANd	Danforth d	A-CP4
CP	DANe	Danforth e	A-CP5
CP	DANf	Danforth f	A-CP6
CP	DANg	Danforth g	A-CP7
CP	DESb	Deserado b	A-CP8
CP	DESd	Deserado c	A-CP9
CP	FRUT	San Juan—Fruitland	A-CP15
CP	KAI	Kaiparowits	A-CP10
CP	LBLAK	S. Wasatch—Lower Blackhawk	A-CP14
CP	SCANY	S. Piceance—South Canyon	A-CP13
CP	YMPA	Yampa A	A-CP16
CP	YMPB	Yampa B	A-CP17
CP	YMPC	Yampa C	A-CP18
CP	YMPD	Yampa D	A-CP19
GC	cz5	Central Texas zone CZ5	A-GC7
GC	cz6	Central Texas zone CZ6	A-GC8
GC	cz8	Central Texas zone CZ8	A-GC9
GC	cz9	Central Texas zone CZ9	A-GC10
GC	czl4	Central Texas zone CZL4	A-GC11
GC	czl6t	Central Texas zone CZL6	A-GC12
GC	czl8	Central Texas zone CZL8	A-GC13
GC	czm4	Central Texas zone CZM4	A-GC14
GC	czm5	Central Texas zone CZM5	A-GC15
GC	LA	Louisiana Sabine	A-GC16
GC	z1iso	NE. Texas zone 1	A-GC1
GC	z2iso	NE. Texas zone 2	A-GC2
GC	z3iso	NE. Texas zone 3	A-GC3
GC	z4iso	NE. Texas zone 4	A-GC4
GC	z5iso	NE. Texas zone 5	A-GC5
GC	z6iso	NE. Texas zone 6	A-GC6
IB	ILDAN	Danville in Illinois	A-IB1
IB	ILHER	Herrin in Illinois	A-IB2
IB	ILSPR	Springfield in Illinois	A-IB3
IB	INDAN	Danville in Indiana	A-IB4
IB	INSPR	Springfield in Indiana	A-IB5
IB	KYBAK	Baker in Kentucky	A-IB6
IB	KYHER	Herrin in Kentucky	A-IB7

Table 1. Assessment units by region and data set ID—*Continued*.

Region	Data set ID	Assessment unit	Computation table in Appendix A
IB	KYSPR	Springfield in Kentucky	A-IB8
RM	BBJB	Greater Green River, Deadman seams, BlackButte/JimBridger	A-NR2
RM	BZ	Williston, Beulah-Zap	A-NR18
RM	CAR	Carbon, Johnson-107	A-NR1
RM	COL	Powder River, Rosebud-Robinson, Colstrip	A-NR13
RM	F23	Hanna, Ferris23	A-NR3
RM	F25	Hanna, Ferris25	A-NR4
RM	F31	Hanna, Ferris31	A-NR5
RM	F50	Hanna, Ferris50	A-NR6
RM	F65	Hanna, Ferris65	A-NR7
RM	H77	Hanna - 77	A-NR8
RM	H78	Hanna - 78	A-NR9
RM	H79	Hanna - 79	A-NR10
RM	H81	Hanna - 81	A-NR11
RM	HAG	Williston, Hagel	A-NR19
RM	HAN	Williston, Hansen	A-NR20
RM	HAR	Williston, Harmon	A-NR21
RM	KNO1	Powder River, Ashland coal field, Knobloch coal bed	A-NR12
RM	WA	Powder River, Wyodak-Anderson	A-NR14
RM	WAC*	Powder River, Wyodak-Anderson, Decker coal field	A-NR15
RM	WAG*	Powder River, Wyodak-Anderson, Gillette coal field	A-NR16
RM	WAS*	Powder River, Wyodak-Anderson, Sheridan coal field	A-NR17

* Subarea of Wyodak-Anderson coal zone.

of geological assurance, namely identified (3 mi or less) and hypothetical (more than 3 mi), were calculated and reported because, in accordance with USGS methodology, the associated drill-hole data could not be verified; therefore, there was concern about data quality supporting more detailed estimates. The variability for all of these units is quite low, with the greatest variance (sill + nugget) being 1.9 ft^2 for the Pocahontas No. 3 bed. The most striking features of these units, from a statistical viewpoint, are the low and similar variability in coal thickness and the difference in ranges (the extent of spatial correlation). The latter vary from less than 0.25 mi for the Pittsburgh bed to 6.9 mi for the Pond Creek bed.

It is unclear why the Pittsburgh coal bed is the only one to exhibit no significant spatial correlation because it is one of the thickest and most laterally extensive coal beds in the

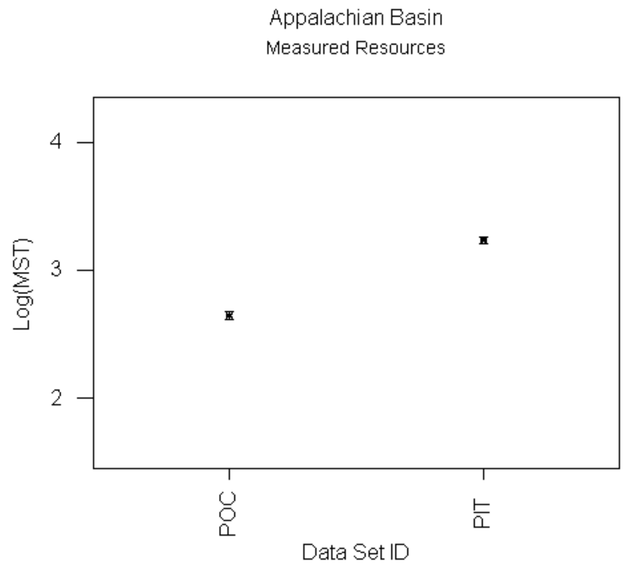

Figure 8. Ninety-percent confidence intervals on measured resources for coal units in the Appalachian Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

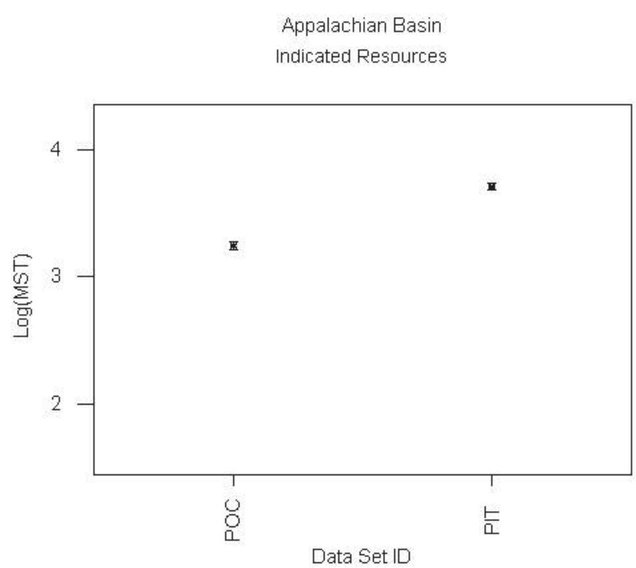

Figure 9. Ninety-percent confidence intervals on indicated resources for coal units in the Appalachian Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

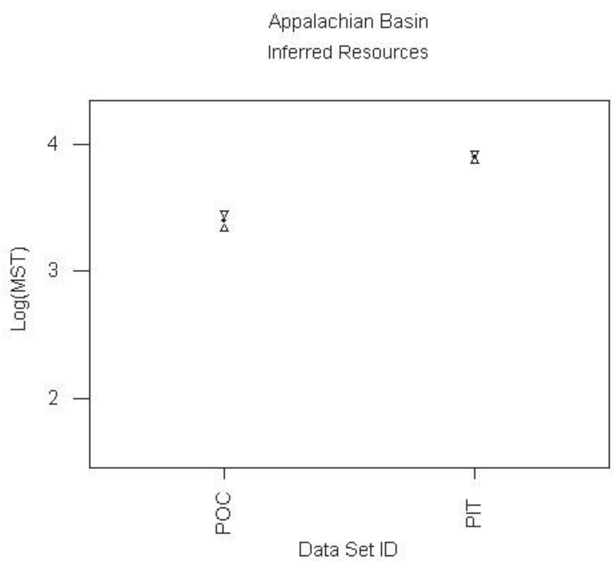

Figure 10. Ninety-percent confidence intervals on inferred resources for coal units in the Appalachian Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

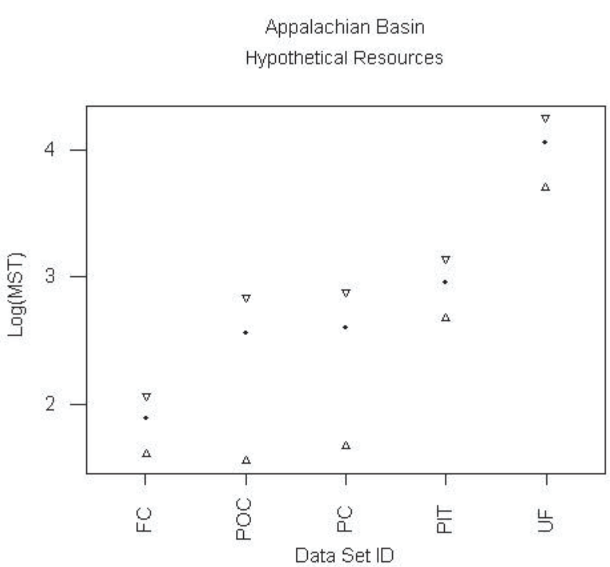

Figure 11. Ninety-percent confidence intervals on hypothetical resources for coal units in the Appalachian Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

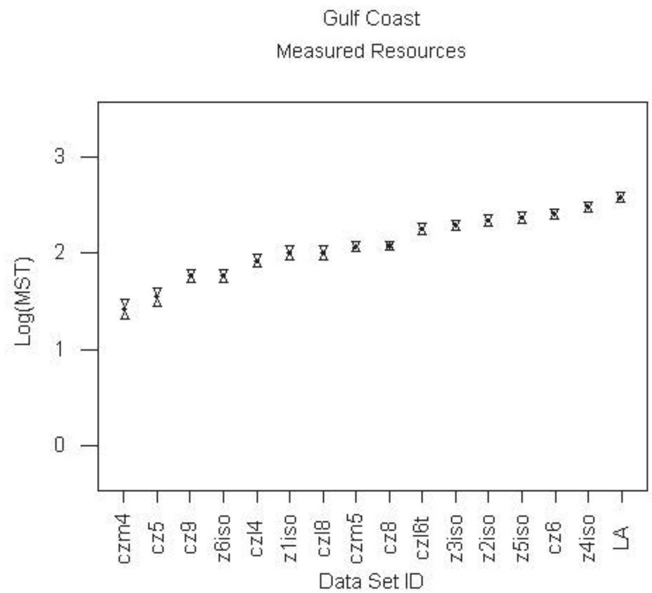

Figure 12. Ninety-percent confidence intervals on measured resources for coal units in the Gulf Coast region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

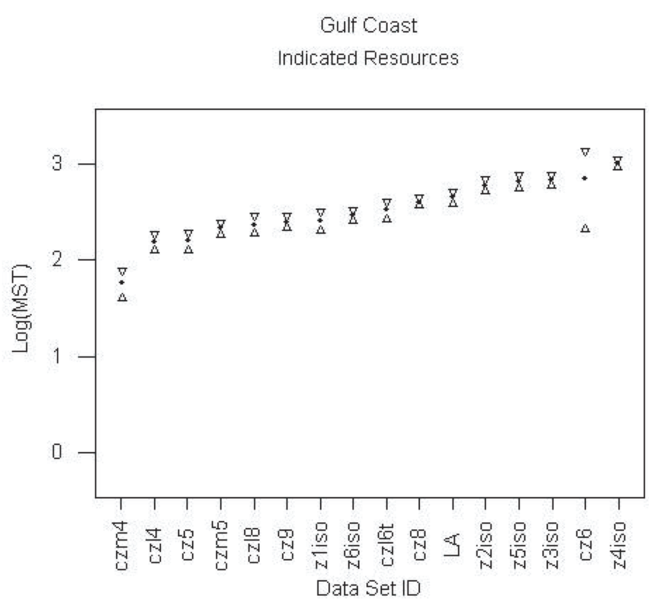

Figure 13. Ninety-percent confidence intervals on indicated resources for coal units in the Gulf Coast region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

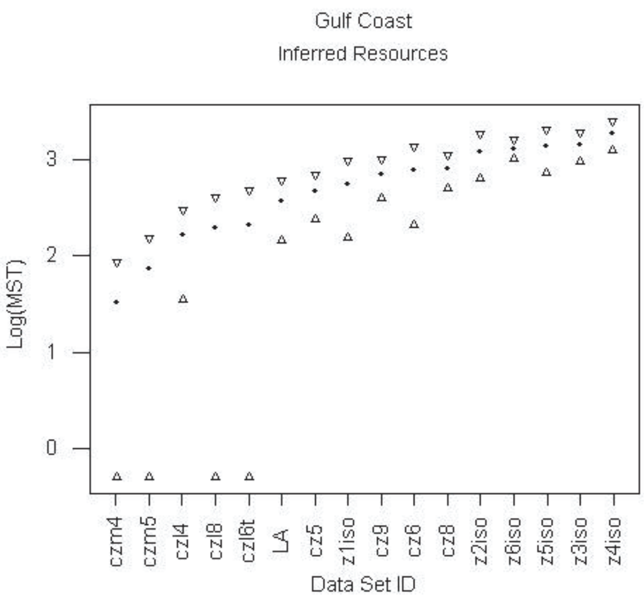

Figure 14. Ninety-percent confidence intervals on inferred resources for coal units in the Gulf Coast region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

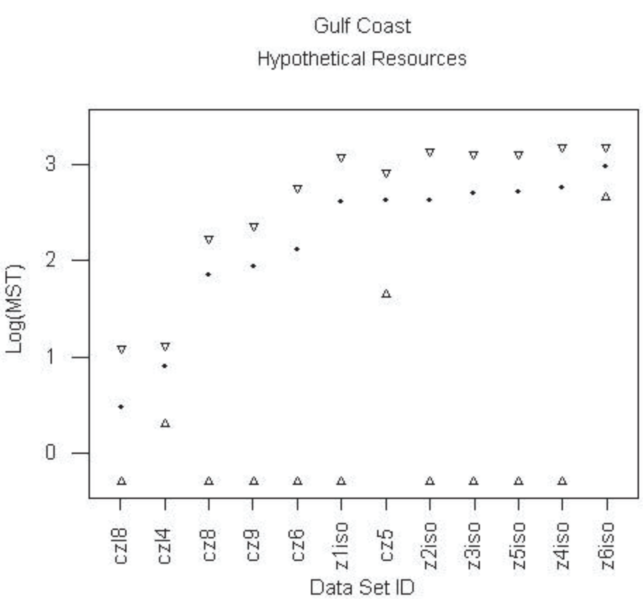

Figure 15. Ninety-percent confidence intervals on hypothetical resources for coal units in the Gulf Coast region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

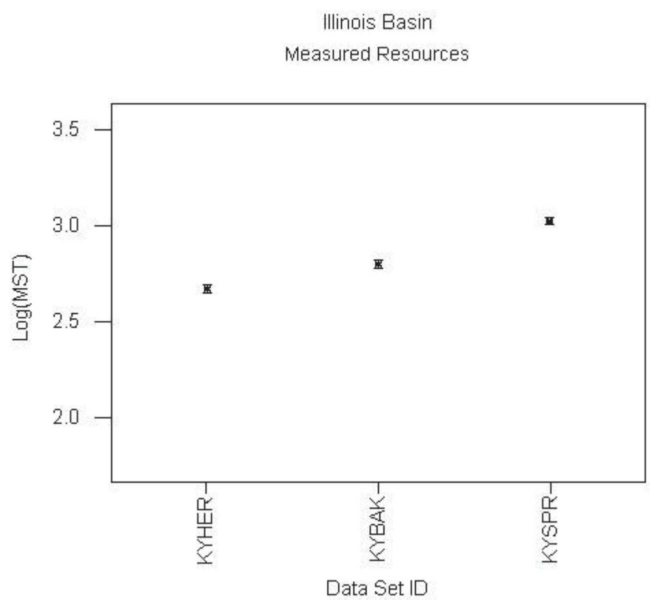

Figure 16. Ninety-percent confidence intervals on measured resources for coal units in the Illinois Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

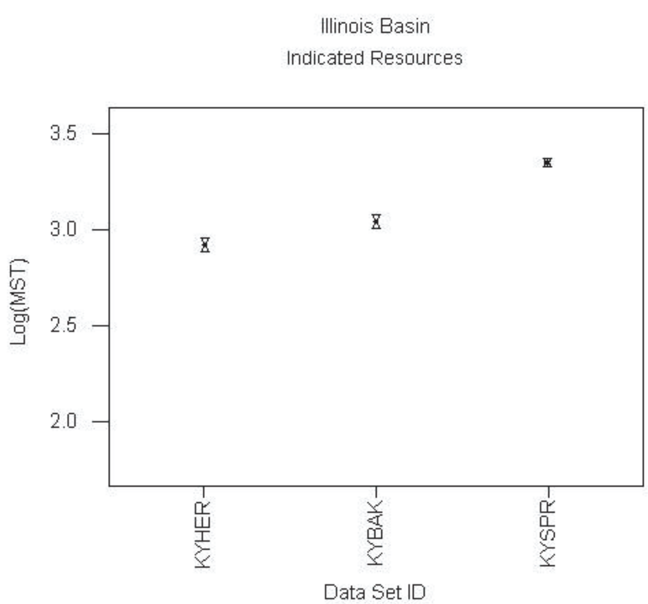

Figure 17. Ninety-percent confidence intervals on indicated resources for coal units in the Illinois Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

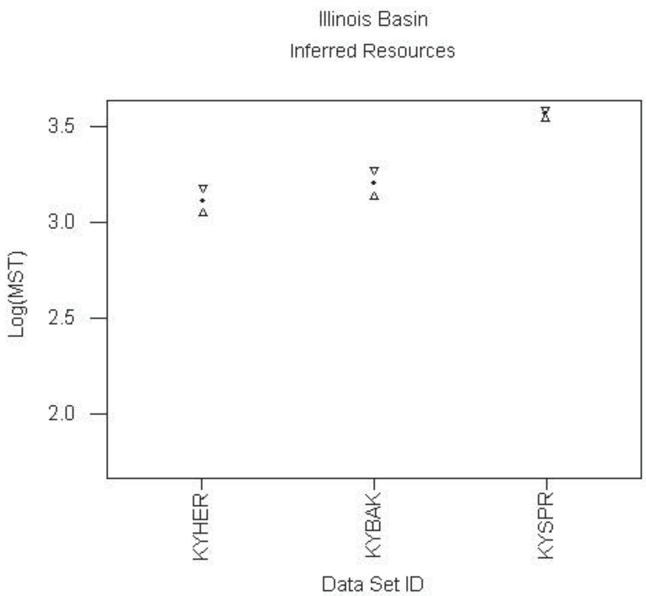

Figure 18. Ninety-percent confidence intervals on inferred resources for coal units in the Illinois Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

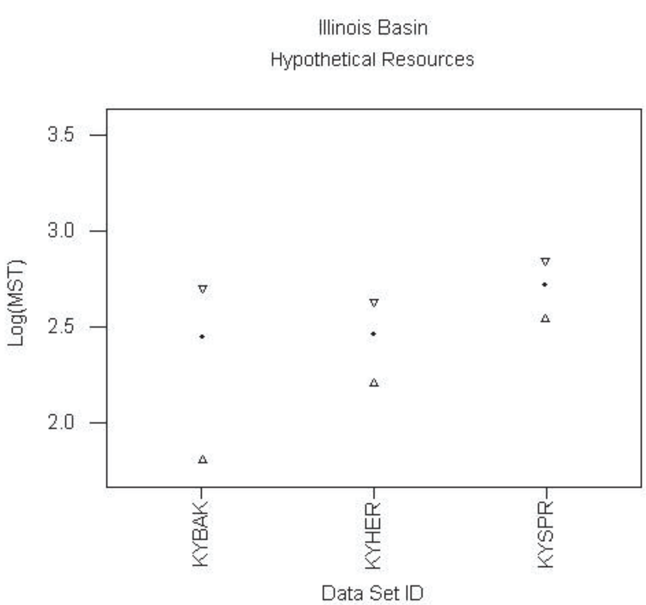

Figure 19. Ninety-percent confidence intervals on hypothetical resources for coal units in the Illinois Basin. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

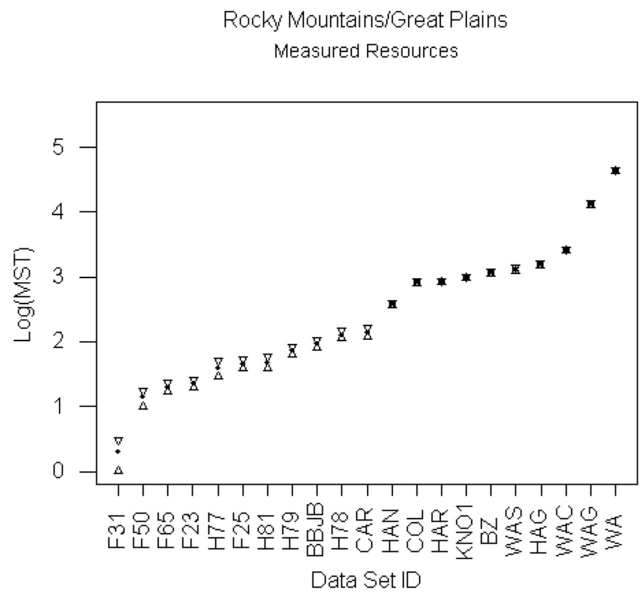

Figure 20. Ninety-percent confidence intervals on measured resources for coal units in the Northern Rocky Mountains and Great Plains region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

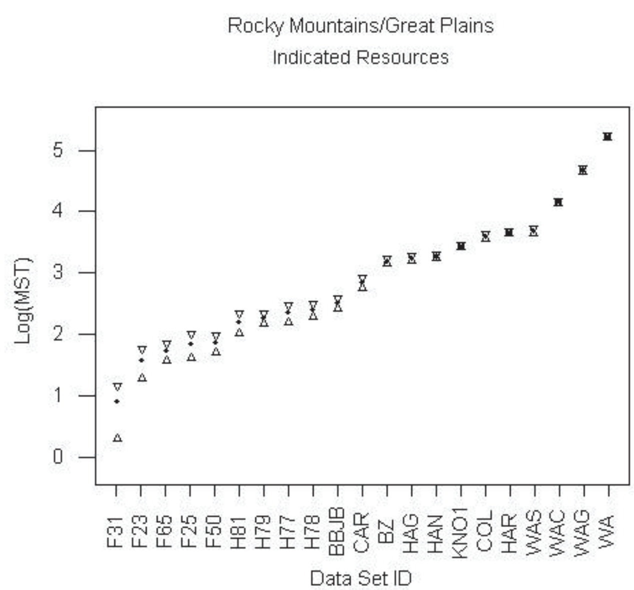

Figure 21. Ninety-percent confidence intervals on indicated resources for coal units in the Northern Rocky Mountains and Great Plains region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

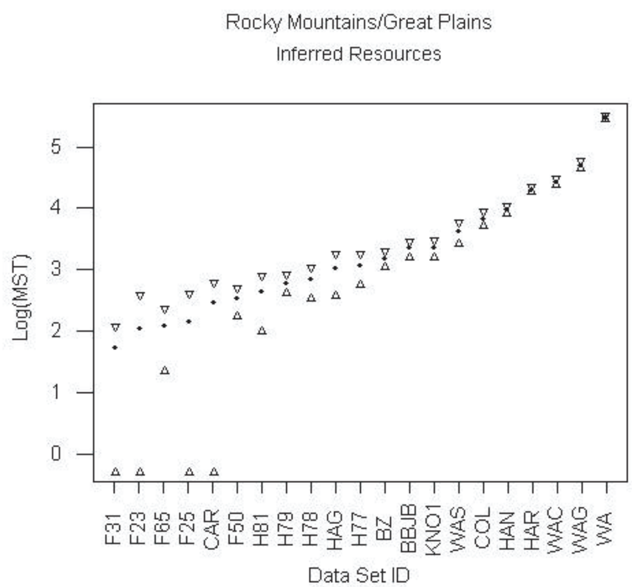

Figure 22. Ninety-percent confidence intervals on inferred resources for coal units in the Northern Rocky Mountains and Great Plains region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

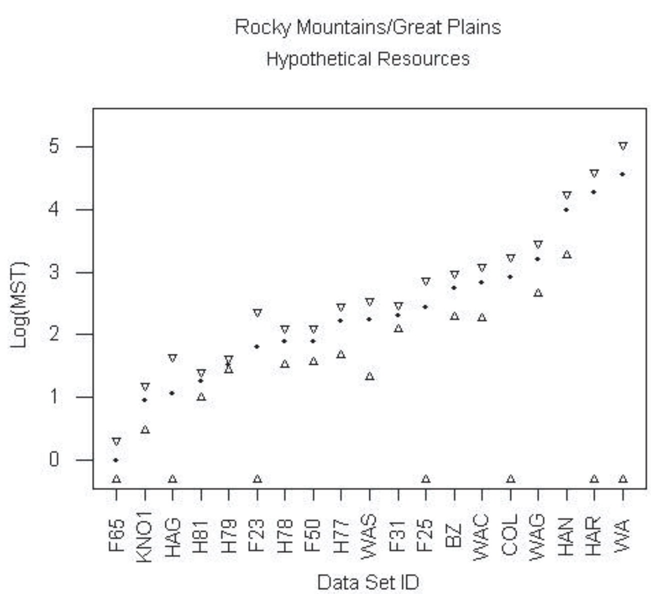

Figure 23. Ninety-percent confidence intervals on hypothetical resources for coal units in the Northern Rocky Mountains and Great Plains region. The lower and upper limits are indicated by upward- and downward-pointing triangles, respectively; Log (MST) is log base 10, millions of short tons.

United States. One of the most distinctive features of the Pittsburgh coal bed is a marked thickening trend from west to east. However, once this thickening feature was removed statistically, only random variation remained. A resource model of the Pittsburgh bed is given in Tewalt, Ruppert, Bragg, Carlton, and others (2000a).

The distribution of the Upper Freeport, Pond Creek, and Fire Clay coal beds contrasts with the areal distribution of the Pittsburgh coal bed by being much more irregular in lateral extent. Yet, these are the beds that show spatial correlations. This actually may be related to the fact that these beds are distributed more irregularly. For example, the minable occurrences of the Upper Freeport coal bed are podlike in nature and separated by large want areas of thin or absent coal (Ruppert and others, 2000). Therefore, in areas of significant spatial correlation, data showing coal occurrence will be concentrated in these thick pods. The stratigraphic database for the Fire Clay coal zone was developed using unique coal identifiers so that the coal benches most likely to be mined were the thickness sources for the resource estimate (Tewalt, Ruppert, Bragg, Weisenfluh, and others, 2000b). Therefore, one would expect a higher degree of spatial correlation than for the other coal beds. It is important to remember that overall variability in coal-bed thickness is quite small so that discontinuities and preferential drilling could magnify effects on spatial correlation.

The 90-percent confidence limits for measured, indicated, and inferred resources for the Pittsburgh and Pocahontas No. 3 beds are given in tables AB3 through AB5. The percent error on the uncertainty estimate (including measurement error) in the measured category for the Pittsburgh bed (table AB3, row PIT), for example, is defined as $\{(1{,}751–1{,}701)/2)/1{,}726\}\times100 = 1.44$, where 1,751, 1,701, and 1,726 are the upper limit, the lower limit, and mean estimates, respectively, in millions of short tons. As expected, the confidence intervals are wider as we move from the measured to the hypothetical category (tables AB3 through AB6) because there are less data and the standard deviation of thickness increases or remains the same. Uncertainty estimates for the units reported as identified resources and total resources for all coal units are given in tables AB7 and AB8, respectively. Detailed computations are given in Appendix A in tables A-AB1 through A-AB5. Percent errors are shown in figures 4 through 7. A graphical comparison of uncertainty intervals is presented in figures 8 through 11.

Colorado Plateau (CP)

Nineteen units were assessed in this region (table CP1). Seven of these units were coal zones in the Danforth Hills coal field, two were at the Deserado mine, four were in the Yampa coal field, one was in the Kaiparowits Plateau, three were in the southern Piceance Basin, one was in the southern Wasatch

Table AB1. Coal units in the Appalachian Basin.

Data set ID	Assessment unit	Area (mi^2)	Sample size, n
PIT	Pittsburgh bed	2,637	4,347
POC	Pocahontas No. 3	1,403	837
UF	Upper Freeport bed	9,149	9,672
FC	Fire Clay zone	1,883	2,292
PC	Pond Creek zone	3,026	3,659

Table AB2. Spatial models and estimated standard deviations for coal units in the Appalachian Basin.

[SD, standard deviation]

Data set	Model	Sill + nugget (ft^2)	Nugget (ft^2)	Range (mi)	Measured SD	Indicated SD	Inferred SD
PIT	Nugget	1.6	1.6	0.0	1.3	1.3	1.3
POC	Spherical	1.9	0.6	5.4	0.9	0.9	1.2
UF	Exponential	0.8	0.4	2.0			0.9
FC	Exponential	0.8	0.2	3.0			0.9
PC	Exponential	1.3	0.5	6.9			1.0

Table AB3. Uncertainty estimates for measured resources for coal units in the Appalachian Basin.

[MST, millions of short tons; n*, pseudo n]

		90 % confidence limits			% error
Data set	Base (MST)	Lower (MST)	Upper (MST)	n*	(measured)
PIT	1,726	1,708	1,744	1,435	1.0
POC	440	433	447	553	1.7

Table AB4. Uncertainty estimates for indicated resources for coal units in the Appalachian Basin.

[MST, millions of short tons; n*, pseudo n]

		90 % confidence limits			% error
Data set	Base (MST)	Lower (MST)	Upper (MST)	n*	(indicated)
PIT	5,122	5,029	5,215	473	1.8
POC	1,755	1,705	1,805	250	2.9

Table AB5. Uncertainty estimates for inferred resources for coal units in the Appalachian Basin.

[MST, millions of short tons; n*, pseudo n]

		90 % confidence limits			% error
Data set	Base (MST)	Lower (MST)	Upper (MST)	n*	(inferred)
PIT	8,063	7,593	8,533	47	5.8
POC	2,541	2,203	2,879	26	13.3

Table AB6. Uncertainty estimates for hypothetical resources for coal units in the Appalachian Basin.

[MST, millions of short tons; *n**, pseudo *n*]

Data set	Base (MST)	90 % confidence limits		*n**	% error
		Lower (MST)	Upper (MST)		(hypothetical)
PIT	923	473	1,372	1	48.7
POC	365	36	694	1	90.3
UF	11,631	5,161	18,100	1	55.6
FC	77	40	114	1	48.2
PC	400	47	753	1	88.3

Table AB7. Uncertainty estimates for identified resources for coal units in the Appalachian Basin.

[MST, millions of short tons; *n**, pseudo *n*]

Data set	Base (MST)	90 % confidence limits		*n**	% error
		Lower (MST)	Upper (MST)		(identified)
UF	19,237	18,574	19,899	190	3.5
FC	4,986	4,597	5,374	66	7.8
PC	8,266	7,704	8,827	101	6.8

Table AB8. Uncertainty estimates for total resources for coal units in the Appalachian Basin.

[MST, millions of short tons]

Data set	Base (MST)	90 % confidence limits		% error
		Lower (MST)	Upper (MST)	(total)
PIT	15,834	14,803	16,864	6.5
POC	5,101	4,376	5,826	14.2
UF	30,867	23,735	37,999	23.1
FC	5,063	4,637	5,488	8.4
PC	8,665	7,751	9,580	10.6

Table CP1. Coal units in the Colorado Plateau region.

Data set ID	Assessment unit	Area (mi^2)	Sample size, *n*
DANa	Danforth a	162	167
DANb	Danforth b	162	205
DANc	Danforth c	143	210
DANd	Danforth d	134	219
DANe	Danforth e	123	301
DANf	Danforth f	96	355
DANg	Danforth g	77	313
DESb	Deserado b	22	202
DESd	Deserado c	22	186
KAI	Kaiparowits	225	193
CAM	S Piceance - Cameo Wheeler	225	618
COALR	S Piceance - Coal Ridge	1,462	220
SCANY	S Piceance - South Canyon	1,472	225
LBLAK	S Wasatch - Lower Blackhawk	323	288
FRUT	San Juan - Fruitland	6,218	733
YMPA	Yampa A	595	94
YMPB	Yampa B	311	114
YMPC	Yampa C	372	111
YMPD	Yampa D	408	30

Plateau, and one was in the San Juan Basin. The resource units varied in areal extent from 6,218 mi^2 (16,105 km^2) for the Fruitland zone in the San Juan basin to 22 mi^2 (56.98 km^2) for the Deserado b and d zones (Brownfield and others, 1998). Uncertainty estimates were not made on the Cameo-Fairfield zone because it only contained 13 data points. We summarize the spatial (semivariogram) models in table CP2. Thirteen data sets (see column 2, table CP2) exhibited significant spatial correlation and were fit with exponential and spherical semivariogram models. Only two categories of geological assurance, namely, identified (3 mi or less) and hypothetical (more than 3 mi), were calculated and reported for coal units in the Colorado Plateau. The range of variability among these units is quite high even within a given basin. The ranges of spatial association also are quite large. The large nugget effect, 176.3 ft^2 (16.4 m^2) for the Kaiparowits Plateau, may be due to additive effects associated with measurement error on bed thickness. By additive effects, we mean that the total variance in a coal zone can be attributed to the sum of the variances of individual beds. The number of beds per data point ranged from 1 to 30, with the median number of beds per hole in the Kaiparowits Plateau being 16. The corresponding large sill, 409.8 ft^2 (38.1 m^2), may be due to the highly varying number of beds.

In the southern Piceance Basin, three coal zones were assessed, and only the lowermost coal zone (CAM) exhibited a spatial correlation; the other two zones were assigned a nugget model (table CP2). This may in part be due to the sample size and distribution of data points available for use in the resource assessment and in part due to the lateral continuity of the coal beds. In the lowermost coal zone, 618 samples were used in the study for an area of 225 mi^2 (583 km^2), whereas the middle coal zone used only 220 samples in an area of 1,462 mi^2 (3,787 km^2) and the lowermost zone used 225 samples in an area of 1,472 mi^2 (3,812 km^2) (Hettinger and others, 2000). In addition, the coal beds of the uppermost coal zone are less continuous than those in the underlying two coal zones, and the coal beds in the middle coal zone are less continuous than those of the lowermost coal zone (Hettinger and others, 2000).

In the Yampa coal field, four coal zones were assessed; only the lowermost zone (YMPA, table CP2) exhibited a spatial relationship, and the other three were assigned a nugget model. These results may be related to the geology of the coal within the four zones. Within all of the coal zones in the Yampa coal field, the number of coal beds and net coal thickness increase to the west (Johnson and others, 2000). However, these trends are significantly more pronounced in the upper three zones as compared to the lowermost zone (Johnson and others, 2000). In addition, coals of the lowermost coal zone are found throughout the coal field, whereas coals in the middle two zones are found only in the central and western portions of the coal field (where the number of beds and net coal thickness significantly increases). There are only three coal beds in the eastern portion of the lowermost coal zone, and they maintain their thickness laterally throughout this portion of the coal field (Johnson and others, 2000), perhaps accounting for the spatial relationships found in the statistical analysis.

The 90-percent confidence limits for identified, hypothetical, and total resources for the Colorado Plateau units are given in tables CP3 through CP5. The percent error on the uncertainty estimate (including measurement

Table CP2. Spatial models and estimated standard deviations for coal units in the Colorado Plateau.

[SD, standard deviation]

Data set ID	Model	Sill + nugget (ft^2)	Nugget (ft^2)	Range (mi)	Identified SD	Hypothetical SD
DANa	Exponential	14.9	2.4	2.9	3.8	3.9
DANb	Exponential	60.4	8.7	5.4	7.1	7.8
DANc	Spherical	29.8	1.9	1.3	5.5	5.5
DANd	Spherical	21.2	10.0	1.7	4.6	4.6
DANe	Spherical	159.9	6.0	1.2	12.6	12.6
DANf	Spherical	77.1	44.2	3.6	8.7	8.8
DANg	Exponential	31.7	10.1	8.5	4.9	5.6
DESb	Spherical	11.7	2.6	1.0	3.4	None
DESd	Exponential	4.3	1.9	4.6	2.0	None
KAI	Exponential	586.1	176.3	12.9	19.6	24.2
CAM	Exponential	114.2	34.5	4.6	8.5	10.7
COALR	Nugget	65.8	65.8	0.0	8.1	8.1
SCANY	Nugget	59.0	59.0	0.0	7.7	7.7
LBLAK	Exponential	94.2	16.9	74.1	5.1	9.7
FRUT	Nugget	140.2	140.2	0.0	11.8	11.8
YMPA	Exponential	167.8	42.5	4.5	12.3	13.0
YMPB	Nugget	74.1	74.1	0.0	8.6	8.6
YMPC	Nugget	30.3	30.3	0.0	5.5	5.5
YMPD	Nugget	213.7	213.7	0.0	14.6	14.6

Table CP3. Uncertainty estimates for identified resources for coal units in the Colorado Plateau.

[MST, millions of short tons; n^*, pseudo n]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error (identified)
		Lower (MST)	Upper (MST)		
DANa	1,997	1,561	2,433	5	22.0
DANb	4,209	3,365	5,053	5	20.0
DANc	3,001	2,393	3,609	5	20.0
DANd	1,814	1,315	2,313	4	28.0
DANe	4,650	3,338	5,962	4	28.0
DANf	2,099	1,318	2,880	3	37.0
DANg	611	250	972	2	59.0
DESb	217	60	374	1	72.4
DESd	149	58	240	1	61.0
KAI	47,148	41,834	52,462	26	11.3
CAM	141,017	136,200	145,834	111	3.4
COALR	14,096	11,287	16,905	42	19.9
SCANY	24,748	22,094	27,402	42	10.7
LBLAK	4,231	3,449	5,013	8	18.5
FRUT	214,553	204,584	224,522	200	4.7
YMPA	21,483	19,276	23,690	11	10.3
YMPB	5,066	3,940	6,192	6	22.2
YMPC	1,893	1,164	2,622	6	38.5
YMPD	6,851	4,836	8,866	7	29.4

Table CP4. Uncertainty estimates for hypothetical resources for coal units in the Colorado Plateau.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits Lower (MST)	Upper (MST)	*n**	% error (hypothetical)
DANa	359	180	538	1	50.0
DANb	483	238	728	1	51.0
DANc	378	227	529	1	40.0
DANd	134	28	240	1	79.0
DANe	577	298	856	1	48.0
DANf	520	312	728	1	40.0
DANg	71	0	295	1	315.0
DESb	0				
DESd	0				
KAI	15,114	4,818	25,410	1	68.0
CAM	31,384	17,033	45,735	1	46.0
COALR	2,537	0	6,842	1	170.0
SCANY	4,690	393	8,987	1	92.0
LBLAK	2,541	899	4,183	1	65.0
FRUT	13,954	0	27,993	1	101.0
YMPA	20,623	13,811	27,435	1	33.0
YMPB	7,657	5,331	9,983	1	30.0
YMPC	1,847	0	3,929	1	113.0
YMPD	10,593	4,471	16,715	1	58.0

Table CP5. Uncertainty estimates for total resources for coal units in the Colorado Plateau.

[MST, millions of short tons]

Data set ID	Base (MST)	90 % confidence limits Lower (MST)	Upper (MST)	% error (total)
DANa	2,356	1,741	2,971	26.0
DANb	4,692	3,603	5,781	23.0
DANc	3,379	2,620	4,138	22.0
DANd	1,948	1,343	2,553	31.0
DANe	5,227	3,636	6,818	30.0
DANf	2,619	1,630	3,608	38.0
DANg	682	98	1,266	86.0
DESb	217	60	374	72.4
DESd	149	58	240	61.0
KAI	62,262	46,652	77,872	25.0
CAM	172,401	153,233	191,569	11.0
COALR	16,633	9,519	23,747	43.0
SCANY	29,438	22,487	36,389	24.0
LBLAK	6,772	4,348	9,196	36.0
FRUT	228,507	204,499	252,515	11.0
YMPA	42,106	33,087	51,125	21.0
YMPB	12,723	9,271	16,175	27.0
YMPC	3,740	928	6,552	75.0
YMPD	17,444	9,307	25,581	47.0

error) in the measured category for the Fruitland (table CP3, row FRUT), for example, is defined as {(224,522–204,584)/2)/214,553}×100 = 4.65, where 224,522, 204,584, and 214,553 are the upper limit, the lower limit, and mean estimates, respectively, in millions of short tons. As expected, the confidence intervals are wider in the hypothetical category (table CP4). Uncertainty estimates for the total resources are given in table CP5. Detailed computations are given in Appendix A in tables A-CP1 through A-CP19.

Gulf Coast (GC)

Sixteen units were assessed in this region (table GC1). Nine of these units were coal zones in central Texas, six were coal zones in northeast Texas, and one coal zone was in Louisiana. The resource units varied in areal extent from 920 mi^2 (2,383 km^2) for the Northeast Texas zone 1 to 29 mi^2 (75 km^2) for the Central Texas m4 zone. We summarize the spatial (semivariogram) models in table GC2. Eleven units (see column 2, table GC2) exhibited significant spatial correlation and were fit with exponential and spherical semivariogram models. With the exception of Central Texas zone 9, the range of variability among these units is consistent with that of other Western United States coals, namely from 1 to 7 mi (1.6 to 11.3 km). The largest variance (sill + nugget) is 25.2 ft^2 (65.3 km^2) for the Central Texas zone 6. The median variance for all 16 units is approximately 9.2 ft^2 (23.8 km^2).

Most of the assessed units in the Gulf Coast region probably exhibited spatial correlation because of the distribution of data points. Relatively little data are available in the Gulf Coast, as compared to other regions in the United States. Coal data are concentrated in areas of current mining activity in the Gulf Coast and occur as clusters of data points. Therefore, where data are available, significant spatial correlation exists.

The 90-percent confidence limits for measured, indicated, inferred, hypothetical, and total resources for the Gulf Coast units are given in tables GC3 through GC7. No hypothetical resources were reported in Central Texas zones l6t, m4, and m5. Detailed computations are given in Appendix A in tables A-GC1 through A-GC16. Percent errors are shown in figures 4 through 7. A graphical comparison of uncertainty intervals is presented in figures 12 through 15.

Illinois Basin (IB)

Four primary units were assessed in the Illinois Basin (table IB1). These units consisted of the Baker, the Danville, the Herrin, and the Springfield coal beds. The Baker coal bed is located entirely in Kentucky, whereas the other coal beds cross State boundaries; however, within-State resource estimates were computed by each of the State geological surveys and so are reported by State. The basic State resource estimates were computed using available public and confidential data, but uncertainty estimates were computed using only the publicly available data. Different categories of geological assurance were used. Because of their long years of experience, thorough knowledge of the coal beds, and the lateral continuity of the coal-bed thickness, geologists from Illinois and Indiana feel confident about extending their distances with greater degrees of assurance. Therefore, Illinois and Indiana reported resources in three categories of geological assurance called I-A (0 to 0.5 mi; 0 to 0.8 km), I-B

Table GC1. Coal units in the Gulf Coast region.

Data set ID	Assessment unit	Area (mi^2)	Sample size, *n*
z1iso	NE TX Zone 1	352	147
z2iso	NE TX Zone 2	648	381
z3iso	NE TX Zone 3	748	454
z4iso	NE TX Zone 4	885	685
z5iso	NE TX Zone 5	659	638
z6iso	NE TX Zone 6	517	289
cz5	Central TX Zone CZ5	269	124
cz6	Central TX Zone CZ6	348	357
cz8	Central TX Zone CZ8	387	308
cz9	Central TX Zone CZ9	338	207
czl4	Central TX Zone CZL4	102	463
czl6t	Central TX Zone CZL6	130	798
czl8	Central TX Zone CZL8	91	237
czm4	Central TX Zone CZM4	29	96
czm5	Central TX Zone CZM5	39	135
LA	Louisiana Sabine	237	940

Table GC2. Spatial models and estimated standard deviations for coal units in the Gulf Coast.

[SD, standard deviation]

Data set	Model	Sill + nugget (ft^2)	Nugget (ft^2)	Range (mi)	Measured SD	Indicated SD	Inferred SD	Hypothetical SD
z1iso	Exponential	11.9	6.6	3.9	2.7	3.0	3.4	3.4
z2iso	Exponential	12.6	6.8	4.2	2.8	3.0	3.4	3.5
z3iso	Exponential	6.3	1.5	1.2	1.9	2.4	2.5	2.5
z4iso	Gaussian	10.7	4.7	5.2	2.2	2.2	2.9	3.3
z5iso	Exponential	13.6	6.0	2.5	2.8	3.2	3.7	3.7
z6iso	Nugget	3.2	3.2	0.0	1.8	1.8	1.8	1.8
cz5	Nugget	4.4	4.4	0.0	2.1	2.1	2.1	2.1
cz6	Exponential	25.2	5.2	6.7	2.7	3.3	4.5	5.0
cz8	Exponential	4.5	0.5	3.5	1.1	1.5	2.0	2.1
cz9	Exponential	7.9	1.6	16.5	1.4	1.5	2.1	2.8
czl4	Spherical	4.3	2.5	0.8	1.8	2.1	2.1	2.1
czl6t	Exponential	20.6	7.1	5.1	3.0	3.5	4.3	0.0
czl8	Nugget	10.6	10.6	0.0	3.2	3.2	3.2	3.2
czm4	Nugget	3.9	3.9	0.0	2.0	2.0	2.0	0.0
czm5	Exponential	11.4	5.0	6.9	2.4	2.6	3.1	0.0
LA	Nugget	7.0	7.0	0.0	2.6	2.6	2.6	2.6

Table GC3. Uncertainty estimates for measured resources for coal units in the Gulf Coast.

[MST, millions of short tons; n*, pseudo n]

Data set	Base (MST)	90 % confidence limits		n*	% error
		Lower (MST)	Upper (MST)		(measured)
z1iso	102	92	112	101	9.8
z2iso	221	206	236	220	6.8
z3iso	197	187	208	226	5.3
z4iso	303	289	317	312	4.6
z5iso	235	219	252	275	7.2
z6iso	59	53	64	75	9.5
cz5	35	30	40	46	14.8
cz6	260	247	272	163	4.8
cz8	119	114	123	144	4.1
cz9	58	54	63	84	7.8
czl4	83	77	90	104	8.0
czl6t	177	165	190	135	7.1
czl8	102	92	112	71	9.8
czm4	26	22	31	35	16.0
czm5	117	110	123	56	5.6
LA	383	367	399	291	4.3

Table GC4. Uncertainty estimates for indicated resources for coal units in the Gulf Coast.

[MST, millions of short tons; *n**, pseudo *n*]

Data set	Base (MST)	90 % confidence limits Lower (MST)	90 % confidence limits Upper (MST)	*n**	% error (indicated)
z1iso	261	205	316	33	21.4
z2iso	614	524	704	83	14.6
z3iso	689	614	764	95	10.9
z4iso	1,030	947	1,114	131	8.1
z5iso	661	558	764	95	15.6
z6iso	297	260	333	40	12.3
cz5	160	128	192	22	20.0
cz6	708	628	788	55	11.3
cz8	410	372	448	58	9.3
cz9	255	223	288	42	12.8
czl4	157	126	188	21	19.6
czl6t	339	273	405	34	19.4
czl8	239	191	286	20	19.9
czm4	58	40	77	8	31.8
czm5	217	188	247	12	13.6
LA	615	550	680	57	10.5

Table GC5. Uncertainty estimates for inferred resources for coal units in the Gulf Coast.

[MST, millions of short tons; *n**, pseudo *n*]

Data set	Base (MST)	90 % confidence limits Lower (MST)	90 % confidence limits Upper (MST)	*n**	% error (inferred)
z1iso	564	157	971	5	72.2
z2iso	1,248	648	1,848	11	48.1
z3iso	1,454	976	1,932	13	32.9
z4iso	1,880	1,277	2,483	16	32.1
z5iso	1,393	744	2,042	12	46.6
z6iso	1,337	1,049	1,625	10	21.6
cz5	475	247	702	4	47.9
cz6	787	211	1,363	6	73.2
cz8	810	506	1,115	8	37.6
cz9	707	408	1,005	8	42.2
czl4	169	36	301	2	78.4
czl6t	210	0	485	2	130.3
czl8	196	0	397	1	102.0
czm4	33	0	86	<1	162.2
czm5	75	0	151	<1	102.5
LA	378	146	610	3	61.4

Table GC6. Uncertainty estimates for hypothetical resources for coal units in the Gulf Coast.

[MST, millions of short tons; *n**, pseudo *n*]

Data set	Base (MST)	90 % confidence limits Lower (MST)	Upper (MST)	*n**	% error (hypothetical)
z1iso	419	0	1,195	1	185.4
z2iso	434	0	1,363	1	214.3
z3iso	512	0	1,258	1	145.6
z4iso	593	0	1,486	1	150.4
z5iso	525	0	1,271	1	142.0
z6iso	980	467	1,493	1	52.3
cz5	427	45	809	1	89.4
cz6	132	0	563	1	327.0
cz8	73	0	165	1	127.3
cz9	88	0	229	1	161.9
czl4	8	2	13	1	74.0
czl6t	0	0	0	0	0.0
czl8	3	0	12	1	256.6
czm4	0	0	0	0	0.0
czm5	0	0	0	0	0.0
LA	0	0	0	0	0.0

Table GC7. Uncertainty estimates for total resources for coal units in the Gulf Coast.

[MST, millions of short tons]

Data set	Base (MST)	90 % confidence limits Lower (MST)	Upper (MST)	% error (total)
z1iso	1,345	96	2,594	92.9
z2iso	2,516	882	4,150	65.0
z3iso	2,853	1,544	4,162	45.9
z4iso	3,807	2,214	5,400	41.9
z5iso	2,815	1,299	4,330	53.8
z6iso	2,672	1,829	3,515	31.5
cz5	1,097	450	1,743	58.9
cz6	1,886	787	2,986	58.3
cz8	1,411	971	1,851	31.2
cz9	1,108	631	1,586	43.1
czl4	417	241	592	42.0
czl6t	727	374	1,080	48.5
czl8	540	274	807	49.3
czm4	118	42	193	64.6
czm5	409	296	521	27.5
LA	1,376	1,063	1,689	22.8

Table IB1. Coal units in the Illinois Basin.

Data set ID	Assessment unit	Area (mi^2)	Sample size, *n* (public data)
ILDAN	Danville in IL	4,722	6,465
ILHER	Herrin in IL	14,046	16,325
ILSPR	Springfield in IL	13,221	10,630
INDAN	Danville in IN	2,084	3,088
INSPR	Springfield in IN	2,820	4,842
KYBAK	Baker in KY	1,145	601
KYHER	Herrin in KY	853	650
KYSPR	Springfield in KY	1,903	984

(>0.5 to 2 mi; >0.8 to 3.2 km), and II-A (>2 to 4 mi; >3.2 to 6.4 km). Kentucky used the four standard USGS categories.

The resource units varied in areal extent from 14,046 mi^2 (36,379 km^2) for the Herrin bed in Illinois to 853 mi^2 (2,209 km^2) for the Herrin bed in Kentucky. The number of drill holes is generally proportional to areal extent. We summarize the spatial (semivariogram) models in table IB2. All coal beds exhibited significant spatial correlation except for the Danville bed in Illinois. The variances (sill + nugget) of the coal-bed thicknesses were low. None exceeded 1.6 ft^2 (0.15 m^2) except for the variance of the Illinois Herrin coal bed at 4.2 ft^2 (0.39 m^2), which exhibited significantly more variability than the other beds. In addition, the range of spatial association in this bed is almost 84 miles (135 km), which is much larger than for the other beds. The range for the Springfield bed in Kentucky is also quite large (table IB2).

We do not know exactly why these two beds exhibit such unusually large ranges. One of the distinguishing characteristics of all of the assessed coal beds in the Illinois Basin is their remarkable lateral continuity and consistent thickness over their extent. There are local exceptions to this, however, especially in the Herrin and Springfield coal beds in areas of eastern and southeastern Illinois (Colin Treworgy, Illinois State Geological Survey, written commun., 1999) in areas where the Walshville channel is present. In areas adjacent to this channel, the variability in thickness is sudden and substantial. Almost all of the coal beds in the basin exhibited spatial correlation probably because of the lack of lateral variability of these coal beds. However, the much larger ranges exhibited by the Herrin in Illinois and the Springfield in Kentucky might be due to the fact that the thickness, when variable, is quite marked.

The 90-percent confidence limits for I-A, I-B, and II-A resources for the Illinois and Indiana beds are given in tables IB3 through IB5. Because the variability in coal-bed thicknesses is quite low, estimates of uncertainty are also low. Estimates of uncertainty for the beds located in Kentucky are given in tables IB6 through IB9, and estimates for total resources are given in table IB10. Appendix A contains detailed computations for individual beds in tables A-IB1 through A-IB8. Percent errors are shown in figures 4 through 7. A graphical comparison of uncertainty intervals is presented in figures 16 through 19.

Northern Rocky Mountains and Great Plains (NR)

Eighteen primary units were assessed in this region, plus three subregions of the Wyodak-Anderson coal zone, namely the Decker, the Gillette, and the Sheridan coal fields (table NR1). The resource units varied in areal extent from 8,460 mi^2 (21,911 km^2) for the Wyodak-Anderson to 23 mi^2 (60 km^2) for the Carbon Basin (table NR1). The number of drill holes (the column labeled sample size, *n*) is generally proportional to the areal size. An exception is the greater Green River Basin where the data came almost exclusively from coal mines. The Fort Union Coal Assessment Team (1999) discusses the geology and resource estimates of this region in detail. We summarize the spatial (semivariogram) models in table NR2. Some of the smaller units, most notably beds in the Hanna Basin, have been assigned a nugget model indicating there is minimal spatial correlation in coal thicknesses in these units. Spatial correlation does exist for resource units in the Williston and Powder River Basins.

These statistical trends—spatial correlations for Williston and Powder River Basin coal zones and no spatial correlation for the Hanna Basin coals—are most likely related to the geology of the coal-bearing units. In all three of these basins, the original environment of formation controlled the physical variations in the resulting strata. In the Williston Basin in the upper part of the Fort Union (that part that contains the coal beds), the peat mires developed in fluvial and deltaic environments (Flores and Keighin, 1999). These environments allowed for relatively thick (as much as 40 ft; 12.2 m) coals to form. Although these coal beds split and merge, they do so over relatively long distances. Similarly, the coal beds within the coal zones of the Powder River Basin (the Wyodak-Anderson consisting of 1 to 11 beds, the Knobloch consisting of 1 to 4 coal beds, and the Rosebud-Robinson, consisting of 1 to 3 beds) have complex lateral relationships, splitting and merging over long distances. Coal zones in this basin are very thick where coal beds merge, forming beds greater than 200 ft

Table IB2. Spatial models for coal units in the Illinois Basin.

Data set ID	Model	Sill + nugget (ft^2)	Nugget (ft^2)	Range (mi)
ILDAN	Nugget	0.2	0.2	0.0
ILHER	Exponential	4.2	1.2	83.7
ILSPR	Exponential	1.5	0.6	11.5
INDAN	Exponential	0.7	0.3	8.9
INSPR	Exponential	1.6	0.7	1.9
KYBAK	Exponential	1.2	0.1	0.9
KYHER	Exponential	1.0	0.5	2.4
KYSPR	Exponential	0.7	0.3	31.0

Table IB3. Uncertainty estimates for I-A resources for coal units in the Illinois Basin.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(I-A)
ILDAN	1,851	1,814	1,888	505	2.0
ILHER	19,193	19,093	19,293	3,479	0.5
ILSPR	6,004	5,956	6,053	1,403	0.8
INDAN	3,316	3,282	3,351	1,407	1.1
INSPR	6,679	6,605	6,752	2,051	1.1

Table IB4. Uncertainty estimates for I-B resources for coal units in the Illinois Basin.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(I-B)
ILDAN	7,513	7,181	7,844	155	4.4
ILHER	34,379	33,770	34,989	452	1.8
ILSPR	19,562	19,143	19,981	311	2.1
INDAN	2,692	2,550	2,834	71	5.3
INSPR	4,739	4,458	5,019	88	5.9

Table IB5. Uncertainty estimates for II-A resources for coal units in the Illinois Basin.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(II-A)
ILDAN	8,448	7,716	9,180	47	8.7
ILHER	25,371	24,081	26,661	112	5.1
ILSPR	35,833	34,496	37,171	163	3.7
INDAN	241	145	337	2	39.9
INSPR	473	296	649	2	37.5

Table IB6. Uncertainty estimates for measured resources for coal units in the Illinois Basin.

[MST, millions of short tons; n^*, pseudo n]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(measured)
KYBAK	631	621	642	956	1.6
KYHER	471	463	480	829	1.8
KYSPR	1,057	1,049	1,065	1,576	0.7

Table IB7. Uncertainty estimates for indicated resources for coal units in the Illinois Basin.

[MST, millions of short tons; n^*, pseudo n]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(indicated)
KYBAK	1,107	1,057	1,156	188	4.5
KYHER	836	799	873	148	4.4
KYSPR	2,235	2,202	2,269	335	1.5

Table IB8. Uncertainty estimates for inferred resources for coal units in the Illinois Basin.

[MST, millions of short tons; n^*, pseudo n]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(inferred)
KYBAK	1,615	1,359	1,872	18	15.9
KYHER	1,307	1,114	1,501	13	14.8
KYSPR	3,698	3,517	3,880	31	4.9

Table IB9. Uncertainty estimates for hypothetical resources for coal units in the Illinois Basin.

[MST, millions of short tons; n^*, pseudo n]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(hypothetical)
KYBAK	282	64	500	1	77.2
KYHER	293	160	425	1	45.2
KYSPR	524	347	700	1	33.7

Table IB10. Uncertainty estimates for total resources for coal units in the Illinois Basin.

[MST, millions of short tons]

Data set ID	Base (MST)	90 % confidence limits Lower (MST)	Upper (MST)	% error (total)
ILDAN	17,811	16,710	18,912	6.2
ILHER	78,943	76,944	80,943	2.5
ILSPR	61,400	59,595	63,205	2.9
INDAN	6,249	5,977	6,522	4.4
INSPR	11,890	11,359	12,421	4.5
KYBAK	3,636	3,102	4,169	14.7
KYHER	2,907	2,536	3,278	12.8
KYSPR	7,514	7,115	7,913	5.3

Table NR1. Coal units in the Northern Rocky Mountains and Great Plains region.

Data set ID	Assessment unit	Area (mi^2)	Sample size, *n*
BBJB	Greater Green River, Deadman seams, BlackButte/JimBridger	111	2,823
BZ	Williston, Beulah-Zap	402	2,112
CAR	Carbon, Johnson-107	23	35
COL	Powder River, Rosebud-Robinson, Colstrip	342	134
F23	Hanna, Ferris23	39	69
F25	Hanna, Ferris25	58	68
F31	Hanna, Ferris31	29	14
F50	Hanna, Ferris50	38	12
F65	Hanna, Ferris65	26	93
H77	Hanna - 77	51	74
H78	Hanna -78	48	217
H79	Hanna -79	38	117
H81	Hanna -81	35	107
HAG	Williston, Hagel	400	1,672
HAN	Williston, Hansen	2,586	258
HAR	Williston, Harmon	4,040	348
KNO1	Powder River, Ashland Coalfield, Knobloch Coal Bed	174	187
WA	Powder River, Wyodak-Anderson	8,460	4,462
WAC*	Powder River, Wyodak-Anderson, Decker Coalfield	858	366
WAG*	Powder River, Wyodak-Anderson, Gillette Coalfield	1,394	2,009
WAS*	Powder River, Wyodak-Anderson, Sheridan Coalfield	234	193

* Subarea of Wyodak-Anderson coal zone.

Table NR2. Spatial models and estimated standard deviations for coal units in the Northern Rocky Mountains and Great Plains.

[SD. standard deviation]

Data set ID	Model	Sill + nugget (ft^2)	Nugget (ft^2)	Range (mi)	Measured SD	Indicated SD	Inferred SD
BBJB	Nugget	39.9	39.9	0.0	6.3	6.3	6.3
BZ	Nugget	17.1	17.1	0.0	4.1	4.1	4.1
CAR	Nugget	189.9	189.9	0.0	13.8	13.8	13.8
COL	Exponential	174.2	55.5	2.6	9.2	11.1	13.0
F23	Linear	40.0	0.0	2.5	2.0	3.5	6.3
F25	Linear	60.0	20.0	3.0	4.7	5.1	6.8
F31	Nugget	5.0	5.0	0.0	2.2	2.2	2.2
F50	Nugget	11.8	11.8	0.0	3.4	3.4	3.4
F65	Nugget	6.1	6.1	0.0	2.5	2.5	2.5
H77	Nugget	97.9	97.9	0.0	9.9	9.9	9.9
H78	Nugget	46.6	46.6	0.0	6.8	6.8	6.8
H79	Nugget	17.2	17.2	0.0	4.1	4.1	4.1
H81	Nugget	51.0	51.0	0.0	7.1	7.1	7.1
HAG	Exponential	45.7	13.7	4.7	4.3	5.1	6.4
HAN	Spherical	16.1	4.0	6.6	2.2	2.5	3.4
HAR	Exponential	30.3	3.7	18.6	2.2	2.6	3.7
KNO1	Spherical	57.4	10.4	4.7	3.8	4.6	7.0
WA	Exponential	741.8	212.0	2.4	18.9	23.2	27.0
WAC	Spherical	258.8	19.0	6.6	5.7	7.7	13.1
WAG	Spherical	693.1	299.1	1.7	19.6	23.3	26.3
WAS	Nugget	247.7	247.7	0.0	15.7	15.7	15.7

(61 m) thick. These coal beds also were formed in peat mires that developed in fluvial and deltaic environments (the lower reaches of the fluvial system) (Flores and Bader, 1999).

The coals of the Hanna Basin, on the other hand, formed in the upper reaches of the fluvial system (braided and meandering environments), and they split and merge within very short distances (0.1 to several miles) (Flores, Cavaroc, and Bader, 1999). There are 77 coal beds in the Hanna and Carbon Basins. Additionally, the strata in the Hanna Basin have been subjected to intensive tectonism, folding, and faulting. All of these geologic factors would contribute to the lack of statistical correlation among spatial trends within the Hanna Basin. The differences in the original peat environment, as well as any subsequent structural overprint, explain why the Powder River and Williston Basin coals have spatial correlations whereas none exist in the Hanna Basin.

Uncertainty estimates were computed for each of these 21 units within the standard categories of geological assurance and for the total coal volume (tables NR3–NR7). For example, the percent error on the uncertainty estimate in the measured category for the Hagel coal zone (table NR3, row HAG) is defined as $\{(1{,}625–1{,}544)/2)/1{,}585\}\times100 = 2.5$, where 1,625, 1,544, and 1,585 are the upper limit, the lower limit, and mean estimates, respectively. The range of the error in the measured category is from 0.9 percent for the Wyodak-Anderson zone (WA) to 55.5 percent for Ferris 31 (F31). This spread largely reflects a decreasing sample size but also differences in thickness variability. As expected, the confidence intervals are wider as we move from the measured to the hypothetical category (table NR3 through NR6). Uncertainty estimates for the total resources are given in table NR7. Details of the computations are given in Appendix A, tables A-NR1 through A-NR21. Percent errors are shown in figures 4 through 7. A graphical comparison of uncertainty intervals is presented in figures 20 through 23.

Recommendations for Future Assessments

A number of issues have arisen during the course of this investigation that might be addressed in future assessments. These include biases associated with estimating standard deviations from semivariogram models, the nonrandom nature of the drilling, possible lack of geologic homogeneity across large regions, errors in thickness measurements, and coverage errors. Some errors are associated with the data. The model, however, induces others. An overall goal is to derive the narrowest possible uncertainty intervals consistent with the use of statistically sound methodology. To accomplish this, we seek to reduce sources of bias and variability associated with both the model and the data.

Spatial correlation clearly exists within much of the data that we analyzed and should be incorporated into uncertainty estimates. A challenge associated with all

Table NR3. Uncertainty estimates for measured resources for coal units in the Northern Rocky Mountains and Great Plains.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		*n**	% error
		Lower (MST)	Upper (MST)		(measured)
WA	43,672	43,298	44,046	2,928	0.9
WAG	13,520	13,314	13,726	819	1.5
WAC	2,621	2,587	2,655	262	1.3
HAG	1,585	1,544	1,625	660	2.5
WAS	1,333	1,266	1,400	136	5.0
BZ	1,172	1,139	1,205	466	2.8
KNO1	980	965	994	109	1.5
HAR	847	832	862	348	1.8
COL	832	797	867	106	4.2
HAN	383	370	395	243	3.2
CAR	141	120	162	18	15.1
H78	130	115	144	34	11.2
BBJB	93	83	103	19	10.9
H79	73	65	81	27	10.7
H81	48	39	57	12	18.9
F25	46	39	52	13	13.6
H77	40	30	51	9	26.5
F23	23	20	25	12	11.2
F65	20	17	23	11	15.0
F50	14	10	17	7	23.7
F31	2	1	3	2	55.5

Table NR4. Uncertainty estimates for indicated resources for coal units in the Northern Rocky Mountains and Great Plains.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		*n**	% error
		Lower (MST)	Upper (MST)		(indicated)
WA	167,701	165,013	170,388	1238.8	1.6
WAG	48,161	46,756	49,566	334.5	2.9
WAC	14,404	14,088	14,720	154.0	2.2
WAS	4,904	4,510	5,298	57.8	8.0
HAR	4,596	4,479	4,714	189.8	2.6
COL	4,017	3,746	4,287	54.6	6.7
KNO1	2,729	2,636	2,822	36.7	3.4
HAN	1,846	1,754	1,938	129.7	5.0
HAG	1,746	1,592	1,901	85.1	8.9
BZ	1,561	1,439	1,683	80.6	7.8
CAR	698	569	828	8.2	18.6
BBJB	320	264	377	7.5	17.7
H78	247	192	302	6.0	22.2
H77	226	157	295	4.5	30.6
H79	181	150	211	5.1	17.0
H81	158	104	212	5.2	33.9
F50	73	52	95	3.7	29.6
F25	70	42	99	2.8	40.5
F65	54	38	70	3.9	29.8
F23	38	19	57	2.8	49.8
F31	8	2	14	0.7	79.6

Table NR5. Uncertainty estimates for inferred resources for coal units in the Northern Rocky Mountains and Great Plains.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(inferred)
WA	303,668	286,108	321,228	152	5.8
WAG	51,256	44,767	57,746	22	12.7
WAC	27,028	24,076	29,979	18	10.9
HAR	20,231	18,717	21,745	59	7.5
HAN	9,743	8,539	10,947	45	12.4
COL	6,948	5,162	8,733	7	25.7
WAS	4,221	2,662	5,780	4	36.9
KNO1	2,285	1,636	2,934	3	28.4
BBJB	2,258	1,651	2,866	3	26.9
BZ	1,546	1,095	1,997	4	29.2
H77	1,162	585	1,740	1	49.7
HAG	1,058	371	1,745	4	64.9
H78	693	338	1,047	1	51.2
H79	607	412	803	1	32.2
H81	443	101	785	1	77.2
F50	338	173	503	1	48.8
CAR	301	0	603	0	100.6
F25	142	0	407	1	185.8
F65	124	22	225	1	82.0
F23	109	0	374	1	241.7
F31	53	0	115	0	118.0

Table NR6. Uncertainty estimates for hypothetical resources for coal units in the Northern Rocky Mountains and Great Plains.

[MST, millions of short tons; *n**, pseudo *n*]

Data set ID	Base (MST)	90 % confidence limits		n^*	% error
		Lower (MST)	Upper (MST)		(hypothetical)
WA	35,612	0	106,394	1	198.8
HAR	19,001	0	39,070	1	105.6
HAN	9,669	1,893	17,445	1	80.4
WAG	1,597	455	2,739	1	71.5
COL	826	0	1,659	1	100.8
WAC	675	184	1,166	1	72.7
BZ	551	193	910	1	65.0
F25	282	0	717	1	154.5
F31	206	123	289	1	40.4
WAS	176	21	332	1	88.2
H77	165	48	282	1	70.9
F50	80	38	123	1	52.6
H78	79	33	125	1	58.6
F23	64	0	228	1	256.1
H79	34	28	41	1	18.8
H81	18	10	25	1	42.6
HAG	12	0	44	1	273.1
KNO1	9	3	15	1	65.8
F65	1	0	2	1	63.7
CAR	0	0	0	1	0.0
BBJB	0	0	0	1	0.0

Table NR7. Uncertainty estimates for total resources for coal units in the Northern Rocky Mountains and Great Plains.

[MST, millions of short tons]

Data set ID	Base (MST)	90 % confidence limits		% error
		Lower (MST)	Upper (MST)	(total)
WA	550,653	459,250	642,056	16.6
WAG	114,535	105,293	123,777	8.1
WAC	44,728	40,936	48,520	8.5
HAR	44,675	22,959	66,391	48.6
HAN	21,641	12,557	30,725	42.0
COL	12,622	9,699	15,546	23.2
WAS	10,635	8,459	12,810	20.5
KNO1	6,002	5,240	6,764	12.7
BZ	4,830	3,866	5,794	20.0
HAG	4,401	3,487	5,315	20.8
BBJB	2,671	1,997	3,346	25.2
H77	1,593	819	2,367	48.6
H78	1,148	678	1,618	40.9
CAR	1,140	687	1,594	39.8
H79	895	655	1,136	26.9
H81	666	254	1,078	61.9
F25	540	0	1,274	136.0
F50	506	273	738	46.0
F31	269	116	422	56.9
F23	234	0	683	192.2
F65	198	77	319	61.1

resource assessments is the manner in which the data, usually coal thickness from drill holes, are produced. Most often, the accessible, economically desirable coal is located and developed early in an exploration process. Uniform coverage in a region of interest is desirable but often is not available. One alternative to correct for an overrepresentation of clustered drill holes is to sample inversely proportional to drilling density. A drawback is that the nearby points provide information about spatial correlation at close distances; therefore, we chose not to subsample.

The measured, indicated, inferred, and hypothetical categories were devised before the advent of high-speed computing. Instead of (or in addition to) reporting coal resources by fixed arbitrary distances from data points, we should consider a modeling process whereby the distance from a data point would be determined from input specifications and the data. For example, one might specify error bounds, say ±5 percent of coal volume, at a given level of confidence and estimate a distance and compute coal volume within that distance from a data point. For coal beds exhibiting very low variability and high spatial correlation, it might be possible to extrapolate several miles from a data point; whereas in coal beds exhibiting high variability, the same level of assurance would only allow us to extrapolate a small fraction of a mile.

Another concern with the present system is that only the measured category (or other category of highest geological assurance) actually contains data (drill holes), in a geometric sense. Of course, estimates made in other categories are functions of these data. Pseudo points were constructed in this study to provide estimates of the number of data points that might occupy the indicated, inferred, and hypothetical categories. These were needed to estimate the standard deviation of the volume of coal resources. An alternative approach would be to dynamically partition the region of interest into high, medium, and low variability. For example, one could construct a grid of sufficient size so that most, if not all, cells would contain some data points. Adjacent cells that have similar variability would be combined to form larger subregions.

In the current method, the estimates of uncertainty on hypothetical resources are the most conservative (most likely, the confidence intervals are too wide). It may be possible to make an inference about uncertainty in the hypothetical region from estimates in the measured, indicated, and inferred regions.

Global estimation using kriging is difficult because the covariance function (a measure of spatial variability) is rarely stationary over a large area, data are seldom uniformly distributed, and dependencies associated with large data sets can cause computational problems. Partitioning a large area and using block kriging to make estimates of global means is one possible procedure. Estimates of global uncertainty can be obtained using simulation; however, these procedures are computationally intensive, requiring hundreds of separate kriging runs. An excellent presentation of simulation methods, which are used to estimate global uncertainty, is given in chapter 8 of Goovaerts (1997). Additional complicating factors are the considerable effort required to process the results of each kriging run in order to eliminate areas in the basin that are mined and to account for overburden and other factors. However, recent advances in the integration of GIS and geostatistical computing may make this approach feasible in the near future. One recommendation for further study is to see if a large region, such as the Powder River Basin, can be partitioned into more geologically homogeneous subregions using geology and statistical methods. Such a partitioning would allow the computation of uncertainty estimates, which, when pooled, should result in a better (narrower) estimate of uncertainty than is possible when considering the entire region.

Further investigation into sources of errors associated with outcrop, mined areas, and other coverages is warranted. A study could rank sources of variability by order of magnitude and then address issues associated with important sources.

Finally, we recommend that the proposed method and a number of alternative schemes be investigated in more detail on one or two data sets to better understand the tradeoffs and to relate statistical to geologic results. The current semivariogram models will provide a starting point for future geostatistical work. In addition, having the drilling and other geologic information stored in a GIS system will make it much easier to implement the above suggestions.

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Appendix A.—Detailed Computations for Beds/Zones

Order of presentation of detailed computational files for the Appalachian Basin (AB).

Data set ID	Assessment unit	Table
PIT	Pittsburgh bed	A-AB1
POC	Pocahontas No. 3	A-AB2
UF	Upper Freeport bed	A-AB3
FC	Fire Clay zone	A-AB4
PC	Pond Creek zone	A-AB5

Table A-AB1. Detailed computations for uncertainty estimates of the Pittsburgh (PIT) coal bed.

[Date of est 9/28/2000. Form revised 4/7/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	729,587,725	2,163,034,279	3,456,671,946	480,812,820	6,830,106,770
3	Percent of area	11	32	51	7	100
4	Area (acres)	180,285	534,497	854,162	118,811	1,687,756
5	Standard deviation, SD (ft) (variogram model including meas err)	1.277	1.277	1.277	1.277	
6	Acre feet (Acres*SD)	230,224	682,553	1,090,765	151,722	
7	Volume (millions short tons)	1,726	5,122	8,063	923	15,834
	Pseudo *n*					
8	*n**=Min num pts in area	1435	473	47	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	11	55	280	268	614
10	Half interval width (90 % confidence interval)	18	91	461	441	1010
11	% Error, Half interval width / Volume * 100	1.02	1.78	5.72	47.75	6.38
12	Lower 90 % confidence bound (millions short tons)	1,708	5,031	7,602	482	14,823
13	Upper 90 % confidence bound (millions short tons)	1,744	5,214	8,524	1,363	16,844
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	11	57	286	273	626
15	Half interval width (90 % confidence interval)	18	93	470	449	1,030
16	% Error, Half interval width / Volume * 100	1.04	1.81	5.83	48.69	6.51
17	Lower 90 % confidence bound (millions short tons)	1,708	5,029	7,593	473	14,803
18	Upper 90 % confidence bound (millions short tons)	1,744	5,215	8,533	1,372	16,864

Row 5, estimate of SD is residual standard error from loess regression with span = .5.

Table A-AB1. Detailed computations for uncertainty estimates of the Pittsburgh (PIT) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	Meas-Ind	1.0	595	618
n	4308	Meas-Infer	1.0	3007	3127
Overall exhaustion (sq.km./hole)	1.6	Meas-Hyp	1.0	2873	2988
		Ind-Inf	1.0	15531	16150
Assumed measurement error std dev (ft)	0.25	Ind-Hyp	1.0	14843	15434
		Inf-Hyp	1.0	75053	78044
		Covariance		223804	232723
		Variance		153447	159563

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	1.631	1.631	1.631	1.631
Variance of measurement error	0.063	0.063	0.063	0.063
Variances, excluding meas error	1.568	1.568	1.568	1.568

Semivariogram model	Nugget
Sill	
Nugget	
Range/3	
Run on residual thickness	
Splus main data set:	PIT

Table A-AB2. Detailed computations for uncertainty estimates of the Pocahontas No. 3 (POC) coal bed.

[Date of est 10/23/2000. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	281,347,998	1,145,663,250	1,877,775,792	329,330,238	3,634,117,278
3	Percent of area	8	32	52	9	100
4	Area (acres)	69,523	283,100	464,009	81,379	898,010
5	Standard deviation, SD (ft) (variogram model including meas err)	0.850	0.944	1.246	1.367	
6	Acre feet (Acres*SD)	59,108	267,233	578,305	111,255	
7	Volume (millions short tons)	440	1,755	2,541	365	5101.42
	Pseudo *n*					
8	*n**=Min num pts in area	553	250	26	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	2	16	158	163	338
10	Half interval width (90 % confidence interval)	3	27	260	267	556
11	% Error, Half interval width / Volume * 100	0.58	1.52	10.21	73.26	10.90
12	Lower 90 % confidence bound (millions short tons)	437	1,729	2,282	98	4,545
13	Upper 90 % confidence bound (millions short tons)	443	1,782	2,801	632	5,658
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	5	30	206	200	441
15	Half interval width (90 % confidence interval)	7	50	338	329	725
16	% Error, Half interval width / Volume * 100	1.69	2.85	13.31	90.27	14.21
17	Lower 90 % confidence bound (millions short tons)	433	1,705	2,203	36	4,376
18	Upper 90 % confidence bound (millions short tons)	447	1,805	2,879	694	5,826

Table A-AB2. Detailed computations for uncertainty estimates of the Pocahontas No. 3 (POC) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	Meas-Ind	1.0	25	138
n	837	Meas-Infer	1.0	245	930
Overall exhaustion (sq.km./hole)	4.3	Meas-Hyp	1.0	252	906
		Ind-Inf	1.0	2557	6250
Measurement error SD (ft) - nugget	0.80	Ind-Hyp	1.0	2633	6089
		Inf-Hyp	1.0	25646	41166
		Covariance		62715	110956
		Variance		51580	83306

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	0.72	0.89	1.55	1.87
Variance of measurement error	0.64	0.64	0.64	0.64
Variance, excluding meas error	0.08	0.25	0.92	1.23

		Units
Semivariogram model	Spherical	
Sill	1.231	ft^2
Nugget	0.638	ft^2
Range	5.438	mi
Residual sum of squares : 0.08543717		
Run on residual thicknesses		
Splus data set	Poc	

Table A-AB3. Detailed computations for uncertainty estimates of the Upper Freeport (UF) coal bed.

[Date of est 10/23/2000]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	13,880,849,167	9,814,172,997	23,695,022,164
3	Percent of area	59	41	100
4	Area (acres)	3,430,033	2,425,135	5,855,167
5	Standard deviation, SD (ft) (variogram model including meas err)	0.899	0.901	
6	Acre feet (Acres*SD)	3,081,949	2,184,840	
7	Volume (millions short tons)	19,237	11,631	30,867
	Pseudo *n*			
8	*n**=Min num pts in area	190	1	
	Estimates of uncertainty: no measurement error			
9	Vol std dev (millions st) sv	387	3,778	4165
10	Half interval width (90 % confidence interval)	637	6215	6852
11	% Error, Half interval width / Volume * 100	3.31	53.44	22.20
12	Lower 90 % confidence bound (millions short tons)	18,600	5,415	24,015
13	Upper 90 % confidence bound (millions short tons)	19,873	17,846	37,719
	Estimates of uncertainty: measurement error included			
14	Vol std dev (millions st) sc	403	3,933	4,336
15	Half interval width (90 % confidence interval)	663	6,469	7,132
16	% Error, Half interval width / Volume * 100	3.45	55.62	23.11
17	Lower 90 % confidence bound (millions short tons)	18,574	5,161	23,735
18	Upper 90 % confidence bound (millions short tons)	19,899	18,100	37,999

Table A-AB3. Detailed computations for uncertainty estimates of the Upper Freeport (UF) coal bed—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800	Identified-Hyp	1.0	1462279	1584627
n	9672	Covariance		2924558	3169254
Overall exhaustion (sq.km./hole)	2.4	Variance		14425058	15628586
Assumed measurement error SD (ft)	0.25				

	Measured	Identified	Hypothetical
Variances, including meas error	0.807	0.807	0.812
Variance of measurement error	0.163	0.063	0.063
Variances, excluding meas error	0.644	0.745	0.749

Meas error variance: var(num of beds) + Cov with rho=.5

Semivariogram model	Exponential
Sill	0.408
Nugget	0.404
Range/3	0.660
Residual sum of squares : 0.01916058	
Run on thickness	
Splus main data set	UF2

Table A-AB4. Detailed computations for uncertainty estimates of the Fire Clay (FC) coal bed.

[Date of est 10/23/2000]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	4,822,091,292	55,538,548	4,877,629,840
3	Percent of area	99	1	100
4	Area (acres)	1,191,565	13,724	1,205,289
5	Standard deviation, SD (ft) (variogram model including meas err)	0.894	0.910	
6	Acre feet (Acres*SD)	1,064,875	12,482	
7	Volume (millions short tons)	4,986	77	5,063
	Pseudo *n*			
8	*n**=Min num pts in area	66	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	197	19	216
10	Half interval width (90 % confidence interval)	324	31	355
11	% Error, Half interval width / Volume * 100	6.50	40.47	7.02
12	Lower 90 % confidence bound (millions short tons)	4,662	46	4,707
13	Upper 90 % confidence bound (millions short tons)	5,310	108	5,418
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	236	22	259
15	Half interval width (90 % confidence interval)	389	37	426
16	% Error, Half interval width / Volume * 100	7.79	48.15	8.41
17	Lower 90 % confidence bound (millions short tons)	4,597	40	4,637
18	Upper 90 % confidence bound (millions short tons)	5,374	114	5,488

Table A-AB4. Detailed computations for uncertainty estimates of the Fire Clay (FC) coal bed—*Continued.*

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800	Inf-Hyp	1.0	3721	5307
n	2292	Covariance		7441	10615
Overall exhaustion (sq.km./hole)	2.1	Variance		39178	56300
Measurement error std dev (feet)-nugget	0.493				
	Identified	Hypothetical			
Variances, including meas error	0.799	0.83			
Variance of measurement error	0.243	0.24			
Variances, excluding meas error	0.556	0.58			
Semivariogram model	Exponential	Units			
Sill	0.584	ft^2			
Nugget	0.243	ft^2			
Range/3	0.995	mi			
Residual sum of squares : 0.01296676	Range = 2.984				
No thickness trend					
Splus data set	FC1				

Table A-AB5. Detailed computations for uncertainty estimates of the Pond Creek (PC) coal bed.

[Date of est 10/23/2000]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	7,412,523,512	424,822,344	7,837,345,856
3	Percent of area	95	5	100
4	Area (acres)	1,831,674	104,976	1,936,650
5	Standard deviation, SD (ft) (variogram model including meas err)	1.041	1.135	
6	Acre feet (Acres*SD)	1,907,414	119,189	
7	Volume (millions short tons)	8,266	400	8,665
	Pseudo *n*			
8	*n**=Min num pts in area	101	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	244	165	408
10	Half interval width (90 % confidence interval)	401	271	672
11	% Error, Half interval width / Volume * 100	4.85	67.71	7.75
12	Lower 90 % confidence bound (millions short tons)	7,864	129	7,994
13	Upper 90 % confidence bound (millions short tons)	8,667	670	9,337
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	341	215	556
15	Half interval width (90 % confidence interval)	561	353	914
16	% Error, Half interval width / Volume * 100	6.79	88.27	10.55
17	Lower 90 % confidence bound (millions short tons)	7,704	47	7,751
18	Upper 90 % confidence bound (millions short tons)	8,827	753	9,580

Table A-AB5. Detailed computations for uncertainty estimates of the Pond Creek (PC) coal bed—*Continued*.

Computational details

				Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07					
Coal density (short tons/acre feet)	1800		Inf-Hyp	1.0	40126	73213
n	3659		Covariance		80252	146426
Overall exhaustion (sq.km./hole)	2.1		Variance		86539	162483
Measurement error std dev (feet)-nugget	0.729					

	Identified	Hypothetical
Variances, including meas error	1.084	1.29
Variance of measurement error	0.531	0.53
Variances, excluding meas error	0.554	0.76

		Units
Semivariogram model	Exponential	
Sill	0.758	ft^2
Nugget	0.531	ft^2
Range/3	2.291	mi
Residual sum of squares : 0.01839057	Range = 6.87	
No thickness trend		
Splus data set	PC	

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Order of presentation of detailed computational files for the Colorado Plateau region (CP).

Data set ID	Assessment unit	Table
DANa	Danforth a	A-CP1
DANb	Danforth b	A-CP2
DANc	Danforth c	A-CP3
DANd	Danforth d	A-CP4
DANe	Danforth e	A-CP5
DANf	Danforth f	A-CP6
DANg	Danforth g	A-CP7
DESb	Deserado b	A-CP8
DESd	Deserado c	A-CP9
KAI	Kaiparowits	A-CP10
CAM	S Piceance - Cameo Wheeler	A-CP11
COALR	S Piceance - Coal Ridge	A-CP12
SCANY	S Piceance - South Canyon	A-CP13
LBLAK	S Wasatch - Lower Blackhawk	A-CP14
FRUT	San Juan - Fruitland	A-CP15
YMPA	Yampa A	A-CP16
YMPB	Yampa B	A-CP17
YMPC	Yampa C	A-CP18
YMPD	Yampa D	A-CP19

Table A-CP1. Detailed computations for uncertainty estimates of the Danforth coal zone a (DANa).

[Date of est 9/28/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	355,440,704	64,758,321	420,199,025
3	Percent of area	85	15	100
4	Area (acres)	87,831	16,002	103,833
5	Standard deviation, SD (ft) (variogram model inc meas err)	3.780	3.856	
6	Acre feet (Acres*SD)	332,030	61,711	
7	Volume (millions short tons)	1,997	359	2,356
	Pseudo *n*			
8	*n**=Min num pts in area	5	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	242	99	341
10	Half interval width (90 % confidence interval)	398	164	562
11	% Error, Half interval width / Volume * 100	19.93	45.57	23.84
12	Lower 90 % confidence bound (millions short tons)	1,599	195	1,794
13	Upper 90 % confidence bound (millions short tons)	2,395	523	2,918
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	265	109	374
15	Half interval width (90 % confidence interval)	436	179	615
16	% Error, Half interval width / Volume * 100	21.85	49.77	26.10
17	Lower 90 % confidence bound (millions short tons)	1,561	180	1,741
18	Upper 90 % confidence bound (millions short tons)	2,433	538	2,971

Table A-CP1. Detailed computations for uncertainty estimates of the Danforth coal zone a (DANa) —*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	24063	28809
n	167	Covariance		48127	57618
Overall exhaustion (sq.km./hole)	2.5	Variance		68428	82153
Measurement error SD (ft)-nugget	1.549				

	Inferred	Hypothetical
Variance, including meas error	14.29	14.87
Variance of measurement error	2.40	2.40
Variance, excluding meas error	11.89	12.47

Semivariogram model	Exponential	Units
Sill	12.471	ft^2
Nugget	2.40	ft^2
Range/3	0.978	mi
Run on loess residuals (span = 0.50)	Range = 2.935	
Splus data set	DANa	

Thickness trend: Somewhat thicker coal in the northwest and southeast with thinner coal in the central region. R^2=0.58.

Table A-CP2. Detailed computations for uncertainty estimates of the Danforth coal zone b (DANb).

[Date of est 9/28/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	376,074,935	44,123,441	420,198,376
3	Percent of area	89	11	100
4	Area (acres)	92,930	10,903	103,833
5	Standard deviation, SD (ft) (variogram model inc meas err)	7.108	7.774	
6	Acre feet (Acres*SD)	660,581	84,759	
7	Volume (millions short tons)	4,209	483	4,692
	Pseudo *n*			
8	*n**=Min num pts in area	5	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	467	138	605
10	Half interval width (90 % confidence interval)	768	227	995
11	% Error, Half interval width / Volume * 100	18.25	47.02	21.21
12	Lower 90 % confidence bound (millions short tons)	3,441	256	3,697
13	Upper 90 % confidence bound (millions short tons)	4,977	710	5,687
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	513	149	662
15	Half interval width (90 % confidence interval)	844	245	1,089
16	% Error, Half interval width / Volume * 100	20.05	50.81	23.22
17	Lower 90 % confidence bound (millions short tons)	3,365	238	3,603
18	Upper 90 % confidence bound (millions short tons)	5,053	728	5,781

Table A-CP2. Detailed computations for uncertainty estimates of the Danforth coal zone b (DANb) —*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	64469	76532
n	205	Covariance		128938	153064
Overall exhaustion (sq.km./hole)	2.0	Variance		237111	285457
Measurement error SD (ft)-nugget	2.944				

	Identified	Hypothetical
Variance, including meas error	50.53	60.43
Variance of measurement error	8.67	8.67
Variance, excluding meas error	41.86	51.76

Semivariogram model	Exponential	Units
Sill	51.763	ft^2
Nugget	8.67	ft^2
Range/3	1.814	mi
No thickness trend	Range = 5.442	
Splus data set	DANb	

Table A-CP3. Detailed computations for uncertainty estimates of the Danforth coal zone c (DANc).

[Date of est 9/28/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	331,329,570	38,662,440	369,992,010
3	Percent of area	90	10	100
4	Area (acres)	81,873	9,554	91,427
5	Standard deviation, SD (ft) (variogram model inc meas err)	5.456	5.456	
6	Acre feet (Acres*SD)	446,680	52,122	
7	Volume (millions short tons)	3,001	378	3,379
	Pseudo *n*			
8	*n**=Min num pts in area	5	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	358	89	446
10	Half interval width (90 % confidence interval)	588	146	734
11	% Error, Half interval width / Volume * 100	19.61	38.64	21.74
12	Lower 90 % confidence bound (millions short tons)	2,413	232	2,645
13	Upper 90 % confidence bound (millions short tons)	3,589	524	4,113
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	370	92	461
15	Half interval width (90 % confidence interval)	608	151	759
16	% Error, Half interval width / Volume * 100	20.26	39.92	22.46
17	Lower 90 % confidence bound (millions short tons)	2,393	227	2,620
18	Upper 90 % confidence bound (millions short tons)	3,609	529	4,138

Table A-CP3. Detailed computations for uncertainty estimates of the Danforth coal zone c (DANc) —*Continued*.

Computational details					
Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	31756	33905
n	210	Covariance		63513	67810
Overall exhaustion (sq.km./hole)	1.8	Variance		135826	145014
Measurement error SD (ft)-nugget	1.373				

	Inferred	Hypothetical
Variance, including meas error	29.77	29.77
Variance of measurement error	1.89	1.89
Variance, excluding meas error	27.88	27.88
Semivariogram model	Spherical	Units
Sill	27.879	ft^2
Nugget	1.89	ft^2
Range	1.296	mi
Run on loess residuals, span = 0.5		
Splus data set	DANc	

Trend is dome-like with thicker coal occurring near the middle and thinning to the northwest and southeast. R^2=.65.

Table A-CP4. Detailed computations for uncertainty estimates of the Danforth coal zone d (DANd).

[Date of est 9/28/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	314,424,526	32,091,409	346,515,935
3	Percent of area	91	9	100
4	Area (acres)	77,696	7,930	85,626
5	Standard deviation, SD (ft) (variogram model inc meas err)	4.599	4.599	
6	Acre feet (Acres*SD)	357,325	36,470	
7	Volume (millions short tons)	1,814	134	1,948
	Pseudo *n*			
8	*n**=Min num pts in area	4	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	221	47	267
10	Half interval width (90 % confidence interval)	363	77	440
11	% Error, Half interval width / Volume * 100	20.01	57.29	22.58
12	Lower 90 % confidence bound (millions short tons)	1,451	57	1,508
13	Upper 90 % confidence bound (millions short tons)	2,177	211	2,388
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	304	64	368
15	Half interval width (90 % confidence interval)	499	106	605
16	% Error, Half interval width / Volume * 100	27.52	78.80	31.05
17	Lower 90 % confidence bound (millions short tons)	1,315	28	1,343
18	Upper 90 % confidence bound (millions short tons)	2,313	240	2,553

Table A-CP4. Detailed computations for uncertainty estimates of the Danforth coal zone d (DANd) —*Continued.*

Computational details					
Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	10299	19481
n	219	Covariance		20597	38962
Overall exhaustion (sq.km./hole)	1.6	Variance		50874	96234
Measurement error SD (ft)-nugget	3.157				

	Inferred	Hypothetical
Variance, including meas error	21.15	21.15
Variance of measurement error	9.97	9.97
Variance, excluding meas error	11.18	11.18

		Units
Semivariogram model	Spherical	
Sill	11.181	ft^2
Nugget	9.97	ft^2
Range	1.726	mi
Run on loess residuals, span = 0.5		
Splus data set	DANd	

Trend is dome-like with thicker coal occurring near the middle and thinning to the northwest and southeast. (Similar to zone c) R^2=.57.

Table A-CP5. Detailed computations for uncertainty estimates of the Danforth coal zone e (DANe).

[Date of est 9/28/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	287,199,604	30,835,317	318,034,921
3	Percent of area	90	10	100
4	Area (acres)	70,969	7,620	78,588
5	Standard deviation, SD (ft) (variogram model inc meas err)	12.644	12.644	
6	Acre feet (Acres*SD)	897,328	96,342	
7	Volume (millions short tons)	4,650	577	5,227
	Pseudo *n*			
8	*n**=Min num pts in area	4	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	782	166	949
10	Half interval width (90 % confidence interval)	1287	274	1560
11	% Error, Half interval width / Volume * 100	27.67	47.42	29.85
12	Lower 90 % confidence bound (millions short tons)	3,363	303	3,667
13	Upper 90 % confidence bound (millions short tons)	5,937	851	6,787
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	797	170	967
15	Half interval width (90 % confidence interval)	1,312	279	1,591
16	% Error, Half interval width / Volume * 100	28.21	48.34	30.43
17	Lower 90 % confidence bound (millions short tons)	3,338	298	3,636
18	Upper 90 % confidence bound (millions short tons)	5,962	856	6,818

Table A-CP5. Detailed computations for uncertainty estimates of the Danforth coal zone e (DANe)—*Continued*.

Computational details

Square meters to square miles	3.86102E-07
Coal density (short tons/acre feet)	1760
n	301
Overall exhaustion (sq.km./hole)	1.1
Measurement error SD (ft)-nugget	2.457

	Assumed correlations	No meas err	Meas err
Inf-Hyp	1.0	130113	135221
Covariance		260227	270443
Variance		639607	664717

	Inferred	Hypothetical
Variance, including meas error	159.87	159.87
Variance of measurement error	6.04	6.04
Variance, excluding meas error	153.83	153.83

		Units
Semivariogram model	Spherical	
Sill	153.832	ft^2
Nugget	6.04	ft^2
Range	1.181	mi
No trend		
Splus data set	DANe	

Table A-CP6. Detailed computations for uncertainty estimates of the Danforth coal zone f (DANf).

[Date of est 9/28/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	214,412,691	33,183,419	247,596,110
3	Percent of area	87	13	100
4	Area (acres)	52,983	8,200	61,182
5	Standard deviation, SD (ft) (variogram model inc meas err)	8.707	8.780	
6	Acre feet (Acres*SD)	461,339	71,992	
7	Volume (millions short tons)	2,099	520	2,619
	Pseudo *n*			
8	*n**=Min num pts in area	3	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	307	83	389
10	Half interval width (90 % confidence interval)	504	136	641
11	% Error, Half interval width / Volume * 100	24.03	26.19	24.46
12	Lower 90 % confidence bound (millions short tons)	1,595	384	1,978
13	Upper 90 % confidence bound (millions short tons)	2,603	656	3,260
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	475	127	601
15	Half interval width (90 % confidence interval)	781	208	989
16	% Error, Half interval width / Volume * 100	37.19	40.08	37.76
17	Lower 90 % confidence bound (millions short tons)	1,318	312	1,630
18	Upper 90 % confidence bound (millions short tons)	2,880	728	3,608

Table A-CP6. Detailed computations for uncertainty estimates of the Danforth coal zone f (DANf) —*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	25388	60124
n	355	Covariance		50776	120249
Overall exhaustion (sq.km./hole)	0.7	Variance		100865	241222
Measurement error SD (ft)-nugget	6.646				

	Inferred	Hypothetical
Variance, including meas error	75.82	77.08
Variance of measurement error	44.16	44.16
Variance, excluding meas error	31.65	32.92

Semivariogram model	Spherical	Units
Sill	32.920	ft^2
Nugget	44.16	ft^2
Range	3.591	mi
No trend		
Splus data set	DANf	

Table A-CP7. Detailed computations for uncertainty estimates of the Danforth coal zone g (DANg).

[Date of est 9/29/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	143,739,702	55,529,757	199,269,459
3	Percent of area	72	28	100
4	Area (acres)	35,519	13,722	49,241
5	Standard deviation, SD (ft) (variogram model inc meas err)	4.913	5.629	
6	Acre feet (Acres*SD)	174,519	77,237	
7	Volume (millions short tons)	611	71	682
	Pseudo *n*			
8	*n**=Min num pts in area	2	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	167	112	280
10	Half interval width (90 % confidence interval)	275	185	460
11	% Error, Half interval width / Volume * 100	45.06	260.13	67.45
12	Lower 90 % confidence bound (millions short tons)	336	0	222
13	Upper 90 % confidence bound (millions short tons)	886	256	1,142
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	219	136	355
15	Half interval width (90 % confidence interval)	361	224	584
16	% Error, Half interval width / Volume * 100	59.03	314.95	85.67
17	Lower 90 % confidence bound (millions short tons)	250	0	98
18	Upper 90 % confidence bound (millions short tons)	972	295	1,266

Table A-CP7. Detailed computations for uncertainty estimates of the Danforth coal zone g (DANg) —*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	18792	29802
n	313	Covariance		37583	59605
Overall exhaustion (sq.km./hole)	0.6	Variance		40620	66544
Measurement error SD (ft)-nugget	3.173				

	Inferred	Hypothetical
Variance, including meas error	24.14	31.68
Variance of measurement error	10.07	10.07
Variance, excluding meas error	14.07	21.61

Semivariogram model	Exponential	Units
Sill	21.613	ft^2
Nugget	10.07	ft^2
Range/3	2.849	mi
No thickness trend	Range = 8.548	
Splus data set	DANg	

Table A-CP8. Detailed computations for uncertainty estimates of the Deserado coal zone b (DESb).

[Date of est 9/28/1999

Row	Reliability category	Identified	No Hypothetical	Entire area
2	Area (sq meters)	56,304,806		56,304,806
3	Percent of area	100		100
4	Area (acres)	13,913		13,913
5	Standard deviation, SD (ft) (variogram model inc meas err)	3.418		
6	Acre feet (Acres*SD)	47,549		
7	Volume (millions short tons)	217		217
	Pseudo *n*			
8	*n**=Min num pts in area	1		
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	84		84
10	Half interval width (90 % confidence interval)	138		138
11	% Error, Half interval width / Volume * 100	63.81		63.81
12	Lower 90 % confidence bound (millions short tons)	79		79
13	Upper 90 % confidence bound (millions short tons)	355		355
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	95		95
15	Half interval width (90 % confidence interval)	157		157
16	% Error, Half interval width / Volume * 100	72.35		72.35
17	Lower 90 % confidence bound (millions short tons)	60		60
18	Upper 90 % confidence bound (millions short tons)	374		374

Table A-CP8. Detailed computations for uncertainty estimates of the Deserado coal zone b (DESb) —*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	0	0
n	202	Covariance		0	0
Overall exhaustion (sq.km./hole)	0.3	Variance		7085	9108
Measurement error SD (ft)-nugget	1.611				

	Inferred	Hypothetical
Variance, including meas error	11.68	0.00
Variance of measurement error	2.59	2.59
Variance, excluding meas error	9.09	

		Units
Semivariogram model	Spherical	
Sill	9.085	ft^2
Nugget	2.594	ft^2
Range	0.985	mi
No trend		
Splus data set	DESb	

Table A-CP9. Detailed computations for uncertainty estimates of the Deserado coal zone d (DESd).

[Date of est 9/28/1999]

Row	Reliability category	Identified	No Hypothetical	Entire area
2	Area (sq meters)	56,264,601		56,264,601
3	Percent of area	100		100
4	Area (acres)	13,903		13,903
5	Standard deviation, SD (ft) (variogram model inc meas err)	1.979		
6	Acre feet (Acres*SD)	27,517		
7	Volume (millions short tons)	149		149
	Pseudo *n*			
8	*n**=Min num pts in area	1		
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	40		40
10	Half interval width (90 % confidence interval)	65		65
11	% Error, Half interval width / Volume * 100	43.65		43.65
12	Lower 90 % confidence bound (millions short tons)	84		84
13	Upper 90 % confidence bound (millions short tons)	214		214
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	55		55
15	Half interval width (90 % confidence interval)	91		91
16	% Error, Half interval width / Volume * 100	61.00		61.00
17	Lower 90 % confidence bound (millions short tons)	58		58
18	Upper 90 % confidence bound (millions short tons)	240		240

Table A-CP9. Detailed computations for uncertainty estimates of the Deserado coal zone d (DESd)—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1760	Inf-Hyp	1.0	0	0
n	186	Covariance		0	0
Overall exhaustion (sq.km./hole)	0.3	Variance		1563	3053
Measurement error SD (ft)-nugget	1.382				

	Inferred	Hypothetical
Variance, including meas error	3.92	0.00
Variance of measurement error	1.91	1.91
Variance, excluding meas error	2.01	

		Units
Semivariogram model	Exponential	
Sill	2.341	ft^2
Nugget	1.911	ft^2
Range/3	1.542	mi
Run on loess residuals, span = 0.5	Range = 4.627	
Splus data set	DESd	

Thickness increases from northwest to southeast; regression $R^2 = 0.6$.

Table A-CP10. Detailed computations for uncertainty estimates of the Kaiparowits (KAI) Formation.

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	1,883,222,810	581,239,604	2,464,462,414
3	Percent of area	76	24	100
4	Area (acres)	465,354	143,627	608,982
5	Standard deviation, SD (ft) (variogram model inc meas err)	19.555	24.210	
6	Acre feet (Acres*SD)	9,100,184	3,477,220	
7	Volume (millions short tons)	47,148	15,114	62,262
	Pseudo *n*			
8	*n**=Min num pts in area	26	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	2,745	5,663	8408
10	Half interval width (90 % confidence interval)	4515	9316	13832
11	% Error, Half interval width / Volume * 100	9.58	61.64	22.22
12	Lower 90 % confidence bound (millions short tons)	42,633	5,798	48,430
13	Upper 90 % confidence bound (millions short tons)	51,663	24,430	76,094
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	3,230	6,259	9,489
15	Half interval width (90 % confidence interval)	5,314	10,296	15,610
16	% Error, Half interval width / Volume * 100	11.27	68.12	25.07
17	Lower 90 % confidence bound (millions short tons)	41,834	4,818	46,652
18	Upper 90 % confidence bound (millions short tons)	52,462	25,410	77,872

Table A-CP10. Detailed computations for uncertainty estimates of the Kaiparowits (KAI) Formation—*Continued*.

Computational details

Square meters to square miles	3.86102E-07
Coal density (short tons/acre feet)	1800
n	193
Overall exhaustion (sq.km./hole)	12.8
Measurement error SD (ft)a	10.308
Assumed meas error SD (ft)	2.5
Median number of beds	16
Assumed correlation between beds	0.5
a sqrt(Var*(Med num beds+2*Assumed corr))	

	Assumed correlations	No meas err	Meas err
Iden-Hyp	1.0	15545573	20217221
Covariance		31091147	40434443
Variance		39608269	49608624

	Identified	Hypothetical
Variance, including meas error	382.41	586.12
Variance of measurement error	106.25	106.25
Variance, excluding meas error	276.16	479.87

		Units
Semivariogram model	Exponential	
Sill	409.799	ft^2
Nugget	176.32	ft^2
Range/3	4.292	mi
Run on loess residuals (span = 0.75)	Range = 12.876	
Splus data set	KAI	

Table A-CP11. Detailed computations for uncertainty estimates of the Cameo Wheeler (CAM) coal zone.

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	8,119,840,067	1,835,545,332	9,955,385,399
3	Percent of area	82	18	100
4	Area (acres)	2,006,456	453,573	2,460,029
5	Standard deviation, SD (ft) (variogram model inc meas err)	8.537	10.686	
6	Acre feet (Acres*SD)	17,129,925	4,846,681	
7	Volume (millions short tons)	141,017	31,384	172,401
	Pseudo *n*			
8	*n**=Min num pts in area	111	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	2,126	7,289	9415
10	Half interval width (90 % confidence interval)	3497	11991	15488
11	% Error, Half interval width / Volume * 100	2.48	38.21	8.98
12	Lower 90 % confidence bound (millions short tons)	137,520	19,393	156,913
13	Upper 90 % confidence bound (millions short tons)	144,514	43,375	187,889
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	2,928	8,724	11,652
15	Half interval width (90 % confidence interval)	4,817	14,351	19,168
16	% Error, Half interval width / Volume * 100	3.42	45.73	11.12
17	Lower 90 % confidence bound (millions short tons)	136,200	17,033	153,233
18	Upper 90 % confidence bound (millions short tons)	145,834	45,735	191,569

Table A-CP11. Detailed computations for uncertainty estimates of the Cameo Wheeler (CAM) coal zone—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800	Iden-Hyp	1.0	15496890	25545598
n	618	Covariance		30993780	51091197
Overall exhaustion (sq.km./hole)	16.1	Variance		57654309	84682928
Measurement error SD (ft) - nugget	5.871				
Median number of beds	6				

	Identified	Hypothetical
Variance, including meas error	72.89	114.18
Variance of measurement error	34.47	34.47
Variance, excluding meas error	38.42	79.71

		Units
Semivariogram model	Exponential	
Sill	79.715	ft^2
Nugget	34.47	ft^2
Range/3	4.561	mi
Run on loess residuals (span = 0.75)	Range = 13.683	
Splus data set	CAM	

Table A-CP12. Detailed computations for uncertainty estimates of the Coal Ridge (COALR) coal zone.

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	3,060,542,666	725,524,646	3,786,067,312
3	Percent of area	81	19	100
4	Area (acres)	756,277	179,281	935,558
5	Standard deviation, SD (ft) (variogram model inc meas err)	8.110	8.110	
6	Acre feet (Acres*SD)	6,133,403	1,453,969	
7	Volume (millions short tons)	14,096	2,537	16,633
	Pseudo *n*			
8	*n**=Min num pts in area	42	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	381	584	965
10	Half interval width (90 % confidence interval)	627	960	1587
11	% Error, Half interval width / Volume * 100	4.45	37.85	9.54
12	Lower 90 % confidence bound (millions short tons)	13,469	1,577	15,046
13	Upper 90 % confidence bound (millions short tons)	14,723	3,497	18,220
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	1,708	2,617	4,325
15	Half interval width (90 % confidence interval)	2,809	4,305	7,114
16	% Error, Half interval width / Volume * 100	19.93	169.70	42.77
17	Lower 90 % confidence bound (millions short tons)	11,287	0	9,519
18	Upper 90 % confidence bound (millions short tons)	16,905	6,842	23,747

Table A-CP12. Detailed computations for uncertainty estimates of the Coal Ridge (COALR) coal zone—*Continued*.

Computational details

Square meters to square miles	3.86102E-07	
Coal density (short tons/acre feet)	1800	
n	220	
Overall exhaustion (sq.km./hole)	17.2	
Measurement error SD (ft)a	7.906	
Assumed meas error SD (ft)	2.5	
Median number of beds	9	
Assumed correlation between beds	0.5	
a - sqrt(Var*(Median num bed+2*Assumed corr))		
	Inferred	Hypothetical
Variance, including meas error	65.77	65.77
Variance of measurement error	62.50	62.50
Variance, excluding meas error	3.27	3.27
Semivariogram model	Nugget	
Sill		
Nugget		
Range/3		
No trend		
Splus data set	COALR	

	Assumed correlations	No meas err	Meas err
Inf-Hyp	1.0	222348	4469381
Covariance		444695	8938763
Variance		485839	9765794

Table A-CP13. Detailed computations for uncertainty estimates of the South Canyon (SCANY) coal zone.

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	3,047,851,131	764,796,450	3,812,647,581
3	Percent of area	80	20	100
4	Area (acres)	753,140	188,985	942,126
5	Standard deviation, SD (ft) (variogram model inc meas err)	7.679	7.679	
6	Acre feet (Acres*SD)	5,783,365	1,451,218	
7	Volume (millions short tons)	24,748	4,690	29,438
	Pseudo *n*			
8	*n**=Min num pts in area	42	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	1,225	1,983	3207
10	Half interval width (90 % confidence interval)	2015	3261	5276
11	% Error, Half interval width / Volume * 100	8.14	69.54	17.92
12	Lower 90 % confidence bound (millions short tons)	22,733	1,429	24,162
13	Upper 90 % confidence bound (millions short tons)	26,763	7,951	34,714
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	1,614	2,612	4,226
15	Half interval width (90 % confidence interval)	2,654	4,297	6,951
16	% Error, Half interval width / Volume * 100	10.73	91.62	23.61
17	Lower 90 % confidence bound (millions short tons)	22,094	393	22,487
18	Upper 90 % confidence bound (millions short tons)	27,402	8,987	36,389

Table A-CP13. Detailed computations for uncertainty estimates of the South Canyon (SCANY) coal zone—*Continued*.

Computational details						
Square meters to square miles	3.86102E-07			Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800		Inf-Hyp	1.0	2428034	4215085
n	225		Covariance		4856068	8430171
Overall exhaustion (sq.km./hole)	16.9		Variance		5430460	9427320
Measurement error SD (ft)a	5.000					
Assumed meas error SD (ft)	2.5					
Median number of beds	3					
Assumed correlation between beds	0.5					
a - sqrt(Var*(Med num of beds+2*Assumed corr))						
	Inferred	Hypothetical				
Variance, including meas error	58.97	58.97				
Variance of measurement error	25.00	25.00				
Variance, excluding meas error	33.97	33.97				
Semivariogram model	Nugget					
Sill						
Nugget						
Range/3						
Loess R2=0.56 with span = 0.5, weak trend						
Splus data set	SCANY					

Table A-CP14. Detailed computations for uncertainty estimates of the Lower Blackhawk (LBLAK) Formation.

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	606,147,301	231,248,497	837,395,798
3	Percent of area	72	28	100
4	Area (acres)	149,782	57,143	206,925
5	Standard deviation, SD (ft) (variogram model inc meas err)	5.073	9.703	
6	Acre feet (Acres*SD)	759,861	554,473	
7	Volume (millions short tons)	4,231	2,541	6,772
	Pseudo *n*			
8	*n**=Min num pts in area	8	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	279	904	1183
10	Half interval width (90 % confidence interval)	458	1487	1945
11	% Error, Half interval width / Volume * 100	10.83	58.53	28.73
12	Lower 90 % confidence bound (millions short tons)	3,773	1,054	4,827
13	Upper 90 % confidence bound (millions short tons)	4,689	4,028	8,717
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	475	998	1,473
15	Half interval width (90 % confidence interval)	782	1,642	2,424
16	% Error, Half interval width / Volume * 100	18.48	64.61	35.79
17	Lower 90 % confidence bound (millions short tons)	3,449	899	4,348
18	Upper 90 % confidence bound (millions short tons)	5,013	4,183	9,196

Table A-CP14. Detailed computations for uncertainty estimates of the Lower Blackhawk (LBLAK) Formation—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	Inf-Hyp	1.0	251799	474477
n	288	Covariance		503598	948954
Overall exhaustion (sq.km./hole)	2.9	Variance		894863	1222114
Measurement error SD (ft)-nugget	4.111				
Median number of beds	2				

	Inferred	Hypothetical
Variance, including meas error	25.74	94.15
Variance of measurement error	16.90	16.90
Variance, excluding meas error	8.83	77.25

Semivariogram model	Exponential	Units
Sill	77.251	ft^2
Nugget	16.902	ft^2
Range/3	24.704	mi
No trend; residual sum of squares = 122.7728	Range = 74.112	
Splus data set	LBLAK	

Table A-CP15. Detailed computations for uncertainty estimates of the Fruitland (FRUT) Formation.

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	14,647,299,621	1,458,524,343	16,105,823,964
3	Percent of area	91	9	100
4	Area (acres)	3,619,427	360,409	3,979,836
5	Standard deviation, SD (ft) (variogram model-inc meas err)	11.840	11.840	
6	Acre feet (Acres*SD)	42,854,010	4,267,245	
7	Volume (millions short tons)	214,553	13,954	228,507
	Pseudo *n*			
8	*n**=Min num pts in area	200	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	5,342	7,523	12866
10	Half interval width (90 % confidence interval)	8788	12376	21164
11	% Error, Half interval width / Volume * 100	4.10	88.69	9.26
12	Lower 90 % confidence bound (millions short tons)	205,765	1,578	207,343
13	Upper 90 % confidence bound (millions short tons)	223,341	26,330	249,671
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	6,060	8,534	14,595
15	Half interval width (90 % confidence interval)	9,969	14,039	24,008
16	% Error, Half interval width / Volume * 100	4.65	100.61	10.51
17	Lower 90 % confidence bound (millions short tons)	204,584	0	204,499
18	Upper 90 % confidence bound (millions short tons)	224,522	27,993	252,515

Table A-CP15. Detailed computations for uncertainty estimates of the Fruitland (FRUT) Formation—*Continued.*

Computational details			
Square meters to square miles	3.86102E-07		
Coal density (short tons/acre feet)	2000		
n	733		
Overall exhaustion (sq.km./hole)	22.0		
Measurement error SD (ft)a	5.590		
Assumed meas error SD (ft)	2.5		
Median number of beds	4		
Assumed correlation between beds	0.5		
a - sqrt(Var*(Med num of beds+2*Assumed corr))			
	Inferred	Hypothetical	
Variance, including meas error	140.19	140.19	
Variance of measurement error	31.25	31.25	
Variance, excluding meas error	108.94	108.94	
Semivariogram model	Nugget		
Sill			
Nugget			
Range/3			
Loess R2=0.62 with span = 0.75, trend			
Splus data set	FRUT		

	Assumed correlations	No meas err	Meas err
Inf-Hyp	1.0	40191257	51720791
Covariance		80382513	103441583
Variance		85139858	109563652

Thickness increases linearly from south to north. Going from west to east, coal is slightly thicker in middle.

Table A-CP16. Detailed computations for uncertainty estimates of the Yampa coal field, A coal zone (YMPA).

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	821,597,223	718,731,565	1,540,328,788
3	Percent of area	53	47	100
4	Area (acres)	203,021	177,602	380,624
5	Standard deviation, SD (ft) (variogram model inc meas err)	12.296	12.954	
6	Acre feet (Acres*SD)	2,496,311	2,300,702	
7	Volume (millions short tons)	21,483	20,623	42,106
	Pseudo *n*			
8	*n**=Min num pts in area	11	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	1,138	3,579	4716
10	Half interval width (90 % confidence interval)	1871	5887	7758
11	% Error, Half interval width / Volume * 100	8.71	28.55	18.43
12	Lower 90 % confidence bound (millions short tons)	19,612	14,736	34,348
13	Upper 90 % confidence bound (millions short tons)	23,354	26,510	49,864
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	1,341	4,141	5,483
15	Half interval width (90 % confidence interval)	2,207	6,812	9,019
16	% Error, Half interval width / Volume * 100	10.27	33.03	21.42
17	Lower 90 % confidence bound (millions short tons)	19,276	13,811	33,087
18	Upper 90 % confidence bound (millions short tons)	23,690	27,435	51,125

Table A-CP16. Detailed computations for uncertainty estimates of the Yampa coal field, A coal zone (YMPA)—*Continued*.

Computational details

Square meters to square miles	3.86102E-07
Coal density (short tons/acre feet)	1800
n	94
Overall exhaustion (sq.km./hole)	16.4
Measurement error SD (ft)-nugget	6.518
Median number of beds	12

	Assumed correlations	No meas err	Meas err
Inf-Hyp	1.0	4071036	5555453
Covariance		8142073	11110905
Variance		14102469	18949656

	Inferred	Hypothetical
Variance, including meas error	151.19	167.81
Variance of measurement error	42.48	42.48
Variance, excluding meas error	108.71	125.33

		Units
Semivariogram model	Exponential	
Sill	125.331	ft^2
Nugget	42.481	ft^2
Range/3	1.485	mi
No trend		Range = 4.455
Splus data set	YMPA	

Table A-CP17. Detailed computations for uncertainty estimates of the Yampa coal field, B coal zone (YMPB).

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	435,812,308	369,195,570	805,007,878
3	Percent of area	54	46	100
4	Area (acres)	107,692	91,230	198,922
5	Standard deviation, SD (ft) (variogram model inc meas err)	8.612	8.612	
6	Acre feet (Acres*SD)	927,440	785,675	
7	Volume (millions short tons)	5,066	7,657	12,723
	Pseudo *n*			
8	*n**=Min num pts in area	6	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	592	1,222	1814
10	Half interval width (90 % confidence interval)	973	2011	2984
11	% Error, Half interval width / Volume * 100	19.21	26.26	23.45
12	Lower 90 % confidence bound (millions short tons)	4,093	5,646	9,739
13	Upper 90 % confidence bound (millions short tons)	6,039	9,668	15,707
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	684	1,414	2,099
15	Half interval width (90 % confidence interval)	1,126	2,326	3,452
16	% Error, Half interval width / Volume * 100	22.22	30.38	27.13
17	Lower 90 % confidence bound (millions short tons)	3,940	5,331	9,271
18	Upper 90 % confidence bound (millions short tons)	6,192	9,983	16,175

Table A-CP17. Detailed computations for uncertainty estimates of the Yampa coal field, B coal zone (YMPB)—*Continued*.

Computational details						
Square meters to square miles	3.86102E-07			Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800		Inf-Hyp	1.0	723103	967762
n	114		Covariance		1446205	1935524
Overall exhaustion (sq.km./hole)	7.1		Variance		1844278	2468283
Measurement error SD (ft)a	4.330					
Assumed meas error SD (ft)	2.5					
Median number of beds	2					
Assumed correlation between beds	0.5					
a - sqrt(Var*(Med num beds+2*Assumed corr))						
	Inferred	Hypothetical				
Variance, including meas error	74.17	74.17				
Variance of measurement error	18.75	18.75				
Variance, excluding meas error	55.42	55.42				
Semivariogram model	Nugget					
Sill						
Nugget						
Range/3						
Run of residuals: loess fit, span = 0.5						
Splus data set	YMPB					

Table A-CP18. Detailed computations for uncertainty estimates of the Yampa coal field, C coal zone (YMPC).

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	447,656,174	517,089,084	964,745,258
3	Percent of area	46	54	100
4	Area (acres)	110,618	127,775	238,394
5	Standard deviation, SD (ft) (variogram model inc meas err)	5.504	5.504	
6	Acre feet (Acres*SD)	608,843	703,276	
7	Volume (millions short tons)	1,893	1,847	3,740
	Pseudo *n*			
8	*n**=Min num pts in area	6	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	185	529	714
10	Half interval width (90 % confidence interval)	305	871	1175
11	% Error, Half interval width / Volume * 100	16.10	47.13	31.43
12	Lower 90 % confidence bound (millions short tons)	1,588	976	2,565
13	Upper 90 % confidence bound (millions short tons)	2,198	2,718	4,915
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	443	1,266	1,709
15	Half interval width (90 % confidence interval)	729	2,082	2,812
16	% Error, Half interval width / Volume * 100	38.52	112.75	75.18
17	Lower 90 % confidence bound (millions short tons)	1,164	0	928
18	Upper 90 % confidence bound (millions short tons)	2,622	3,929	6,552

Table A-CP18. Detailed computations for uncertainty estimates of the Yampa coal field, C coal zone (YMPC)—*Continued*.

Computational details						
Square meters to square miles	3.86102E-07			Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800		Inf-Hyp	1.0	98057	561111
n	111		Covariance		196113	1122222
Overall exhaustion (sq.km./hole)	8.7		Variance		314378	1798968
Measurement error SD (ft)a	5.000					
Assumed meas error SD (ft)	2.5					
Median number of beds	3					
Assumed correlation between beds	0.5					
a - sqrt(Var*(Med num beds+2*Assumed corr))						
	Inferred	Hypothetical				
Variance, including meas error	30.29	30.29				
Variance of measurement error	25.00	25.00				
Variance, excluding meas error	5.29	5.29				
Semivariogram model	Nugget					
Sill						
Nugget						
Range/3						
No trend						
Splus data set	YMPC					

Table A-CP19. Detailed computations for uncertainty estimates of the Yampa coal field, D coal zone (YMPD).

[Date of est 10/18/1999]

Row	Reliability category	Identified	Hypothetical	Entire area
2	Area (sq meters)	484,931,645	572,429,241	1,057,360,886
3	Percent of area	46	54	100
4	Area (acres)	119,829	141,450	261,280
5	Standard deviation, SD (ft) (variogram model inc meas err)	14.616	14.616	
6	Acre feet (Acres*SD)	1,751,424	2,067,438	
7	Volume (millions short tons)	6,851	10,593	17,444
	Pseudo *n*			
8	*n**=Min num pts in area	7	1	
	Estimates of uncertainty: no measurement error			
9	Vol SD (millions st) sv	1,030	3,130	4160
10	Half interval width (90 % confidence interval)	1695	5149	6844
11	% Error, Half interval width / Volume * 100	24.74	48.61	39.23
12	Lower 90 % confidence bound (millions short tons)	5,156	5,444	10,600
13	Upper 90 % confidence bound (millions short tons)	8,546	15,742	24,288
	Estimates of uncertainty: measurement error included			
14	Vol SD (millions st) sc	1,225	3,721	4,946
15	Half interval width (90 % confidence interval)	2,015	6,122	8,137
16	% Error, Half interval width / Volume * 100	29.42	57.79	46.65
17	Lower 90 % confidence bound (millions short tons)	4,836	4,471	9,307
18	Upper 90 % confidence bound (millions short tons)	8,866	16,715	25,581

Table A-CP19. Detailed computations for uncertainty estimates of the Yampa coal field, D coal zone (YMPD)—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800	Inf-Hyp	1.0	3225223	4559041
n	30	Covariance		6450446	9118081
Overall exhaustion (sq.km./hole)	35.2	Variance		10858827	15349583

Measurement error SD (ft)-nugget	7.906	
Assumed meas error SD (ft)	2.5	
Median number of beds	9	
Assumed correlation between beds	0.5	
a - sqrt(Var*(Med num beds+2*Assumed corr))		
	Inferred	Hypothetical
Variance, including meas error	213.63	213.63
Variance of measurement error	62.50	62.50
Variance, excluding meas error	151.13	151.13
Semivariogram model	Nugget	
Sill		
Nugget		
Range/3		
No trend		
Splus data set	YMPD	

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Order of presentation of detailed computational files for the Gulf Coast region (GC).

Data set ID	Assessment unit	Table
z1iso	NE TX zone 1	A-GC1
z2iso	NE TX zone 2	A-GC2
z3iso	NE TX zone 3	A-GC3
z4iso	NE TX zone 4	A-GC4
z5iso	NE TX zone 5	A-GC5
z6iso	NE TX zone 6	A-GC6
cz5	Central TX zone CZ5	A-GC7
cz6	Central TX zone CZ6	A-GC8
cz8	Central TX zone CZ8	A-GC9
cz9	Central TX zone CZ9	A-GC10
czl4	Central TX zone CZL4	A-GC11
czl6t	Central TX zone CZL6	A-GC12
czl8	Central TX zone CZL8	A-GC13
czm4	Central TX zone CZM4	A-GC14
czm5	Central TX zone CZM5	A-GC15
LA	Louisiana Sabine	A-GC16

Table A-GC1. Detailed computations for uncertainty estimates of the NE Texas Zone 1 (z1iso) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	51,611,435	150,100,727	393,607,739	316,818,365	912,138,266
3	Percent of area	6	16	43	35	100
4	Area (acres)	12,753	37,091	97,263	78,288	225,394
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.746	2.987	3.368	3.445	
6	Acre feet (Acres*SD)	35,024	110,782	327,620	269,737	
7	Volume (millions short tons)	102	261	564	419	1,345
	Pseudo *n*					
8	*n**=Min num pts in area	101	33	5	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	2	17	160	314	493
10	Half interval width (90 % confidence interval)	3	28	262	516	810
11	% Error, Half interval width / Volume * 100	3.42	10.84	46.54	123.24	60.23
12	Lower 90 % confidence bound (millions short tons)	99	232	301	0	535
13	Upper 90 % confidence bound (millions short tons)	105	289	826	935	2,155
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	6	34	247	472	759
15	Half interval width (90 % confidence interval)	10	56	407	777	1,249
16	% Error, Half interval width / Volume * 100	9.81	21.37	72.16	185.41	92.85
17	Lower 90 % confidence bound (millions short tons)	92	205	157	0	96
18	Upper 90 % confidence bound (millions short tons)	112	316	971	1,195	2,594

Table A-GC1. Detailed computations for uncertainty estimates of the NE Texas Zone 1 (z1iso) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	36	206
n	147	Meas-Infer	1.0	338	1505
Overall exhaustion (sq.km./hole)	6.2	Meas-Hyp	1.0	665	2872
		Ind-Inf	1.0	2739	8372
Measurement error std dev (feet)a	2.574	Ind-Hyp	1.0	5387	15980
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	50046	116735
Median number of beds	2	Covariance		118422	291338
Assumed correlation between beds	0.5	Variance		124187	285161
a - sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	7.54	8.92	11.35	11.87
Variance of measurement error	6.63	6.63	6.63	6.63
Variances, excluding meas error	0.92	2.29	4.72	5.24

		Units
Semivariogram model	Exponential	
Sill	5.245	ft^2
Nugget	6.626	ft^2
Range/3	1.304	mi
No trend, run on thickness, residual ss = 31.47	Range = 3.911	
Splus data set	z1iso	

Table A-GC2. Detailed computations for uncertainty estimates of the NE Texas Zone 2 (Z2iso) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	111,973,519	378,946,232	818,029,721	368,720,399	1,677,669,871
3	Percent of area	7	23	49	22	100
4	Area (acres)	27,669	93,640	202,140	91,113	414,561
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.781	3.031	3.448	3.543	
6	Acre feet (Acres*SD)	76,953	283,861	696,892	322,821	
7	Volume (millions short tons)	221	614	1,248	434	2,516
	Pseudo *n*					
8	*n**=Min num pts in area	220	83	11	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	3	28	239	383	653
10	Half interval width (90 % confidence interval)	5	46	393	630	1074
11	% Error, Half interval width / Volume * 100	2.37	7.48	31.51	145.28	42.69
12	Lower 90 % confidence bound (millions short tons)	215	568	855	0	1,442
13	Upper 90 % confidence bound (millions short tons)	226	660	1,641	1,063	3,590
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	9	55	365	565	993
15	Half interval width (90 % confidence interval)	15	90	600	929	1,634
16	% Error, Half interval width / Volume * 100	6.77	14.62	48.10	214.34	64.95
17	Lower 90 % confidence bound (millions short tons)	206	524	648	0	882
18	Upper 90 % confidence bound (millions short tons)	236	704	1,848	1,363	4,150

Table A-GC2. Detailed computations for uncertainty estimates of the NE Texas Zone 2 (Z2iso) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	89	495
n	381	Meas-Infer	1.0	760	3312
Overall exhaustion (sq.km./hole)	4.4	Meas-Hyp	1.0	1217	5127
		Ind-Inf	1.0	6672	19921
Measurement error std dev (feet)a	2.605	Ind-Hyp	1.0	10689	30842
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	91515	206141
Median number of beds	2	Covariance		221884	531675
Assumed correlation between beds	0.5	Variance		204528	455362
a - sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	7.73	9.19	11.89	12.55
Variance of measurement error	6.79	6.79	6.79	6.79
Variances, excluding meas error	0.95	2.40	5.10	5.77

		Units
Semivariogram model	Exponential	
Sill	5.767	ft^2
Nugget	6.787	ft^2
Range/3	1.391	mi
No trend, run on thickness, residual ss =22.89	Range = 4.174	
Splus data set	z2iso	

Table A-GC3. Detailed computations for uncertainty estimates of the NE Texas Zone 3 (Z3iso) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	114,825,444	434,400,674	972,598,012	416,136,433	1,937,960,563
3	Percent of area	6	22	50	21	100
4	Area (acres)	28,374	107,343	240,334	102,830	478,880
5	Standard deviation, SD (ft) (variogram model-inc meas err)	1.939	2.365	2.518	2.518	
6	Acre feet (Acres*SD)	55,005	253,859	605,106	258,959	
7	Volume (millions short tons)	197	689	1,454	512	2,853
	Pseudo *n*					
8	*n**=Min num pts in area	226	95	13	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	5	39	253	394	691
10	Half interval width (90 % confidence interval)	8	64	416	648	1136
11	% Error, Half interval width / Volume * 100	4.10	9.26	28.59	126.61	39.83
12	Lower 90 % confidence bound (millions short tons)	189	625	1,038	0	1,717
13	Upper 90 % confidence bound (millions short tons)	205	753	1,870	1,161	3,989
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	6	46	291	453	796
15	Half interval width (90 % confidence interval)	11	75	478	745	1,309
16	% Error, Half interval width / Volume * 100	5.34	10.88	32.87	145.55	45.89
17	Lower 90 % confidence bound (millions short tons)	187	614	976	0	1,544
18	Upper 90 % confidence bound (millions short tons)	208	764	1,932	1,258	4,162

Table A-GC3. Detailed computations for uncertainty estimates of the NE Texas Zone 3 (Z3iso) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	191	292
n	454	Meas-Infer	1.0	1243	1861
Overall exhaustion (sq.km./hole)	4.3	Meas-Hyp	1.0	1939	2903
		Ind-Inf	1.0	9807	13250
Measurement error std dev (feet)a	1.242	Ind-Hyp	1.0	15297	20665
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	99634	131679
Median number of beds	2	Covariance		256223	341302
Assumed correlation between beds	0.5	Variance		220813	291921
a - sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	3.76	5.59	6.34	6.34
Variance of measurement error	1.54	1.54	1.54	1.54
Variances, excluding meas error	2.22	4.05	4.80	4.80

		Units
Semivariogram model	Exponential	
Sill	4.799	ft^2
Nugget	1.543	ft^2
Range/3	0.404	mi
No trend, run on thickness, residual ss = 7.94	Range = 1.211	
Splus data set	z3iso	

Table A-GC4. Detailed computations for uncertainty estimates of the NE Texas Zone 4 (z4iso) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	158,588,336	600,566,209	1,149,853,318	382,890,014	2,291,897,877
3	Percent of area	7	26	50	17	100
4	Area (acres)	39,188	148,403	284,135	94,614	566,340
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.165	2.191	2.532	3.277	
6	Acre feet (Acres*SD)	84,860	325,186	719,445	310,034	
7	Volume (millions short tons)	303	1,030	1,880	593	3,807
	Pseudo *n*					
8	*n**=Min num pts in area	312	131	16	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	8	165	408	582
10	Half interval width (90 % confidence interval)	1	13	272	671	957
11	% Error, Half interval width / Volume * 100	0.25	1.29	14.47	113.01	25.13
12	Lower 90 % confidence bound (millions short tons)	302	1,017	1,608	0	2,850
13	Upper 90 % confidence bound (millions short tons)	304	1,044	2,152	1,264	4,764
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	8	50	318	543	918
15	Half interval width (90 % confidence interval)	14	82	523	893	1,511
16	% Error, Half interval width / Volume * 100	4.57	7.93	27.80	150.40	39.68
17	Lower 90 % confidence bound (millions short tons)	289	949	1,358	0	2,296
18	Upper 90 % confidence bound (millions short tons)	317	1,112	2,403	1,486	5,318

Table A-GC4. Detailed computations for uncertainty estimates of the NE Texas Zone 4 (z4iso) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	4	418
n	685	Meas-Infer	1.0	76	2672
Overall exhaustion (sq.km./hole)	3.3	Meas-Hyp	1.0	189	4563
		Ind-Inf	1.0	1333	15785
Measurement error std dev (feet)a	2.162	Ind-Hyp	1.0	3288	26954
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	67410	172388
Median number of beds	2	Covariance		144599	445557
Assumed correlation between beds	0.5	Variance		193611	397862
a - sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	4.69	4.80	6.41	10.74
Variance of measurement error	4.67	4.67	4.67	4.67
Variances, excluding meas error	0.01	0.13	1.74	6.06

		Units
Semivariogram model	Gaussian	
Sill	6.063	ft^2
Nugget	4.675	ft^2
Range	5.165	mi
No trend, run on thickness, residual ss = 2.59		
Splus data set	z4iso	

Table A-GC5. Detailed computations for uncertainty estimates of the NE Texas Zone 5 (z5iso) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	139,801,302	436,029,651	846,993,233	284,049,560	1,706,873,746
3	Percent of area	8	26	50	17	100
4	Area (acres)	34,546	107,745	209,297	70,190	421,778
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.823	3.248	3.665	3.692	
6	Acre feet (Acres*SD)	97,538	349,980	767,048	259,141	
7	Volume (millions short tons)	235	661	1,393	525	2,815
	Pseudo *n*					
8	*n**=Min num pts in area	275	95	12	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	5	41	294	340	681
10	Half interval width (90 % confidence interval)	9	68	484	560	1120
11	% Error, Half interval width / Volume * 100	3.61	10.30	34.76	106.53	39.81
12	Lower 90 % confidence bound (millions short tons)	227	593	909	0	1,694
13	Upper 90 % confidence bound (millions short tons)	244	729	1,877	1,085	3,935
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	10	63	395	453	921
15	Half interval width (90 % confidence interval)	17	103	649	746	1,515
16	% Error, Half interval width / Volume * 100	7.19	15.62	46.61	142.01	53.84
17	Lower 90 % confidence bound (millions short tons)	219	558	744	0	1,299
18	Upper 90 % confidence bound (millions short tons)	252	764	2,042	1,271	4,330

Table A-GC5. Detailed computations for uncertainty estimates of the NE Texas Zone 5 (z5iso) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	214	646
n	638	Meas-Infer	1.0	1522	4063
Overall exhaustion (sq.km./hole)	2.7	Meas-Hyp	1.0	1759	4669
		Ind-Inf	1.0	12185	24767
Measurement error std dev (feet)a	2.441	Ind-Hyp	1.0	14081	28457
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	100147	178995
Median number of beds	2	Covariance		259818	483192
Assumed correlation between beds	0.5	Variance		204134	365490
a - sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	7.97	10.55	13.43	13.63
Variance of measurement error	5.96	5.96	5.96	5.96
Variances, excluding meas error	2.01	4.59	7.47	7.67

Semivariogram model	Exponential	Units
Sill	7.671	ft^2
Nugget	5.960	ft^2
Range/3	0.822	mi
No trend, run on thickness, residual ss = 3.52	Range = 2.466	
Splus data set	z5iso	

Table A-GC6. Detailed computations for uncertainty estimates of the NE Texas Zone 6 (z6iso) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	38,286,123	183,657,896	711,316,649	406,053,518	1,339,314,186
3	Percent of area	3	14	53	30	100
4	Area (acres)	9,461	45,383	175,770	100,338	330,952
5	Standard deviation, SD (ft) (variogram model-inc meas err)	1.775	1.775	1.775	1.775	
6	Acre feet (Acres*SD)	16,791	80,547	311,961	178,082	
7	Volume (millions short tons)	59	297	1,337	980	2,672
	Pseudo *n*					
8	*n**=Min num pts in area	75	40	10	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	0	0	0	0
10	Half interval width (90 % confidence interval)	0	0	0	0	0
11	% Error, Half interval width / Volume * 100	0.00	0.00	0.00	0.00	0.00
12	Lower 90 % confidence bound (millions short tons)	59	297	1,337	980	2,672
13	Upper 90 % confidence bound (millions short tons)	59	297	1,337	980	2,672
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	3	22	175	312	512
15	Half interval width (90 % confidence interval)	6	37	288	513	843
16	% Error, Half interval width / Volume * 100	9.47	12.33	21.55	52.32	31.54
17	Lower 90 % confidence bound (millions short tons)	53	260	1,049	467	1,829
18	Upper 90 % confidence bound (millions short tons)	64	333	1,625	1,493	3,515

Table A-GC6. Detailed computations for uncertainty estimates of the NE Texas Zone 6 (z6iso) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	0	75
n	289	Meas-Infer	1.0	0	593
Overall exhaustion (sq.km./hole)	4.6	Meas-Hyp	1.0	0	1055
		Ind-Inf	1.0	0	3898
Measurement error std dev (feet)a	1.775	Ind-Hyp	1.0	0	6935
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	0	54590
Median number of beds	2	Covariance		0	134292
Assumed correlation between beds	0.5	Variance		0	128312

a - sqrt(Var*(Med num beds+2*Assumed corr))

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	3.15	3.15	3.15	3.15
Variance of measurement error	3.15	3.15	3.15	3.15
Variances, excluding meas error	0.00	0.00	0.00	0.00

		Units
Semivariogram model	Nugget	
Sill	0.000	ft^2
Nugget	3.150	ft^2
Range/3	0.000	mi
No trend, run on thickness	Range = 0.000	
Splus data set	z6iso	

Table A-GC7. Detailed computations for uncertainty estimates of the Central Texas Zone 5 (c5a) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	23,185,427	100,959,770	315,939,533	255,662,058	695,746,788
3	Percent of area	3	15	45	37	100
4	Area (acres)	5,729	24,948	78,070	63,175	171,923
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.100	2.100	2.100	2.100	
6	Acre feet (Acres*SD)	12,031	52,390	163,948	132,668	
7	Volume (millions short tons)	35	160	475	427	1,097
	Pseudo *n*					
8	*n**=Min num pts in area	46	22	4	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	0	0	0	0
10	Half interval width (90 % confidence interval)	0	0	0	0	0
11	% Error, Half interval width / Volume * 100	0.00	0.00	0.00	0.00	0.00
12	Lower 90 % confidence bound (millions short tons)	35	160	475	427	1,097
13	Upper 90 % confidence bound (millions short tons)	35	160	475	427	1,097
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	3	20	138	232	393
15	Half interval width (90 % confidence interval)	5	32	227	382	646
16	% Error, Half interval width / Volume * 100	14.78	20.03	47.88	89.41	58.94
17	Lower 90 % confidence bound (millions short tons)	30	128	247	45	450
18	Upper 90 % confidence bound (millions short tons)	40	192	702	809	1,743

Table A-GC7. Detailed computations for uncertainty estimates of the Central Texas Zone 5 (c5a) coal zone—*Continued*.

Computational details			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	0	61
n	124	Meas-Infer	1.0	0	431
Overall exhaustion (sq.km./hole)	5.6	Meas-Hyp	1.0	0	724
		Ind-Inf	1.0	0	2696
Measurement error std dev (feet)	2.100	Ind-Hyp	1.0	0	4532
		Inf-Hyp	1.0	0	32070
		Covariance		0	81027
		Variance		0	73373

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	4.41	4.41	4.41	4.41
Variance of measurement error	4.41	4.41	4.41	4.41
Variances, excluding meas error	0.00	0.00	0.00	0.00

		Units
Semivariogram model	Nugget	
Sill		ft^2
Nugget	4.410	ft^2
Range/3		mi
No spatial correlation, nugget model used	Range = 0.000	
Splus data set	c5a	

Table A-GC8. Detailed computations for uncertainty estimates of the Central Texas Zone 6 (c6a) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	82,977,095	250,563,665	446,605,890	120,675,835	900,822,485
3	Percent of area	9	28	50	13	100
4	Area (acres)	20,504	61,916	110,359	29,820	222,598
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.712	3.309	4.475	5.024	
6	Acre feet (Acres*SD)	55,615	204,863	493,883	149,818	
7	Volume (millions short tons)	260	708	787	132	1,886
	Pseudo *n*					
8	*n**=Min num pts in area	163	55	6	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	4	35	301	233	573
10	Half interval width (90 % confidence interval)	7	58	495	384	943
11	% Error, Half interval width / Volume * 100	2.59	8.13	62.87	291.09	49.99
12	Lower 90 % confidence bound (millions short tons)	253	650	292	0	943
13	Upper 90 % confidence bound (millions short tons)	266	765	1,282	516	2,829
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	8	48	350	262	668
15	Half interval width (90 % confidence interval)	13	80	576	431	1,099
16	% Error, Half interval width / Volume * 100	4.83	11.26	73.15	326.97	58.28
17	Lower 90 % confidence bound (millions short tons)	247	628	211	0	787
18	Upper 90 % confidence bound (millions short tons)	272	788	1,363	563	2,986

Table A-GC8. Detailed computations for uncertainty estimates of the Central Texas Zone 6 (c6a) coal zone—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	143	369
n	357	Meas-Infer	1.0	1230	2667
Overall exhaustion (sq.km./hole)	2.5	Meas-Hyp	1.0	955	1998
		Ind-Inf	1.0	10526	16958
Measurement error std dev (feet)	2.288	Ind-Hyp	1.0	8169	12704
Assumed meas error std (ft)		Inf-Hyp	1.0	70202	91758
Median number of beds		Covariance		182451	252907
Assumed correlation between beds		Variance		146183	193632

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	7.36	10.95	20.03	25.24
Variance of measurement error	5.24	5.24	5.24	5.24
Variances, excluding meas error	2.12	5.71	14.79	20.01

Semivariogram model	Exponential	Units
Sill	20.005	ft^2
Nugget	5.236	ft^2
Range/3	2.231	mi
No trend, run on thickness, residual ss = 40.04	Range = 6.693	
Splus data set	c6a	

Table A-GC9. Detailed computations for uncertainty estimates of the Central Texas Zone 8 (c8a) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	73,446,857	265,749,916	601,048,233	61,482,489	1,001,727,495
3	Percent of area	7	27	60	6	100
4	Area (acres)	18,149	65,668	148,522	15,193	247,532
5	Standard deviation, SD (ft) (variogram model-inc meas err)	1.115	1.537	2.041	2.116	
6	Acre feet (Acres*SD)	20,231	100,949	303,113	32,145	
7	Volume (millions short tons)	119	410	810	73	1,411
	Pseudo *n*					
8	*n**=Min num pts in area	144	58	8	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	2	21	174	53	250
10	Half interval width (90 % confidence interval)	4	34	287	87	412
11	% Error, Half interval width / Volume * 100	3.21	8.32	35.38	120.33	29.19
12	Lower 90 % confidence bound (millions short tons)	115	376	524	0	999
13	Upper 90 % confidence bound (millions short tons)	122	444	1,097	160	1,823
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	3	23	185	56	268
15	Half interval width (90 % confidence interval)	5	38	305	93	440
16	% Error, Half interval width / Volume * 100	4.08	9.31	37.59	127.28	31.18
17	Lower 90 % confidence bound (millions short tons)	114	372	506	0	971
18	Upper 90 % confidence bound (millions short tons)	123	448	1,115	165	1,851

Table A-GC9. Detailed computations for uncertainty estimates of the Central Texas Zone 8 (c8a) coal zone—*Continued.*

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	48	68
n	308	Meas-Infer	1.0	403	545
Overall exhaustion (sq.km./hole)	3.3	Meas-Hyp	1.0	123	166
		Ind-Inf	1.0	3610	4293
Measurement error std dev (feet)	0.690	Ind-Hyp	1.0	1102	1304
		Inf-Hyp	1.0	9266	10416
		Covariance		29104	33584
		Variance		33625	37993

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	1.24	2.36	4.17	4.48
Variance of measurement error	0.48	0.48	0.48	0.48
Variances, excluding meas error	0.77	1.89	3.69	4.00

Semivariogram model	Exponential	Units
Sill	4.001	ft^2
Nugget	0.476	ft^2
Range/3	1.175	mi
No trend, run on thickness, residual ss = 15.05	Range = 3.526	
Splus data set	c8a	

Table A-GC10. Detailed computations for uncertainty estimates of the Central Texas Zone 9 (c9a) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	42,969,260	192,766,723	569,421,920	71,018,052	876,175,955
3	Percent of area	5	22	65	8	100
4	Area (acres)	10,618	47,634	140,707	17,549	216,508
5	Standard deviation, SD (ft) (variogram model-inc meas err)	1.360	1.541	2.056	2.807	
6	Acre feet (Acres*SD)	14,438	73,395	289,246	49,252	
7	Volume (millions short tons)	58	255	707	88	1,108
	Pseudo *n*					
8	*n**=Min num pts in area	84	42	8	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	1	12	144	77	234
10	Half interval width (90 % confidence interval)	2	19	237	127	384
11	% Error, Half interval width / Volume * 100	3.02	7.43	33.50	144.93	34.70
12	Lower 90 % confidence bound (millions short tons)	57	236	470	0	724
13	Upper 90 % confidence bound (millions short tons)	60	274	944	214	1,492
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	3	20	182	86	290
15	Half interval width (90 % confidence interval)	5	33	299	142	477
16	% Error, Half interval width / Volume * 100	7.76	12.75	42.24	161.94	43.09
17	Lower 90 % confidence bound (millions short tons)	54	223	408	0	631
18	Upper 90 % confidence bound (millions short tons)	63	288	1,005	229	1,586

Table A-GC10. Detailed computations for uncertainty estimates of the Central Texas Zone 9 (c9a) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	12	54
n	207	Meas-Infer	1.0	154	499
Overall exhaustion (sq.km./hole)	4.2	Meas-Hyp	1.0	83	237
		Ind-Inf	1.0	1660	3593
Measurement error std dev (feet)	1.252	Ind-Hyp	1.0	890	1706
		Inf-Hyp	1.0	11105	15646
		Covariance		27809	43469
		Variance		26810	40779

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	1.85	2.37	4.23	7.88
Variance of measurement error	1.57	1.57	1.57	1.57
Variances, excluding meas error	0.28	0.81	2.66	6.31

Semivariogram model	Exponential	Units
Sill	6.309	ft^2
Nugget	1.568	ft^2
Range/3	5.485	mi
Exponential model residual SS= 6.67	Range =	16.455
Splus data set	c9a	

Trend, run on loess residual thicknesses, span=0.5, R^2=0.6.

Table A-GC11. Detailed computations for uncertainty estimates of the Central Texas Zone I4 (czl4) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	53,123,665	95,910,903	110,287,881	3,861,086	263,183,535
3	Percent of area	20	36	42	1	100
4	Area (acres)	13,127	23,700	27,253	954	65,034
5	Standard deviation, SD (ft) (variogram model-inc meas err)	1.802	2.060	2.066	2.066	
6	Acre feet (Acres*SD)	23,659	48,832	56,315	1,972	
7	Volume (millions short tons)	83	157	169	8	417
	Pseudo *n*					
8	*n**=Min num pts in area	104	21	2	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	2	12	52	2	69
10	Half interval width (90 % confidence interval)	3	20	86	4	113
11	% Error, Half interval width / Volume * 100	3.96	12.70	51.13	48.25	27.16
12	Lower 90 % confidence bound (millions short tons)	80	137	82	4	303
13	Upper 90 % confidence bound (millions short tons)	87	177	255	11	530
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	4	19	80	3	106
15	Half interval width (90 % confidence interval)	7	31	132	6	175
16	% Error, Half interval width / Volume * 100	8.01	19.55	78.35	73.95	42.04
17	Lower 90 % confidence bound (millions short tons)	77	126	36	2	241
18	Upper 90 % confidence bound (millions short tons)	90	188	301	13	592

Table A-GC11. Detailed computations for uncertainty estimates of the Central Texas Zone I4 (czl4) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	24	76
n	463	Meas-Infer	1.0	105	325
Overall exhaustion (sq.km./hole)	0.6	Meas-Hyp	1.0	5	14
		Ind-Inf	1.0	636	1499
Measurement error std dev (feet)	1.566	Ind-Hyp	1.0	27	64
		Inf-Hyp	1.0	118	277
		Covariance		1830	4511
		Variance		2902	6826

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	3.25	4.25	4.27	4.27
Variance of measurement error	2.45	2.45	2.45	2.45
Variances, excluding meas error	0.80	1.79	1.82	1.82

		Units
Semivariogram model	Spherical	
Sill	1.818	ft^2
Nugget	2.452	ft^2
Range	0.830	mi
No trend, run on thickness, residual ss = 0.831		
Splus data set	czl4	

Table A-GC12. Detailed computations for uncertainty estimates of the Central Texas Zone l6t (czl6t) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	68,649,254	156,947,933	110,880,339	0	336,477,526
3	Percent of area	20	47	33	0	100
4	Area (acres)	16,964	38,783	27,399	0	83,145
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.992	3.452	4.278	0.000	
6	Acre feet (Acres*SD)	50,756	133,887	117,207	0	
7	Volume (millions short tons)	177	339	210	0	727
	Pseudo *n*					
8	*n**=Min num pts in area	135	34	2	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	3	25	130		159
10	Half interval width (90 % confidence interval)	6	42	214		262
11	% Error, Half interval width / Volume * 100	3.22	12.32	101.90		36.03
12	Lower 90 % confidence bound (millions short tons)	172	297	0		465
13	Upper 90 % confidence bound (millions short tons)	183	381	425		989
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	8	40	167		214
15	Half interval width (90 % confidence interval)	13	66	274		353
16	% Error, Half interval width / Volume * 100	7.09	19.40	130.32		48.51
17	Lower 90 % confidence bound (millions short tons)	165	273	0		374
18	Upper 90 % confidence bound (millions short tons)	190	405	485		1,080

Table A-GC12. Detailed computations for uncertainty estimates of the Central Texas Zone l6t (czl6t) coal zone—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	88	306
n	798	Meas-Infer	1.0	452	1274
Overall exhaustion (sq.km./hole)	0.4	Meas-Hyp	1.0	0	0
		Ind-Inf	1.0	3312	6669
Measurement error std dev (feet)	2.667	Ind-Hyp	1.0	0	0
		Inf-Hyp	1.0	0	0
		Covariance		7705	16499
		Variance		17647	29445

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	8.95	11.92	18.30	
Variance of measurement error	7.11	7.11	7.11	
Variances, excluding meas error	1.84	4.81	11.19	

		Units
Semivariogram model	Exponential	
Sill	13.521	ft^2
Nugget	7.110	ft^2
Range/3	1.707	mi
No trend, run on thickness, residual ss = 25.96	Range = 5.121	
Splus data set	czl6t	

Table A-GC13. Detailed computations for uncertainty estimates of the Central Texas Zone I8 (czl8) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	36,243,596	92,515,775	102,499,828	3,724,323	234,983,522
3	Percent of area	15	39	44	2	100
4	Area (acres)	8,956	22,861	25,328	920	58,066
5	Standard deviation, SD (ft) (variogram model-inc meas err)	3.249	3.249	3.249	3.249	
6	Acre feet (Acres*SD)	29,102	74,285	82,302	2,990	
7	Volume (millions short tons)	102	239	196	3	540
	Pseudo *n*					
8	*n**=Min num pts in area	71	20	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	0	0	0	0
10	Half interval width (90 % confidence interval)	0	0	0	0	0
11	% Error, Half interval width / Volume * 100	0.00	0.00	0.00	0.00	0.00
12	Lower 90 % confidence bound (millions short tons)	102	239	196	3	540
13	Upper 90 % confidence bound (millions short tons)	102	239	196	3	540
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	6	29	122	5	162
15	Half interval width (90 % confidence interval)	10	48	200	9	266
16	% Error, Half interval width / Volume * 100	9.77	19.92	101.96	256.64	49.31
17	Lower 90 % confidence bound (millions short tons)	92	191	0	0	274
18	Upper 90 % confidence bound (millions short tons)	112	286	397	12	807

Table A-GC13. Detailed computations for uncertainty estimates of the Central Texas Zone I8 (czl8) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	0	174
n	237	Meas-Infer	1.0	0	734
Overall exhaustion (sq.km./hole)	1.0	Meas-Hyp	1.0	0	32
		Ind-Inf	1.0	0	3520
Measurement error std dev (feet)a	3.249	Ind-Hyp	1.0	0	151
Assumed meas error std (ft)	2.5	Inf-Hyp	1.0	0	637
Median number of beds	2	Covariance		0	10498
Assumed correlation between beds	0.5	Variance		0	15720
a - sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	10.56	10.56	10.56	10.56
Variance of measurement error	10.56	10.56	10.56	10.56
Variances, excluding meas error	0.00	0.00	0.00	0.00

		Units
Semivariogram model	Nugget	
Sill		ft^2
Nugget	10.559	ft^2
Range/3		mi
No spatial correlation	Range = 0.000	
Splus data set	czl8	

Table A-GC14. Detailed computations for uncertainty estimates of the Central Texas Zone m4 (czm4) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	17,825,904	38,366,797	19,557,560	0	75,750,261
3	Percent of area	24	51	26	0	100
4	Area (acres)	4,405	9,481	4,833	0	18,718
5	Standard deviation, SD (ft) (variogram model-inc meas err)	1.972	1.972	1.972	0.000	
6	Acre feet (Acres*SD)	8,686	18,694	9,529	0	
7	Volume (millions short tons)	26	58	33	0	118
	Pseudo *n*					
8	*n**=Min num pts in area	35	8	0	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	0	0		0
10	Half interval width (90 % confidence interval)	0	0	0		0
11	% Error, Half interval width / Volume * 100	0.00	0.00	0.00		0.00
12	Lower 90 % confidence bound (millions short tons)	26	58	33		118
13	Upper 90 % confidence bound (millions short tons)	26	58	33		118
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	3	11	32		46
15	Half interval width (90 % confidence interval)	4	19	53		76
16	% Error, Half interval width / Volume * 100	16.02	31.81	162.17		64.57
17	Lower 90 % confidence bound (millions short tons)	22	40	0		42
18	Upper 90 % confidence bound (millions short tons)	31	77	86		193

Table A-GC14. Detailed computations for uncertainty estimates of the Central Texas Zone m4 (czm4) coal zone—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	0	29
n	96	Meas-Infer	1.0	0	83
Overall exhaustion (sq.km./hole)	0.8	Meas-Hyp	1.0	0	0
		Ind-Inf	1.0	0	365
Measurement error std dev (feet)	1.972	Ind-Hyp	1.0	0	0
		Inf-Hyp	1.0	0	0
		Covariance		0	953
		Variance		0	1176

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	3.89	3.89	3.89	
Variance of measurement error	3.89	3.89	3.89	
Variances, excluding meas error	0.00	0.00	0.00	

		Units
Semivariogram model	Nugget	
Sill		ft^2
Nugget	3.888	ft^2
Range/3		mi
Weak spatial correlation, used nugget model		
Splus data set	czm4	

Table A-GC15. Detailed computations for uncertainty estimates of the Central Texas Zone m5 (czm5) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	28,636,707	55,420,294	16,302,508	0	100,359,509
3	Percent of area	29	55	16	0	100
4	Area (acres)	7,076	13,695	4,028	0	24,799
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.388	2.611	3.112	0.000	
6	Acre feet (Acres*SD)	16,896	35,752	12,537	0	
7	Volume (millions short tons)	117	217	75	0	409
	Pseudo *n*					
8	*n**=Min num pts in area	56	12	0	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	1	9	32		43
10	Half interval width (90 % confidence interval)	2	15	53		70
11	% Error, Half interval width / Volume * 100	1.88	6.94	70.91		17.18
12	Lower 90 % confidence bound (millions short tons)	115	202	22		338
13	Upper 90 % confidence bound (millions short tons)	119	232	128		479
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	4	18	46		68
15	Half interval width (90 % confidence interval)	6	30	76		113
16	% Error, Half interval width / Volume * 100	5.55	13.62	102.46		27.54
17	Lower 90 % confidence bound (millions short tons)	110	188	0		296
18	Upper 90 % confidence bound (millions short tons)	123	247	151		521

Table A-GC15. Detailed computations for uncertainty estimates of the Central Texas Zone m5 (czm5) coal zone—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	12	71
n	135	Meas-Infer	1.0	43	183
Overall exhaustion (sq.km./hole)	0.7	Meas-Hyp	1.0	0	0
		Ind-Inf	1.0	295	836
Measurement error std dev (feet)	2.246	Ind-Hyp	1.0	0	0
		Inf-Hyp	1.0	0	0
		Covariance		700	2180
		Variance		1121	2501

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	5.70	6.82	9.69	
Variance of measurement error	5.05	5.05	5.05	
Variances, excluding meas error	0.65	1.77	4.64	

Semivariogram model	Exponential	Units
Sill	6.378	ft^2
Nugget	5.047	ft^2
Range/3	2.309	mi
No trend, run on thickness, residual ss = 12.75	Range = 6.927	
Splus data set	czm5	

Table A-GC16. Detailed computations for uncertainty estimates of the Louisiana Sabine (la) coal zone.

[Date of est 11/25/2000. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	147,923,500	258,985,191	207,217,034	0	614,125,725
3	Percent of area	24	42	34	0	100
4	Area (acres)	36,553	63,997	51,204	0	151,754
5	Standard deviation, SD (ft) (variogram model-inc meas err)	2.647	2.647	2.647	0.000	
6	Acre feet (Acres*SD)	96,767	169,420	135,554	0	
7	Volume (millions short tons)	383	615	378	0	1,376
	Pseudo *n*					
8	*n**=Min num pts in area	291	57	3	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	0	0	0	0
10	Half interval width (90 % confidence interval)	0	0	0	0	0
11	% Error, Half interval width / Volume * 100	0.00	0.00	0.00	0.00	0.00
12	Lower 90 % confidence bound (millions short tons)	383	615	378	0	1,376
13	Upper 90 % confidence bound (millions short tons)	383	615	378	0	1,376
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	10	39	141	0	190
15	Half interval width (90 % confidence interval)	16	65	232	0	313
16	% Error, Half interval width / Volume * 100	4.26	10.54	61.37	0.00	22.76
17	Lower 90 % confidence bound (millions short tons)	367	550	146	0	1,063
18	Upper 90 % confidence bound (millions short tons)	399	680	610	0	1,689

Table A-GC16. Detailed computations for uncertainty estimates of the Louisiana Sabine (la) coal zone —*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1750	Meas-Ind	1.0	0	391
n	940	Meas-Infer	1.0	0	1400
Overall exhaustion (sq.km./hole)	0.7	Meas-Hyp	1.0	0	0
		Ind-Inf	1.0	0	5558
Measurement error std dev (feet)	2.647	Ind-Hyp	1.0	0	0
		Inf-Hyp	1.0	0	0
		Covariance		0	14699
		Variance		0	21539

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	7.01	7.01	7.01	0.00
Variance of measurement error	7.01	7.01	7.01	0.00
Variances, excluding meas error	0.00	0.00	0.00	0.00

		Units
Semivariogram model	Nugget	
Sill		ft^2
Nugget	7.008	ft^2
Range/3		mi
No spatial correlation, nugget model used	Range = 0.000	
Splus data set	la	

Nugget is pooled variance estimate.

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Order of presentation of detailed computational files for the Illinois Basin (IB).

Data set ID	Assessment unit	Table
ILDAN	Danville in IL	A-IB1
ILHER	Herrin in IL	A-IB2
ILSPR	Springfield in IL	A-IB3
INDAN	Danville in IN	A-IB4
INSPR	Springfield in IN	A-IB5
KYBAK	Baker in KY	A-IB6
KYHER	Herrin in KY	A-IB7
KYSPR	Springfield in KY	A-IB8

Table A-IB1. Detailed computations for uncertainty estimates of the Danville (ILDAN) bed in Illinois.

[Date of est 8/25/2000. Form revised 6/11/99]

Row	Reliability category	I-A (0–0.5 mi)	I-B (0.5–2 mi)	II-A (2–4 mi)	Entire area
2	Area (sq meters)	1,026,294,929	5,048,299,606	6,154,163,827	12,228,758,362
3	Percent of area	8	41	50	100
4	Area (acres)	253,603	1,247,462	1,520,727	3,021,792
5	Standard deviation, SD (ft) (variogram model inc meas err)	1.118	1.118	1.118	
6	Acre feet (Acres*SD)	283,528	1,394,663	1,700,173	
7	Volume (millions short tons)	1,851	7,513	8,448	17,811
	Pseudo *n*				
8	*n**=Min num pts in area	505	155	47	
	Estimates of uncertainty: no measurement error				
9	Vol std dev (millions st) sv	21	189	418	628
10	Half interval width (90 % confidence interval)	35	311	687	1033
11	% Error, Half interval width / Volume * 100	1.89	4.14	8.13	5.80
12	Lower 90 % confidence bound (millions short tons)	1,816	7,202	7,761	16,778
13	Upper 90 % confidence bound (millions short tons)	1,886	7,824	9,135	18,844
	Estimates of uncertainty: measurement error included				
14	Vol std dev (millions st) sc	23	202	445	669
15	Half interval width (90 % confidence interval)	37	332	732	1,101
16	% Error, Half interval width / Volume * 100	2.02	4.41	8.67	6.18
17	Lower 90 % confidence bound (millions short tons)	1,814	7,181	7,716	16,710
18	Upper 90 % confidence bound (millions short tons)	1,888	7,844	9,180	18,912

Table A-IB1. Detailed computations for uncertainty estimates of the Danville (ILDAN) bed in Illinois—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	I-A – I-B	1.0	4030	4580
n (publically available data)	6465	I-A – II-A	1.0	8900	10113
Overall exhaustion (sq.km./hole)	1.9				
		I-B – II-A	1.0	78953	89720
Measurement error std dev (feet) - nugget	0.387				
Median number of beds	1	Covariance		183765	208825
		Variance		210553	239267

	I-A	I-B	II-B
Variances, including meas error	1.25	1.25	1.25
Variance of measurement error	0.15	0.15	0.15
Variances, excluding meas error	1.10	1.10	1.10

		Units
Semivariogram model	Nugget	
Sill		
Nugget	0.150	ft^2
Range/3		
No trend, thicknesses used		
Splus data set	ILDAN	

Table A-IB2. Detailed computations for uncertainty estimaes of the Herrin (ILHER) bed in Illinois.

[Date of est 7/7/1999. Form revised 6/11/99]

Row	Reliability category	I-A (0–0.5 mi)	I-B (0.5–2 mi)	II-A (2–4 mi)	Entire area
2	Area (sq meters)	7,076,762,107	14,718,655,573	14,583,357,022	36,378,774,702
3	Percent of area	19	40	40	100
4	Area (acres)	1,748,706	3,637,059	3,603,626	8,989,391
5	Standard deviation, SD (ft) (variogram model inc meas err)	1.140	1.204	1.280	
6	Acre feet (Acres*SD)	1,992,859	4,378,052	4,610,861	
7	Volume (millions short tons)	19,193	34,379	25,371	78,943
	Pseudo *n*				
8	*n**=Min num pts in area	3479	452	112	
	Estimates of uncertainty: no measurement error				
9	Vol SD (millions st) sv	12	138	383	533
10	Half interval width (90 % confidence interval)	20	228	630	878
11	% Error, Half interval width / Volume * 100	0.10	0.66	2.48	1.11
12	Lower 90 % confidence bound (millions short tons)	19,173	34,152	24,741	78,066
13	Upper 90 % confidence bound (millions short tons)	19,213	34,607	26,000	79,821
	Estimates of uncertainty: measurement error included				
14	Vol SD (millions st) sc	61	371	784	1,216
15	Half interval width (90 % confidence interval)	100	610	1,290	2,000
16	% Error, Half interval width / Volume * 100	0.52	1.77	5.08	2.53
17	Lower 90 % confidence bound (millions short tons)	19,093	33,770	24,081	76,944
18	Upper 90 % confidence bound (millions short tons)	19,293	34,989	26,661	80,943

Table A-IB2. Detailed computations for uncertainty estimaes of the Herrin (ILHER) bed in Illinois—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	I-A – I-B	1.0	1683	22537
n (publically available data)	16325	I-A – II-A	1.0	4655	47691
Overall exhaustion (sq.km./hole)	2.2				
		I-B – II-A	1.0	52997	290591
Measurement error std dev (feet) - nugget	1.117				
Median number of beds	1	Covariance		118670	721638
		Variance		165909	755943

	I-A	I-B	II-B
Variances, including meas error	1.30	1.45	1.64
Variance of measurement error	1.25	1.25	1.25
Variances, excluding meas error	0.05	0.20	0.39

		Units
Semivariogram model	Exponential	
Sill	2.921	ft^2
Nugget	1.247	ft^2
Range/3	27.886	mi
No trend	Range = 83.657	
Splus data set	ILHER	

Table A-IB3. Detailed computations for uncertainty estimates of the Springfield (ILSPR) bed in Illinois.

[Date of est 6/30/1999. Form revised 6/11/99]

Row	Reliability category	I-A (0–0.5 mi)	I-B (0.5–2 mi)	II-A (2–4 mi)	Entire area
2	Area (sq meters)	2,853,604,385	10,124,372,788	21,265,307,816	34,243,284,989
3	Percent of area	8	30	62	100
4	Area (acres)	705,141	2,501,787	5,254,772	8,461,700
5	Standard deviation, SD (ft) (variogram model inc meas err)	0.866	0.998	1.098	
6	Acre feet (Acres*SD)	610,883	2,497,970	5,771,565	
7	Volume (millions short tons)	6,004	19,562	35,833	61,400
	Pseudo *n*				
8	*n**=Min num pts in area	1403	311	163	
	Estimates of uncertainty: no measurement error				
9	Vol std dev (millions st) sv	11	152	555	717
10	Half interval width (90 % confidence interval)	18	249	912	1180
11	% Error, Half interval width / Volume * 100	0.30	1.27	2.55	1.92
12	Lower 90 % confidence bound (millions short tons)	5,986	19,313	34,921	60,220
13	Upper 90 % confidence bound (millions short tons)	6,023	19,811	36,746	62,580
	Estimates of uncertainty: measurement error included				
14	Vol std dev (millions st) sc	29	255	813	1,097
15	Half interval width (90 % confidence interval)	48	419	1,337	1,805
16	% Error, Half interval width / Volume * 100	0.80	2.14	3.73	2.94
17	Lower 90 % confidence bound (millions short tons)	5,956	19,143	34,496	59,595
18	Upper 90 % confidence bound (millions short tons)	6,053	19,981	37,171	63,205

Table A-IB3. Detailed computations for uncertainty estimates of the Springfield (ILSPR) bed in Illinois—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	I-A – I-B	1.0	1672	7484
n (publically available data)	10630	I-A – II-A	1.0	6119	23864
Overall exhaustion (sq.km./hole)	3.2				
		I-B – II-A	1.0	84075	207226
Measurement error std dev (feet) - nugget	0.803				
Median number of beds	1	Covariance		183731	477148
		Variance		330796	726589

	I-A	I-B	II-B
Variances, including meas error	0.75	1.00	1.21
Variance of measurement error	0.64	0.64	0.64
Variances, excluding meas error	0.11	0.35	0.56

		Units
Semivariogram model	Exponential	
Sill	0.869	ft^2
Nugget	0.645	ft^2
Range/3	3.843	mi
No trend	Range = 11.530	
Splus data set	ILSPR	

Table A-IB4. Detailed computations for uncertainty estimates of the Danville (INDAN) bed in Indiana.

[Date of est 6/23/1999. Form revised 6/11/99]

Row	Reliability category	I-A (0–0.5 mi)	I-B (0.5–2 mi)	II-A (2–4 mi)	Entire area
2	Area (sq meters)	2,861,685,469	2,310,016,408	226,232,657	5,397,934,534
3	Percent of area	53	43	4	100
4	Area (acres)	707,138	570,817	55,903	1,333,859
5	Standard deviation, SD (ft) (variogram model inc meas err)	0.622	0.707	0.765	
6	Acre feet (Acres*SD)	440,012	403,793	42,747	
7	Volume (millions short tons)	3,316	2,692	241	6,249
	Pseudo *n*				
8	*n**=Min num pts in area	1407	71	2	
	Estimates of uncertainty: no measurement error				
9	Vol SD (millions st) sv	8	50	38	96
10	Half interval width (90 % confidence interval)	13	82	63	157
11	% Error, Half interval width / Volume * 100	0.39	3.03	26.06	2.52
12	Lower 90 % confidence bound (millions short tons)	3,304	2,610	178	6,092
13	Upper 90 % confidence bound (millions short tons)	3,329	2,774	304	6,407
	Estimates of uncertainty: measurement error included				
14	Vol SD (millions st) sc	21	86	58	166
15	Half interval width (90 % confidence interval)	35	142	96	273
16	% Error, Half interval width / Volume * 100	1.05	5.27	39.86	4.36
17	Lower 90 % confidence bound (millions short tons)	3,282	2,550	145	5,977
18	Upper 90 % confidence bound (millions short tons)	3,351	2,834	337	6,522

Table A-IB4. Detailed computations for uncertainty estimates of the Danville (INDAN) bed in Indiana—*Continued*.

Computational details

			Assumed corr	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	I-A – I-B	1.0	386	1822
n (publically available data)	3088	I-A – II-A	1.0	296	1233
Overall exhaustion (sq.km./hole)	1.7				
		I-B – II-A	1.0	1894	5036
Measurement error std dev (feet) - nugget	0.579				
Median number of beds	1	Covariance		5152	16180
		Variance		3980	11296

	I-A	I-B	II-B
Variances, including meas error	0.39	0.50	0.58
Variance of measurement error	0.33	0.33	0.33
Variances, excluding meas error	0.05	0.17	0.25

		Units
Semivariogram model	Exponential	
Sill	0.337	ft^2
Nugget	0.335	ft^2
Range/3	2.962	mi
No trend	Range = 8.886	
Splus data set	IND	

Table A-IB5. Detailed computations for uncertainty estimates of the Springfield (INSPR) bed in Indiana.

[Date of est 6/23/1999. Form revised 6/11/99]

Row	Reliability category	I-A (0–0.5 mi)	I-B (0.5–2 mi)	II-A (2–4 mi)	Entire area
2	Area (sq meters)	4,172,879,479	2,852,544,120	277,580,981	7,303,004,580
3	Percent of area	57	39	4	100
4	Area (acres)	1,031,141	704,879	68,592	1,804,612
5	Standard deviation, SD (ft) (variogram inc meas err)	1.092	1.258	1.272	
6	Acre feet (Acres*SD)	1,125,561	886,593	87,253	
7	Volume (millions short tons)	6,679	4,739	473	11,890
	Pseudo *n*				
8	*n**=Min num pts in area	2051	88	2	
	Estimates of uncertainty: no measurement error				
9	Vol SD (millions st) sv	30	130	83	243
10	Half interval width (90 % confidence interval)	49	215	136	400
11	% Error, Half interval width / Volume * 100	0.74	4.53	28.87	3.37
12	Lower 90 % confidence bound (millions short tons)	6,630	4,524	336	11,490
13	Upper 90 % confidence bound (millions short tons)	6,728	4,953	609	12,290
	Estimates of uncertainty: measurement error included				
14	Vol SD (millions st) sc	45	170	108	323
15	Half interval width (90 % confidence interval)	74	280	177	531
16	% Error, Half interval width / Volume * 100	1.10	5.92	37.45	4.47
17	Lower 90 % confidence bound (millions short tons)	6,605	4,458	296	11,359
18	Upper 90 % confidence bound (millions short tons)	6,752	5,019	649	12,421

Table A-IB5. Detailed computations for uncertainty estimates of the Springfield (INSPR) bed in Indiana—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	I-A – I-B	1.0	3909	7625
n (publically available data)	4842	I-A – II-A	1.0	2486	4811
Overall exhaustion (sq.km./hole)	1.5				
		I-B – II-A	1.0	10813	18335
Measurement error std dev (feet) - nugget	0.810				
Median number of beds	1	Covariance		34417	61543
		Variance		24779	42628

	I-A	I-B	II-B
Variances, including meas error	1.19	1.58	1.62
Variance of measurement error	0.66	0.66	0.66
Variances, excluding meas error	0.54	0.93	0.96

		Units
Semivariogram model	Exponential	
Sill	0.963	ft^2
Nugget	0.656	ft^2
Range/3	0.617	mi
No trend	Range = 1.850	
Splus data set	INSPR	

Table A-IB6. Detailed computations for uncertainty estimates of the Baker (KYBAK) bed in Kentucky.

[Date of est 7/7/1999. Form revised 3/16/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	485,934,783	858,754,669	1,352,443,229	267,529,584	2,964,662,265
3	Percent of area	16	29	46	9	100
4	Area (acres)	120,077	212,203	334,196	66,108	732,584
5	Standard deviation, SD (ft) (variogram model inc meas err)	0.875	1.073	1.113	1.113	
6	Acre feet (Acres*SD)	105,106	227,626	372,012	73,590	
7	Volume (millions short tons)	631	1,107	1,615	282	3,636
	Pseudo *n*					
8	*n**=Min num pts in area	956	188	18	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	6	28	146	132	312
10	Half interval width (90 % confidence interval)	9	46	241	218	514
11	% Error, Half interval width / Volume * 100	1.43	4.16	14.91	77.20	14.13
12	Lower 90 % confidence bound (millions short tons)	622	1,061	1,374	64	3,122
13	Upper 90 % confidence bound (millions short tons)	641	1,153	1,856	500	4,149
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	6	30	156	132	324
15	Half interval width (90 % confidence interval)	10	49	256	218	533
16	% Error, Half interval width / Volume * 100	1.59	4.45	15.87	77.20	14.67
17	Lower 90 % confidence bound (millions short tons)	621	1,057	1,359	64	3,102
18	Upper 90 % confidence bound (millions short tons)	642	1,156	1,872	500	4,169

Table A-IB6. Detailed computations for uncertainty estimates of the Baker (KYBAK) bed in Kentucky—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	Meas-Ind	1.0	154	183
n (total data points used for volume estimation)	2343	Meas-Infer	1.0	806	954
Overall exhaustion (sq.km./hole)	1.3	Meas-Hyp	1.0	729	811
n (publically available data used for uncertainty)	601	Ind-Inf	1.0	4091	4661
Measurement error std dev (feet) - from nugget	0.382	Ind-Hyp	1.0	3703	3962
		Inf-Hyp	1.0	19387	20640
Median number of beds	1	Covariance		57740	62420
		Variance		39779	42757

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	0.77	1.15	1.24	1.24
Variance of measurement error	0.15	0.15	0.15	0.00
Variances, excluding meas error	0.62	1.00	1.09	1.24

		Units
Semivariogram model	Exponential	
Sill	1.093	ft^2
Nugget	0.146	ft^2
Range/3	0.298	mi
Semivariogram on thickness	Range = 0.895	
Splus data set	KYBAK	

Table A-IB7. Detailed computations for uncertainty estimates of the Herrin (KYHER) bed in Kentucky.

[Date of est 7/7/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	421,338,861	677,791,795	933,402,578	177,639,595	2,210,172,829
3	Percent of area	19	31	42	8	100
4	Area (acres)	104,115	167,486	230,649	43,896	546,145.60
5	Standard deviation, SD (ft) (inc meas err)	0.787	0.902	1.011	1.018	
6	Acre feet (Acres*SD)	81,973	151,024	233,239	44,679	
7	Volume (millions short tons)	471	836	1,307	293	2,907
	Pseudo *n*					
8	*n**=Min num pts in area	829	148	13	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	3	15	87	80	184
10	Half interval width (90 % confidence interval)	4	24	143	132	303
11	% Error, Half interval width / Volume * 100	0.89	2.87	10.90	45.22	10.42
12	Lower 90 % confidence bound (millions short tons)	467	812	1,165	160	2,604
13	Upper 90 % confidence bound (millions short tons)	475	860	1,450	425	3,210
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	5	22	118	80	225
15	Half interval width (90 % confidence interval)	8	37	193	132	371
16	% Error, Half interval width / Volume * 100	1.79	4.40	14.80	45.22	12.76
17	Lower 90 % confidence bound (millions short tons)	463	799	1,114	160	2,536
18	Upper 90 % confidence bound (millions short tons)	480	873	1,501	425	3,278

Table A-IB7. Detailed computations for uncertainty estimates of the Herrin (KYHER) bed in Kentucky—*Continued*.

Computational details

Square meters to square miles	3.86102E-07		Assumed correlations	No meas err	Meas err
Coal density (short tons/acre feet)	1800	Meas-Ind	1.0	37	115
n (total data points used for volume estimation)	2562	Meas-Infer	1.0	220	603
Overall exhaustion (sq.km./hole)	0.9	Meas-Hyp	1.0	204	412
n (publically available data used for uncertainty)	650	Ind-Inf	1.0	1262	2627
Measurement error std dev (feet) - from nugget	0.684	Ind-Hyp	1.0	1171	1797
		Inf-Hyp	1.0	6968	9457
Median number of beds	1	Covariance		19725	30020
		Variance		14193	20821

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	0.62	0.81	1.02	1.04
Variance of measurement error	0.47	0.47	0.47	0.00
Variances, excluding meas error	0.15	0.35	0.56	1.04

		Units
Semivariogram model	Exponential	
Sill	0.569	ft^2
Nugget	0.467	ft^2
Range/3	0.801	mi
Semivariogram on loess residuals, span = 0.5	Range = 2.403	
Splus data set	KYHER	

Table A-IB8. Detailed computations for uncertainty estimates of the Springfield (KYSPR) bed in Kentucky.

[Date of est 7/6/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	801,671,331	1,535,411,725	2,292,046,805	298,570,997	4,927,700,857
3	Percent of area	16	31	47	6	100
4	Area (acres)	198,097	379,409	566,377	73,779	1,217,661
5	Standard deviation, SD (ft) (inc meas err)	0.529	0.545	0.605	0.807	
6	Acre feet (Acres*SD)	104,760	206,850	342,926	59,574	
7	Volume (millions short tons)	1,057	2,235	3,698	524	7,514
	Pseudo *n*					
8	*n**=Min num pts in area	1576	335	31	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	1	6	56	107	171
10	Half interval width (90 % confidence interval)	1	10	93	176	281
11	% Error, Half interval width / Volume * 100	0.13	0.45	2.51	33.69	3.74
12	Lower 90 % confidence bound (millions short tons)	1,056	2,225	3,605	347	7,234
13	Upper 90 % confidence bound (millions short tons)	1,058	2,245	3,791	700	7,795
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	5	20	110	107	243
15	Half interval width (90 % confidence interval)	8	33	181	176	399
16	% Error, Half interval width / Volume * 100	0.74	1.50	4.91	33.69	5.31
17	Lower 90 % confidence bound (millions short tons)	1,049	2,202	3,517	347	7,115
18	Upper 90 % confidence bound (millions short tons)	1,065	2,269	3,880	700	7,913

Table A-IB8. Detailed computations for uncertainty estimates of the Springfield (KYSPR) bed in Kentucky—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1800	Meas-Ind	1.0	5	97
n (total data points used for volume estimation)	2390	Meas-Infer	1.0	48	524
Overall exhaustion (sq.km./hole)	2.1	Meas-Hyp	1.0	92	509
n (publically available data for uncertainty estimation)	984	Ind-Inf	1.0	344	2243
Measurement error std dev (feet) - from nugget	0.520	Ind-Hyp	1.0	653	2180
		Inf-Hyp	1.0	6056	11831
Median number of beds	1	Covariance		14397	34768
		Variance		14726	24108

	Measured	Indicated	Inferred	Hypothetical
Variances, including meas error	0.28	0.30	0.37	0.65
Variance of measurement error	0.27	0.27	0.27	0.00
Variances, excluding meas error	0.01	0.03	0.10	0.65

		Units
Semivariogram model	Exponential	
Sill	0.381	ft^2
Nugget	0.271	ft^2
Range/3	10.342	mi
Semivariogram on thickness	Range = 31.026	
Splus data set	KYSPR	

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Order of presentation of detailed computational files for the Northern Rocky Mountains and Great Plains region (NR).

Data set ID	Assessment unit	Table
CAR	Carbon, Johnson-107	A-NR1
BBJB	Greater Green River, Deadman seams, BlackButte/JimBridger	A-NR2
F23	Hanna, Ferris 23	A-NR3
F25	Hanna, Ferris 25	A-NR4
F31	Hanna, Ferris 31	A-NR5
F50	Hanna, Ferris 50	A-NR6
F65	Hanna, Ferris 65	A-NR7
H77	Hanna - 77	A-NR8
H78	Hanna - 78	A-NR9
H79	Hanna - 79	A-NR10
H81	Hanna - 81	A-NR11
KNO1	Powder River, Ashland coal field, Knobloch coal bed	A-NR12
COL	Powder River, Rosebud-Robinson, Colstrip	A-NR13
WA	Powder River, Wyodak-Anderson	A-NR14
WAC*	Powder River, Wyodak-Anderson, Decker coal field	A-NR15
WAG*	Powder River, Wyodak-Anderson, Gillette coal field	A-NR16
WAS*	Powder River, Wyodak-Anderson, Sheridan coal field	A-NR17
BZ	Williston, Beulah-Zap	A-NR18
HAG	Williston, Hagel	A-NR19
HAN	Williston, Hansen	A-NR20
HAR	Williston, Harmon	A-NR21

* subarea of Wyodak-Anderson coal zone.

Table A-NR1. Detailed computations for uncertainty estimates of the Johnson-107 (CAR) coal zone.

[Date of est 3/26/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred[a]	Hypothetical	Entire area
2	Area (sq meters)	9,114,330	37,519,215	12,687,826	0	59,321,371
3	Percent of area	15	63	21	0	100
4	Area (acres)	2,252	9,271	3,135	0	14,659
5	Standard deviation, SD (ft) (variogram model inc meas err)[b]	13.780	13.780	13.780	0.000	
6	Acre feet (Acres*SD)	31,035	127,757	43,203	0	
7	Volume (millions short tons)	141	698	301	0	1,140
	Pseudo *n*					
8	*n**=Min num pts in area	18	8	0.17	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	12	72	168	0	252
10	Half interval width (90 % confidence interval)	20	119	276	0	414
11	% Error, Half interval width / Volume * 100	13.83	17.00	91.90	0.00	36.36
12	Lower 90 % confidence bound (millions short tons)	122	580	24	0	726
13	Upper 90 % confidence bound (millions short tons)	161	817	577	0	1,555
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	13	79	184	0	276
15	Half interval width (90 % confidence interval)	21	130	302	0	453
16	% Error, Half interval width / Volume * 100	15.14	18.60	100.55	0.00	39.78
17	Lower 90 % confidence bound (millions short tons)	120	569	0	0	687
18	Upper 90 % confidence bound (millions short tons)	162	828	603	0	1,594

Table A-NR1. Detailed computations for uncertainty estimates of the Johnson-107 (CAR) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	856	1025
n	35	Meas-Infer	1.0	1992	2384
Overall exhaustion (sq.km./hole)	1.7	Meas-Hyp	1.0	0	0
		Ind-Inf	1.0	12122	14510
Measurement error SD (ft)[c]	5.59	Ind-Hyp	1.0	0	0
Assumed meas error SD (ft)	2.5	Inf-Hyp	1.0	0	0
Median number of beds	4	Covariance		29939	35837
Assumed correlation between beds	0.5	Variance		33548	40157

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	189.89	189.89	189.89	0.00
Variance of measurement error	31.25	31.25	31.25	0.00
Variance, excluding meas error	158.64	158.64	158.64	0.00

Semivariogram model	Nugget
Sill	
Nugget	
Range/3	
Residuals std error from loess, span = 0.5	
Splus data set	CAR

a In the inferred category, there is only room for 0.17 points, thus the uncertainty results for this category are not statistically meaningful.
b Standard deviation, SD (row 5) is residual standard error from loess regression.
c sqrt(Var*(Med num beds+2*Assumed corr)).

Table A-NR2. Detailed computations for uncertainty estimates of the Black Butte–Jim Bridger (BBJB) coal mine.

[Date of est 3/25/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	9,717,393	34,140,778	243,970,122	0	287,828,292
3	Percent of area	3	12	85	0	100
4	Area (acres)	2,401.22	8,436.37	60,286.33	0	71,124
5	Standard deviation, SD (ft) (variogram model inc meas err)	6.317	6.317	6.317	0.000	
6	Acre feet (Acres*SD)	15,169	53,294	380,841	0	
7	Volume (millions short tons)	92.7381	320.49	2,258.07	0.00	2671.30
	Pseudo *n*					
8	*n**=Min num pts in area	19	7	3	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	6	32	339	0	377
10	Half interval width (90 % confidence interval)	9	52	558	0	619
11	% Error, Half interval width / Volume * 100	10.01	16.28	24.71	0.00	23.19
12	Lower 90 % confidence bound (millions short tons)	83	268	1,700	0	2,052
13	Upper 90 % confidence bound (millions short tons)	102	373	2,816	0	3,291
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	6	35	369	0	410
15	Half interval width (90 % confidence interval)	10	57	608	0	674
16	% Error, Half interval width / Volume * 100	10.89	17.73	26.90	0.00	25.25
17	Lower 90 % confidence bound (millions short tons)	83	264	1,651	0	1,997
18	Upper 90 % confidence bound (millions short tons)	103	377	2,866	0	3,346

Table A-NR2. Detailed computations for uncertainty estimates of the Black Butte–Jim Bridger (BBJB) coal mine—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	179	212
n	2,823	Meas-Infer	1.0	1913	2268
Overall exhaustion (sq.km./hole)	0.1	Meas-Hyp	1.0	0	0
		Ind-Inf	1.0	10758	12755
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	0	0
		Inf-Hyp	1.0	0	0
Median number of beds	1	Covariance		25700	30472
		Variance		116069	137622

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	39.91	39.91	39.91	0.00
Variance of measurement error	6.25	6.25	6.25	0.00
Variance, excluding meas error	33.66	33.66	33.66	0.00

No significant spatial correlation in any of the subareas			
Run on thicknesses			
Splus data set	BBJB		
	JB	BB1-3	BB4
Standard deviation (ft)	6.756	5.637	6.261
n	1224	793.00	806.00
Pooled estimate	6.317		
ARC areas used	2,401.22	8,436.37	60,286.33

Table A-NR3. Detailed computations for uncertainty estimates of the Ferris-23 (F23) coal bed.

[Date of est 3/27/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	6,116,176	12,591,713	46,035,986	36,008,928	100,752,804
3	Percent of area	6	12	46	36	100
4	Area (acres)	1,511	3,111	11,376	8,898	24,897
5	Standard deviation, SD (ft) (variogram model inc meas err)	2.000	3.464	6.325	6.325	
6	Acre feet (Acres*SD)	3,023	10,778	71,946	56,276	
7	Volume (millions short tons)	22.6	38.0	109.3	64.0	233.8
	Pseudo *n*					
8	*n**=Min num pts in area	12	3	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	1.5	11.5	160.6	99.6	273
10	Half interval width (90 % confidence interval)	3	19	264	164	450
11	% Error, Half interval width / Volume * 100	11.22	49.85	241.72	256.12	192.23
12	Lower 90 % confidence bound (millions short tons)	20	19	0	0	0
13	Upper 90 % confidence bound (millions short tons)	25	57	374	228	683
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	2	12	161	100	273
15	Half interval width (90 % confidence interval)	3	19	264	164	450
16	% Error, Half interval width / Volume * 100	11.22	49.85	241.72	256.12	192.23
17	Lower 90 % confidence bound (millions short tons)	20	19	0	0	0
18	Upper 90 % confidence bound (millions short tons)	25	57	374	228	683

Table A-NR3. Detailed computations for uncertainty estimates of the Ferris-23 (F23) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	18	18
n	69	Meas-Infer	1.0	248	248
Overall exhaustion (sq.km./hole)	1.5	Meas-Hyp	1.0	154	154
		Ind-Inf	1.0	1847	1847
Measurement error SD (ft) - nugget	0.00	Ind-Hyp	1.0	1146	1146
		Inf-Hyp	1.0	15998	15998
Median number of beds	1	Covariance		38821	38821
		Variance		35853	35853

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	4.00	12.00	40.00	40.00
Variance of measurement error	0.00	0.00	0.00	0.00
Variance, excluding meas error	4.00	12.00	40.00	40.00

		Units
Semivariogram model	Linear	
Sill	40	ft^2
Nugget	0	ft^2
Range	2.5	mi
Run on thicknesses	Slope=16	
Splus data set	F23	

Table A-NR4. Detailed computations for uncertainty estimates of the Ferris-25 (F25) coal bed.

[Date of est 3/27/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	6,563,920	12,895,672	40,318,426	89,497,646	149,275,664
3	Percent of area	4	9	27	60	100
4	Area (acres)	1,621.98	3,186.59	9,962.90	22,115.35	36,886.82
5	Standard deviation, SD (ft) (variogram model inc meas err)	4.705	5.141	6.760	6.760	
6	Acre feet (Acres*SD)	7,632	16,382	67,351	149,504	
7	Volume (millions short tons)	45.6	70.1	142.2	281.8	539.7
	Pseudo *n*					
8	*n**=Min num pts in area	13	3	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	3	15	149	246	413
10	Half interval width (90 % confidence interval)	5	25	246	404	680
11	% Error, Half interval width / Volume * 100	11.49	35.41	172.66	143.54	126.01
12	Lower 90 % confidence bound (millions short tons)	40	45	0	0	0
13	Upper 90 % confidence bound (millions short tons)	51	95	388	686	1,220
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	4	17	161	265	446
15	Half interval width (90 % confidence interval)	6	28	264	435	734
16	% Error, Half interval width / Volume * 100	13.57	40.52	185.83	154.49	136.04
17	Lower 90 % confidence bound (millions short tons)	39	42	0	0	0
18	Upper 90 % confidence bound (millions short tons)	52	99	407	717	1,274

Table A-NR4. Detailed computations for uncertainty estimates of the Ferris-25 (F25) coal bed—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	48	65
n	68	Meas-Infer	1.0	475	604
Overall exhaustion (sq.km./hole)	2.2	Meas-Hyp	1.0	783	995
		Ind-Inf	1.0	2253	2775
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	3711	4571
		Inf-Hyp	1.0	36700	42514
Median number of beds	1	Covariance		87942	103050
		Variance		82968	96149

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	22.14	26.43	45.70	45.70
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	15.89	20.18	39.45	39.45

		Units
Semivariogram model	Linear	
Sill	40	ft^2
Nugget	20	ft^2
Range	3	mi
Run on thicknesses	Slope=8.57	
Splus data set	F25	

Table A-NR5. Detailed computations for uncertainty estimates of the Ferris-31 (F31) coal bed.

[Date of est 3/28/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	1,023,193	3,264,636	20,455,234	51,626,255	76,369,319
3	Percent of area	1	4	27	68	100
4	Area (acres)	253	807	5,055	12,757	18,871
5	Standard deviation, SD (ft) (variogram model inc meas err)	2.241	2.241	2.241	2.241	
6	Acre feet (Acres*SD)	567	1,808	11,328	28,591	
7	Volume (millions short tons)	2.1	7.8	52.9	206.1	268.9
	Pseudo *n*					
8	*n**=Min num pts in area	2.0	0.7	0.3	1.0	
	Estimates of uncertainty: no measurement error (not meaningful)					
9	Vol SD (millions st) sv	0	2	17	23	42
10	Half interval width (90 % confidence interval)	1	3	28	38	69
11	% Error, Half interval width / Volume * 100	25.06	35.92	53.25	18.23	25.68
12	Lower 90 % confidence bound (millions short tons)	2	5	25	169	200
13	Upper 90 % confidence bound (millions short tons)	3	11	81	244	338
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	1	4	38	51	93
15	Half interval width (90 % confidence interval)	1	6	62	83	153
16	% Error, Half interval width / Volume * 100	55.53	79.58	118.00	40.39	56.91
17	Lower 90 % confidence bound (millions short tons)	0.93	1.60	0.00	122.88	115.89
18	Upper 90 % confidence bound (millions short tons)	3.26	14.07	115.30	289.38	422.00

Table A-NR5. Detailed computations for uncertainty estimates of the Ferris-31 (F31) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	1	3
n	14	Meas-Infer	1.0	5	27
Overall exhaustion (sq.km./hole)	5.5	Meas-Hyp	1.0	7	36
		Ind-Inf	1.0	29	144
Measurement error SD (ft) - nugget	2.00	Ind-Hyp	1.0	39	192
		Inf-Hyp	1.0	391	1920
Median number of beds	1	Covariance		945	4641
		Variance		818	4015

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	5.02	5.02	5.02	5.02
Variance of measurement error	4.00	4.00	4.00	4.00
Variance, excluding meas error	1.02	1.02	1.02	1.02

Semivariogram model	Nugget
Sill	
Nugget	
Range	
Run on thicknesses	
Splus data set	F31

Note: Very small sample size—results may not be statistically meaningful.

Table A-NR6. Detailed computations for uncertainty estimates of the Ferris-50 (F50) coal bed.

[Date of est 3/28/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	3,330,441	16,842,693	60,894,465	17,082,509	98,150,108
3	Percent of area	3	17	62	17	100
4	Area (acres)	823	4,162	15,047	4,221	24,253
5	Standard deviation, SD (ft) (variogram model inc meas err)	3.438	3.438	3.438	3.438	
6	Acre feet (Acres*SD)	2,830	14,310	51,739	14,514	
7	Volume (millions short tons)	13.6	73.4	338.2	80.3	505.5
	Pseudo *n*					
8	*n**=Min num pts in area	6.5	3.7	0.8	1.0	
	Estimates of uncertainty: no measurement error (not meaningful)					
9	Vol SD (millions st) sv	1	6	49	13	69
10	Half interval width (90 % confidence interval)	2	11	81	21	114
11	% Error, Half interval width / Volume * 100	11.56	14.45	23.87	25.71	22.46
12	Lower 90 % confidence bound (millions short tons)	12	63	257	60	392
13	Upper 90 % confidence bound (millions short tons)	15	84	419	101	619
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	2	13	100	26	141
15	Half interval width (90 % confidence interval)	3	22	165	42	232
16	% Error, Half interval width / Volume * 100	23.66	29.58	48.85	52.62	45.97
17	Lower 90 % confidence bound (millions short tons)	10.39	51.71	172.98	38.05	273.13
18	Upper 90 % confidence bound (millions short tons)	16.83	95.15	503.38	122.57	737.93

Table A-NR6. Detailed computations for uncertainty estimates of the Ferris-50 (F50) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	6	26
n	12	Meas-Infer	1.0	47	197
Overall exhaustion (sq.km./hole)	8.2	Meas-Hyp	1.0	12	50
		Ind-Inf	1.0	317	1326
Measurement error SD (ft)a	3.00	Ind-Hyp	1.0	81	339
Assumed meas error SD (ft)	2.5	Inf-Hyp	1.0	616	2580
Median number of beds	1.5	Covariance		2157	9036
Assumed correlation between beds	0.5	Variance		2608	10924
a sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	11.82	11.82	11.82	11.82
Variance of measurement error	9.00	9.00	9.00	9.00
Variance, excluding meas error	2.82	2.82	2.82	2.82

Semivariogram model	Nugget
Sill	
Nugget	
Range	
Run on thicknesses	
Data set:	F50

Note: Very small sample size—results may not be statistically meaningful.

Table A-NR7. Detailed computations for uncertainty estimates of the Ferris-65 (F65) coal bed.

[Date of est 3/28/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	5,417,001	17,736,198	44,443,346	352,117	67,948,662
3	Percent of area	8	26	65	1	100
4	Area (acres)	1,339	4,383	10,982	87	16,790
5	Standard deviation, SD (ft) (variogram model inc meas err)	2.469	2.469	2.469	2.469	
6	Acre feet (Acres*SD)	3,305	10,820	27,113	215	
7	Volume (millions short tons)	19.6	53.7	123.5	1.0	197.8
	Pseudo *n*					
8	*n**=Min num pts in area	10.7	3.9	0.6	1.0	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	0	2	14	0	17
10	Half interval width (90 % confidence interval)	1	4	24	0	28
11	% Error, Half interval width / Volume * 100	3.52	6.99	19.23	14.93	14.33
12	Lower 90 % confidence bound (millions short tons)	19	50	100	1	169
13	Upper 90 % confidence bound (millions short tons)	20	57	147	1	226
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	2	10	62	0	74
15	Half interval width (90 % confidence interval)	3	16	101	1	121
16	% Error, Half interval width / Volume * 100	15.00	29.82	82.04	63.70	61.12
17	Lower 90 % confidence bound (millions short tons)	16.70	37.66	22.18	0.36	76.90
18	Upper 90 % confidence bound (millions short tons)	22.60	69.67	224.85	1.61	318.72

Table A-NR7. Detailed computations for uncertainty estimates of the Ferris-65 (F65) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	1	17
n	93	Meas-Infer	1.0	6	110
Overall exhaustion (sq.km./hole)	0.7	Meas-Hyp	1.0	0	1
		Ind-Inf	1.0	33	599
Measurement error SD (ft)[a]	2.40	Ind-Hyp	1.0	0	4
Assumed meas error SD (ft)	2.5	Inf-Hyp	1.0	1	23
Median number of beds	1.5	Covariance		83	1510
Assumed correlation between beds	0.5	Variance		214	3893

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	6.09	6.09	6.09	6.09
Variance of measurement error	5.76	5.76	5.76	5.76
Variance, excluding meas error	0.33	0.33	0.33	0.33

Semivariogram model	Nugget
Sill	
Nugget	
Range	
Run on thicknesses	
Splus data set	F65

[a] sqrt(Var*(Med num beds+2*Assumed corr))

Note: F65 is two areas, northwest (77 drill holes) and south east (16 drill holes).

SD was a pooled estimate on thicknesses: SD (nw) = 2.544 SD (se)=2.0458 ft.

Table A-NR8. Detailed computations for uncertainty estimates of the Hanna-77 (H77) coal bed.

[Date of est 3/29/1999. Form revised 3/16/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	4,466,515.72	20,546,927.46	89,799,994.30	16,425,437.91	131,238,875
3	Percent of area	3	16	68	13	100
4	Area (acres)	1,103.70	5,077.26	22,190.06	4,058.81	32,429.83
5	Standard deviation, SD (ft) (variogram model inc meas err)	9.894	9.894	9.894	9.894	
6	Acre feet (Acres*SD)	10,920	50,236	219,555	40,159	
7	Volume (millions short tons)	40.43	225.71	1,162.28	164.89	1593.3
	Pseudo *n*					
8	*n**=Min num pts in area	9	4	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	6	41	340	69	455
10	Half interval width (90 % confidence interval)	10	67	559	113	749
11	% Error, Half interval width / Volume * 100	25.67	29.59	48.06	68.61	47.00
12	Lower 90 % confidence bound (millions short tons)	30	159	604	52	844
13	Upper 90 % confidence bound (millions short tons)	51	293	1,721	278	2,342
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	7	42	351	71	471
15	Half interval width (90 % confidence interval)	11	69	577	117	774
16	% Error, Half interval width / Volume * 100	26.53	30.59	49.67	70.91	48.58
17	Lower 90 % confidence bound (millions short tons)	30	157	585	48	819
18	Upper 90 % confidence bound (millions short tons)	51	295	1,740	282	2,367

Table A-NR8. Detailed computations for uncertainty estimates of the Hanna-77 (H77) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	256	274
n	74	Meas-Infer	1.0	2143	2289
Overall exhaustion (sq.km./hole)	1.8	Meas-Hyp	1.0	434	464
		Ind-Inf	1.0	13787	14727
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	2793	2983
		Inf-Hyp	1.0	23352	24945
Median number of beds	1	Covariance		85530	91363
		Variance		121710	130010

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	97.90	97.90	97.90	97.90
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	91.65	91.65	91.65	91.65

Semivariogram model	Nugget
Sill	
Nugget	
Range	
Run on thicknesses	
Splus data set	H77

Table A-NR9. Detailed computations for uncertainty estimates of the Hanna-78 (H78) coal bed.

[Date of est 3/29/1999. Form revised 3/16/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	17,355,244.68	27,276,138.99	71,020,583.16	9,390,185.15	125,042,152
3	Percent of area	14	22	57	8	100
4	Area (acres)	4,288.57	6,740.08	17,549.57	2,320.37	30,898.59
5	Standard deviation, SD (ft) (variogram model inc meas err)	6.827	6.827	6.827	6.827	
6	Acre feet (Acres*SD)	29,279	46,017	119,816	15,842	
7	Volume (millions short tons)	129.87	247.06	692.53	78.73	1148.2
	Pseudo *n*					
8	*n**=Min num pts in area	34	6	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	8	31	200	26	266
10	Half interval width (90 % confidence interval)	14	51	330	43	437
11	% Error, Half interval width / Volume * 100	10.46	20.67	47.60	54.52	38.08
12	Lower 90 % confidence bound (millions short tons)	116	196	363	36	711
13	Upper 90 % confidence bound (millions short tons)	143	298	1,022	122	1,585
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	9	33	215	28	286
15	Half interval width (90 % confidence interval)	15	55	354	46	470
16	% Error, Half interval width / Volume * 100	11.24	22.21	51.15	58.59	40.92
17	Lower 90 % confidence bound (millions short tons)	115	192	338	33	678
18	Upper 90 % confidence bound (millions short tons)	144	302	1,047	125	1,618

Table A-NR9. Detailed computations for uncertainty estimates of the Hanna-78 (H78) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	256	296
n	217	Meas-Infer	1.0	1654	1910
Overall exhaustion (sq.km./hole)	0.6	Meas-Hyp	1.0	215	249
		Ind-Inf	1.0	6222	7185
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	810	936
		Inf-Hyp	1.0	5229	6038
		Covariance		28773	33228
		Variance		41870	48353

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	46.61	46.61	46.61	46.61
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	40.36	40.36	40.36	40.36

Semivariogram model	Nugget
Sill	
Nugget	
Range	
Run on thicknesses	
Splus data set	H78

Table A-NR10. Detailed computations for uncertainty estimates of the Hanna-79 (H79) coal bed.

[Date of est 3/31/1999. Form revised 3/16/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	13,615,932.25	23,226,193.29	58,562,863.45	2,157,338.58	97,562,328
3	Percent of area	14	24	60	2	100
4	Area (acres)	3,364.57	5,739.32	14,471.20	533.09	24,108.18
5	Standard deviation, SD (ft) (variogram model inc meas err)	4.147	4.147	4.147	4.147	
6	Acre feet (Acres*SD)	13,953	23,801	60,012	2,211	
7	Volume (millions short tons)	73.27	180.57	607.23	34.17	895.2
	Pseudo *n*					
8	*n**=Min num pts in area	27	5	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	4	15	95	3	117
10	Half interval width (90 % confidence interval)	6	25	156	5	192
11	% Error, Half interval width / Volume * 100	8.55	13.59	25.67	15.03	21.43
12	Lower 90 % confidence bound (millions short tons)	67	156	451	29	703
13	Upper 90 % confidence bound (millions short tons)	80	205	763	39	1,087
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	5	19	119	4	146
15	Half interval width (90 % confidence interval)	8	31	195	6	240
16	% Error, Half interval width / Volume * 100	10.72	17.04	32.18	18.84	26.86
17	Lower 90 % confidence bound (millions short tons)	65	150	412	28	655
18	Upper 90 % confidence bound (millions short tons)	81	211	803	41	1,136

Table A-NR10. Detailed computations for uncertainty estimates of the Hanna-79 (H79) coal bed—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	57	89
n	117	Meas-Infer	1.0	361	567
Overall exhaustion (sq.km./hole)	0.8	Meas-Hyp	1.0	12	19
		Ind-Inf	1.0	1414	2221
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	47	73
		Inf-Hyp	1.0	296	465
Median number of beds	1	Covariance		4372	6868
		Variance		9228	14497

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	17.20	17.20	17.20	17.20
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	10.95	10.95	10.95	10.95

Semivariogram model	Nugget
Sill	
Nugget	
Range	
Run on loess residual std error	
Splus data set	H79

Table A-NR11. Detailed computations for uncertainty estimates of the Hanna-81 (H81) coal bed.

[Date of est 3/31/1999. Form revised 3/16/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	6,030,944.78	23,789,169.77	60,454,785.25	1,459,791.64	91,734,691
3	Percent of area	7	26	66	2	100
4	Area (acres)	1,490.28	5,878.43	14,938.70	360.72	22,668.14
5	Standard deviation, SD (ft) (variogram model inc meas err)	7.145	7.145	7.145	7.145	
6	Acre feet (Acres*SD)	10,648	42,000	106,734	2,577	
7	Volume (millions short tons)	47.52	158.14	442.95	17.61	666.2
	Pseudo *n*					
8	*n**=Min num pts in area	12	5	1	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	5	31	195	4	235
10	Half interval width (90 % confidence interval)	8	50	320	7	386
11	% Error, Half interval width / Volume * 100	17.75	31.78	72.34	39.93	57.96
12	Lower 90 % confidence bound (millions short tons)	39	108	123	11	280
13	Upper 90 % confidence bound (millions short tons)	56	208	763	25	1,052
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	5	33	208	5	251
15	Half interval width (90 % confidence interval)	9	54	342	8	412
16	% Error, Half interval width / Volume * 100	18.95	33.92	77.22	42.62	61.87
17	Lower 90 % confidence bound (millions short tons)	39	104	101	10	254
18	Upper 90 % confidence bound (millions short tons)	57	212	785	25	1,078

Table A-NR11. Detailed computations for uncertainty estimates of the Hanna-81 (H81) coal bed—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	157	178
n	108	Meas-Infer	1.0	999	1138
Overall exhaustion (sq.km./hole)	0.8	Meas-Hyp	1.0	22	25
		Ind-Inf	1.0	5950	6780
Measurement error SD (ft) - nugget	2.50	Ind-Hyp	1.0	131	149
		Inf-Hyp	1.0	832	949
Median number of beds	1	Covariance		16180	18437
		Variance		38917	44347

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	51.05	51.05	51.05	51.05
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	44.80	44.80	44.80	44.80

Semivariogram model:	Nugget
Sill	
Nugget	
Range	
Run on thickness	
Splus data set	H81

Note: Weak spatial correlation-not used.
Note: Coal bed thickness distribution is bimodal.

Table A-NR12. Detailed computations for uncertainty estimates of the Knobloch (KN01) coal unit.

[Assessment excludes Forest Service Land. Date of est 4/13/1999. Form revised 4/7/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	55,222,034	168,110,743	225,695,422	1,060,821	450,089,020
3	Percent of area	12	37	50	0	100
4	Area (acres)	13,646	41,541	55,771	262	111,219
5	Standard deviation, SD (ft) (variogram model inc meas err)	3.757	4.640	7.020	7.576	
6	Acre feet (Acres*SD)	51,264	192,732	391,488	1,986	
7	Volume (millions short tons)	979.5	2,729.0	2,285.1	8.8	6,002.5
	Pseudo *n*					
8	*n**=Min num pts in area	109	37	3	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	4	41	351	3	399
10	Half interval width (90 % confidence interval)	7	67	577	5	656
11	% Error, Half interval width / Volume * 100	0.75	2.44	25.25	59.56	10.93
12	Lower 90 % confidence bound (millions short tons)	972	2,662	1,708	4	5,346
13	Upper 90 % confidence bound (millions short tons)	987	2,796	2,862	14	6,659
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	9	56	395	4	463
15	Half interval width (90 % confidence interval)	14	93	649	6	762
16	% Error, Half interval width / Volume * 100	1.46	3.39	28.41	65.80	12.69
17	Lower 90 % confidence bound (millions short tons)	965	2,636	1,636	3.0	5,240
18	Upper 90 % confidence bound (millions short tons)	994	2,822	2,934	14.6	6,764

Table A-NR12. Detailed computations for uncertainty estimates of the Knobloch (KNO1) coal unit—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	182	490
n	141	Meas-Infer	1.0	1574	3437
Overall exhaustion (sq.km./hole)	3.2	Meas-Hyp	1.0	14	31
		Ind-Inf	1.0	14216	22217
Measurement error SD (ft) - nugget	3.219	Ind-Hyp	1.0	129	198
		Inf-Hyp	1.0	1116	1387
Median number of beds	2	Covariance		34462	55520
		Variance		124696	159050

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	14.11	21.53	49.27	57.39
Variance of measurement error	10.36	10.36	10.36	10.36
Variance, excluding meas error	3.75	11.16	38.91	47.03

		Units
Semivariogram model	Spherical	
Sill	47.028	ft^2
Nugget	10.365	ft^2
Range	4.700	mi
Run on loess residuals (span = 0.75)		
Splus data set	KNO1	

Note: Thickness increases to the north—shift upward at about 45.45 latitude.

Table A-NR13. Detailed computations for uncertainty estimates of the Colstrip (COL) coal field.

[Date of est 4/24/1999. Form revised 4/7/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	53,972,398	249,745,998	493,881,231	87,696,026	885,295,653
3	Percent of area	6	28	56	10	100
4	Area (acres)	13,337	61,714	122,041	21,670	218,761
5	Standard deviation, SD (ft) (variogram model inc meas err)	9.216	11.122	13.049	13.197	
6	Acre feet (Acres*SD)	122,916	686,387	1,592,500	285,976	
7	Volume (millions short tons)	832	4,017	6,948	826	12,622
	Pseudo *n*					
8	*n**=Min num pts in area	106	55	7	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	19	151	1,024	478	1672
10	Half interval width (90 % confidence interval)	31	249	1684	787	2751
11	% Error, Half interval width / Volume * 100	3.69	6.20	24.24	95.24	21.79
12	Lower 90 % confidence bound (millions short tons)	801	3,767	5,264	39	9,872
13	Upper 90 % confidence bound (millions short tons)	863	4,266	8,632	1,612	15,373
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	21	164	1,085	506	1,777
15	Half interval width (90 % confidence interval)	35	271	1,785	833	2,923
16	% Error, Half interval width / Volume * 100	4.17	6.74	25.70	100.82	23.16
17	Lower 90 % confidence bound (millions short tons)	797	3,746	5,162	0	9,699
18	Upper 90 % confidence bound (millions short tons)	867	4,287	8,733	1,659	15,546

Table A-NR13. Detailed computations for uncertainty estimates of the Colstrip (COL) coal field—*Continued*.

Computational details

Square meters to square miles	3.86102E-07
Coal density (short tons/acre feet)	1770
n	134
Overall exhaustion (sq.km./hole)	6.6
Measurement error SD (ft) - nugget	4.330
Assumed meas error SD (ft)	2.5
Median number of beds	2
Assumed correlation between bedsa	0.5
a - sqrt(Var*(Med num beds+2*Assumed corr))	

	Assumed correlations	No meas err	Meas err
Meas-Ind	1.0	2824	3473
Meas-Infer	1.0	19088	22922
Meas-Hyp	1.0	8914	10690
Ind-Inf	1.0	155109	178511
Ind-Hyp	1.0	72436	83249
Inf-Hyp	1.0	489577	549401
Covariance		1495895	1696492
Variance		1300277	1461785

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	84.94	123.70	170.27	174.15
Variance of measurement error	18.75	18.75	18.75	18.75
Variance, excluding meas error	66.19	104.95	151.52	155.40

		Units
Semivariogram model	Exponential	
Sill	118.636	ft^2
Nugget	55.519	ft^2
Range/3	0.877	mi
Run on loess residuals (span = 0.75)	Range = 2.632	
Splus data set	COL	

Table A-NR14. Detailed computations for uncertainty estimates of the Wyodak-Anderson (WA) coal zone.

[Date of est 11/13/1998. Form revised: 2/5/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	1,488,759,443	5,670,020,546	11,140,313,431	3,612,068,158	21,911,161,578
3	Percent of area	7	26	51	16	100
4	Area (acres)	367,880	1,401,093	2,752,831	892,561	5,414,366
5	Standard deviation, SD (ft) (variogram model inc meas err)	18.879	23.191	27.021	27.236	
6	Acre feet (Acres*SD)	6,945,055	32,492,811	74,385,050	24,309,673	
7	Volume (millions short tons)	43,672	167,701	303,668	35,612	550,653
	Pseudo *n*					
8	*n**=Min num pts in area	2928	1239	152	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	221	1,605	10,537	42,481	54844
10	Half interval width (90 % confidence interval)	364	2641	17333	69881	90218
11	% Error, Half interval width / Volume * 100	0.83	1.57	5.71	196.23	16.38
12	Lower 90 % confidence bound (millions short tons)	43,308	165,060	286,335	0	460,435
13	Upper 90 % confidence bound (millions short tons)	44,036	170,341	321,001	105,494	640,872
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	227	1,634	10,675	43,028	55,564
15	Half interval width (90 % confidence interval)	374	2,688	17,560	70,781	91,403
16	% Error, Half interval width / Volume * 100	0.86	1.60	5.78	198.75	16.60
17	Lower 90 % confidence bound (millions short tons)	43,298	165,013	286,108	0	459,250
18	Upper 90 % confidence bound (millions short tons)	44,046	170,388	321,228	106,394	642,056

Table A-NR14. Detailed computations for uncertainty estimates of the Wyodak-Anderson (WA) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas error	Meas error
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	354988	371239
n	4462	Meas-Inf	1.0	2330086	2425244
Overall exhaustion (sq.km./hole)	4.9	Meas-Hyp	1.0	9394183	9775810
		Ind-Inf	1.0	16914318	17442481
Measurement error SD (ft)a	4.33	Ind-Hyp	1.0	68193279	70308128
Assumed meas error SD (ft)	2.5	Inf-Hyp	1.0	447609962	459311695
Median number of beds	2	2*Sum covariance terms		1089593631	1119269193
Assumed correlation between beds	0.5	Sum of variance terms		1918273095	1968089794
a sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	356.4002	537.8249	730.15	741.7917
Variance of measurement error	18.7489	18.7489	18.7489	18.7489
Variance, excluding meas error	337.6513	519.076	711.4011	723.0428
Standard deviation, including meas error	18.879	23.191	27.021	27.236
Acre feet SD (with meas err) * Area	6,945,055	32,492,811	74,385,050	24,309,673

Meas error variance: var(num of beds) + Cov with rho=.5

		Units
Semivariogram model	Exponential	
Sill	529.756	ft^2
Nugget	212.036	ft^2
Range/3	0.786	mi
Range	2.357	mi
Run on residual thickness		
Splus data set	WA	

Table A-NR15. Detailed computations for uncertainty estimates of the Anderson Canyon (WAC) subarea.

[Date of est 4/7/1999. Form revised 4/7/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	133,426,743	704,761,677	1,340,332,461	42,411,593	2,220,932,473
3	Percent of area	6	32	60	2	100
4	Area (acres)	32,970	174,150	331,203	10,480	548,804
5	Standard deviation, SD (ft) (variogram model inc meas err)	5.712	7.730	13.093	16.089	
6	Acre feet (Acres*SD)	188,333	1,346,167	4,336,582	168,610	
7	Volume (millions short tons)	2,621	14,404	27,028	675	44,728
	Pseudo *n*					
8	*n**=Min num pts in area	262	154	18	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	13	159	1,692	287	2151
10	Half interval width (90 % confidence interval)	22	261	2783	473	3538
11	% Error, Half interval width / Volume * 100	0.84	1.81	10.30	70.01	7.91
12	Lower 90 % confidence bound (millions short tons)	2,599	14,143	24,245	202	41,190
13	Upper 90 % confidence bound (millions short tons)	2,643	14,665	29,811	1,148	48,266
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	21	192	1,794	298	2,305
15	Half interval width (90 % confidence interval)	34	316	2,951	491	3,792
16	% Error, Half interval width / Volume * 100	1.29	2.19	10.92	72.73	8.48
17	Lower 90 % confidence bound (millions short tons)	2,587	14,088	24,076	184	40,936
18	Upper 90 % confidence bound (millions short tons)	2,655	14,720	29,979	1,166	48,520

Table A-NR15. Detailed computations for uncertainty estimates of the Anderson Canyon (WAC) subarea—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07	Meas-Ind	1.0	2110	3952
Coal density (short tons/acre feet)	1770	Meas-Infer	1.0	22512	36923
n	366	Meas-Hyp	1.0	3823	6142
Overall exhaustion (sq.km./hole)	6.1	Ind-Inf	1.0	268325	344505
Measurement error SD (ft) - nugget	4.36	Ind-Hyp	1.0	45562	57305
		Inf-Hyp	1.0	486050	535448
Median number of beds	2	Covariance		1656765	1968550
		Variance		2970303	3345345

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	32.63	59.75	171.44	258.84
Variance of measurement error	18.99	18.99	18.99	18.99
Variance, excluding meas error	13.64	40.76	152.45	239.85

		Units
Semivariogram model	Spherical	
Sill	239.854	ft^2
Nugget	18.989	ft^2
Range	6.591	mi
Run on loess residuals (span = 0.5)		
Splus data set	WAC	

Table A-NR16. Detailed computations for uncertainnty estimates of the Gillette (WAG) coal field.

[Date of est 3/16/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	416,538,074	1,530,925,727	1,602,753,691	60,295,123	3,610,512,615
3	Percent of area	12	42	44	2	100
4	Area (acres)	102,929	378,300	396,049	14,899	892,177
5	Standard deviation, SD (ft) (variogram model inc meas err)	19.645	23.329	26.327	26.327	
6	Acre feet (Acres*SD)	2,022,084	8,825,319	10,426,851	392,255	
7	Volume (millions short tons)	13,520.09	48,161.13	51,256.46	1,597.25	114,534.94
	Pseudo *n*					
8	*n**=Min num pts in area	819	334	22	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	123	844	3,909	688	5564
10	Half interval width (90 % confidence interval)	202	1389	6431	1132	9154
11	% Error, Half interval width / Volume * 100	1.50	2.88	12.55	70.86	7.99
12	Lower 90 % confidence bound (millions short tons)	13,318	46,772	44,826	465	105,381
13	Upper 90 % confidence bound (millions short tons)	13,722	49,550	57,687	2,729	123,688
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	125	854	3,945	694	5,618
15	Half interval width (90 % confidence interval)	206	1,405	6,489	1,142	9,242
16	% Error, Half interval width / Volume * 100	1.52	2.92	12.66	71.50	8.07
17	Lower 90 % confidence bound (millions short tons)	13,314	46,756	44,767	455	105,293
18	Upper 90 % confidence bound (millions short tons)	13,726	49,566	57,746	2,739	123,777

Table A-NR16. Detailed computations for uncertainnty estimates of the Gillette (WAG) coal field—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	103854	106812
n	2009	Meas-Infer	1.0	480890	493340
Overall exhaustion (sq.km./hole)	1.8	Meas-Hyp	1.0	84635	86826
		Ind-Inf	1.0	3300289	3369376
Measurement error SD (ft)a	3.54	Ind-Hyp	1.0	580839	592998
Assumed meas error SD (ft)	2.5	Inf-Hyp	1.0	2689528	2738923
Median number of beds	1	Covariance		14480070	14776550
Assumed correlation between beds	0.5	Variance		16482938	16789551
a sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	385.94	544.24	693.12	693.12
Variance of measurement error	12.50	12.50	12.50	12.50
Variance, excluding meas error	373.44	531.74	680.62	680.62

		Units
Semivariogram model	Spherical	
Sill	393.980	ft^2
Nugget	299.142	ft^2
Range	1.690	mi
Run on loess residuals with span = 0.5		
Splus data set	WAG	

Table A-NR17. Detailed computations for uncertainty estimates of the Sheridan (WAS) subarea.

[Date of est 3/16/1999. Form revised 2/5/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	68,915,982	264,330,666	258,679,514	13,736,407	605,662,568
3	Percent of area	11	44	43	2	100
4	Area (acres)	17,030	65,318	63,921	3,394	149,662
5	Standard deviation, SD (ft) (variogram model inc meas err)	15.740	15.740	15.740	15.740	
6	Acre feet (Acres*SD)	268,044	1,028,098	1,006,118	53,427	
7	Volume (millions short tons)	1,333	4,904	4,221	176	10,635
	Pseudo *n*					
8	*n**=Min num pts in area	136	58	4	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	39	227	898	90	1254
10	Half interval width (90 % confidence interval)	64	373	1478	148	2062
11	% Error, Half interval width / Volume * 100	4.77	7.62	35.01	83.67	19.39
12	Lower 90 % confidence bound (millions short tons)	1,269	4,531	2,743	29	8,572
13	Upper 90 % confidence bound (millions short tons)	1,396	5,278	5,699	324	12,697
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	41	239	948	95	1,322
15	Half interval width (90 % confidence interval)	67	394	1,559	156	2,175
16	% Error, Half interval width / Volume * 100	5.03	8.03	36.93	88.24	20.45
17	Lower 90 % confidence bound (millions short tons)	1,266	4,510	2,662	21	8,459
18	Upper 90 % confidence bound (millions short tons)	1,400	5,298	5,780	332	12,810

Table A-NR17. Detailed computations for uncertainty estimates of the Sheridan (WAS) subarea—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	8774	9759
n	193	Meas-Infer	1.0	34720	38616
Overall exhaustion (sq.km./hole)	3.1	Meas-Hyp	1.0	3465	3854
		Ind-Inf	1.0	203990	226885
Measurement error SD (ft)[a]	5.00	Ind-Hyp	1.0	20359	22644
Assumed meas error SD (ft)	2.5	Inf-Hyp	1.0	80561	89602
Median number of beds	3	Covariance		703737	782720
Assumed correlation between beds	0.5	Variance		868275	965726
a sqrt(Var*(Med num beds+2*Assumed corr))					

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	247.7476	247.7476	247.7476	247.7476
Variance of measurement error	25.0000	25.0000	25.0000	25.0000
Variance, excluding meas error	222.7476	222.7476	222.7476	222.7476
SD, including meas error	15.740	15.740	15.740	15.740
Acre feet SD (with meas err) * Area	268,044	1,028,098	1,006,118	53,427

Semivariogram model	Nugget
Sill	
Nugget	
Range/3	
Residual thickness with loess span = 0.5	
Splus data set	WAS

[a] sqrt(Var*(Med num beds+2*Assumed corr))

Table A-NR18. Detailed computations for uncertainty estimates of the Beulah-Zap (BZ) coal zone.

[Date of est 3/23/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	237,120,736	368,807,104	314,035,128	120,633,512	1,040,596,479
3	Percent of area	23	35	30	12	100
4	Area (acres)	58,594	91,134	77,600	29,809	257,137
5	Standard deviation, SD (ft) (variogram model inc meas err)	4.132	4.132	4.132	4.132	
6	Acre feet (Acres*SD)	242,110	376,567	320,642	123,172	
7	Volume (millions short tons)	1,172	1,561	1,546	551	4,830
	Pseudo *n*					
8	*n**=Min num pts in area	466	81	4	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	16	59	218	174	467
10	Half interval width (90 % confidence interval)	26	97	359	286	768
11	% Error, Half interval width / Volume * 100	2.22	6.23	23.22	51.78	15.89
12	Lower 90 % confidence bound (millions short tons)	1,146	1,464	1,187	266	4,062
13	Upper 90 % confidence bound (millions short tons)	1,198	1,658	1,905	837	5,598
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	20	74	274	218	586
15	Half interval width (90 % confidence interval)	33	122	451	359	964
16	% Error, Half interval width / Volume * 100	2.79	7.83	29.16	65.04	19.96
17	Lower 90 % confidence bound (millions short tons)	1,139	1,439	1,095	193	3,866
18	Upper 90 % confidence bound (millions short tons)	1,205	1,683	1,997	910	5,794

Table A-NR18. Detailed computations for uncertainty estimates of the Beulah-Zap (BZ) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	934	1474
n	2040	Meas-Infer	1.0	3448	5439
Overall exhaustion (sq.km./hole)	0.5	Meas-Hyp	1.0	2743	4327
		Ind-Inf	1.0	12900	20349
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	10262	16188
		Inf-Hyp	1.0	37877	59749
Median number of beds	1	Covariance		136328	215051
		Variance		81490	128547

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	17.07	17.07	17.07	17.07
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	10.82	10.82	10.82	10.82

		Units
Semivariogram model	Nugget	
Sill		
Nugget	17.07	ft^2
Range/3		
Run on loess residuals, span = 0.5		
Splus data set	BZ	

Table A-NR19. Detailed computations for uncertainty estimates of the Hagel (HAG) coal zone.

[Date of est 3/20/1999. Form revised 3/16/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	335,432,395	389,435,954	303,702,006	6,609,852	1,035,180,207
3	Percent of area	32	38	29	1	100
4	Area (acres)	82,887	96,232	75,046	1,633	255,799
5	Standard deviation, SD (ft) (variogram model inc meas err)	4.295	5.088	6.403	6.762	
6	Acre feet (Acres*SD)	355,982	489,643	480,516	11,045	
7	Volume (millions short tons)	1,585	1,746	1,058	12	4,401
	Pseudo *n*					
8	*n**=Min num pts in area	660	85	4	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	20	82	384	18	504
10	Half interval width (90 % confidence interval)	33	135	632	30	830
11	% Error, Half interval width / Volume * 100	2.07	7.71	59.78	253.79	18.86
12	Lower 90 % confidence bound (millions short tons)	1,552	1,612	425	0	3,571
13	Upper 90 % confidence bound (millions short tons)	1,617	1,881	1,690	42	5,230
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	25	94	418	20	556
15	Half interval width (90 % confidence interval)	40	155	687	32	914
16	% Error, Half interval width / Volume * 100	2.55	8.85	64.94	273.15	20.77
17	Lower 90 % confidence bound (millions short tons)	1,544	1,592	371	0	3,487
18	Upper 90 % confidence bound (millions short tons)	1,625	1,901	1,745	44	5,315

Table A-NR19. Detailed computations for uncertainty estimates of the Hagel (HAG) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	1632	2305
n	1672	Meas-Infer	1.0	7670	10246
Overall exhaustion (sq.km./hole)	0.6	Meas-Hyp	1.0	362	480
		Ind-Inf	1.0	31464	39239
Assumed measurement error SD (ft)	2.50	Ind-Hyp	1.0	1486	1837
		Inf-Hyp	1.0	6984	8164
Median number of beds	1	Covariance		99197	124543
		Variance		155257	184235

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	18.45	25.89	41.00	45.72
Variance of measurement error	6.25	6.25	6.25	6.25
Variance, excluding meas error	12.20	19.64	34.75	39.47

		Units	
Semivariogram model	Exponential		
Sill	31.992	ft^2	
Nugget	13.733	ft^2	
Range/3	1.569	mi	
Run on thicknesses			Range= 4.708
Splus data set	HAG		

Table A-NR20. Detailed computations for uncertainty estimates of the Hansen (HAN) coal zone.

[Date of est 3/17/1999. Form revised 3/16/99]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	123,667,036	593,688,851	3,286,461,611	2,693,673,550	6,697,491,047
3	Percent of area	2	9	49	40	100
4	Area (acres)	30,559	146,704	812,102	665,621	1,654,986
5	Standard deviation, SD (ft) (variogram model inc meas err)	2.155	2.451	3.411	4.012	
6	Acre feet (Acres*SD)	65,844	359,567	2,769,859	2,670,629	
7	Volume (millions short tons)	383	1,846	9,743	9,669	21,641
	Pseudo *n*					
8	*n**=Min num pts in area	243	130	45	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	3	33	594	4,105	4735
10	Half interval width (90 % confidence interval)	5	54	978	6753	7790
11	% Error, Half interval width / Volume * 100	1.24	2.91	10.04	69.84	35.99
12	Lower 90 % confidence bound (millions short tons)	378	1,792	8,765	2,916	13,851
13	Upper 90 % confidence bound (millions short tons)	387	1,900	10,721	16,422	29,430
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	7	56	732	4,727	5,522
15	Half interval width (90 % confidence interval)	12	92	1,204	7,776	9,084
16	% Error, Half interval width / Volume * 100	3.21	4.98	12.36	80.42	41.98
17	Lower 90 % confidence bound (millions short tons)	370	1,754	8,539	1,893	12,557
18	Upper 90 % confidence bound (millions short tons)	395	1,938	10,947	17,445	30,725

Table A-NR20. Detailed computations for uncertainty estimates of the Hansen (HAN) coal zone—*Continued*.

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	94	418
n	258	Meas-Infer	1.0	1708	5469
Overall exhaustion (sq.km./hole)	26.0	Meas-Hyp	1.0	11796	35328
		Ind-Inf	1.0	19411	40895
Measurement error SD (ft) - nugget	1.99	Ind-Hyp	1.0	134038	264147
		Inf-Hyp	1.0	2440564	3459381
Median number of beds	1	Covariance		5215221	7611274
		Variance		17207544	22883408

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error	4.64	6.01	11.63	16.10
Variance of measurement error	3.96	3.96	3.96	3.96
Variance, excluding meas error	0.69	2.05	7.68	12.14

		Units
Semivariogram model	Spherical	
Sill	12.142	ft^2
Nugget	3.956	ft^2
Range	6.632	mi
Run on thicknesses		
Splus data set	HAN	

Table A-NR21. Detailed computations for uncertainty estimates of the Harmon (HAR) coal zone.

[Date of est 2/8/1999. Form revised 2/8/1999]

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area (sq meters)	177,067,168	868,859,831	4,352,969,100	5,065,252,495	10,464,148,594
3	Percent of area	2	8	42	48	100
4	Area (acres)	43,754	214,700	1,075,642	1,251,651	2,585,747
5	Standard deviation, SD (ft) (variogram model inc meas err)	2.174	2.590	3.727	5.507	
6	Acre feet (Acres*SD)	95,125	556,065	4,008,751	6,892,834	
7	Volume (millions short tons)	847	4,596	20,231	19,001	44,675
	Pseudo *n*					
8	*n**=Min num pts in area	348	190	59	1	
	Estimates of uncertainty: no measurement error					
9	Vol SD (millions st) sv	4	48	789	11,437	12279
10	Half interval width (90 % confidence interval)	7	79	1298	18814	20199
11	% Error, Half interval width / Volume * 100	0.83	1.72	6.42	99.02	45.21
12	Lower 90 % confidence bound (millions short tons)	840	4,517	18,932	186	24,476
13	Upper 90 % confidence bound (millions short tons)	854	4,676	21,529	37,815	64,874
	Estimates of uncertainty: measurement error included					
14	Vol SD (millions st) sc	9	71	920	12,200	13,201
15	Half interval width (90 % confidence interval)	15	118	1,514	20,070	21,716
16	% Error, Half interval width / Volume * 100	1.75	2.56	7.48	105.63	48.61
17	Lower 90 % confidence bound (millions short tons)	832	4,479	18,717	0	22,959
18	Upper 90 % confidence bound (millions short tons)	862	4,714	21,745	39,070	66,391

Table A-NR21. Detailed computations for uncertainty estimates of the Harmon (HAR) coal zone—*Continued.*

Computational details

			Assumed correlations	No meas err	Meas err
Square meters to square miles	3.86102E-07				
Coal density (short tons/acre feet)	1770	Meas-Ind	1.0	205	645
n	348	Meas-Infer	1.0	3360	8304
Overall exhaustion (sq.km./hole)	30.1	Meas-Hyp	1.0	48691	110087
		Ind-Inf	1.0	37913	65742
Measurement error SD (ft)a	1.92	Ind-Hyp	1.0	549422	871526
a sqrt(Var*(Med num beds+2*Assumed corr))		Inf-Hyp	1.0	9026819	11228081
		Covariance		19332821	24568769
Assumed correlation between beds	0.5	Variance		131438117	149699877

	Measured	Indicated	Inferred	Hypothetical
Variance, including meas error from variogram	4.727	6.708	13.889	30.327
Variance of measurement error	3.675	3.675	3.675	3.675
Variance, excluding meas error	1.052	3.033	10.215	26.652

		Units	
Residuals with loess span=0.5			
Semivariogram model	Exponential		
Sill	26.652	ft^2	
Nugget	3.675	ft^2	
Range/3	6.207	mi	
Splus main data set	HAR	Range =	18.622

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Appendix B.—Uncertainty Estimation for Resource Assessment—An Application to Coal

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Uncertainty Estimation for Resource Assessment—An Application to Coal

By John H. Schuenemeyer and Helen C. Power

Abstract

The U.S. Geological Survey is conducting a national assessment of coal resources. As part of that assessment, a geostatistical procedure has been developed to estimate the uncertainty of coal resources for the historical categories of geological assurance: measured, indicated, inferred, and hypothetical coal. Data consist of spatially clustered coal-thickness measurements from coal beds and (or) zones that cover, in some cases, several thousand square kilometers. Our procedure involved trend removal, an examination of spatial correlation, computation of a sample semivariogram, and fitting a semivariogram model. This model provided standard deviations for the uncertainty estimates. The number of sample points (drill holes) in each historical category also was estimated. Measurement error in the thickness of the coal bed/zone was obtained from the fitted model or supplied exogenously. From this information, approximate estimates of uncertainty on the historical categories were computed. We illustrate the methodology using drill-hole data from the Harmon coal bed located in southwestern North Dakota. The methodology will be applied to approximately 50 coal data sets.

Introduction

The purpose of this study was to develop a procedure for the estimation of uncertainty on the volume of coal resources. It is part of the U.S. Geological Survey's National Coal Resource Assessment (NCRA) Program. The historical categories of reliability of coal resources are measured, indicated, inferred, and hypothetical as specified in U.S. Geological Circular 891 (Wood and others, 1983). The first three categories express a decreasing amount of geological assurance about the amount of coal to be found within a 0.25-, 0.75-, and 3-mi radius, respectively, of a data point, which most often is a drill hole. The hypothetical category is for resources greater than 3 mi from a data point and reflects the lowest degree of geological assurance. These categories, with their arbitrary fixed boundaries, provide some heuristic measure of reliability; however, they do not utilize measures of variability or spatial correlation taken directly from the data. The U.S. Geological Survey is committed, at least in the short term, to report resources by these historical categories. Thus, a procedure was devised that incorporated features of the data into the construction of uncertainty estimates on the volume of coal in the historical categories.

There are several sources of variability in the data, which we isolated and modeled. These included spatial trends, local geologic variability, spatial correlation of coal-bed-thickness measurements, and measurement error. We discuss the sources of measurement error and propose decomposition into more geologically meaningful units.

In the first phase of this study, we investigated large-scale spatial trends in coal-bed thickness. We must remove this variation prior to estimating spatial variability, else the fitted semivariogram model will be biased upward. This is analogous to the problem of estimating the auto-covariance of a time series in the presence of a long-term trend. Our problem, as we shall see, is somewhat more complicated because residual thicknesses lead to bias in the estimation of the semivariogram model parameters. We examined spatial correlation using a semivariogram defined as

$$\gamma(\mathrm{h}) = \mathrm{var}\,[Z(\mathrm{u}) - Z(\mathrm{u}+\mathrm{h})]/2$$

where

$Z(\mathbf{u})$ is a random variable at location $\mathbf{u}$,

$Z(\mathbf{u}+\mathbf{h})$ is a random variable at location $\mathbf{u}+\mathbf{h}$, and

var represents the variance.

(Bold letters are used to denote vectors such as $\mathbf{h}$, which is used to represent distance and direction; $h = |\mathbf{h}|$ will be used to represent only distance.) In our study, Z is coal bed/zone thickness (in feet). A sufficient condition for the existence of $\gamma(\mathbf{h})$ is that $Z(\mathbf{u}) - Z(\mathbf{u} + \mathbf{h})$ is stationary of order two (the intrinsic hypothesis). The sample semivariogram based upon the method-of-moments is

$$\hat{\gamma}(\mathbf{h}) = \frac{1}{2N(\mathbf{h})}\sum_{i=1}^{N(\mathbf{h})}[z(\mathbf{u}_i) - z(\mathbf{u}_i + \mathbf{h})]^2$$

where

$\hat{\gamma}(\mathbf{h})$ is an estimate of $\gamma(\mathbf{h})$,

$N(\mathbf{h})$ is the number of pairs of data located a distance $\mathbf{h}$ apart, and

z is a specific occurrence of Z.

Kriging has been most often used to obtain point estimates and associated measures of local uncertainty (see discussion in the Appendix). Goovaerts (1997) argues for the use of simulation to estimate global uncertainty and discusses a variety of algorithms to implement this concept. In a procedure established by the U.S. Geological Survey, volumetric estimates of remaining coal were generated using EarthVision and ARC/INFO software, which required considerable hands-on work to remove mined-out areas and adjust other coverages. This precluded our use of simulation.

In this paper, we illustrate our procedure using the Harmon coal bed, located in southwestern North Dakota. However, we make additional comments based upon our experience analyzing about half of the approximately 50 coal beds in this assessment. We begin with a brief description of the data used in our example, followed by a discussion of sources of variability and possible biases. The spatial analytic techniques and computations of uncertainty are then applied to the Harmon data set. Most of the computing was done using Splus 4.5[1] statistical software, including the S+SPATIALSTATS module.

Data

The Harmon coal bed covers an area of 10,464 km^2. Our data set consisted of coal-bed-thickness measurements. Partings (non coal) and thickness sections less than 2.5 ft were removed from the data set because they cannot be mined and thus were not used in the estimate of coal volume. This left us with 348 drill holes. The drill-hole locations (referenced to an arbitrary origin) and the bed boundary are shown in figure 1. These data are measurements from drill holes that go completely through a bed or zone. The distribution of coal-bed thicknesses is right skewed (fig. 2). The mean thickness is 10.66 ft, and the standard deviation is 7.39 ft, with a maximum thickness of 39 ft. The depth of the bed and the overburden are not considered in this study but were considered in the NCRA study. There are measurement errors in the recording of coal-bed thicknesses, which will be discussed in the next section.

Variability and Bias

The three major sources of variability in this method are sampling variability, estimation variability, and measurement error. The major sources of bias are preferential and clustered sampling, and bias in estimation and measurement.

Sampling Variability and Bias

Since geological, geochemical, and other techniques can be used to identify promising areas, the search for minable coal often results in preferential sampling aimed at finding the most economically viable resources. Once a mine site has been established, numerous closely spaced holes are drilled to help develop the mine plan. The Harmon coal bed data set illustrates a fairly typical nonrandom drilling pattern (fig. 1). More than 50 percent of the drill-hole data are clustered in mined areas located in the south-central region of the bed, while no drilling occurred in much of the northern and northeastern parts of the bed.

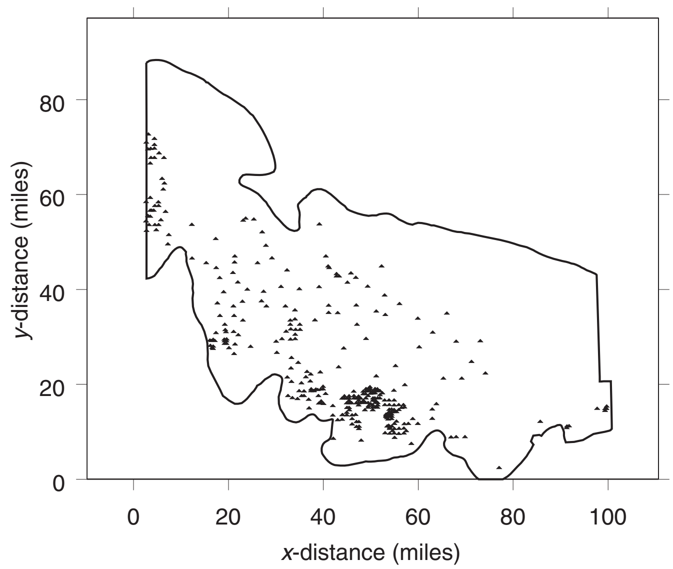

Figure 1. Harmon coal-bed drill-hole locations and boundary.

We seek to develop a method to place a confidence interval on the volume of coal in each of the geologic assurance categories. Many of the usual assumptions, including that of a random sample, will not be met. If the highly drilled areas predominate and contain thicker and less variable coal than is present in the rest of the bed, then a confidence interval estimate on the mean volume of remaining coal would be too narrow and biased upward. (The procedures we propose for estimating the confidence intervals will be discussed later.) In some instances it is possible to test for biases. Often, however, such tests have little power because drilling is sparser in the areas where the resources need to be estimated. Some bias-correction procedures adjust the sample mean (mean thickness) and (or) the variance (for example, Goovaerts, 1997, p. 77–82). Reducing the influence of these oversampled areas by subsampling is risky because, particularly in this study, we need information that can be obtained only from closely spaced points.

In the estimation process we assumed that thickness of the coal beds/zones varied continuously and that once we removed the large-scale trend, the residual thickness $Z(\mathbf{u})$ is such that the random function increments $Z(\mathbf{u}) - Z(\mathbf{u} + \mathbf{h})$ are stationary of order two. Discontinuities sometimes exist and may be caused by channeling, splitting of a bed

[1]Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey, the University of Delaware, or the University of South Carolina.

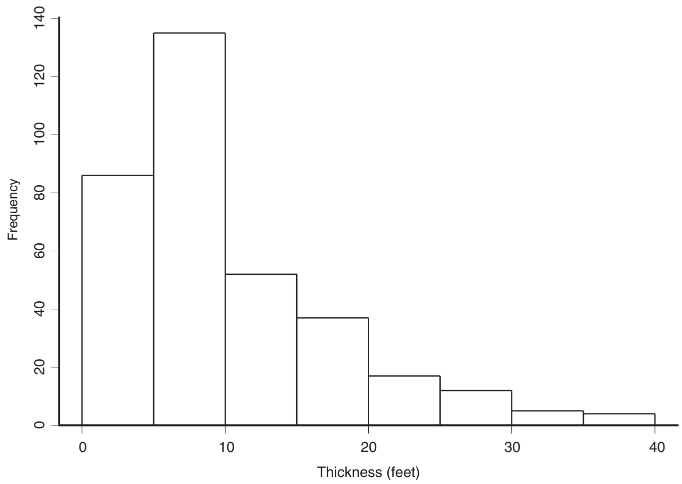

Figure 2. Histogram of coal thicknesses.

into two or more parts, and tapering (Ferm and Weisenfluh, 1984, and G.A. Weisenfluh, Kentucky Geological Survey, oral commun., 1998). These factors may be more of a concern when economic filters are applied to the resource base. However, if drill holes that were terminated have been incorrectly classified as completed, variability and bias could be affected. Any significant relationship between local means and standard deviations, referred to as the proportional effect, may invalidate the intrinsic hypothesis. Graphical techniques will be used to investigate this phenomenon. In this paper we refer to coal beds and zones. The Harmon is a bed or single stratum. A zone refers to two or more beds. We would prefer to analyze beds; however, due to geologic complexity it is not always possible to identify individual beds.

Estimation Variability and Bias

The method that we recommend requires the computation of a sample semivariogram and fitting a model. Coal thickness in most beds/zones displays a trend. We refer to this as large-scale variability. Cressie (1991) showed that over- or under-specifying the trend could bias the estimation of the semivariogram. Goovaerts (1997, p. 143) cautioned that, "the semivariogram of estimated residuals,, strongly depends on the algorithm used to estimate the trend component." Consider the representation of a random variable Z at location $\mathbf{u}$ (Cressie, 1991, p. 290) as

$$Z(\mathbf{u}) = \mu(\mathbf{u}) + \tau(\mathbf{u}), \qquad \mathbf{u} \in D$$

where

$\mu(\mathbf{u})$ represents a possible trend (large-scale variation),

$\tau(\mathbf{u})$ is a correlated error process, which will be modeled using variography (the technique of estimating and modeling a semivariogram), and

D is the area of interest.

When trend can be removed with a low-order polynomial, a weighted least-squares procedure (Beckers and Bogaert, 1998) provides an unbiased estimate of the semivariogram model. However, in the 25 coal beds that we have investigated, more complicated surfaces are usually required. Part of the difficulty in trend removal is one of scale. Coal beds/zones cover hundreds to thousands of square kilometers, and trends are complicated. In some beds/zones, it might be possible to partition the data into more geologically homogeneous areas, make separate estimates of uncertainty within each area, and aggregate the results. It is desirable but not currently feasible to implement such a procedure, particularly given the large areal extent of the data. Cressie (1991, p. 165–169) has shown that, under certain conditions, the bias in $\hat{\gamma}(\mathbf{h})$ is positive and quadratic in h, and of order $1/n$. Concern about this bias is mitigated because absolute bias declines as the sample size $N(h)$ increases, and it is less for small h. There are hundreds to thousands of data points in most of the coal beds/zones, and the estimates of uncertainty are for h less than or equal to 3 mi.

Dimitrakopoulos (1991) suggested the use of intrinsic random functions of order k (IRF-k) and a generalized covariance function, which linearly filters the data and removes trends of order (k–1). Goovaerts (1997, p. 143) warns, without accompanying support, that high-order differences may not be available for nongridded data and automated modeling often results in relatively high nugget effects (defined below). We continue to investigate the feasibility of such an approach; however, computational and estimation problems are formidable.

The volume of coal in a geologic assurance category is estimated by U.S. Geological Survey coal geologists using a combination of EarthVision and ARC/INFO contouring software (Ellis and others, 1999). A grid was constructed with EarthVision using inverse distance weighting based on the four nearest data points. Contour lines were also created in EarthVision from this grid. These lines were exported to ARC/INFO, where polygons were created using the median values between contour lines. The volume of coal resulted from summing volumes in each of these small polygons after clipping of excluded areas. Sensitivity analyses (see Ellis and others, 1999) suggested that volumetric estimates are relatively insensitive to small changes in parameter setting in the contour programs; however, the possibility of small but unknown bias clearly exists. We assume, however, that the point estimate of the remaining volume V of coal in a bed or zone is an unbiased estimate of the mean, that is, that $E(V) = \mu_V$.

Measurement Error

Measurement error can occur in the definition of a coverage area of remaining resources and in reported coal bed/zone thicknesses. The former source of error can be subdivided into the following: (1) identification of the bed boundary, (2) mines missing from the mined cover—usually smaller, older mines, (3) using a permit area as the frame for a mined area (often the permit area is larger than the mined area), (4) combining permit and mine areas to create a mined area cover, (5) no mine cover although some mining has occurred, and (6) lack of consistency in the definition of mined cover areas over time. The last four categories relate to removal of mined-out areas from consideration. Unfortunately, we do not have estimates of errors in coverage although this problem is being investigated.

Measurement error, in the context of the Harmon study, is the error that may be attributed to differences in interpretation and recording of coal-bed thicknesses from electrical logs or other recording devices. We assume that there is a true value, Z_i, and a measured value, z_i, of coal-bed thickness at the ith drill hole, where i may index a geographic location. The difference $d_i = z_i - Z_i$ is the error in measurement. (The ensuing discussion on models of measurement error follows Cochran, 1968.) The simplest model from which to decompose variability assumes unbiased, uncorrelated errors with constant variance. Our situation is more complicated. Studies from other fields found that measurement error was often biased and there was a positive correlation between measurements recorded by the same person or organization. A more realistic model for the true thickness, Z_{ij}, is

$$Z_{ij} = z_i + \alpha_j + \beta_{ij} + d_{ij}$$

where

z_i is the measured coal thickness of the ith hole,

α_j is the overall bias of the jth recorder, and

β_{ij} is the bias and d_{ij} is the measurement error, respectively, of the jth recorder on the ith hole.

If all variables are assumed to be uncorrelated with each other, the variance of $\overline{Z}$ is

$$\sigma^2_{\overline{Z}} = (\sigma^2_z + \overline{\sigma}^2_\beta + \overline{\sigma}^2_d)/n \ + \ \sigma^2_\alpha / k$$

where

$$E(d^2_{ij}|i) = \sigma^2_i,$$

$$\overline{\sigma}^2_d = E(\sigma^2_i),$$

k is the number of persons or organizations making measurements,

m is the number of measurements each person or organization makes, and

$n = k \bullet m$.

It is impossible to ascertain from historical coal-bed data if the correlation assumptions are justified. Also, it is not possible to estimate σ^2_α from the data. As an added complication, there is the possibility of an intrazone correlation when multiple beds occur. In addition, measurement error can differ as a function of drilling intent. Some drill holes in coal beds were drilled to find oil or gas.

When the variables are uncorrelated, the variance σ^2_α can be expressed as

$$\sigma\frac{2}{z} = \frac{1}{n}\sigma^2_z\left\{1+(m-1)\rho_w\right\}$$

where

ρ_w is the intrarecording correlation.

This equation shows that the term σ^2_α / k may dominate $\sigma^2_{\overline{Z}}$.

When measurement error is small relative to sampling variability, it can be incorporated into the overall variability and causes, at most, a small bias. In many of our data sets, including the Harmon, measurement error appears to be relatively large. We obtained estimates of measurement error from the semivariogram model or expert judgment. However, much of the information needed to make appropriate adjustments to the measurement error is not available. We present this analysis to show a reasonable decomposition of the variability in the hope that data will become available that will allow us to model measurement error more effectively.

Spatial Analysis of the Harmon Coal Bed

Removing Trends in Coal-Bed Thickness

In the Harmon coal bed, a contour map of thickness (fig. 3) indicates a peak thickness in the south-central part of the bed as well as a large-scale trend. We used two approaches to investigate the possibility of a trend. The first was to fit the Harmon coal-bed thickness data with a fourth-order polynomial with distances expressed in miles. It only accounted for 31 percent of the variability in thickness. We then used a loess model, which is a locally weighted least-squares regression model available in Splus 4.5. With a span of 0.5, we obtained a multiple R^2 of 0.54 and a residual standard error of 5.15 with 14.4 equivalent parameters. A

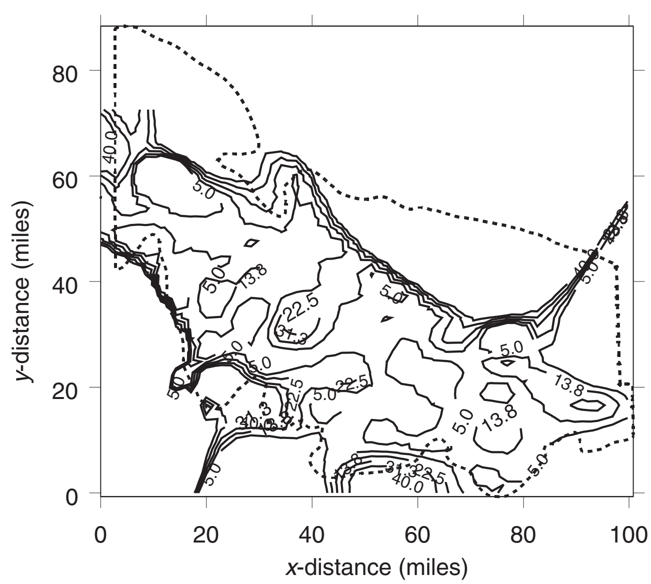

Figure 3. Contour plot of coal thicknesses.

span of 0.5 means that the model used the nearest 50 percent of the data to estimate the regression model. The residual thicknesses were normally distributed. A residual-thickness surface generated from loess regression is shown in figure 4. The thickness measurements, which are clearly not uniformly distributed in x and y, are the open circles. Lawrence Drew (oral commun., 1999) of the U.S. Geological Survey questioned whether a “geologic” surface that could not be adequately fit by a fourth-order polynomial was indeed a global trend. We believe that, with a span of 0.5 or greater, the resultant trend captured by the loess model was global and that it provided a reasonable fit to the data and removed a significant part of the spatial trend. There is not a clear demarcation between global and local trends. Indeed, not all data sets have a large-scale trend.

The residuals from the loess model were then used as input to compute the sample semivariogram. Clearly, the results of this process should be interpreted cautiously for reasons discussed previously.

Modeling Spatial Correlation

In addition to our concern about preferential sampling, we were also interested in any relationship that might exist between the magnitude of local mean residual thicknesses and variability, namely, the proportional effect. To examine this, we applied a grid of 5-mile by 5-mile cells to the coal bed and computed the means and standard deviations on the residual thicknesses of all data within each cell. Figure 5 shows no obvious relationship between grid cell means and standard deviations. To see if a systematic change in variability is related to location, we compared (fig. 6) the gridded standard deviations versus grid location. Circle size is proportional to the standard deviation of the gridded residual thicknesses. There is no obvious spatial trend in variability.

Figure 7 plots $\hat{\gamma}(h)$ versus the distance h computed on the thickness measurements (circles) and on the residual thicknesses (diamonds). The fact that they are different strongly suggests that there is nonstationarity. This lower plot in figure 7 indicates a high degree of spatial correlation up to a range of approximately 18 mi. Thereafter, the sample semivariogram exhibits periodicity. Journel and Huijbregts (1978) refer to this as a hole effect. Possible reasons for this include sampling from a population containing multiple geologic processes or second-order nonstationarity (essentially nonhomogeneous variance). The hole effect may be related to systematic changes in variability or other geologic processes. Further investigation is warranted because the hole effect might lead to a spatial partitioning of the data into more geologically homogeneous units. However, we do not believe it will affect estimates of variability for $h \leq 3$ mi. The upper sample semivariogram reflects the presence of a trend, and we believe its use would bias estimates of the standard deviation upward. Thus, we chose the sample semivariogram based upon residual thicknesses.

The range of 18.6 mi observed for the Harmon coal-bed thickness is large among United States coal beds/zones. Other beds/zones of equal or greater size that we examined have ranges of 6 mi or less. When there is spatial correlation and the thickness sample semivariogram is similar to the residual-

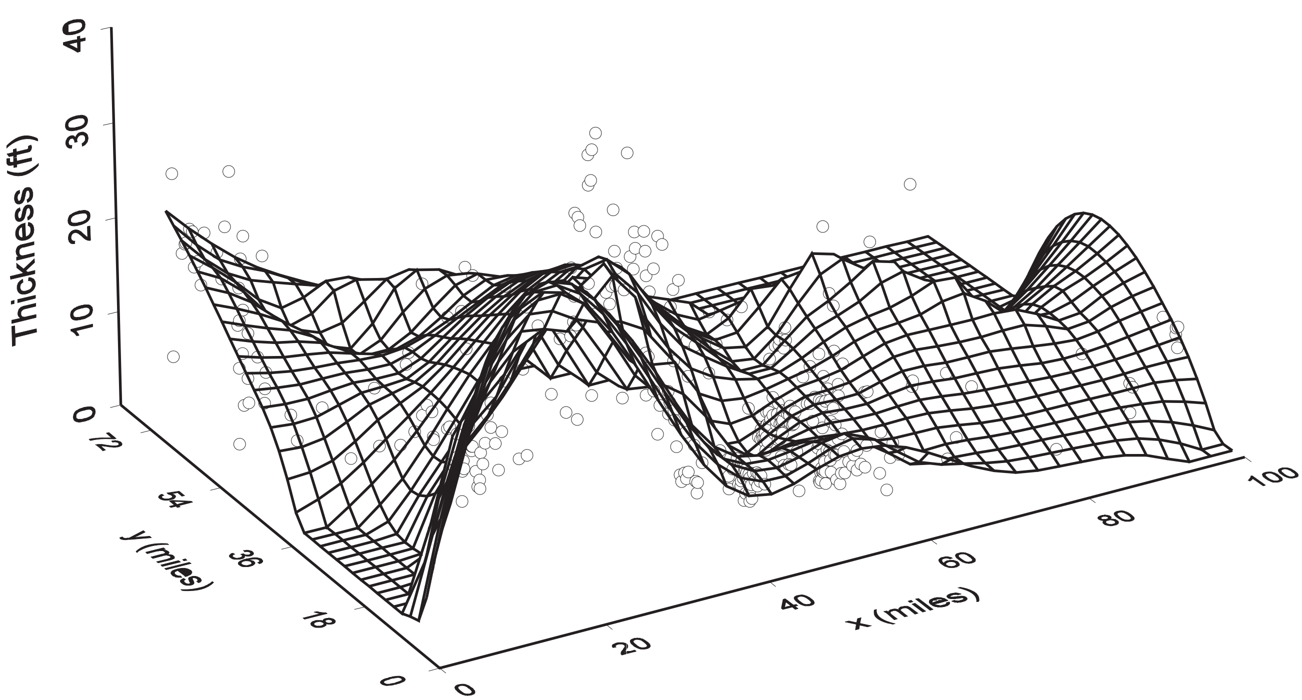

Figure 4. Contour surface of fitted thicknesses and thickness data.

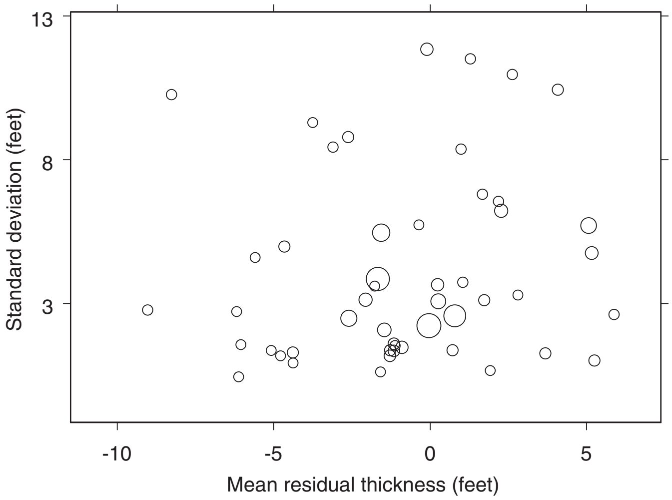

Figure 5. Means versus standard deviations of residual thicknesses computed on 5-mile by 5-mile grid cells.

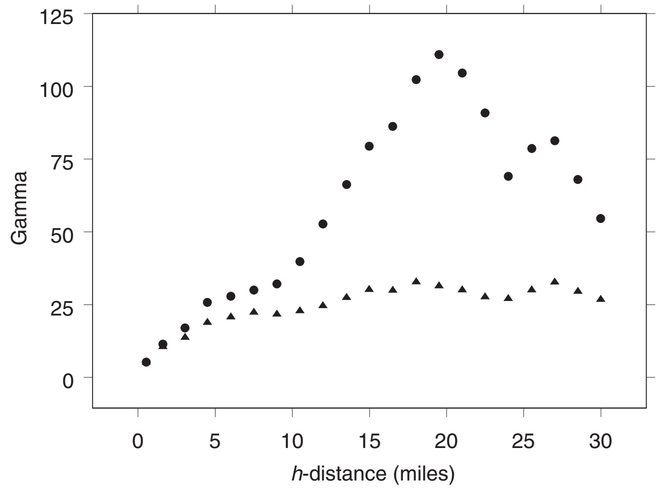

Figure 7. Sample-thickness and loess residual-thickness semivariograms.

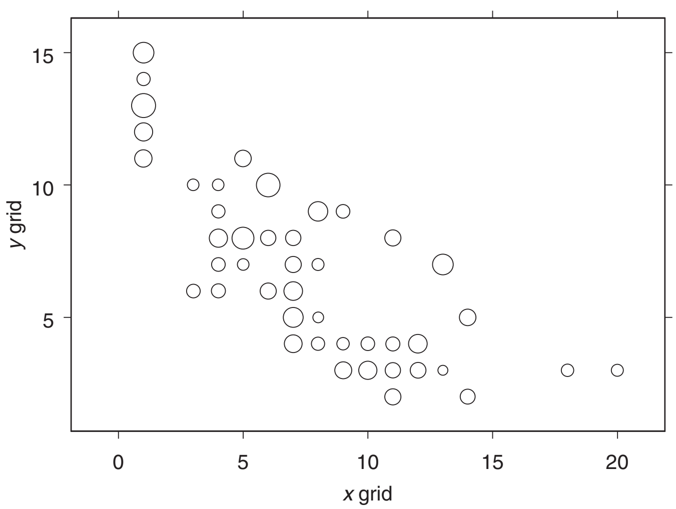

Figure 6. Spatial distribution of standard deviations of residual thicknesses computed on 5-mile by 5-mile grid cells.

thickness sample semivariogram, as determined by subjective judgment, we use the one associated with the raw data.

We also investigated the possibility of anisotropy by computing a sample semivariogram at θ = 0°, 30°, 60°, 90°, 120° and 150° with an angle tolerance of ±15°. Figure 8 indicates that there are some differences in range and direction among the sample semivariograms. The hole effect may be observed in the 150° semivariogram. We did not judge these differences to be sufficiently strong as to warrant a correction, and thus we assumed isotropy.

There is often no theoretical reason for choosing among possible semivariogram models. In fortuitous circumstances, geologic theory may justify the selection of a particular semivariogram model. We chose to ignore the possible hole effect previously noted for the Harmon coal bed because we judged it would not influence estimates of thickness variability within 3 mi. We tried different models and chose the exponential model based upon a low residual sum of squares and visual inspection, particularly at distances of less than 10 mi, the primary focus of our study. The form of the exponential model, $g(h;a)$, is

$$g(h;a) = 1 - \exp(-3h/a)$$

where

h is the distance (in miles), and

a = 18.622 mi, the estimated range.

The fitted model is

$$\gamma_s(h;\hat{\theta}) = \hat{\delta}_u + S_\ell \cdot g(h;a)$$

where

$\hat{\theta}^T = (a, \hat{\delta}_u, S_\ell)$, T is transpose, and

δ_u = 3.675 is an estimate of $\delta_u = \sigma_\varepsilon^2 + C^0(0)$, the nugget σ_ε^2, and microscale variation $C^\circ(0)$.

The estimated sill is S_λ = 26.652. The model is illustrated in figure 9. Since the minimum distance between drill holes is 0.02 mi, we concluded that most of the magnitude of δ_u was due to the nugget effect and therefore we considered 3.675 to be an estimate of the measurement error σ_ε^2 . Thus, σ_ε^2 = 1,917. This value is consistent with geologists' estimates of the error resulting from interpretation of the slope of the signal from electric logs. We then used $s_h^2 = S_\ell g(h)$ as the estimated variance of coal bed/zone thickness. For the

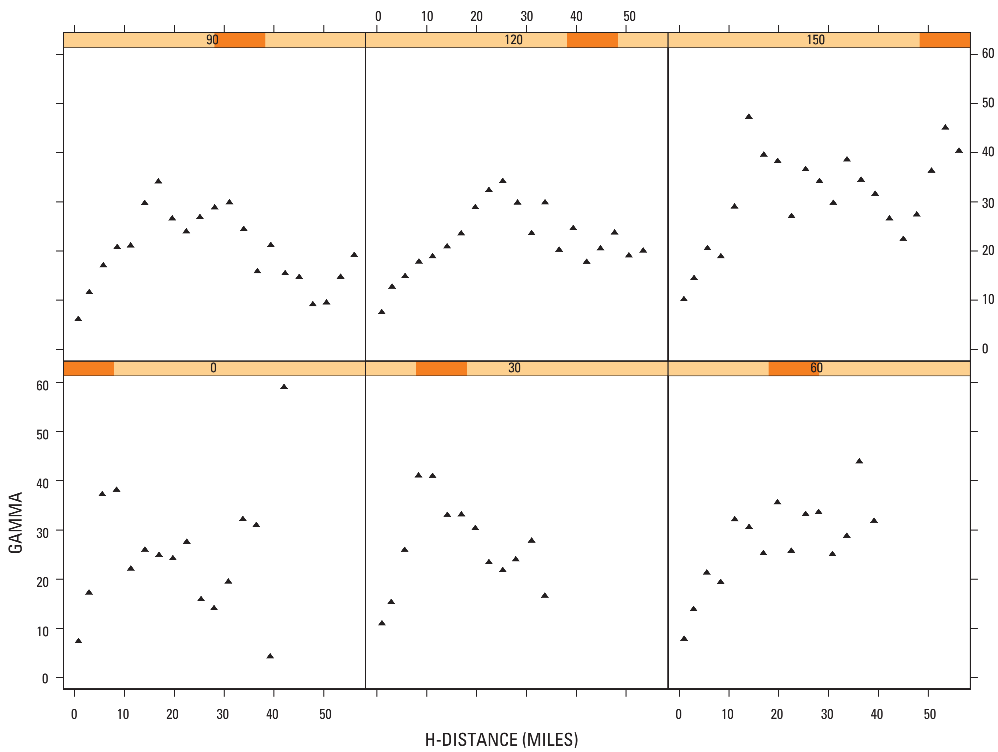

Figure 8. Loess residual-thickness directional semivariograms.

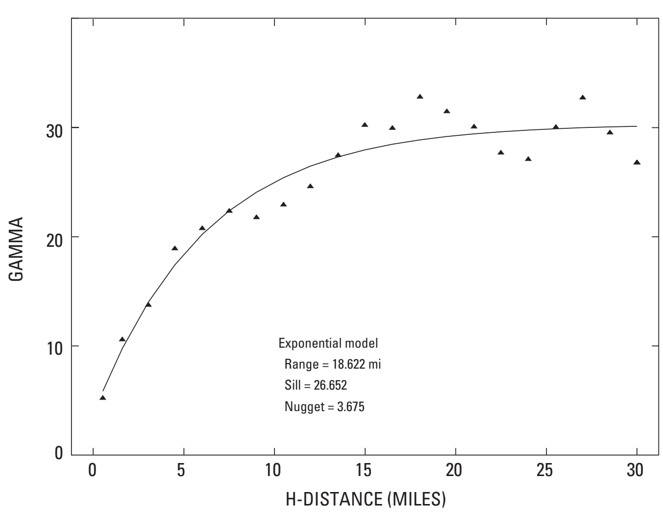

Figure 9. Exponential fit to loess residual-thickness-sample semivariogram.

U.S. Geological Survey categories of geological assurance we need estimates of variability at distances, $h = 0.25$, 0.75, and 3.0 mi. For example, to estimate uncertainty for the measured category ($h = 0.25$) we evaluated

$$\begin{aligned} s^2_{0.25} &= S_\ell\, g(0.25;18.622) \\ &= 26.652 \cdot 0.0395 \\ &= 1.052 \end{aligned}$$

Note that s^2_h excludes measurement error.

One of the concerns in this study was the variation in the half-squared differences $0.5\,(z(\mathbf{u}+\mathbf{h}) - z(\mathbf{u}))^2$, referred to as a variogram cloud. Figure 10 shows boxplots of a cloud generated from the loess residual thicknesses. For purposes of illustration, we only show the distance h up to 10 mi. It is clear that a pattern similar to that in figure 9 emerged; however, the distribution of $[z(\mathbf{u}) - z(\mathbf{u}+\mathbf{h})]^2$ at any h is, as expected, right skewed and highly variable. To obtain a plot having a more symmetric distribution, we made the transformation $\gamma^*(\mathbf{h}) = (|z(\mathbf{u}) - z(\mathbf{u}+\mathbf{h})|)^{1/2}/2$ suggested by Cressie (1991). With this transformation (fig. 11), it is easier to observe the systematic change in variability as a function of h. A lack of predictive power associated with data where the measure of dissimilarity is so variable is common to most real data sets.

The estimated parameters of the semivariogram model are sensitive to the fitting procedure and to the transformations performed on the data due to the highly skewed distributions (fig. 10). A possible solution to this problem is to estimate the

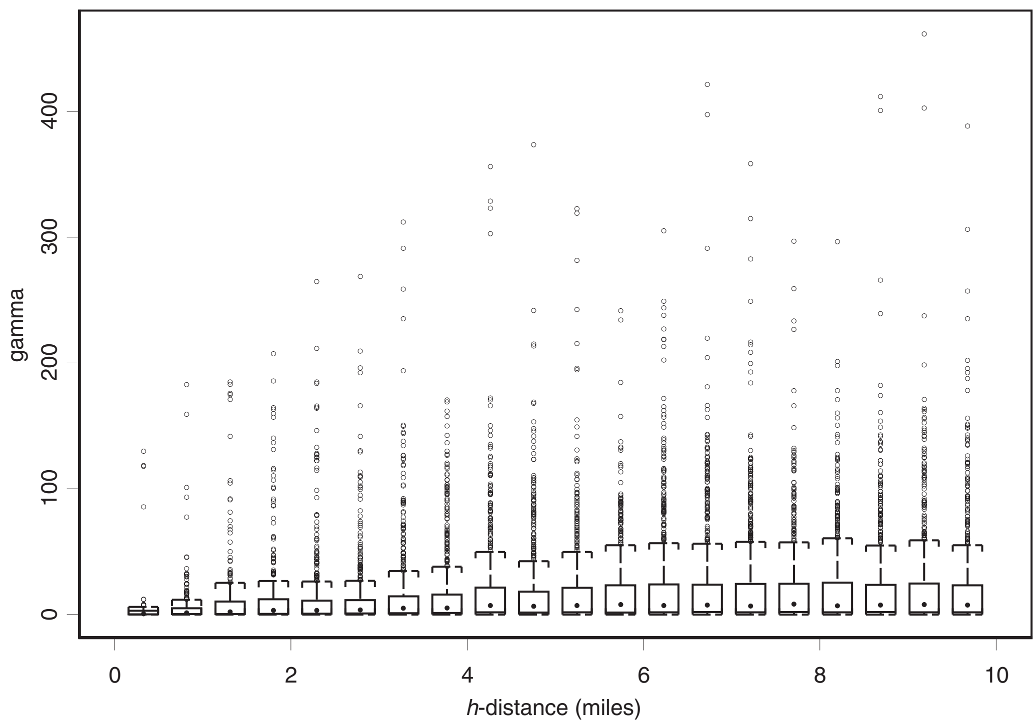

Figure 10. Loess residual-thickness-sample semivariogram cloud. The boxplot shows (from bottom to top) the minimum, lower quartile, median (the dot), upper quartile, 1.5 × interquartile range (top T), and possible outliers (open circles).

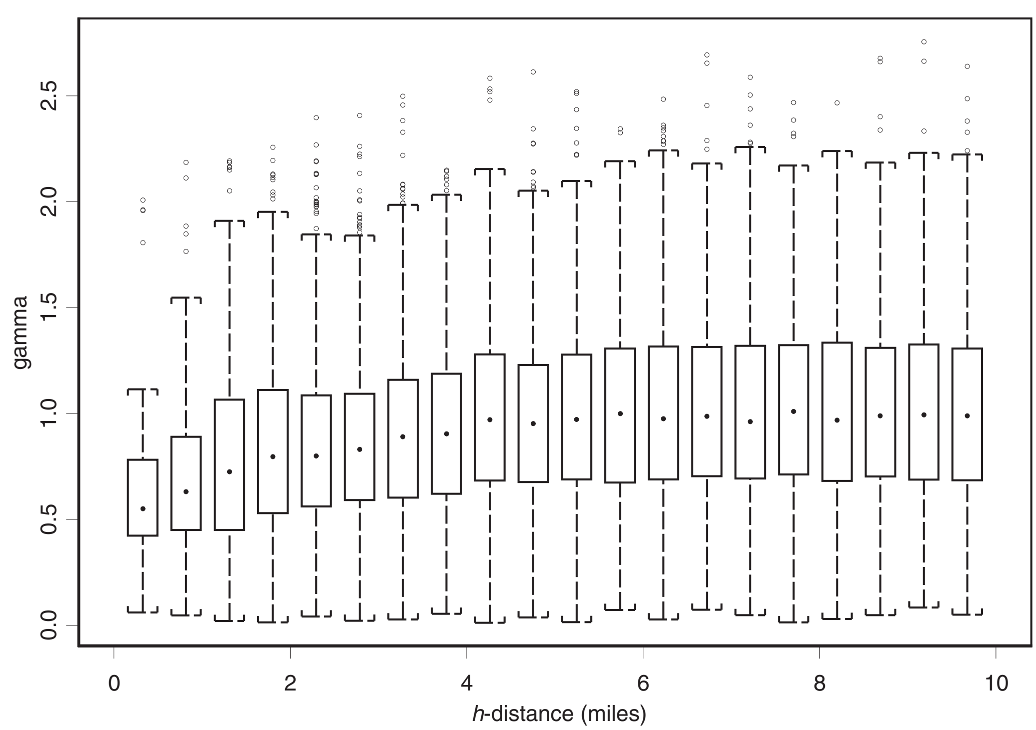

Figure 11. Loess residual-thickness-sample semivariogram cloud with transformation. The boxplot shows (from bottom to top) the minimum, lower quartile, median (the dot), upper quartile, 1.5 × interquartile range (top T), and possible outliers (open circles).

semivariogram with a procedure that is robust to the presence of outliers (for example, Genton, 1998). However, we decided to use the least-squares fitted values, in part, because this estimation technique provided a more conservative (larger) estimate of dissimilarity than we obtained with a nonparametric procedure or by using a data transformation. One of the difficulties of this study is that we would like to have the best fit for h where $0 < h \leq 3$. However, it is in this region that the data are the sparsest and (or) least trustworthy—again, a common problem.

Comparison of Thickness Categories

We also considered possible changes in variation and (or) spatial correlation as a function of thickness categories. These categories, as defined in U.S. Geological Survey Circular 891 (Wood and others, 1983), are 2.5 to 5 ft, 5 to 10 ft, 10 to 20 ft, and 20 to 40 ft. We investigated this possibility by partitioning the data into these categories. However, because they differ appreciably in thickness interval and because the sample sizes became quite small in some intervals, we judged that to make separate uncertainty estimates by thickness category was not statistically meaningful. In some beds/zones it may be possible and meaningful to make such an estimate.

Estimates of Uncertainty

Establishing the Sample Size

If the drilling pattern is random, the uncertainty interval on the volume of coal in a bed should decrease as the number of drill holes increases. However, in the Harmon coal bed and in many other data sets, we find that approximately one-half of the drill holes are closely spaced and located in the mined areas. This raises the question of what is the appropriate sample size to use in computing estimates of the standard error of coal-bed thickness. Some investigators have suggested sampling from the given data in order to produce a subset of data on a regular grid. However, this would result in a loss of information from closely spaced drill holes, which is needed to estimate microscale variation and nugget effects. Others (for example, Goovaerts, 1997, p. 76–82) recommend the use of a declustering algorithm. This approach may reduce the bias in the estimation of means and variances; however, it does not adjust the sample size.

The standard deviation of the mean thickness of coal for the entire bed could be estimated by the expression $s_h / \sqrt{n}$ if it were possible to obtain a random sample of thicknesses. However, we are presented with two problems: the first is the clustered drilling pattern and the second is the need to generate estimates of uncertainty in the reliability categories. Consider first the measured category. There are $n = 348$ drill holes in this category; however, they are clustered. We argue that instead of using n in the denominator of the standard error we should create a "pseudo n" (hereinafter referred to as n^*) that will be less than or equal to n. We estimated n^* for the measured category by dividing the area of the measured category by the size of a circle of radius 0.25 mi (the definition of this category). Although no data points exist in the other reliability categories, we chose to "estimate" the number of points in the indicated and inferred categories by dividing their areas by circles of 0.75 and 3 mi, respectively. For the hypothetical category, we let n^* equal 1. The area in the hypothetical category (fig. 12, nonshaded area) is the area within the Harmon boundary but outside of the union of circles of radius 3 mi. Most of the nonshaded area is outside the cluster of drill-hole data, and thus an estimate made in this area would be an extrapolation, as opposed to an interpolation. Thus, we believe that using a value of 1 for the denominator is an appropriate, if somewhat conservative, choice. Values of n^* are given in table 1, row 8. In the measured category for the Harmon coal bed, $n^* = 348$, which is the same as the original sample size. In many other beds/zones that we assessed, n^* is less.

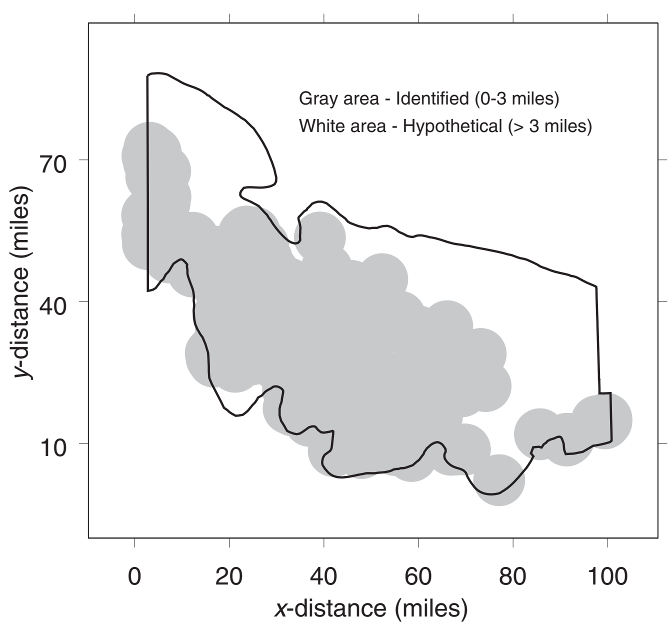

Figure 12. Identified and hypothetical areas.

Procedure

The procedure to estimate the uncertainty for each reliability category is summarized below.

1. Graphical methods revealed a possible large-scale trend in coal thickness. A loess regression with span = 0.5 was used to remove it. We have maintained the span at greater than or equal to 0.5 for all data sets analyzed. Residual thicknesses were used if the loess or other trend model accounted for at least 50

percent of the variability. Subsequent computations on the Harmon bed are made on residual thickness.

2. A sample semivariogram on residual thickness was computed and an exponential model fitted. The parameter estimates were given previously. Gaussian and spherical models fitted best for some other coal bed/zone data sets. Statistical measures of fit and visual inspection were used to select the model.

3. The standard deviation of thicknesses, s_h, (table 1, row 4) was computed for the measured, indicated, and inferred categories (h = 0.25, 0.75, and 3.0, respectively) from the fitted semivariogram model. We illustrated the computation of $s_{0.25}$ previously. For the hypothetical category $s_h = \sqrt{S_\ell}$.

4. We computed n^* (table 1, row 8), the number of (pseudo) data points. $n^* = (A/640)/(\pi h^2)$, where A (table 1, row 2) is the bed/zone reliability category area in acres, and h = 0.25, 0.75, and 3.0. For the hypothetical category, n^* = 1.

5. An approximate estimated variance of V (the estimated volume of coal in short tons, shown in table 1, row 7), excluding measurement error, is $s_V^2 = (kA)^2 s_h^2 / n^*$ (s_v is given in table 1, row 9), where k is the coal density in short tons per acre-foot.

6. An estimate of uncertainty of the volume (without measurement error) is $V \pm z_{\alpha/2} s_V$ (table 1, rows 12 and 13), where $z_{\alpha/2}$ is a standard normal deviate at the $\alpha/2$ significance level. The estimated volume V was assumed to be normally distributed because it was a summation of a large number of smaller, but not independent, volumes created within ARC/INFO.

7. For this example, the standard deviation of the measurement error, $\hat{\sigma}_\varepsilon = 1.917$, is the square root of the nugget from the fitted semivariogram model. The measurement error must be supplied exogenously when it cannot be estimated by the nugget effect.

8. An estimate of the variability of volume, which included measurement error is $s_C = kA(s_{hM}^2 / n^*)^{1/2}$, thus $s_C^2 = (kA)^2 s_{hM}^2 / n^*$, where $s_{hM}^2 = s_h^2 + \hat{\sigma}_\varepsilon^2$. ($s_c$ is given in table 1, row 14.) We assumed that sampling and measurement errors were additive and uncorrelated.

9. The uncertainty intervals that include measurement error are given in table 1, rows 17 and 18.

Overall Estimate of Uncertainty

An overall estimate of uncertainty (including measurement error) is derived by summing the variances s_c^2 across the four reliability categories and then adding the pairwise covariances assuming that the correlation between categories was 1.0. The interval estimate at the 90-percent confidence level is 22,959 to 66,391 millions of short tons[1] (table 1, Entire area column, rows 17 and 18).

Discussion and Conclusions

A major contribution of this study is the understanding of variability and spatial correlation within and across coal beds and zones. We have used coal-bed/zone thicknesses obtained from drilling to make uncertainty estimates on the volume of coal within categories of geologic assurance. We urge caution in the interpretation of results, as some assumptions could not be verified. We are concerned about the effects of preferential sampling, model fitting, and measurement error. However, we believe that our estimates of uncertainty are conservative.

We now have the ability to compare beds by variability and spatial correlation and relate statistical results to geologic phenomena. It is this ability to rank and correlate across beds and zones that we believe is potentially significant. In addition, we have identified a number of areas for further study, including simulation, the use of generalized covariance functions, and the use of indicator variables to estimate uncertainty by thickness category.

[1]Estimates of the volume of coal in the Harmon bed are preliminary and are presented to illustrate the method.

Table 1. Uncertainty estimates for the Harmon coal bed.

Row	Reliability category	Measured	Indicated	Inferred	Hypothetical	Entire area
2	Area A (acres)$^{+}$	43,754	214,700	1,075,642	1,251,651	2,585,747
3	Percent of area	2	8	42	48	100
4	Standard deviation, s_h (feet), from semivariogram model	1.026	1.742	3.196	5.163	
5	Standard deviation, s_{hM} (feet), with measurement error	2.174	2.590	3.727	5.507	
6	Acre feet ($A*s_{hM}$)	95,125	556,065	4,008,751	6,892,834	11,552,776
7	Volume V (millions of short tons)$^{+}$	847	4,596	20,231	19,001	44,675
	Pseudo *n*					
8	n^* = Minimum points in category	348	190	59	1	
	Estimates of uncertainty: No measurement error					
9	Volume standard deviation, s_v (millions of short tons)	4.3	48.0	789.2	11,437.3	12,278.9
10	Half interval width (90 % confidence interval)	7.0	79.0	1,298.3	18,814.4	20,198.8
11	% error: (half interval width / V) * 100	0.8	1.7	6.4	99.0	45.2
12	Lower 90 % confidence bound (millions of short tons)	840.0	4,517.5	18,932.4	186.2	24,476.2
13	Upper 90 % confidence bound (millions of short tons)	854.1	4,675.5	21,529.1	37,815.1	64,873.7
	Estimates of uncertainty: Measurement error included					
14	Volume standard deviation, s_c (millions of short tons)	9.0	71.4	920.3	12,200.3	13,201.1
15	Half interval width (90 % confidence interval)	14.8	117.5	1,513.9	20,069.5	21,715.8
16	% error: (half interval width / V) * 100	1.8	2.6	7.5	105.6	48.6
17	Lower 90 % confidence bound (millions of short tons)	832.2	4,479.0	18,716.8	0.0	22,959.1
18	Upper 90 % confidence bound (millions of short tons)	861.9	4,714.0	21,744.7	39,070.2	66,390.7

$^{+}$ Supplied exogenously.

Acknowledgments

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Appendix—Kriging

Kriging is a statistical procedure frequently used to model spatially correlated data (see, for example, Goovaerts, 1997). It has an advantage over typical inverse weighting contour programs in that it provides an estimate of the standard error of the fit at **u** and, under certain conditions, has desirable and tractable statistical properties. Kriging has been used most successfully to estimate the mean and uncertainty of blocks of coal or other resources in a mine, which are typically rather small in geographic area compared to the coal beds in this study.

Global estimation using kriging is difficult because the covariance function (a measure of spatial variability) rarely is stationary over a large area, data are seldom evenly distributed, and dependencies associated with large data sets can cause computational problems. Estimates of global means can be made by partitioning a large area and using block kriging; however, problems of aggregation remain. Estimates of global uncertainty can be obtained using simulation (Deutsch and Journel, 1998); however, these procedures are computationally intensive, requiring hundreds of separate kriging runs. In addition, considerable effort is required to process the results of each kriging run in order to eliminate areas in the basin that are mined and to account for overburden and other factors.

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