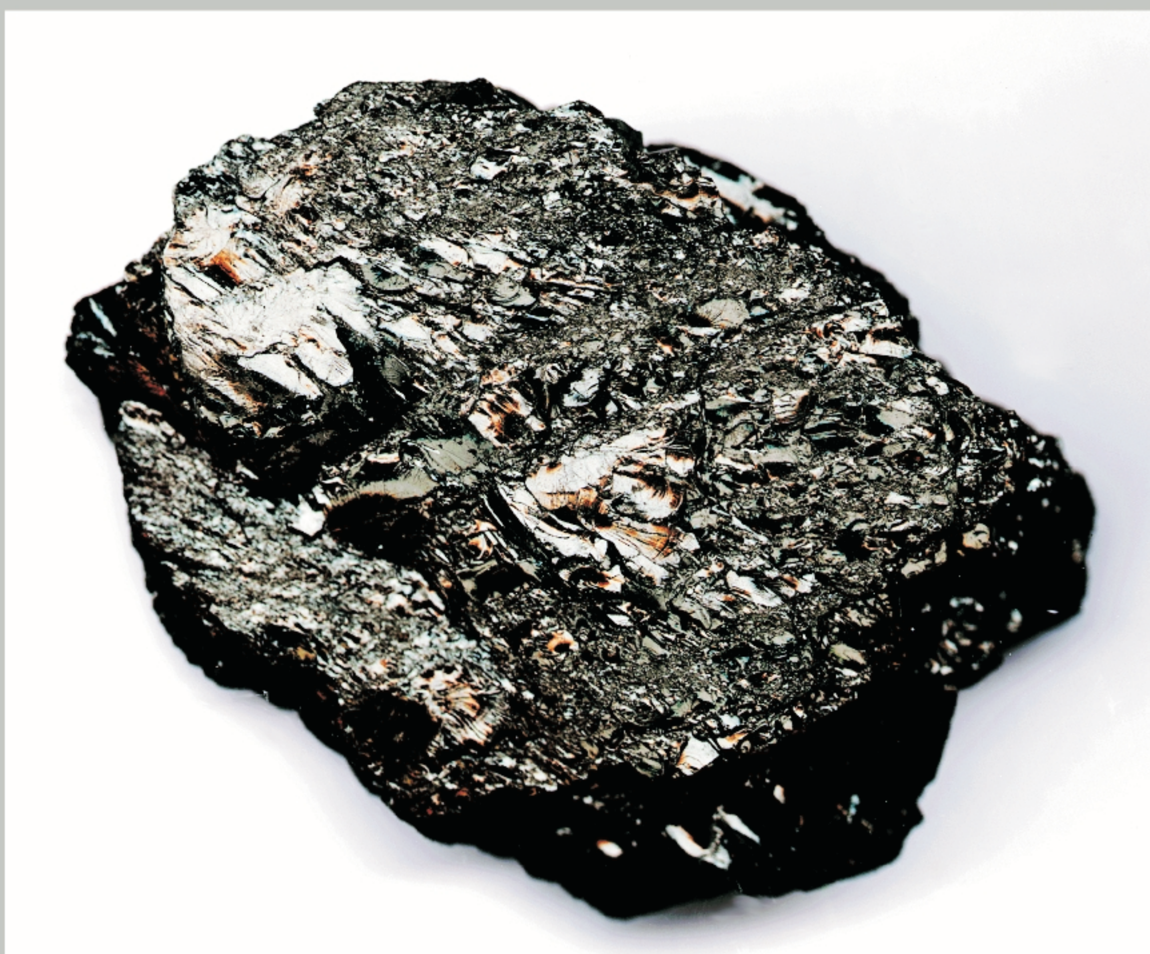
THE AVAILABLE COAL RESOURCES FOR NINE 7.5-MINUTE QUADRANGLES IN THE NORTHERN WASATCH PLATEAU COALFIELD, CARBON AND EMERY COUNTIES, UTAH

by

David E. Tabet, Jeffrey C. Quick, Brigitte P. Hucka, and John A. Hanson



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ABSTRACT

This report provides estimates of the available coal resources in nine 7.5-minute quadrangles that encompass the northern half of the Wasatch Plateau coalfield. Coal production from this area has doubled during the last decade and accounts for more than 70 percent of Utah's 1996 total production.

Calculations show that the nine quadrangles in the study area originally contained more than 9.2 billion tons of coal, of which 5.4 billion tons occurred in beds that could be mined underground. The calculations are based on data from over 600 drill holes and measured sections entered into a Geographic Information System (GIS) software program on a personal computer. The GIS program was used to produce maps showing the spatial distribution and thickness of individual coalbeds from which estimates of coal tonnage were made. Examples of these maps and derived tonnage data are provided; together, they show the extent of past mining, the remaining available coal, and deductions from the original coal resource base due to technical and land-use restrictions (appendix A). Comparison of underground mine maps with associated coalbed isopach maps show mining has removed, or made unrecoverable, 1 billion tons of the original minable coal. If restrictions to mining (such as the prohibition to mining under streams, lakes, and roads) are also considered, derived maps show that 3.8 billion tons are available for future mining. Assuming 30 percent resource recovery, a maximum of 1.1 billion tons of this coal might ultimately be produced from the northern Wasatch Plateau. Depletion of the most attractive coal resources is anticipated by 2040.

INTRODUCTION

Coal is vital to Utah's economy since it fuels about 95 percent of the electricity generated in the state. In addition, Utah coal is a major overseas export commodity, accounting for more than $100 million in 1996 exports sales (Jahanbani, 1997). Demand for Utah coal has grown nearly 100 percent during the past 15 years.

In 1996, about 90 percent of the coal produced in Utah originated from the Wasatch Plateau coalfield. From the beginning of mining in the 1870s through the end of 1996, over 400 million tons of coal were removed from the Wasatch Plateau (Jahanbani, 1997). Most of this coal (351 million tons) came from the northern half of the Wasatch Plateau coalfield corresponding to the study area of this report (figure 1). The eight active underground mines in the study area produced 19.4 million tons of coal accounting for 72 percent of Utah's 1996 coal production. Future production from the area may temporarily drop following the closure of the Star Point mine, but new mines and expansion of existing mines will compensate for most of the lost production.

Figure 2 shows that coal production in the study area increased dramatically from 1980 to 1997. Given increased production and limited coal resources, the question arises of how long these high production levels can be sustained. The answer to this question requires estimates of the amount, type, and location of coal resources available for development. This information is also useful for county, state, and federal agencies involved with natural resource development. Accordingly, the Utah Geological Survey (UGS) and U.S. Geological Survey (USGS) have jointly undertaken an assessment of the amount of coal remaining for future development in the Wasatch Plateau. The project is part of a national effort, coordinated by the USGS, to estimate the available coal resources of the United States. The UGS examined the northern half of the coalfield (figure 1) and the USGS examined the southern half. This report presents results for the UGS assessment of the coal remaining in the northern half of the Wasatch Plateau coalfield.

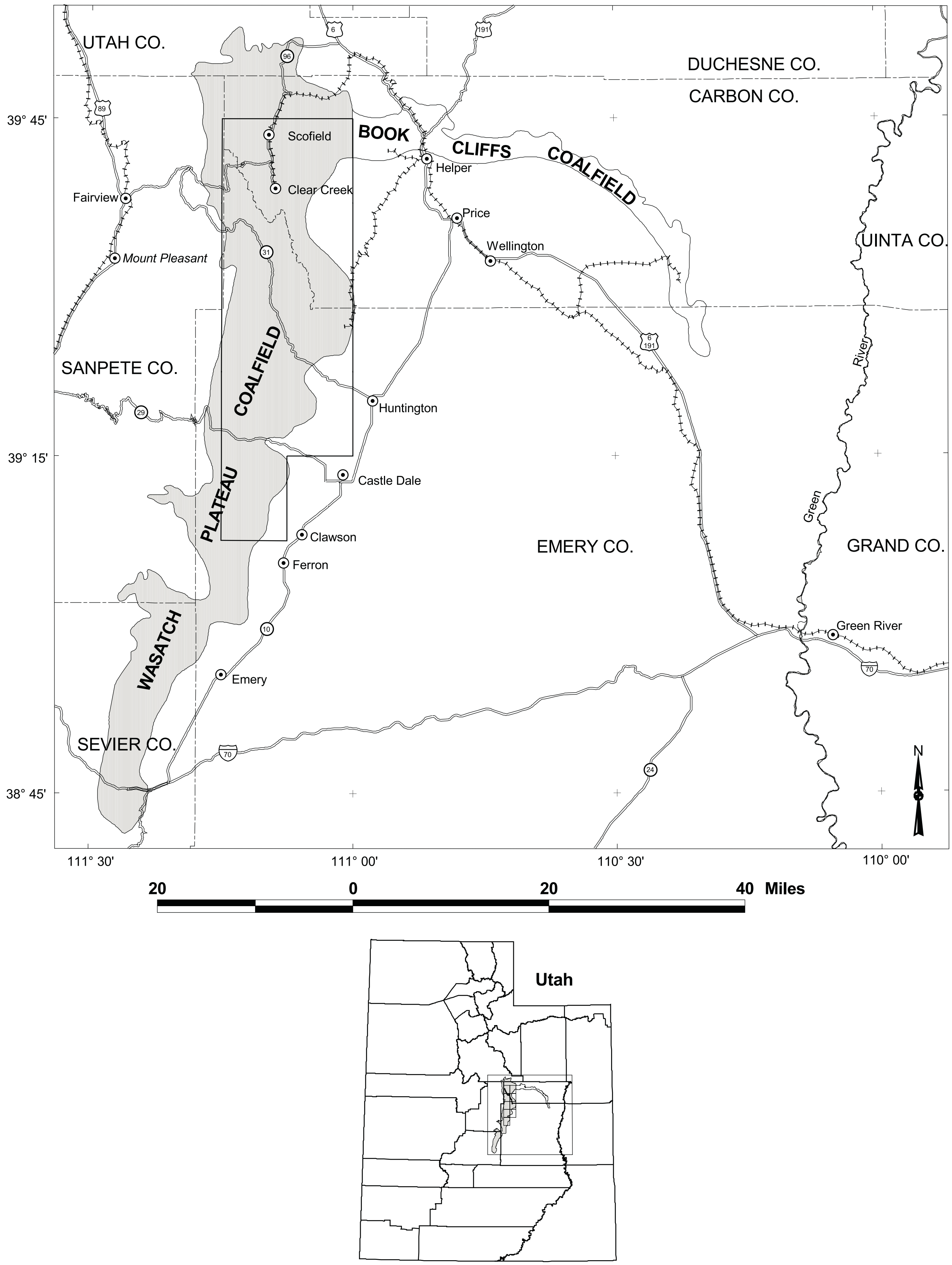

Figure 1. Location and geographic setting of the nine 7.5-minute quadrangle study area.

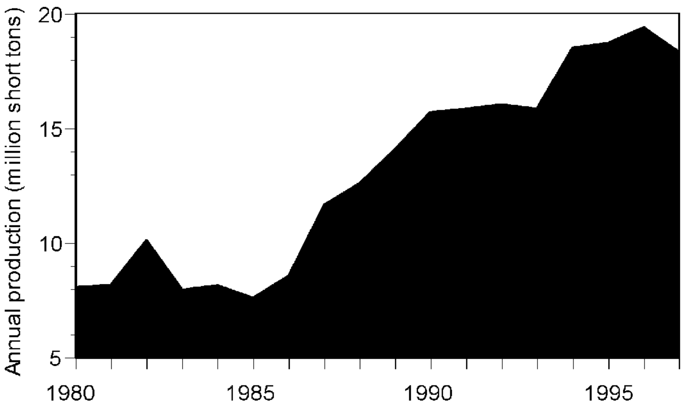

Figure 2. *Annual coal production from 1980 to 1997 for the northern Wasatch Plateau coalfield, Utah.*

LOCATION AND GEOLOGY

Available coal resources that occur in the Blackhawk Formation are estimated for nine 7.5-minute quadrangles shown in figure 3. These nine quadrangles cover most of the northern half of the Wasatch Plateau coalfield, which lies in western Carbon and northwestern Emery Counties (figure 1). Two small towns, Scofield and Clear Creek, are found in the northern part of the study area and are served by a spur of the Southern Pacific Railroad as well as by State Highway 96. U.S. Highway 31 also crosses the study area, running up Huntington Canyon.

We recognize 13 coalbeds in the study area (figure 4) that occur in the 700- to 1,100- foot-thick Upper Cretaceous Blackhawk Formation (Doelling, 1972). The Blackhawk Formation conformably overlies the Star Point Sandstone, and is unconformably overlain by the Castlegate Sandstone Member of the Price River Formation. These Cretaceous strata, as well as some younger Tertiary units, cap the highly dissected Wasatch Plateau.

The Wasatch Plateau lies along the gently dipping western flank of the San Rafael Swell. Dips of the strata are generally shallow, usually no more than six degrees to the west or northwest. The strata are broken by a series of en echelon, north-trending grabens with displacements on the graben-bounding faults of up to 1,500 feet (figure 5). The Joe's Valley and Pleasant Valley grabens cut the northern Wasatch Plateau study area.

The principal coalbeds occur in the lower half of the Blackhawk Formation. According to USGS personnel, the important lower beds in the area are named (in ascending order) the Acord Lakes, Axel Anderson, Cottonwood, Blind Canyon, Bear Canyon, and Wattis (Sanchez and Brown, 1986, 1987; Brown and others, 1987). Note that the Acord Lakes, Axel Anderson, and Cottonwood beds were previously considered a single coalbed called the Hiawatha. A better understanding of intertonguing of the basal Star Point Sandstone within the Blackhawk Formation allowed these individual coalbeds to be distinguished.

Blanchard (1981) and Mercier and others (1982) observed that complex intertonguing and graben faulting along the Pleasant Valley graben hindered correlation of the coalbeds in this area. Consequently, these coalbeds were given local names such as the Upper O'Connor, Lower O'Connor, and Flat Canyon. We have correlated these locally named beds with regionally recognized beds; the Upper O'Connor is correlated with the Wattis bed, the Lower O'Connor B with the Blind Canyon bed, the Lower O'Connor A with the Cottonwood bed, and the Flat Canyon with the Axel Anderson bed.

In the Gordon Creek mining area (figure 5), the bed formerly named the Hiawatha is now correlated with the Wattis bed, whereas the Castlegate A bed has not been renamed. This area also contains many of the stratigraphically higher beds including the Gordon, the Castlegate A, B, C, and D beds, the Gilson, and the Rock Canyon. Although these higher beds make relatively minor contributions to the resources in the study area, they are more significant, and regionally extensive, in the Book Cliffs coalfield immediately to the east. Some of these upper beds are also found locally in the southern part of the study area. For example, a bed that occurs in the middle of the study area, formerly known as the Tank bed, is correlated in this study with the Castlegate D bed (figure A9). A correlation chart giving the coalbed names used in this study and names previously assigned to these same beds is presented in figure 6.

Although we recognize 13 different coalbeds in the study area (figure 4), coal production has come from only six of these beds; these include the Axel Anderson, Cottonwood, Blind Canyon, and Wattis, with lesser contributions from the Castlegate A and Castlegate D. Despite their extensive exploitation, all of these coalbeds have potential for future mining.

METHOD

Approach

This study was undertaken using ArcView® software (version 3.0, Environmental Systems Research Institute [ESRI]) with ESRI's Spatial Analyst software extension running on a personal computer with a Windows 95 operating system. This GIS software allows for the simultaneous analysis of various combinations of resource parameters and the ability to easily repeat an analysis using different assumptions and parameters. Specific details related to the GIS methodology are provided in appendix B.

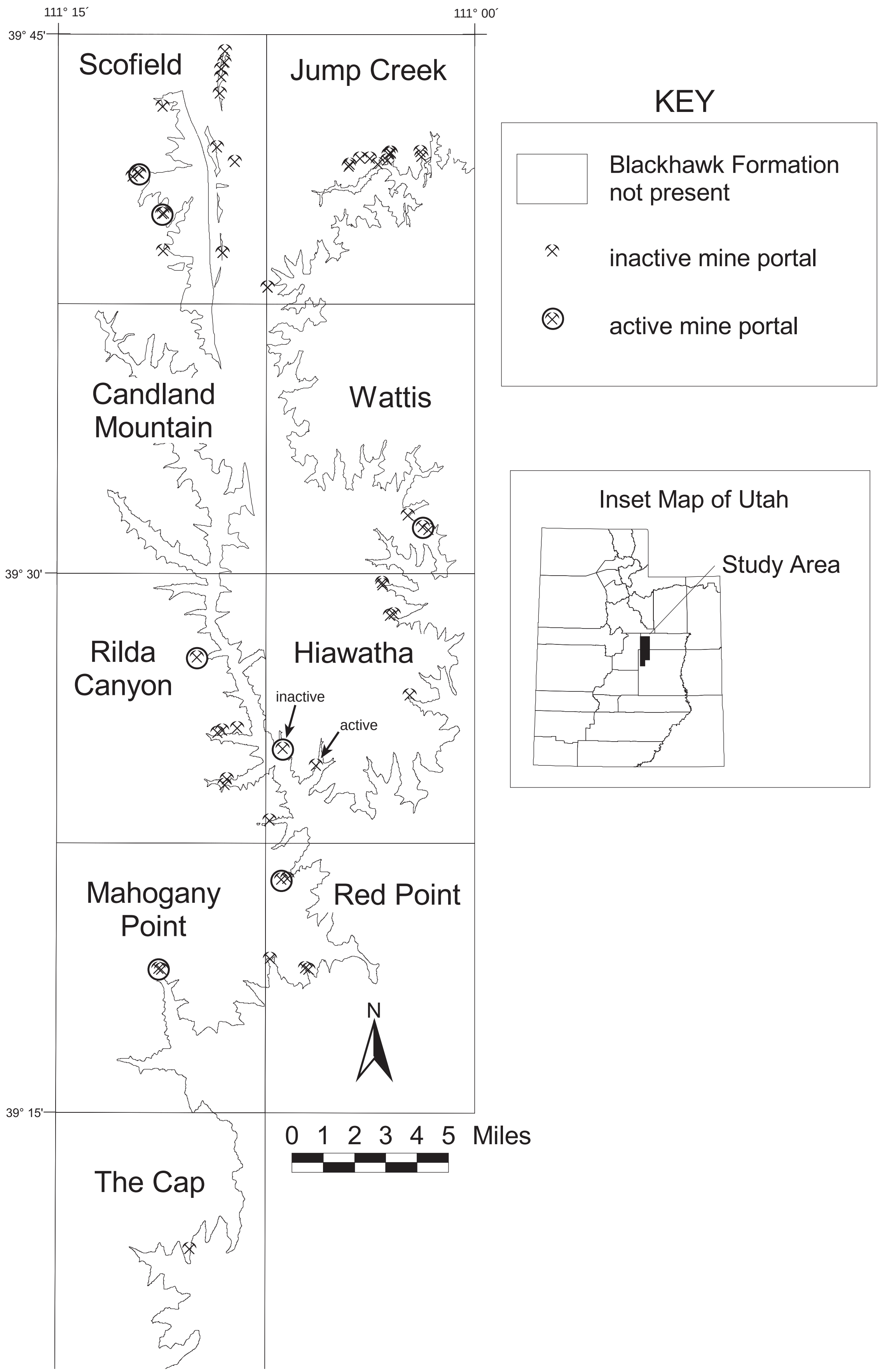

Figure 3. *Index map showing the nine 7.5-minute quadrangles in the study area with locations of active and abandoned mine portals.*

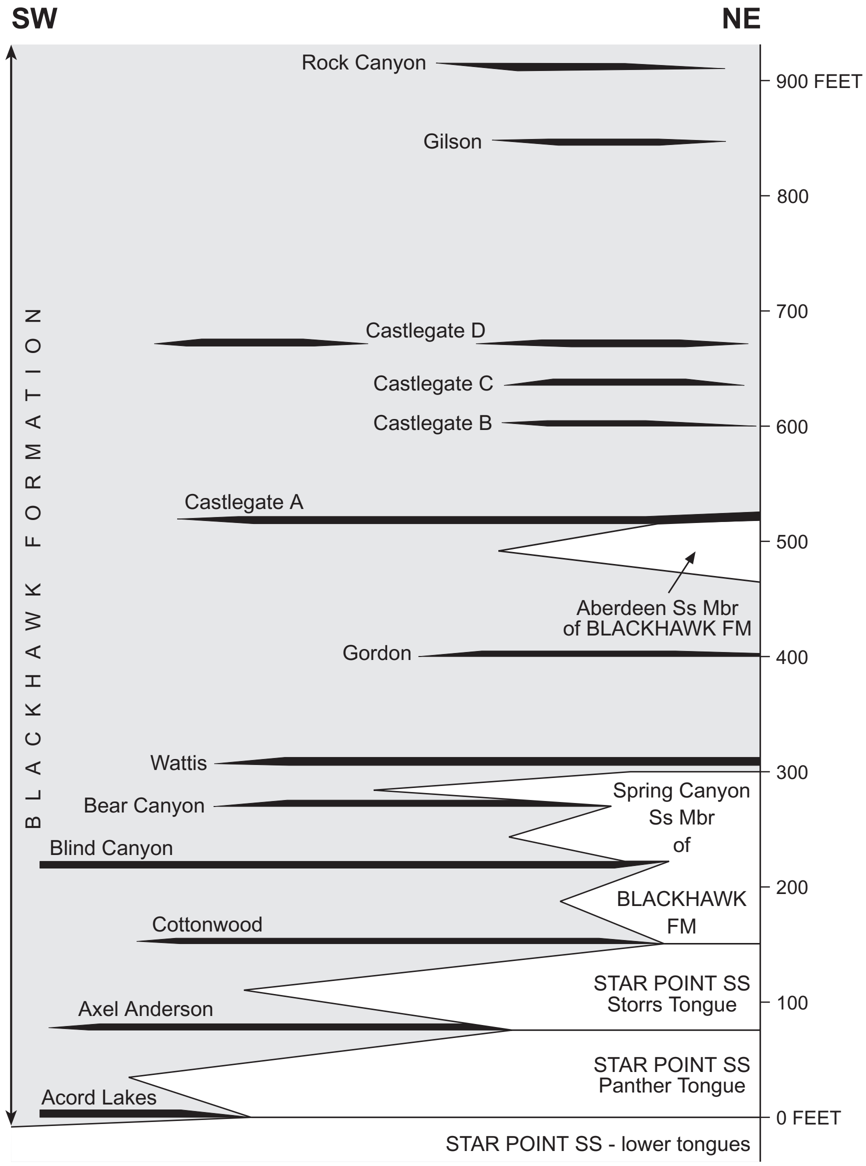

Figure 4. *Idealized stratigraphic section showing named coalbeds in the Blackhawk Formation, northern Wasatch Plateau, Utah.*

Maps showing the areal extent and thickness of identified coalbeds were constructed from scattered points of observation (drill hole records and outcrop measurements). The initial maps do not distinguish areas where the coal has been removed by past mining or, because of technical or regulatory reasons, is unlikely to be mined. Consequently, such restrictions to mining are examined by construction of associated maps, each corresponding to a particular restriction. Various map to map subtractions allow tabulation of the (remaining) available coal; these data, as well as associated maps showing the location of the available coal, are provided in appendix A.

Point Data Preparation

Point data used in this study originate from a database compiled by the UGS over the past 18 years for the National Coal Resources Data System (NCRDS), which is a state cooperative program with the USGS. The U.S. Bureau of Land Management (BLM) provided additional records as part of a cooperative data sharing agreement. Data from over 1,100 point locations were examined for possible use. Figure 7 shows the resulting 612 drill hole and measured section locations that we selected. We preferentially selected drill hole data since they provide the most reliable coalbed thickness, depth, and location values. Measured section data were selected in areas where drill hole data are lacking; such data indicate minimum coal thickness since coalbeds often thin at the outcrop as a result of weathering, slumping, or burning (Doelling, 1968). Furthermore, the precise elevation of coalbeds in the measured sections was difficult to determine. Accordingly, where we judged an elevation record for a measured section unreliable, the record was not

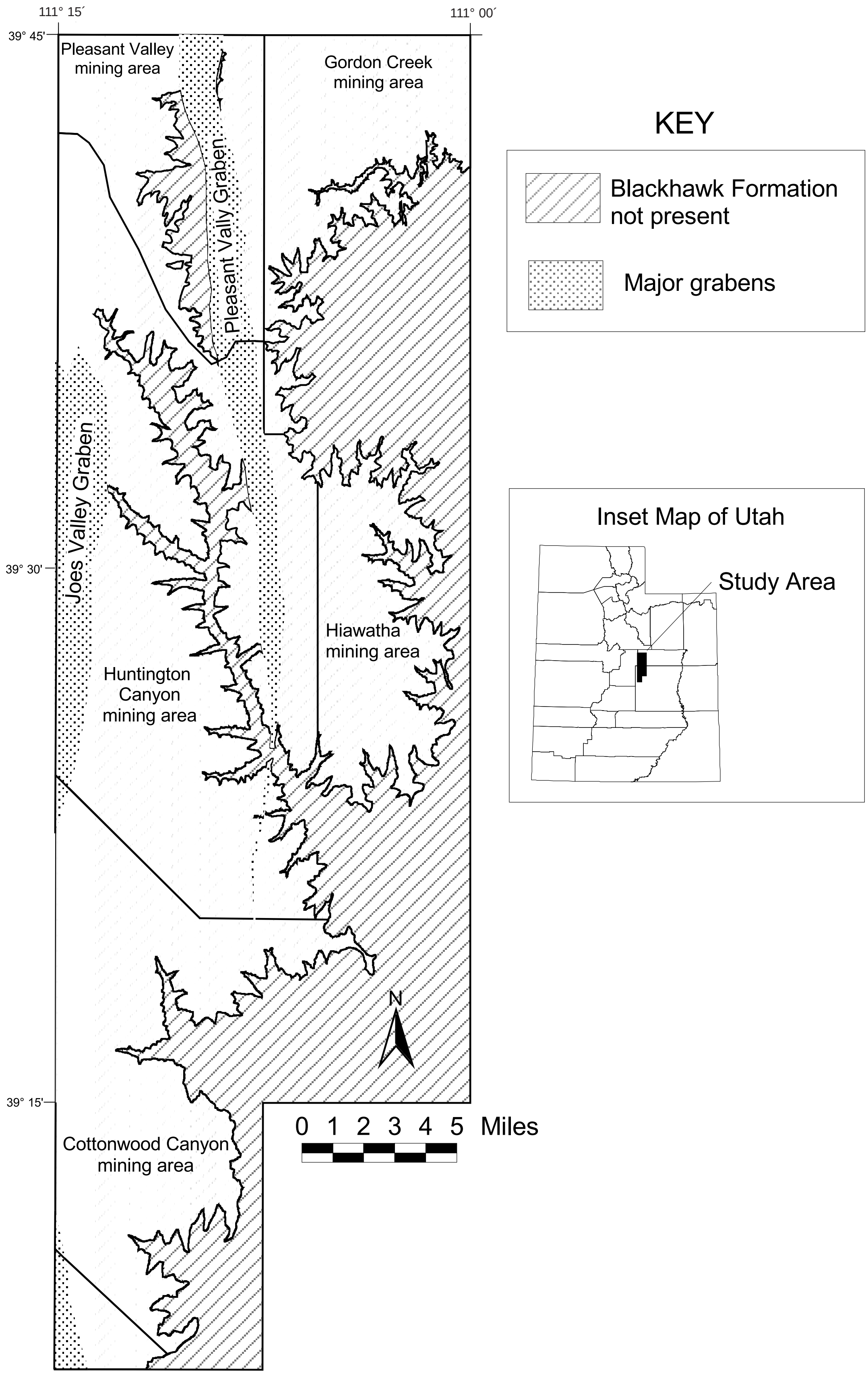

Figure 5. *Mining areas in the northern Wasatch Plateau, Utah.*

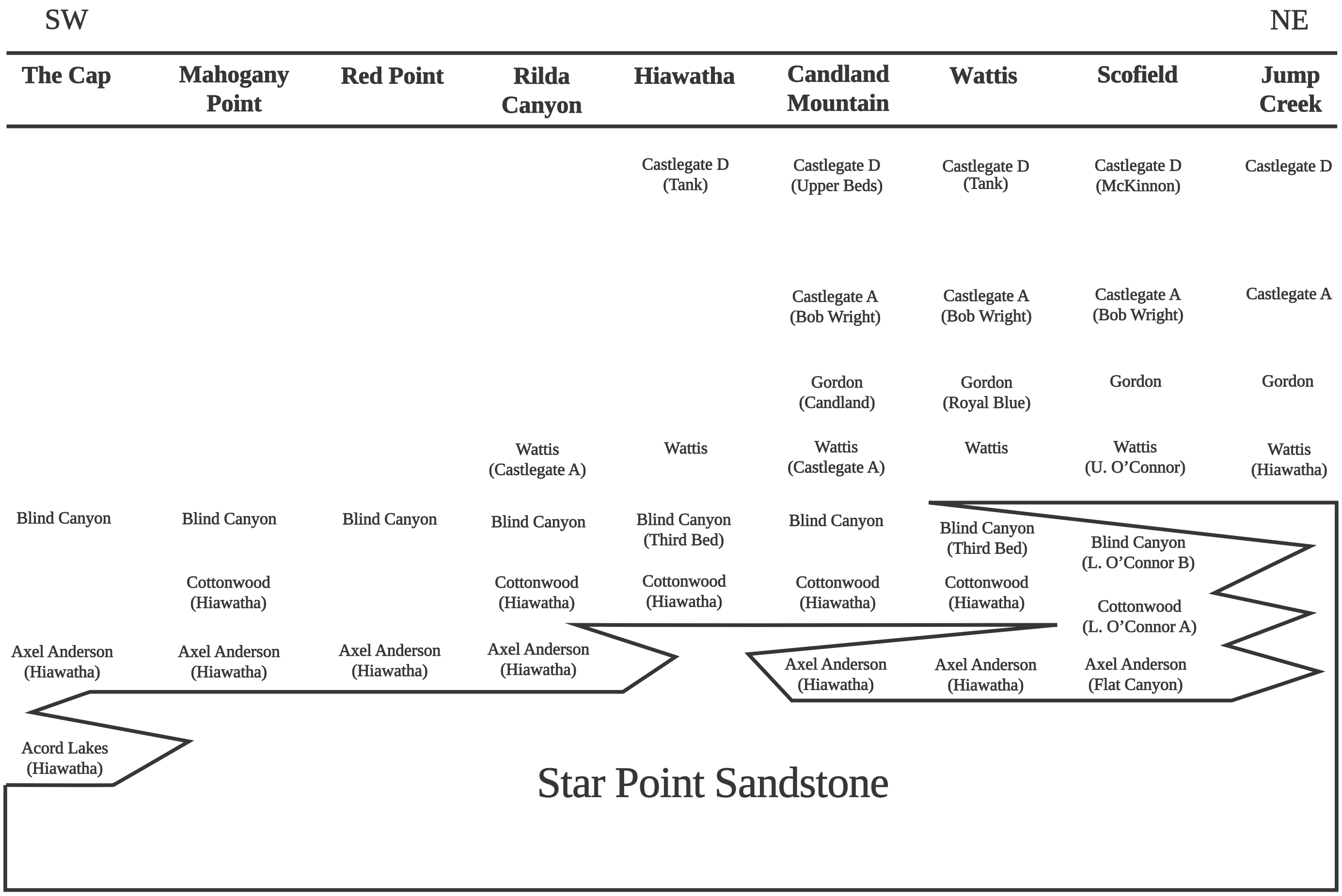

Figure 6. *Correlation chart showing the currently used (and previously used) coalbed names in the study area.*

used to construct a coalbed elevation map. Point data shown in figure 7 were used to prepare coalbed elevation, interburden, and thickness maps.

Restrictions to Mining

Besides maps showing the thickness, extent, and elevation of individual coalbeds, other mapped data are also required to estimate the available coal resource. For example, maps showing the extent and location of existing and abandoned mines are required to identify areas where coal has been removed or undermined. Likewise, maps of various cultural, geographic and geologic features are required to identify areas where mining is prohibited or unlikely due to technical problems related to the safe and economic recovery of coal. Three broad categories of restrictions to mining are considered: restrictions due to past mining activity, restrictions due to land-use valuation, and restrictions due to technical problems.

Past Mining

Maps of abandoned and active, underground mine workings were used to delineate areas where coalbeds have been mined or undermined and consequently are no longer available for future mining. We assume that undermining destroys the continuity of the overlying coalbeds and creates difficult floor and roof conditions that cause the higher beds to be unminable. A 50-foot buffer was added to the perimeter of abandoned mines; regulations require coal operators to leave a barrier of 50 feet from abandoned coal mine workings to avoid potential ventilation or water infusion problems. For simplicity, numerous small pillars indicated for some of the abandoned mines were not included in the mine maps (although large pillars were retained).

Land-Use Restrictions

Land-use restrictions prohibit mining under, or near, certain man-made or natural surface features; these restrictions are usually outlined in federal and state regulations. Land-use restrictions identified for the northern Wasatch Plateau study area include pipelines, power lines, oil and gas wells, highways, railroads, radio towers, towns and residences, perennial streams, and lakes or reservoirs.

Technical Restrictions

Technical restrictions are derived from current engi-

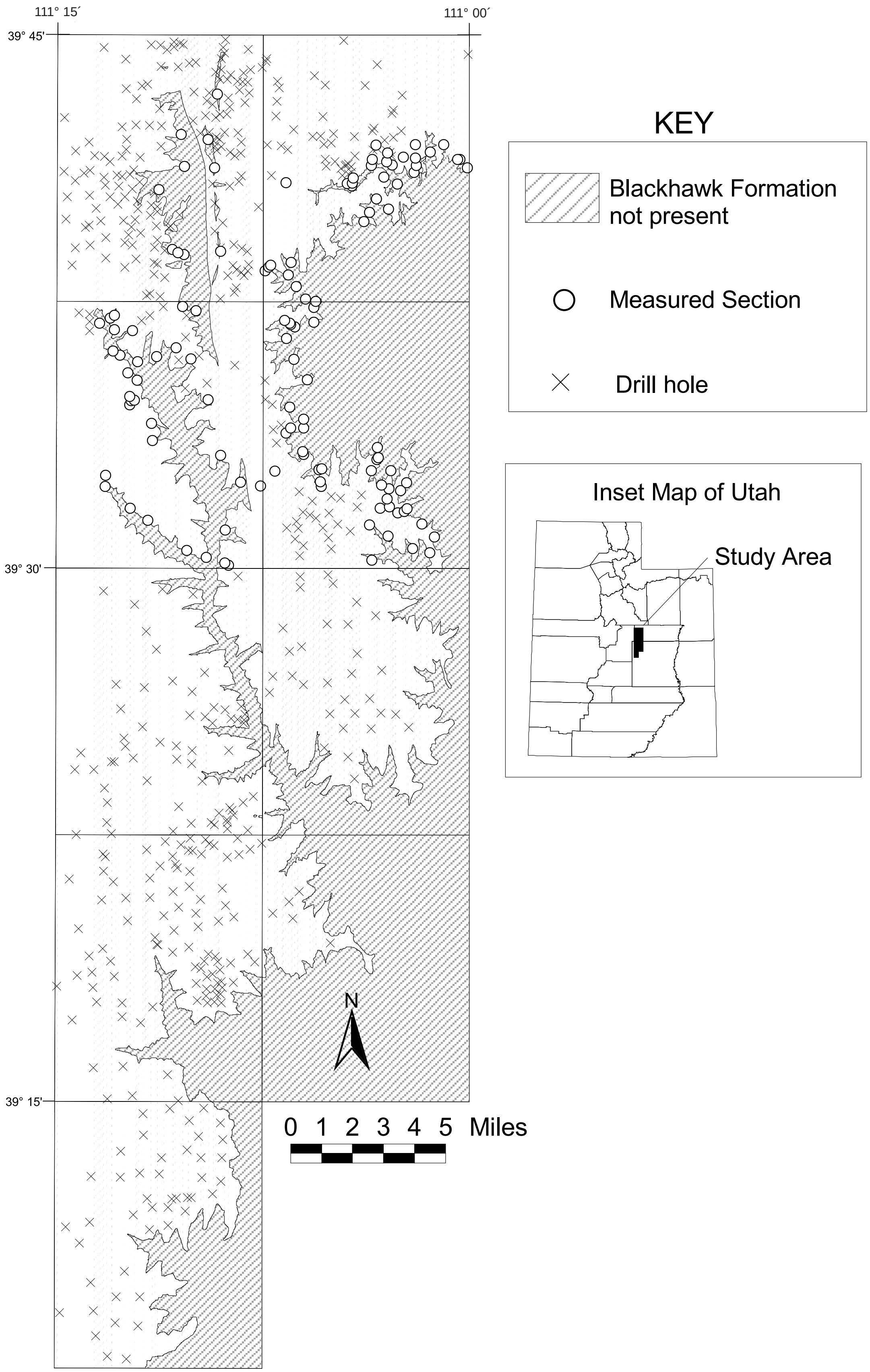

Figure 7. *Locations of measured sections and drill holes used to estimate the coal resources in the northern Wasatch Plateau coalfield, Utah.*

neering practices used by active local mines for the safe and efficient recovery of coal. Most Utah coal mines use continuous mining machines to develop mains and other entries, and longwall machines for bulk production. Equipment currently used at most mines limits recovery to coalbeds between 6 and 14 feet thick; for comparison with earlier studies we chose a minimum minable coalbed thickness of 4 feet. To avoid unstable roof conditions and possible water infusions, most mines leave a 50-foot barrier near known faults. Burned or oxidized coal behind the outcrop commonly causes operators to avoid mining coal near the outcrop; a 100-foot minimum overburden restriction was used to account for this coal. In areas where multiple beds can be sequentially mined, the interburden between two thick beds must be at least 40 feet to allow for stable roof and floor conditions. The maximum amount of overburden planned for at most mines is 2,500 feet. However, some companies are considering mining coal at depths up to 3,000 feet, so that limit was used in this study. Table 1 lists past mining, land-use, and technical restrictions occurring in the study area and the associated buffers and factors applied in this study.

Table 1.
Restrictions, and their associated buffers and factors, that prevent mining in the northern Wasatch Plateau coalfield.

LAND-USE RESTRICTIONS	**BUFFER**
Power lines	100 feet on either side
Pipelines	100 feet on either side
Highways	100 feet on either side
Railroads	100 feet on either side
Perennial streams	100 feet on either side
Lakes or reservoirs	100 feet inland from shore
Radio towers	100-foot radius
Oil and gas wells	100-foot radius
Towns or residences	300-foot perimeter
TECHNICAL RESTRICTIONS	**FACTOR**
Minimum bed thickness	4 feet
Maximum bed thickness	14 feet
Minimum overburden	100 feet
Maximum overburden	3,000 feet
Minimum interburden	40 feet
Faults[1]	50 feet on either side
PAST MINING	**FACTOR**
Barrier for active mines	none
Barrier for abandoned mines	50 feet around margin

[1] *Includes igneous dikes.*

Data Sources for Mapped Features that Restrict Mining

Transformation of information on paper maps to an electronic (digital) map format was done using a digitizing table and various AutoCAD® software (Autodesk Inc.). Electronic files of the resulting digital maps were usually imported directly into ArcView®. In some instances spatial buffers were added to mapped features using ESRI ArcInfo® software. Most of the mapped features we used to identify areas where mining is restricted were either directly digitized from standard 7.5-minute topographic quadrangles (1:24,000 scale) or drawn on these maps and then digitized.

We used several data sources to construct maps showing cultural, geographic and geologic features that identify areas where mining is restricted. Maps of active mines were acquired from coal operators' annual reports filed with the Utah Division of Oil, Gas and Mining (UDOGM) whereas maps of abandoned mines came from UGS files. Maps of features related to land-use restrictions (such as restrictions to mining under perennial streams, lakes, reservoirs, railroads, roads, pipelines, power lines, radio towers, towns, residences and municipalities) originate from recent 7.5-minute quadrangle maps, and updated where more current data were available. Faults were digitized from USGS 30 X 60-minute geologic maps (1:100,000 scale) of the area (Witkind and others, 1987; Weiss and others, 1990; Witkind and Weiss, 1991). Igneous dikes were hand-drawn on 7.5-minute quadrangle maps (1:24,000 scale) using data from Doelling (1972) and Tingey (1989).

Digital maps compiled by other agencies were also used. Digital land grid and topographic maps (USGS digital elevation models) came from the Utah Automated Geographic Reference Center (UAGRC). Digital maps of active oil and gas well locations were provided by the UDOGM.

RESOURCE CATEGORIES

Our estimates of coal resources were made in general accordance with the coal resource classification system outlined by Wood and others (1983). Departures from this classification were made according to local geology and mining practice.

Coal Categories

For each coalbed, we made maps corresponding to the total coal resources, minable coal resources, and available coal resources. This section discusses how these coal resource categories are defined and how the data used to make these maps were selected. Data used to create the maps are from varied sources; some data records include detailed observations of coalbeds that are inches thick whereas others only identify economically significant coalbeds that are several feet thick. To reduce the inherent variability of the data set we included only those data for coalbeds that are at least 1 foot thick. We also use 1 foot as the minimum coalbed thickness for reporting coal resources.

Total Coal Resources

The Wasatch Plateau coalfield is characterized by numerous coalbeds greater than 4 feet thick that occur at depths that require underground mining methods. Often a named coal corresponds to a zone of several discrete coalbeds and interbedded rock partings that occur within a 10- to 30-foot-thick interval. For the total coal resources calculation, we simply summed the thickness values of all the discrete coalbeds within a named coal zone. Consequently, isopach maps of total coal resources correspond to all of the coal that occurs in the named coal zone regardless of whether this coal occurs in a single bed that could be realistically recovered by underground mining.

Minable Coal Resources

The minable coal resources correspond to coal in single coalbeds that could potentially be recovered by underground mining. Accordingly, data used for construction of minable coal isopach maps were tabulated in a different manner than data used to construct the total coal isopach maps discussed above. This difference is illustrated in figure 8 which shows how total and minable coal are recognized in a single drill hole record corresponding to a point location in figure 7. Point data used to define minable coal resources are restricted to the thickest single coalbed in a coal zone. Some arbitrary rules used to identify the thickest single coal include:

1. the thickness of the individual minable coalbed is truncated where a rock parting is greater than or equal to 1.0 foot thick,
2. the minable interval may include partings less than 1.0 foot thick where the coals above and below the parting are at least twice the thickness of the included parting, and,
3. the included partings account for less than 20 percent of the minable coalbed thickness.

Occurrences where thin partings are included in the minable coal resource are rare. More commonly, a named coalbed is identified in a zone that contains two or more coalbeds in which only the thickest bed is considered minable.

Current mining practice of most companies in the northern Wasatch Plateau essentially restricts mining to coalbeds greater than 6 feet thick. Nonetheless, we include coalbeds as thin as 4 feet thick in our estimate of the minable coal resources since 4-foot-thick coalbeds have been mined in the past.

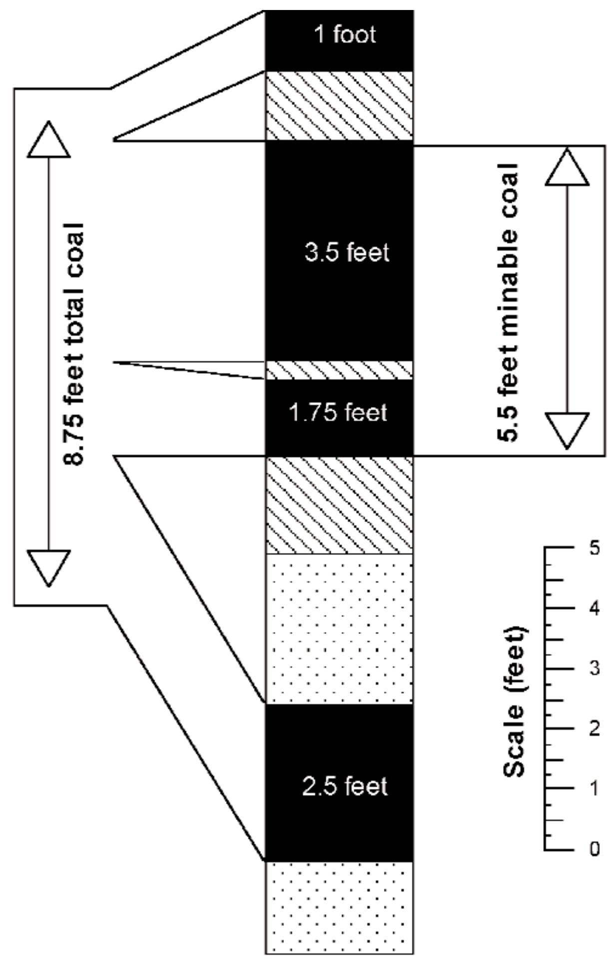

Figure 8. *Example of method used to tabulate total coal thickness and minable coal thickness in a drill hole or measured section.*

Available Coal Resources

Available coal resources are those parts of the minable coal resources remaining after subtraction of coal in areas disturbed by past mining as well as areas where technical or land-use restrictions prohibit mining. All of the coal resources identified as available for mining do not have the same costs to mine associated with them, and some of the available coal may not be economic to mine under the current market conditions.

Reliability Categories

Our calculation of the amount of minable coal in the study area is based on maps constructed from records of coal thickness measurements at specific locations (largely drill holes). Confidence in these maps is high in areas close to measurement points and decreases in areas farther away from these measurement locations. Consequently, the reliability of the derived tonnage estimate depends on the spatial distribution of the measurement point locations in relation to the mapped coalbed thickness.

Wood and others (1983) define the three reliability categories used in this report; they include demonstrated coal resources, inferred coal resources, and hypothetical coal resources. Demonstrated coal resources occur within 0.75 mile of a thickness measurement point. Inferred coal resources occur between 0.75 and 3 miles from a thickness measurement point. Hypothetical coal resources occur more than 3 miles from a thickness measurement point.

Thickness Categories

Standard resource thickness categories for bituminous coal resources (Wood and others, 1983) are not appropriate for this study given the characteristically thick beds and current mining practices in the northern Wasatch Plateau coalfield. Consequently, we used thickness categories suited to this area. Minable coal resources are assigned to one of four coal-bed thickness categories: 4 to 6 feet, 6 to 10 feet, 10 to 14 feet, and greater than 14 feet.

As noted above, we consider coalbeds less than 4 feet thick to be too thin to mine. Nonetheless, to conform with thinner USGS thickness categories (Wood and others, 1983), coal tonnages in beds 1 to 2 feet thick and 2 to 4 feet thick are reported in several tables.

Overburden Categories

Overburden maps were prepared by comparison of coalbed elevation maps with ground surface elevation maps. For simplicity, coalbed elevations correspond to the top of recognized coal zones. Four overburden categories appropriate to the geology and mining practice of the northern Wasatch Plateau are reported: 0 to 100 feet, 100 to 1,000 feet, 1,000 to 2,000 feet, and 2,000 to 3,000 feet.

Wood and others (1983) recommend a 0- to 500-foot overburden category to identify potentially strippable coal resources. However, the responsible land management agencies do not favor strip mining on the steep terrain characteristic of the study area. Consequently, we omit the recommended 500-foot overburden category but include a 0- to 100-foot category. The 0- to 100-foot overburden category is used to delineate coal that is not minable due to weathering or burning that is characteristic of these coals near the outcrop. All of the coal in the study area occurs at depths less than 3,000 feet, which is the maximum overburden limit being considered by local coal mining companies.

RESOURCE CALCULATION RESULTS

Original Total Coal Resources

Table 2 shows the original total coal resources calculated for 13 coalbeds in the study area. Examination of the table shows the original total coal resources exceed 9 billion tons. The Blind Canyon coal zone is the most widespread and contains the greatest original total coal resources (about 2.3 billion tons). Other important coal zones, each containing over 1 billion tons of original total coal resources, are the Axel Anderson, Cottonwood, and Wattis. More than 75 percent of the original total coal resources occurs in coal zones that contain more than 4 feet of coal and about 13 percent occurs in coal zones that contain more than 14 feet of coal.

Original Minable Coal Resources

Original minable coal resources correspond to coalbeds greater than 4 feet thick prior to subtractions due to past mining, land-use restrictions, and technical restrictions. Focusing on just the potentially minable coal typically reduces the coal thickness value used to calculate coal resources by ignoring thinner rider coalbeds above, or sub-beds below, the minable bed.

Table 3 shows the original minable coal resources total 5.4 billion tons, which is about 60 percent of the original total coal resources; about half of this difference is due to the exclusion of thin coal (less than 4 feet thick) in the tabulation of the minable coal resources and the remainder is due to the exclusion of rider and sub-beds (table 3). Table 3 also shows that the Gilson coalbed does not attain a minable thickness. Consequently, the Gilson coalbed is omitted from subsequent tables and discussion. Further examination of table 3 shows that 74 percent of the original minable coal resources occurs in beds greater than 6 feet thick and that 4 coalbeds (the Axel Anderson, Blind Canyon, Cottonwood, and Wattis) account for almost 90 percent of the original minable coal resources.

Table 2.
Original total coal resources for 13 coal zones in the northern Wasatch Plateau coalfield by coal thickness category (resources in millions of short tons).

	TOTAL COAL THICKNESS[2]						
COALZONE[1]	1 to 2 feet	2 to 4 feet	4 to 6 feet	6 to 10 feet	10 to 14 feet	>14 feet	TOTAL[3]
Rock Canyon	75.3	23.3	38.1	34.5	3.0	0.0	174.1
Gilson	82.6	20.2	0.0	0.0	0.0	0.0	102.6
Castlegate D	76.5	336.8	144.8	193.7	41.8	0.0	739.5
Castlegate C	18.5	11.1	4.1	0.0	0.0	0.0	33.7
Castlegate B	24.7	37.8	2.0	0.0	0.0	0.0	64.5
Castlegate A	44.9	85.5	47.3	47.5	4.0	1.1	230.3
Gordon	165.8	137.1	38.9	28.5	28.4	23.0	421.8
Wattis	71.3	180.9	249.3	742.7	193.1	106.1	1,543.3
Bear Canyon	41.4	72.7	76.2	27.0	0.0	0.0	217.4
Blind Canyon	34.4	211.9	309.3	614.8	489.8	622.5	2,282.7
Cottonwood	64.9	206.0	156.5	282.3	222.6	374.3	1,306.6
Axel Anderson	36.0	180.6	365.7	698.0	364.9	76.8	1,722.0
Acord Lakes	2.2	6.7	39.0	124.4	96.4	0.0	268.7
TOTAL[3]	738.6	1,510.6	1,471.2	2,793.4	1,444.0	1,203.8	9,161.4
PERCENT	8.1	16.5	16.1	30.5	15.8	13.1	

[1] COAL ZONE is used here rather than "coalbed" to indicate that the total coal thickness may represent the summed thickness of multiple, closely spaced coalbeds.
[2] TOTAL COAL THICKNESS includes all of the coal that occurs in the named coal zone regardless of whether this coal could be realistically recovered by underground mining.
[3] Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.

Depth of Original Minable Coal Resources

The original minable coal resources are classified by coalbed and depth category in table 4. All of the original minable coal resources are found at depths that allow mining (less than 3,000 feet overburden) and most (88 percent) occur at depths between 100 and 2,000 feet, which is the optimum range for underground mining.

Reliability of Estimates

Table 5 shows the reliability of original minable coal resources in the northern Wasatch Plateau according to coalbed and thickness interval. Over 75 percent of the original minable coal resources are demonstrated whereas less than 1 percent are hypothetical.

Available Coal Resources

The available coal resources are the original minable coal resources remaining after subtraction of coal in areas disturbed by past mining and coal in areas subject to technical or land-use restrictions. This section provides further details on how these areas are delineated as well as their individual and cumulative impacts on the tabulation of available coal resources.

Mined-Out and Undermined Coal

Past mining accounts for the largest reduction of the original minable coal resource in the calculation of the available coal resources in the northern Wasatch Plateau. The tonnage of coal in beds directly disturbed by past mining was calculated by considering the thickness of original minable coal within the mapped perimeters of active mines (as of December 31, 1996) and the buffered perimeters of abandoned mines. A bituminous coal density factor (1,800 tons per acre-foot) was applied to the disturbed acreage. A 50-foot buffer was added to the perimeter of the abandoned mine; no buffer was added to active mines. For consistency, numerous small pillars indicated in a few of the abandoned mines were deleted; relatively large pillars and encircled blocks were retained.

Our collection of abandoned mine maps, although extensive, apparently does not represent the full extent of

Table 3.
Original minable coal resources for 13 coalbeds in the northern Wasatch Plateau coalfield by bed thickness category (resources in millions of short tons).

	COALBED THICKNESS						
	Thin Coal[1]		Minable Coal				
	1 to 2 feet	2 to 4 feet	4 to 6 feet	6 to 10 feet	10 to 14 feet	>14 feet	
COALBED							**TOTAL[2,3]**
Rock Canyon	74.9	36.6	24.0	3.2	3.0	0.0	30.2
Gilson	32.5	8.4	0.0	0.0	0.0	0.0	0.0
Castlegate D	110.3	320.8	158.1	49.2	2.1	0.0	209.4
Castlegate C	18.5	11.1	4.1	0.0	0.0	0.0	4.2
Castlegate B	24.7	37.9	2.0	0.0	0.0	0.0	2.0
Castlegate A	53.4	79.3	38.5	30.1	0.1	0.0	68.7
Gordon	175.6	103.2	30.0	16.6	7.0	15.5	69.0
Wattis	82.8	184.4	250.6	696.7	130.7	62.4	1,140.4
Bear Canyon	45.1	89.4	42.5	15.5	0.0	0.0	58.0
Blind Canyon	59.3	279.4	283.1	588.0	330.2	282.7	1,483.9
Cottonwood	76.7	209.2	150.6	225.1	183.0	320.6	879.2
Axel Anderson	49.2	209.4	373.3	560.8	293.3	44.7	1,272.2
Acord Lakes	2.4	35.0	35.7	107.0	15.7	0.0	158.4
TOTAL[3]	805.3	1,604.1	1,392.5	2,292.2	965.1	725.9	5,375.6
PERCENT	—	—	25.9	42.6	18.0	13.5	

[1] Not considered part of minable coal resources.
[2] Does not include thin (<4-foot-thick) coal.
[3] Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.

past mining. Some of these maps predate the abandoned mine's closure date and may not represent the maximum area that was mined. Published records (Doelling, 1972) also indicate that some of the abandoned mines, particularly in the Pleasant Valley area (figure 5), worked multiple beds whereas our maps only show a single mined area without notation of which coalbeds were mined. Therefore, our calculation of mined-out tonnage is a conservative estimate (even with a 50-foot buffer included around abandoned mines).

Calculation of the original minable coal affected by past mining shows that 674 million tons of coal have been directly disturbed within the perimeters of active mines and the buffered perimeters of abandoned mines. This is 13 percent of the original minable coal resource.

Besides coalbeds directly disturbed by mining, some coal resources have also been made unavailable to future mining where a coalbed has been disturbed by mining of an underlying bed. We assume that undermining destroys the continuity of the overlying coalbed and creates difficult roof and floor conditions that cause the higher beds to be unminable. Perhaps some of these upper beds were mined by past operations for which we simply lack mine maps. Regardless of whether such beds were directly mined or undermined, the affected coal in these areas is not considered part of the available coal resources. Our calculations show undermining removes an additional 296 million tons of the original minable coal resources from future development. Combining the mined-out and undermined coal shows that roughly one billion tons of coal have been either removed or made unrecoverable by past mining. Table 6 shows a tabulation of coal tonnages directly disturbed by mining (mined), made unrecoverable by undermining (undermined), and remaining after subtraction of mined and undermined coal (remaining).

Examination of table 6 shows 4.4 billion tons of original minable coal remain after subtractions due to mining; this is 82 percent of the original minable coal resources. The percentage of remaining minable coal resources for individual coalbeds varies from 69 percent for the Castlegate A bed to 100 percent for unmined beds like the Acord Lakes.

Doelling (1972) calculated that 98 million tons of

Table 4.
Original minable coal resources for 12 coalbeds in the northern Wasatch Plateau coalfield by depth category (resources in millions of short tons).

	DEPTH CATEGORY				
	0 to 100[1] feet	100 to 1,000 feet	1,000 to 2,000feet	2,000 to 3,000 feet	
COALBED					**TOTAL[2]**
Rock Canyon	5.5	24.7	0.0	0.0	30.2
Castlegate D	16.0	123.6	67.7	2.1	209.4
Castlegate C	1.5	2.7	0.0	0.0	4.2
Castlegate B	0.1	1.9	0.0	0.0	2.0
Castlegate A	12.1	53.6	3.1	0.0	68.7
Gordon	14.7	52.8	1.6	0.0	69.0
Wattis	57.1	673.3	401.0	9.0	1,140.4
Bear Canyon	3.3	37.4	17.3	0.0	58.0
Blind Canyon	59.1	669.7	611.3	143.9	1,483.9
Cottonwood	32.5	391.3	439.1	16.3	879.2
Axel Anderson	33.3	503.7	532.1	203.1	1,272.2
Acord Lakes	0.1	36.4	79.5	42.4	158.4
TOTAL[2]	235.2	2,571.0	2,152.7	416.7	5,375.6
PERCENT	4.4	47.8	40.0	7.8	

[1] Although we consider coals in the northern Wasatch Plateau with less than 100 feet overburden to be weathered, the tonnages shown here correspond to original minable coal resources; this shallow coal is excluded from tabulation of available coal resources.
[2] Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.

coal were produced from the nine-quadrangle study area from 1874 through the end of 1969. Coal production records from Jahanbani (1997) indicate that 351 million tons of coal have been produced from the northern Wasatch Plateau study area through the end of 1996. These observations indicate that mining during the past 27 years (1970-1996) has removed 2.5 times more coal than was removed during the first 95 years of production.

The 351 million cumulative tons of coal produced from northern Wasatch Plateau mines through 1996 accounts for 52 percent of the 674 million tons of original minable resources in beds that were directly affected by these mines. This observation suggests a recovery factor of over 50 percent. However, if the 970 million tons of the combined mined and undermined coal is considered, then 36 percent recovery of the original minable coal is indicated.

Technical Restrictions to Coal Mining

Technical restrictions are related to engineering and economic factors that limit the coal that can be mined with existing technology and economic conditions. Although barriers around abandoned mines, and coal lost to undermining, might be considered technical restrictions, the affected coal tonnage was considered in the previous section and is not discussed here. Cumulatively, technical restrictions eliminate 9 percent of the minable coal resources remaining after deductions due to past mining

The largest amount of technically restricted coal occurs where coalbeds have less than 100 feet of overburden. The quality of these shallow coal resources is usually poor due to oxidative weathering near the outcrop. In some instances the coal has been completely destroyed by burning. Although the steep topography of the area limits the shallow resources to a narrow band, the extensive outcrops along the many canyons of the highly dissected plateau country result in a significant resource restriction. This restriction excludes 235 million tons of coal from the available coal resources.

The second most significant technical restriction occurs where coalbeds are too thick for full-bed-thickness extraction using current mining equipment. This restriction affects parts of the Axel Anderson, Cottonwood, Blind Canyon, Wattis, and Gordon coalbeds since

Table 5.
Original minable coal resources for 12 coalbeds in the northern Wasatch Plateau coalfield by thickness and reliability categories (resources in millions of short tons).

	COALBED THICKNESS												
	4 to 6 feet			**6 to 10 feet**			**10 to 14 feet**			**> 14 feet**			
Reliability Category [1]	***Dem***	***Inf***	***Hyp***	***Dem***	***Inf***	***Hyp***	***Dem***	***Inf***	***Hyp***	***Dem***	***Inf***	***Hyp***	
COALBED													**TOTAL** [2]
Rock Canyon	5.5	13.1	5.4	2.8	0.4	0.0	3.0	0.0	0.0	0.0	0.0	0.0	30.2
Castlegate D	68.4	79.0	10.7	46.5	2.8	0.0	2.1	0.0	0.0	0.0	0.0	0.0	209.5
Castlegate C	3.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
Castlegate B	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Castlegate A	31.9	6.7	0.0	24.8	5.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	68.8
Gordon	15.7	14.3	0.0	11.6	4.9	0.0	2.3	4.7	0.0	14.0	1.5	0.0	69.0
Wattis	158.9	91.7	0.0	540.3	156.3	0.0	115.4	15.3	0.0	62.4	0.0	0.0	1,140.3
Bear Canyon	29.3	13.1	0.0	14.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.9
Blind Canyon	191.6	91.5	0.0	434.9	153.0	0.0	268.7	61.5	0.0	257.0	25.7	0.0	1,483.9
Cottonwood	108.6	42.0	0.0	192.1	33.0	0.0	142.4	40.6	0.0	271.7	48.8	0.0	879.2
Axel Anderson	246.8	126.5	0.0	436.3	124.5	0.0	212.8	80.5	0.0	37.6	7.1	0.0	1,272.1
Acord Lakes	17.2	18.5	0.0	69.0	38.0	0.0	12.3	3.5	0.0	0.0	0.0	0.0	158.5
TOTAL [2]	879.8	496.6	16.1	1,773.2	518.8	0.0	759.1	206.1	0.0	642.7	83.1	0.0	5,375.5
PERCENT	16.4	9.2	0.3	33.0	9.7	0.0	14.1	3.8	0.0	12.0	1.5	0.0	

[1] *Reliability Category abbreviations, Dem is Demonstrated, Inf is Inferred, and Hyp is Hypothetical (after Wood and others, 1983).*
[2] *Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.*

they are sometimes more than 14 feet thick. Most of the coal that is too thick for full-bed-thickness extraction occurs in the Cottonwood and Blind Canyon beds. About 155 million tons of the original minable coal resources occurs in those parts of coalbeds that exceed 14 feet thickness.

A third technical restriction on future mining occurs where two thick coalbeds have insufficient interburden between them (less than 40 feet) to allow both beds to be safely mined. These areas were identified by constructing interburden isopach maps. The maps were made from observed separations of the tops of adjacent coal zones for point locations in the data set. Where interburden between two minable beds was less than 40 feet, one coalbed was included and the other coalbed excluded from our calculation of available coal resources. The selection of which bed to include and which bed to exclude was subjectively made to maximize the total available coal resources according to the relative continuity and thickness of the affected beds. Interburden restrictions exclude 114 million tons of otherwise minable coal in the Axel Anderson, Cottonwood, Blind Canyon, and Wattis beds.

The final technical restriction occurs where coalbeds are cut by faults. In these areas, roof instability and water infusions create safety problems and abrupt vertical coalbed displacements create problems for longwall mining. Faulting is common in the study area and all of the major coalbeds are affected by this restriction. A 50-foot buffer on either side of mapped faults delineates areas of restricted coal. These narrow, restricted areas contain 88 million tons of the original minable coal resources which is excluded from the available coal resources. Only major faults with significant displacements have been mapped; minor, unmapped faults with small offsets are common in graben areas (see figure 5). Although displacements on these minor faults are small, they can disrupt the continuity of coalbeds enough to make longwall mining impractical. Minor faulting is problematic within the Joes Valley Graben and the Pleasant Valley Graben; the area within the Joes Valley Graben is shown as a "shattered zone" on maps made by Sanchez and Brown (1986, 1987). The areal extent of affected coalbeds is not easily determined since these faults lack obvious surface expression and have not been mapped. Consequently, the 88 million tons of coal we calculate to be unavailable due to faulting is probably less than the actual amount of coal affected by faulting.

Table 6.
Remaining minable coal resources for 12 coalbeds in the northern Wasatch Plateau coalfield by thickness category after subtraction of coal disturbed by past mining as of the end of 1996 (resources in millions of short tons).

		COALBED THICKNESS				
COALBED		**4 to 6 feet**	**6 to 10 feet**	**10 to 14 feet**	**>14 feet**	**TOTAL[1]**
Rock Canyon	mined	0.0	0.0	0.0	0.0	0.0
	undermined	0.4	0.0	0.0	0.0	0.4
	remaining	23.6	3.3	3.0	0.0	29.8
Castlegate D	mined	1.3	1.9	0.0	0.0	3.3
	undermined	52.0	8.1	0.6	0.0	60.7
	remaining	104.8	39.2	1.5	0.0	145.5
Castlegate C	mined	0.0	0.0	0.0	0.0	0.0
	undermined	0.0	0.0	0.0	0.0	0.0
	remaining	4.2	0.0	0.0	0.0	4.2
Castlegate B	mined	0.0	0.0	0.0	0.0	0.0
	undermined	0.0	0.0	0.0	0.0	0.0
	remaining	2.0	0.0	0.0	0.0	2.0
Castlegate A	mined	5.8	8.9	0.0	0.0	14.7
	undermined	3.6	2.7	0.0	0.0	6.4
	remaining	29.1	18.4	0.1	0.0	47.6
Gordon	mined	0.0	0.0	0.0	0.0	0.0
	undermined	2.4	0.4	0.0	0.0	2.8
	remaining	27.6	16.1	7.0	15.5	66.2
Wattis	mined	14.6	67.9	22.6	35.0	140.1
	undermined	24.0	66.3	9.3	0.5	100.2
	remaining	211.9	562.4	98.8	26.9	900.0
Bear Canyon	mined	0.0	0.0	0.0	0.0	0.0
	undermined	2.4	0.0	0.0	0.0	2.4
	remaining	40.1	15.5	0.0	0.0	55.6
Blind Canyon	mined	7.1	73.7	51.6	36.2	168.7
	undermined	29.1	58.5	21.8	1.5	110.9
	remaining	246.9	455.7	256.8	245.0	1,204.3
Cottonwood	mined	15.4	35.4	45.4	111.1	207.2
	undermined	7.9	2.7	0.9	1.0	12.5
	remaining	127.3	187.0	136.7	208.5	659.5
Axel Anderson	mined	10.0	83.8	41.5	5.0	139.7
	undermined	0.0	0.0	0.0	0.0	0.0
	remaining	363.3	477.6	251.8	39.7	1,132.4
Acord Lakes	mined	0.0	0.0	0.0	0.0	0.0
	undermined	0.0	0.0	0.0	0.0	0.0
	remaining	35.7	107.0	15.7	0.0	158.4
TOTAL DISTURBED [1, 2]		176.1	409.9	193.7	190.3	970.0
TOTAL REMAINING [1]		1,216.4	1,882.2	771.5	535.5	4,405.5

[1] Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.
[2] TOTAL DISTURBED is the sum of mined and undermined coal.

Some areas are subject to multiple restrictions. Consequently, simple summing of coal excluded from the available coal resources due to individual technical restrictions overestimates the amount of coal that cannot be mined. Accordingly, coal in areas subjected to multiple restrictions is deducted only once from the original minable coal resources. Thus, taking care to avoid double counting, we observe that 490 million tons of coal, or 9 percent of the original minable coal resources, cannot be mined due to technical restrictions. Table 7 shows how each technical restriction affects the original minable coal resources for individual coalbeds, as well as the net reduction of coal resources due to the combined effect of these restrictions.

Table 7.
Coal resources in the northern Wasatch Plateau coalfield that cannot be mined due to technical factors (resources in millions of short tons).

	TECHNICAL RESTRICTIONS [1]				
	Minable coal with less than 100 feet overburden	**Minable coal in excess of 14 feet thickness**	**Minable coal within 40 feet of a better coalbed**	**Minable coal within 50 feet of a fault**	**NET RESTRICTED COAL [2]**
COALBED					
Rock Canyon	5.5	0.0	0.0	0.5	5.7
Castlegate D	16.0	0.0	0.0	3.2	12.3
Castlegate C	1.5	0.0	0.0	0.1	1.5
Castlegate B	0.1	0.0	0.0	0.0	0.1
Castlegate A	12.1	0.0	0.0	1.4	10.1
Gordon	14.7	2.7	0.0	1.5	17.8
Wattis	57.1	10.3	36.1	26.6	106.6
Bear Canyon	3.3	0.0	0.0	0.4	3.7
Blind Canyon	59.1	49.4	2.0	19.4	113.8
Cottonwood	32.5	90.3	36.9	16.7	129.9
Axel Anderson	33.3	2.0	38.8	17.1	87.4
Acord Lakes	0.0	0.0	0.0	0.9	1.0
TOTAL [3]	235.2	154.7	113.8	87.7	489.9

[1] TECHNICAL RESTRICTIONS are individually tabulated on original minable coal resources prior to subtraction of coal made unavailable due to past mining.
[2] Tabulation of NET RESTRICTED COAL does not double count coal in areas subject to multiple restrictions and is calculated from minable coal remaining after subtraction of coal made unavailable due to past mining. For example, shallow coal that has also been undermined is included in the tabulation of individual TECHNICAL RESTRICTIONS but excluded in the tabulation of NET RESTRICTED COAL.
[3] Listed totals may differ from values obtained by summing columns due to independent rounding of values to the nearest 0.1 million tons.

Land-Use Restrictions to Coal Mining

Land-use restrictions arise from conflicts with other resource and land-use valuations. Some land use restrictions can be mitigated, and partial, or full, coal extraction might be allowed in the future. Conversely, additional restrictions can be imposed in response to changing land-use valuations or mining practices. For example, longwall mining causes more widespread surface subsidence than older room and-pillar methods. Consequently, larger buffers around lakes and perennial streams, calculated according to the angle of draw from the subsided area, are required where longwall mines are planned. In newer longwall mine plans buffer zones are also required along the escarpment faces of the Wasatch Plateau to protect to protect against potential debris slides caused by subsidence. Since we do not have maps showing the location of the escarpments that need to be buffered, and some of this coal was already removed in our minimum overburden restriction, we did not calculate the coal tonnage made unavailable due to escarpment protection. Although room-and-pillar mining may allow coal extraction nearer to escarpments and waterways, the greater cost of room-and-pillar mining may make coal recovery from the expanded buffer areas uneconomic. Detailed engineering studies are required for more accurate estimates of affected coal tonnage. Thus, the values listed in table 1 that we use to calculate the amount of coal made unavailable due to land-use restrictions are conservative; our results are tabulated in table 8.

Of the minable coal resources remaining after subtractions due to past mining and technical restrictions, land-use restrictions individually exclude a total of 155 million tons of coal and cumulatively exclude 146 million tons; the smaller cumulative (net) exclusion results from counting areas subject to multiple restrictions only once. Net coal tonnage excluded due to land-use restrictions is about 3 percent of the original minable coal. Coalbeds most affected by land-use restrictions are the Axel Anderson, Cottonwood, Blind Canyon, and Wattis. The prohibition of mining under perennial streams and lakes excludes 73 million tons of coal which is about half of the total net coal excluded due to land-use restrictions.

Tabulation of Available Coal Resources

Table 9 shows that 3.8 billion tons of coal are available for future mining in the northern Wasatch Plateau;

Table 8.
Coal resources in the northern Wasatch Plateau coalfield that cannot be mined due to land-use restrictions (resources in millions of short tons).

	LAND-USE RESTRICTIONS[1]								
	Streams and lakes	Towns	Roads	Pipe-lines	Rail-roads	Buildings and radio towers	Power-lines	Oil wells	NET RESTRICTED COAL[2, 3]
COALBED									
Rock Canyon	0.5	3.6	0.6	0.0	0.3	0.1	0.0	0.0	3.9
Castlegate D	0.9	0.4	0.0	0.3	0.0	0.0	0.0	0.0	1.6
Castlegate C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Castlegate B	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Castlegate A	0.7	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.9
Gordon	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.3
Wattis	26.5	10.1	3.2	1.8	1.7	1.0	0.0	0.0	41.9
Bear Canyon	0.4	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.8
Blind Canyon	17.7	8.4	3.5	2.7	0.2	0.5	1.9	0.1	34.3
Cottonwood	8.9	21.2	1.9	2.5	1.7	1.1	0.0	0.0	34.3
Axel Anderson	17.1	3.6	3.0	1.9	0.3	0.7	0.9	0.1	25.9
Acord Lakes	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	1.6
TOTAL[3]	72.9	47.4	14.0	9.7	4.3	3.5	2.7	0.2	145.6

[1] Tonnages are calculated from minable coal remaining after subtraction of coal in areas disturbed by mining or subject to technical restrictions.
[2] NET RESTRICTED COAL does not double count coal in areas subject to multiple land-use restrictions.
[3] Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.

Table 9.
Available coal resources in the northern Wasatch Plateau coalfield at the end of 1996 (resources in millions of short tons).

	COALBED THICKNESS				
	4 to 6 feet	6 to 10 feet	10 to 14 feet	> 14 feet	TOTAL AVAILABLE COAL[1]
COALBED					
Rock Canyon	14.8	2.6	2.7	0.0	20.1
Castlegate D	94.2	35.9	1.5	0.0	131.6
Castlegate C	2.6	0.0	0.0	0.0	2.6
Castlegate B	1.9	0.0	0.0	0.0	1.9
Castlegate A	23.7	12.9	0.0	0.0	36.6
Gordon	21.4	12.6	4.9	9.1	48.0
Wattis	189.0	463.7	84.1	14.6	751.5
Bear Canyon	36.9	14.3	0.0	0.0	51.2
Blind Canyon	229.8	415.0	230.3	181.2	1,056.3
Cottonwood	112.4	151.6	108.9	122.3	495.2
Axel Anderson	305.5	443.0	233.9	36.6	1,019.1
Acord Lakes	35.1	105.4	15.3	0.0	155.8
TOTAL[1]	1,067.3	1,657.1	681.6	363.8	3,769.9
PERCENT	28.3	44.0	18.1	9.7	

[1] Listed totals may differ from values obtained by summing rows or columns due to independent rounding of values to the nearest 0.1 million tons.

this is about 70 percent of the original minable coal resources. About 28 percent of the available coal resources occurs in beds between 4 and 6 feet thick; rarely is such thin coal actively mined in Utah. Available coal resources in beds greater than 6 feet thick equal 2.7 billion tons.

FRAGMENTATION OF AVAILABLE COAL RESOURCES BY MINING

Another factor affecting the amount of coal available for future mining is fragmentation of coalbeds by past mining. Our work revealed numerous small blocks of coal resources left behind by previous mining operations. Some of these isolated blocks are probably too small to economically recover. To evaluate the possible significance of fragmentation in the study area, we examined the Blind Canyon bed, which contains about 1 billion tons of available coal (table 9). For this example, we tested the effect of limiting the minimum size of an available resource block to 1,000 acres. Our examination showed that these small blocks contain about 16 percent of the available coal in the Blind Canyon bed (table 10). Other coalbeds in the area may be more or less fragmented by past mining, but this example provides an indication of the amount of coal that may be lost due to fragmentation. More importantly, if these small blocks cannot be mined, then observed resource recovery factors overestimate the amount of coal that might be recovered from the coalfield. Engineering studies that examine the economics of mining various sized blocks are required to estimate how much of the fragmented coal will ultimately be recovered.

COMPARISON TO PREVIOUS WORK

The most recent study of coal resources in all nine quadrangles examined here was by Doelling (1972). Studies by the USGS (Sanchez and others, 1986, 1987; Brown and others, 1987) provide coal resource estimates for only the five southern quadrangles in the study area.

Doelling (1972) tabulated coal resources for the whole Wasatch Plateau coalfield by coalbed, quadrangle, and reliability category. Because Doelling did not provide coalbed isopach maps, and used older bed names, a meaningful comparison for individual coalbeds is difficult. Nonetheless, some comparisons are possible. For example, Doelling's Class I and Class II reserves are roughly equivalent to our demonstrated original minable coal resources, his Class III reserves correspond to our inferred original minable coal resources, and his Class IV reserves match our hypothetical original minable coal resources. A comparison based on these categories is presented in table 11.

Our estimate of the original minable coal in the northern Wasatch Plateau coalfield is 1.1 billion tons higher than that estimated by Doelling (1972). Some of this increase undoubtedly arises from the large number of coal exploration drill holes that have been completed during the 25 years since Doelling finished his study. Despite having more data available for our study, examination of table 11 shows that a comparatively greater proportion of our estimated coal resources occurs in less reliable resource categories. This suggests that our extrapolation of coal into areas farther from drill hole measurements was more extensive than in Doelling's study. Furthermore, Doelling's (1972) estimate of original minable coal is based on data for "principal reserves

Table 10.
Available coal resources in blocks of less than 1,000 acres for the Blind Canyon bed, northern Wasatch Plateau coalfield (resources in millions of short tons).

	COALBED THICKNESS				
	4 to 6 feet	**6 to 10 feet**	**10 to 14 feet**	**>14 feet**	**TOTAL [1]**
All blocks	229.8	415.0	230.3	181.2	1,056.3
Blocks <1,000 acres	56.8	71.0	34.1	7.8	169.6
Percent of coal in small blocks	24.7	17.1	14.8	4.3	16.1

[1] Listed totals may differ from values obtained by summing rows due to independent rounding of values to the nearest 0.1 million tons.

Table 11.
Comparison of original minable coal resources in the northern Wasatch Plateau coalfield reported in this study with comparable estimates reported by Doelling (1972) (resources in millions of short tons).

	RESOURCE RELIABILITY CATEGORY			
SOURCE	**Demonstrated**	**Inferred**	**Hypothetical**	**TOTAL**
Doelling (1972)	3,505.1	720.1	1.8	4,227.0
This study	4,054.8	1,304.6	16.1	5,375.5

only" (p. 126), whereas our study attempts a more exhaustive inventory all minable coal beds. These factors likely contribute to the higher coal resources estimate reported here.

RESOURCE RECOVERY

From the time mining began in the 1870s, through the end of 1996, 351 million tons of coal have been produced from mines in the northern Wasatch Plateau (Jahanbani, 1997). This equals 52 percent of the 674 million tons of original coal that occurs within the perimeters of active and abandoned mines and suggests a coal recovery factor of more than 50 percent. However, if the 296 million tons of undermined coal is also considered, then 36 percent coal recovery is observed.

Although our analysis shows 36 percent coal recovery from the northern Wasatch Plateau, the ultimate recovery of coal from this area is likely to be closer to the 30 percent recovery predicted by Doelling (1972). There are several reasons that ultimate recovery of the resource is likely to be lower than the 36 percent observed to date. Since all of the available coal resources listed in this report can not be mined at the same price, the ultimate recovery will depend on what price the market is willing to pay to recover the last bit of available coal. As noted by Doelling (1972, p. 129), "much of the easy-to-get coal has been mined." Indeed, figure 9 shows that past mining has disproportionately targeted thicker coalbeds; remaining resources are less attractive. Past mining has also resulted in isolated blocks of coal that may be difficult to economically recover. For example, table 11 shows that 16 percent of the available coal in the Blind Canyon is in blocks smaller than 1,000 acres. Furthermore, 220 million tons of the available coal resource is within the Joes Valley Graben; Sanchez and Brown (1987) call this area a "shattered zone" suggesting that faulting may limit coal recovery in the graben. Significant coal recovery from the Joes Valley Graben is even more doubtful since this deeply buried coal must be accessed by vertical shafts. Finally, an unknown amount of coal will probably not be recovered because of the larger buffers required for longwall mines. Thus, the ultimate recovery of coal from this area will probably be closer to the 30 percent predicted by Doelling (1972) than the 36 percent recovery currently observed.

FUTURE PRODUCTION

Coal availability maps like those presented in appendix A are being used in detailed recoverability studies undertaken by the USGS to estimate how much coal can be economically recovered from the northern half of the Wasatch Plateau coalfield. Notwithstanding results from such detailed studies, our results do allow rough estimates of the duration of future coal production from this area. Assuming 30 percent recovery, 1.1 billion tons of the 3.8 billion tons available coal could potentially be produced from the northern Wasatch Plateau. If the current 19 million ton annual coal production rate continues, the available coal resources in the northern Wasatch Plateau will be gone in 2054. However, coal production rates will probably decline before 2054. For example, only 2.7 billion tons of the available coal resources occur in coalbeds that are more than 6 feet thick (table 9). Assuming mining companies continue to select this thicker coal for mining (figure 9) then, at current production rates, depletion of the most attractive coal resources can be anticipated by 2040. Consequently, production will likely decline well before complete exhaustion of the resource as thick, efficiently mined blocks are depleted and smaller mining operations target the remaining, less easily mined coal. Thus, some reduced level of production can be anticipated beyond 2054. Nonetheless, state and local planners should consider the impacts of

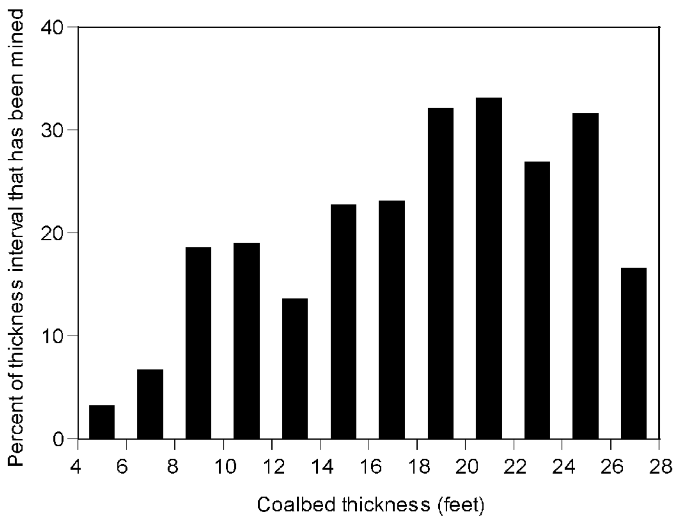

Figure 9. *Percent of coal that has been mined in different thickness intervals for the northern Wasatch Plateau coalfield.*

resource depletion as coal production shifts to other areas.

SUMMARY

GIS analyses indicate that the northern half of the Wasatch Plateau coalfield originally contained more than 9.2 billion tons of coal of which 5.4 billion tons occurred in beds that could be mined underground; 3.8 billion tons of this original minable coal remain available for future mining. Assuming a 30 percent resource recovery rate and that all available coal can be economically recovered, then 1.1 billion tons of the remaining available coal resources might ultimately be produced. Factors responsible for reduction of the original minable coal resources include past mining activity (-970 million tons), technical restrictions to mining (-490 million tons), and coal made unavailable due to land-use restrictions (-146 million tons). Our estimate of original minable coal is about 27 percent higher than previously estimated for this area (Doelling, 1972). Greater availability of drill hole information, more extensive extrapolation of coal resources, and inclusion of less significant coalbeds contributed to the higher resource estimate. Assuming current mining practice, coal production from this area can be expected to decline by 2040.

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APPENDICES

APPENDIX A
MAPS AND TABULAR DATA

Maps showing the distribution of the available coal in the Blackhawk Formation in the northern half of the Wasatch Plateau coalfield are provided for 10 coalbeds; maps of coalbeds containing little coal are not shown. Areas where these coals have been disturbed by mining are also shown. Patterns used to show coal thickness do not show fine detail. Hence, restrictions to mining due to streams, roads, and other small features may not be apparent.

Tabular data to accompany the maps, as well as data for two coalbeds that contain little coal, are provided; the data show the original minable coal tonnage, coal tonnage lost due to technical and land-use restrictions, and the net available coal tonnage for each coalbed. Methods used for these tabulations are the same as those discussed in the text except that tonnage lost due to past mining (mined and undermined coal) is included with the technical restrictions.

Table A1.
Available coal resources in the Acord Lakes coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	35.7	107.0	15.7	0.0	158.4
Technical restrictions [1]					
mined-out	—	—	—	—	0.0
undermined	—	—	—	—	0.0
excessive thickness	—	—	—	-0.0	-0.0
interburden	—	—	—	—	0.0
weathered	-0.1	—	—	—	-0.1
faulted	-0.4	-0.5	—	-0.0	-0.9
Net technically minable coal [2, 5]	35.2	106.5	15.7	0.0	157.4
Land-use restrictions [3]					
streams and lakes	—	—	—	—	0.0
cities	—	—	—	—	0.0
roads	-0.1	-1.1	-0.4	—	-1.6
pipelines	—	—	—	—	0.0
railroads	—	—	—	—	0.0
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	35.1	105.4	15.3	0.0	155.8

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

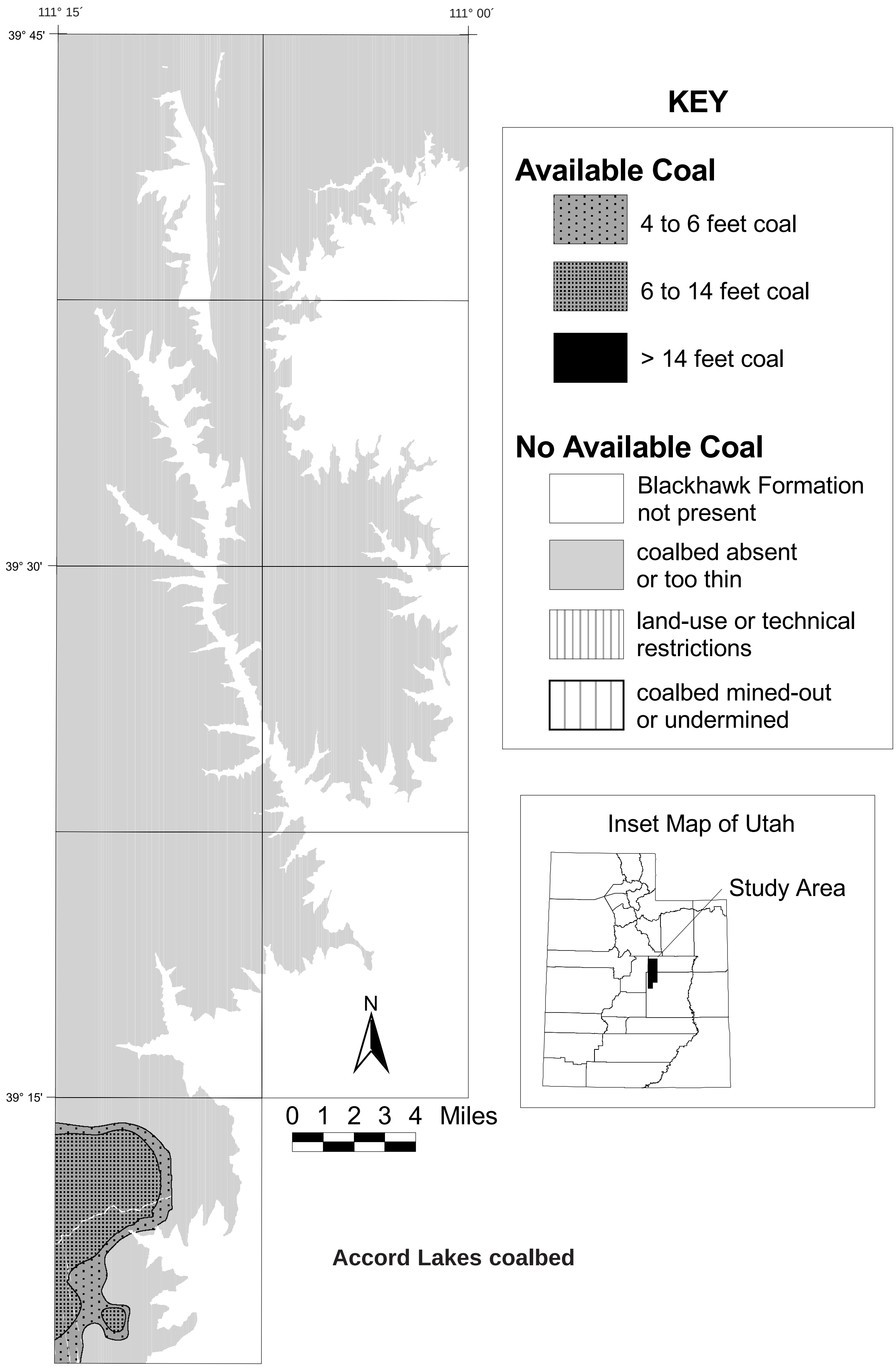

Figure A1. *Available coal resources in the Acord Lakes coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A2.
Available coal resources in the Axel Anderson coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	6 to 10 ft	10 to 14 ft	> 14 ft	Total [5]
Original minable coal	373.3	560.8	293.3	44.7	1,272.2
Technical restrictions [1]					
mined-out	-10.0	-83.3	-41.5	-5.0	-139.7
undermined	—	—	—	—	0.0
excessive thickness	—	—	—	-2.0	-2.0
interburden	-33.2	-5.6	—	—	-38.8
weathered	-11.8	-11.9	-9.0	-0.6	-33.3
faulted	-6.5	-5.1	-4.8	-0.8	-17.1
Net technically minable coal [2, 5]	314.2	455.7	238.5	36.6	1,045.0
Land-use restrictions [3]					
streams and lakes	-6.0	-7.5	-3.5	-0.0	-17.1
cities	-0.8	-2.7	-0.2	—	-3.6
roads	-0.9	-1.9	-0.2	—	-3.0
pipelines	-0.2	-0.9	-0.7	—	-1.9
railroads	-0.3	—	—	—	-0.3
buildings	-0.2	-0.3	-0.3	—	-0.7
powerlines	-0.5	-0.4	—	—	-0.9
oil and gas wells	-0.0	-0.1	—	—	-0.1
radio towers	—	-0.0	—	—	-0.0
Net available coal [4, 5]	305.5	443.0	233.9	36.6	1,019.1

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

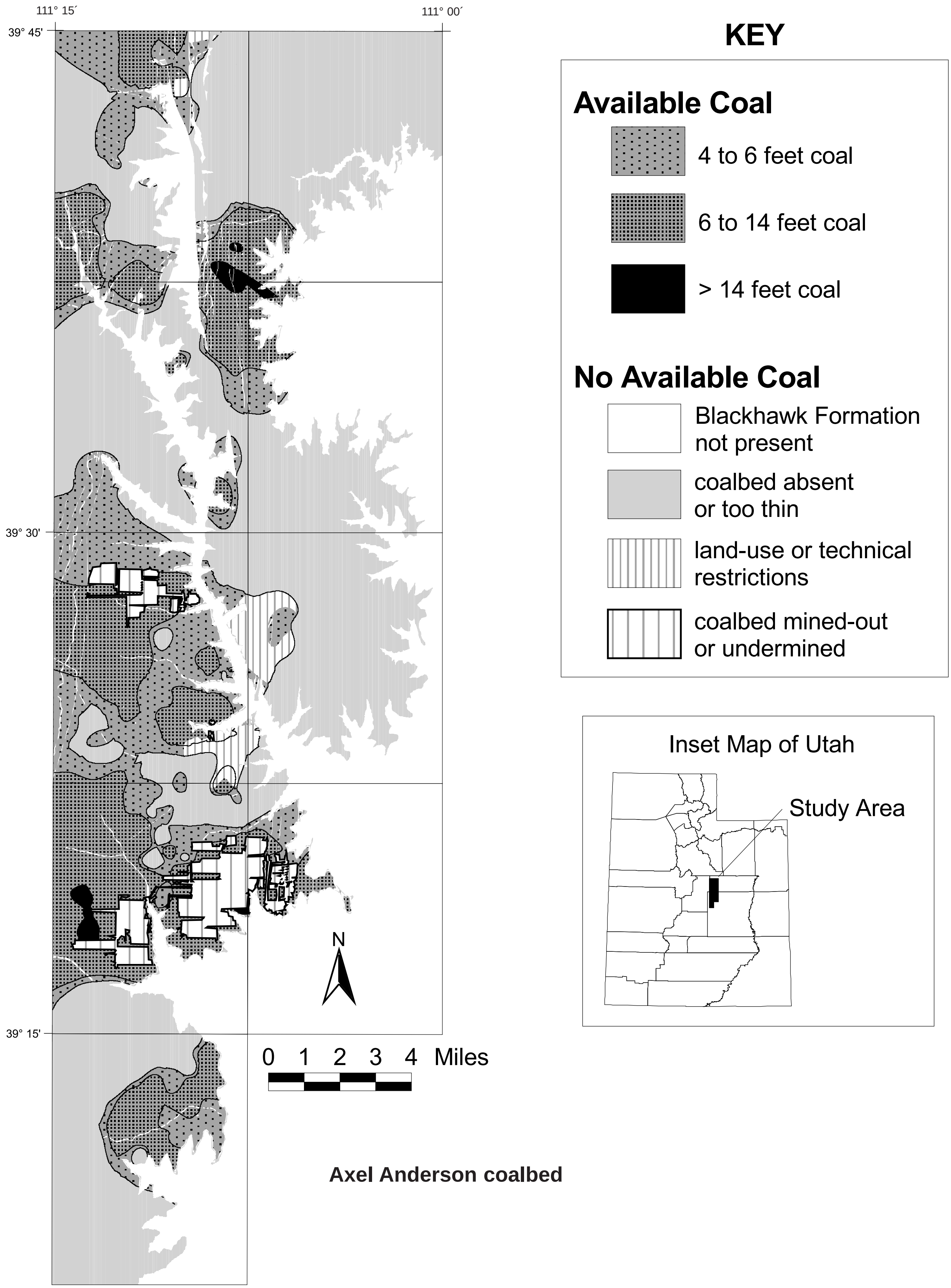

Figure A2. *Available coal resources in the Axel Anderson coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A3.
Available coal resources in the Cottonwood coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	150.6	225.1	183.0	320.6	879.2
Technical restrictions [1]					
mined-out	-15.4	-35.4	-45.4	-111.1	-207.2
undermined	-7.9	-2.7	-0.9	-1.0	-12.5
excessive thickness	—	—	—	-90.3	-90.3
interburden	-7.0	-14.9	-6.2	-8.8	-36.9
weathered	-7.5	-8.1	-12.1	-4.7	-32.5
faulted	-2.6	-4.2	-2.7	-7.1	-16.7
Net technically minable coal [2, 5]	116.5	160.9	117.4	134.8	529.5
Land-use restrictions [3]					
streams and lakes	-3.1	-2.0	-0.8	-3.0	-8.9
cities	-0.4	-7.1	-7.2	-6.6	-21.2
roads	-0.5	-0.3	-0.7	-0.5	-1.9
pipelines	-0.2	-0.2	-0.3	-1.8	-2.5
railroads	-0.2	-0.2	-0.4	-0.9	-1.7
buildings	-0.0	—	-0.0	-1.0	-1.1
powerlines	—	—	—	—	0.0
oil and gas wells	-0.0	-0.0	—	—	-0.0
radio towers	-0.0	—	—	-0.0	-0.0
Net available coal [4, 5]	112.4	151.6	108.9	122.3	495.2

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

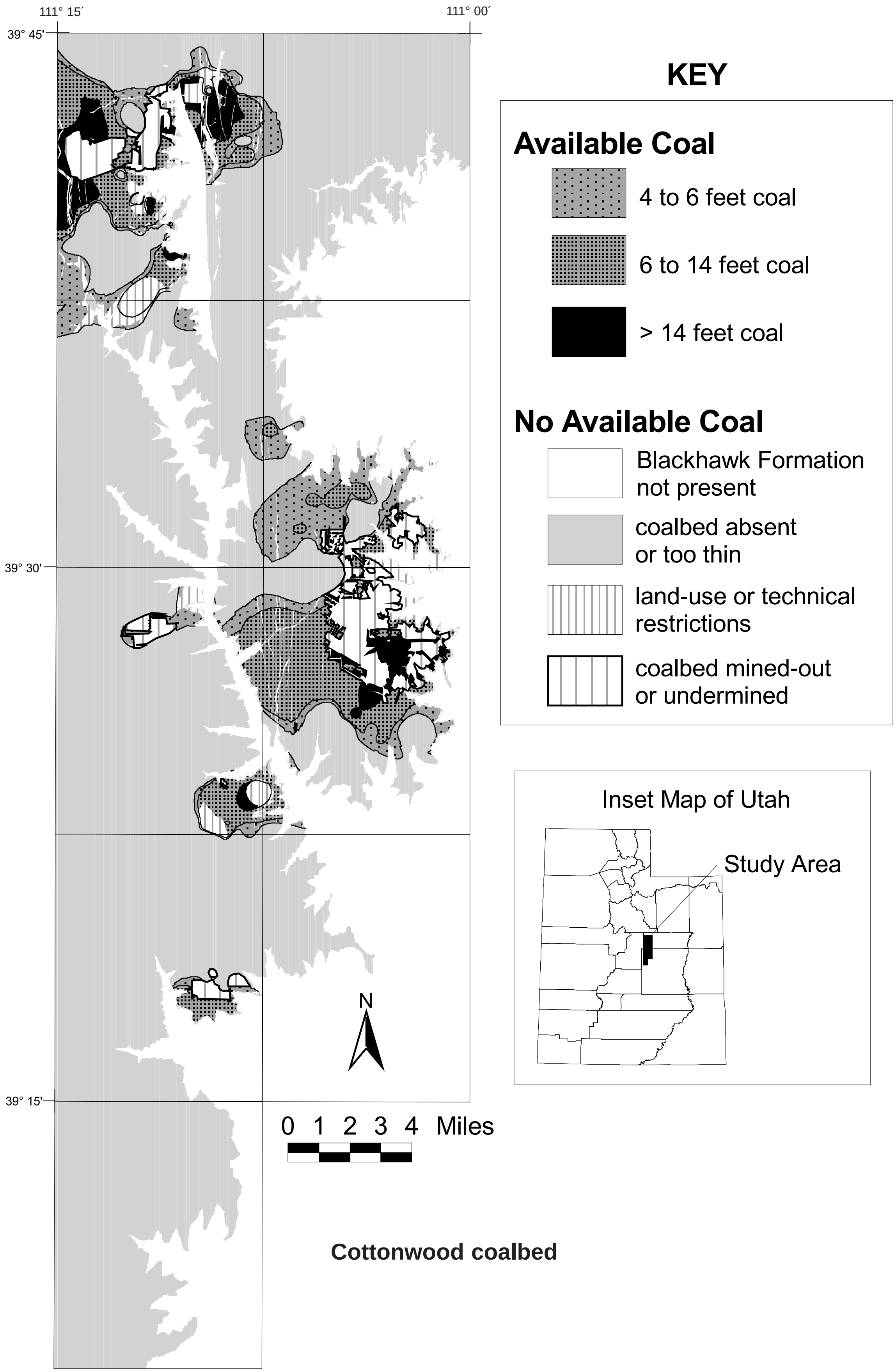

Figure A3. *Available coal resources in the Cottonwood coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A4.
Available coal resources in the Blind Canyon coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**>14 ft**	**Total [5]**
Original minable coal	283.1	588.0	330.2	282.7	1,483.9
Technical restrictions [1]					
mined-out	-7.1	-73.7	-51.6	-36.2	-168.7
undermined	-29.1	-58.5	-21.8	-1.5	-110.9
excessive thickness	—	—	—	-49.4	-49.4
interburden	-1.2	-0.7	—	—	-2.0
weathered	-11.2	-21.0	-15.8	-11.1	-59.1
faulted	-2.5	-6.6	-5.6	-4.7	-19.4
Net technically minable coal [2, 5]	234.1	430.4	237.3	188.8	1,090.5
Land-use restrictions [3]					
streams and lakes	-2.0	-9.1	-1.9	-4.6	-17.7
cities	-1.3	-4.2	-3.0	—	-8.4
roads	-0.8	-0.8	-0.3	-1.6	-3.5
pipelines	-0.0	-0.0	-1.0	-1.6	-2.7
railroads	-0.2	—	—	—	-0.2
buildings	-0.0	—	-0.5	—	-0.5
powerlines	-0.3	-1.2	-0.3	—	-1.9
oil and gas wells	-0.0	-0.0	—	-0.0	-0.1
radio towers	-0.0	—	—	-0.0	-0.0
Net available coal [4, 5]	229.8	415.0	230.3	181.2	1,056.3

[1] *Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.*
[2] *Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.*
[3] *Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.*
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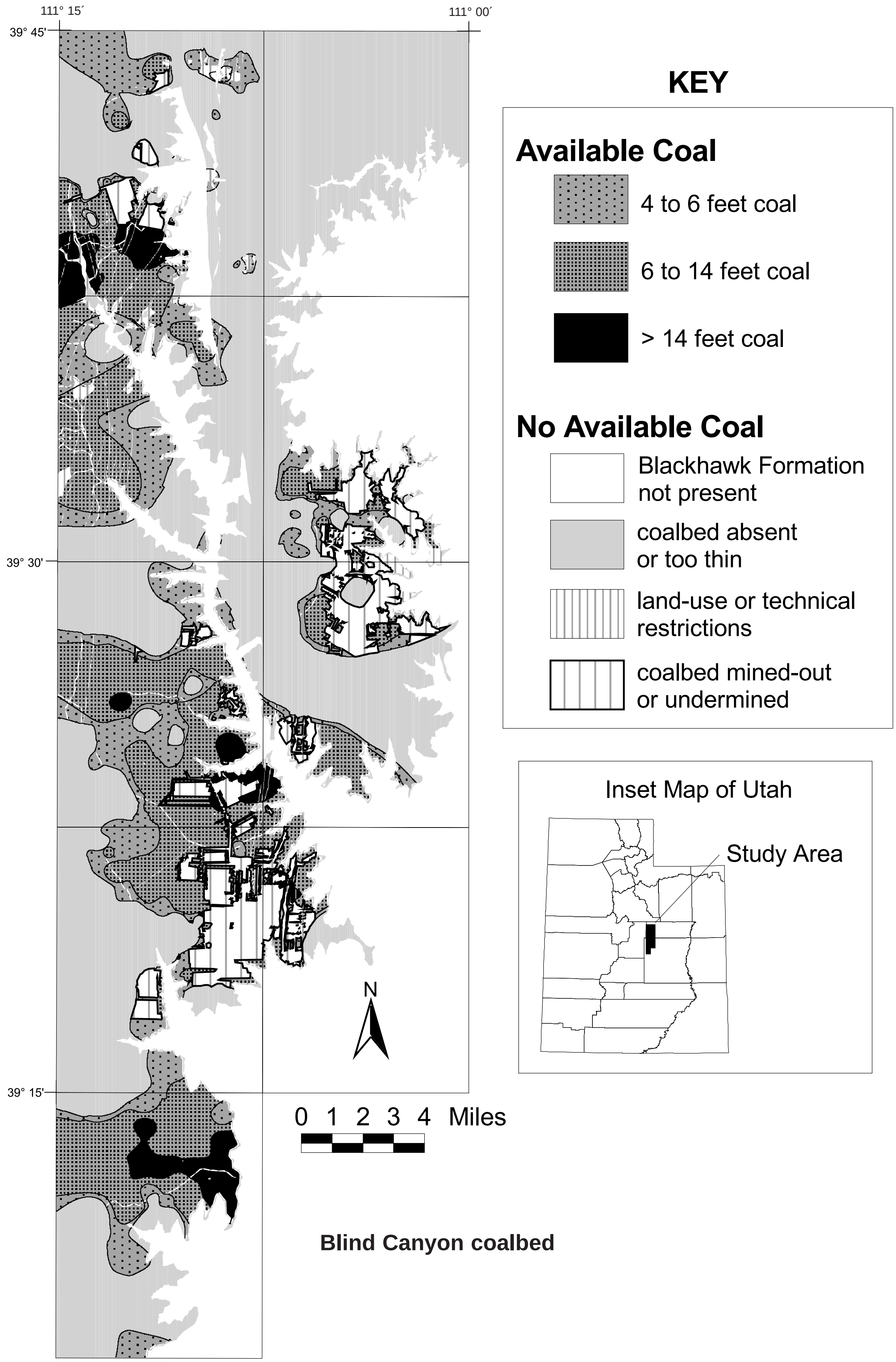

Figure A4. *Available coal resources in the Blind Canyon coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A5.
Available coal resources in the Bear Canyon coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	42.5	15.5	0.0	0.0	58.0
Technical restrictions [1]					
mined-out	—	—	—	—	0.0
undermined	-2.4	—	—	—	-2.4
excessive thickness	—	—	—	—	0.0
interburden	—	—	—	—	0.0
weathered	-2.3	-1.0	—	—	-3.3
faulted	-0.3	-0.1	—	—	-0.4
Net technically minable coal [2, 5]	37.6	14.4	0.0	0.0	52.0
Land-use restrictions [3]					
streams and lakes	-0.4	-0.1	—	—	-0.4
cities	—	—	—	—	0.0
roads	-0.2	—	—	—	-0.2
pipelines	—	—	—	—	0.0
railroads	-0.1	—	—	—	-0.1
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	-0.0	—	—	—	-0.0
Net available coal [4, 5]	36.9	14.3	0.0	0.0	51.2

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

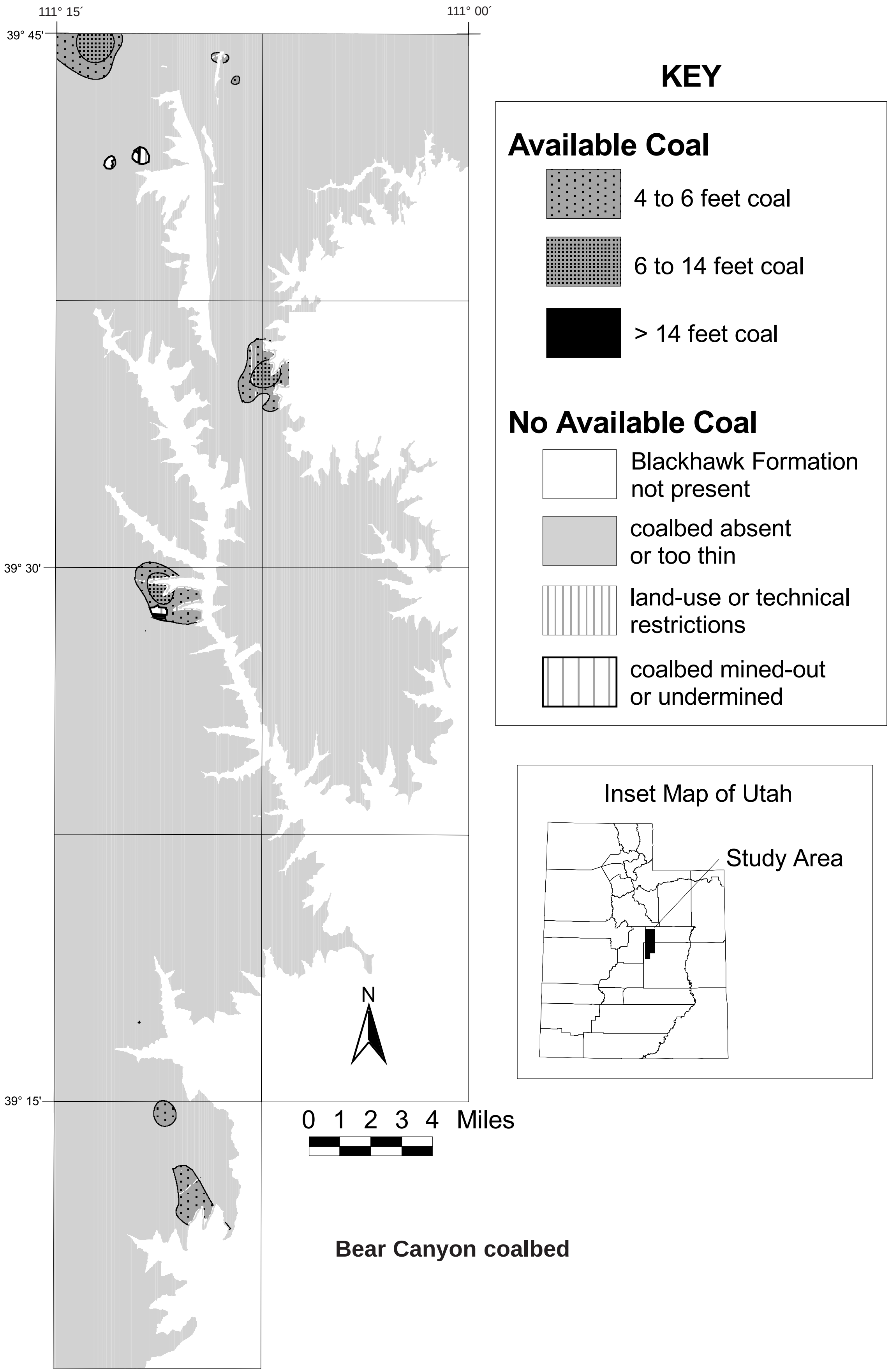

Figure A5. *Available coal resources in the Bear Canyon coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A6.
Available coal resources in the Wattis coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	250.6	696.7	130.7	62.4	1,140.4
Technical restrictions [1]					
mined-out	-14.6	-67.9	-22.6	-35.0	-140.1
undermined	-24.0	-66.3	-9.3	-0.5	-100.2
excessive thickness	—	—	—	-10.3	-10.3
interburden	—	-36.1	-0.0	—	-36.1
weathered	-15.1	-33.6	-5.1	-3.3	-57.1
faulted	-5.9	-14.7	-3.7	-2.3	-26.6
Net technically minable coal [2, 5]	196.9	486.1	91.4	19.0	793.4
Land-use restrictions [3]					
streams and lakes	-5.3	-13.6	-4.7	-2.9	-26.5
cities	-1.7	-6.5	-1.7	-0.3	-10.1
roads	-0.2	-2.0	-0.7	-0.3	-3.2
pipelines	-0.9	-0.7	-0.1	-0.3	-1.8
railroads	-0.1	-0.9	-0.3	-0.4	-1.7
buildings	-0.1	-0.5	-0.0	-0.4	-1.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	-0.0	—	—	-0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	189.0	463.7	84.1	14.6	751.5

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

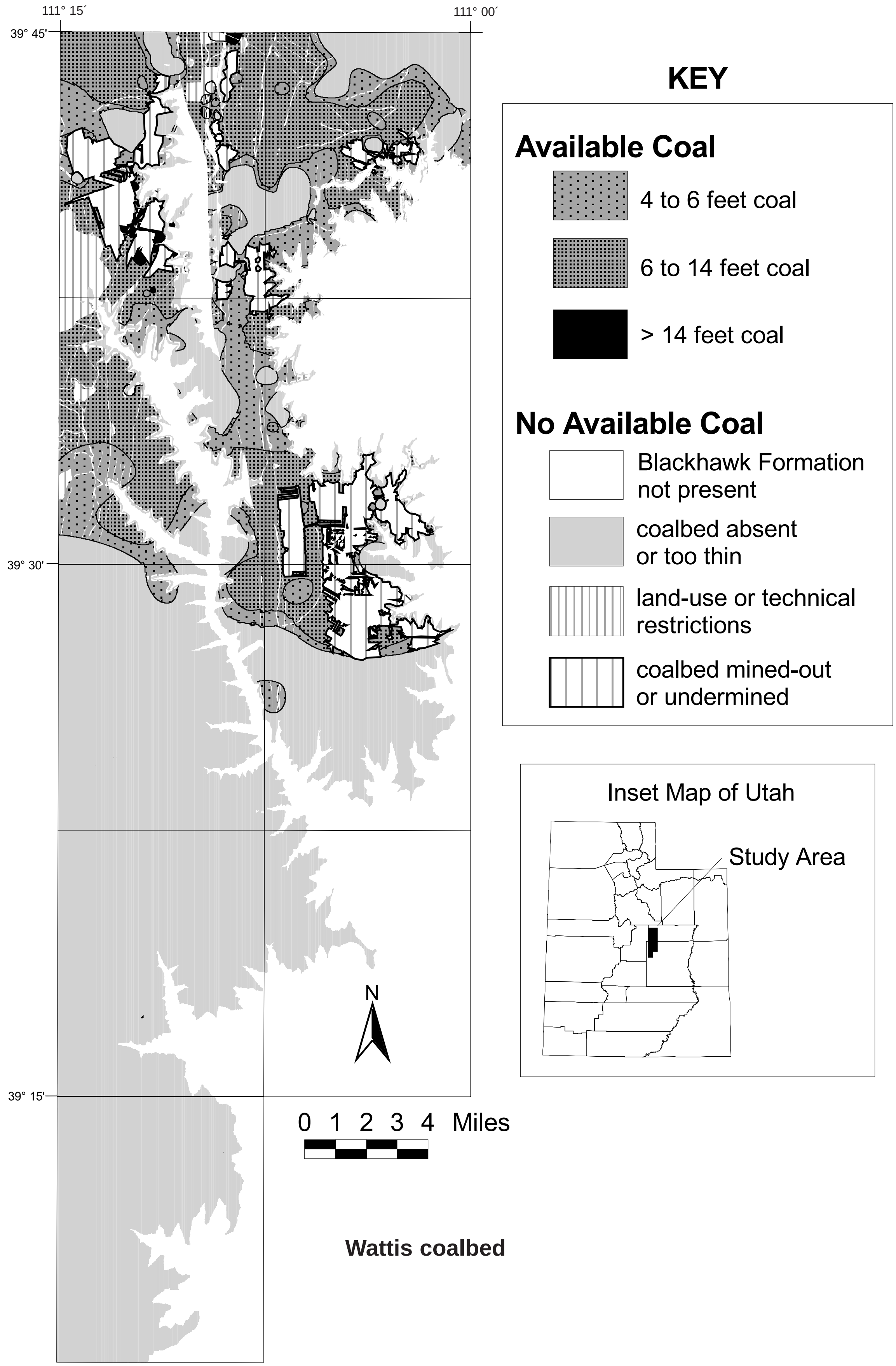

Figure A6. *Available coal resources in the Wattis coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A7.
Available coal resources in the Gordon coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	30.0	16.6	7.0	15.5	69.0
Technical restrictions [1]					
mined-out	—	—	—	—	0.0
undermined	-2.4	-0.4	—	—	-2.8
excessive thickness	—	—	—	-2.7	-2.7
interburden	—	—	—	—	0.0
weathered	-5.3	-3.2	-2.0	-4.2	-14.7
faulted	-0.9	-0.4	-0.1	-0.2	-1.5
Net technically minable coal [2, 5]	21.7	12.6	4.9	9.1	48.4
Land-use restrictions [3]					
streams and lakes	-0.0	—	—	—	-0.0
cities	—	—	—	—	0.0
roads	-0.0	—	—	—	-0.0
pipelines	-0.2	—	—	—	-0.2
railroads	—	—	—	—	0.0
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	21.4	12.6	4.9	9.1	48.1

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is sub tracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

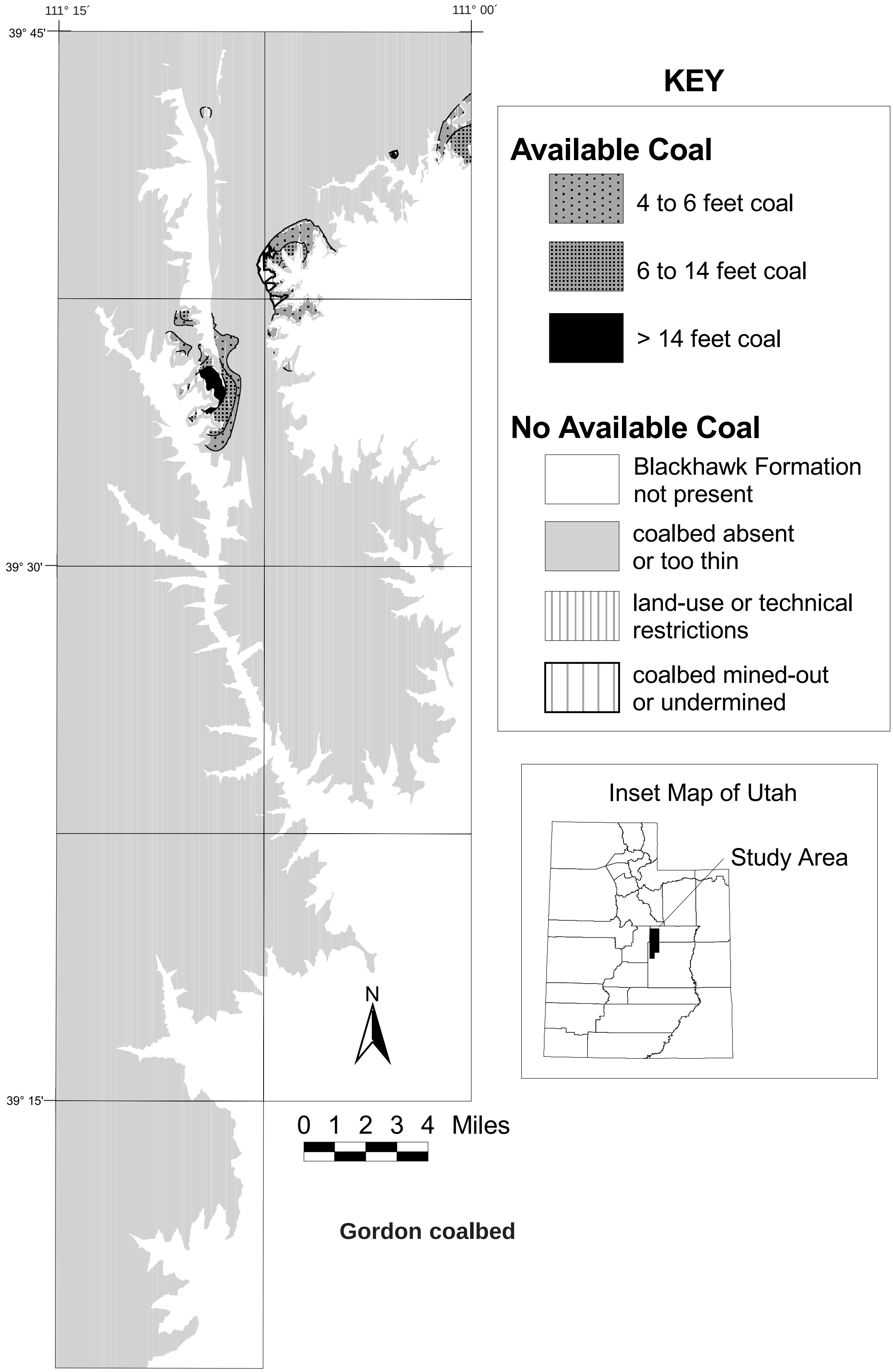

Figure A7. Available coal resources in the Gordon coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.

Table A8.
Available coal resources in the Castlegate A coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	38.5	30.1	0.1	0.0	68.7
Technical restrictions [1]					
mined-out	-5.8	-8.9	—	—	-14.7
undermined	-3.6	-2.7	—	—	-6.4
excessive thickness	—	—	—	—	0.0
interburden	—	—	—	—	0.0
weathered	-5.2	-6.8	-0.1	—	-12.1
faulted	-0.5	-0.8	—	—	-1.4
Net technically minable coal [2, 5]	24.4	13.1	0.0	0.0	37.5
Land-use restrictions [3]					
streams and lakes	-0.7	-0.0	—	—	-0.7
cities	—	—	—	—	0.0
roads	—	—	—	—	0.0
pipelines	-0.1	-0.2	—	—	-0.2
railroads	—	—	—	—	0.0
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	23.7	12.9	0.0	0.0	36.6

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

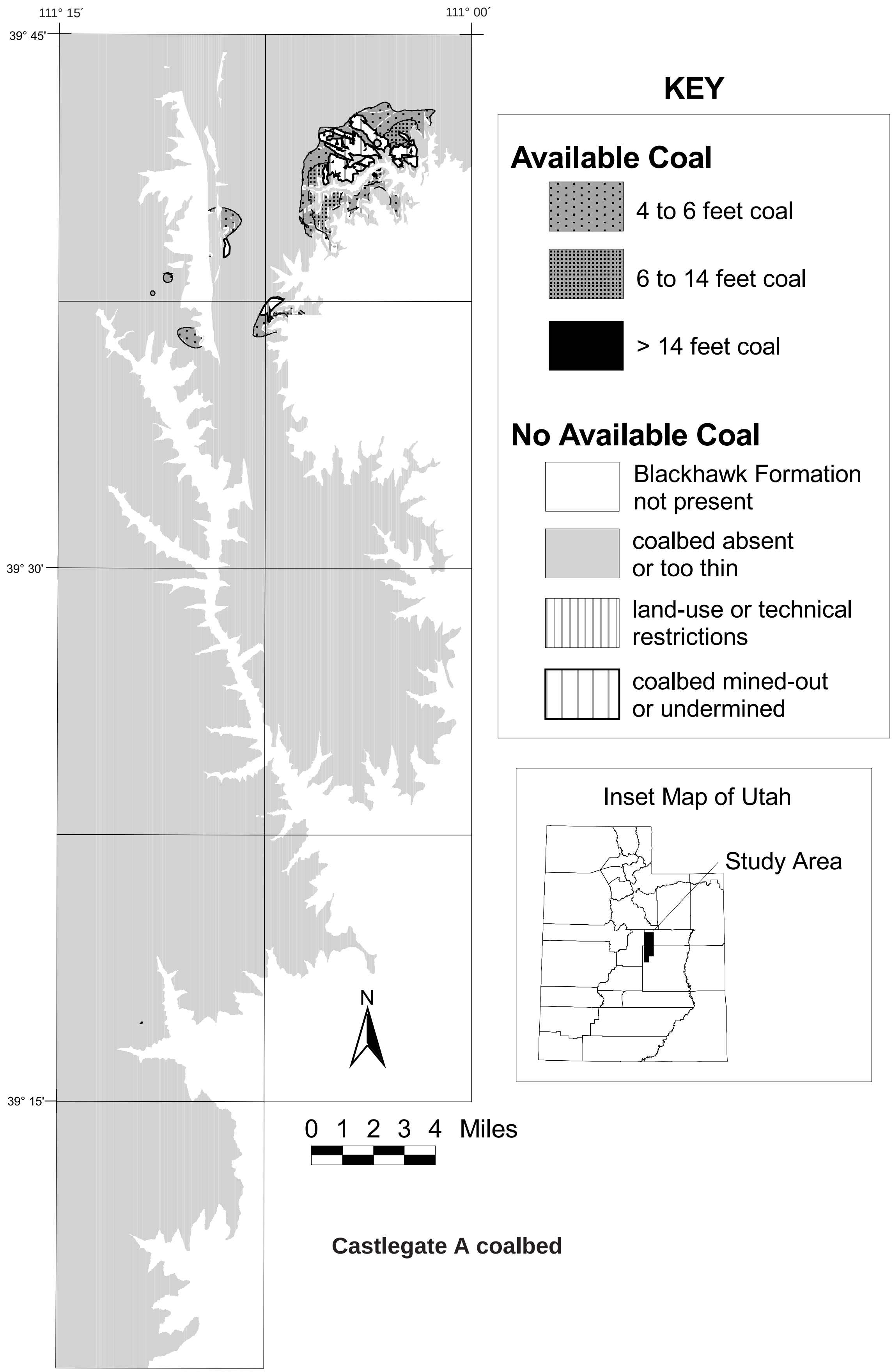

Figure A8. Available coal resources in the Castlegate A coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.

Table A9.
Available coal resources in the Castlegate B coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons). No map is associated with this table since the coalbed contains little coal.

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	2.0	0.0	0.0	0.0	2.0
Technical restrictions [1]					
mined-out	—	—	—	—	0.0
undermined	—	—	—	—	0.0
excessive thickness	—	—	—	—	0.0
interburden	—	—	—	—	0.0
weathered	-0.1	—	—	—	-0.1
faulted	—	—	—	—	0.0
Net technically minable coal [2, 5]	1.9	0.0	0.0	0.0	1.9
Land-use restrictions [3]					
streams and lakes	-0.1	—	—	—	-0.1
cities	—	—	—	—	0.0
roads	—	—	—	—	0.0
pipelines	—	—	—	—	0.0
railroads	—	—	—	—	0.0
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	1.9	0.0	0.0	0.0	1.9

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

Table A10.
Available coal resources in the Castlegate C coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons). No map is associated with this table since the coalbed contains little coal.

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	4.2	0.0	0.0	0.0	4.2
Technical restrictions [1]					
mined-out	—	—	—	—	0.0
undermined	—	—	—	—	0.0
excessive thickness	—	—	—	—	0.0
interburden	—	—	—	—	0.0
weathered	-1.5	—	—	—	-1.5
faulted	-0.1	—	—	—	-0.1
Net technically minable coal [2, 5]	2.7	0.0	0.0	0.0	2.7
Land-use restrictions [3]					
streams and lakes	-0.0	—	—	—	-0.0
cities	—	—	—	—	0.0
roads	—	—	—	—	0.0
pipelines	—	—	—	—	0.0
railroads	—	—	—	—	0.0
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	2.6	0.0	0.0	0.0	2.6

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

Table A11.
Available coal resources in the Castlegate D coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	158.1	49.2	2.1	0.0	209.4
Technical restrictions [1]					
mined-out	-1.3	-1.9	—	—	-3.3
undermined	-52.0	-8.1	-0.6	—	-60.7
excessive thickness	—	—	—	—	0.0
interburden	—	—	—	—	0.0
weathered	-12.1	-3.9	—	—	-16.0
faulted	-2.4	-0.8	—	—	-3.2
Net technically minable coal [2, 5]	95.4	36.3	1.5	0.0	133.2
Land-use restrictions [3]					
streams and lakes	-0.6	-0.3	—	—	-0.9
cities	-0.4	—	—	—	-0.4
roads	—	—	—	—	0.0
pipelines	-0.1	-0.2	—	—	-0.3
railroads	—	—	—	—	0.0
buildings	—	—	—	—	0.0
powerlines	—	—	—	—	0.0
oil and gas wells	-0.0	—	—	—	-0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	94.2	35.9	1.5	0.0	131.6

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

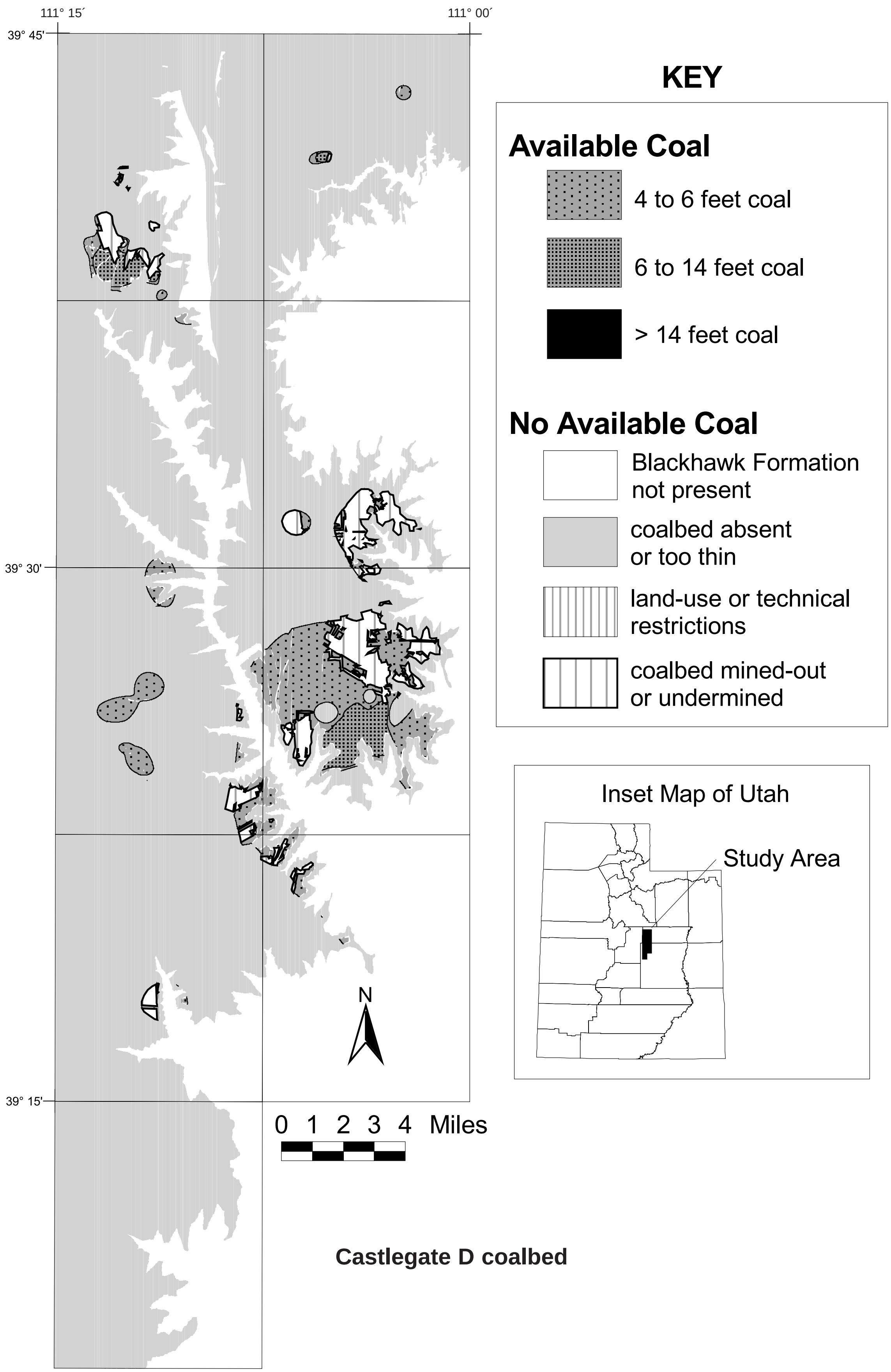

Figure A9. *Available coal resources in the Castlegate D coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

Table A12.
Available coal resources in the Rock Canyon coalbed, northern Wasatch Plateau coalfield, Utah (millions of short tons).

	Coalbed thickness				
	4 to 6 ft	**6 to 10 ft**	**10 to 14 ft**	**> 14 ft**	**Total [5]**
Original minable coal	24.0	3.3	3.0	0.0	30.2
Technical restrictions [1]					
mined-out	—	—	—	—	0.0
undermined	-0.4	—	—	—	-0.4
excessive thickness	—	—	—	—	0.0
interburden	—	—	—	—	0.0
weathered	-4.7	-0.5	-0.2	—	-5.5
faulted	-0.5	-0.0	—	—	-0.5
Net technically minable coal [2, 5]	18.7	2.7	2.7	0.0	24.1
Land-use restrictions [3]					
streams and lakes	-0.4	-0.1	—	—	-0.5
cities	-3.6	—	—	—	-3.6
roads	-0.6	—	—	—	-0.6
pipelines	—	—	—	—	0.0
railroads	-0.3	—	—	—	-0.3
buildings	-0.1	—	—	—	-0.1
powerlines	—	—	—	—	0.0
oil and gas wells	—	—	—	—	0.0
radio towers	—	—	—	—	0.0
Net available coal [4, 5]	14.8	2.6	2.7	0.0	20.2

[1] Applied to original minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of technical restrictions.
[2] Values may be slightly higher than indicated by subtraction of technical restrictions from original minable coal because coal in areas subject to multiple restrictions is subtracted only once.
[3] Applied to net technically minable coal. Dashes indicate the coal thickness interval is not affected by the restriction. See text for discussion of land-use restrictions.
[4] Values may be slightly higher than indicated by subtraction of land-use restrictions from net technically minable coal since coal in areas subject to multiple restrictions is subtracted only once.
[5] Values may differ from those indicated by sums of values in rows, or subtactions of values in columns, due to independent rounding to the nearest 0.1 million tons.

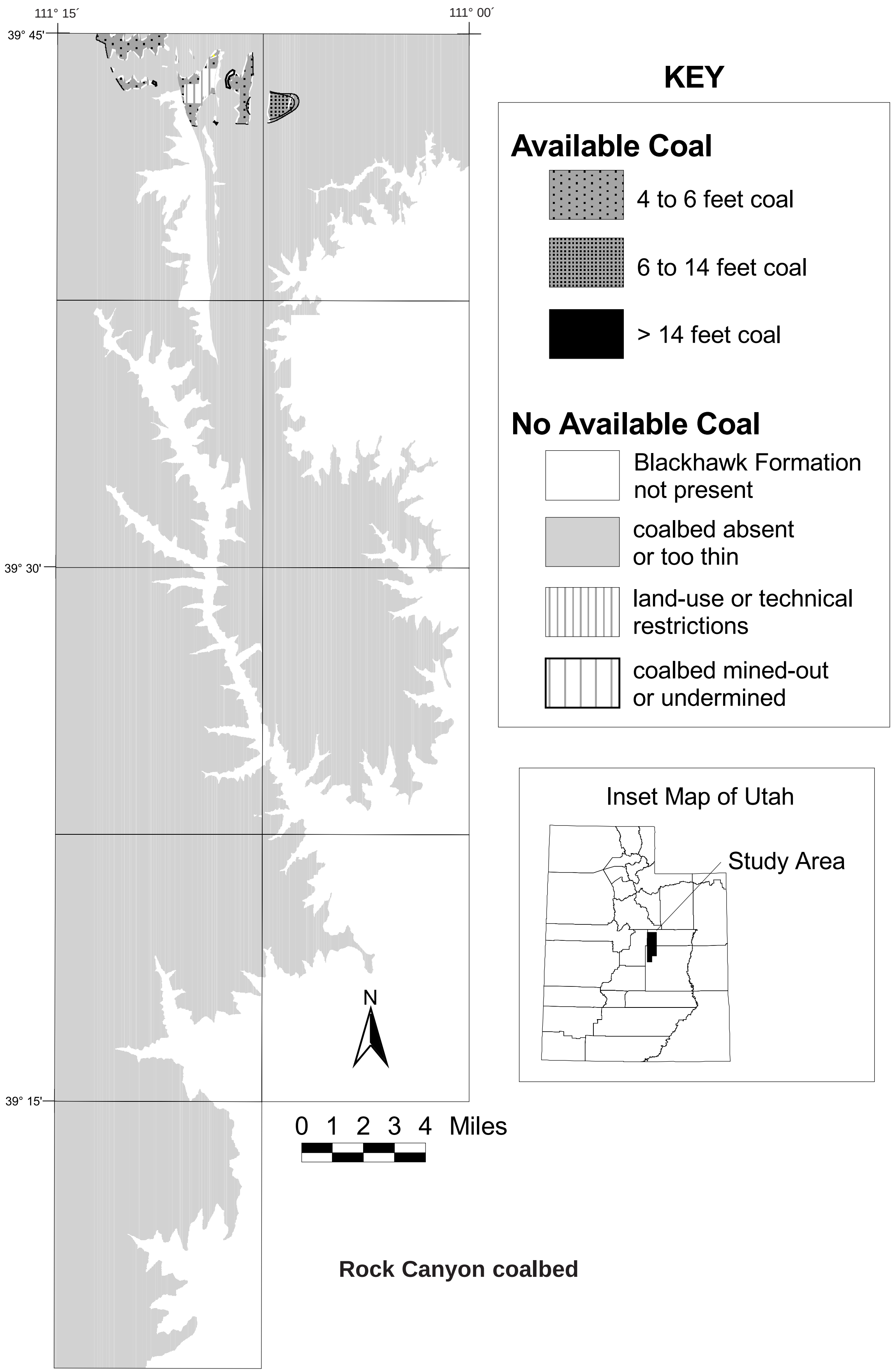

Figure A10. *Available coal resources in the Rock Canyon coalbed, Blackhawk Formation, northern Wasatch Plateau, Utah.*

APPENDIX B
GIS METHODOLOGY

Calculation of coal resources requires the determination of three parameters: the extent of each coalbed (area), the thickness of each bed, and an estimation of the density of the coal. Maps showing the areal extent and thickness of identified coalbeds were constructed from scattered points of observation (drill hole records and outcrop measurements). Environmental Systems Research Institute's Spatial Analyst® software extension allows the choice of different mathematical methods to interpolate between, and extrapolate beyond, point data to construct maps. We selected an inverse distance weighting method (set to six nearest neighbors and a fourth-order distance function) to assign thickness values to individual 30- by 30-meter cells in a grid covering the areal extent of the Blackhawk Formation in the study area. The resulting grid was converted from a floating-point (decimal) format to integer values. For example, all cells with coalbed thickness values greater than 4 but less than 5 feet were reclassified to the integer 4; for resource calculations we assume that these cells contain 4.5 feet of coal. This approximation significantly reduces the size of the resulting data sets and allows subsequent analyses to be undertaken in a reasonable amount of computation time (minutes rather than hours). Classification of coalbed thickness as integer data also allows convenient tabulation of the areal extent of these thickness intervals; tables containing these data were exported to a spreadsheet for final calculation of the total tons of coal in each thickness interval. This final calculation was accomplished by applying the U.S. Geological Survey standard coal density factor for bituminous coal of 1,800 tons of coal per acre-foot (Wood and others, 1983).

The initial maps do not distinguish areas where the coal has been removed by past mining or, because of technical or regulatory reasons, is unlikely to be mined. Consequently, such restrictions to mining are examined by construction of associated, identically registered grids, each corresponding to a particular restriction. Various grid-to-grid subtractions allow tabulation of the remaining available coal; these data, and associated maps showing the extent of the remaining coal, are provided in appendix A.

Point Data Preparation

"Keypunch" National Coal Resources Data System files in ASCII format, as well as U.S. Bureau of Land Management files in dBase format, were imported into a spreadsheet for simplification as a table of X, Y, Z data (easting, northing, and thickness or elevation) for each coalbed and exported as version IV dBase (*.dbf) files for use in the ArcView® GIS program. All data records were re-examined to verify correlations and spatial accuracy. Where necessary, spatial coordinates were converted to the Universal Transverse Mercator zone 12 coordinate system and bed identifications were revised or assigned. Bed thickness is recorded to the nearest tenth of a foot. Elevation (mean sea level) and spatial coordinates are uniformly recorded to the nearest tenth of a meter. However, the overall precision of the elevation and spatial data is probably closer to tens (rather than tenths) of meters; varied sources and vintages of the data hinder more exacting precision estimates.