AVAILABLE COAL RESOURCE FOR THE SALINA CANYON AND SOUTHWESTERN PART OF THE WASATCH PLATEAU COALFIELDS, SEVIER COUNTY, UTAH

by David E. Tabet, Brigitte P. Hucka, Jeffrey C. Quick, and Sharon I. Wakefield

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Cover photo: *View eastward along Salina Canyon at slope-forming Blackhawk Formation (lower part of canyon wall), which is overlain by cliffs of Castlegate Sandstone; Price River Formation caps the ridge.*

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ABSTRACT

Within the four quadrangles studied in central Utah, about 690 million tons of coal are available for underground mining in the Blackhawk Formation of the Salina Canyon coalfield, and another 80 million tons are available in the Blackhawk of the southwestern part of the Wasatch Plateau coalfield. Over 62% of the 80 million tons of coal identified in the Wasatch Plateau coalfield is a demonstrated resource (within 0.75 miles of a measurement location), whereas only 12% of the 690 million tons of coal in the Salina Canyon portion is demonstrated. The remainder of the coal in both areas is less reliably defined (inferred). Subsurface data included six logs from abandoned oil and gas wells that penetrated the coal-bearing Emery Sandstone (1000 to 3000 feet deep) and Ferron Sandstone (3000 to 5000 feet deep) Members of the Mancos Shale. Some of these deeper coal beds, notably in the Emery Sandstone, are greater than four feet thick, but there are too few data to calculate meaningful resource estimates for these deeper coals.

The available coal resource of the Salina Canyon portion of the study area includes six Blackhawk Formation coal beds, which are named (in ascending stratigraphic order) the A, B, Knight, Acord Lakes (Ivie), Wattis (Sevier), and Castlegate A (Wilson) beds. For the Wasatch Plateau portion of the study area, about 99% of the available coal resource occurs in the Knight, and insignificant resource is found in (in ascending stratigraphic order) the Acord Lakes, Wattis, and Castlegate A beds. Maps and associated tables showing the distribution and quantity of the available coal are provided for each significant coal bed (appendix). The Acord Lakes bed of the Salina Canyon Plateau field contains the largest coal resource (38% of the total) in the study area, whereas the Wattis and Castlegate A beds contain the least amount of coal. Coal rank is high volatile C bituminous in both coalfields, and the coal is slightly lower in sulfur content in the Wasatch Plateau field. Average sulfur content in the Salina Canyon coalfield is below 1.2 pounds sulfur per million Btu (lbs S/10^6 Btu) in all coal beds, but is lowest in the Wattis (Sevier) bed. Available data indicate that the in-ground coal should average about 4 pounds mercury per trillion Btu, similar to the mercury content of the other Wasatch Plateau coal beds.

Considering coal bed thickness, distribution, and current mining practices, we estimate that about 100 million tons of the 690-million-ton available coal resource might be recovered from the Salina Canyon coalfield, and 25 million tons might be recovered from the Wasatch Plateau coalfield portion of the study area.

INTRODUCTION

From the 1870s through 2007, Utah coal mines produced more than 980 million tons of coal, of which about 0.43 million tons came from the Salina Canyon coalfield, and over 131 million tons came from the nearby Southern Utah Fuel Company (SUFCO) mine in the southern Wasatch Plateau coalfield (Doelling, 1972a, 1972b; Vanden Berg, 2008). The coal resources in the eastern (Wasatch Plateau) part of the study area could help extend the life of the SUFCO mine. Although the Salina Canyon coalfield accounts for less than 1% of Utah's cumulative coal production, its substantial in-ground coal resource and proximity to power plants in Utah and Nevada suggest the Salina Canyon coalfield may one day contribute to Utah's coal supply. This study provides an estimate of the amount and distribution of the available coal resource in the Salina Canyon coalfield, as well as some additional coal in the southern Wasatch Plateau coalfield.

We used a Geographic Information System (GIS) to identify and measure the available coal resource in the entire Salina Canyon coalfield and a small part of the Wasatch Plateau coalfield. Resource and other units used in this report are in U.S. customary units; table 1 provides conversion factors to the International System of Units. The words million, billion, and trillion are used in this document to mean 10^6, 10^9, and 10^{12}, respectively. Results of this study will be useful to government agencies, industry, landowners, academic workers, and public advocacy groups.

Table 1. Selected conversion factors and unit abbreviations for U.S. customary units used in this report and the International System of Units. Modified from American Society for Testing and Materials (1990), Institute of Electrical and Electronics Engineers (1997), and Hylland and Lund (2003).

To convert from this unit (abbreviation)	To this unit (abbreviation)	Multiply by
Inch (in)	meter (m)	0.0254
Foot (ft)	meter (m)	0.3048
Mile, statute (mi)	kilometer (km)	1.609
Pound (lb)	kilogram (kg)	0.4536
Ton[a] (ton)	Metric ton (t)[b]	0.9072
British thermal unit per pound (Btu/lb)	megajoule per kilogram (MJ/kg)	0.002326
Square mile (mi^2)	square kilometer (km^2)	2590
Acre-foot (acre-ft)	cubic meter (m^3)	1233.5
Cubic foot (ft^3)	cubic meter (m^3)	0.02832
pound per million Btu (lbs/10^6 Btu)	microgram per joule (µg/J)	0.4300
pound per trillion Btu (lbs/10^{12} Btu)	picogram per joule (pg/J)	0.4300

[a] *a short ton (2000 lb)*
[b] *a commercial term (1000 kg)*

Location

The study area (figure 1) covers about 232.5 square miles in northeast Sevier County, Utah. The study area is defined by the four 7.5-minute quadrangles shown in figure 2, and encompasses all of the Salina Canyon, and a small part of the Wasatch Plateau coalfields. The Musinia fault zone separates the Wasatch Plateau coalfield on the east from the Salina Canyon coalfield on the west, and the Water Hollow fault zone separates the Salina Canyon field into two parts (figure 2). Both coalfields underlie the southern part of the Wasatch Plateau physiographic sub-province (Stokes, 1986).

Ground surface elevation in the Salina Canyon and Wasatch Plateau coalfields ranges from about 5900 to 8500 feet above sea level. Most of the minable Blackhawk Formation coal occurs at elevations between 5000 and 7000 feet (Doelling, 1972a).

U.S. Interstate Highway 70 runs through the center of the study area and provides good access to highway transport for minable coal in the study area (figure 1). No railroads serve the Salina Canyon or southern part of the Wasatch Plateau coalfields, and the nearest rail is about 50 miles northwest in eastern Juab County, or about 75 miles northeast near the town of Price in western Carbon County. No towns occur in the study area, however there are some summer cabins in the northeastern part in the Wasatch Plateau portion. The nearest town is Salina, which is about 10 miles west in northwestern Sevier County.

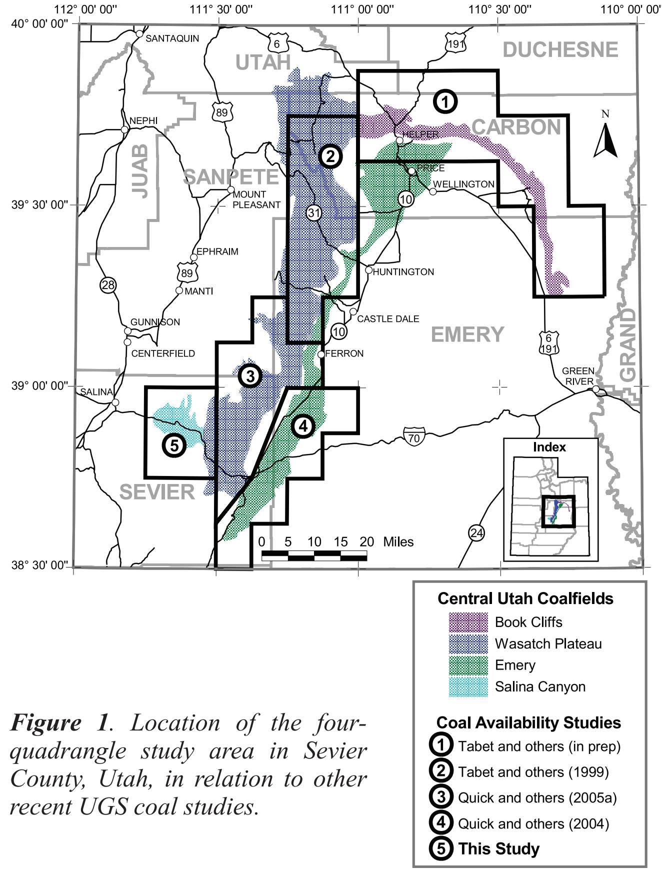

Figure 1. Location of the four-quadrangle study area in Sevier County, Utah, in relation to other recent UGS coal studies.

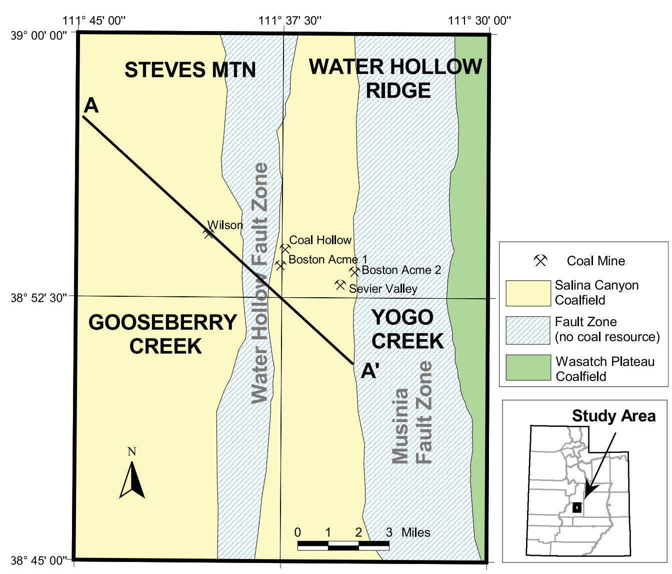

Figure 2. Index showing the location and name of each of the four 7.5-minute-quadrangles in the study area, the locations of the unminable fault zones and coalfields, abandoned coal mines in the Blackhawk Formation, and the line of section for figure 3.

General Geology

The Salina Canyon and southern Wasatch Plateau coalfields lie along the gently westward dipping flank of the Wasatch Plateau. The westerly dips of the coal-bearing strata are generally less than three degrees over most of the study area, but are locally steepened by drag caused by movement along the Musinia and Water Hollow fault zones (Spieker and Baker, 1928). A gentle, east-west trending anticlinal fold runs along Salina Canyon and modifies the general westerly dip of the strata in that part of the study area (Doelling, 1972a, 1972b). The north-south trending Musinia and Water Hollow zones (figure 2) cut the study area and divide it into three sub-areas for the purpose of resource calculations. The vertical displacement along the east and west normal faults bounding the approximately three-mile-wide Musinia zone is 2000 feet or more. The downthrown blocks in the middle of the Musinia zone are broken into numerous smaller blocks (Baughman, 1959; Doelling, 1972a). The Water Hollow zone lies about three miles west of the western edge of the Musinia zone. Like the Musinia zone, the Water Hollow zone has two major bounding faults with a graben in the middle (Bachman, 1959; Doelling, 1972a). Displacements of the strata cut by the Water Hollow zone range from 100 to 900 feet. The strata in the Musinia and Water Hollow fault zones appear to be broken into blocks too small to be attractive for coal mining and therefore no resource was calculated within the two fault zones.

The oldest significant coal-bearing unit beneath the study area is the Ferron Sandstone Member of the Mancos Shale, which does not crop out, and is only known to occur from logs of six oil and gas drill holes penetrating the subsurface (figure 3). The Ferron is about 700 feet thick and consists of interbedded nearshore sandstone and continental sandstone, mudstone, siltstone, and coal beds. Conformably overlying the Ferron is the Blue Gate Shale Member of the Mancos. The Blue Gate consists of 1500 feet of gray marine shale. Above the Blue Gate is the Emery Sandstone Member of the Mancos Shale. The 1300-foot-thick Emery has a transitional contact with the underlying Blue Gate and the lowermost part consists of a coarsening and thickening upward sequence of nearshore marine sandstones. The middle part of the Emery is composed of a continental sequence of sandstone, mudstone, siltstone, and coal beds, like the middle part of the Ferron, but it is much thicker and it contains more laterally persistent and thicker coal beds. The upper part of the Emery consists of a transgressive sequence of near-shore marine sandstones. Conformably above the Emery is the Masuk Shale Member of the Mancos Shale. The Masuk consists of gray, silty, marine shale with minor thin sandstone interbeds; it is 400 feet thick on the eastern side of the study area and thins to the west. West of the study area, where the Blue Gate and Masuk members disappear, exposures of the Upper Cretaceous strata above the Allen Valley Shale (Tununk equivalent) consist of sediments deposited in a predominantly fluvial environment that are referred to as the Funk Valley and Sixmile Canyon Formations of the Indianola Group, in ascending order (Lawton, 1982).

The final regression of the Mancos sea from the area is recorded by the Star Point Sandstone, a regressive marine to nearshore sandstone that has a gradational contact with the underlying Masuk. The Star Point is only exposed in the extreme eastern part of the study area. This cliff-forming unit

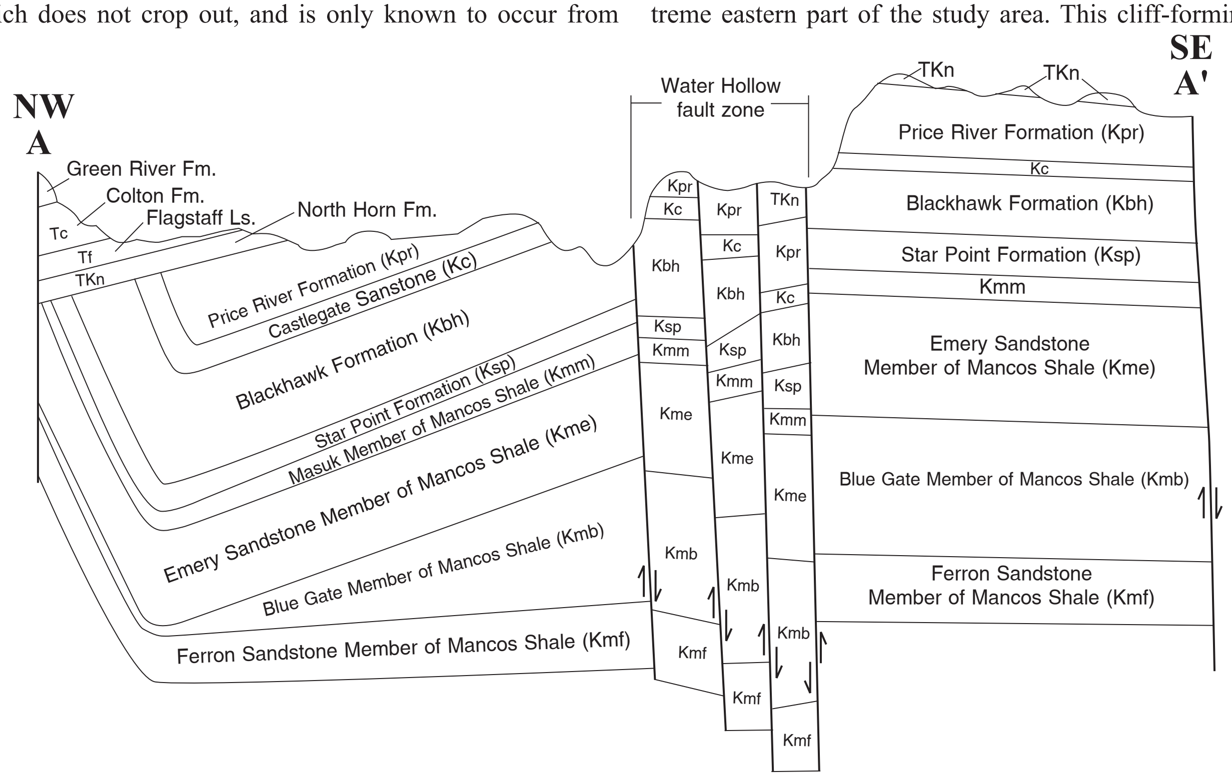

Figure 3. *Diagrammatic NW-SE cross section showing the Upper Cretaceous coal-bearing and overlying Tertiary units beneath the Salina Canyon coalfield; the number of faults in the Water Hollow fault zone is simplified. Location of the section is shown on figure 2; unit thickness based on drill-hole data, but with the vertical scale about eight times the horizontal scale.*

consists of 200 to 300 feet of light gray to tan, fine-grained sandstone (Doelling, 1972a).

The Upper Cretaceous Blackhawk Formation is 750 to 800 feet thick along the eastern escarpment of the Musinia fault zone and conformably overlies the Star Point Sandstone (Doelling, 1972a). However, west of the Musinia fault zone, only the upper 500 to 600 feet of the Blackhawk is exposed along Salina Canyon, whereas the lower part of the formation is buried in the subsurface. The Blackhawk is composed of interbedded braided fluvial channel sandstones, overbank mudstones and siltstones, and lenticular coal beds that are thickest in the lower few hundred feet of the unit (Doelling, 1972a; Adams and Bhattacharya, 2005).

For this study, several coal beds were mapped in the Blackhawk Formation in the Salina Canyon and Wasatch Plateau coalfields (figure 4). In ascending order, the coal beds in the western part of the Salina Canyon field are designated the A, B, Knight, Acord Lakes (formerly Ivie), Wattis (Sevier), and the Castlegate A (Wilson). Spieker and Baker (1928) were the first to study the coal resource of the Salina Canyon field comprehensively. Maurer (1966), Doelling (1972a, 1972b), and Rigby and Uresk (1975) have completed more recent studies of the coal deposits of the Salina Canyon coalfield.

In ascending order, the coal beds mapped in the Wasatch Plateau portion (figure 4) of the study area are the Knight, Acord Lakes, Wattis, and Castelgate A (Quick and others 2005a). The coal deposits of southern Wasatch Plateau were first thoroughly studied by Spieker (1931), and were later examined by Maurer (1966), Doelling (1972c), Dubiel and others (2000), and Quick and others (2005a).

Over most of the study area, the 200- to 250-foot-thick Castlegate Sandstone, a distinctive and easily mappable unit, disconformably overlies the Blackhawk Formation (Ribgy and Uresk, 1975). The Castlegate Sandstone consists of medium-grained, trough cross-stratified sandstone with some mudstone layers and sparse pebble horizons (Guiseppe and Heller, 1998). The Castlegate is generally overlain, in respective order, by the Cretaceous Price River; Cretaceous-Tertiary North Horn Formation; and the Tertiary Flagstaff, Colton, and Green River Formations (McGookey, 1960; Doelling, 1972a; Stanley and Collinson, 1979). These units form the cap of the Wasatch Plateau and comprise 800 to 2100 feet of continental fluvial and lacustrine clastic strata. Near the western margin of the study area, drilling and mapping data (Willis, 1986) indicate that the Upper Cretaceous strata have been upturned, the Blackhawk and Price River units have locally been removed by erosion, and the Tertiary formations rest unconformably on a beveled surface of progressively older Cretaceous and Jurassic strata to the west. The southern part of the study area includes additional capping beds of Oligocene volcanic flows of the Fish Lake Plateau (Doelling, 1972a). Quaternary landslides cover many steep hillsides in the study, and some of the stream courses are filled with Quaternary alluvium, particularly along Salina Canyon.

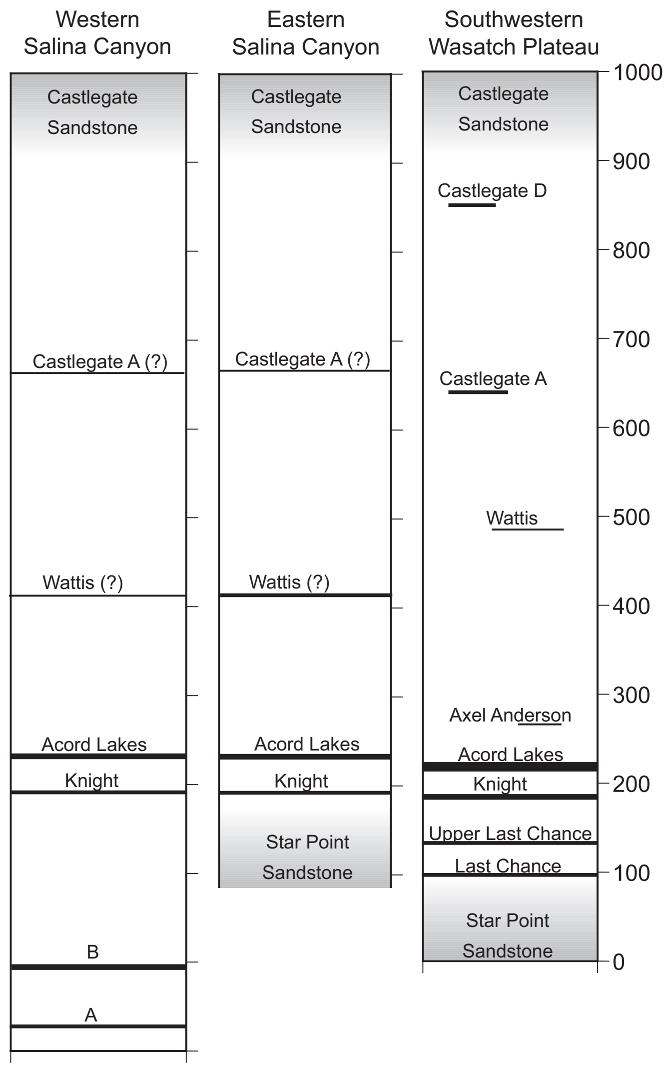

Figure 4. Idealized stratigraphic sections showing coal beds in the Blackhawk Formation, Salina Canyon (western and eastern parts) and Wasatch Plateau coalfields. The stratigraphic position of the coal beds is based on drill-hole data from the study area; the scale on the right side of the figure is in feet. Queried beds have an uncertain correlation across major fault zones, while beds with a discontinuous line indicate they do not persist throughout the whole area.

Mining History

A review of production records, mine maps, and descriptions of prospects indicates that the only coal production from the study area has come from the Blackhawk Formation of the Salina Canyon coalfield (figure 2). Production from this field through 2007 is estimated to total about 430,000 tons; the last recorded production was in 1953. No coal has been mined from the Blackhawk Formation in the southwestern part of the Wasatch Plateau coalfield included within the study area, although the large SUFCO mine is a few miles to the east of the study area. Also, no coal has been mined from the underlying Emery or Ferron Sandstone Members of the Mancos Shale, which are not exposed but known only from drilling into the subsurface. The coals in the Emery are 1000 to 3000 below the surface, whereas the Ferron coals are at depths ranging from 3000 to 5000 feet.

Complete production records are not available, but the earliest production dates back to the early 1900s (Spieker and Baker, 1928; Doelling, 1972a, 1972b). Coal production from the Salina Canyon coalfield has come mostly from a few small mines that were opened to provide fuel for local residents during the winter months; the largest of these mines was the Sevier Valley Coal Company (Crystal City) mine. Production at the Sevier Valley mine began in 1924, was suspended from 1933 through 1943, and resumed from 1944 through 1953, when the mine closed (Doelling, 1972a, 1972b). Early work at the mine opened a small tunnel into the thinner, exposed Sevier bed (Wattis in this study) to supply fuel to the construction camp while a vertical shaft was sunk to the thicker Ivie bed (Acord Lakes in this study), which lies 182 feet below the valley bottom (Tomlinson, 1930).

Doelling (1972a) gives limited information on the history and extent of two other mines in the Salina Canyon coalfield, the Coal Hollow mine (also known as the Kearns & Duggins) that exploited the Sevier (Wattis in this study) bed, and the Wilson mine that extracted coal from the Wilson bed (Castlegate A this study). In addition, a few small prospects have been identified in the Salina Canyon field. Small-scale coal production from the Salina Canyon field probably stopped in the 1950s with the development of more easily mined, and lower cost, reserves elsewhere in the Wasatch Plateau coalfield. About the same time, demand for coal was declining as diesel fuel replaced the coal in railroad engines. Figure 2 shows the locations of coal mines in the study area; most of the coal production from the Salina Canyon coalfield has come from the Acord Lakes (Ivie) bed, with smaller amounts from the Wattis (Sevier) and Castlegate A (Wilson) beds (table 2).

COAL RANK, QUALITY, AND GAS CONTENT

Blackhawk Formation Coals

Assay data for 18 coal samples from the Blackhawk Formation of the Salina Canyon coalfield were collected, but only 14 were used to evaluate the rank and quality of coal in that coalfield (table 3). The assay data are from Spieker and Baker (1928), Maurer (1966), Doelling (1972a), and unpublished data from Utah Geological Survey files. Except for the samples from the Simplot well (table 3), which are on a dry basis, the rest of the samples are reported on an as-received basis. Some of the samples having less than 5% moisture may be air dried and not representative of the in-ground coal quality. Coal from the nearby SUFCO mine in the Wasatch Plateau contains about 10% moisture as delivered to power plants (U.S. Energy Information Administration, 2006).

Only four coal samples (not reported individually here) are available from the Blackhawk Formation in the portion of the Wasatch Plateau coalfield in the study area. However, these samples are included in a broader study of coal to the east of the study area, where Quick and others (2005a) report that the Blackhawk Formation coals have an arithmetic average sulfur content of 0.7%, an ash content of 8.4%, and a heat content of 11,140 Btu/lb, on an as-received basis. The coal rank for the few Blackhawk Formation coal samples from the study area is similar to the rank of the coals in the adjacent larger part of the southern Wasatch Plateau coalfield to the east, where Quick and others (2005a) reported the Blackhawk coal is high volatile C bituminous.

Available data show the sulfur and ash values vary within and between the various Blackhawk coal beds sampled (table 3). All the coal beds contain less than 1.0% sulfur; the Wattis (Sevier) bed has the lowest average sulfur content (0.48%). The ash content of the beds varies considerably, generally from 4

Table 2. *Location, cumulative production, and years of activity for coal mines in the Salina Canyon coalfield.*

Mine Name	UTM N [1]	UTM E [1]	Coal bed	Estimated Tons Mined	Years of Activity
Sevier Valley*	4,303,730	448,717	Acord Lakes (Ivie)	416,500	1926 – 1953
Sevier Valley*	?	?	Wattis (Sevier)	?	1924 – 1926
Coal Hollow*/ Kearns & Duggins	4,306,230	445,687	Wattis (Sevier)	1,500	1925 – 1932?
Boston Acme No. 1	4,305,145	446,307	Wattis (Sevier)	165	1923?
Boston Acme No. 2	4,304,155	449,802	?	?	1925?
Wilson*	4,306,565	441,846	Castlegate A (Wilson)	7,000	1911 – 1931
TOTAL			**All beds**	**425,165**	**1911 – 1953**

*[1] zone 12, NAD83, Universal Transverse Mercator northing (UTM N) and Easting (UTM E) coordinates (meters). Data are from Tomlinson (1930), Spieker and Baker (1928), Doelling (1972a, 1972b), and U.S. Bureau of Land Management files; * = mine map available. Coal bed name given first is name used in this study, name in parenthesis is older name.*

Table 3. Coal analyses from the Salina Canyon coalfield on an as-received basis unless otherwise noted as dry; FC = Fixed Carbon, VM = Volatile Matter.

Sample	Bed	Btu/lb	Ash%	Sulfur%	Moisture%	FC	VM
Sevier Valley mine	Acord Lakes	11,820	10.7	0.4	5.7	43.8	45.5
Sevier Valley mine	Acord Lakes	12,030	9.1	0.6	6.3	45.9	45.0
Crystal Valley mine	Acord Lakes	11,540	9.7	0.4	7.8	44.7	45.6
Ivie Creek	Acord Lakes	11,300	7.8	0.7	7.6	46.8	37.7
Ivie Creek	Acord Lakes	10,210	7.3	0.6	13.9	43.7	35.2
Simplot #1 well	Acord Lakes (u)*	NA	10.7	0.7	dry	45.6	43.7
Simplot #1 well	Acord Lakes (l)*	NA	5.8	0.6	dry	48.1	46.1
Prospect	Wattis	11,856	4.2	0.5	10.0	48.3	37.6
Prospect	Wattis	9,690	8.4	0.4	5.9	40.4	36.3
Prospect	Wattis	11,886	10.8	0.5	5.9	37.8	45.5
Prospect	Wattis	12,775	4.5	0.5	3.0	52.1	40.5
Prospect	Wattis	10,910	9.5	0.5	4.2	45.5	40.8
Coal Hollow mine	Wattis	12,311	11.2	0.5	2.5	39.2	47.1
Wilson mine	Castlegate A	9,502	5.7	0.7	16.0	39.7	38.6

**(u) = upper bench, on a dry basis *(l) = lower bench, on a dry basis*

to 11%, and averages about 8.2%. The as-received heat content of the coal ranges from 9500 Btu/lb to over 12,500 Btu/lb, and averages 11,347 Btu/lb.

Emery and Ferron Sandstone Member Coals

No coal samples are available from the deeper coal in the Emery or Ferron Sandstone Members of the Mancos Shale at greater depths within the study area. Nothing has been published on the quality of the coal in the Emery Sandstone, but the quality of the coal in the Ferron Sandstone from the Emery coalfield to the east of the study area has been reported by various workers (Lupton, 1916; Doelling, 1972d; Affolter and others, 1979; Crowley and others, 1989; and Quick and others, 2004). Affolter and others (1979) provide the following as-received arithmetic mean values for various quality parameters of the Ferron coals in the area to the east of the study area: 5.1% moisture, 13.0% ash, 1.4% sulfur, 38.3% volatile matter, 43.6% fixed carbon, and 11,450 Btu/lb. The Ferron coals are high volatile B bituminous to subbituminous A in rank (decreasing in rank southward) according to Quick and others (2004). The Ferron and Emery coals might increase slightly in rank to the west where they are more deeply buried, but are probably still in the bituminous rank.

Maceral and Mercury Content of the Blackhawk Formation Coals

Hucka and others (1997) have no petrographic data from the Salina Canyon coalfield, but report two petrographic analyses from Blackhawk coals from the southern Wasatch Plateau coalfield near the eastern side of the study area, which contain an average of 79.4% vitrinite, 5.5% liptinite, and 15.2% inertinite. This compares well to the average petrographic composition reported from Blackhawk coals from the southern Wasatch Plateau field just east of the present study area, which is 81% vitrinite, 7% liptinite, and 12% inertinite (Quick and others, 2005a). The Blackhawk coals from the Salina Canyon coalfield are expected to have a similar average maceral composition to that found in the coals of the same formation in the southern Wasatch Plateau coalfield. Within the study area, Buranek and Crawford (1943) report that the Acord Lakes (Ivie) bed is exceptionally low in resin content, the Wattis (Sevier) bed carries resin contents up to 15% by volume, and the Castlegate A (Wilson) bed averages between 6 and 7% resin by volume.

Mercury emissions from electric utilities will be regulated beginning in 2010 (U.S. Environmental Protection Agency, 2005). Although we have no data on the mercury content of the coal from the various formations in the Salina Canyon coalfield proper, we assume that the mercury content of the Blackhawk Formation coal here is similar to that found in the coal from the Blackhawk Formation in the adjacent Wasatch Plateau and Book Cliffs coalfields (table 4). We expect that the average mercury content of in-ground Blackhawk coal in the Salina Canyon coalfield is less than the U.S. average of 11 lbs Hg/trillion (10^{12}) Btu, if it matches the average 3.7 lbs Hg/10^{12} Btu observed for in-ground Blackhawk coal from the Wasatch Plateau and Book Cliffs coalfields (Bragg and others, 1997; Quick and others, 2003, 2005a, 2005b).

Table 4. *In-ground and delivered mercury content for Blackhawk Formation and average U.S. coals.*

Values in lbs Hg per trillion Btu	Blackhawk Formation, in ground(1)	Blackhawk Formation, as delivered(2)	U.S. Average*, in ground(1)	U.S. Average*, as delivered(2)
Average mercury content:	3.7	4.2	11.0	8.3
Median mercury content	2.3	3.9	---	---
Number of data records	53	443	5,059	25,825

**US Average values weighted by state production tonnage*
(1) from Bragg and others, 1997
(2) from U.S. Environmental Protection Agency, 1999

Coal-bed Methane

The Salina Canyon and southwestern Wasatch Plateau coalfields are about 40 miles southwest of the coal-bed methane development in Carbon and Emery Counties. In central Utah's Drunkards Wash area, Ferron coals have produced more than 200 billion cubic feet of coal-bed methane from 470 wells (Montgomery and others, 2001; Lamarre, 2003). No coal-bed methane production has been recorded from the coals in the Salina Canyon or Wasatch Plateau coalfields.

Doelling and others (1979) and Smith (1986) tested 26 core samples from the Blackhawk Formation for gas content from 20 locations within the southern Wasatch Plateau coalfield slightly to the east of the current study area. The gas trapped in the various beds ranged from zero to 13 standard cubic feet of gas per ton coal (scf/ton); the average gas content was 2.5 scf/ton. The Blackhawk coal samples' low gas contents may relate to low rank of the coal, and similar low gas contents would be expected for the Blackhawk Formation coals in the Salina Canyon field. No desorption tests are available from the study area's deeper coal beds in the Emery and Ferron Sandstone. Mud logs from one oil and gas well in the study area indicated gas kicks in the coals in the Emery Sandstone. The abandoned Phillips Petroleum Company Maple Springs Unit #1 well (section 3, T. 23 S., R. 2 E., Salt Lake Base Line and Meridian) was drilled in the study area during 1981 and 1982, and reported shows of gas from the Emery Sandstone coal-bearing intervals at depths between 4000 and 4200 feet. A well drilled in 2001 by Prima Resources near Scofield, farther north in the Wasatch Plateau, encountered a 22-foot-thick Emery coal bed that contained 280 scf/ton of gas. Although Emery coal beds of sufficient thickness to be considered good reservoirs are present in the study area, more precise, quantitative testing of the gas content of these coals is needed to determine if commercial quantities of coal-bed gas are present.

SPATIAL DATA USED TO CALCULATE COAL RESOURCE TONNAGE

Two kinds of spatial data were used to calculate the coal resource of the Salina Canyon and southern Wasatch Plateau coalfields. Geographic data are typically electronic or paper maps compiled by various agencies. We used these maps to evaluate the impact of geologic, geographic, and land-use features on coal mining. Stratigraphic data are numeric data sets that list coal bed thickness and depth values together with drill-hole location coordinates; we used these data to create new maps showing the thickness, extent, and depth of coal beds.

Geographic Data

Our study used digital maps of perennial streams, lakes, power lines, and roads from the Utah Automated Geographic Reference Center (UAGRC, 2006), as well as U.S. Geological Survey (USGS) digital elevation models with square grid cells measuring 30 meters on a side. No municipalities, railroads, producing oil or gas wells, or pipelines occur in the study area. Mine maps were found for the Crystal City, Coal Hollow, and Wilson mines; no maps could be found for the Boston Acme mines or various small prospects in the study area. Data for abandoned oil and gas wells and are from the Utah Division of Oil, Gas, and Mining (UDOGM, 2006). Faults were taken from the 1:42,400 scale geologic map of the area by Doelling (1972a), and an unpublished 1:24,000 scale map by Rigby and Uresk (1975).

Stratigraphic Data

Coal exploration drill hole data and outcrop measurements listing the location, thickness, and depth or elevation of coal beds are from various sources; all of the data records are from electronic files compiled by the UGS for the National Coal Resources Data System. Original sources of the coal thickness data include records from Spieker and Baker (1928), Maurer (1966), Doelling (1972a), oil and gas well logs, old mine maps, and unpublished files and reports (such as Rigby and Uresk, 1975). Data for 161 drill holes and 25 outcrop/mine measurements (figure 5) were used in this study. Most of the drill holes are located east of the study area in the Wasatch Plateau coalfield (not shown on figure 5). The data coverage for the Salina Canyon coalfield portion of the study area is not well distributed, and includes only 11 drill holes and all (25) of the outcrop measurements; most are located in a narrow area along Salina Canyon. The complex structure of the Salina Canyon coalfield, combined with the lenticular nature of the coal beds and the clustered and non-uniform distribution of the coal measurements, makes the correlation of the coal beds and the extrapolation of coal information difficult in this area. For this reason we have not calculated any hypothetical coal resources that may exist in areas more than three miles from non-zero coal thickness measurement points.

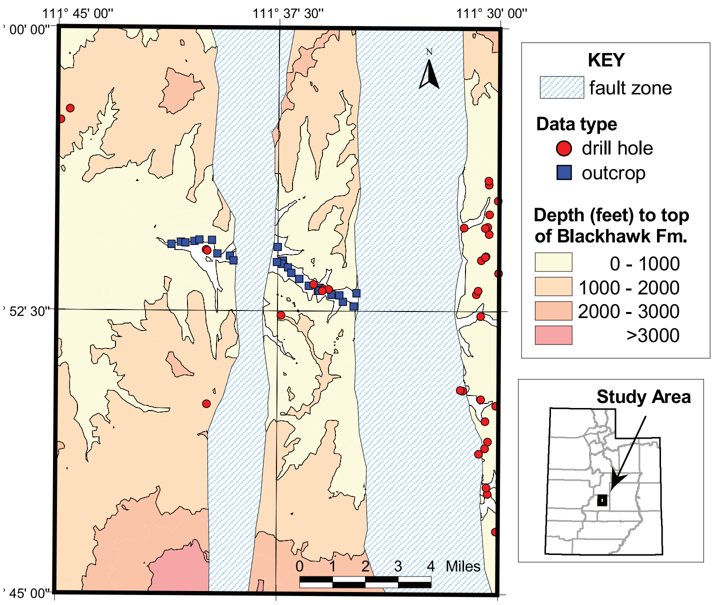

Figure 5. *Map of the four 7.5-minute-quadrangle study area, the locations of data points used, fault zones, and depth to the top of the coal-bearing Blackhawk Formation. Data for each drill hole include depth and thickness of one or more coal beds; outcrop data are generally for an individual bed. Drill holes that are adjacent to the study area from the Wasatch Plateau to the east were included to improve the reliability of derived maps near the edge of the study area.*

METHOD USED TO CALCULATE COAL RESOURCE TONNAGE

Calculation of the in-ground coal tonnage requires knowing the areal extent, thickness, and density of each coal bed. Values for the areal extent and thickness for each coal bed were tabulated in Arcview® and entered into a spreadsheet where the coal tonnage was calculated using a coal density value of 1770 tons per acre-foot of coal (Wood and others, 1983). For example, GIS analysis revealed 12,983 acres where the available, underground-minable coal in the Knight coal bed of the Salina Canyon field is between 4 and 6 feet thick. The spreadsheet calculation,

$$12{,}983 \text{ acres x } 5 \text{ feet coal x } \frac{1770 \text{ tons coal}}{\text{acre-foot}} = 114{,}899{,}550 \text{ tons coal,}$$

showed that there are 114.9 million tons of 4- to 6-foot-thick coal in the Knight coal bed that are available for underground mining.

Creating Maps Using ArcView®

As noted earlier, many of the maps used in this study were previously compiled by several agencies. However, some were newly created. This section describes how these latter maps were made.

We created maps showing coal bed thickness and depth from data for drill holes using the Spatial Analyst (v.1.1) extension for ArcView (®, v.3.2) software. The calculations are based on identically registered, square grid cells measuring 30 meters on a side (0.2224 acres) using zone 12, NAD83, UTM coordinates (meters). Coal bed thickness and interburden maps were made using a fourth-order, six-nearest-neighbor, inverse-distance, mapping function. Coal bed elevation maps were made using a tension, four to six-nearest-neighbor, spline, mapping function; these elevation maps were made separately for each of the three contiguous coal-bearing areas (Salina Canyon west and east, and Wasatch Plateau). The intersection of the coal bed elevation and surface elevation defined the coal bed outcrop, which we verified by comparison to digitized outcrop lines from Doelling (1972a).

Coal Bed Thickness Maps

Coal oxidation and burning near the outcrop often reduces the thickness of coal beds in Utah. Burning can also cause slumping of overlying sediments, which further reduces the apparent coal bed thickness at the outcrop Doelling (1968). Thus, outcrop observations in Utah are rarely representative of the amount of coal buried behind the outcrop. Because we have limited information from drill holes (figure 5), we also used in-mine thickness measurements, and less-reliable outcrop thickness observations.

The steep, rugged topography of the study area, and the general management preferences of the surface management agencies, preclude mining by surface (open-pit) methods where beds can be successively exposed and recovered. Because the coal is generally deeply buried, underground mining methods are required and only the thickest of the successive beds can be recovered. Consequently, the available coal resource was only determined for underground minable coal. Coal bed thickness maps were constructed to include only those parts of the bed that might be recovered using underground mining methods; these maps exclude coal in thinner splits, riders, and sub-beds that are separated from the thickest bed by more than one foot of rock.

In places, coal beds in the study area consist of several successive benches separated by one or more feet of rock parting. Identifying the underground-minable part of a coal bed is sometimes difficult where numerous partings, splits, riders, and sub-beds occur. Accordingly, we used some arbitrary but consistent rules to distinguish the underground-minable part of a coal bed. For our maps of the underground-minable coal resource, the thickness of the coal bed was truncated at partings that are more than 1 foot thick. Note that an underground-minable interval sometimes included rock partings that are less than 1 foot thick if: (a) the coal above or below a parting was at least twice the thickness of the included parting, and (b) the included partings accounted for less than 20% of the minable coal thickness.

Coal Bed Depth Maps

Depth maps were made for tops of coal beds encountered in the 36 drill holes shown on figure 5; areas on either side of the Musinia and Water Hollow fault zones were mapped independently because of the large displacement and the great width of the fault zones. Because most of the coal beds in the Salina Canyon coalfield are poorly exposed, or not exposed at all, and we lacked numerous uniformly spaced drill hole observations, we first developed a structure contour map on the top of the Blackhawk Formation using geologic maps of the areas for elevation control of this surface. From this surface, and the calculated average distance from the top of the Blackhawk to each coal bed below, we derived structure contour maps for each underlying coal bed by subtraction from the Blackhawk Formation's upper surface map. The depth of each coal bed was calculated by subtraction of the newly created structure contour maps from surface elevations obtained from the USGS digital elevation model (intermediate maps not included with this report).

Coal Bed Interburden Maps

The thickness of sediment between adjacent coal beds (the interburden) is significant because two beds having less than 40 feet of interburden cannot both be mined safely by underground mining methods. The interburden between the minable portions of the coal beds in the current study area is nowhere less than 40 feet, and therefore this restriction did not apply in this study.

Resource Classification

The USGS (Wood and others, 1983) narrowly defines a coal reserve as coal that can be economically produced at the time of determination, whereas a coal resource is broadly defined to include coal for which economic extraction is potentially feasible. In this study, we did not rigorously consider coal-production costs, the percent of the in-ground-coal that can be recovered, or other factors required to estimate the coal reserve. Instead, we identified a subset of the in-ground coal resource, which we call the available coal resource.

The Available Coal Resource

The available coal resource is that part of the total coal resource remaining after subtraction of coal in areas affected by past mining, or where mining is prohibited because of technical or land-use restrictions. Restrictions to underground mining are considered in two groups. Technical restrictions limit mining to areas where the coal can be safely recovered using current technology. Land-use restrictions limit mining to areas where mining will not harm human infrastructure or environmental assets. Table 5 lists the land-use and technical restrictions that are used in this study, together with their associated buffers and restriction factors. These restrictions vary from place to place (Eggleston and others, 1990).

Table 5. *Restrictions to underground mining in the Salina Canyon and southern Wasatch Plateau coalfields, Utah (modified from Rohrbacher and others, 1993).*

Land-use restrictions[1]	**Buffer or factor**
Highways	100 feet on either side
Railroads	100 feet on either side
Power lines	100 feet on either side
Perennial streams	100 feet on either side
Lakes or reservoirs	100 feet around margin
Producing petroleum wells	100-foot radius
Towns or cemeteries	300-foot radius
National park or monument	100 feet around margin
Technical restrictions	**Buffer or factor**
Minimum bed thickness	4 feet
Minimum overburden	50 feet
Maximum bed thickness	14 feet
Maximum overburden	3000 feet
Minimum interburden	40 feet
Faults	50 feet on either side
Barrier for abandoned mines (Included with mined-out coal)	50 feet around margin

[1]No railroads, towns, cemeteries, producing petroleum wells, pipelines, national parks or monuments are present in the coal-bearing parts of the study area.

Restrictions for Underground-Minable Coal

All active Utah coal mines are underground mines, and most use continuous mining machines to develop mains and entries, and longwall mining machines for bulk production. Longwall machines used in Utah are usually designed for 6- to 14-feet-thick coal beds. In the eastern United States, underground coal mines sometimes work beds as thin as 2 or 3 feet thick. However, this is done only where some special circumstance or use of the coal justifies a premium price. Moreover, underground mining of thinner coal beds in the eastern United States is also possible because these Carboniferous-age coal beds typically show uniform thickness over large areas, which allows sufficient production to recover the cost of thin-coal mining equipment. Cretaceous-age coal beds in Utah show more thickness variation. Because Utah coal is sold to power plants, rather than to more lucrative specialty markets, it seems unlikely that thin Utah coal beds can be economically mined under current market conditions. Furthermore, even if a premium price were offered for Utah coal, mining these thinner coal beds will be challenging because they are not uniformly thick over large areas. Given these circumstances, we used a 4-foot minimum thickness restriction to identify the underground-minable coal resource.

Although coal beds greater than 14 feet thick are actively mined in Utah, current underground mining methods can recover only a maximum 14-foot-thick segment of the coal bed; the remaining coal is lost in the gob pile behind the longwall mining machine. To date, however, coal beds more than 14 feet thick have not been identified in the study area, so this restriction has not been applied.

Other technical restrictions to underground mining were also considered. To avoid unstable roof conditions and possible water infusions, most mines leave a 50-foot barrier near faults. Burned or oxidized coal behind the outcrop commonly causes operators to leave coal near the outcrop. Weathering near the outcrop sometimes extends to several hundred feet of burial. We chose a minimum 50-foot burial depth restriction to exclude weathered coal. In areas where there are multiple coal beds, 40 feet of interburden is required to allow for stable roof and floor conditions if both of the coal beds are mined; no such areas exist in the current study area. The maximum amount of overburden routinely planned for at most Utah coal mines is 2500 feet. However, some operators are considering mining to depths of 3000 feet, so a 3000-foot maximum burial depth restriction was used in this study. Regulations require coal operators to leave a 50-foot barrier between abandoned and active coal mine workings to avoid potential ventilation or water infusion problems. Accordingly, we applied a 50-foot buffer restriction to the perimeter of abandoned coal mines.

Land-use restrictions for underground mining are intended to protect surface features from damage that might result from surface subsidence above underground mines. Protected surface features in the study area include highways, perennial streams, lakes and reservoirs, and power lines. Land-use restrictions that prohibit mining under railroads, radio towers, towns, cemeteries, producing petroleum wells, pipelines, and National Parks or Monuments were not considered because these features do not occur in the study area.

Thickness Categories

Coal bed thickness categories used in this study are similar to those recommended by the USGS (Wood and others, 1983), but we use thinner increments. We also deviated from the USGS classification to account for current Utah mining practice, which preferentially selects coal beds that are more than 6 feet thick. Table 6 compares the coal bed thickness categories used in this report to those recommended by the USGS.

Overburden Categories

Table 7 compares the overburden categories used in this report to those recommended by the USGS (Wood and others, 1983). To identify shallow coal that is probably weathered or burned, we used a 0- to 50-foot depth restriction for underground-minable coal; coal deeper than 50 feet was considered underground minable. For underground minable coal deeper than 1000 feet, we used equal 1000-foot intervals down to 3000 feet; no coal deeper than 3000 feet was delineated in the study area within three miles of a coal thickness measurement point.

Table 6. *Coal bed thickness categories used in this report compared to those used in the Coal Resource Classification System of the USGS (Wood and others, 1983).*

This Report		USGS	
Feet	Inches	Feet	Inches
1 to 2	12 to 24	1.2 to 2.3	14 to 28
2 to 4	24 to 48	2.3 to 3.5	28 to 42
4 to 6	48 to 72	3.5 to 7.0	42 to 84
6 to 8	72 to 96	7 to 14	84 to 168
8 to 10	96 to 120		
10 to 12	120 to 144	+ 14	+ 168

Table 7. *Overburden categories used in this report compared to those used in the Coal Resource Classification System of the USGS (Wood and others, 1983).*

This Report (feet)	USGS (feet)
0 to 50[1]	0 to 500
50 to 1000	500 to 1000
1000 to 2000	1000 to 2000
2000 to 3000	2000 to 3000

[1]A 0- to 50-foot restriction is applied to calculate the coal excluded from the underground-minable, available coal resource due to weathering.

Reliability Categories

Only two reliability categories (Wood and others, 1983) were used in this study. The demonstrated coal resource must be within 0.75 miles of a measured thickness location. The inferred coal resource is between 0.75 and 3 miles of a measured thickness location. Because of the few drill holes, their lack of uniform spacing across the study area, and the lenticular nature of the coal beds in the study area, we did not feel confident extending our resource calculations to include the hypothetical coal resource found more than 3 miles from a measured thickness location.

The small part of the Wasatch Plateau coalfield along the eastern side of the study area has an adequate number of uniformly spaced drill holes (26), which allow the coal resource there to be determined with at least an inferred reliability. However, the Salina Canyon coalfield has relatively few drill hole or other coal measurements (11 drill holes, 25 measured sections), and most of those measurements are clustered along the narrow trace of Salina Canyon itself (figure 5). The non-uniform and sparse nature of the data, along with the complex faulting in the Salina Canyon field, and the lenticular nature of the coal beds makes correlation of the coal beds in this field problematic and the resource determination less reliable (only 12% demonstrated resource). More drilling is required in the Salina Canyon field to increase the reliability of the resource estimate there.

RESOURCE CALCULATION RESULTS

The Original Coal Resource

The original coal resource is the tonnage of minable coal that existed in the study area before mining, and without consideration of land-use or technical restrictions. Two factors are important when considering the original coal resource. The thickness of the individual coal beds has obvious significance; coal in thin beds has little economic potential whereas coal in thick beds is potentially minable. The depth of the original coal resource is also important. Deeply buried coal beds have less economic significance whereas coal at shallow to modest depths is more economically attractive.

Thickness of the Original Coal Resource

Table 8 shows tonnage values according to thickness categories for the six coal beds in the Salina Canyon and Wasatch Plateau coalfields. All of the original coal resource (1173 million tons) is underground minable. About 32% of the underground-minable coal is in beds that are more than 4 feet thick. Coal thicker than 6 feet thick is limited to the B, Knight, Acord Lakes, and Wattis beds; most of this thicker coal is in the B and Acord Lakes coal beds of the Salina Canyon coalfield. The A and B coal beds of the Salina Canyon coalfield are only known from a single drill hole so each of their estimated resource was confined to a single thickness category; more drilling data is needed to get a reasonable thickness distribution for the coal resource for these two beds.

Table 8. *Original coal resource for all coal beds thicker than 1 foot in the study area by thickness (million tons).*

COAL BED	TONNAGE BY THICKNESS CATEGORY (feet)						TOTAL TONNAGE	
	1-2	2-4	4-6	6-8	8-10	10-12	Underground minable	Percent of total
A	0	0	105.5	0	0	0	105.5	9.0
B	0	0	0	168.9	0	0	168.9	14.4
Knight	3.3	72.1	138.2	17.9	40.1	3.1	274.8	23.4
Acord Lakes	8.0	62.3	144.8	128.7	5.1	0.8	349.7	29.8
Wattis	31.6	69.7	33.0	16.5	0	0	150.7	12.8
Castlegate A	35.4	86.9	1.3	0	0	0	123.6	10.5
TOTAL	**78.3**	**291.0**	**422.8**	**332.0**	**45.2**	**3.9**	**1173.2**	**100.0**
PERCENT	**6.7**	**24.8**	**36.0**	**28.3**	**3.9**	**0.3**	**100.0**	

TOTAL may differ from results obtained by summing rows or columns due to rounding.

Table 9. *Original coal resource for all coal beds thicker than 1 foot in the study area by overburden depth (million tons).*

COAL BED	TONNAGE BY DEPTH CATEGORY (feet)				TOTAL	TOTAL	PERCENT
	0 to 50	50 to 1000	1000 to 2000	2000 to 3000	All Depths	50 to 3000 feet deep	50 to 3000 feet deep
A	0	7.2	78.3	20.1	105.5	105.5	100.0
B	0	14.8	129.5	24.6	168.9	168.8	100.0
Knight	0.1	52.3	150.1	72.4	274.8	274.7	99.9
Acord Lakes	0.1	69.8	220.4	59.4	349.7	349.6	99.9
Wattis	0.7	51.2	86.0	12.9	150.7	150.0	99.5
Castlegate A	1.1	65.3	57.2	0	123.6	122.5	99.1
TOTAL	2.0	260.6	721.5	189.4	1173.2	1171.2	99.8
PERCENT	0.2	22.2	61.4	16.1	100.0	99.8	

TOTAL may differ from results obtained by summing rows or columns due to rounding.

Depth of the Underground-Minable, Original Coal Resource

Table 9 shows the distribution of the underground-minable, original coal resource by overburden depth, for all coal beds that are more than 1 foot thick and within three miles of a coal thickness measurement point. All of this coal is found under less than 3000 feet of cover and is thus at suitable depths for underground mining. The steep nature of the topography of the study area means that less than 1% of the coal is too shallow (weathered) to be considered for future underground mining. About 84% of the original coal resource is under less than 2000 feet of cover, or at very favorable depths for underground mining. Since most of the coal measurements are found along Salina Canyon where the Blackhawk Formation is exposed, more widespread drilling north and south of Salina Canyon will undoubtedly find more coal at greater depths than the resource identified in this study. Figure 5 shows an area in the southwestern part of the study area where the Blackhawk Formation is projected to be deeper than 3000 feet.

Calculation of the Available Coal Resource

The available coal resource includes that part of the original coal resource that remains after subtraction of coal in areas affected by past mining as well as subtraction of coal that cannot be mined due to technical or land-use restrictions. Table 10 shows the effect of technical and land-use restrictions on the available coal resource. Note that the available coal tonnage may be greater than the value obtained by sequentially subtracting the individual tonnage restrictions. This is because multiple coal restrictions are not double counted in areas subject to more than one restriction; table 10 also tabulates the net amount of coal restricted from the multiple restrictions found in the study area. Coal that is too thin to mine is subtracted out first before other restrictions area applied to an individual coal bed.

Coal Lost to Technical Restrictions

About 32% (370 million tons) of the original coal resource is in beds that are too thin for underground mining (less than 4 feet thick). None of the original coal resource identified is in beds that are too deep to mine; however there are portions of the study area that have not been drilled that would contain coal at depths greater than 3000 feet. Where minable (greater than four feet thick), all of the coal beds could be fully mined by underground technology; none of the coal beds is thicker than 14 feet thick and subject to a maximum thickness cutoff. Faulting, shallow weathered coal, and past mining are the other technical restrictions that limit mining of a small amount

Table 10. *Coal tonnage lost to technical and land-use restrictions, and tabulation of the net available coal resource for all coal beds in the study area (million tons).*

COAL BED	ORIGINAL COAL RESOURCE	TECHNICAL RESTRICTIONS				LAND-USE RESTRICTIONS			NET RESTRICTED	AVAILABLE COAL RESOURCE
	TOTAL	*Too Thin*	*Too Shallow*	*Mined*	*Faults*	*Water Bodies*	*Roads*	*Power Lines*	TOTAL	TOTAL
A	105.5	0	0	0	1.6	1.5	1.0	1.4	5.2	100.3
B	168.9	0	0	0	2.6	2.4	1.6	2.2	8.5	160.4
Knight	274.8	75.4	0.1	0	1.6	2.9	0.7	0.7	81.3	193.5
Acord Lakes	349.7	70.3	0.1	1.3	3.4	3.7	3.7	2.2	82.3	267.4
Wattis	150.7	101.2	0.7	0.6	0.2	0	0	0.2	101.6	49.0
Castlegate A	123.6	122.3	1.1	0	0	0.2	0.1	0	122.6	1.0
TOTAL	**1173.2**	**369.3**	**2.0**	**1.9**	**9.4**	**10.7**	**7.1**	**6.7**	**401.6**	**771.7**
PERCENT	**100**	**31.5**	**0.2**	**0.2**	**0.8**	**0.9**	**0.6**	**0.6**	**34.2**	**65.8**

ORIGINAL COAL RESOURCE is underground-minable coal in beds more than 1 foot thick (generally excluding riders, splits, and subbeds).
RESTRICTIONS are individually tabulated for:
Too Thin — underground-minable coal in beds less than 4 feet thick.
Too Shallow — underground-minable coal less than 50 feet deep.
Mined — coal previously mined, or undermined (including a 50-foot buffer).
Faults — underground-minable coal within 50 feet of a fault.
Water Bodies — coal under a perennial stream or water body (100-foot buffer).
Roads — coal under an improved road (100-foot buffer).
Power Lines — coal under power lines (100-foot buffer).
AVAILABLE COAL RESOURCE is the net total coal remaining after subtraction of restricted coal; coal in areas subject to multiple restrictions is only subtracted once.
TOTAL values may differ from results obtained by summing columns due to rounding.
PERCENT is percentage of total original coal tonnage (1173.2 million tons).

of the original resource (table 10) in the study area, but these restriction do not individually affect more than 1% of the total coal resource. Much of the shallow weathered coal was eliminated before tabulation because it is also too thin to mine.

Coal Lost to Land-Use Restrictions

Land-use restrictions individually exclude about 24.5 million tons of coal (table 10), which is about 2% of the original coal resource in the study area. About 11 million tons is lost because of rules that prohibit mining under lakes and perennial streams, 7 million tons is lost where the coal is under improved roads, and another 7 million tons underlie power lines in the study area. No coal in the study area underlies railroads, pipelines, towns, cemeteries, producing petroleum wells, or National Parks or Monuments.

THE AVAILABLE COAL RESOURCE

Table 10 shows that of the 1173-million-ton original coal resource, 772 million tons (65.8%) is available for future mining. The Acord Lakes coal bed accounts for over 34% of the 770-million-ton available coal resource in the study area. The Castlegate A bed accounts for only 1 million tons of available coal and this amount is too small to be an economic accumulation attractive for mining. As listed in the appendix, the total available resource is not divided equally between the two coalfields; the Salina Canyon field contains 693 million tons (89.8%) of the available resource and the Wasatch Plateau contains the remaining 79 million tons (10.2 %).

The 772-million-ton available coal resource that we calculated for the study area coalfields (table 10) is an estimate. In the following sections we use two approaches to evaluate the reliability of this estimate. First, we considered the spatial distribution of drill-hole observations used to calculate the available coal resource. Second, we compared the results from this study with results from a previous study.

The reliability of the available coal resource estimate is evaluated using a resource classification scheme developed by the U.S. Geological Survey (Wood and others, 1983). About 84.5 million tons (12.2%) of the available coal resource calculated for the Salina Canyon coalfield (table 11a) is classified as a demonstrated resource (less than 0.75 miles from a thickness location), whereas 608.3 million tons (87.8%) is classified as an inferred resource (0.75 to 3 miles from a thickness location). Table 11b shows that the coal in the Wasatch Plateau portion of the study area is more reliably known with 49.5 million tons (62.7%) of the available coal resource classified as demonstrated, and 29.5 million tons (37.6%) of the available coal classified as inferred resource. Obviously, it would be helpful to have more widely spaced drill hole data in the Salina Canyon field so that the resource could be more reliably determined.

Table 11a. *The available coal resource tonnage for the Salina Canyon coalfield area by coal bed and reliability category (million tons).*

COAL BED	Reliability Category		TOTAL TONNAGE
	Demonstrated	Inferred	
Castlegate A (Wilson)	0.8	0.0	0.8
Wattis (Sevier)	12.7	36.3	49.0
Acord Lakes (Ivie)	33.1	234.1	267.2
Knight	13.7	101.2	114.9
B	14.9	145.6	160.4
A	9.3	91.0	100.3
TOTAL	**84.5**	**608.3**	**692.7**
PERCENT OF TOTAL	**12.2**	**87.8**	**100.0**

Reliability Category(ies) from Wood and others (1983). Demonstrated is coal within 0.75 miles of an observation location. Inferred is coal between 0.75 and 3 miles of an observation location. TOTAL may differ from results obtained by summing rows or columns due to rounding.

Table 11b. *The available coal resource tonnage for the Wasatch Plateau coalfield area by coal bed and reliability category (million tons).*

COAL BED	Reliability Category		TOTAL TONNAGE
	Demonstrated	Inferred	
Castlegate A	0.2	0.0	0.2
Acord Lakes	0.2	0.0	0.2
Knight	49.1	29.5	78.6
TOTAL	**49.5**	**29.5**	**79.0**
PERCENT OF TOTAL	**62.7**	**37.3**	**100.0**

Reliability Category(ies) from Wood and others (1983). Demonstrated is coal within 0.75 miles of an observation location. Inferred is coal between 0.75 and 3 miles of an observation location. TOTAL may differ from results obtained by summing rows or columns due to rounding.

Table 12a compares our available coal resource estimate for the Salina Canyon coalfield to a similar estimate reported by Spieker and Baker (1928). The 1928 estimate lacked any of the drill-hole information available to us, and Doelling's (1972a) subsequent study suggested that Spieker and Baker's 1928 estimate was conservative. Because most of the thicker coal beds in the Salina Canyon coalfield are known only from the subsurface, we are not surprised that the 1928 estimate is orders of magnitude lower than our current resource estimate. However, our estimate is likewise based on sparse data and is subject to change upon completion of more exploration drilling in the Salina Canyon field. Hopefully, future exploration will improve the reliability of the resource estimate by allowing more than 12% of the coal to be classified as a demonstrated resource.

Table 12b compares our new resource estimate with one made by Doelling (1972c). Doelling's resource estimate was for coal beds more than 4 feet thick and under less than 3000 feet of cover. Although we also tabulate the coal resource for coal beds with the same characteristics, the comparisons shown in table 12 is approximate rather than exact because Doelling (1972c) did not use the same resource reliability classification scheme we did, which was developed later by Wood and others (1983) of the U.S. Geological Survey. Interestingly, our current resource estimate, although of the same order of magnitude as Doelling's (1972c), is actually slightly less than that determined in 1972. This difference illustrates that, in some instances, additional drilling data can reduce the coal resource of an area by showing the coal beds are more lenticular than originally thought. Lenticular coal beds, like those present in the study area, usually require more drill-hole information to capture the resource complexity caused by abrupt changes in coal bed thickness.

***Table 12a**. Original coal resource tonnage estimate from Spieker and Baker (1928) compared to results from this study, Salina Canyon coalfield (million tons, for beds generally ≥ 4 feet).*

COAL BED	Spieker & Baker's tonnage	Tonnage this study
Castlegate A (Wilson)	14.8	1.0
Wattis (Sevier)	15.3	49.5
Acord Lakes (Ivie)	7.0	279.2
Knight	0.0	118.2
B	0.0	168.9
A	0.0	105.5
TOTAL	**37.1**	**722.3**

***Table 12b.** Original coal resource tonnage estimate from Doelling (1972c) compared to results from this study of the Wasatch Plateau coalfield portion (million tons, for beds generally ≥ 4 feet).*

COAL BED	Doelling's tonnage	Tonnage this study
Castlegate A (Wilson)	0.0	0.3
Wattis (Sevier)	0.0	0.0
Acord Lakes (Ivie)	0.0	0.2
Knight	107.1	81.1
TOTAL	**107.1**	**81.6**

DISCUSSION

The significance of our 772-million-ton available coal resource estimate depends on how much of this coal is produced in the future. To estimate the coal production potential of the Salina and Wasatch Plateau portions of the study areas we considered the thickness and distribution of the available coal resource, as well as the current local mining practices.
Table 13 shows that about 53% (411 million tons) of the underground-minable, available coal resource is in coal beds that are less than 6 feet thick. Such relatively thin coal is rarely mined in Utah at present. About 360 million tons (47%) of the available coal resource is in beds that are more than 6 feet thick.

Coal mines in central Utah's Wasatch Plateau coalfield have historically recovered about 35% of the available coal resource (Rohrbacher and others, 2001). Recovery from the study area will probably equal at least that same percentage recovery because the coal beds are similar to those in the Wasatch Plateau (Doelling, 1972c). Table 10 shows a small amount of coal (1.9 million tons) affected by past mining, because very little of the original coal resource in the study area has been removed from future mining consideration, either directly by mining or by undermining. The actual coal produced from the study area is estimated to be 0.42 million tons, which would indicate that past mining only recovered about 22% of the in-place resource; this relatively low recovery rate is partly due to the fact that mining prior to 1960 was far less efficient than highly mechanized modern mining. Past mining in the study area was by room and pillar methods, while future mining will likely utilize more-efficient longwall mining methods. Thus, an estimated future coal mining recovery rate of 35% for the study area, similar to that of the other nearby central Utah coalfields, is not unreasonable. Assuming a 35% recovery rate for future mining means 126 million tons of coal

***Table 13**. The > 6-foot-thick, underground-minable, available coal resource tonnage for the Salina Canyon and Wasatch Plateau portions of the study area reported by bed thickness (million tons).*

COAL-FIELD	COAL BED	TONNAGE BY THICKNESS (feet)			TOTAL TONNAGE
		6-8	8-10	10-12	+6 feet
Salina Canyon	**Wattis**	16.5	0.0	0.0	16.5
Salina Canyon	**Acord Lakes**	122.1	4.1	0.4	126.6
Salina Canyon	**B**	160.4	0.0	0.0	160.4
Wasatch Plateau	**Knight**	17.4	38.8	3.1	59.3
TOTAL	**All beds**	**316.4**	**42.9**	**3.5**	**360.2**

TOTAL may differ from results obtained by summing rows or columns due to rounding could be recovered from the study area. Two caveats bear on this estimate. First, still more coal could be produced if future drilling delineates additional coal resource, or if future technological advances enable economic mining of thinner coal and increase the recovery factor. Second, less coal might be produced if the quality of the coals in the study area limits their marketability, or if mining is restricted due to changing environmental valuations.

SUMMARY AND CONCLUSIONS

Maps showing the thickness and distribution of the available coal resource for six coal beds in the Salina Canyon and Wasatch Plateau coalfields are provided in the Appendix. Of the 1173 million ton original coal resource, 772 million tons make up the available coal resource. Over 360 million tons of the original coal resource are in beds that are too thin (less than 4 feet thick) for mining. Past mining has disturbed very little of the original coal resource (<2 million tons), whereas 34 million tons is subject to other technical land-use restrictions. Other findings include:

- Only 17% of the available coal resource identified in this study is demonstrated (within 0.75 miles of a measurement location).
- Over 62% of the available coal resource in the Wasatch Plateau field is demonstrated, whereas 12% of the coal resource in the Salina Canyon field is demonstrated.
- Blackhawk Formation coal rank is generally high volatile C bituminous.
- Average sulfur content for the Blackhawk Formation coal beds of the study area is expected to be well below the 1.2 pounds of sulfur per million Btu limit that necessitates scrubbing when burned at a power plant.
- As-received basis ash values are typically less than 10% for the Blackhawk coal beds of the study area.
- Available data indicate that the in-ground coal in the study area should have an average mercury content similar to the coal in the nearby Wasatch Plateau coalfield, which is about 4 pounds mercury per trillion Btu (lbs Hg/10^{12} Btu), and which is considerably less than the U.S. average of 11 lbs Hg/10^{12} Btu.

Nearly 53% (411 million tons) of the underground-minable, available coal resource occurs in beds that are less than 6 feet thick. Because Utah's underground coal mines rarely produce from beds that are less than 6 feet thick, this coal is unlikely to be mined in the near future. Excluding the relatively thin, 4- to 6-foot-thick coal, and assuming 35% recovery from underground mines, about 126 million tons of coal might be produced from the study area coalfields. This coal resource is sufficient to support a 4-million-ton-per-year underground mine for about 31 years.

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APPENDIX

Tabulations of the available coal resource with associated maps, for the coal beds in the Salina Canyon and Wasatch Plateau coalfields, Sevier County, Utah

Notes to tables:

The coal bed thickness may include rock partings less than 1 foot thick.

The underground-minable, original coal resource generally excludes coal in associated riders, splits, and sub-beds.

Restricted coal cannot be mined due to land-use or technical restrictions. Land-use restrictions exclude coal under roads, power lines, perennial streams, water bodies, towns, cemeteries, pipelines, or National Parks and Monuments. Technical restrictions exclude coal near mined-out areas and producing petroleum wells, as well as underground-minable coal near faults, affected by interburden conflicts, less than 4 feet thick, in parts of a coal bed more than 14 feet thick, and coal more than 3000 feet deep. A 50-foot minimum depth is applied to underground-minable coal to exclude weathered or burned coal. The net restricted coal shows the total amount of restricted coal where coal in areas subject to multiple restrictions is only counted once.

The available coal resource is that part of the original coal resource that is not restricted. Two reliability categories (Wood and others, 1983) are recognized: Demonstrated, includes the available coal resource within 0.75 miles of a measured thickness location; and Inferred, includes the available coal resource between 0.75 and 3 miles of a measured thickness location.

Reporting conventions used in the tables include:

Numeric values show million tons coal, rounded to the nearest whole value.

Coal in beds less than 4 feet thick is not included in sums of the underground-minable available coal resource.

Table A1. *Original and available coal resource for all coal beds by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	**Original coal resource**	**Restrictions**							**Net restricted coal**	**Reliability**		**Available coal resource**
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	54.1	0	54.1	—	—	—	—	—	54.1	—	—	—
2-4	246.4	0.6	246.4	—	—	—	—	—	246.4	—	—	—
4-6	402.3	0	—	0.1	3.7	3.2	3.2	5.1	13.1	36.8	352.4	389.2
6-8	314.1	0.6	—	0	4.8	3.4	3.3	4.2	15.1	43.8	255.3	299.0
8-10	5.1	0.6	—	0	0.1	0.1	0	0.1	1.0	3.5	0.6	4.1
10-12	0.8	0.1	—	0	0	0.1	0	0.1	0.4	0.4	0	0.4
Sum	1022.8	1.9	300.5	0.1	8.6	6.8	6.5	9.5	330.2	84.5	608.3	692.7

Table A2. *Original and available coal resource for all coal beds by thickness, Wasatch Plateau coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	**Original coal resource**	**Restrictions**							**Net restricted coal**	**Reliability**		**Available coal resource**
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	24.2	0	24.2	—	—	—	—	—	24.2	—	—	—
2-4	44.6	0	44.6	—	—	—	—	—	44.6	—	—	—
4-6	20.5	0	—	0	0.1	0.3	0.2	0.2	0.7	9.6	10.1	19.7
6-8	17.9	0	—	0	0.2	0	0	0.3	0.5	9.6	7.8	17.4
8-10	40.1	0	—	0	0.5	0	0	0.7	1.3	27.2	11.6	38.8
10-12	3.1	0	—	0	0	0	0	0	0	3.1	0	3.1
Sum	150.4	0	68.8	0	0.8	0.3	0.2	1.2	71.4	49.5	29.5	79.0

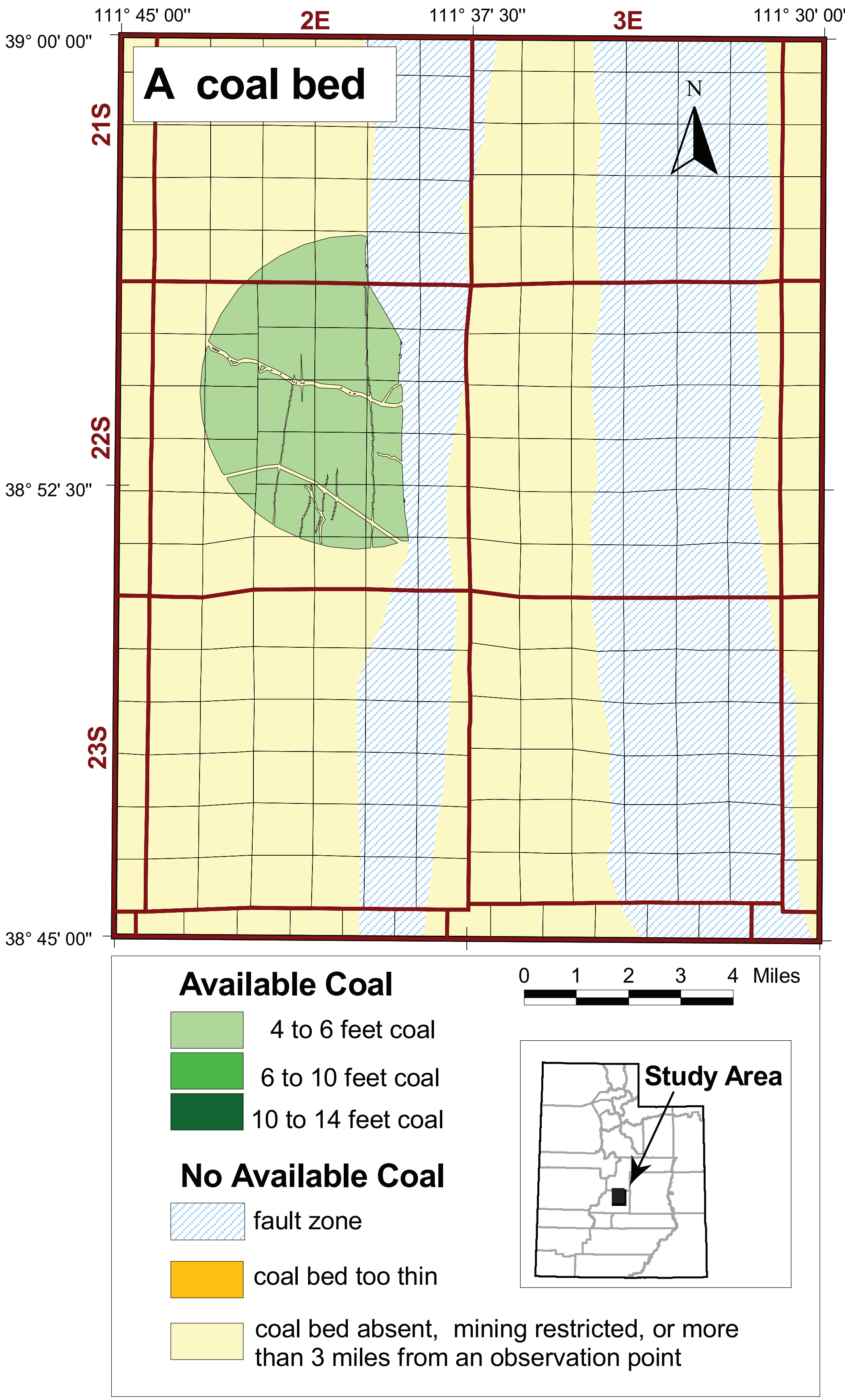

***Figure A1**. Location of the available coal resource for the A coal bed, Salina Canyon coalfield.*

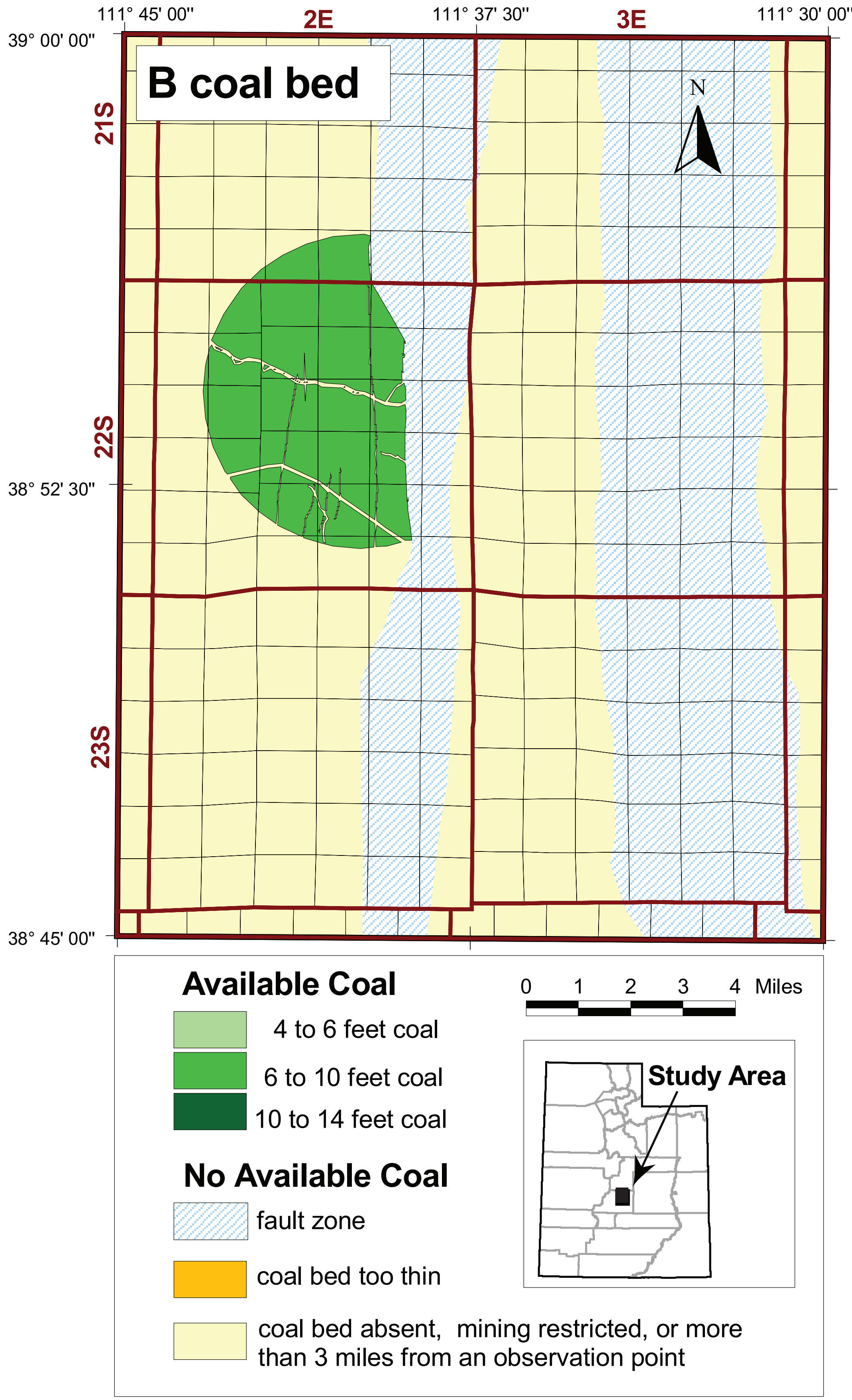

Figure A2*. Location of the available coal resource for the B coal bed, Salina Canyon coalfield.*

Table A3. *Original and available coal resource for the A coal bed by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	0	0	0	—	—	—	—	—	0	—	—	—
2-4	0	0	0	—	—	—	—	—	0	—	—	—
4-6	105.5	0	—	0	1.6	1.0	1.4	1.5	5.2	9.3	91.0	100.3
6-8	0	0	—	0	0	0	0	0	0	0	0	0
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	105.5	0	0	0	1.6	1.0	1.4	1.5	5.2	9.3	91.0	100.3

Table A4. *Original and available coal resource for the B coal bed by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	0	0	0	—	—	—	—	—	0	—	—	—
2-4	0	0	0	—	—	—	—	—	0	—	—	—
4-6	0	0	—	0	0	0	0	0	0	0	0	0
6-8	168.9	0	—	0	2.6	1.6	2.2	2.4	8.5	14.9	145.6	160.4
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	168.9	0	0	0	2.6	1.6	2.2	2.4	8.5	14.9	145.6	160.4

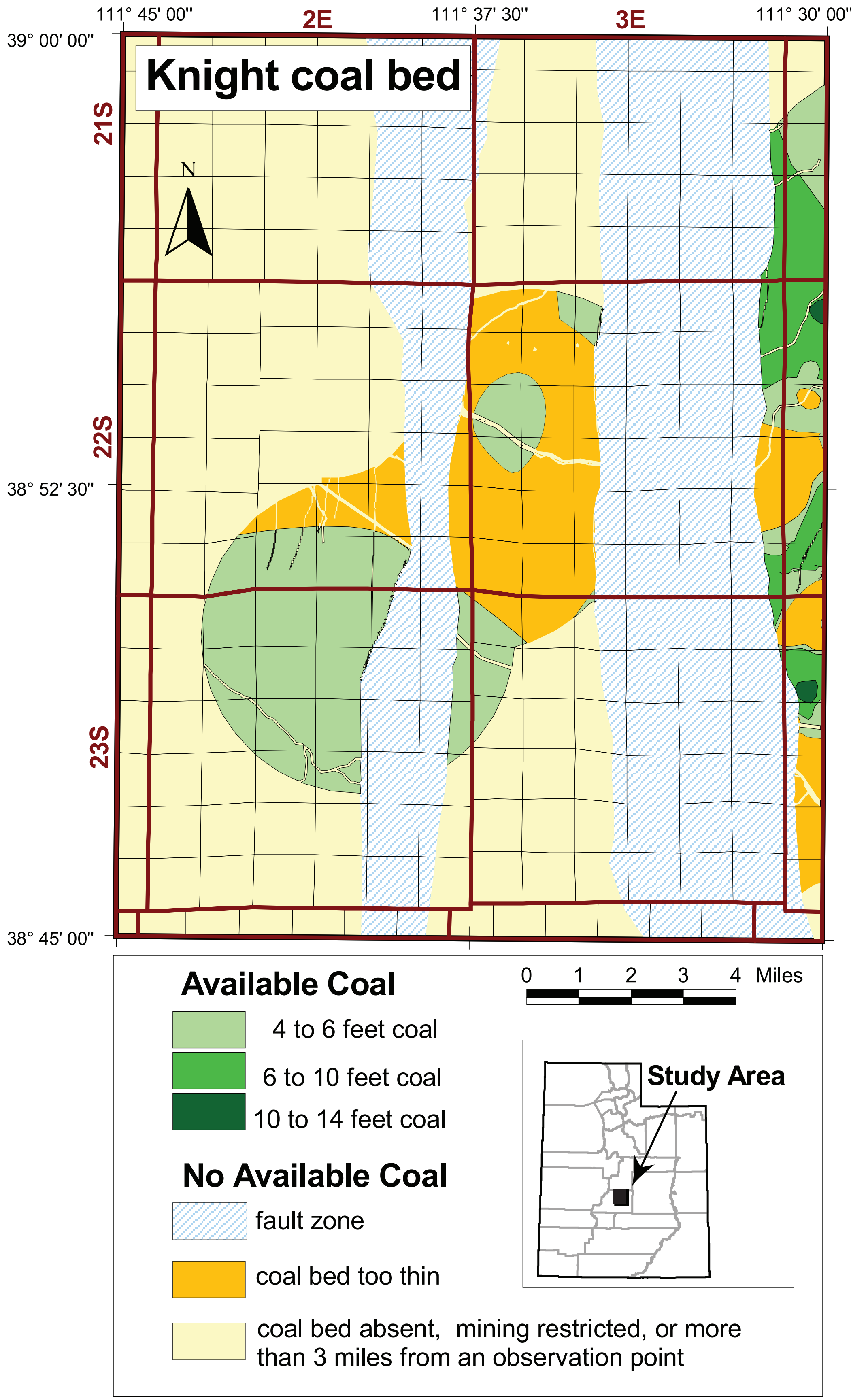

Figure A3*. Location of the available coal resource for the Knight coal bed, Salina Canyon and Wasatch Plateau coalfields.*

Table A5. *Original and available coal resource for the Knight coal bed by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	1.7	0	1.7	—	—	—	—	—	1.7	—	—	—
2-4	59.9	0	59.9	—	—	—	—	—	59.9	—	—	—
4-6	118.2	0	—	0	0.8	0.4	0.5	1.7	3.3	13.7	101.2	114.9
6-8	0	0	—	0	0	0	0	0	0	0	0	0
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	179.9	0	61.6	0	0.8	0.4	0.5	1.7	65.0	13.7	101.2	114.9

Table A6. *Original and available coal resource for the Knight coal bed by thickness, Wasatch Plateau coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	1.6	0	1.6	—	—	—	—	—	1.6	—	—	—
2-4	12.2	0	12.2	—	—	—	—	—	12.2	—	—	—
4-6	20.0	0	—	0	0.1	0.3	0.2	0.2	0.7	9.2	10.1	19.3
6-8	17.9	0	—	0	0.2	0	0	0.3	0.5	9.6	7.8	17.4
8-10	40.1	0	—	0	0.5	0	0	0.7	1.3	27.2	11.6	38.8
10-12	3.1	0	—	0	0	0	0	0	0	3.1	0	3.1
Sum	94.9	0	13.8	0	0.8	0.3	0.2	1.2	16.3	49.1	29.5	78.6

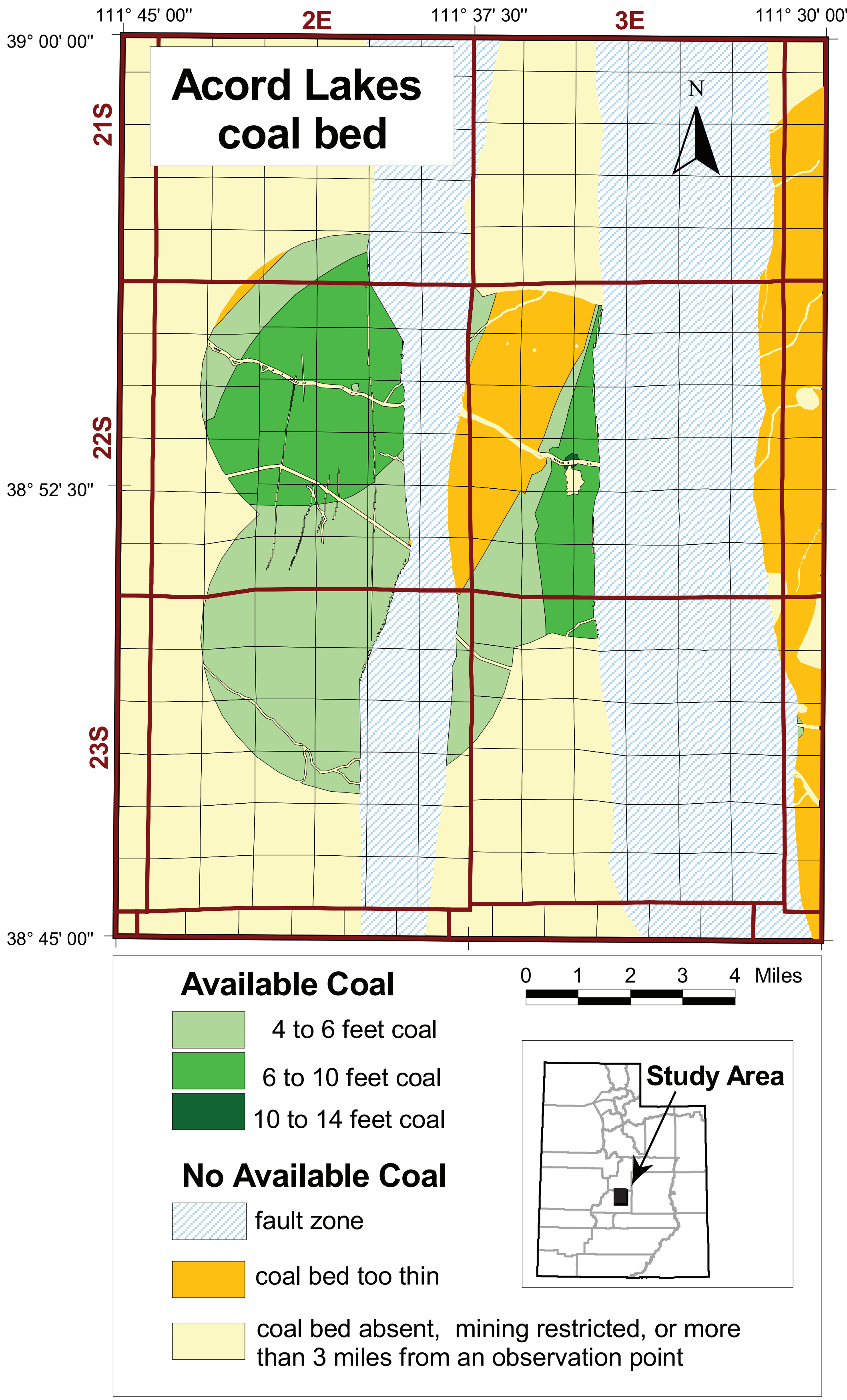

Figure A4. *Location of the available coal resource for the Acord Lakes coal bed, Salina Canyon and Wasatch Plateau coalfields.*

Table A7. *Original and available coal resource for the Acord Lakes coal bed by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	0	0	0	—	—	—	—	—	0	—	—	—
2-4	33.9	0	33.9	—	—	—	—	—	33.9	—	—	—
4-6	144.6	0	—	0	1.1	1.7	1.1	1.7	4.0	9.6	131.0	140.6
6-8	128.7	0.6	—	0	2.2	1.8	1.1	1.8	6.6	19.6	102.5	122.1
8-10	5.1	0.6	—	0	0.1	0.1	0	0.1	1.0	3.5	0.6	4.1
10-12	0.8	0.1	—	0	0	0.1	0	0.1	0.4	0.4	0	0.4
Sum	313.1	1.3	33.9	0	3.4	3.7	2.2	3.7	45.9	33.1	234.1	267.2

Table A8. *Original and available coal resource for the Acord Lakes coal bed by thickness, Wasatch Plateau coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	8.0	0	8.0	—	—	—	—	—	8.0	—	—	—
2-4	28.4	0	28.4	—	—	—	—	—	28.4	—	—	—
4-6	0.2	0	—	0	0	0	0	0	0	0.2	0	0.2
6-8	0	0	—	0	0	0	0	0	0	0	0	0
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	36.6	0	36.4	0	0	0	0	0	36.4	0.2	0	0.2

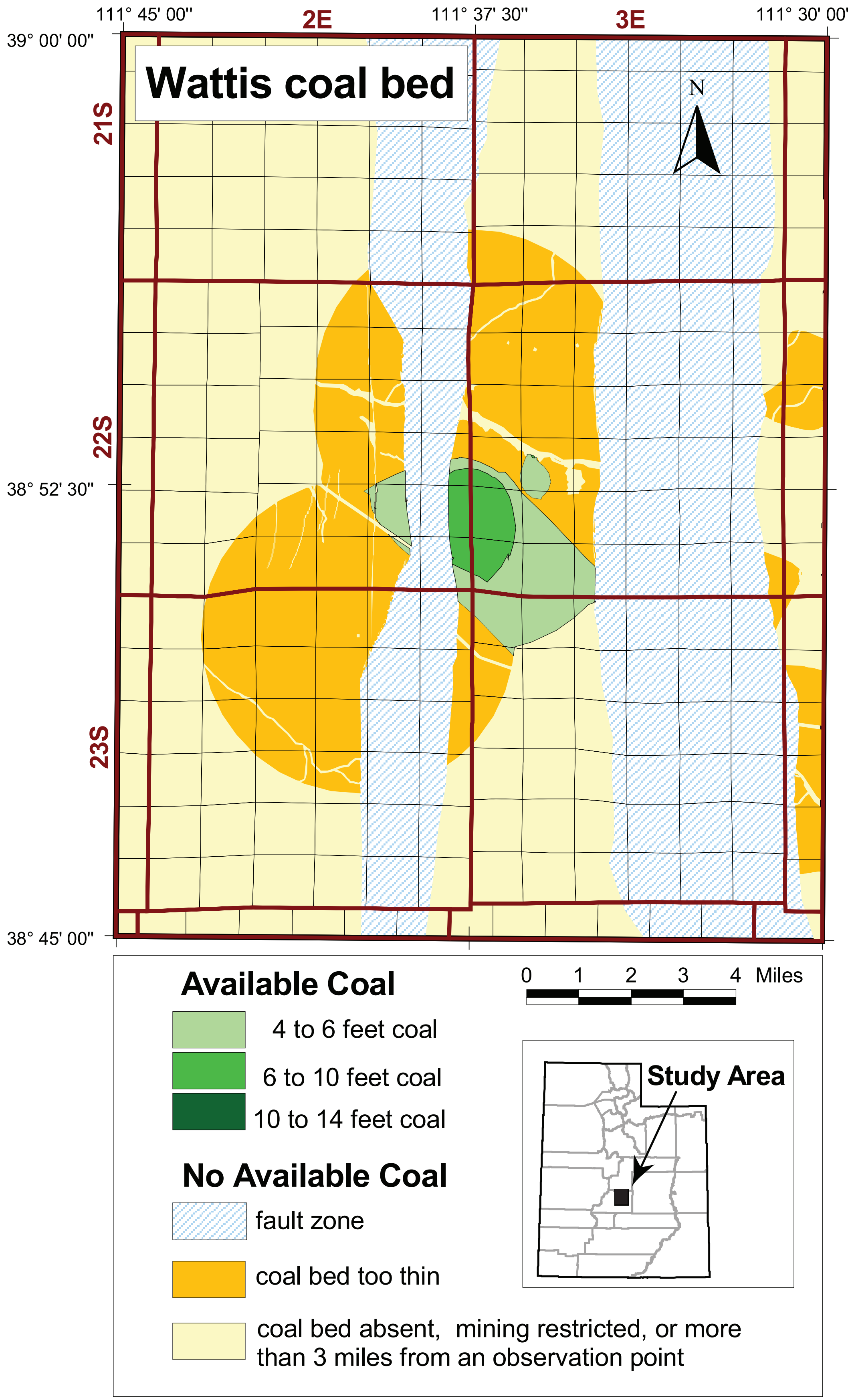

Figure A5. Location of the available coal resource for the Wattis coal bed, Salina Canyon and Wasatch Plateau coalfields.

Table A9. *Original and available coal resource for the Wattis coal bed by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	25.2	0	25.2	—	—	—	—	—	25.2	—	—	—
2-4	68.2	0.6	68.2	—	—	—	—	—	68.2	—	—	—
4-6	33.0	0	—	0	0.2	0	0.2	0	0.4	3.4	29.2	32.6
6-8	16.5	0	—	0	0	0	0	0	0	9.3	7.2	16.5
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	142.9	0.6	93.4	0	0.2	0	0.2	0	93.8	12.7	36.3	49.0

Table A10. *Original and available coal resource for the Wattis coal bed by thickness, Wasatch Plateau coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	Original coal resource	Restrictions							Net restricted coal	Reliability		Available coal resource
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	6.4	0	6.4	—	—	—	—	—	6.4	—	—	—
2-4	1.5	0	1.5	—	—	—	—	—	1.5	—	—	—
4-6	0	0	—	0	0	0	0	0	0	0	0	0
6-8	0	0	—	0	0	0	0	0	0	0	0	0
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	7.8	0	7.8	0	0	0	0	0	7.8	0	0	0

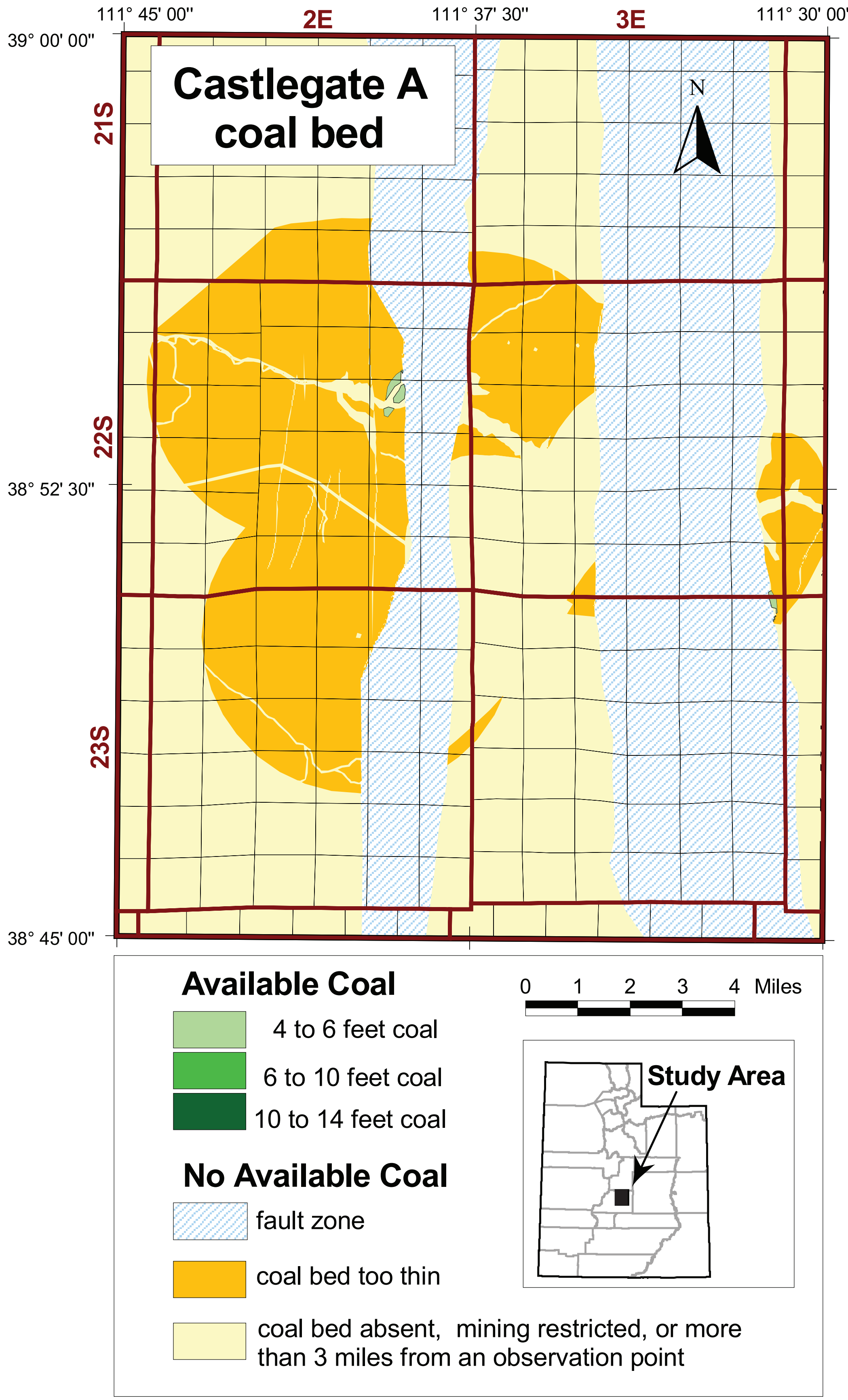

Figure A6. *Location of the available coal resource for the Castlegate A coal bed, Salina Canyon and Wasatch Plateau coalfields, Utah.*

Table A11. *Original and available coal resource for Castlgate A coal bed by thickness, Salina Canyon coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	**Original coal resource**	**Restrictions**							**Net restricted coal**	**Reliability**		**Available coal resource**
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	27.2	0	27.2	—	—	—	—	—	27.2	—	—	—
2-4	84.4	0	84.4	—	—	—	—	—	84.4	—	—	—
4-6	1.0	0	—	0.1	0	0.1	0	0.2	0.2	0.8	0	0.8
6-8	0	0	—	0	0	0	0	0	0	0	0	0
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	112.6	0	111.6	0.1	0	0.1	0	0.2	111.8	0.8	0	0.8

Table A12. *Original and available coal resource for Castlgate A coal bed by thickness, Wasatch Plateau coalfield, Sevier County, Utah (million tons).*

Coal bed thickness (feet)	**Original coal resource**	**Restrictions**							**Net restricted coal**	**Reliability**		**Available coal resource**
		Mined	Too thin	Too Shallow	Faulted	Roads	Power lines	Water bodies		Demonstrated	Inferred	
1-2	8.2	0	8.2	—	—	—	—	—	8.2	—	—	—
2-4	2.5	0	2.5	—	—	—	—	—	2.5	—	—	—
4-6	0.3	0	—	0	0	0	0	0	0.1	0.2	0	0.2
6-8	0	0	—	0	0	0	0	0	0	0	0	0
8-10	0	0	—	0	0	0	0	0	0	0	0	0
10-12	0	0	—	0	0	0	0	0	0	0	0	0
Sum	11.0	0	10.7	0	0	0	0	0	10.8	0.2	0	0.2