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Coal availability in the Hilight quadrangle, Powder River Basin, Wyoming: a prototype study in a western coal field

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Contents

Tables

Figures

Appendix

Tables 4 through 13—Coal Resource tables: the following 3 tables [a,b,c] for each bed listed below.

(a) Summary table showing original, remaining, and available resources.
(b) Coal tonnage unavailable, by specific land-use restriction.
(c) Coal tonnage unavailable, by specific technological restriction.

Table 4a, b, c. — Main Wyodak bed, Category 1
Table 5a, b, c. — Rider Wyodak bed, Category 1
Table 6a, b, c. — Lower Wyodak bed, Category 1
Table 7a, b, c. — Wildcat bed, Category 1
Table 8a, b, c. — Moyer bed, Category 1
Table 9a, b, c. — Main Wyodak bed, Category 2
Table 10a, b, c. — Rider Wyodak bed, Category 2
Table 11a, b, c. — Lower Wyodak bed, Category 2
Table 12a, b, c. — Wildcat bed, Category 2
Table 13a, b, c. — Moyer bed, Category 2

Abbreviations and Conversions

To convert from	To	Multiply by
Inches (in.)	Centimeters	2.54
Feet (ft)	Meters	0.3048
Miles (mi)	Kilometers	1.609344
Short tons (2,000 lbs.)	Metric tons (2,204.6 lbs.)	0.90718474

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ABSTRACT

The U.S. Geological Survey (USGS), in cooperation with the Bureau of Land Management (BLM), Geological Survey of Wyoming, and U.S. Bureau of Mines (USBM), has produced an estimate of the amount of available coal in an area about 35 miles south of Gillette, Wyo., where the Wyodak coal bed is, in places, more than 100 ft thick. Available coal is the quantity of the total coal resource that is accessible for mine development under current regulatory, land-use, and technologic constraints. This first western coal availability study, of the Hilight 7½-minute quadrangle, indicates that approximately 60 percent (2.7 billion short tons) of the total 4.4 billion tons of coal in-place in the quadrangle is available for development. (There has been no commercial mining in the Hilight quadrangle.) Approximately 67 percent (1.9 billion tons) of the Main Wyodak coal bed is considered available. All tonnage measurements in this report are given in short tons.

Coal-development considerations in the quadrangle include dwellings, railroads, pipelines, power lines, wildlife habitat (eagles), alluvial valley floors, cemeteries, and the Hilight oil and gas field and gas plant. Some of these considerations could be mitigated so that surface mining of the coal may proceed; others could not be mitigated and would preclude mining in their vicinity. Other technological constraints that influence the availability of the coal include overburden thickness, coal beds too thin, and areas of clinker.

ACKNOWLEDGMENTS

We could not have successfully completed this project without the help of Vickie L. Clark, the U.S. Geological Survey computer system administrator. Employees of the U.S. Bureau of Mines Coal Recoverability Program—Timothy J. Rohrbacher, Lee M. Osmonson, Gerald L. Sullivan, David C. Scott, and Dale D. Teeters—were extremely helpful with describing local mining practice and assisting with GIS (geographic information systems) software. The Wyoming State Geological Survey supplied information and helped with project logistics. James E. Fassett and Timothy J. Rohrbacher reviewed the manuscript and offered thoughtful and constructive comments. Sally J. Dyson, Robert K. Wells, Cheryl W. Adkisson, and Richard P. Walker assisted in preparing a digital version of this report to appear as a World Wide Web release.

BACKGROUND AND PURPOSE OF STUDY

Traditional Federal and State coal resource estimates have not taken into account the multitude of land-use, environmental, regulatory, technologic, and economic restrictions to coal mining and coal resource recoverability. This has led some Federal, State, and local planners to overestimate the future supply of the Nation's coal. A cooperative program, referred to as "Coal Availability," between the U.S. Geological Survey and other Federal agencies and State geological surveys, was initiated in 1986 to identify major constraints on the availability of coal resources for development and to estimate the amount of remaining coal resources that may be accessible for development under those constraints (Carter and Gardner, 1989, 1994; Eggleston and others, 1990). Coal availability studies have been done at the 7½-minute-quadrangle scale; the results are modeled statistically and can be indicative of larger areas that have similar developmental restrictions and geologic conditions.

The data generated during the coal availability studies were shared with the U.S. Bureau of Mines for use in their coal recoverability studies, where recovery and cost factors were applied to the estimated available coal resources. This results in an estimate

of the amount of economically **recoverable** coal [coal reserves], which is usually far less than the amount available for development (Rohrbacher and others, 1994).

The coal availability program was first conducted in the Eastern United States. The results there (see **Comparison to Other Coal Availability Studies** section of this report) were useful to the coal mining industry and other resource managers. Seventeen quadrangles were modeled in the central Appalachian region of West Virginia, Kentucky, and Virginia. Coal availability studies have expanded into the northern Appalachian region, the Illinois Basin, and the Western United States. There was great interest in extending the program to western coal fields to see what factors would be involved and how the process could be applied to the different geologic and mining conditions in the Western United States. The Hilight quadrangle study is the first coal availability study in the western United States.

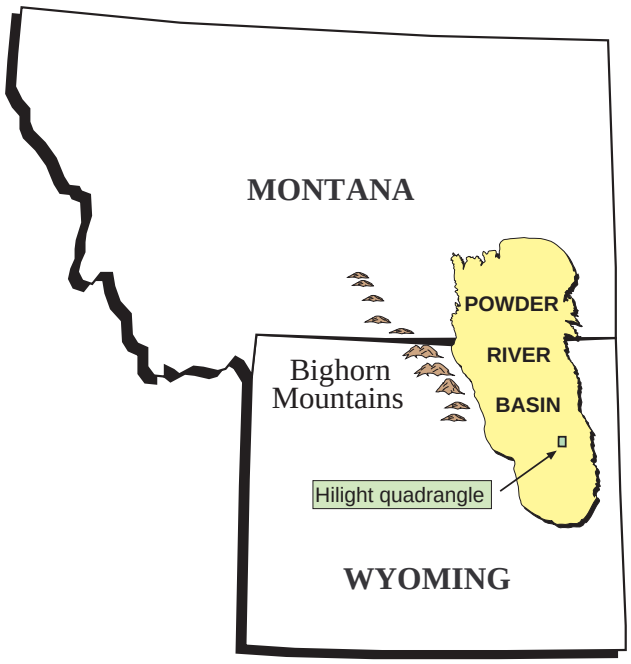

Figure 1. Map showing location of the Powder River Basin and the Hilight 7$^1/_2$-minute quadrangle.

GEOLOGIC SETTING AND COAL MINING

The Powder River Basin covers about 22,000 sq miles in northeastern Wyoming and southeastern Montana (fig. 1) and is located in the Northern Great Plains physiographic province. The structural axis of the basin trends northwest and is near the western edge of the basin. The Powder River Basin has a narrow, steeply dipping western side and a broad, gently dipping eastern side. The Paleocene Fort Union Formation along the eastern side of the Powder River Basin contains some of the thickest and most extensive deposits of low-sulfur subbituminous coal in the world (Molnia and Pierce, 1992), including the thick Wyodak coal bed found in the Hilight quadrangle.

The Powder River Basin of Wyoming was chosen as the study site for the first western coal availability study because of its vast coal resources and its importance in U.S. coal production—nine of the ten coal mines with the largest production in the United States in 1995 are located in the Powder River Basin (Keystone Coal Industry Manual, 1997, p. 730). All the coal mines in the Powder River Basin are surface mines. The Wyoming portion of the Powder River Basin provides about 20 percent of the coal produced annually in the United States (Weakly, 1994).

The study site—the Hilight 7$^1/_2$-minute quadrangle (fig. 2)—is an area of about 52 sq miles and is located in Campbell County, Wyoming, about 35 miles south of Gillette. The Hilight quadrangle is situated between the Coal Creek mine (owned by Thunder Basin Coal Co., a subsidiary of ARCO Coal Co.) and the Jacobs Ranch mine (owned by Kerr-McGee Coal Co.) (fig.2). The northern limit of the Jacobs Ranch mine tract extends into the very southeastern edge of the Hilight 7$^1/_2$-minute quadrangle. The formerly proposed Keeline coal mine (Neil Butte Co.) lies fully within the quadrangle (see fig. 3); that Federal coal lease has been relinquished. The productive capacity of that mine would have been as much as 12 million short tons annually. The Hilight quadrangle was chosen for our study because of its location between two active mines, the interest that had been shown in developing the coal deposit at one time, and the issues in multiple-use land management of the area.

The Eocene Wasatch Formation is at the surface everywhere in the Hilight quadrangle except along the east-central edge, in the drainage of Black Thunder Creek, where the Paleocene Fort Union Formation crops out (Coates, 1977; IntraSearch, 1979).

The main coal bed in the Hilight quadrangle is the Wyodak coal bed of the Tongue River Member of the Fort Union Formation. Figure 4 shows a composite columnar section that is typical of the Hilight area. In the quadrangle, the Wyodak coal bed is up to 120 ft thick, and, in many places, has 1-5 partings that vary in thickness. Overburden thickness

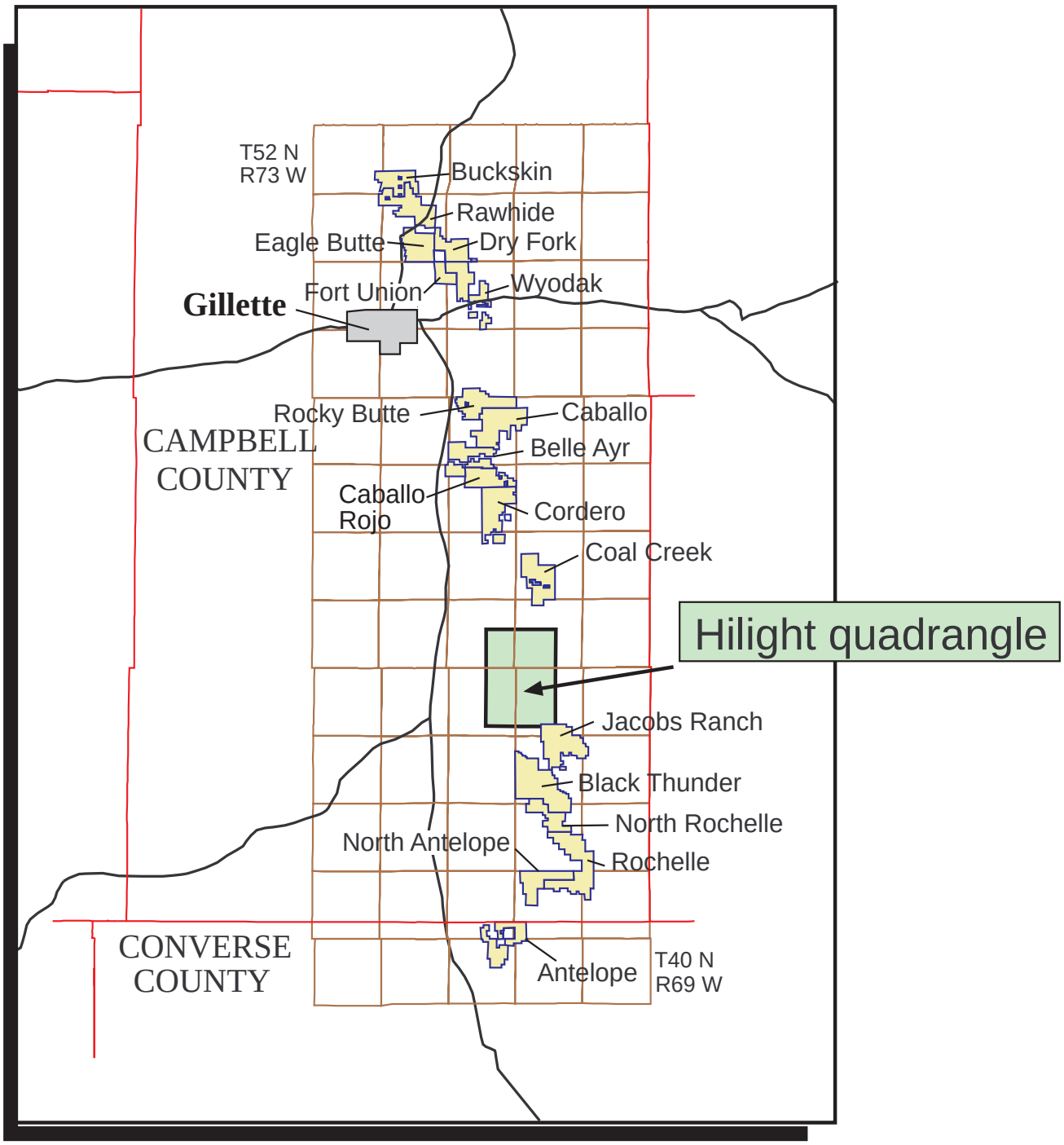

Figure 2. Map showing locations of surface coal mines near the Hilight 7½-minute quadrangle.

in the quadrangle for this coal bed ranges from 15 to more than 600 ft. (See **Major Coal Zones Studied** section for a more detailed description of occurrence of the Wyodak coal bed.)

According to the information in the mine and reclamation plan for the Keeline mine (Neil Butte Company, 1985), the Wyodak coal bed in the Keeline lease area is a non-agglomerating subbituminous class C coal which averages approximately 9,150 Btu/lb on a moist, mineral-matter-free basis. On an as-received basis, the heating value of the coal ranges from 7,905 to 8,960 Btu/lb with an average value of 8,350 Btu/lb. As-received moisture ranges from 24.9 to 31.6 percent by weight with an average of 27.7 percent; as-received ash content ranges from 4.9 to 12.4 percent by weight with an average value of 7.9 percent; and as-received sulfur content ranges from 0.3 to 2.0 percent by weight

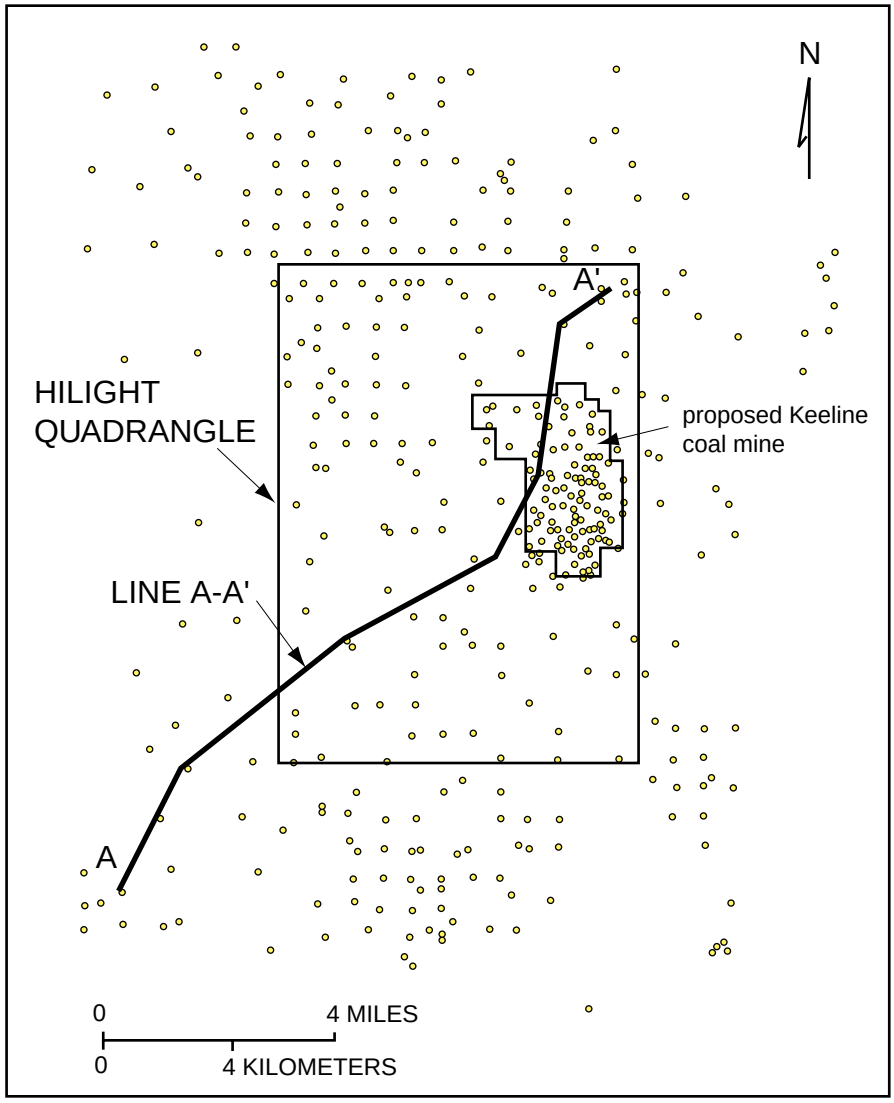

Figure 3. Map showing data points used for this study within the Hilight quadrangle and in an area three miles around the quadrangle (approximately 350 points total). The outline of the proposed Keeline coal mine is shown. Line A-A' is the trace of the coal-correlation diagram shown in figs. 10 and 11.

with an average value of 0.6 percent. These quality values are for the coal in-place and will vary slightly from the coal as-mined due to atmospheric exposure (Neil Butte Company, 1985). (See Keystone Coal Manual, 1997, pgs. 687 - 696, for further information about the Wyodak coal bed and other major coal beds in the Powder River Basin.)

FACTORS AFFECTING AVAILABILITY OF COAL RESOURCES

There are many factors which can affect the availability of coal for mining. The three general groups of factors or considerations in Powder River Basin coal development are: legal unsuitability criteria, land-use conflicts, and technological factors. Table 1 shows a listing of the factors we considered under each of these groups. It is important to note that not every factor became a restriction within the Hilight quadrangle.

Unsuitability Criteria Determinations for the Hilight Quadrangle

The coal unsuitability criteria are listed in the Federal Regulations, Title 43, Subpart 3461 (43 CFR 3461). These 20 specific legal criteria are used to determine if an area can be mined by surface mining methods. The 43 CFR 3461 regulations are issued under the authority of, and implement several major provisions of, Public Law 95-87, which is the Surface Mining Control and Reclamation Act of 1977 (30

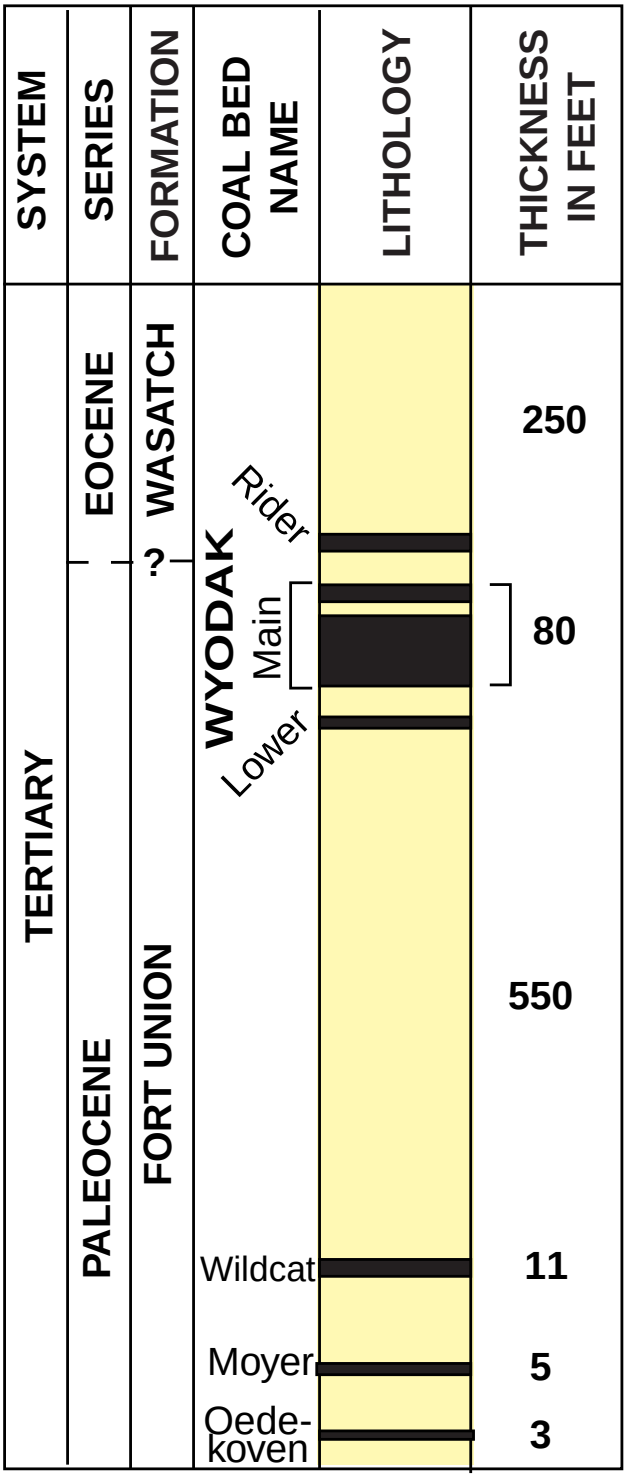

Figure 4. Generalized composite stratigraphic section for the Hilight quadrangle. Thicknesses are averages, in feet. Non-coal rocks are siltstones, claystones, shales, and sandstones. (After IntraSearch, 1979.)

U.S.C. 1201 et seq.). The 20 unsuitability criteria involve consideration of scenic areas, natural and historic values, wildlife, flood plains, alluvial valley floors, and other special values (Bureau of Land Management, 1984).

Table 1. Listing of possible restrictions

(Printed in bold and italics if applicable to Hilight quadrangle):

A. Coal-leasing unsuitability criteria from the Federal Coal Management Regulations (43 CFR 3461.5)

1. Federal Land Systems
2. ***Rights of way and easements [i.e., railroad]***
3. ***Dwellings, roads, cemeteries, and public buildings***
4. Wilderness Study Areas
5. Lands with Outstanding Scenic Quality
6. Lands Used for Scientific Study
7. Historic Lands and Sites
8. Natural Areas
9. Critical Habitat for Threatened or Endangered Plant and Animal Species
10. State Listed Threatened or Endangered Species
11. ***Bald or Golden Eagle Nests***
12. Bald and Golden Eagle Roost and Concentration Areas
13. Federal Lands containing Active Falcon Cliff Nesting Site
14. Habitat for Migratory Bird Species
15. Fish and Wildlife Habitat for Resident Species
16. Floodplains
17. Municipal Watersheds
18. National Resource Waters
19. ***Alluvial Valley Floors***
20. State or Indian Tribe Criteria

B. Other applicable land-use restrictions:

- Towns
- ***Pipelines***
- ***Oil and gas development [is a land-use restriction for surface mining]***
- ***Gas plant***
- ***Power lines***
- Gravel pits
- Archaeological areas
- Surface and coal ownership issues
- Wetlands

C. Technological restrictions considered:

- Coal quality
- Overburden geochemistry
- ***Overburden thickness (coal too deep)***
- Mined-out areas
- ***Limit of coal***
- Surface subsidence over abandoned mines
- ***Active mines***
- Abandoned mines
- ***Clinkered areas***
- Coal beds too close together
- ***Coal beds too thin (coal beds less than 2.5 ft thick were considered too thin)***
- ***Coal beds too thick [for underground mining]***
- ***Coal bed discontinuities***
- Roof or floor problems
- Barrier pillars
- ***Oil and gas development [technological restriction for underground mining]***
- Coalbed methane developments

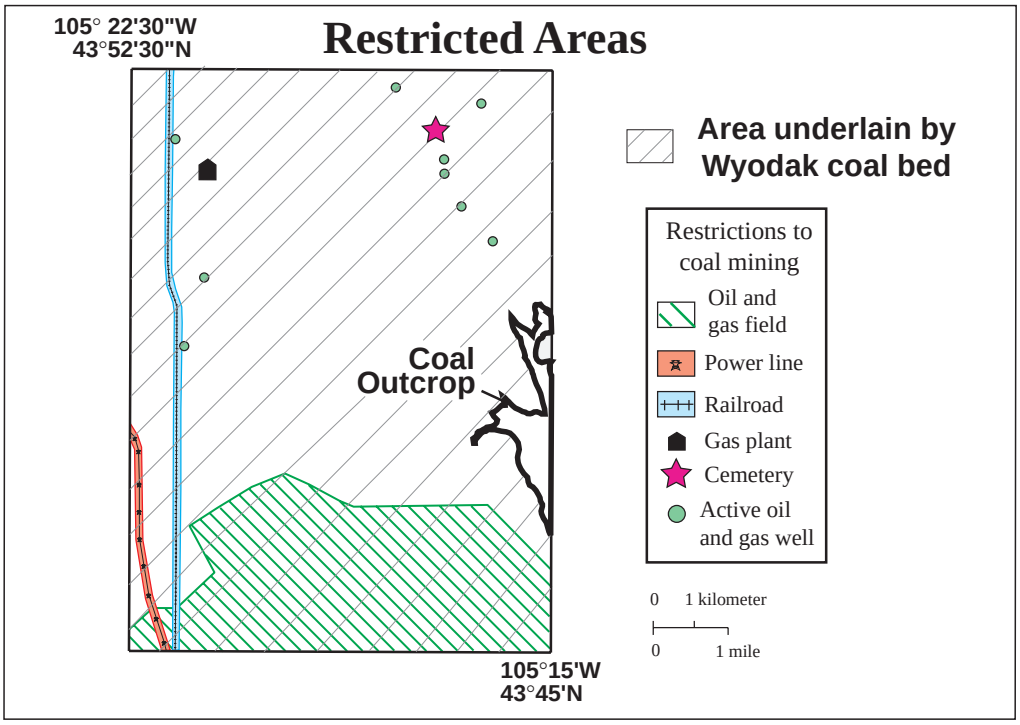

Figure 5. Map of Hilight quadrangle showing area underlain by the Wyodak coal bed, and showing Category 1 considerations: areas not available for surface mining because of land-use and technologic restrictions.

The following sections (a) and (b) are discussions of particular unsuitability criteria and how they might affect mining within the Hilight quadrangle.

(a) Unsuitability Criteria that are Restrictions to Mining:

RAILROAD CORRIDOR: There is a 300 ft buffer, shown in figure 5, along the main and trunk lines of the existing rail routes through the Hilight quadrangle. This area is determined to be unsuitable for mining at the present time.

CEMETERY: There is a small cemetery (Kintz Cemetery) in the northern part of the quadrangle. The cemetery and its buffer cover a circular area that is 600 ft in diameter; this area is shown on figure 5. This area would be considered unsuitable for mining.

Note: It is conceivable that both the railroad and the cemetery could be relocated to allow mining to proceed, once the appropriate agreements and permits are acquired. But for the purposes of this study, we will consider them to be restrictions to coal mining.

(b) Unsuitability Criteria that are Considerations in Mining and Mine Planning:

In these cases (alluvial valley floors, raptor sites, roads, lands in certain federal land systems, dwellings), an area could be declared unsuitable for coal mining; alternatively, a mitigation measure could be defined to limit the effects of mining, and the area could be mined with the appropriate mitigation. Detailed studies, which would determine unsuitability or mitigation, would be made at a later time if an expression of interest was received for coal development in the area (Bureau of Land Management, 1984). Economic analyses by the coal developer would help to determine whether costs for mitigation would preclude mining.

ALLUVIAL VALLEY FLOORS (AVF): There is one potential AVF (as currently defined in the coal-screening process) along Black Thunder Creek (fig. 6). All lands identified as AVF's where mining would interrupt, discontinue, or preclude farming, are unsuitable for surface coal mining. Additionally, when mining Federal lands outside an AVF would damage the quality or quantity of water in surface or underground systems that would supply AVF's, the land shall be considered unsuitable.

These determinations have not been made concerning the Black Thunder Creek area within the Hilight quadrangle; the area will need AVF determinations by the Wyoming State Department of Environmental Quality. The area is currently open to coal leasing until a negative determination has been made.

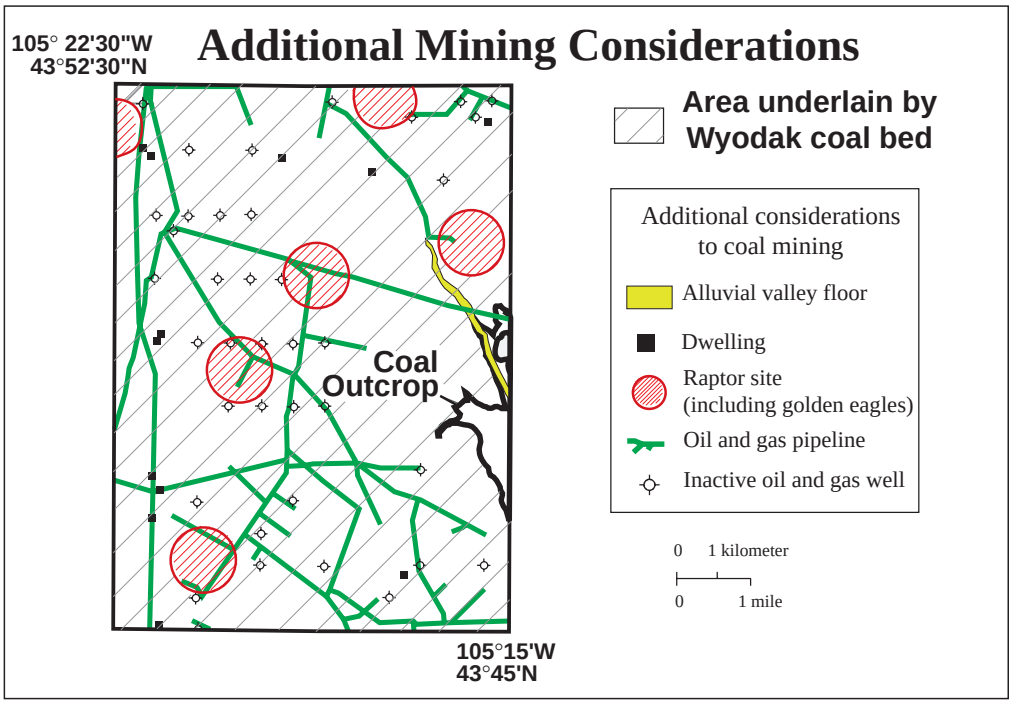

Figure 6. Map of Hilight quadrangle showing area underlain by the Wyodak coal bed, and showing Category 2 considerations: other land-use and technologic considerations that would need to be resolved before surface mining could occur. These areas could probably be available for mining with certain mitigations and stipulations.

RAPTOR SITES: In the proposed final environmental impact statement for the Buffalo Resource Area (Bureau of Land Management, 1985), golden eagle sites (with buffers) were identified as unsuitable for mining. However, currently, these and other raptor sites (with buffers) are considered open to leasing and coal mining, pending further study; the mining effects at the sites could probably be mitigated. Each site with its buffer covers a circular area about 1 mile in diameter, as shown in figure 6.

ROADS: County roads (gravel) cross the quadrangle. They are shown on figure 7 with a buffer; the roads, including buffers on each side, are about 150 ft across. These gravel roads can be moved and should not affect coal mining. There are no State Highways in the quadrangle. [A few miles south of the Hilight quadrangle, State Highway 450 and its buffer have been determined to be unsuitable for coal mining.]

FEDERAL LAND SYSTEMS: None of the Federal land systems that are unsuitable for coal leasing are present in the Hilight quadrangle. The quadrangle does contain a portion of the Thunder Basin National Grassland (TBNG), a large area in northeastern Wyoming that includes scattered Federal lands under the jurisdiction of the U.S. Forest Service (USFS); but TBNG is not part of a National Forest. The same unsuitability criteria and land use considerations discussed in this report apply to coal mining on the Thunder Basin National Grassland. Where the mineral ownership in the National Grassland is Federal, the Bureau of Land Management develops the coal-leasing and mining stipulations in conjunction and cooperation with the USFS. Figure 7 shows the boundary of the TBNG within the Hilight quadrangle.

DWELLINGS: The area is sparsely populated and relatively undeveloped. The few dwellings that exist would probably be bought by the coal company and would not prohibit mining. The dwellings and their buffers are shown in figure 6; each site and buffer cover a circular area about 600 ft in diameter.

Other Considerations to Mining (in addition to those in the Unsuitability Criteria):

(a) Multiple-Use Issues:

The Bureau of Land Management (1985) Resource Management Plan (RMP) for the Buffalo Resource Area covers this part of the Powder River Basin. The RMP provides planning and guidance, in accordance with Federal laws and regulations, concerning energy and mineral development, cultural resources, grazing management, wildlife habitat, recreation, and other uses of public lands. Within the Hilight quadrangle, multiple-use considerations that might affect

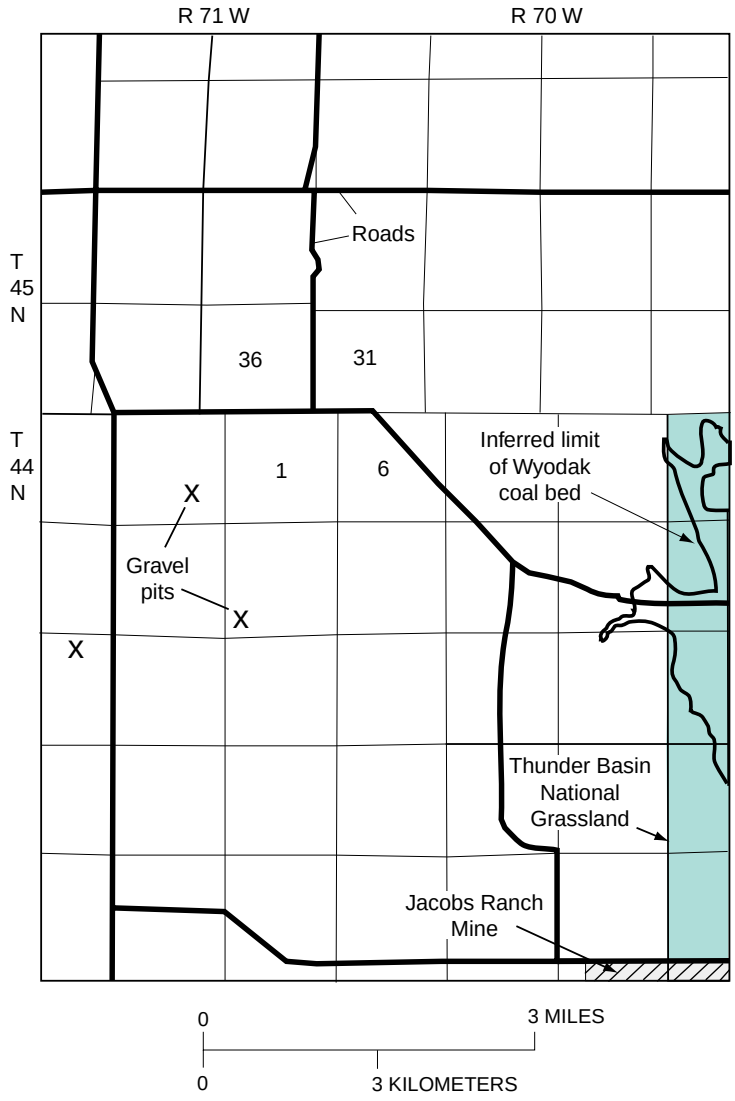

Figure 7. Map showing additional land-use features of the Hilight quadrangle.

coal availability were identified in the RMP and other documents; these considerations include: pipelines, the Hilight oil and gas field and gas plant, power lines, gravel pits, archaeological sites, and surface- and mineral-estate ownership. Certain multiple-use conflicts could be mitigated to allow for the surface mining of coal; other situations may render some coal unavailable for mining. Economic analyses by the coal developer would determine whether an area could be profitably mined, especially if mitigation measures are mandated. Individual factors are discussed below.

PIPELINES: There is a network of oil and gas pipelines throughout the Hilight quadrangle (fig. 6). Most likely, these pipelines would be moved so that surface mining could proceed, but moving and restoring them would represent an added economic consideration to mining.

HILIGHT OIL AND GAS FIELD: This large oil and gas field (fig. 5) extends beyond the boundaries of the quadrangle. The entire field had 125 producing wells as of December, 1992, (Wyoming Oil and Gas Conservation Commission, 1993) and a water-flood project is underway to enhance recovery. As of June 1994, there were about 40 active producing wells within the Hilight quadrangle. Total cumulative production of the entire field (to 1992) was 77 million barrels of oil and 255 million thousand cubic feet of gas. The main producing formation is the Lower Cretaceous Muddy Sandstone, about 9,000 ft below ground level (Wyoming Geological Association, 1981).

How land-use conflicts between coal mining and the oil and gas field development would be resolved will depend on economic conditions, regulations, and negotiations between oil developers and coal developers. Perhaps an area around a major cluster

of active wells would be eliminated from mining activities until these wells are no longer actively producing. Or, mining activities might proceed around individual active wells that are given a buffer zone. Conversely, specific wells might be plugged and then reestablished after mining.

HILIGHT GAS PLANT: The plant, operated by Western Gas Processors, has a capacity of about 60 million cubic feet per day (De Bruin and Boyd, 1991). The plant (fig. 5) connects to several major pipelines for gas and crude oil, as well as to a pipeline for gas-processing-plant products. This installation, with a 500 ft buffer, would probably be considered a restriction to coal mining during the time that the neighboring oil and gas fields are still producing.

POWER LINES: A major power line (fig. 5) crosses the southwest corner of the quadrangle. At the time of mining, the implications of moving this power line would be determined. If it were not moved, there would be a 300 ft buffer placed on both sides of the power line, and the coal in that area would be considered unavailable.

GRAVEL PITS: There are three gravel pits in the quadrangle (fig. 7). They are developed in clinker and would not preclude mining. There are numerous other clinker deposits in this part of the Powder River Basin.

ARCHAEOLOGICAL AREAS: No major archaeological areas that prevent mining are known in the quadrangle. There are several minor archaeological sites and also several minor historic sites within the Hilight quadrangle. A mitigation plan would be developed before these areas are disturbed by coal mining.

SURFACE OWNERSHIP: Almost the entire surface of the Hilight quadrangle is privately owned. Surface-owner consultation would be necessary before mining on this land. There are about 2.5 sq miles of State-owned surface and less than 1 sq mile of Federally owned surface, in a quadrangle whose area is about 52 sq miles.

COAL OWNERSHIP: The Federal Government owns all of the coal in the Hilight quadrangle except that beneath about 1/4 sq mile of privately owned land, and beneath the 2.5 sq miles of State-owned surface.

(b) Technologic Factors:

These are geologic and mining considerations that could affect the development of coal in the Hilight quadrangle.

ACTIVE MINES: There are no active mines within the quadrangle. The northernmost segment of the Jacobs Ranch coal lease extends into the southern edge of the Hilight quadrangle (fig. 7), but this area has not yet been mined.

MINED-OUT AREAS: None.

LIMIT OF COAL: The "Coal resource occurrence map of the Hilight quadrangle" (IntraSearch, 1979) shows an inferred outcrop trace for the Wyodak coal bed on the eastern edge of the quadrangle. This is the only area of Wyodak outcrop within the Hilight quadrangle. Part of that area has formed clinker from the burning of the coal bed at or near the outcrop. The limit of coal (fig. 7) is drawn so that these clinkered areas are not included in the area considered for resource assessment and mine planning.

OVERBURDEN GEOCHEMISTRY: The only data on overburden geochemistry came from the Keeline mine permit application (Neil Butte Company, 1985), which covered an area in the east-central part of the quadrangle (see fig. 3). There, potentially toxic heavy metals and minor elements were present in relatively small concentrations. Salinity (based on electrical conductivity measurements) and sodium adsorption ratios (SAR) were within acceptable limits with only a few isolated exceptions. Only one component, potentially acid-producing overburden, was encountered in significant areal extent on parts of the former lease area. However, there is abundant overburden without these components; those strata would be blended with the poor-quality overburden to produce an acceptable mixture. No more than five percent of all overburden and parting materials was estimated to require special management because of a variety of chemical parameters encountered in unsuitable concentrations (Neil Butte Company, 1985). This will be an additional expense for the mining operation but probably will not prevent mining of any area.

OVERBURDEN THICKNESS AND MINING CONSIDERATIONS: We assumed that 300 ft of overburden would be the limit for surface mining, based on general mining practice in the western United States and the Powder River Basin. Figure 8 shows the areas of the Hilight quadrangle where the overburden on the Wyodak coal bed is less than 300 ft thick. This 300-ft cut-off is not an absolute rule, especially in the case of a coal bed as thick as the Wyodak bed. Overburden exceeds 600 ft in the quadrangle, but where the Wyodak coal is about 80 ft thick, the mining ratio (8 feet of overburden : 1 foot of coal) could be attractive under certain economic conditions. At the present time, however, coal mines in the Powder River Basin are not surface mining beyond approximately 300 ft of overburden.

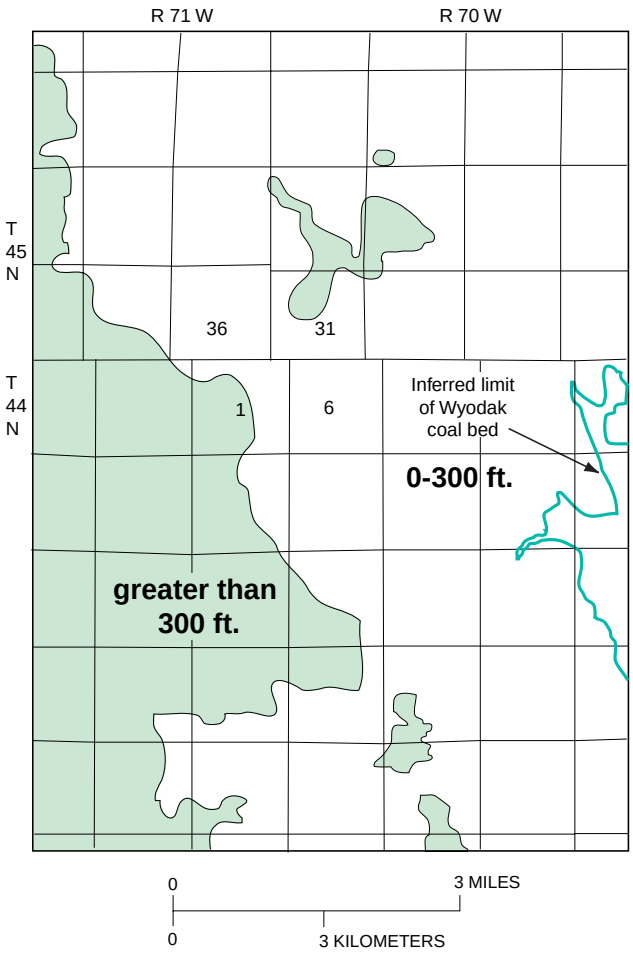

Figure 8. Map of Hilight quadrangle showing areas where overburden for the Main Wyodak coal bed is 0-300 ft thick (white), and areas where this overburden is greater than 300 ft thick (green). For the purposes of this study, we assumed that 300 ft of overburden would be the limit for surface mining. Maximum overburden for the Main Wyodak coal bed in the Hilight quadrangle exceeds 600 ft.

We also assumed that underground mining would occur where overburden depths range from 300 ft to 1000 ft. We realize that there are no underground coal mines presently operating in the Powder River Basin and there are not likely to be in the near future. However, there has been a feasibility study regarding future longwall mining of a coal bed that is over 200 ft thick in places (the Big George coal bed) which has a minimum of 1000 ft of overburden (Ahcan and others, 1991). (Additional discussion of underground mining for thick coal beds in the western United States is found in Hackett and others, 1990.) The Big George coal bed is down-dip from the Wyodak coal bed and closer to the center of the Basin; subsurface evidence indicates that the Big George coal bed correlates with the Wyodak coal bed (Molnia and Pierce, 1992; Keystone Coal Industry Manual, 1997, p. 693).

We assumed that subsidence (local lowering and deformation of the land surface) could be likely if underground mining were to occur, depending upon the depth to coal, thickness of coal removed, type of overburden, and other engineering factors. Dunrud and Osterwald (1980) discuss the higher likelihood of subsidence in instances where the overburden is less than about 10-15 times the thickness of the coal that is mined underground—a situation that could exist with the Big George coal bed or the Wyodak coal bed.

GROUPING OF CONSTRAINTS TO MINING IN THE HILIGHT QUADRANGLE

The actual constraints or restrictions that were used in the coal availability calculation for the quadrangle were grouped in many overlapping ways. Those included: (1) whether the constraint was a land-use restriction or a technologic restriction; (2) whether the land-use restriction arose from the Unsuitability Criteria or from other multiple-use management plans; (3) whether the restriction was located and applicable where overburden thickness is 0-300 ft., 300-1,000 ft., or both; and (4) whether the constraint was likely to restrict a mining operation (as judged by common local practice) or could be mitigated in some way to allow mining to proceed. Table 2 shows the restrictions that were used for the coal availability calculation in the Hilight quadrangle. The following discussion explains the terms used and how the groupings were determined.

The software that we use for coal availability calculations (see **Computer Techniques** section) divides the availability restrictions into two types: land-use and technologic. Land-use restrictions are placed upon mining by societal policies to preserve those surface features or entities that could be adversely affected by mining (Carter and Gardner, 1989). Land-use restrictions, therefore, may change if societal interests change. Typically, land-use restrictions apply to surface mining, but may also affect underground mining.

Technologic restrictions affect the economics, safety, or resource extraction during mining and coal preparation, and are determined by current mining industry practice. These restrictions change with advances in science and engineering or with changes in economic conditions. Technologic restrictions affect both surface and underground mining but are generally more

Table 2. Constraints to coal mining in the Hilight quadrangle.

[* indicates overburden thickness. "Yes" indicates actual situations that occur in the quadrangle. "Unsuitability" refers to the coal Unsuitability Criteria listed in the Federal Regulations (43 CFR 3461)]

Restriction	Category (1 or 2)	Type of restriction	Land-use; 0-300 ft*	Land-use; 300-1,000 ft*	Technologic; 0-300 ft*	Technologic; 300-1,000 ft*
Railroad	1	Unsuitability	Yes	Yes		
Power line	1	Multiple use		Yes		
Cemetery	1	Unsuitability	Yes			
Producing oil & gas field; active wells	1	Multiple use	Yes			Yes
Gas plant	1	Multiple use	Yes			
Dwellings	2	Unsuitability	Yes	Yes		
Potential alluvial valley floor	2	Unsuitability	Yes			
Pipelines	2	Multiple use	Yes	Yes		
Raptor sites	2	Unsuitability	Yes	Yes		
Inactive oil & gas wells	2	Multiple use	Yes			Yes

prohibitive to underground mining (Carter and Gardner, 1989).

The USGS coal resource calculation program computes these resources by overburden thickness categories; for this study (see fig. 8) we divided the overburden thickness into two categories: 0-300 ft and 300-1000 ft (surface and underground mining, respectively).

We further grouped the factors affecting the availability of coal into two sets: Category 1, those factors that were likely to restrict a mining operation; and Category 2, those factors that probably could be mitigated in some way. The two Unsuitability Criteria that are restrictions to mining (railroad corridor and cemetery) are included in Category 1. Category 1 considerations would result in a certain amount of coal tonnage being unavailable for coal mining; in contrast, Category 2 considerations would perhaps increase the cost and complexity of the mining operation, but, through mitigating measures, might allow for mining of the coal involved.

The following are the Category 1 considerations (areas unavailable because of present land-use and technologic conflicts). These areas are depicted on Figure 5.

Category 1

1. Railroad corridor
2. Power line
3. Cemetery
4. Active oil and gas wells
5. Hilight gas plant

Because of the concentration of active oil and gas wells in the southern half of the quadrangle, we assumed that an area around this entire cluster of actively producing wells would be eliminated from mining until these wells are no longer producing. The area delineated is shown as "Active oil field" on fig. 5. We felt that, because there was such a large quantity of actively producing wells in a small area, it would not be efficient to try to develop a plan to mine around each well, and thus we outlined an enclosing area that would be unavailable for coal mining.

We considered that the railroad, power line, cemetery, and gas plant would be land-use restrictions to mining at both overburden categories (0-300 ft [surface mining] and 300-1000 ft [underground mining]). Because Powder River Basin overburden is typically weak, low in rock strength (Ahcan and others, 1991; Dunrud and Osterwald, 1980) and susceptible to subsidence, we restricted mining below these surface features.

We considered the actively producing oil and gas wells (individual wells in the north part of the quadrangle and the cluster of wells in the south part) to be a land-use restriction at 0-300 ft overburden category [surface mining] and a technologic restriction at the 300-1000 ft overburden category [underground mining]. The latter determination is because of the technologic difficulties involved in underground mining where producing oil and gas wells intersect the mine.

The following are the Category 2 considerations (may allow for the mining of coal, through mitigating measures). These areas are depicted on Figure 6.

Category 2

1. Dwellings
2. Potential alluvial valley floor of Black Thunder Creek
3. Pipelines
4. Raptor sites
5. Inactive oil and gas wells

We grouped the alluvial valley floor, raptor sites, dwellings, and pipelines as land-use restrictions for surface mining operations. They were also considered to be land-use restrictions for underground mining operations because of the likelihood that they could be disturbed by surface subsidence. (We included the raptor sites here because of the possibility that their flora and hydrology might be destroyed or disrupted by subsidence.) Inactive (but not abandoned) oil and gas wells would be a land-use restriction for surface mining and a technologic restriction for underground mining.

For the purpose of the coal availability resource calculation, we assumed that the smaller number of inactive oil and gas wells (in contrast to the actively producing oil and gas wells) would not need to be grouped together into a single area unavailable to mining, but rather could be considered on an individual basis and factored into the mine plan, so that mining could still proceed through them (if they are adequately plugged) or around them.

Resource and availability calculations were completed for each of the major coal zones, for the considerations in Category 1 [restrictions to mining] and in Category 2 [additional considerations to mining]—by land-use and technologic designations, and by overburden thickness. (See **Computer Techniques** and **Results** sections.)

MAJOR COAL ZONES STUDIED

Resources were calculated on five Fort Union Formation coal intervals (fig. 4). Not all drill holes encountered all five coal intervals. If a drill hole started and (or) ended in a coal bed of interest, we included that partial measurement in our resource calculations. We did not include coal beds whose thickness is less than 2.5 ft, because: 1) these beds, although common in the Fort Union Formation, are of limited extent and cannot be correlated over a significant distance; and 2) USGS Circular 891 (Wood and others, 1983) defines 2.5 ft as the minimum thickness of subbituminous coal for resource calculations.

The five coal zones for which resources were calculated are the **Rider Wyodak**, the **Main Wyodak**, the **Lower Wyodak**, the **Wildcat**, and the **Moyer**.

Resources were not calculated for the Oedekoven coal bed (fig. 4) because of insufficient data within the quadrangle. Figure 9 shows some representative sections from the Hilight study area which include the Rider Wyodak, Main Wyodak, and Lower Wyodak coal beds.

The **Main Wyodak** coal bed is herein defined as that part of the Wyodak coal interval that occurs as one bed according to the definition in USGS Circular 891 (Wood and others, 1983, p. 36). Figures 10 and 11 show the variability of the Main Wyodak coal bed; it can contain many partings, but as long as the partings are not as thick as either of the coal benches they separate, the Main Wyodak coal bed is considered to be one bed (Wood and others, 1983). Using this criteria, the Main Wyodak coal bed contains 5-120 ft of coal in an interval that is 5-156 ft thick. We used two thickness categories for the Main Wyodak coal bed: 5-40 ft and greater than 40 ft. Overburden thickness for the Main Wyodak coal bed is 15- 625 ft.

If benches of the Wyodak bed are separated by partings which exceed the thickness of either adjacent bench, then the bench must be considered a separate bed for the purposes of resource calculation (Wood and others, 1983), and its thickness is not included in the thickness of the Main Wyodak coal bed. These separated beds (they do not occur in every drill hole) were grouped as discussed below.

(a) *Wyodak benches above the Main Wyodak bed* were called the **Rider Wyodak** bed (see figures 9, 10, and 11). The Rider Wyodak bed can include multiple benches of Wyodak coal above the Main Wyodak, and is designed to include all the rest of the benches of the Wyodak coal bed above the Main Wyodak, regardless of parting thicknesses. The analysis, currently underway, of recoverable coal in the Hilight quadrangle will determine where the Rider Wyodak coal beds can be economically mined in conjunction with mining of the Main Wyodak coal bed.

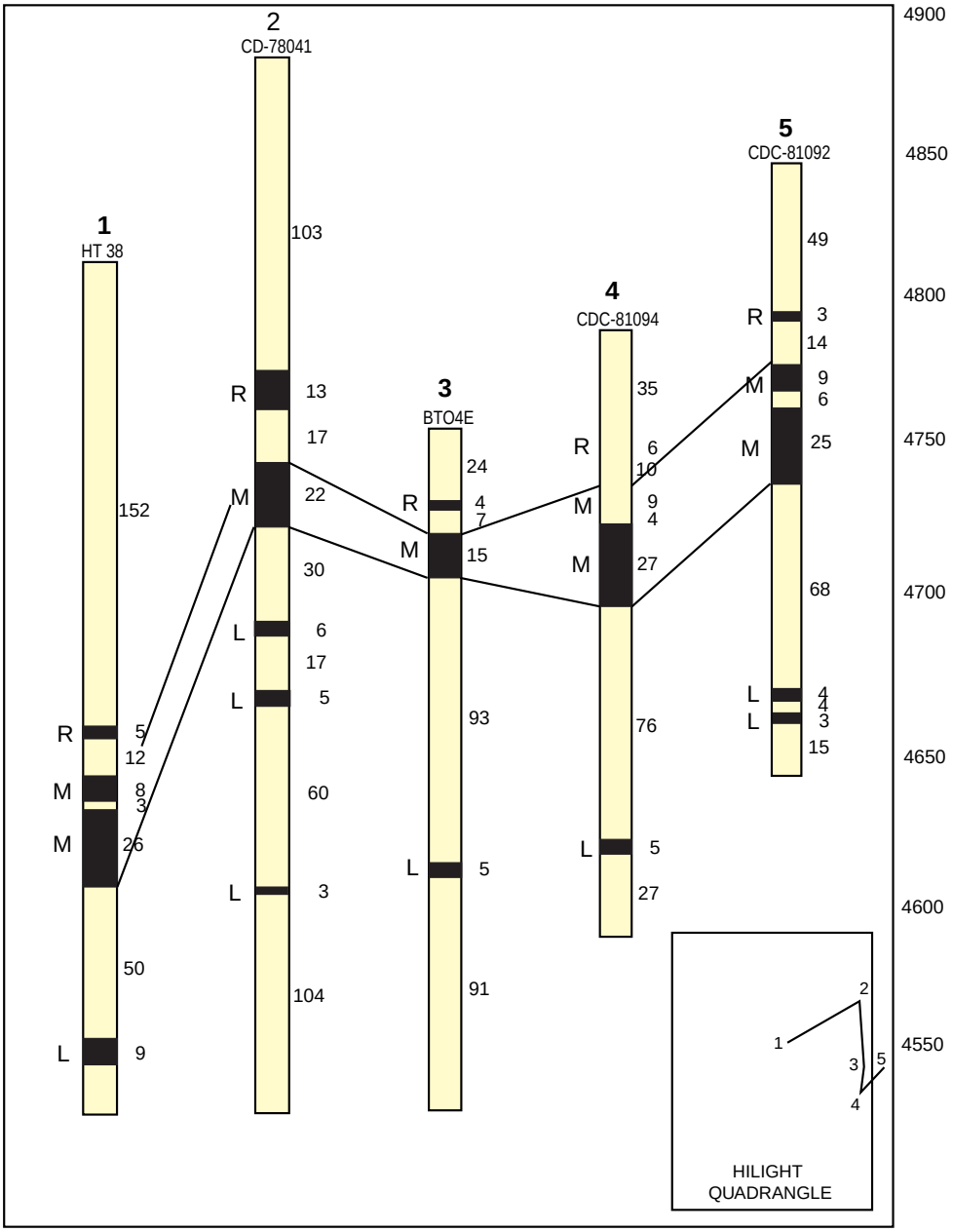

Figure 9. Coal-correlation diagram showing representative sections from the Hilight study area. R, Rider Wyodak; M, Main Wyodak; L, Lower Wyodak coal beds, as used in this report. Numbers are in feet; elevations above sea level are shown on right margin of figure. Inset map shows location of sections.

Total coal thickness of the Rider Wyodak bed is 3-24 ft, in a stratigraphic interval of 3-90 ft. We used two coal thickness categories for the Rider Wyodak coal bed: 3-5 ft and 5-40 ft. [This second category was chosen to parallel the 5-40 ft thickness category for the Main Wyodak bed, even though total coal in the Rider Wyodak bed in the Hilight quadrangle is no more than 24 ft thick.] Overburden thickness for the Rider Wyodak coal bed is 0-400 ft.

(b) *Wyodak coal benches below the Main Wyodak bed* were called the **Lower Wyodak** coal bed (figures 9, 10, and 11). The Lower Wyodak bed can include multiple benches of Wyodak coal below the Main Wyodak, and is designed to include all the rest of the benches of the Wyodak coal bed below the Main Wyodak bed, regardless of parting thicknesses. The analysis, currently underway, of recoverable coal in the Hilight quadrangle will determine where the Lower Wyodak coal beds can be economically mined in conjunction with mining of the Main Wyodak coal bed.

Total coal thickness of the Lower Wyodak bed is 3-25 ft, in a stratigraphic interval of 3-90 ft. We used

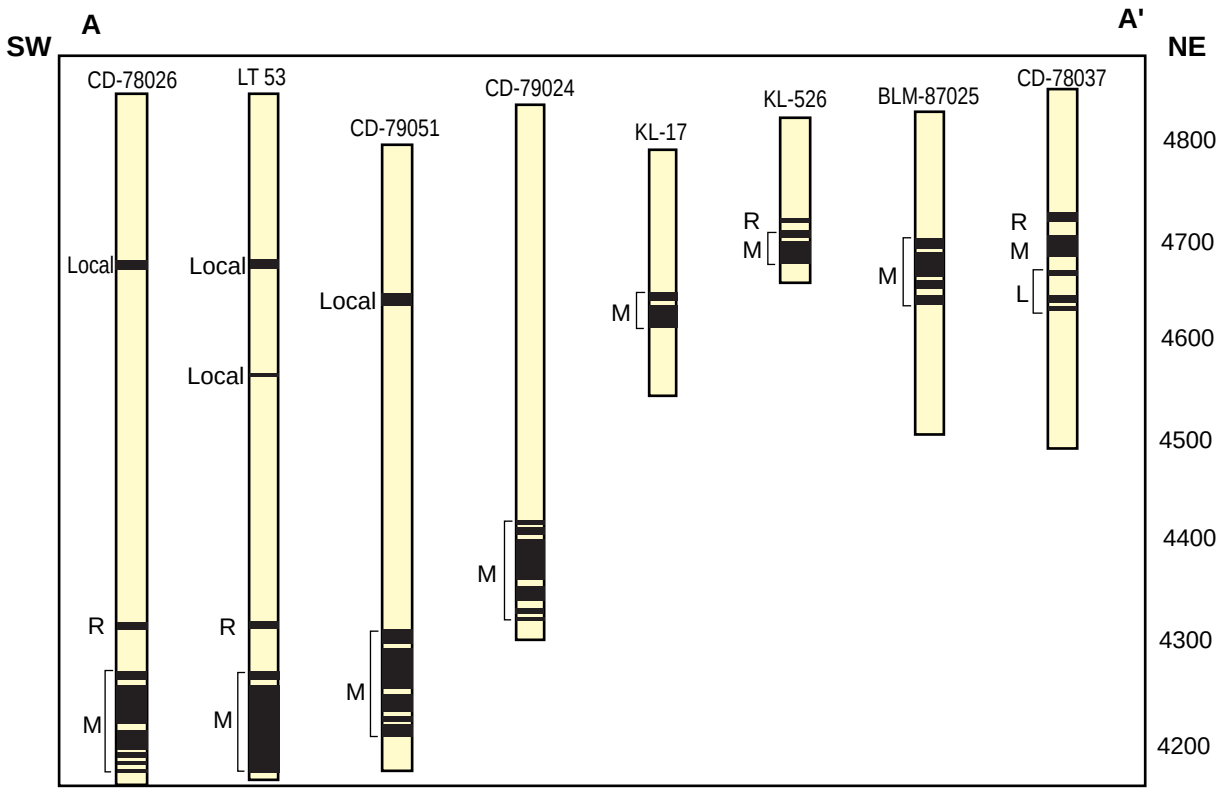

Figure 10. Coal-correlation diagram A-A', showing coal beds in the Wyodak coal interval. Datum is elevation (ft) above sea level; no horizontal scale. Note variations in thickness in the Main Wyodak coal bed and in number of partings. This Main Wyodak interval is shown in detail in Figure 11. See Figure 3 for the location of Line A-A'. R, Rider Wyodak; M, Main Wyodak; L, Lower Wyodak coal beds; Local, unnamed coal bed of limited areal extent.

two coal thickness categories for the Lower Wyodak coal bed: 3-5 ft and 5-40 ft. Overburden thickness for the Lower Wyodak coal bed is 75-600 ft.

The **Wildcat** coal bed is 3-16 ft thick and typically occurs in one bench. We used two thickness categories for the Wildcat coal bed: 3-5 ft and 5-40 ft. Overburden thickness for the Wildcat bed is 500-1300 ft.

The **Moyer** coal bed is 3-11 ft thick and typically occurs in one bench. The two thickness categories that we used for the Moyer coal bed are: 3-5 ft and 5-40 ft. Overburden thickness for the Moyer bed is 650-1370 ft.

The data set of stratigraphic information used for resource calculations and for the determinations discussed above includes data points within the Hilight quadrangle and data points within a three-mile-wide band surrounding the quadrangle. The total was approximately 350 data points (fig.3). The data in the three-mile band around the Hilight quadrangle were used to guide and control the computer-generated grids of coal thickness and overburden thickness in the quadrangle, and to complete the calculation of measured, indicated, and inferred coal resources for data points within the Hilight quadrangle but close to the quadrangle border.

COMPUTER TECHNIQUES

The study involved compilation of three basic types of data. The first is point-source data on coal-bed thickness, elevation above sea level, and coal quality. BLM supplied digital files of publicly available drill-hole data in and around the Hilight area; these files contained coal-bed names and correlations, especially for the Wyodak coal bed, and were used after minor revisions. Additional public drill-hole data, which also contained coal-bed thickness, bed name, and elevation (from the Coal Resource Occurrence—Coal Development Potential studies of Federal coal resources) were retrieved from the USGS National Coal Resources Data System for the Hilight quadrangle and for the surrounding eight quadrangles, and were used after minor revisions.

The second data type consists of line data that define coal outcrops, boundaries, and areas that pose potential restrictions to mining, as well as other land-use considerations. Many of these data were also provided by the BLM in digital format. Other line data were plotted on 7½-minute topographic maps and digitized by the USGS. Most of the line data which

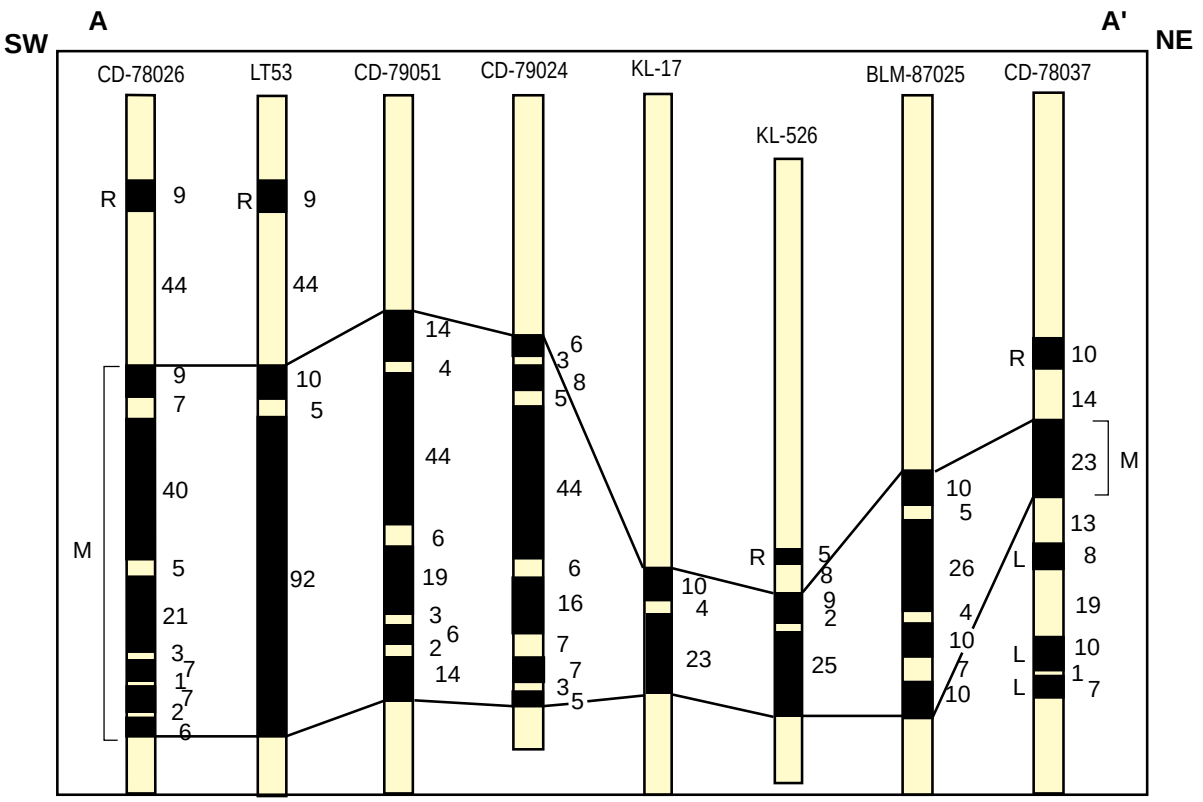

Figure 11. Enlargement of coal-correlation diagram A-A' from Figure 10; no vertical datum and no horizontal scale. Note variations in thickness in the Main Wyodak coal bed and variations in number of partings. Thickness values shown in feet. See Figure 3 for the location of Line A-A'. R, Rider Wyodak; M, Main Wyodak; L, Lower Wyodak coal beds.

define areas of technological restrictions, i.e., coal too deep or too thin, were generated by our public-domain GIS software, GRASS (**G**eographical **R**esource **A**nalysis **S**upport **S**ystem, U.S. Army Construction Engineering Research Laboratory), from grids of coal thickness and overburden thickness.

The third type of data is the digital elevation models (DEM's), which are digital files of surface topography, produced by the National Mapping Division of the USGS. The DEM surface-elevation raster is used to calculate overburden thickness. A computer program subtracted one raster (the elevation of the top of the coal) from a second raster (the DEM raster of surface elevation) to generate a raster of overburden thickness.

The overall steps required to calculate coal resources for this study included: (1) acquisition of coal stratigraphic and analytical data, and their transfer into a point-data management system; (2) correlation and grouping of coal beds by bed or zone; (3) transfer of point-source and line data into a geographic information system (GIS); (4) conversion of point-source and line data into rasters using GIS programs; (5) calculation of original coal resources from rasters; and, finally, (6) calculation of restricted coal tonnages and coal tonnages available to mining, by overburden thickness and by Category 1 and 2 restrictions. The methodology for coal-resource calculations used in this study follows the Coal Resource Classification System of the USGS (Wood and others, 1983).

Computerized techniques are used to facilitate visualization of coal-bed correlations and calculation of original, restricted, and available resources. The point-source geologic data were initially processed using StratiFact software (GRG Corporation) to store, manipulate, and graphically display cross sections throughout the quadrangle; to correlate coal beds between drill holes; and to group coal beds and partings by assigning coal bed designations. Then, coal-bed data were retrieved by bed designations and brought into GRASS, which contains the USGS coal resource calculation programs.

Digital line data obtained from BLM was processed using a GIS called ARC/INFO (Environmental Systems Research Institute, Inc.) to clean the data (delete dangles, intersect lines, and create topology) and to reformat the BLM digital files so they also could be imported into GRASS. Line data digitized by the

Table 3. Summary of coal resources and available coal, by bed, in millions of short tons, for the Hilight quadrangle.

Coal bed name	Original resources	Category 1					Category 2		
		Land Use Restrictions	Technologic Restrictions	TOTAL Restrictions	Available	% available	Land Use Restrictions	Technologic Restrictions	TOTAL Restrictions
Rider Wyodak	396	86	7	91	305	77%	85	0	85
Main Wyodak	2,851	678	274	942	1,909	67%	604	3	607
Lower Wyodak	540	52	45	96	444	82%	110	2	112
Wildcat	344			344					
Moyer	293			293					
OVERALL	***4,424***	***816***	***326***	***1,766***	***2,658***	***60%***	***799***	***5***	***804***

Notes: Totals are not necessarily sums because of overlapping restrictions.
Wildcat and Moyer coal beds are considered entirely unavailable because of their depth.

USGS were also brought into GRASS. GRASS volumetric programs were run to calculate original, remaining, restricted, and available coal tonnages, by coal bed. Table 3 is a summary of these calculations; complete results are shown in Tables 4 through 13. The GRASS software generated estimates of restricted and available coal tonnages for the Wildcat and Moyer coal beds (Tables 7-8a,b,c and 12-13a,b,c); however, these coal beds are considered entirely unavailable because of their depth. No rounding to significant numbers is done by the GRASS programs.

Each of these resource estimates in the tables are subdivided into categories by overburden thickness, coal thickness, and reliability of estimate. Reliability categories used were: measured (coal within 1/4 mile of a coal-thickness measurement); indicated (coal 1/4- to 3/4- mile from a coal-thickness measurement); inferred (coal 3/4- to 3 miles from a coal-thickness measurement); and hypothetical (coal more than 3 miles from a coal-thickness measurement).

These coal tonnage estimates can be compared to previous resource estimates for this quadrangle and can indicate the amount of available coal in other parts of the Powder River Basin that have similar geologic and land-use conditions.

RESULTS

Coal Availability Calculation Using Category 1 Restrictions

(Likely restrictions to mining)

The Hilight quadrangle contains 4.4 billion tons of total coal resources (fig. 12). Original and remaining coal resources for the quadrangle are the same because no commercial mining has yet taken place. Under Category 1 restrictions (railroad, power line, cemetery, oil and gas field and producing wells, Hilight gas plant) about 60 percent or 2.7 billion tons of the original coal resource are considered available for development in the Hilight quadrangle (fig. 13). This 60 percent represents the sum of the available Rider, Lower, and Main Wyodak coal resources (totaling approximately 2.7 billion tons) as a proportion of the total 4.4 billion tons of original coal in the quadrangle (fig. 14; table 3). The coal resources of the Wildcat and Moyer beds are considered unavailable because of depth.

The Main Wyodak coal bed in the Hilight quadrangle contains 2.9 billion tons of coal, of which 1.9 billion tons (67 percent) are considered available for development. Figure 15 shows the total available resources of the Main Wyodak coal bed, and the amount of coal that is restricted by land-use considerations (24 percent) and by technological considerations (9 percent). The relative proportions of these land-use considerations are depicted in fig. 18. The large oil and gas field is the technological consideration which limits the availability of the Wyodak coal bed.

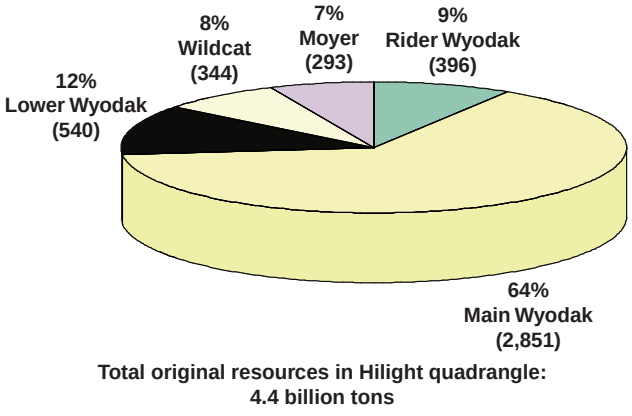

Figure 12. Chart showing total original coal resources in the Hilight quadrangle. Numbers in parentheses are in millions of short tons.

Figure 13. Chart showing amount of available coal in Hilight quadrangle (Category 1 restrictions).

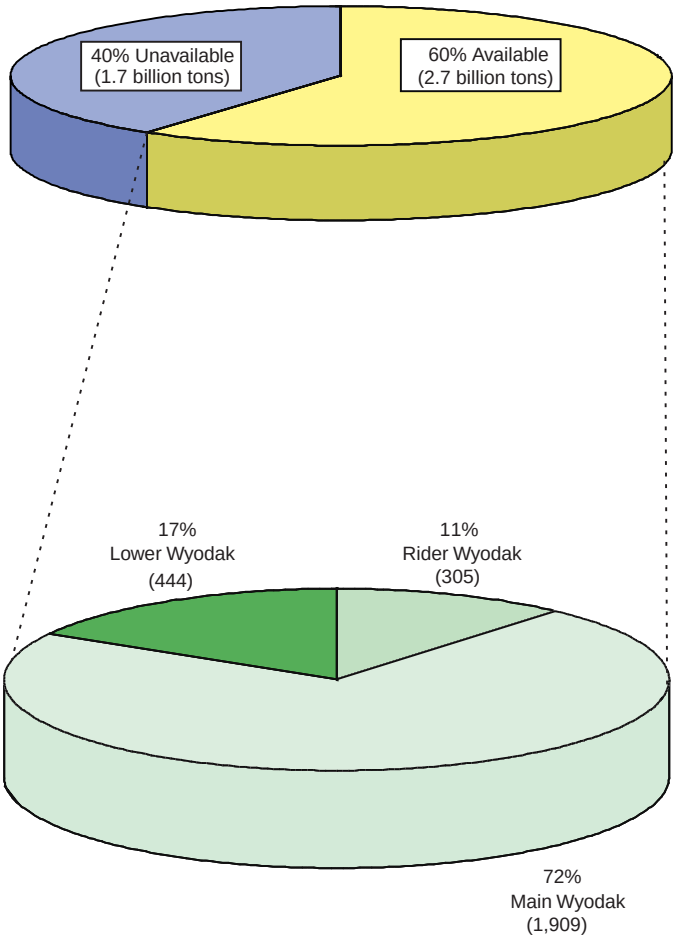

Figure 14. Chart showing proportions of Main, Rider, and Lower Wyodak coal beds that together make up the available coal for the Hilight quadrangle (Category 1 restrictions). Numbers in parentheses are in millions of short tons.

Figures 16 and 17 show the amount of available coal and the amounts of coal restricted because of land-use and technological restrictions for the Rider Wyodak coal bed and the Lower Wyodak coal bed, respectively, in the Hilight quadrangle.

Coal Availability Calculation Including Category 2 Restrictions

(Considerations that probably will be mitigated)

If Category 2 restrictions (dwellings, alluvial valley floor, pipelines, raptor areas, inactive oil and gas wells) for the Rider, Lower, and Main Wyodak beds are added to Category 1 restrictions, an additional 807 million tons of coal would be restricted from mining (this figure is approximate because of overlap between some Category 1 and Category 2 considerations). Thus 42 percent (1,851 million tons) of the Wyodak coal beds would be available for mining.

COMPARISON TO OTHER COAL AVAILABILITY STUDIES

This coal availability study—the first in the Western United States—indicates that about 67 percent of the coal in the Main Wyodak bed is available for mining, and about 60 percent of the total coal in the quadrangle is available for mining. Studies in the Appalachian coal region indicate that, overall, only 50 percent of the **original** coal resource in that region is available for development (Carter and Gardner, 1994). In many areas of the Appalachian region, much of the original resource is already mined-out; whereas in the Hilight quadrangle, there has been no mining. Of the **remaining** Appalachian coal resource, no more than 60 percent is considered available for future development, because of restrictions to mining (Carter and Gardner, 1994).

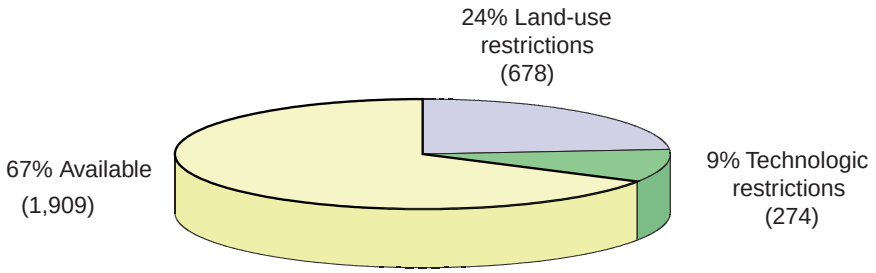

Figure 15. Chart showing three divisions of the Main Wyodak coal bed resources: available coal; coal restricted by land-use considerations; and coal restricted by technologic considerations (Category 1 restrictions). Numbers in parentheses are in millions of short tons.

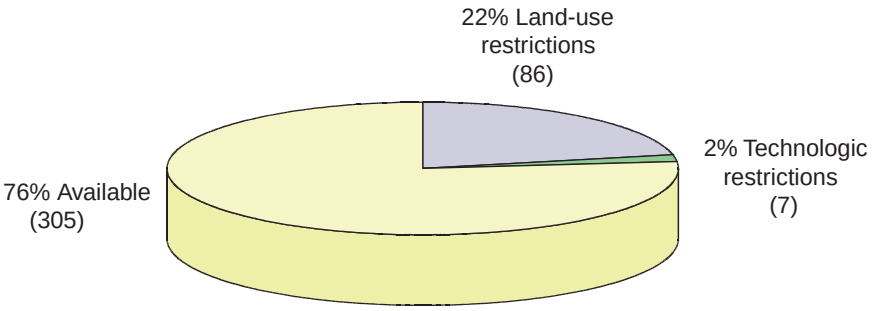

Figure 16. Chart showing three divisions of the Rider Wyodak coal bed resources: available coal; coal restricted by land-use considerations; and coal restricted by technologic considerations (Category 1 restrictions). Numbers in parentheses are in millions of short tons.

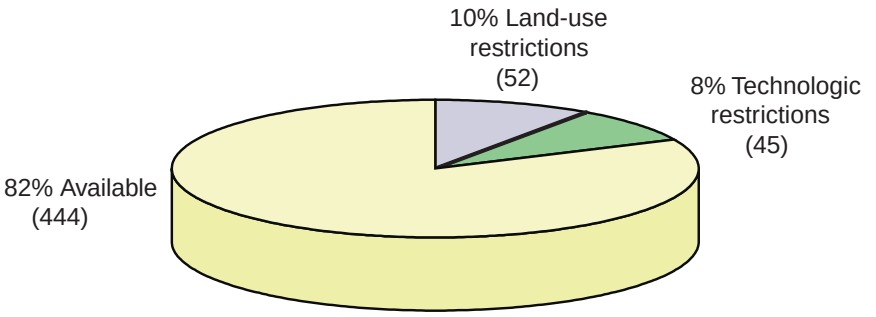

Figure 17. Chart showing three divisions of the Lower Wyodak coal bed resources: available coal; coal restricted by land-use considerations; and coal restricted by technologic considerations (Category 1 restrictions). Numbers in parentheses are in millions of short tons.

There are significant differences in several coal quality parameters between Appalachian coals and Powder River coals; these differences must be considered in any comparison of available resources of different regions. In general, the Powder River Basin coals are lower in rank, higher in moisture content, and lower in sulfur content than the Appalachian coals.

There are also major differences between Appalachian and Powder River Basin coal development. Different land-ownership patterns, mineral-ownership patterns, environmental regulations, mining methods, topography, and land-management policies exist in the two regions. Powder River Basin coal development occurs in an area which is relatively undeveloped and contains no large population centers. Powder River Basin topography is relatively flat; there are numerous, gently-dipping, relatively shallow, thick coal beds. No underground mining is planned. Coal mining in the Powder River Basin involves Federally-owned coal resources and Federal coal mining laws and development regulations. All of these factors influence the amount of coal that is available, and how that coal will be developed.

The U.S. Bureau of Mines coal recoverability studies of the Appalachian region have shown that less than 10 percent of the original resource can be mined and marketed at a profit (Rohrbacher and others, 1994).

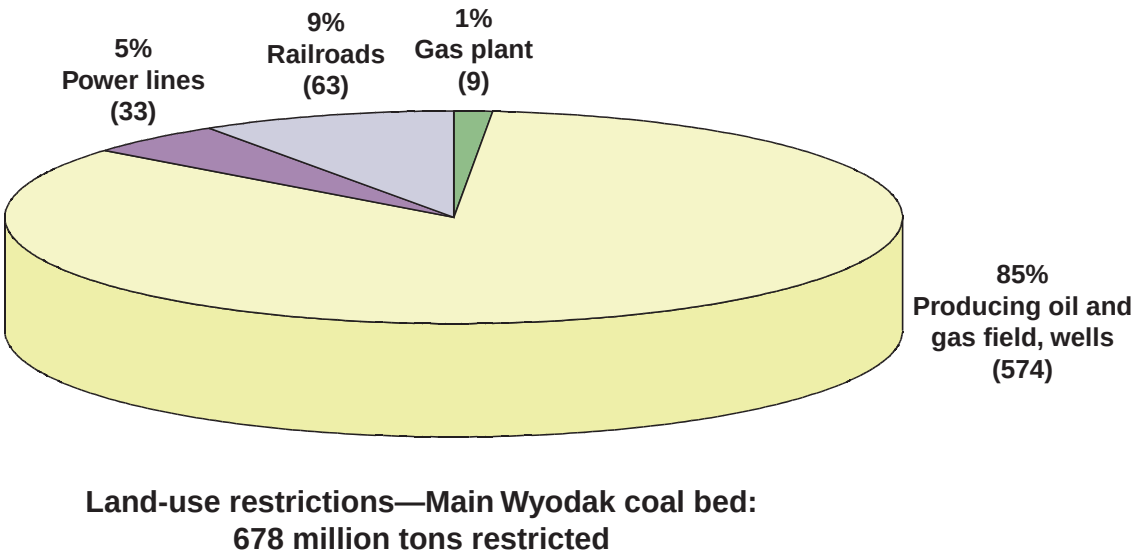

Figure 18. Chart showing land-use restrictions for the Main Wyodak coal bed (Category 1 restrictions). The chart segment for "Cemetery" is too small to be shown at this scale. Numbers in parentheses are in millions of short tons.

The coal recoverability study of the Hilight quadrangle is presently being conducted by the U.S. Geological Survey, to determine what percent of the available coal is economically recoverable, through design of a theoretical mine plan for the quadrangle. This mine plan takes into account the restricted areas within the quadrangle and mining practices common in the Powder River Basin.

COMPARISON TO OTHER COAL RESOURCE CALCULATIONS FOR THE QUADRANGLE

Two earlier calculations were compared to our assessment:

(1) IntraSearch (1979) evaluated the coal resources of all unleased Federal coal beds in the quadrangle which are 5 feet or greater in thickness and occur at depths down to 3000 ft. Using these criteria, IntraSearch reported that there are 3.7 billion short tons of unleased Federal coal resources in the Hilight quadrangle. The IntraSearch study computed no resources or reserves for leased Federal coal, State coal, fee (private) coal, or lands encompassed by coal prospecting permits and preference right lease applications.

Our estimate of 4.4 billion tons of coal as the total coal resources in the quadrangle compares well with this previous estimate of 3.7 billion tons by IntraSearch (1979), in view of the fact that the IntraSearch estimate did not include all of the coal in the quadrangle.

(2) A second resource estimate for the area (Berryhill and others, 1950) provided a calculation of total original reserves of subbituminous coal in Wyoming by township, by overburden thickness and coal-bed thickness. Coal-tonnage estimates given for the four townships that occur within the Hilight quadrangle are as follows:

T. 44 N., R. 70 W.	303 million short tons
T. 44 N., R. 71 W.	485 million short tons
T. 45 N., R. 70 W.	390 million short tons
T. 45 N., R. 71 W.	520 million short tons

These estimates of original reserves, which total 1.7 billion tons, are for coal beds greater than 2.5 ft thick and with overburden less than 1000 ft; and are the sum of measured, indicated, and inferred reserve estimates (as defined by Berryhill and others, 1950) for each township.

Because the Hilight quadrangle does not include any one of these townships in its entirety, we used a percent (based on surface area) of each of the above township reserve estimates to approximate a coal reserve figure for the quadrangle. That total came to 780 million short tons.

We believe that this resource figure derived from Berryhill and others (1950) for the Hilight quadrangle is much smaller than later estimates because very few surface coal mines were operating in the Powder River Basin at that time, and thus a limited amount of data on subsurface coal was available. Also, the resource

estimates for this area by Berryhill and others (1950) did not include coal resources with over 1000 feet of overburden.

Comparison of these Hilight resource estimates show the usefulness of periodically recalculating coal resources for an area when there have been increases in data quantity and quality over time. The coal availability calculation is a further refinement—it determines how much of the total coal resource has already been mined, and how much would actually be accessible for development. These kinds of determinations can better guide us as an economy and a society as we develop our natural resources and the lifestyles that depend on them.

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Appendix

Tables 4 through 13—Coal Resource tables