Chapter PAR

COAL AVAILABILITY AND RECOVERABILITY STUDIES IN THE POWDER RIVER BASIN, WYOMING AND MONTANA

By Carol L. Molnia,[1] Lee M. Osmonson,[1]
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"Determining the amount of coal that can be mined under current environmental, societal, technologic, and economic conditions"

Part 1. Definitions and concepts

COAL AVAILABILITY STUDIES

ORIGINAL COAL

- minus -

AREAS ALREADY MINED

- minus -

LAND-USE RESTRICTIONS

- minus -

TECHNOLOGIC CONSIDERATIONS

- equals -

AVAILABLE COAL

Coal availability

The quantity of coal resources within the United States has been debated for many years. Past figures were based on gross estimates of coal in the ground and did not address the amount that might realistically be available for production after environmental and technological constraints were considered. Regulatory and land-use restrictions, the presence of towns and other cultural resources, current mining technology, geologic conditions, coal quality, and other factors significantly reduce the amount of coal actually available for mining.

Since 1986, the U.S. Geological Survey (USGS), in cooperation with State geological surveys, has been producing estimates of available coal in coal production areas of the country by identifying constraints on potentially minable coal resources. The results of these availability studies make it possible for Federal and State agencies, utilities, social planners, and energy consumers and producers to make informed decisions regarding energy use and policies.

COAL RECOVERABILITY STUDIES

COAL AVAILABLE FOR MINING

- minus -

MINING LOSSES

- minus -

WASHING LOSSES

- equals -

RECOVERABLE RESOURCES

- minus -

MINABLE RESOURCES TOO COSTLY TO EXTRACT

- equals -

ECONOMICALLY RECOVERABLE RESOURCE

(Reserve)

Coal recoverability

In coal recoverability studies, the available coal resource estimates are analyzed to determine that part which is economically recoverable. Coal recoverability addresses the many technological, economic, and environmental restrictions that affect the profitable extraction of coal. Mining production costs, current mining machinery and methods, present and near-future market conditions, and the impact of the Clean Air Act regulations all determine what coal resources can be profitably developed.

The ultimate objectives of coal recoverability are to contribute background data for local, State, and Federal energy policy decisions and to assist governmental entities in determining the socio-economic effects on coal-mining areas within their jurisdictions as the profitable coal resources become depleted.

Coal recoverability studies began as a cooperative effort with the U.S. Bureau of Mines in 1989. Now the program is conducted solely within the USGS as an important adjunct to coal availability studies.

Coal recoverability terms

- ***Recoverable Resource*—That part of the available coal that is left after normal mining and cleaning losses are subtracted. Costs involved with the extraction and cleaning of the coal are not considered, nor is the potential selling price of the coal.**

- ***Economically Recoverable Resource*—That part of the recoverable coal that can be mined, cleaned, and marketed at a profit (depends on the mine location, the characteristics of the coal bed, the quality of the coal, and the mining methods used). Also known as a reserve.**

Helpful concepts

- **Both the U.S. Geological Survey and the U.S. Bureau of Mines (USBM) separately studied coal availability in the Hilight quadrangle (see Part 3 and Part 4) as part of a cooperative effort to develop availability methodology for the western United States. The two agencies used different techniques and assumptions, and thus their results are not directly comparable.**

- **The USBM, however, added to its availability study a coal recoverability calculation (see Part 4) that built on the same techniques and assumptions used in the USBM availability study. Thus the two parts of the USBM study can be legitimately compared and contrasted.**

Helpful concepts, continued

- Restrictions to mining vary with location and local land-management regulations. Thus, different study areas can have different mining restrictions and availability considerations.

- This report reflects reasonable assumptions concerning restrictions to mining based on local practices in the Powder River Basin, Wyoming and Montana. A more detailed determination of restrictions and other availability considerations would occur during the leasing and mine-planning phases of property development.

- All tonnage figures are in short tons.

Part 2. Powder River Basin study areas

Availability and recoverability areas in Wyoming and Montana

Factors in selecting study areas (fig. PAR-1)

- Presence of Coal Resource
- Mining Activity—Past and Current
- Geologic and Cultural Characteristics
- Resource Management Issues
- Data Accessibility

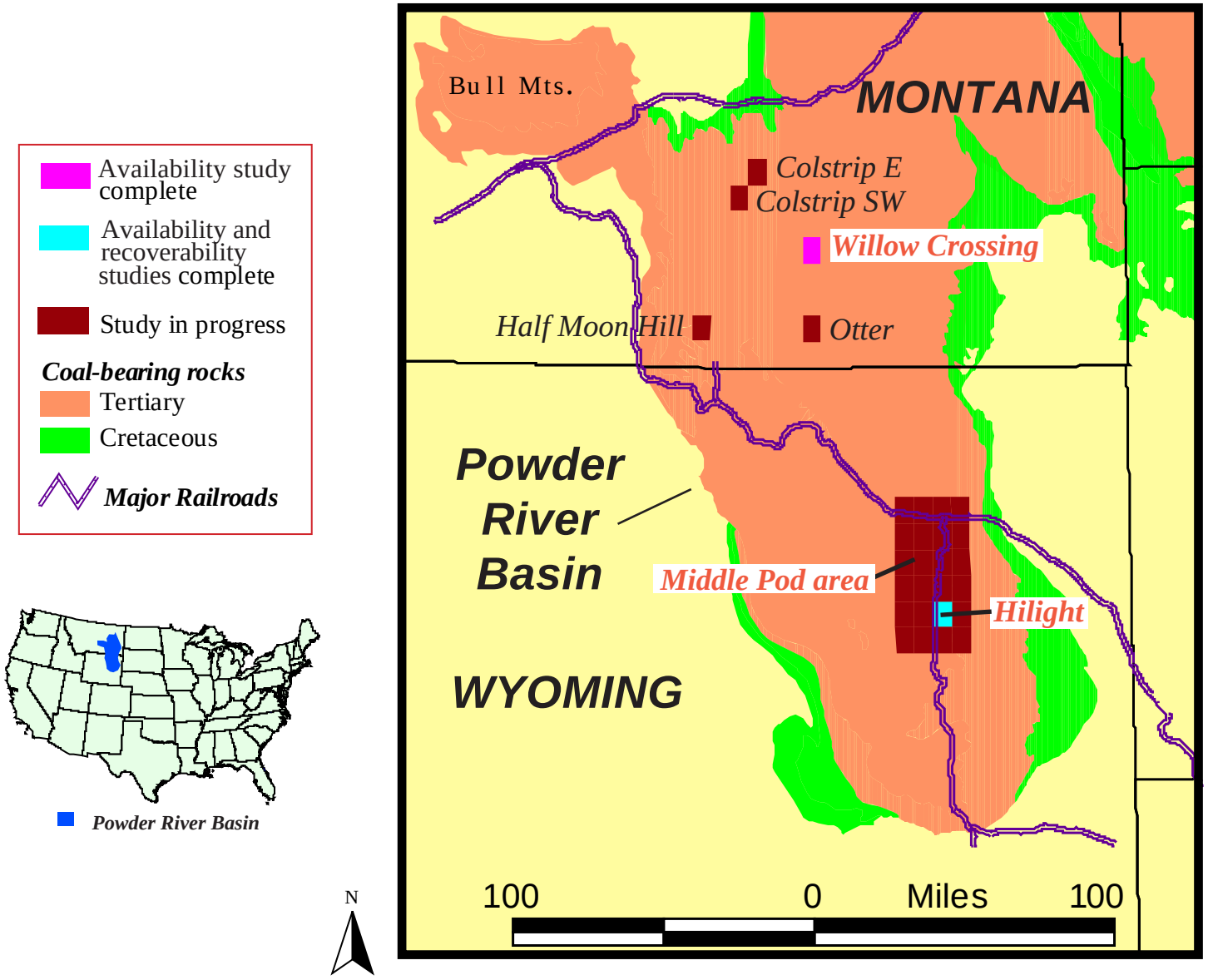

Figure PAR-1. Powder River Basin study areas for coal availability and recoverability. All areas shown are 7.5-minute quadrangles except the Middle Pod area.

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Part 3. U.S. Geological Survey study of coal availability in the Hilight quadrangle, Wyoming

Determining the amount of coal that can be developed

- **Click here to read Summary text in Appendix** PAR-1

COAL AVAILABILITY STUDIES

ORIGINAL COAL

- minus -

AREAS ALREADY MINED

- minus -

LAND-USE RESTRICTIONS

- minus -

TECHNOLOGIC CONSIDERATIONS

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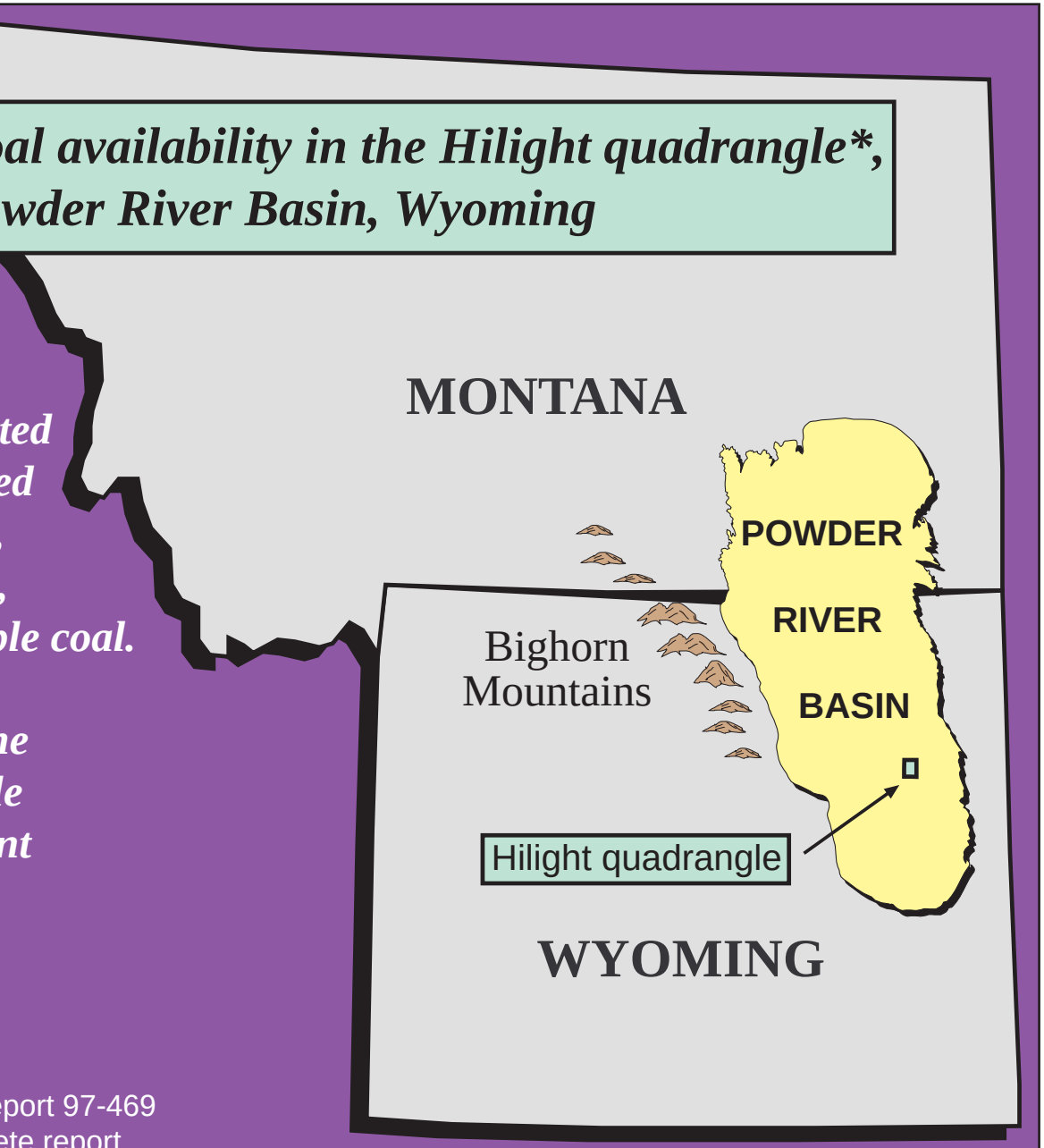
Table PAR-1. Differences between the two studies of the Hilight quadrangle

USGS availability study	*USBM availability and recoverability study*
• Original resources: 4.4 billion tons • Percent of original available: 60	• Original resources: 3.6 billion tons • Percent of original available : 95 • Percent of original recoverable: 89 • Percent economically recoverable: 11
• Modeled 5 coal beds	• Modeled 2 coal-bed mining intervals
• Power line and cemetery included as restrictions to mining	• Power line and cemetery *not* included as restrictions to mining
• Entire area of Hilight oil and gas field considered unavailable for mining	• Only areas around individual oil and gas wells considered unavailable for mining

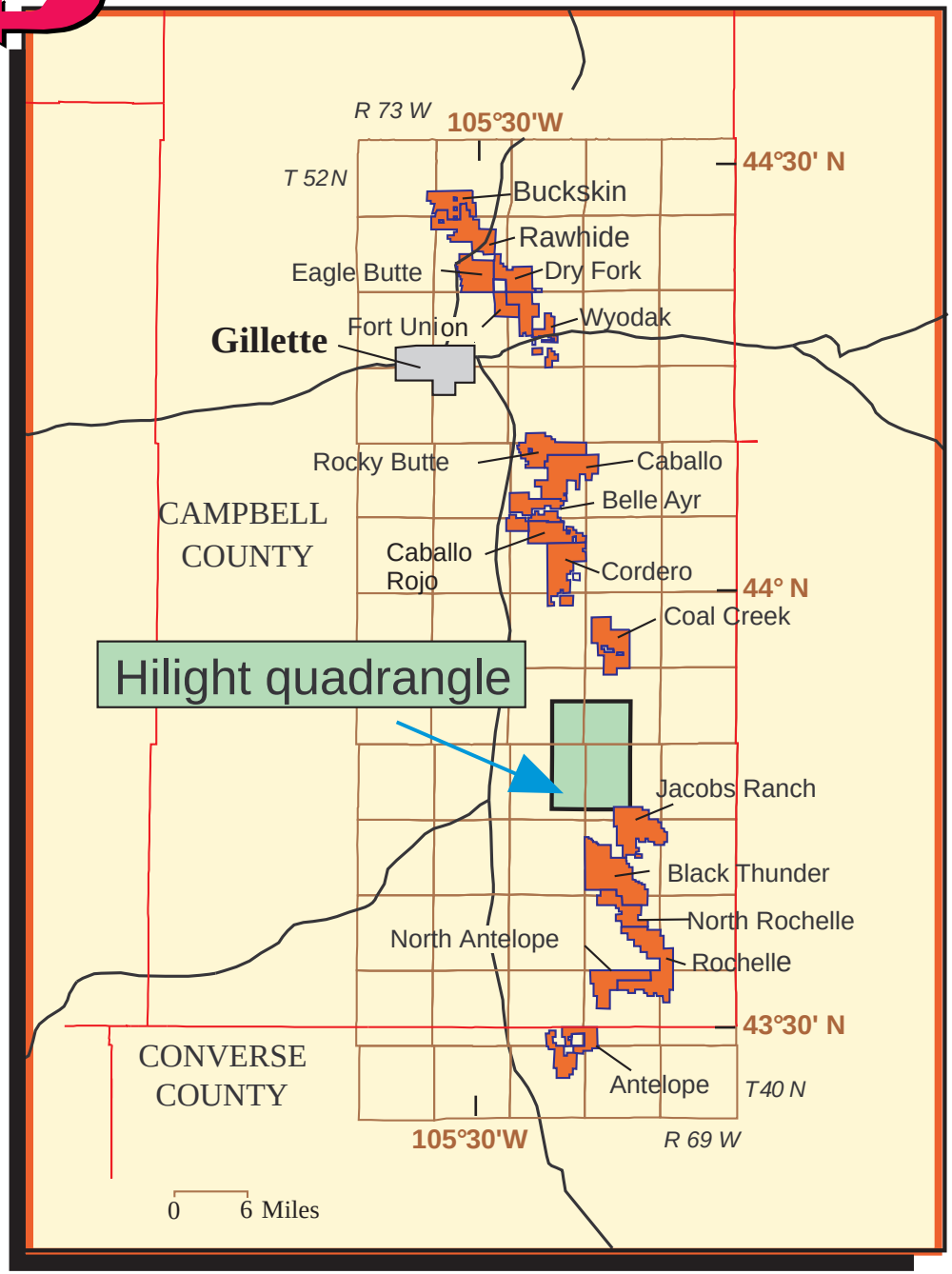
USGS study of coal availability in the Hilight quadrangle, Powder River Basin, Wyoming*

As a complement to the regional scope of the National Coal Assessment, the USGS has completed a coal availability study of a selected portion of the Powder River Basin, the Hilight 7.5-minute quadrangle, to determine the amount of available coal.

Available coal is that quantity of the total coal resource that is accessible for mine development under current regulatory, land-use, and technologic considerations.



* See U.S. Geological Survey Open-File Report 97-469 (Molnia and others, 1997) for the complete report on the Hilight availability study.

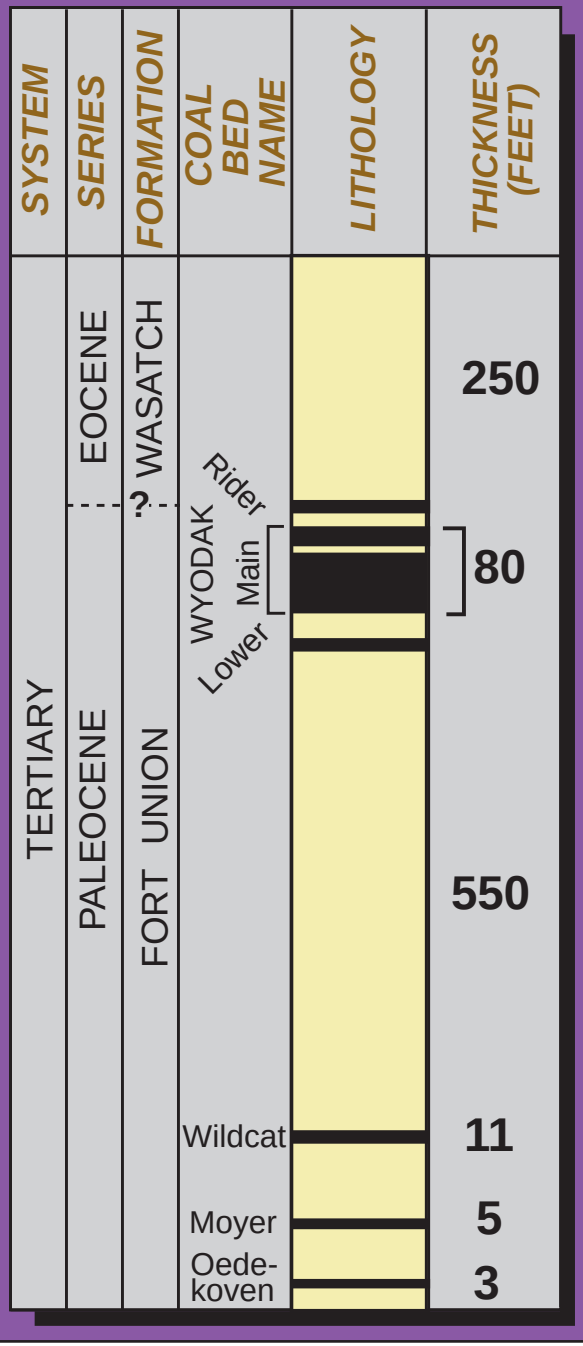


Surface coal mines near the Hilight quadrangle

Our study determined that approximately 60 percent, or 2.7 billion tons of coal in the quadrangle, is available for development.

Coal development considerations in the quadrangle include dwellings, railroads, pipelines, power lines, wildlife habitat, alluvial valley floors, a cemetery, and the Hilight oil and gas field and gas plant.

The Hilight quadrangle was chosen because of its location between two producing coal mines, the interest in developing coal in the Hilight area, and the issues that exist in multiple-use management of the land. This quadrangle has also been studied for coal recoverability (see next chapter).



Generalized composite stratigraphic section for the Hilight quadrangle

- Coal
- Non-coal rock: siltstone, mudstone, claystone, shale, and sandstone

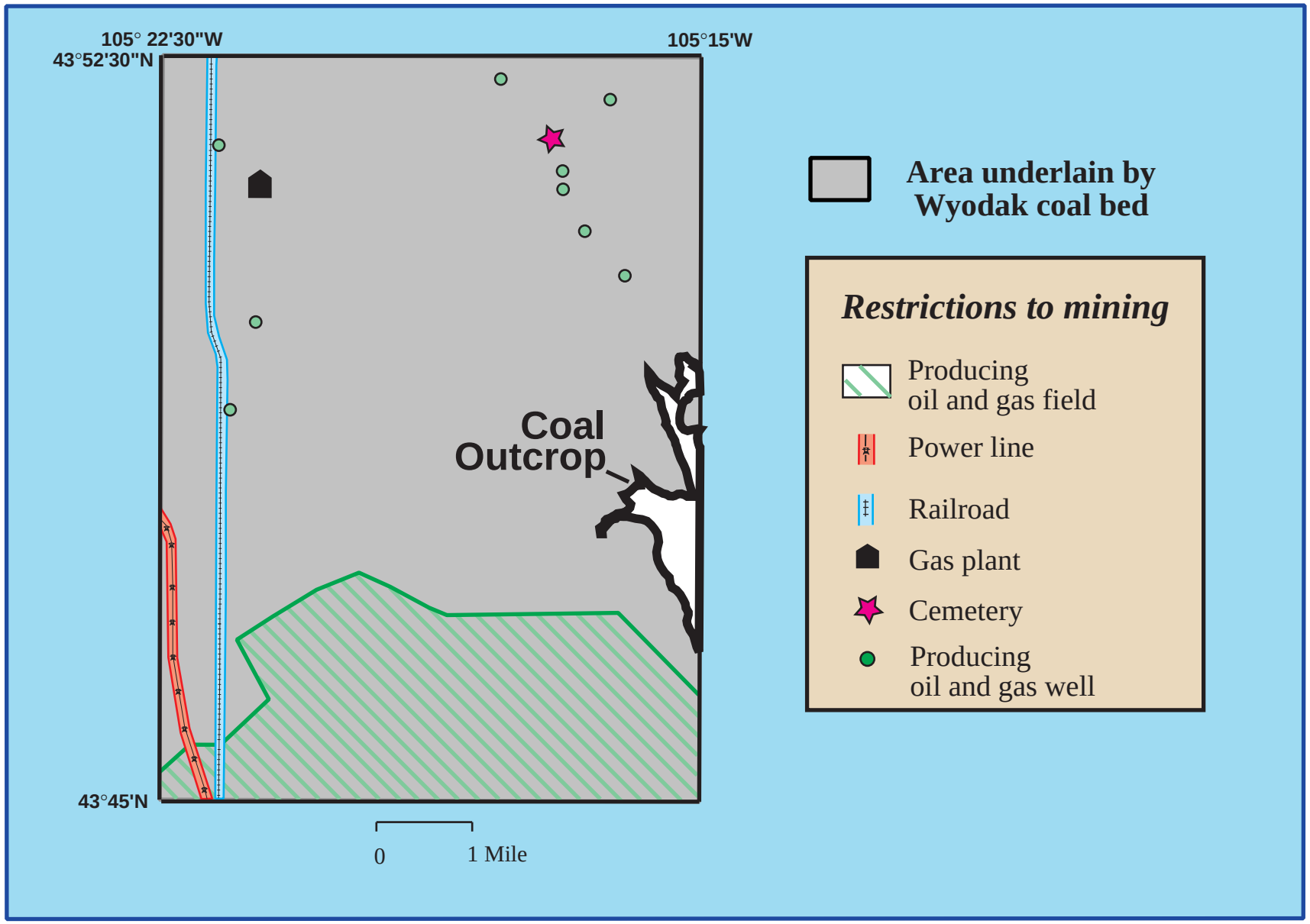
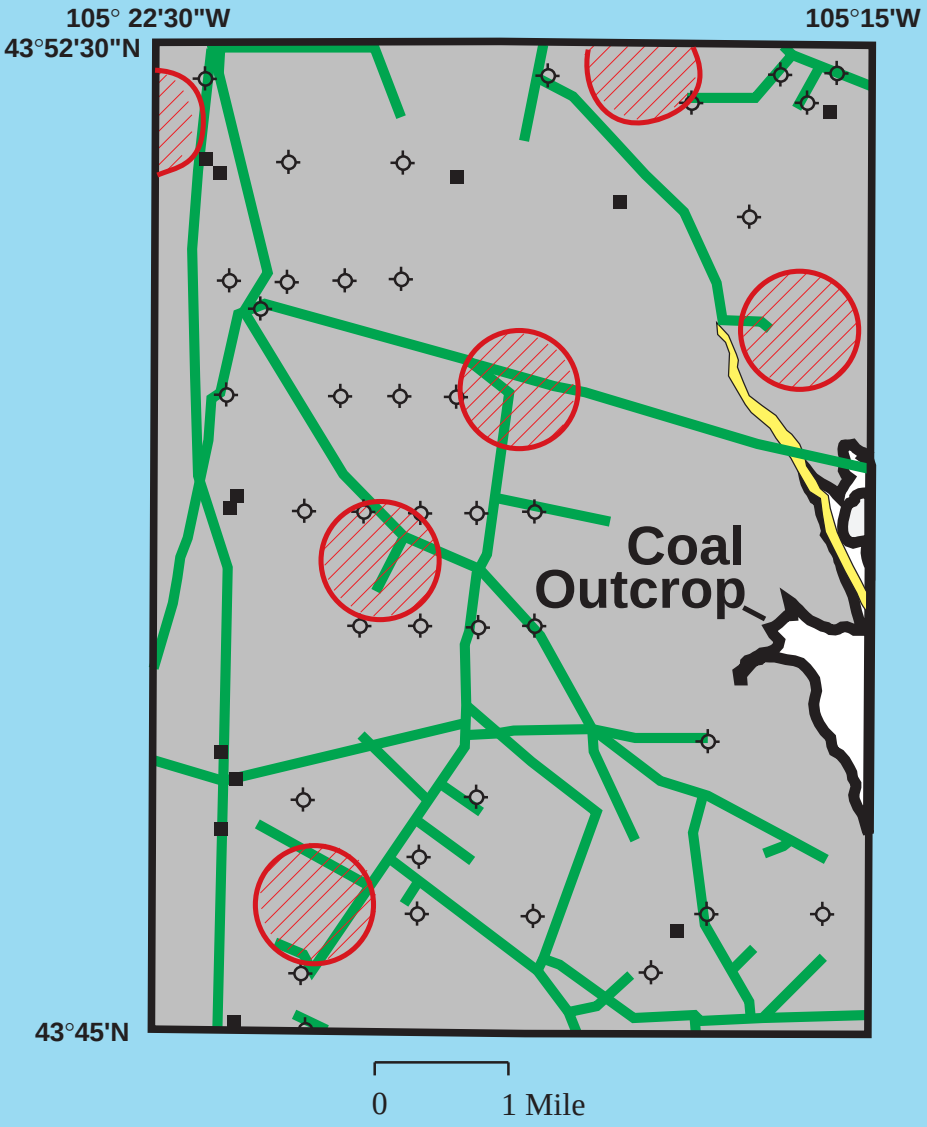


Figure PAR-2. Restrictions to mining. These areas are not available for surface mining because of land-use and technologic constraints.



Area underlain by Wyodak coal bed

Considerations to mitigate

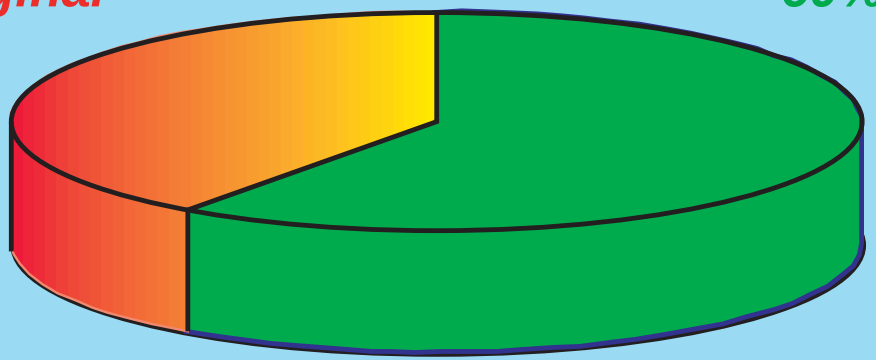
- Alluvial valley floor
- Dwellings
- Raptor sites (including golden eagles)
- Oil and gas pipeline
- Inactive oil and gas well

Additional mining considerations. Most likely, coal under these areas would be available for mining, but with certain mitigations and stipulations which might add to the complexity and cost of the mining operation.

Coal availability in the Hilight quadrangle—Total original resources of 4.4 billion tons

Unavailable:
1.7 billion tons
40% of original

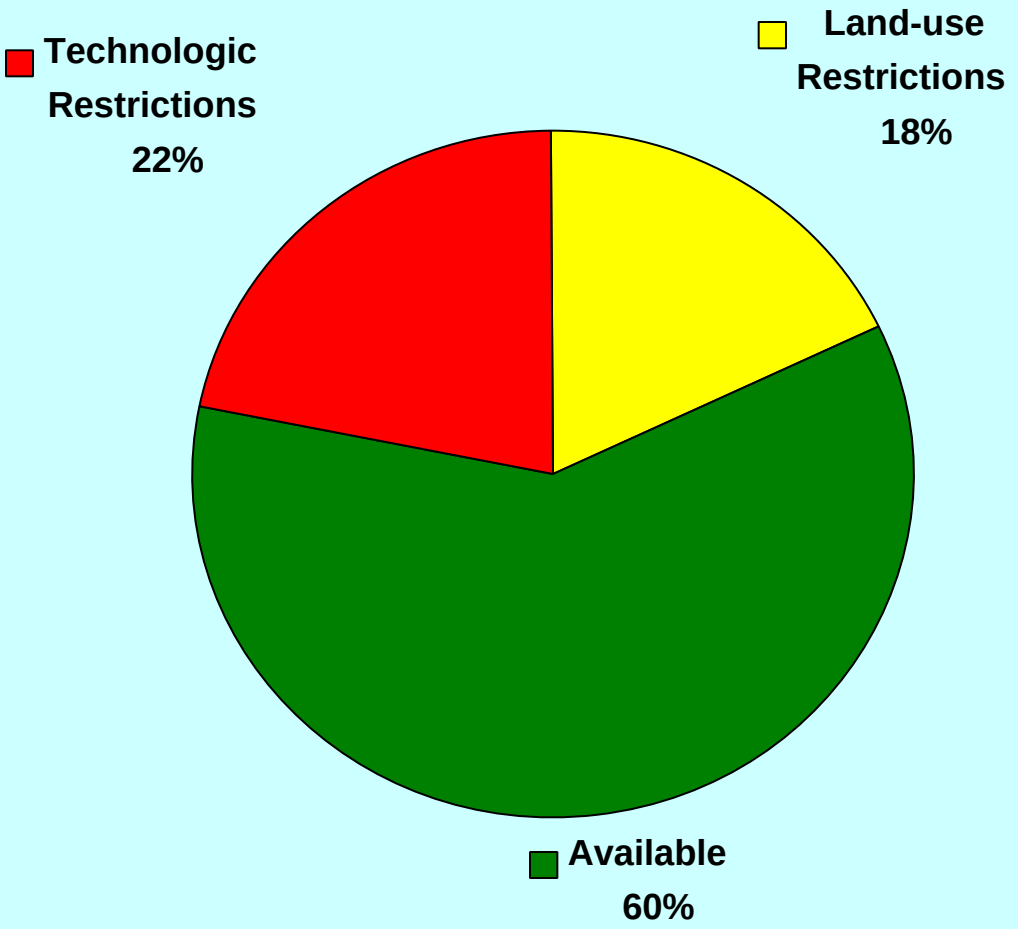
Available:
2.7 billion tons
60% of original



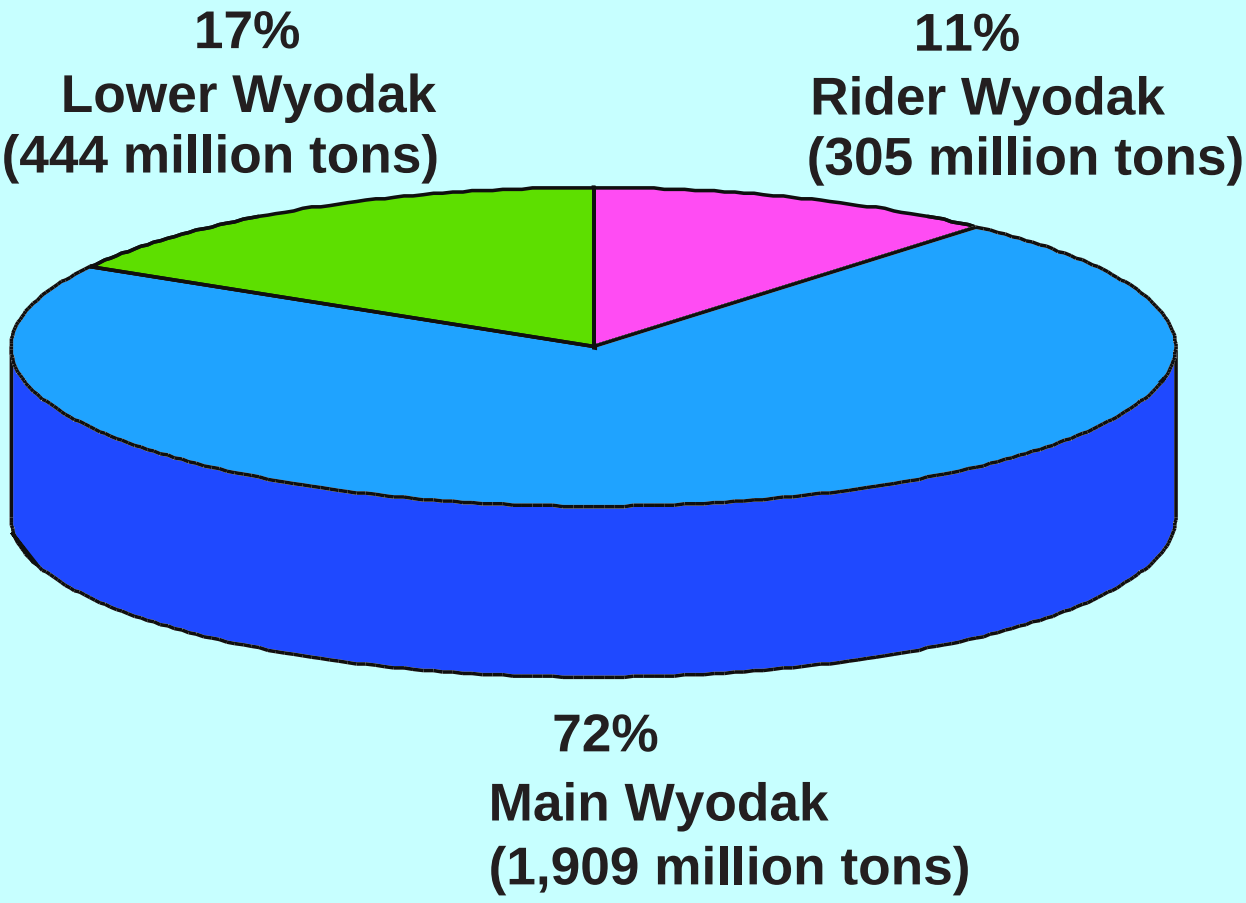
This USGS study shows that approximately 60 percent (2.7 billion tons) of the total 4.4 billion tons of coal in the quadrangle is available for development.

Results of Hilight Quadrangle Coal Availability Study by USGS

Original Coal: 4.4 Billion Tons



Land-use Restrictions	18 %
Technologic Restrictions	22 %
Available	60 %



The total available coal (fig. PAR-2) is composed of these three beds.

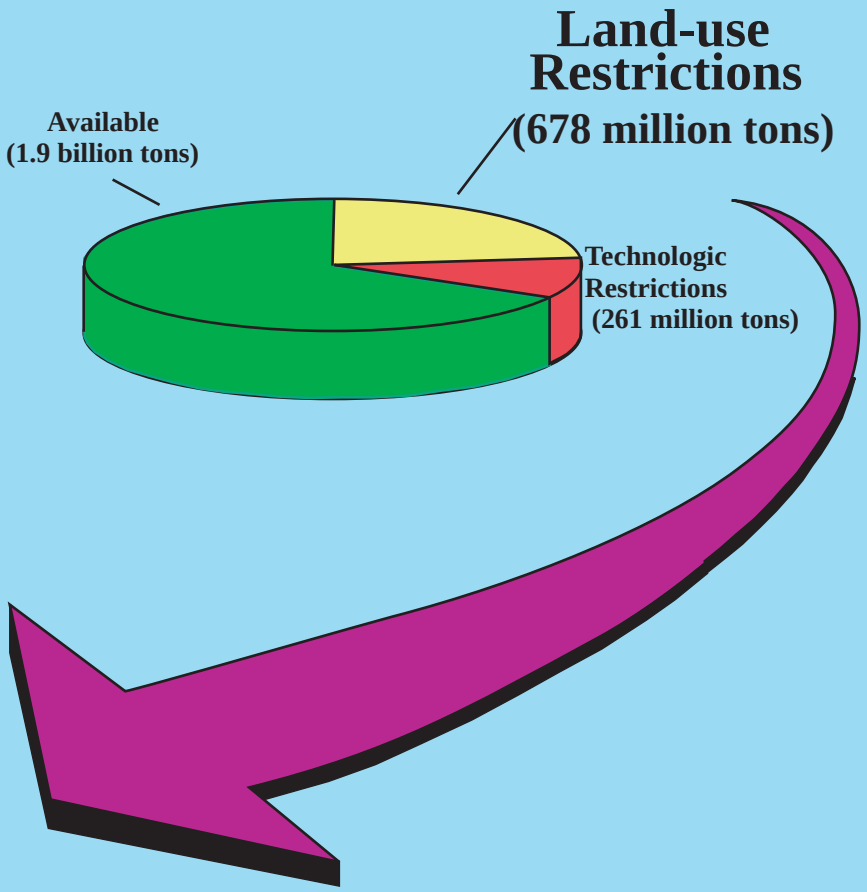
Sixty percent of the total resources, or 2.7 billion tons, is available for mine development.

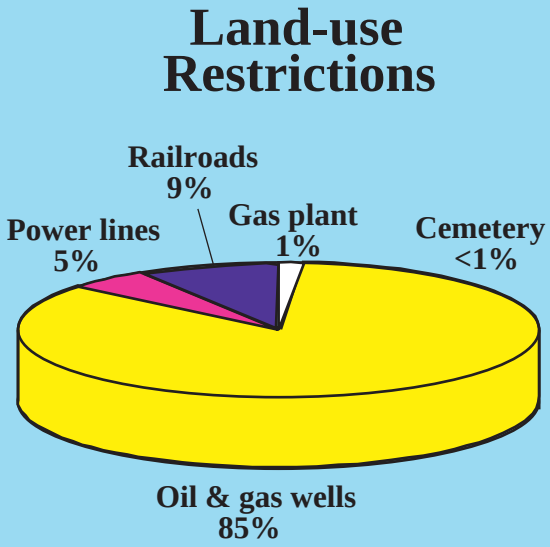
Main Wyodak coal bed

67% Available

24% Restricted by land-use considerations

9% Restricted by technologic considerations





Comparing resource calculations

The Rider Wyodak, Main Wyodak, and Lower Wyodak coal beds together contain 3.8 billion tons, as calculated for this coal availability study. In another study, Ellis and others (1999, and Chapter PN) calculated that the Wyodak (-Anderson) coal interval contains 3.5 billion tons in the Hilight quadrangle. These two resource estimates are quite similar, considering that the Wyodak coal beds were designated somewhat differently in the two studies.

Part 4. U.S. Bureau of Mines study of coal availability *and recoverability* in the Hilight quadrangle

Determining the amount of coal that is profitable to mine

Location of the Hilight quadrangle

COAL RECOVERABILITY STUDIES

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- minus -

MINING LOSSES

- minus -

WASHING LOSSES

- equals -

RECOVERABLE RESOURCES

- minus -

MINABLE RESOURCES TOO COSTLY TO EXTRACT

- equals -

ECONOMICALLY RECOVERABLE RESOURCE

(Reserve)

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Helpful concepts

- **Some factors (such as coal thickness and overburden thickness) are considerations in both availability and recoverability calculations. The recoverable resource is a part or a subset of the available resource.**

  For example, coal beds that are thick enough to be considered available resources may be too thin *to be profitably mined*, and thus would not be part of the recoverable coal estimate.

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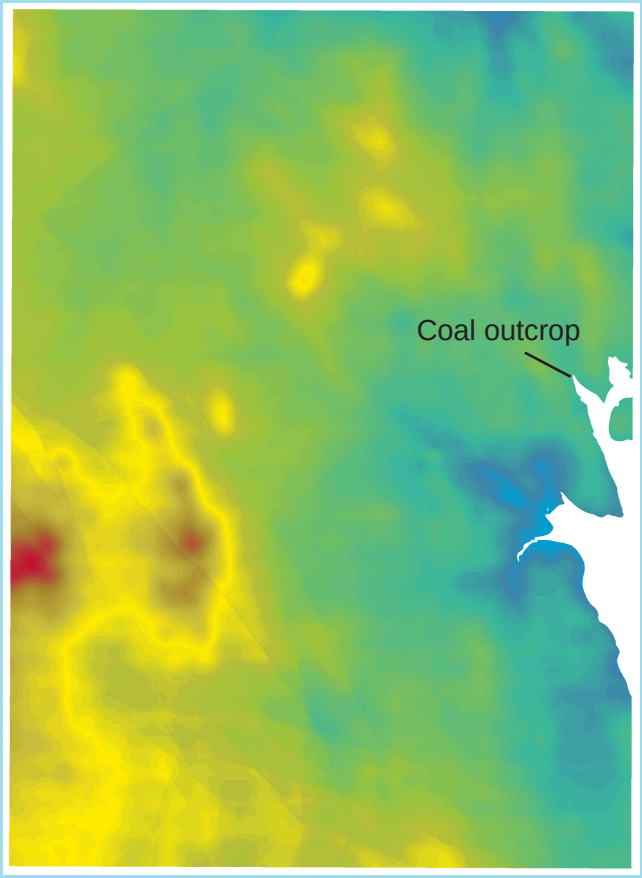
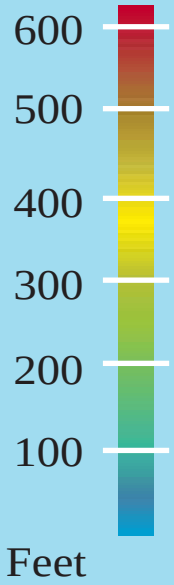
Hilight quadrangle



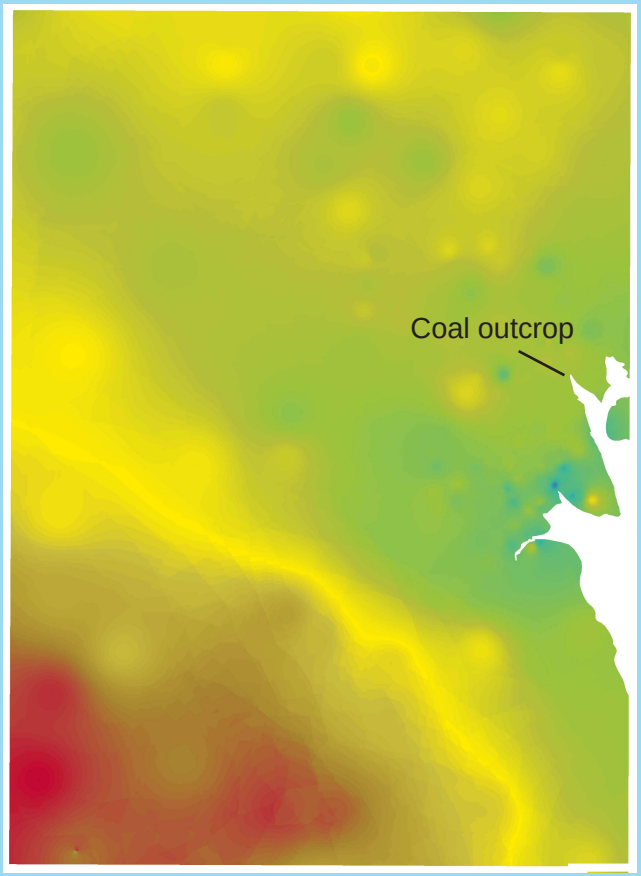
3 Miles

Thickness of overburden and interburden to be removed during mining



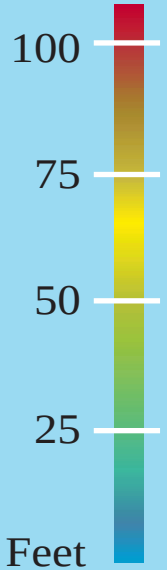
The coal recoverability process calculates the amount of overburden and interburden (waste rock) which would need to be removed to access the coal beds of interest.

Hilight quadrangle



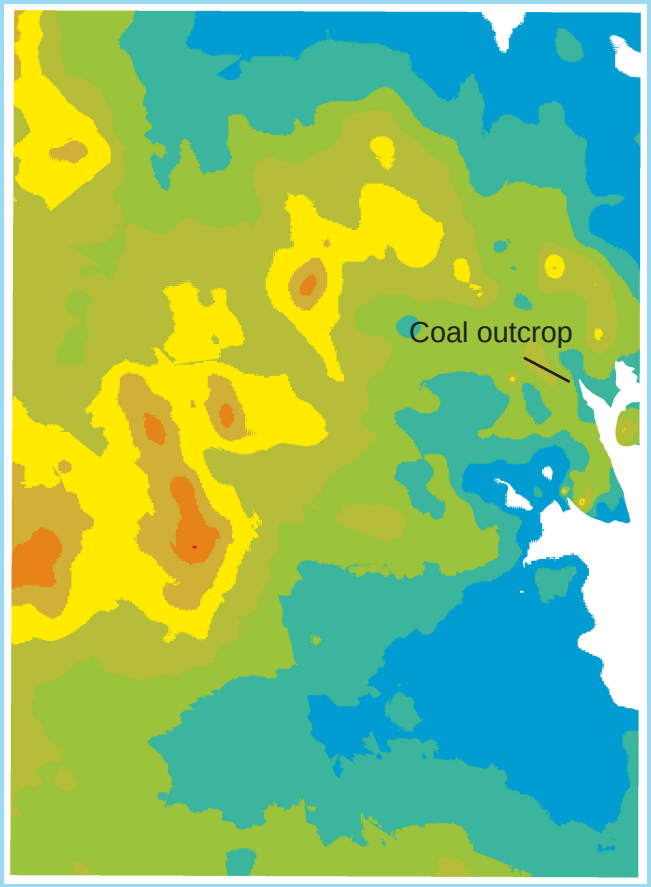
Total coal thickness

(Rider+Main+Lower Wyodak)



From drill hole data, we derive the total thickness of coal beds that meet the mining criteria for adequate thickness and coal quality.

Hilight quadrangle

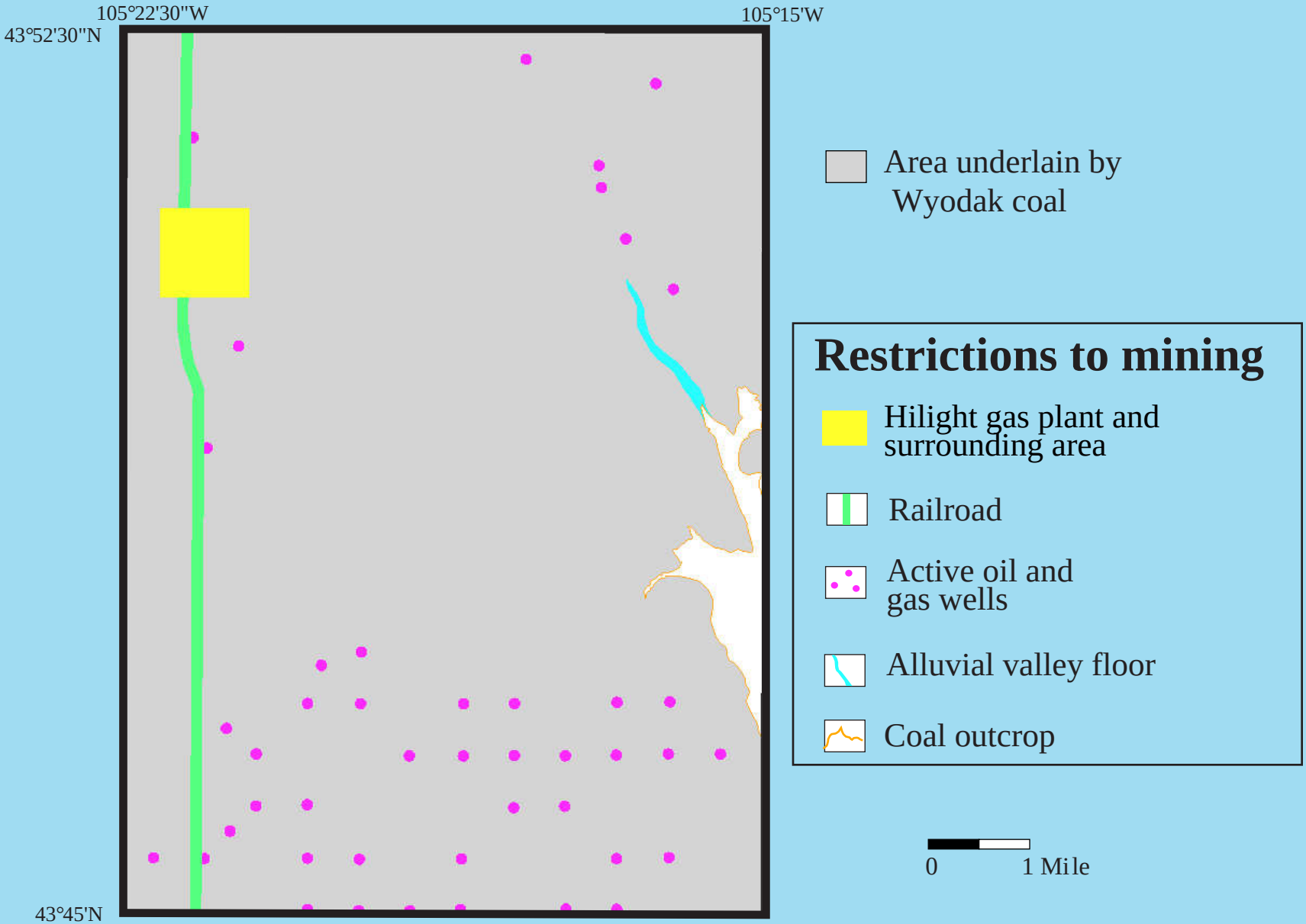


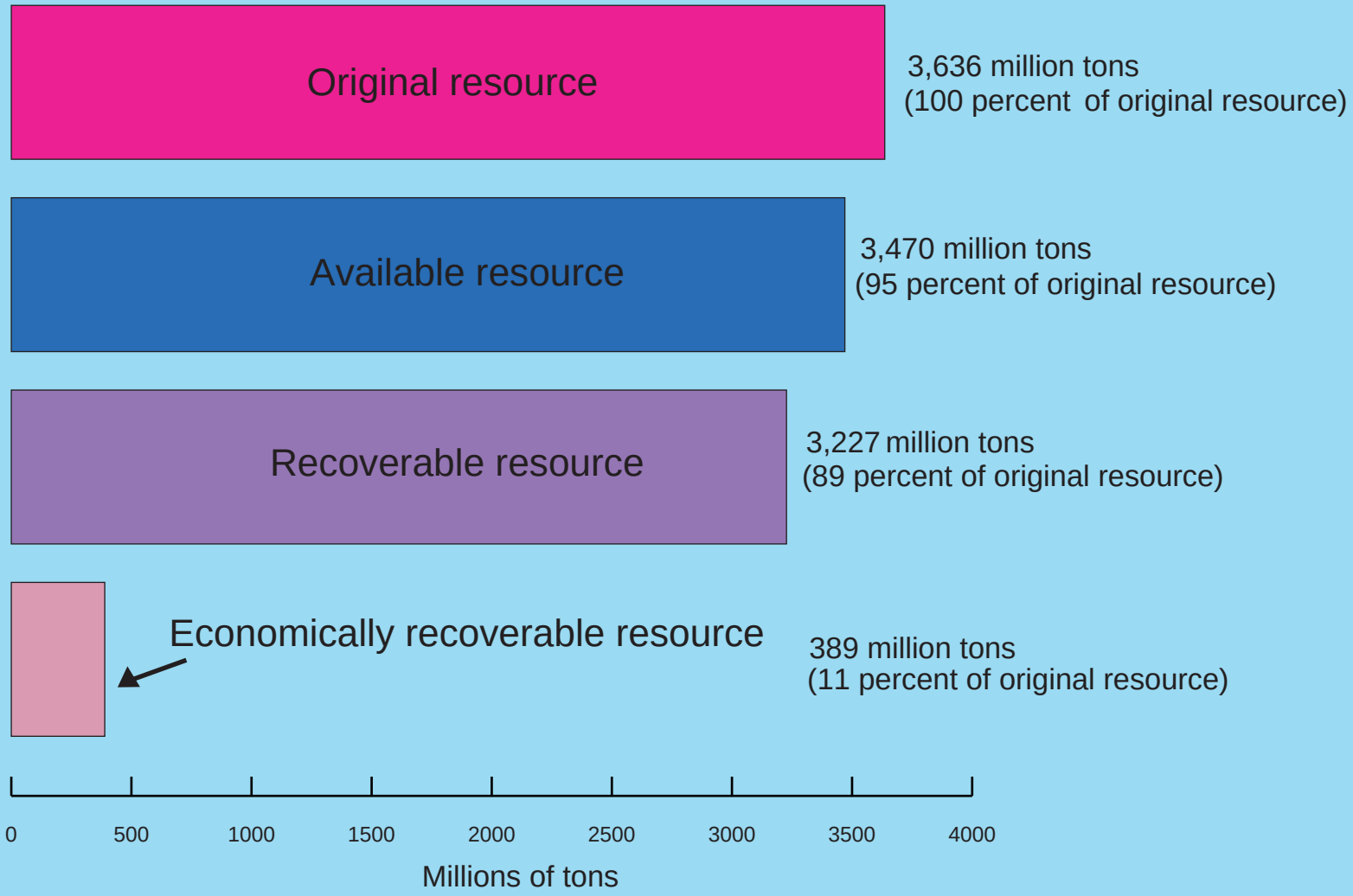
Ratio of waste rock to minable coal (Stripping ratio)

3 Miles

It is most economic to mine areas that have the lowest stripping ratios (for example, 1:1 or 2:1). In current practice in the Powder River Basin, it is not profitable for coal mines to operate in areas where the stripping ratio is higher than about 3:1.

U.S. Bureau of Mines availability study





U.S. Bureau of Mines results: Hilight coal availability and recoverability

U.S. Bureau of Mines results: Hilight coal availability and recoverability

Part 5. Coal availability in the Willow Crossing 7.5' quadrangle, Montana

A completed study in the Montana part of the Powder River Basin

• Click here to read Summary text in Appendix PAR-2

COAL AVAILABILITY STUDIES

ORIGINAL COAL

- minus -

AREAS ALREADY MINED

- minus -

LAND-USE RESTRICTIONS

- minus -

TECHNOLOGIC CONSIDERATIONS

- equals -

AVAILABLE COAL

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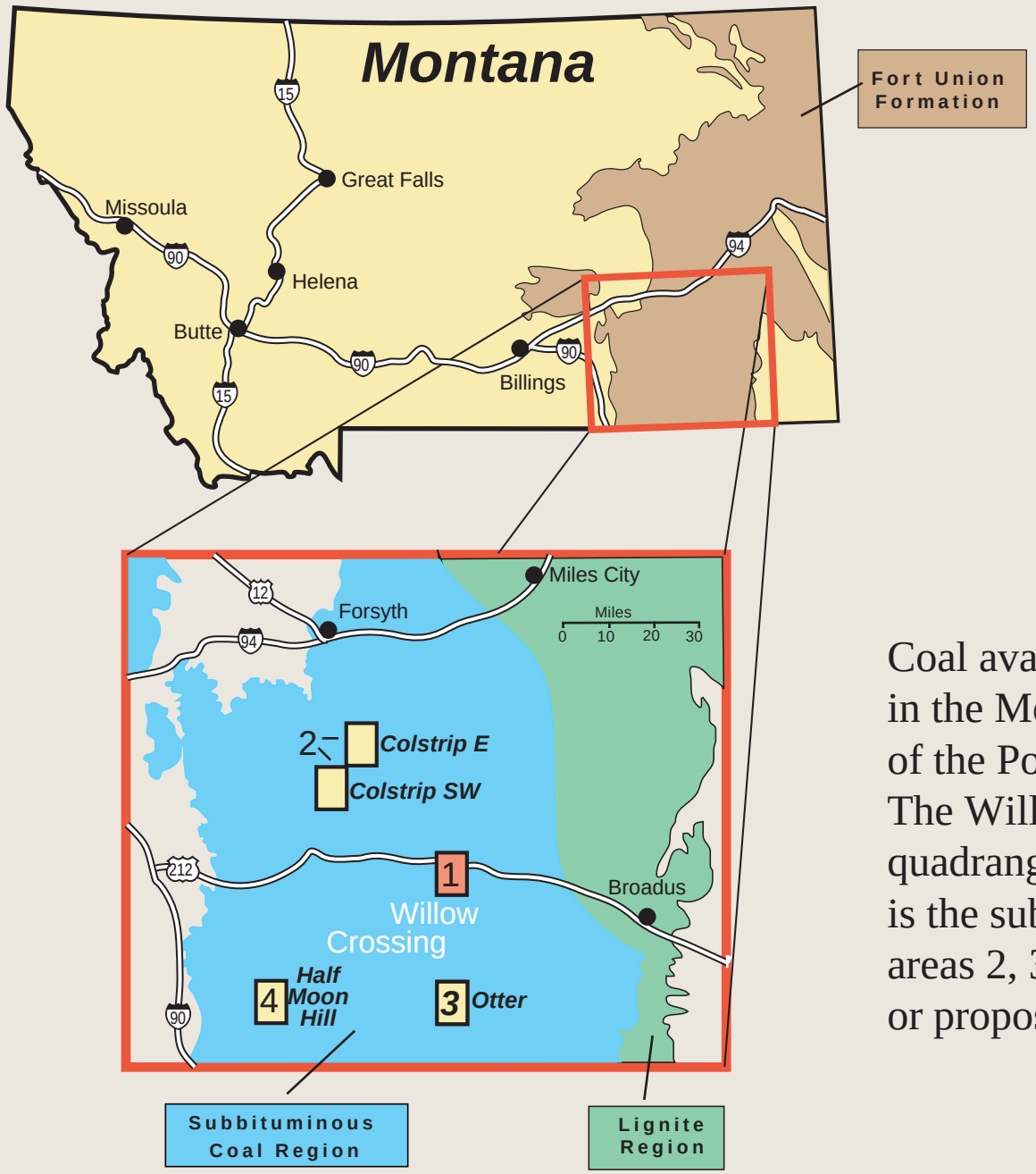
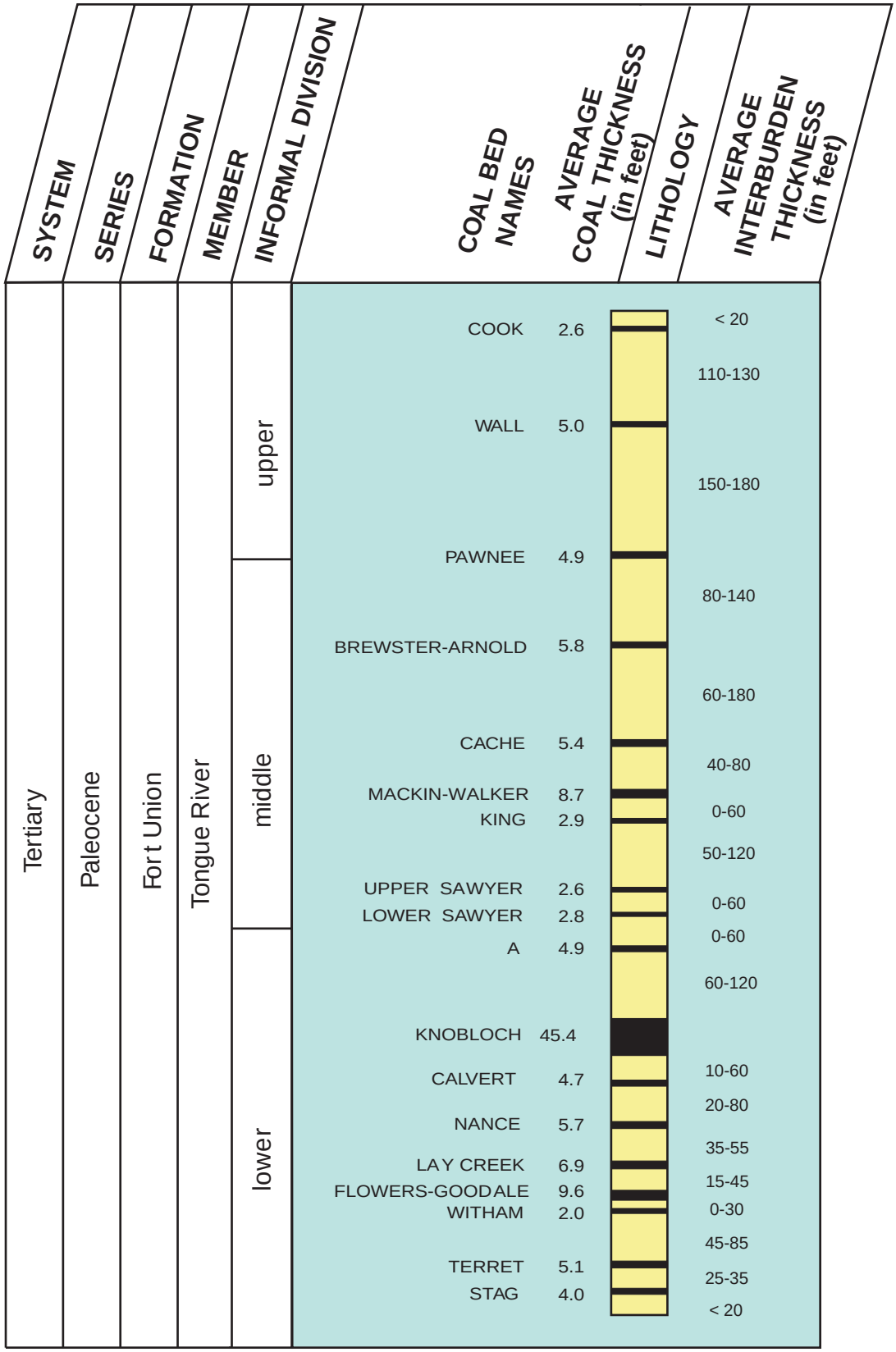


Coal availability study areas in the Montana part of the Powder River Basin. The Willow Crossing 7.5-minute quadrangle (number 1 on lower map) is the subject of this report. Studies in areas 2, 3, and 4 are underway or proposed.



Rocks between the coal beds are sandstone, siltstone, shale, claystone, and clinker.

Generalized composite stratigraphic section for the Willow Creek quadrangle

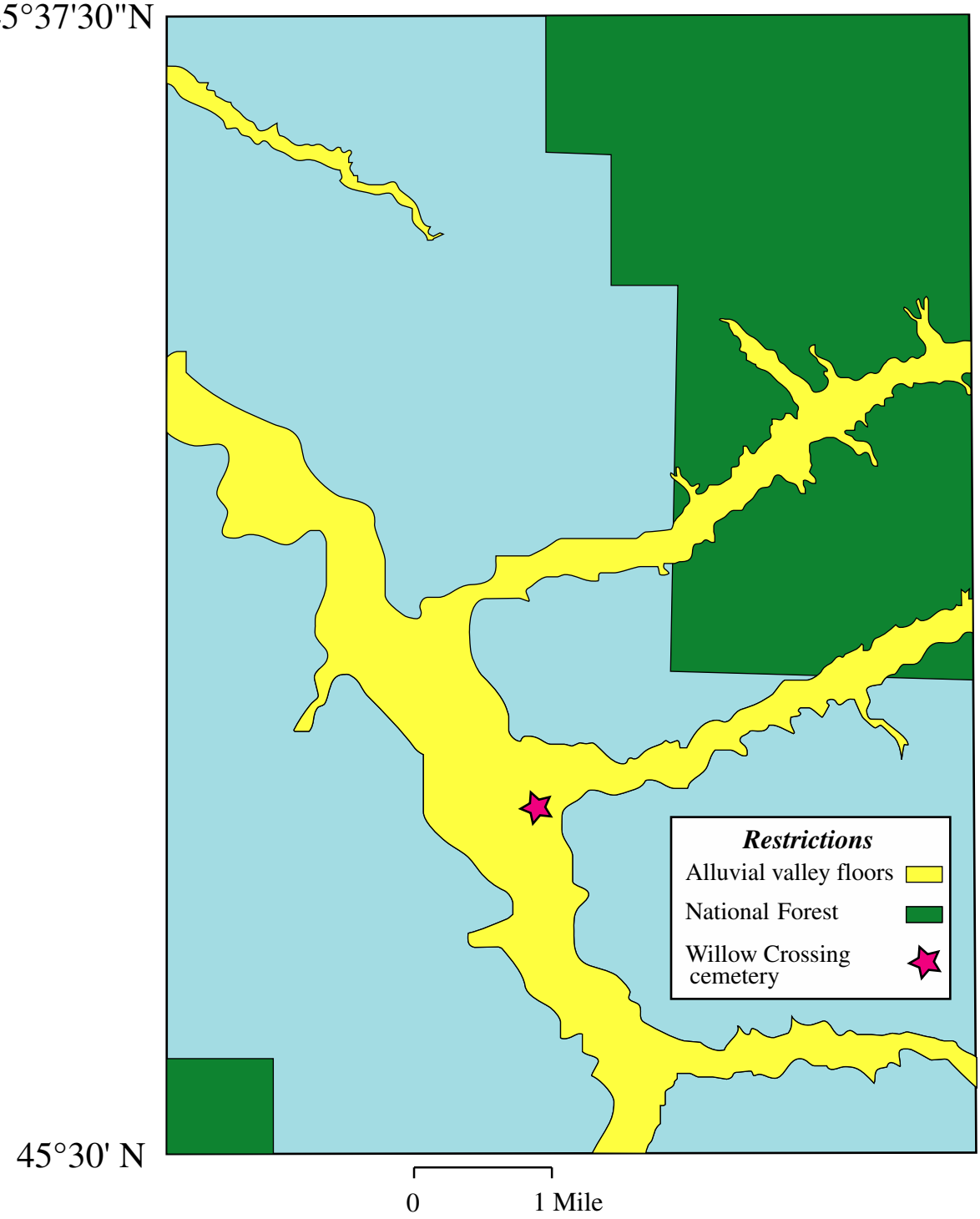


Figure PAR-3. Mining restrictions in the Willow Crossing quadrangle. These areas are not available for surface mining because of land-use or technologic restrictions.

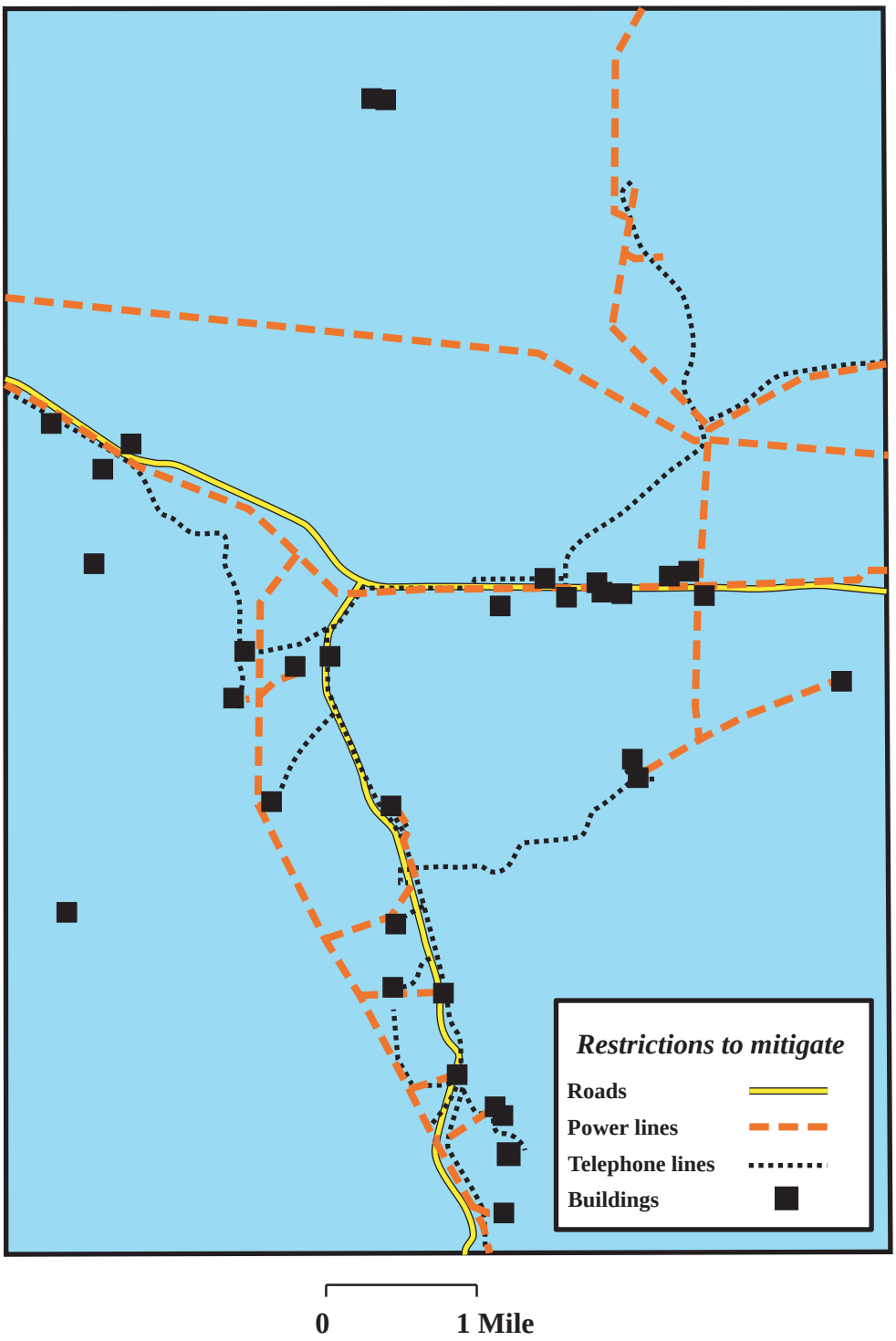
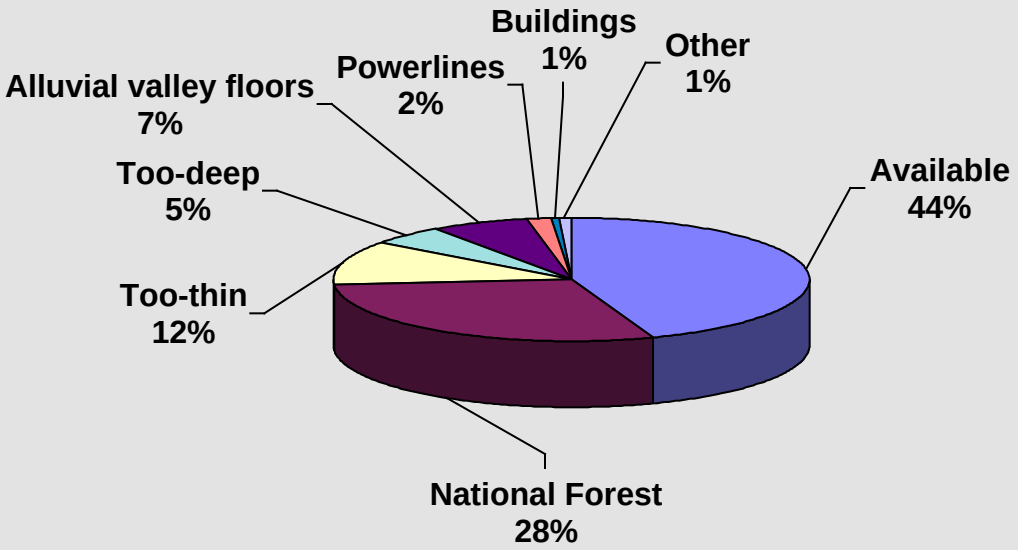
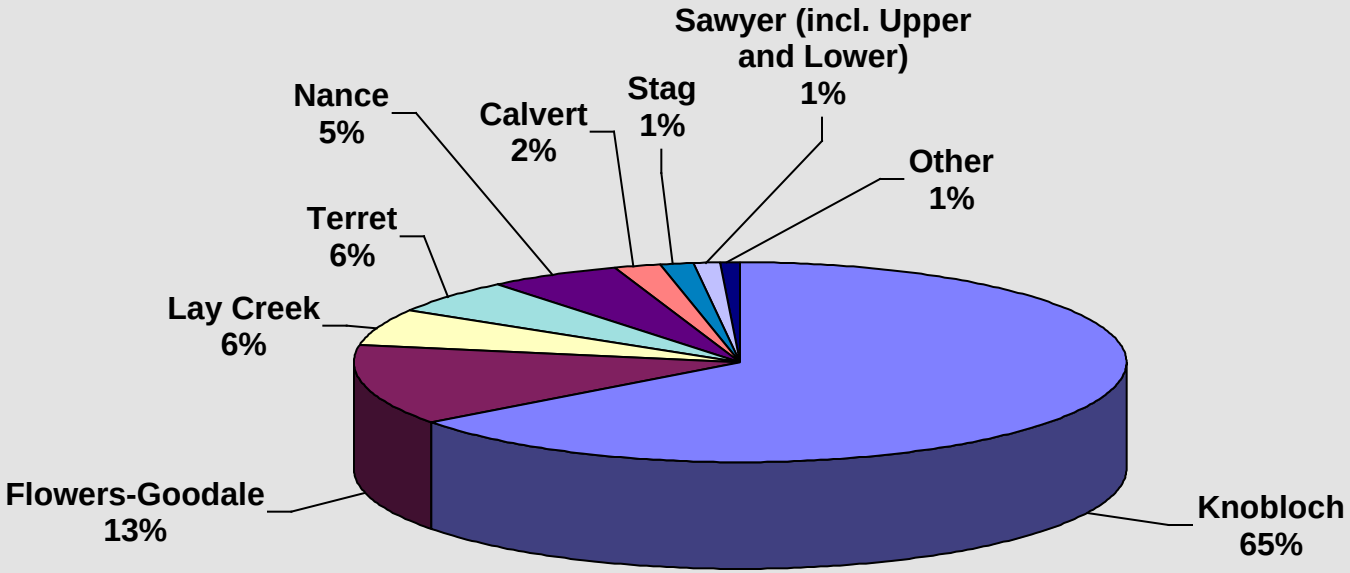


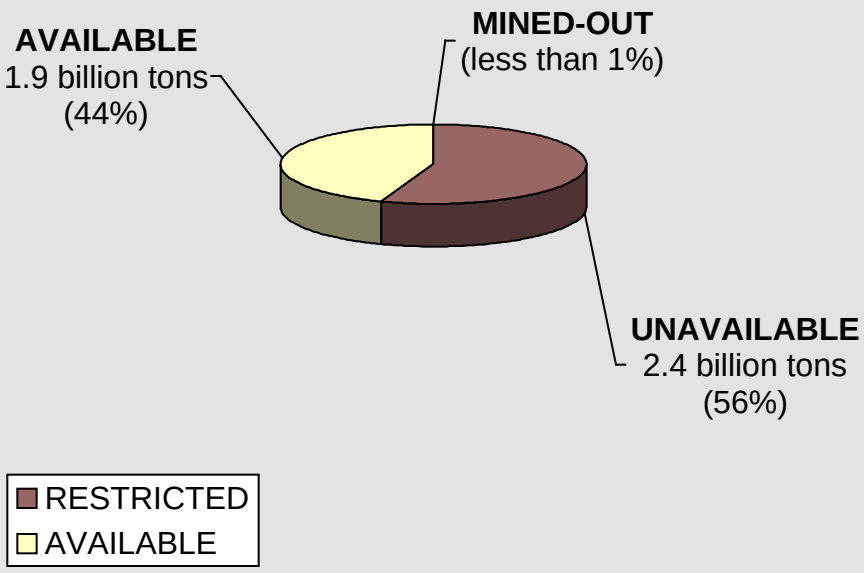
Figure PAR-4. Additional restrictions affecting mining in the Willow Crossing quadrangle. These land-use restrictions encompass both unsuitable areas and multiple-use areas where mitigation would be necessary in order to mine.



This chart shows the percentage of the original coal resource that is contained in each mining restriction and the percentage that is available. Total unavailable coal in the Willow Crossing quadrangle is 2.4 billion tons.



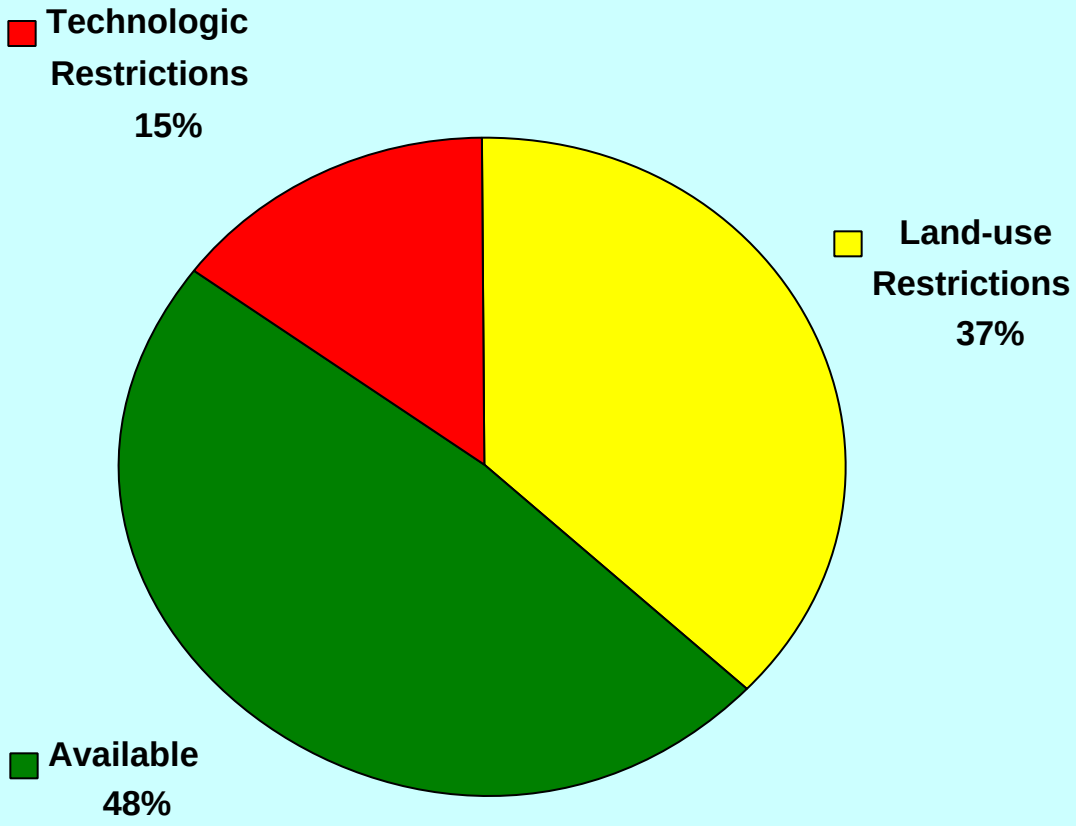
This chart shows the percentage of the total available resource contained in each coal bed. The total available resource in the Willow Crossing quadrangle is 1.9 billion tons.



Results of the availability study of the Willow Crossing quadrangle (under restrictions shown in fig. **PAR-3** and fig. **PAR-4**).

Results of the Willow Crossing Coal Availability Study (Using only restrictions in fig. PAR-3)

Original Coal: 4.3 Billion Tons



Land-use Restrictions	37 %
Technologic Restrictions	15 %
Available	48 %

Classification of restraints to coal mining in the Willow Crossing quadrangle

TYPE	CATEGORIES	
	TECHNOLOGICAL	LAND-USE
Restrictions to mining	COAL THICKNESS OVERBURDEN THICKNESS	ALLUVIAL VALLEY FLOORS NATIONAL FOREST LANDS CEMETERIES
Restrictions that are commonly mitigated		INHABITED BUILDINGS TELEPHONE LINES POWER LINES ROADS

Summary of tonnages for original, mined-out, remaining, restricted, and available coal resources in the Willow Crossing quadrangle
(in thousands of short tons; rounded to whole tons)

COAL BED	ORIGINAL	MINED-OUT	REMAINING	RESTRICTED	AVAILABLE
Cook	12	0	12	12	0
Wall	131	0	131	131	0
Pawnee	2,268	0	2,268	2,268	0
Brewster-Arnold	9,657	0	9,657	9,657	0
Cache	13,337	0	13,337	13,337	0
Mackin-Walker	35,086	0	35,086	35,086	0
King	10,580	0	10,580	10,312	268
Upper Sawyer	13,415	0	13,415	11,232	2,183
Sawyer	72,689	114	72,575	58,595	13,980
Lower Sawyer	20,383	0	20,383	15,787	4,596
A	55,321	0	55,321	39,403	15,918
Knobloch	1,973,875	0	1,973,875	730,787	1,243,088
Calvert	235,873	0	235,873	197,975	37,898
Nance	346,735	0	346,735	242,067	104,669
Lay Creek	364,679	0	364,679	251,451	113,228
Flowers-Goodale	556,163	0	556,163	303,231	252,932
Witham	91,928	0	91,928	91,928	0
Terret	281,505	0	281,505	173,994	107,511
Stag	237,587	0	237,587	210,785	26,802
TOTAL	4,321,223	114	4,321,110	2,398,037	1,923,073

Part 6. The Middle Pod study area, Gillette Coalfield, Wyoming

Availability considerations in a large area of active coal mining

Factors in selecting study areas (fig. PAR-1)

- Presence of Coal Resource
- Mining Activity—Past and Current
- Geologic and Cultural Characteristics
- Resource Management Issues
- Data Accessibility

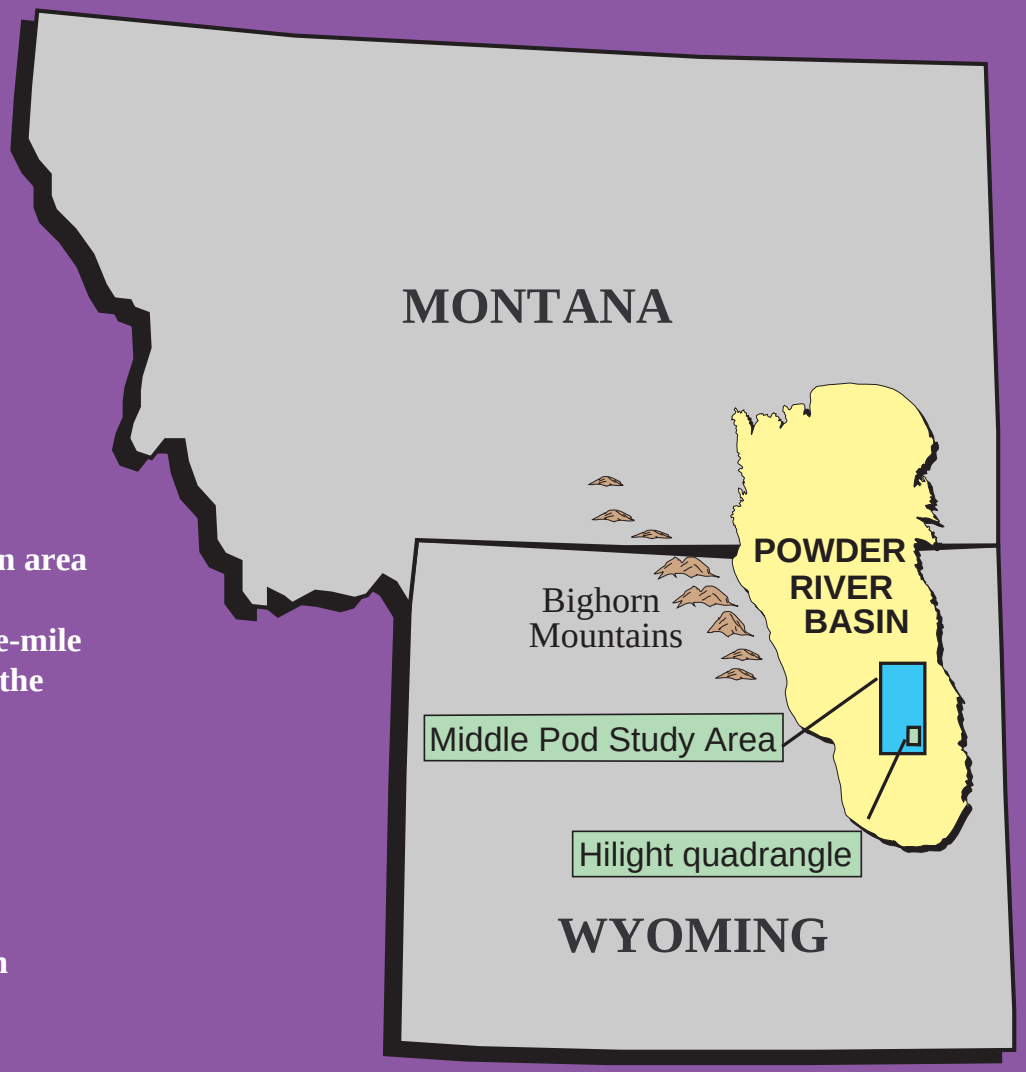
Middle Pod of the Gillette Coalfield

The USGS designed this study to calculate available and recoverable coal in a large area of the Powder River Basin and to better characterize the extensive Wyodak coal deposit in the Gillette coalfield.

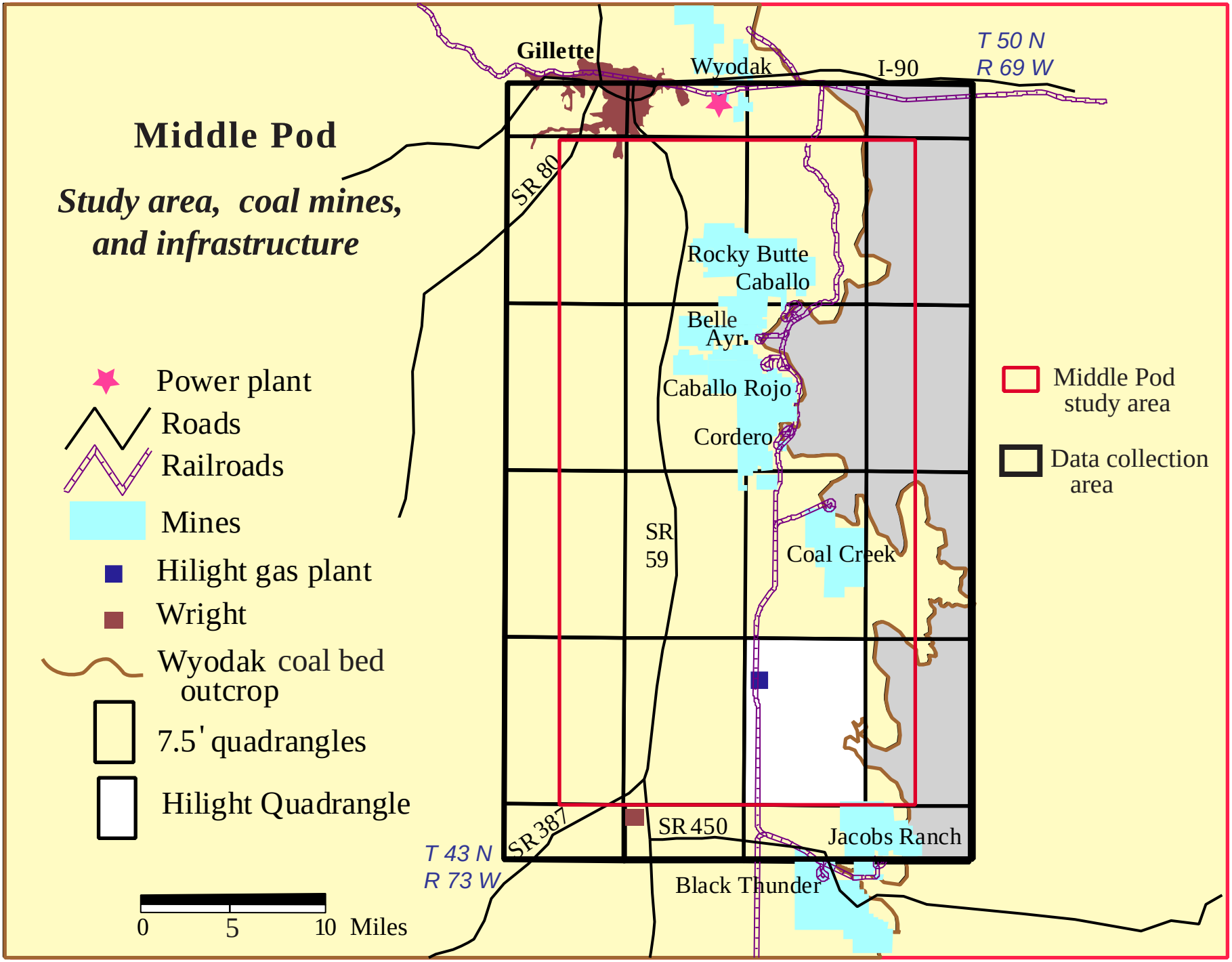
We delineated an area we call "Middle Pod" study area. It encompasses eight full 7.5-minute quadrangles and parts of eight additional quadrangles; the total area is about 600 square miles. The full data-collection area extends three miles beyond the study area, in all directions. We examine data in this three-mile border to help us verify geologic trends within the study area.

The Middle Pod study area is in the central part of the Wyodak coal deposit, which also has a Northern Pod and a Southern Pod. Each pod of the Wyodak coal deposit is currently being mined. The mines in the Middle Pod are shown in the next frame.

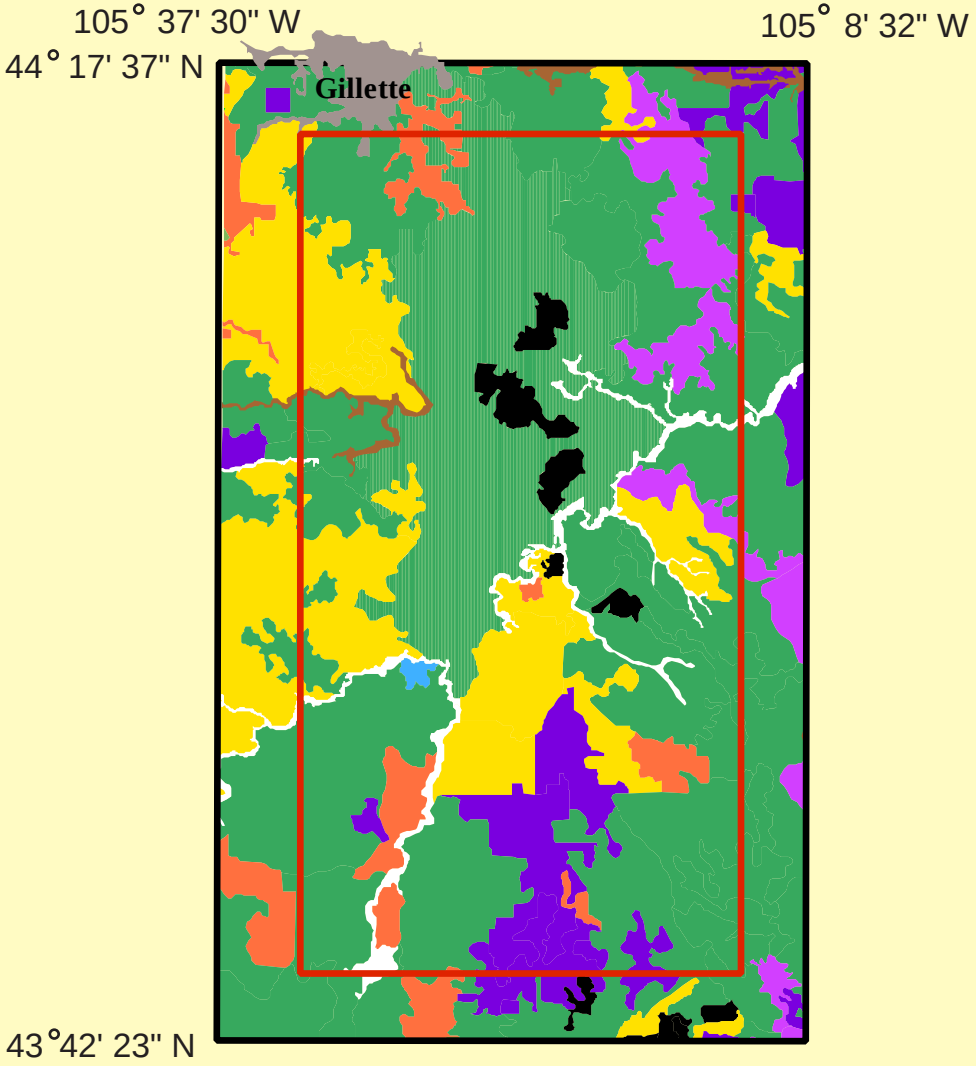
The Middle Pod study is just beginning. The graphics in this chapter illustrate some of the factors that will be considered when available and recoverable coal resources are calculated in this study area.



Index map showing the Middle Pod coal availability and recoverability study area. The Hilight 7.5-minute quadrangle is within the Middle Pod study area.

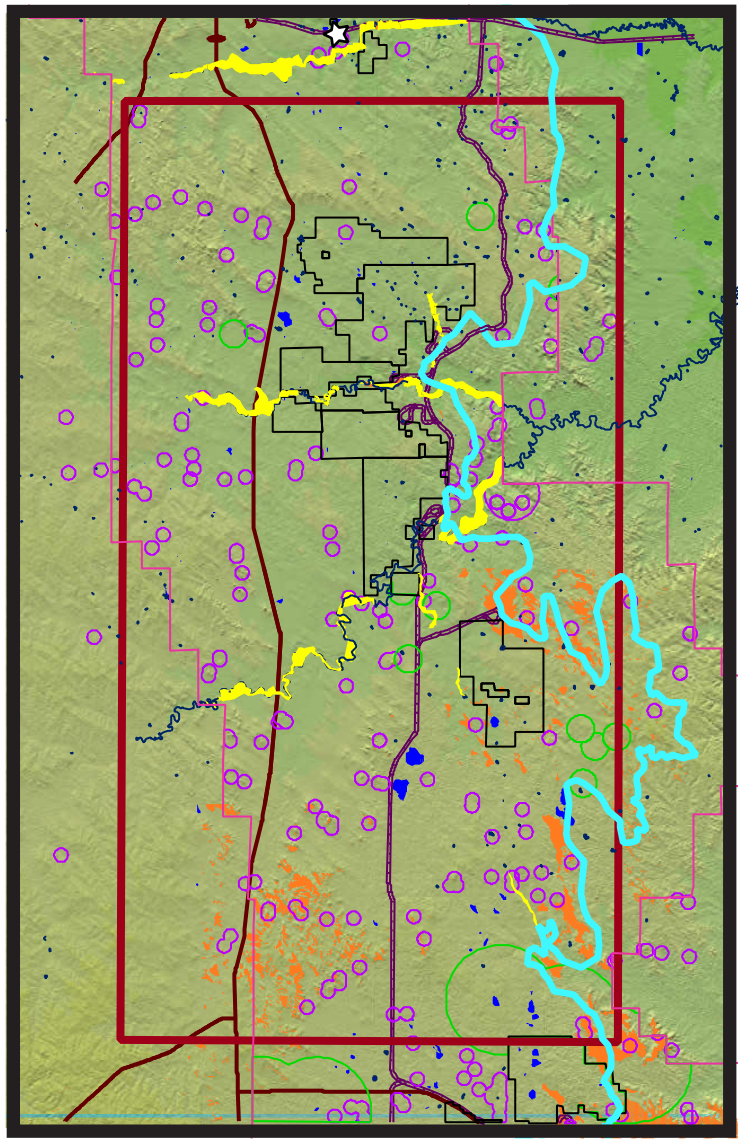


Land cover in the Middle Pod study area



Availability factors to be considered in the Middle Pod study area

- Sage grouse areas
- Raptor areas
- Perennial streams
- Alluvial valley floors
- Water bodies
- Power plant
- Roads
- Railroads
- Coal mines
- Wyodak coal outcrop
- Clinker areas

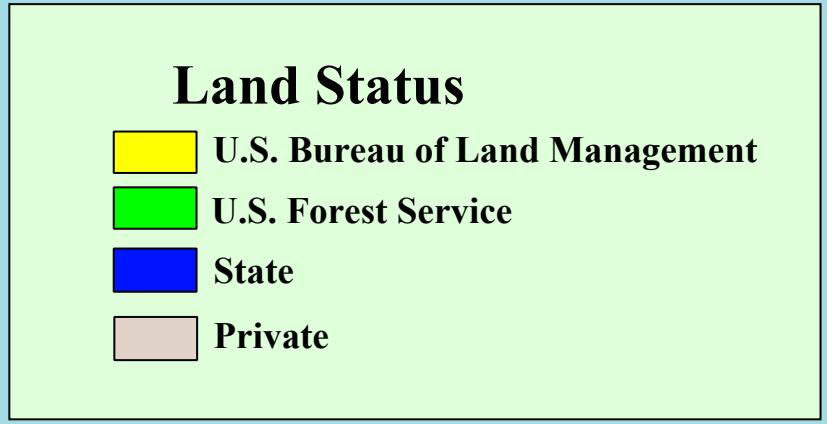


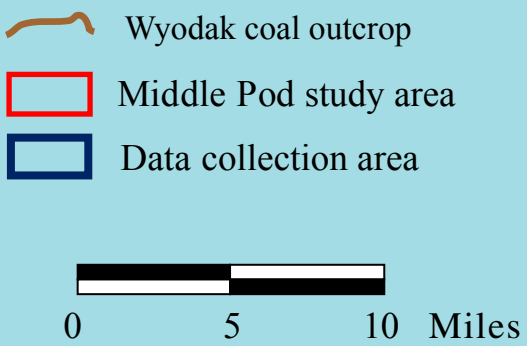
0 5 Miles

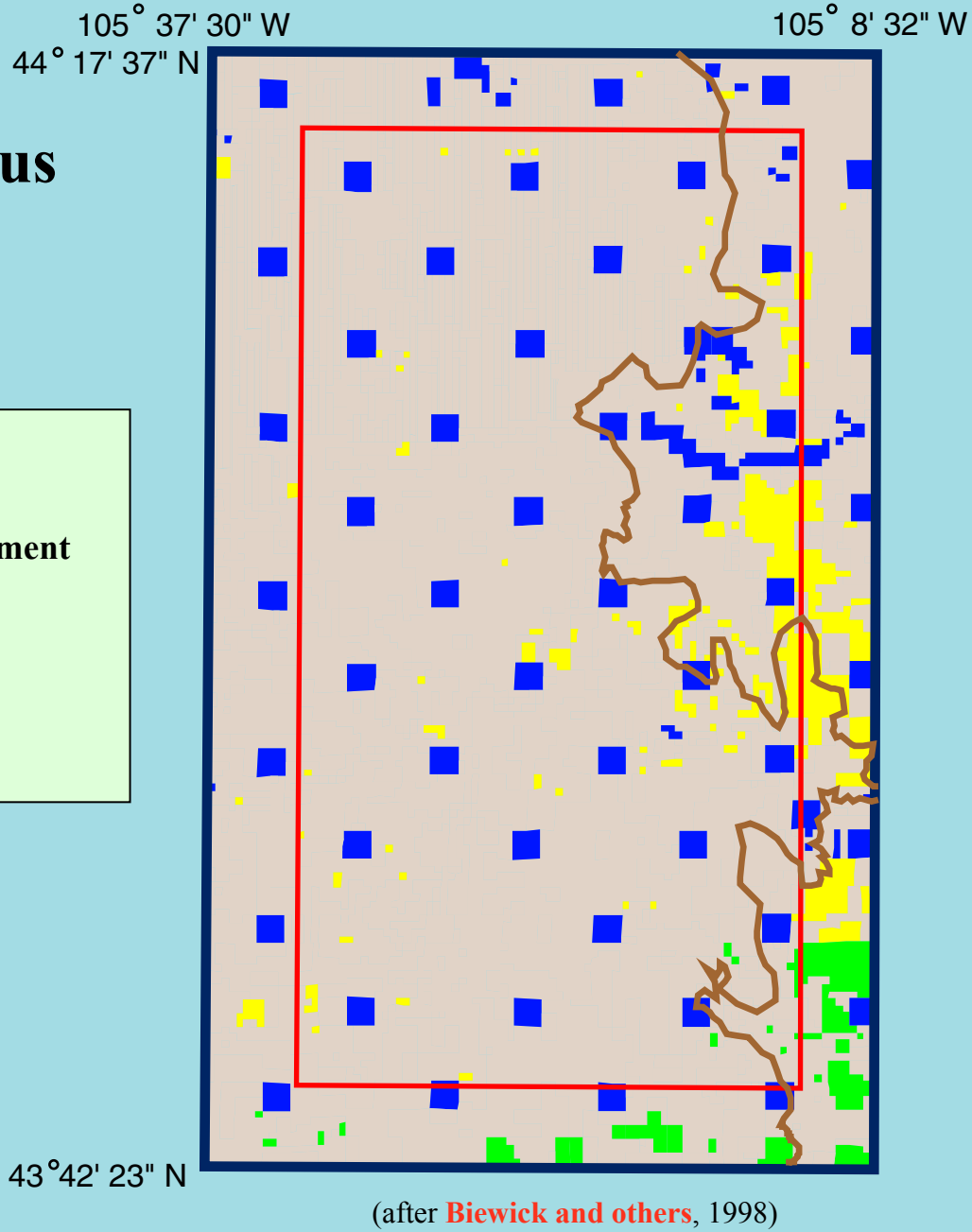
- Middle Pod study area
- USGS data collection area
- Area in which BLM supplied land-use data

Surface ownership status

5.9 percent of the surface is Federally owned



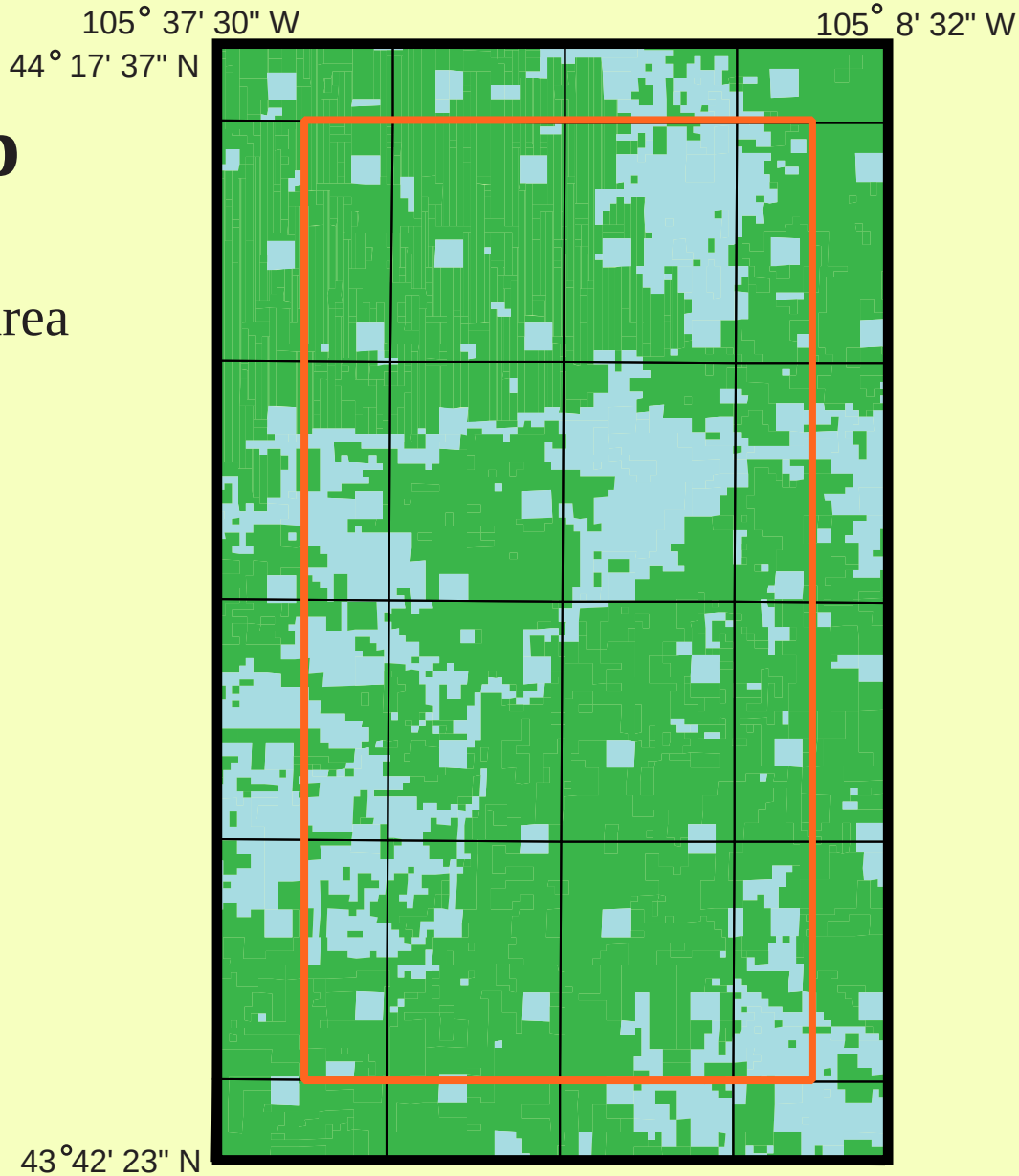




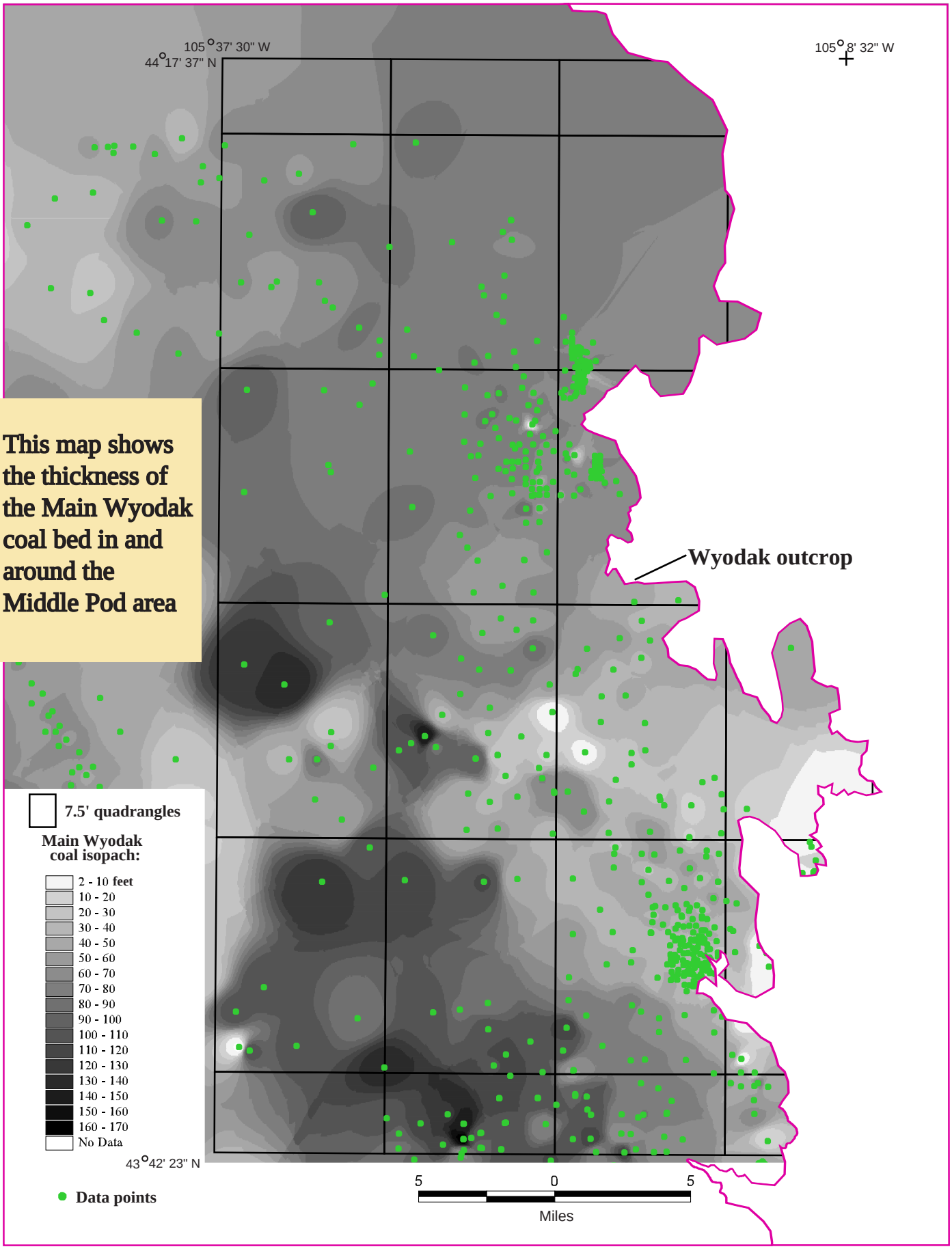
(after Biewick and others, 1998)

Coal Ownership

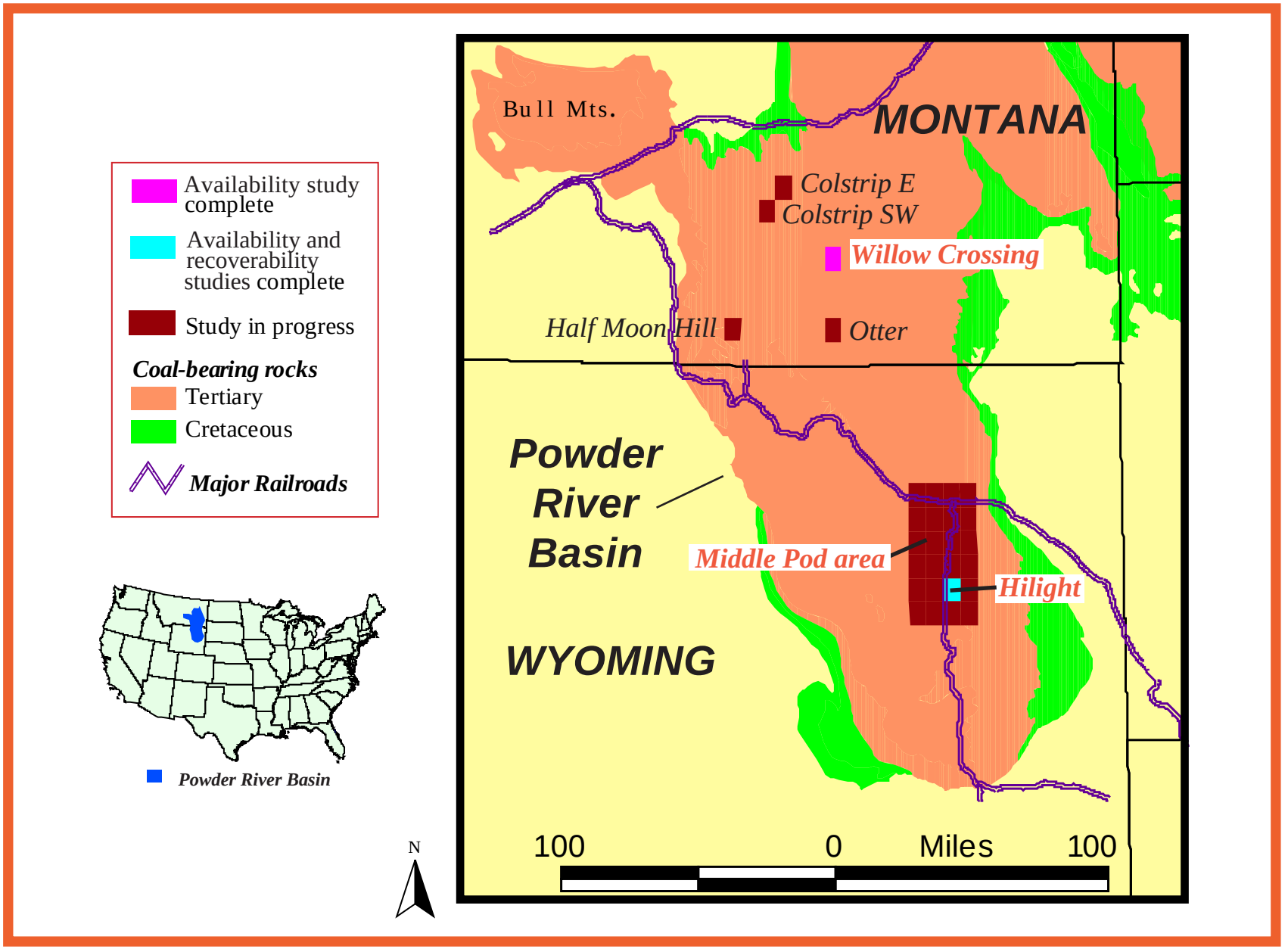
84 percent
of the Middle Pod study area
is underlain by
Federally owned coal



(after **Biewick and others,** 1998)



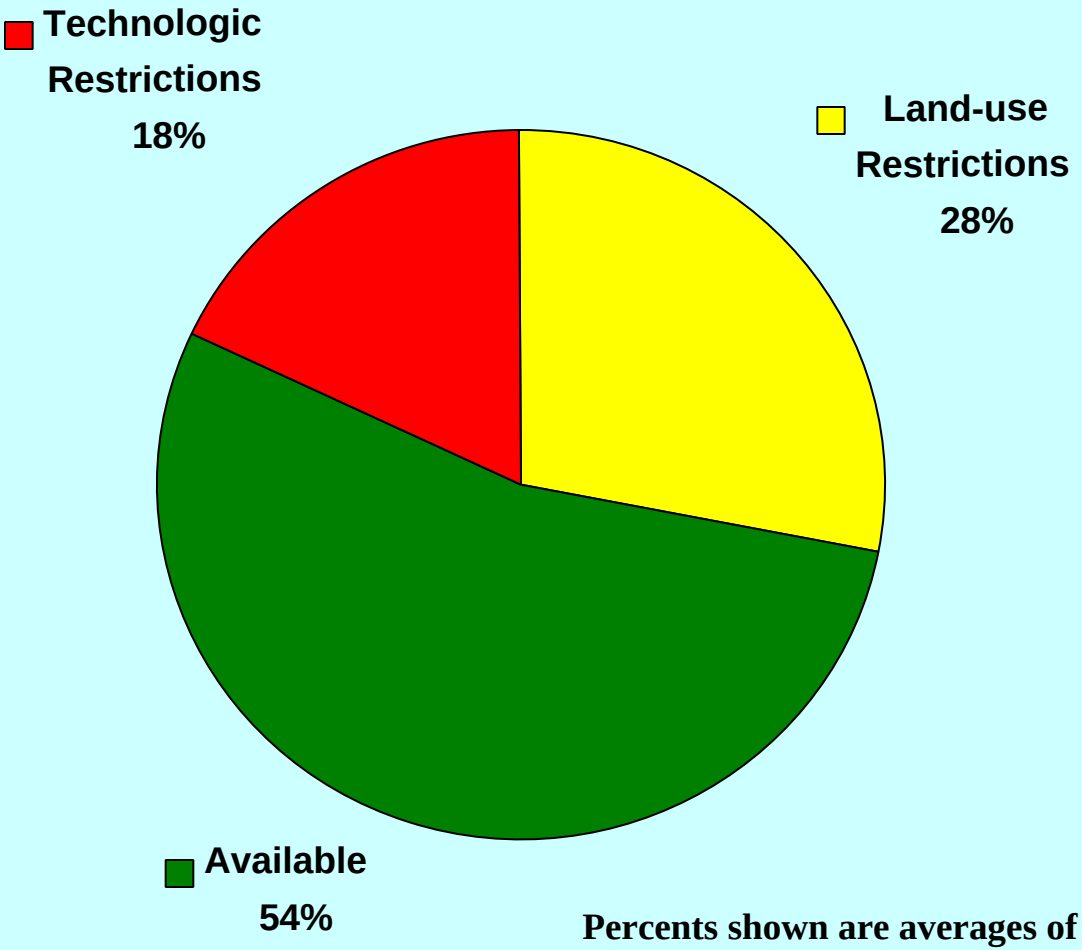
Part 7. Results and conclusions



Powder River Basin study areas for coal availability and recoverability.
All areas shown are 7.5-minute quadrangles except the Middle Pod area.

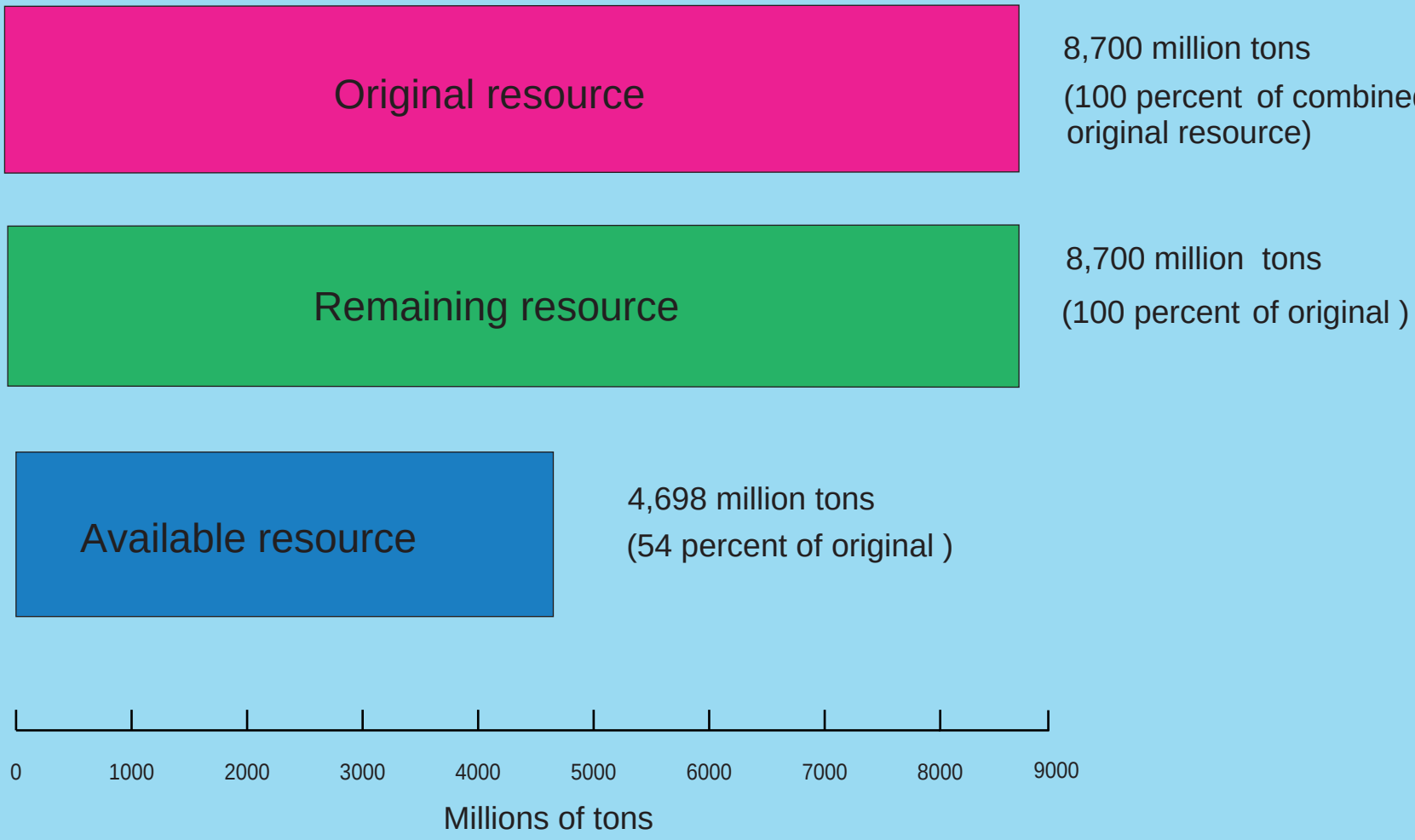
Averaged Results:
Hilight and Willow Crossing Availability Studies

Combined Original Coal: 8.7 Billion Tons



Land-use Restrictions	28 %
Technologic Restrictions	18 %
Available	54 %

Percents shown are averages of values from the two completed studies.
Hilight values are taken from the USGS availability study.

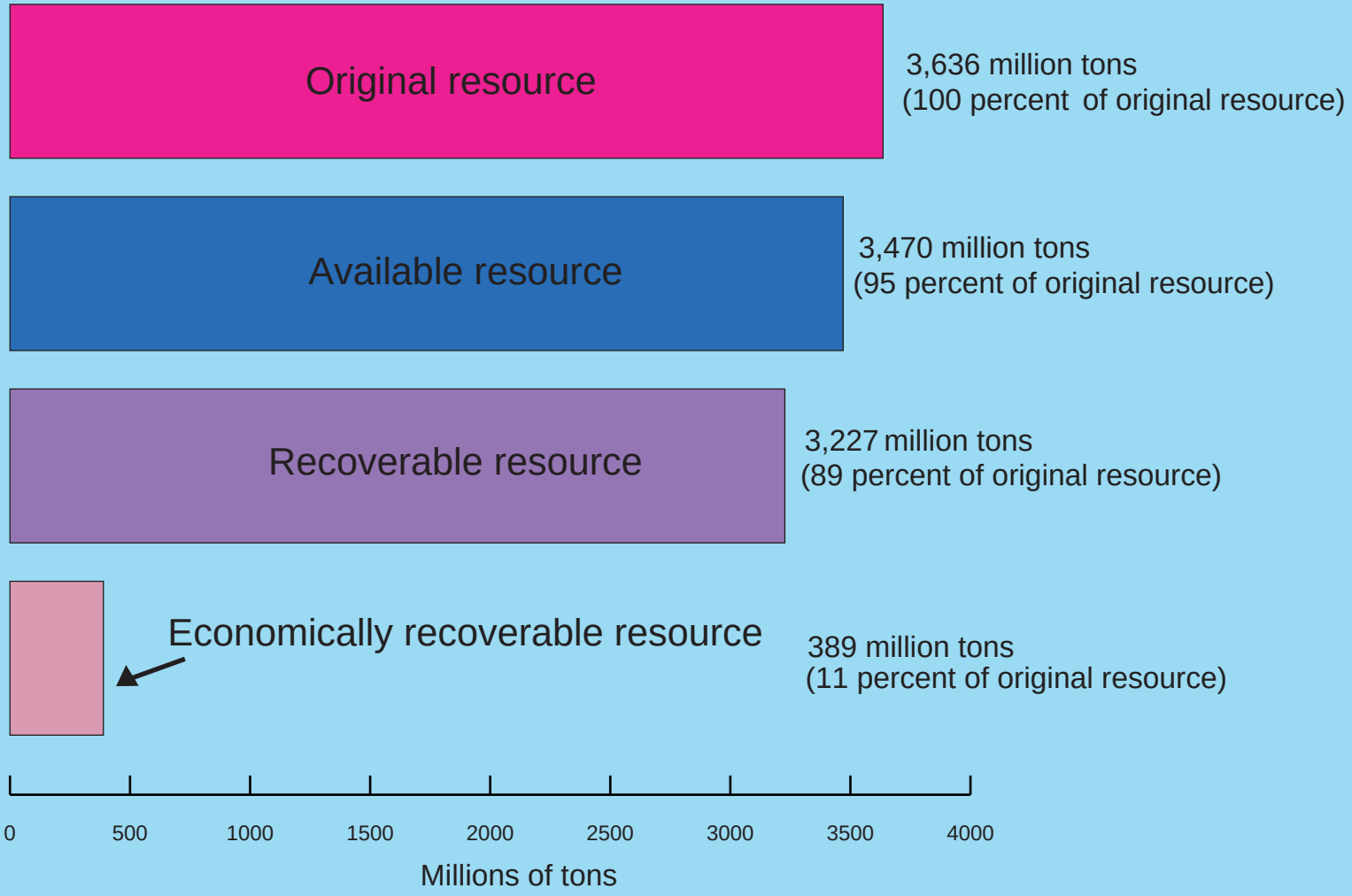


Combined results: Hilight (USGS study) and Willow Crossing availability studies

Coal recoverability terms

- ***Recoverable Resource*—That part of the available coal that is left after normal mining and cleaning losses are subtracted. Costs involved with the extraction and cleaning of the coal are not considered, nor is the potential selling price of the coal.**

- ***Economically Recoverable Resource*—That part of the recoverable coal that can be mined, cleaned, and marketed at a profit (depends on the mine location, the characteristics of the coal bed, the quality of the coal, and the mining methods used). Also known as a reserve.**



U.S. Bureau of Mines results: Hilight coal availability and recoverability*

** See Table PAR-1 for study criteria*

U.S. Bureau of Mines results*: Hilight coal availability and recoverability

***See Table PAR-1 for study criteria**

Conclusions about available and recoverable coal in the Powder River Basin

- The average of the two availability studies in the Basin show that 54 percent of the original coal is available for development. Land-use restrictions remove about 28 percent of the original coal from development; technological considerations remove another 18 percent.

- The U.S. Bureau of Mines study showed that only 11 percent of the original coal resource calculated for the Hilight quadrangle is economically recoverable.

- Many availability considerations in the Powder River Basin can be mitigated so that mining can still proceed. However, mitigation might add complexity and cost to the mining operation.

General findings, Coal availability and recoverability

- Methodologies for determining availability and recoverability can be applied routinely to future coal production regions, including multiple-quadrangle areas.
- Only a fraction of the coal resource is available for development. Even less of the resource is economically recoverable.
- Traditional coal-producing regions and local economies may be severely impacted by lack of economic coal reserve.
- National, regional, and local planners are becoming aware of these projections.
- Coal availability and recoverability 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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- **Molnia, Carol L., Biewick, Laura R.H., Blake, Dorsey, Tewalt, Susan J., Carter, M. Devereux, and Gaskill, Charlie, 1997, *Coal availability in the Hilight quadrangle, Powder River Basin, Wyoming: a prototype study in a western coal field: U.S. Geological Survey Open-File Report 97-469.***

Available on the Web at:
http://energy.cr.usgs.gov:8080/coal/OF-97-469.html

Appendices

Appendix PAR-1. Summary text for Part 3.
"Results of the first western coal availability study—Hilight quadrangle, Powder River Basin, Wyoming"

Appendix PAR-2. Summary text for Part 5.
"Coal availability in the Willow Crossing 7.5-minute quadrangle, Montana"

Helpful concepts

- Restrictions to mining vary with location and with local and State land-management regulations. Thus, different study areas can have different restrictions and availability considerations.

- In the Willow Crossing summary text (Appendix PAR-2), the restriction classifications "Type 1" and "Type 2" are equivalent to "Category 1" and "Category 2," respectively, as used in the Hilight summary text (Appendix PAR-1).

- All tonnage figures are in short tons.

Appendix PAR-1

Summary text for Part 3 of Chapter PAR

RESULTS OF THE FIRST WESTERN COAL AVAILABILITY STUDY¾ HILIGHT QUADRANGLE, POWDER RIVER BASIN, WYOMING

By C.L. Molnia[1], L.R.H. Biewick[1], Dorsey Blake[1], S.J. Tewalt[2], M.D. Carter[2], and Charlie Gaskill[3]

Note: This text is modified from: Molnia, C. L., Biewick, L. R. H., Blake, D., Tewalt, S. J., Carter, M. D., and Gaskill, C., 1996, Results of the first western coal availability study—Hilight quadrangle, Powder River Basin, Wyoming, in Chiang, S.-H., ed., Coal— Energy and the Environment, 1996: Thirteenth Annual International Pittsburgh Coal Conference Proceedings, p. 798-803.

[1] U.S. Geological Survey, Denver, Colorado
[2] U.S. Geological Survey, Reston, Virginia
[3] U.S. Bureau of Land Management, Casper, Wyoming

ABSTRACT

The U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, Geological Survey of Wyoming, and U.S. Bureau of Mines, has produced an estimate of the amount of available coal in an area about 35 mi south of Gillette, Wyoming, where the Wyodak coal bed is, in places, more than 100 ft thick. Available coal is coal that actually is accessible for development under current regulatory, land-use, and technologic conditions. This first western coal availability study, in the Hilight quadrangle, has shown that approximately 60 percent (2.7 billion tons[4]) of the total 4.4 billion tons of original coal resources in the quadrangle is available for development (fig. PAR-5). Of this total 4.4 billion tons, 2.9 billion tons are contained in the Main Wyodak coal bed; 67 percent (1.9 billion tons) of this coal bed is considered available.

Local coal-development considerations include dwellings, railroads, pipelines, power lines, wildlife habitat (eagles), alluvial valley floors, cemeteries, the Hilight oil and gas field, and the Hilight gas plant. Some of these considerations would be mitigated so that surface mining could proceed; others presently preclude mining in their vicinity.

[4] All tonnage measurements in this report are given in short tons.

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Traditional Federal and State coal resource estimates have not taken into account the multitude of land-use, environmental, regulatory, and technologic restrictions affecting coal mining. This has led some Federal, State, and local planners to probably overestimate the future supply of the Nation's coal. A cooperative program, referred to as "Coal Availability," among the U.S. Geological Survey and other Federal agencies and State geological surveys, was initiated in 1987 to identify current 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).

Because the Coal Availability Program has been successful in the Eastern United States, there was great interest in extending the program to western coalfields to see what factors would be involved and how the process could be applied to the different geologic and mining conditions. This Hilight study is the first western Coal Availability study.

GEOLOGIC SETTING AND COAL MINING

The Powder River Basin covers about 22,000 sq mi in northeastern Wyoming and southeastern Montana. Along the eastern side of the Powder River Basin, the Fort Union Formation (Paleocene) contains some of the most significant 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 Wyoming part of the Powder River Basin provides about 20 percent of the coal produced annually in the United States (Mining Engineering, 1994).

The study site, the Hilight 7.5-minute quadrangle, is an area of about 50 sq mi and is located in Campbell County, Wyoming, about 35 mi south of the town of Gillette (fig. PAR-6). The Hilight quadrangle is situated between the Coal Creek mine (owned by Thunder Basin Coal Co., subsidiary of ARCO Coal Co.) and the Jacobs Ranch mine (owned by Kerr-McGee Coal Co.). There has been no commercial mining todate in the Hilight quadrangle, but the site of the formerly proposed Keeline coal mine (Neil Butte Co.) is fully within the quadrangle. The proposed productive capacity of that mine was to have been as much as 12 million tons annually.

The economic coal bed in the Hilight quadrangle is the Wyodak coal bed of the Tongue River Member of the Fort Union Formation (fig. PAR-7). We recognize three divisions of the Wyodak coal bed: Rider, Main, and Lower. The Main Wyodak bed is much thicker than the others; in places, it contains 120 ft of coal, and has several partings. Overburden thickness for the Main Wyodak coal bed ranges from 15 to more than 600 ft within the Hilight quadrangle.

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 moisture, mineral-matter-free basis (Neil Butte Company, 1985). On an as-received basis, heating value of the coal averages 8,350 BTU/lb; average moisture is 28 percent, ash content is 7.9 percent, and sulfur content is 0.6 percent.

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GENERAL FACTORS AFFECTING AVAILABILITY OF COAL RESOURCES

[Note: Not every factor listed will ultimately restrict coal mining in the quadrangle.]

UNSUITABILITY CRITERIA DETERMINATIONS

The coal unsuitability criteria listed in the Federal Regulations (43 CFR 3461) are applicable to the Hilight quadrangle. The unsuitability 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 U.S.C. 1201 et seq.). Within the Hilight quadrangle, the U.S. Bureau of Land Management (1984) has identified the following six elements of the unsuitability criteria:

- Railroad corridor
- Cemetery
- Dwellings
- Raptor sites, including golden eagles
- Lands in certain Federal systems
- Alluvial valley floor (potential)

AVAILABILITY FACTORS TO BE CONSIDERED IN ADDITION TO UNSUITABILITY CRITERIA

Other land-use conflicts		*½Geological and mining factors*
Pipelines	½	Active mines; previously mined areas
Hilight oil and gas field	½	Limit of coal¾ Outcrop and clinker
Hilight gas plant	½	Overburden depth
Power line	½	Overburden geochemistry
Gravel pits	½	Coal quality
Surface- and coal-ownership	½	Coal beds too thin
Roads	½	

GROUPING OF CONSIDERATIONS FOR USE IN AVAILABILITY CALCULATIONS

After studying local mining practices and consulting with the land-management agency, we grouped the factors affecting the availability of coal into two sets: those (Category 1) that were likely to be restrictions to a mining operation in the Hilight quadrangle (fig. PAR-8), and those (Category 2) that probably could be mitigated (fig. PAR-9). Category 1 considerations would result in a certain amount of coal tonnage being unavailable for coal mining; in contrast, Category 2 considerations would likely increase the cost and complexity of the mining operation, but, through mitigating measures, may allow for mining of the coal involved.

Category 1 considerations:

(1) Railroad corridor
(2) Power line
(3) Cemetery
(4) Hilight oil and gas field and other active oil and gas wells
(5) Hilight gas plant

Category 2 considerations:

(1) Dwellings
(2) Alluvial valley floor
(3) Pipelines
(4) Raptor areas
(5) Inactive oil and gas wells

COMPUTER TECHNIQUES

The major steps required in calculating coal resources for this study include: (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 name; (3) transfer of point-source and line data into a geographic information system (GIS); (4) conversion of point-source and line data into grids (raster data) using GIS programs; (5) calculation of original coal resources from grids; and, finally, (6) calculation of restricted coal tonnages and available coal tonnages 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, as described in (Wood and others, 1983).

RESULTS—COAL AVAILABILITY CALCULATION

Because no commercial mining has yet taken place in the Hilight quadrangle, the original resources are equal to the remaining resources (4.4 billion tons). However,

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were mining to take place under the Category 1 restrictions, about 60 percent of the original coal resources in the Hilight quadrangle would be considered available for development. 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. All of the resources contained within the Wildcat, Moyer, and Oedekoven coal beds are considered unavailable because of their depth.

Of the total 4.4 billion tons in the quadrangle, 2.9 billion tons are contained in the Main Wyodak coal bed; 67 percent, or 1.9 billion tons of the Main Wyodak coal bed are considered available for development.

If the Category 2 restrictions (fig. PAR-9) for the Rider, Lower, and Main Wyodak beds are added to the Category 1 restrictions, then an additional 807 million tons of coal would be unavailable. Addition of the Category 2 restrictions would mean that only 1.9 billion tons of the three Wyodak coal beds would be available for mining; this represents 42 percent of the original coal resources in the quadrangle.

COMPARISON TO OTHER COAL AVAILABILITY STUDIES

Studies in the Appalachian coal region indicate that, overall, only 50 percent of the **original** coal resource in that area is available for development (Carter and Gardner, 1994). In the Hilight quadrangle, there has been no mining yet; whereas in the Appalachian region, much of the **original** coal resource is already mined-out. Of the **remaining** Appalachian coal resource, no more than 60 percent is considered available for future development Carter and Gardner, 1984). Further, the U.S. Bureau of Mines Coal Recoverability Studies of the Appalachian region

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have shown that less than 10 percent of the **original** resource can be mined and marketed at a currently economic profit (Rohrbacher and others, 1993).

There are significant differences in coal quality parameters between Appalachian coal and Powder River coal; these differences must be considered in any comparison of available resources of different regions. In general, Powder River Basin coal is lower in rank, lower in sulfur content, and higher in moisture content than Appalachian coal. Also, there are several differences between Appalachian and Powder River Basin coal development. Powder River Basin coal development involves relatively flat topography; numerous, gently-dipping, thick coal beds; undeveloped areas and few population centers; no underground mining; mostly Federally-owned coal deposits; and different land-ownership patterns, environmental regulations, and land management policies than in the Appalachian coal region. All of these factors influence the amount of coal that is available in a region. Availability determinations 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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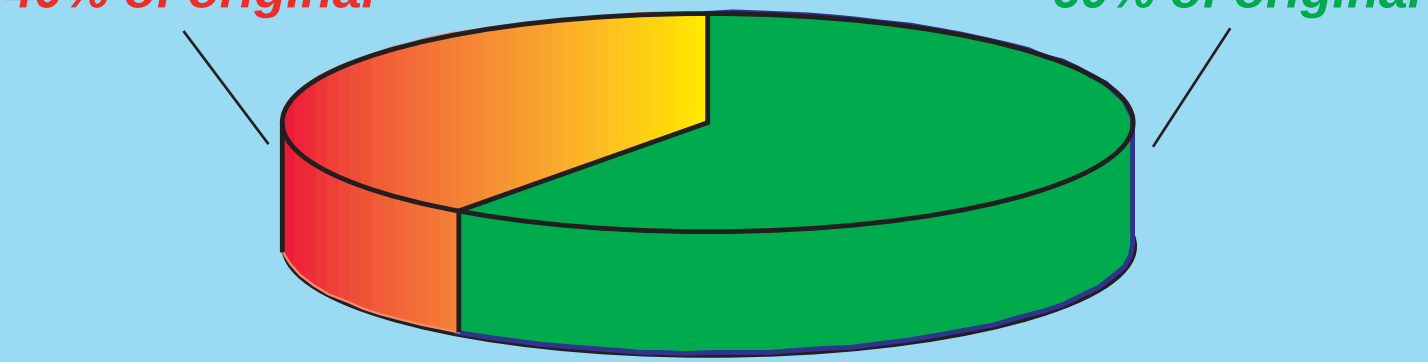


Figure PAR-5. This USGS study shows that approximately 60 percent (2.7 billion tons) of the total 4.4 billion tons of coal in the Hilight quadrangle is available for development.

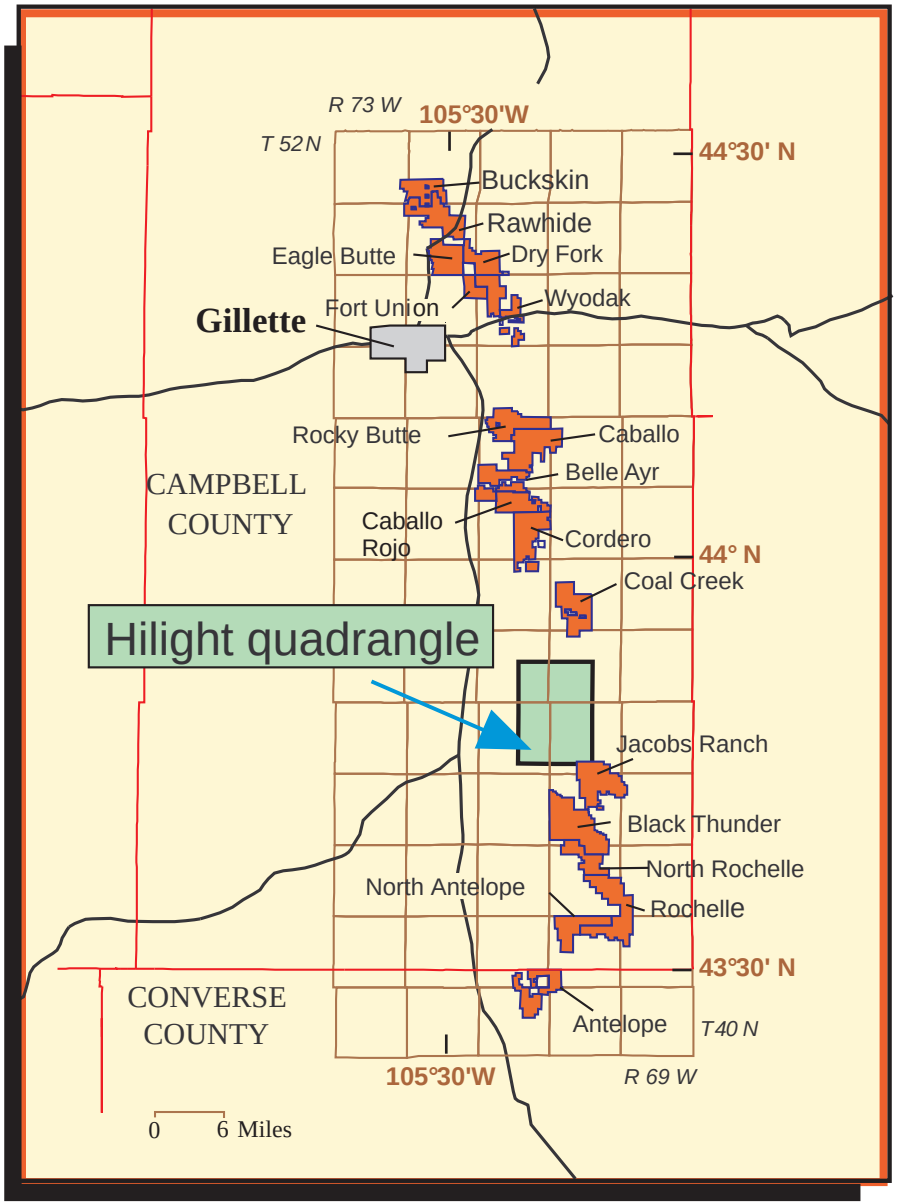
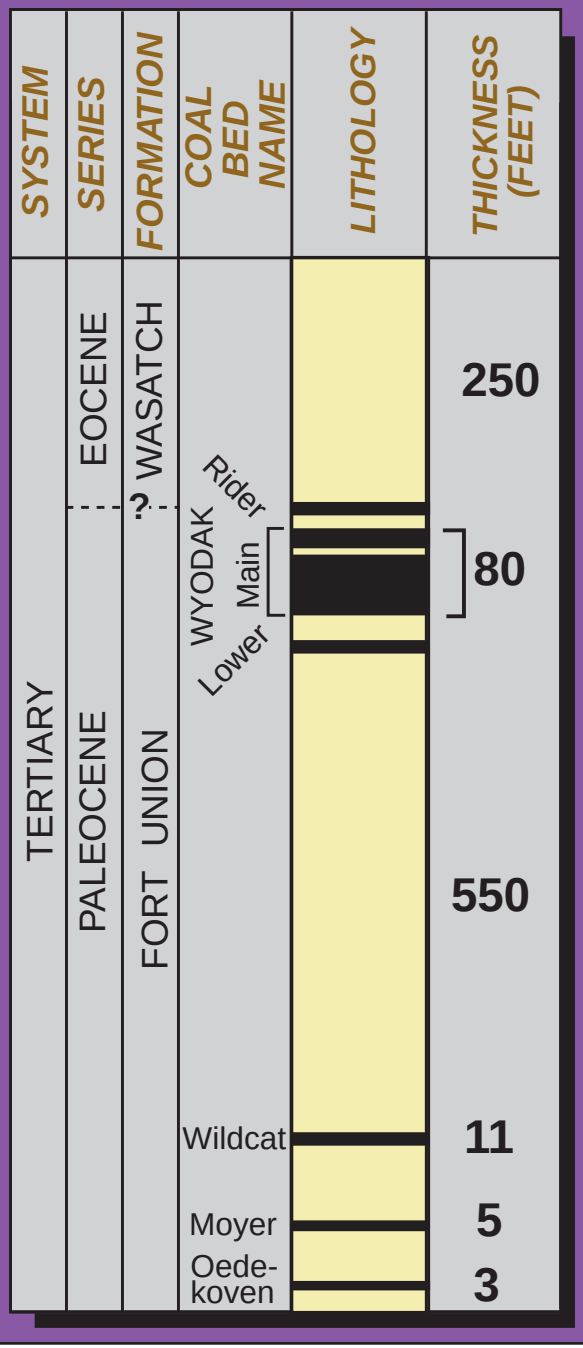


Figure PAR-6. Surface coal mines near the Hilight quadrangle.



Coal

Non-coal rock: siltstone, mudstone, claystone, shale, and sandstone

Figure PAR-7. Generalized composite stratigraphic section for the Hilight quadrangle.

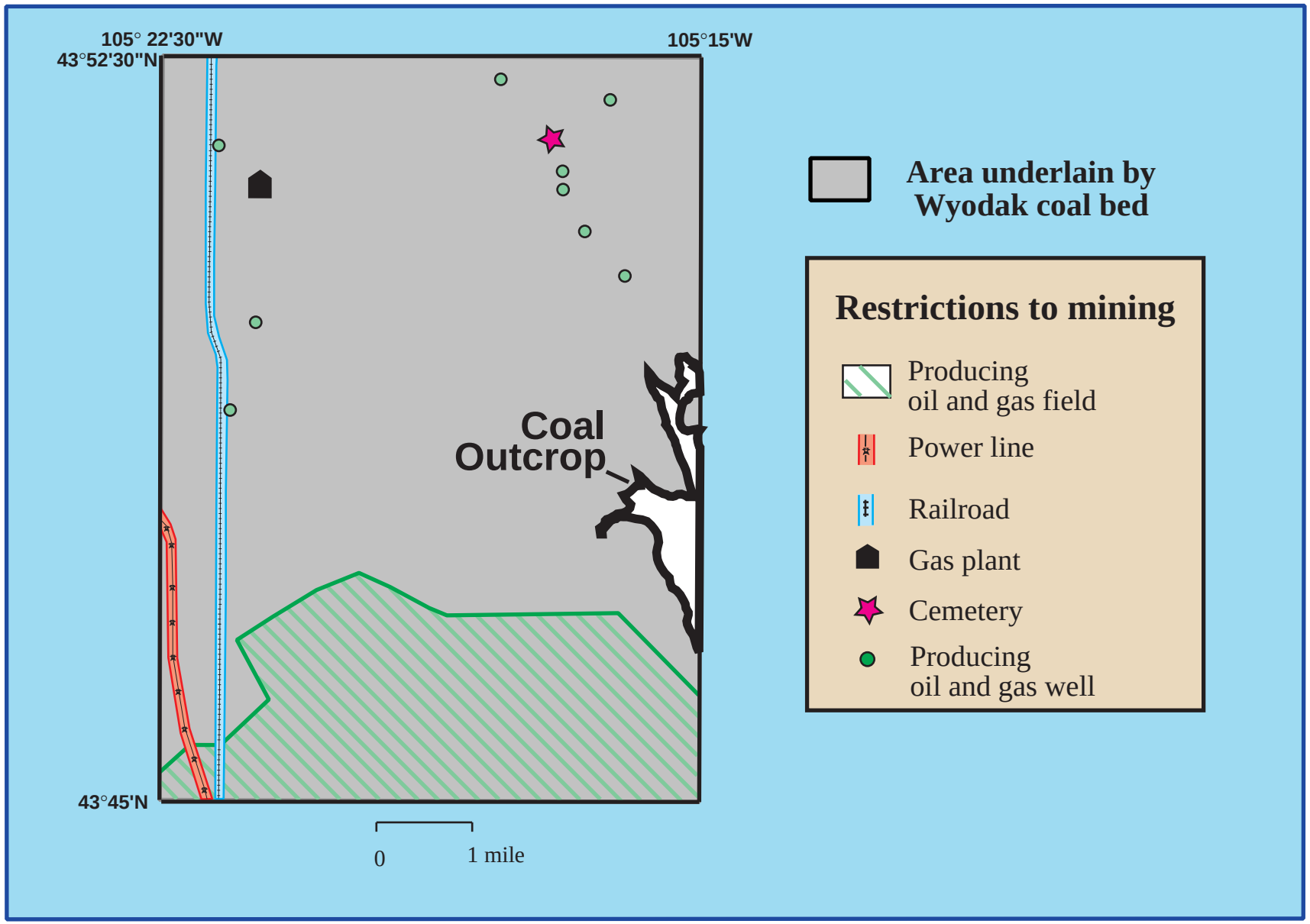


Figure PAR-8. Restrictions to mining. These areas are not available for surface mining because of land-use and technologic constraints.

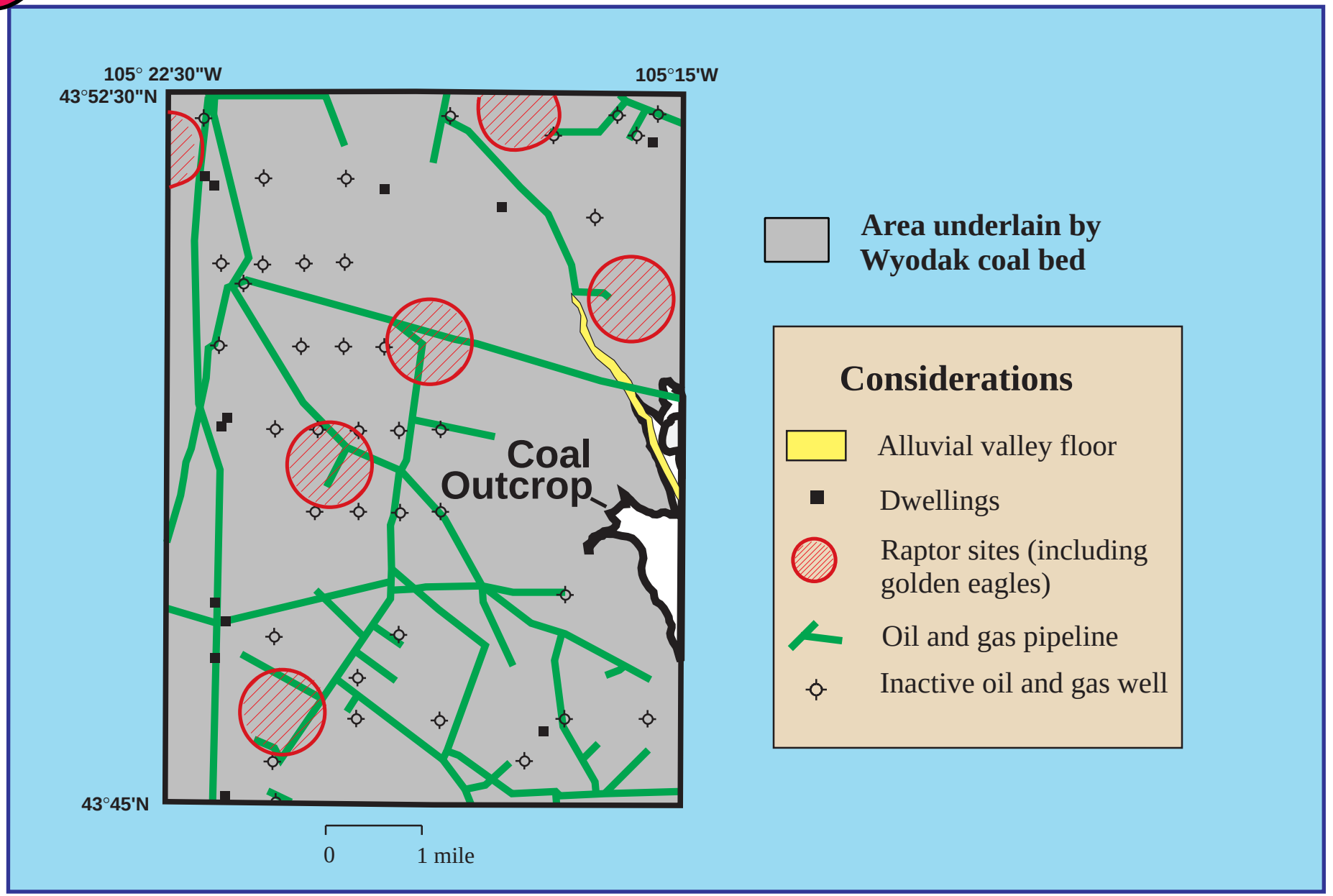


Figure PAR-9. Additional mining considerations. Most likely, the coal under these areas would be available for mining, but with certain mitigations and stipulations which might add to the complexity and cost of the mining operation.

Appendix PAR-2

Summary text for Part 5 of Chapter PAR

COAL AVAILABILITY IN THE WILLOW CROSSING 7.5-MINUTE QUADRANGLE, POWDER RIVER BASIN, MONTANA

By Edith M. Wilde[1]

[1] Montana Bureau of Mines and Geology, Butte, Montana

ABSTRACT

The total original resource in the Willow Crossing 7.5-minute quadrangle is estimated to be 4.3 billion tons[2] (Wilde, in press). The restricted coal is estimated at 2.4 billion tons (56 percent), and the total available resource is 1.9 billion tons (44 percent). Eighty percent of the available resource underlies overburden less than 300 ft thick, and 20 percent underlies from 300 to 500 ft of overburden.

The beds most attractive for future mining are the Knobloch (1.2 billion tons available), the Flowers-Goodale (252 million tons), and the Sawyer (20.7 million tons). The entire Sawyer resource area (including the available areas in the Upper Sawyer, Lower Sawyer, and where the splits merge to form the Sawyer) underlies overburden less than 150 ft thick.

INTRODUCTION

The Willow Crossing 7.5-minute quadrangle is located in the central part of the Montana part of the Powder River Basin (fig. PAR-10); for coal evaluation purposes, it is considered representative of the immediately surrounding area. A geographic information system (GIS) called GRASS (Geographical Resource Analysis Support System, U.S. Army Construction Engineering Research Laboratory) was used to estimate tonnages for the original, mined-out, and remaining coal; for restrictions to mining; and for available resources. Data from a total of 948 locations were used for these calculations.

[2] All tonnage measurements in this report are given in short tons.

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The availability of coal for future mining in the Willow Crossing 7.5-minute quadrangle is limited by several factors that are broadly categorized as either technological restrictions or as land-use restrictions (table PAR-2). The restrictions are also separated into two types based on the possibility of gaining mining rights through legal action (table PAR-2): Type 1 restrictions are unlikely to be legally reversible, while Type 2 restrictions are generally mitigated so that mining can proceed.

Under the currently existing land-use and technological restrictions, ten beds (King, Sawyer, A, Knobloch, Calvert, Nance, Lay Creek, Flowers-Goodale, Terret, and Stag) have available resources. The Sawyer bed was locally mined in the past, but no commercial mines are currently active in any bed. The Knobloch coal bed is the thickest bed and contains the largest minable resource.

COAL DESCRIPTION

The coal in the Willow Crossing quadrangle is typically rated as subbituminous, with heating values ranging between 7,000 and 9,500 Btu's per pound, as received. Ash content varies between 6 and 8 percent, and sulfur content varies between 0.3 and 0.7 percent, both on an as-received basis. Average quality information is from Warren (1959), Bass (1932), Matson and others (1973), and McKay (1976).

Excluding splits, 11 coal beds crop out in the area, and 6 additional coal beds are present in the subsurface (table PAR-3 and fig. PAR-11). All coal in this area exists in the Tongue River Member of the Fort Union Formation (Paleocene). The general sequence of beds in the Willow Crossing area is shown in figure PAR-11.

RESTRICTION ISSUES

Factors that would restrict or limit the availability of coal for mining are categorized as either technological or land-use restrictions (table PAR-2). Technological restrictions considered in the study are thickness of overburden and thickness of coal beds. Land-use restrictions considered are the location of alluvial valley floors, National Forests (public lands), cemeteries, roads, inhabited buildings, telephone lines and power lines. Technological and land-use restrictions are also separated into two types (table PAR-2) as follows, based on the possibility of gaining mining rights through legal action.

Type 1 restrictions (fig. PAR-12) are unlikely to be legally reversible and include both of the technological restrictions, as well as three of the land-use restrictions: location of alluvial valley floors, National Forest lands, and cemeteries. Coal underlying these areas is considered unavailable for mining.

Type 2 restrictions (fig. PAR-13) are generally mitigated and include the remaining land-use restrictions: locations of roads, inhabited buildings, telephone lines, and power lines. They are considered limited restrictions in this report because these features are generally moved during mining operations. However, the mitigation and moving process generally increases the production costs for mining.

TYPE 1 RESTRICTIONS

Technological Restrictions

Coal-Thickness Factors. The standard U.S. Geological Survey (USGS) criterion for coal resource classification (Wood, and others, 1983) includes all resources which are 2.5 or more ft thick and are less than 1,000 ft deep. Some subroutines in the GRASS GIS programs will not accept decimal ft (that is, numbers in tenths of feet, such as 10.2) for calculations. Therefore, 2 ft was used as the lower limit for original resources.

Five ft is considered to be the minimum economically minable thickness by companies working near the area. The USGS's thickness categories for minable reserves of subbituminous coal are listed (Wood, and others, 1983) as 5-10 ft, 10-20 ft, 20-40 ft and greater than 40 ft. The USGS resources module in GRASS allows only two thickness categories, so "5-40 ft" and "greater than 40 ft" were the categories used for calculating available resources.

Overburden-Thickness Factors. The common surface-mining practice in the Powder River Basin area of Montana is to use a ratio of coal thickness to overburden thickness ("stripping ratio") as a guide to minability. Companies mining in the area quote ratios that vary from 3:1 to 10:1. According to mine representatives, coal under overburden thicknesses of as much as 150 ft will usually be economic to surface mine. The 150-300-ft range is often surface-mined as well, but this is a range that might become uneconomic because of conditions such as bed thickness and production costs. The 300-500-ft range is usually uneconomic, but may be surface-mined for very thick, good quality beds. It should

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be noted that underground mining has not been a common practice in this area because of the nature of the overburden.

The following divisions were determined to be most applicable for this study:

0-150 ft	¾	Minable by surface techniques;
150-300 ft	¾	Might be surface minable (deep pit);
300-500 ft	¾	Probably too deep, but might be surface minable under some conditions;
500-1000 ft	¾	Underground minable only;
1000 ft or greater	¾	Probably too deep to mine by either surface or underground methods.

Land-use Restrictions

Section 82-4-227 of the Montana Strip and Underground Mine Reclamation Act of 1993 (MCA) lists the land-use restrictions along with the boundary limits (the closest mining can approach the feature) for each restriction. This state legislation is based on the Federal law known as the Surface Mine Control and Reclamation Act of 1977 (Public Law 95-87). The areas used for restrictions in this report (fig. PAR-12 and fig. PAR-13) are based on the limits stated in these documents.

National Forest. The Montana state legislation states "... no strip- or underground-coal mining operations..., may be conducted on lands within the boundaries of units of the national park system, ...", but this document does not specifically mention National Forests. The Federal regulation states that coal in public parks and historic sites cannot be mined, except in the extremely rare case in which all agencies responsible for managing them approve. It also states that

mining may be allowed on National Forest land, but only if the mining will not interfere in any way with the original purpose for which the land was set aside. In the Willow Crossing quadrangle, there are two areas of Custer National Forest which were originally set aside as public recreation areas (fig. PAR-12) and thus are considered land-use restrictions in this study.

Alluvial Valley Floors. Because ground and surface water is of such great concern in Montana, and particularly in the semi-arid regions of eastern Montana, a considerable amount of discussion is given to the subject in the state legislation, which goes beyond the flowing-stream restrictions listed in the Federal regulation. The definition of "alluvial valley floor" is given in section 82-4-203 (2) MCA as "...unconsolidated stream-laid deposits holding streams where water availability is sufficient for sub-irrigation or flood irrigation agricultural activities; ..." Section 82-4-227(3)(b)(I) MCA, states that no mining will be permitted which will "...interrupt, discontinue, or preclude farming on alluvial valley floors..." Section 82-4-227(3)(b)(ii) MCA states that no mining will be permitted that would "...materially damage the quantity or quality of water in surface water or underground water systems that supply these valley floors..." In the Willow Crossing quadrangle, the valleys of Otter Creek, Threemile Creek, Home Creek and East Fork Creek (fig. PAR-12) have been defined and mapped as alluvial valley floors (Malde and others, 1976) and thus are considered land-use restrictions in this study.

Cemeteries. Section 82-4-227(7) MCA states that no mining will be permitted if "....the operation will constitute a hazard to a dwelling house, public building, school, church, cemetery, commercial or institutional building, public road, stream, lake, or other public property." Additionally, section 82-4-227(7) MCA prohibits mining within 100 ft of any cemetery. The Federal regulation states that surface

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mining cannot be conducted through a cemetery; and the Office of Surface Mining Reclamation and Enforcement (OSM) requests a 100-foot buffer. The Willow Crossing Cemetery is located in the central part of the quadrangle. It falls within the confines of the alluvial valley floor restriction (fig. PAR-12), and therefore does not cause any additional restriction.

TYPE 2 (LIMITED) RESTRICTIONS

The Willow Crossing quadrangle contains a number of inhabited buildings, two paved public roads, phone lines and power lines (fig. PAR-13). These features are often moved by mining companies if located on land that will be mined, but are considered in this report as limited restrictions to mining because of the increase in cost associated with moving such features.

Inhabited Buildings. No mining is permitted within 300 ft of any inhabited building according to section 82-4-227(7) MCA. Federal law requires the same buffer zone. However, according to the state regulations "individual homeowners may sign a waiver allowing mining up to or through the house." There are homes and ranches scattered throughout the Willow Crossing quadrangle (fig. PAR-13).

Roads and Highways. Highway 212 runs east-west through the north-central part of the quadrangle. Another paved road (fig. PAR-13) runs south from Highway 212 through the central part of the area and generally along Otter Creek. Section 82-4-227(7) MCA states that no mining will be allowed within 100 ft of the road right-of-way. Federal regulation requires the same buffer zone. Both State and Federal laws allow moving these features during mining.

Utility Lines. There are both power line and phone line rights-of-way located within the Willow Crossing quadrangle which service homes and ranches in the area. A restriction of 100 ft from power lines and 50 ft from phone lines is used in this report. No specific State or Federal regulation prohibits mining through these areas. However, the lines within the study area are the major line networks for the entire area and would have to be moved in order to maintain service (fig. PAR-13).

SUMMARY OF RESULTS

ORIGINAL COAL RESOURCES

Original coal resources were calculated for all beds in the area. Total original resources for the Willow Crossing quadrangle were estimated at **4.3 billion** tons (table PAR-3). Approximately **22 percent** of that total **(951.3 million** tons) underlies less than 150 ft of overburden. An additional **45 percent (2.0 billion** tons) underlies 150-300 ft of overburden; 300-500 ft of overburden cover **26 percent (1.1 billion** tons); and 500-1000 ft of overburden cover **6 percent (277.8 million** tons).

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MINED-OUT AND REMAINING COAL RESOURCES

Past mining in the area was very limited. Coal was mined from the Sawyer bed, but the total area and tonnage affected were very small¾less than **113.8 thousand** tons were removed. Therefore, nearly all of the original resources of the Sawyer coal bed still remain (**106.5 million** tons, or **99.9 percent.)**

RESTRICTED COAL

Most of the mining restrictions in this area result from land-use conflicts, primarily because of land defined as alluvial valley floors and National Forest (fig. PAR-14). Total restricted coal is **2.4 billion** tons **(56 percent** of the original and remaining resources). Type 1 restrictions (technological restrictions: coal too deep or too thin to mine; land-use restrictions unlikely to be removed by legal processes) account for **94 percent** of the total restricted tonnage. Type 2 restrictions (land-use restrictions which are usually mitigated) account for only **6 percent** of the total restrictions. By themselves, the technological restrictions account for **34 percent** of the total restricted coal. Without regard to either overlapping areas of occurrence or type, the total land-use restrictions account for **81 percent** of the total restricted coal.

AVAILABLE COAL RESOURCES

The available resources are estimated to be **1.9 billion** tons, or **44 percent** of the original resource (table PAR-3, fig.PAR-15, fig. PAR-16). If only the Type 1 restrictions are included, **48 percent** of the original is then available to be mined (fig. PAR-17). The beds most likely to be mined are the Knobloch, Flowers-Goodale and the Sawyer, because of factors such as overall bed thickness, accessibility, and bed depth.

CONCLUSIONS

Previous studies have estimated Montana's total identified coal resources to be about 291.6 billion tons (Averitt, 1975), and the strippable subbituminous reserves to be about 32.0 billion tons (Matson and others, 1973). By itself, the Willow Crossing quadrangle contains an estimated 4.3 billion tons in original resources, and the total restricted resource is estimated at 2.4 billion tons (56 percent). The total available resource is 1.9 billion tons (44 percent) (fig. PAR-15).

The beds most likely to be mined in the near future are the Sawyer, Knobloch, and Flowers-Goodale, although considerable resources are available from other beds as well. The Sawyer coal zone averages 11 ft thick in this quadrangle, with 100 percent of the available coal underlying less than 150 ft of overburden. The 21 million available tons (1 percent of total available) are distributed in the Upper Sawyer, Lower Sawyer, and the Sawyer beds.

The largest single resource is the Knobloch coal bed, which averages over 50 ft thick in the quadrangle. It contains 1.2 billion tons (65 percent of the total original resource). A total of 32 percent (399 million tons) underlies less than 150 ft of overburden, and 64 percent (791 million tons) underlies 150-300 ft.

The Flower-Goodale coal bed averages 11 ft thick and is the next largest resource at 0.2 billion tons (13 percent of the total available). However, less than 1 percent (1.3 million tons) underlies less than 150 ft of overburden. An additional 45 percent (114.3 million tons) underlies 150-300 ft of overburden.

Restrictions to mining not included in this study are surface ownership (other than National Forest lands), mineral ownership, most economic considerations (recoverability), geologic configurations such as channel cuts, most bed splitting, and coal-quality parameters. Additionally, the assumption that the subsurface beds cover the entire quadrangle might not be correct in all cases. For the deepest beds, very few data points were available, so the results should be considered preliminary.

Several areas used in this study were checked using manual calculations of area, thickness, and volume to determine if computer computations produced comparable results. Results from both methods were within 10 percent of each other.

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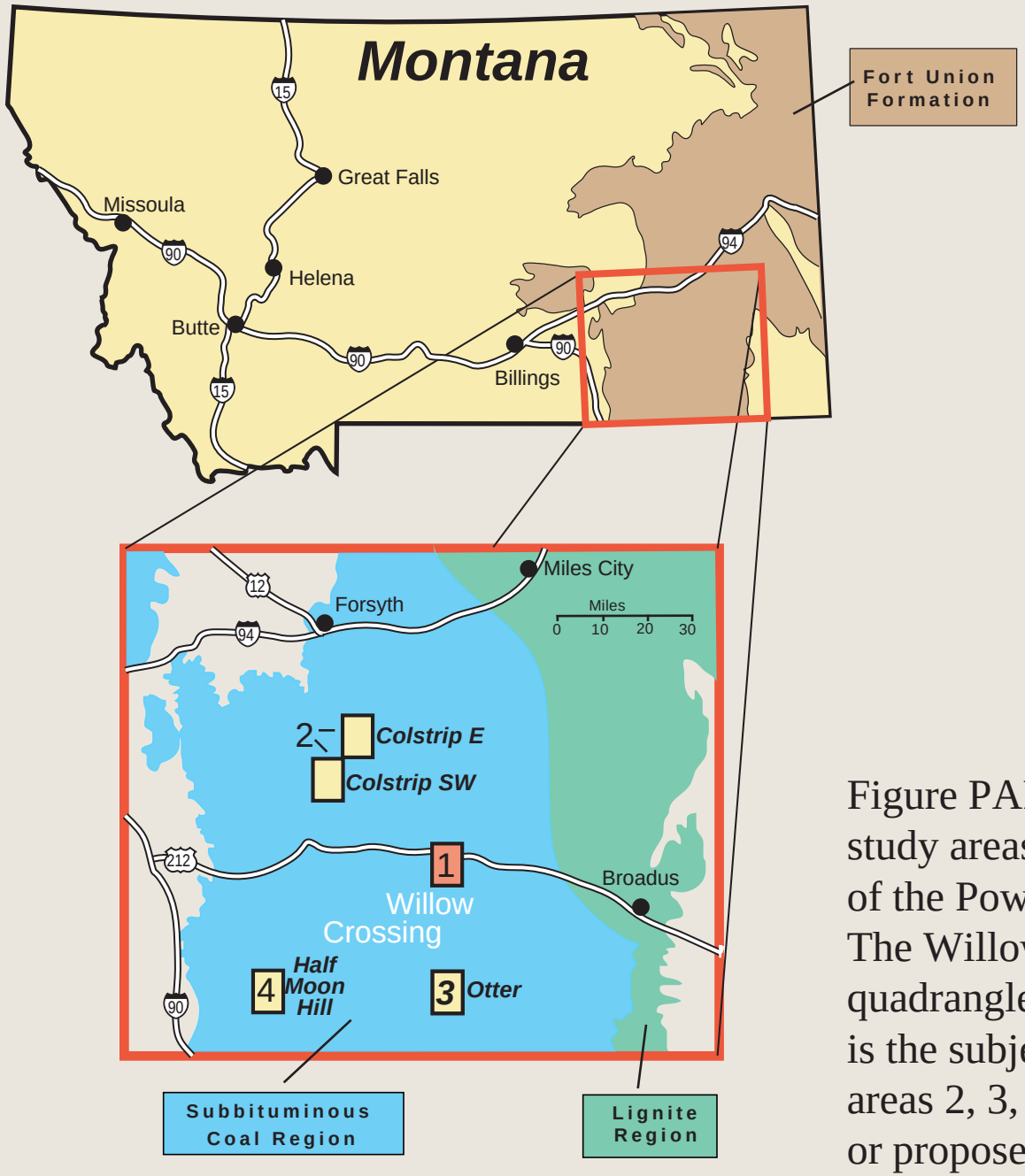


Figure PAR-10. Coal availability study areas in the Montana part of the Powder River Basin. The Willow Crossing 7.5-minute quadrangle (number 1 on lower map) is the subject of this report. Studies in areas 2, 3, and 4 are underway or proposed.

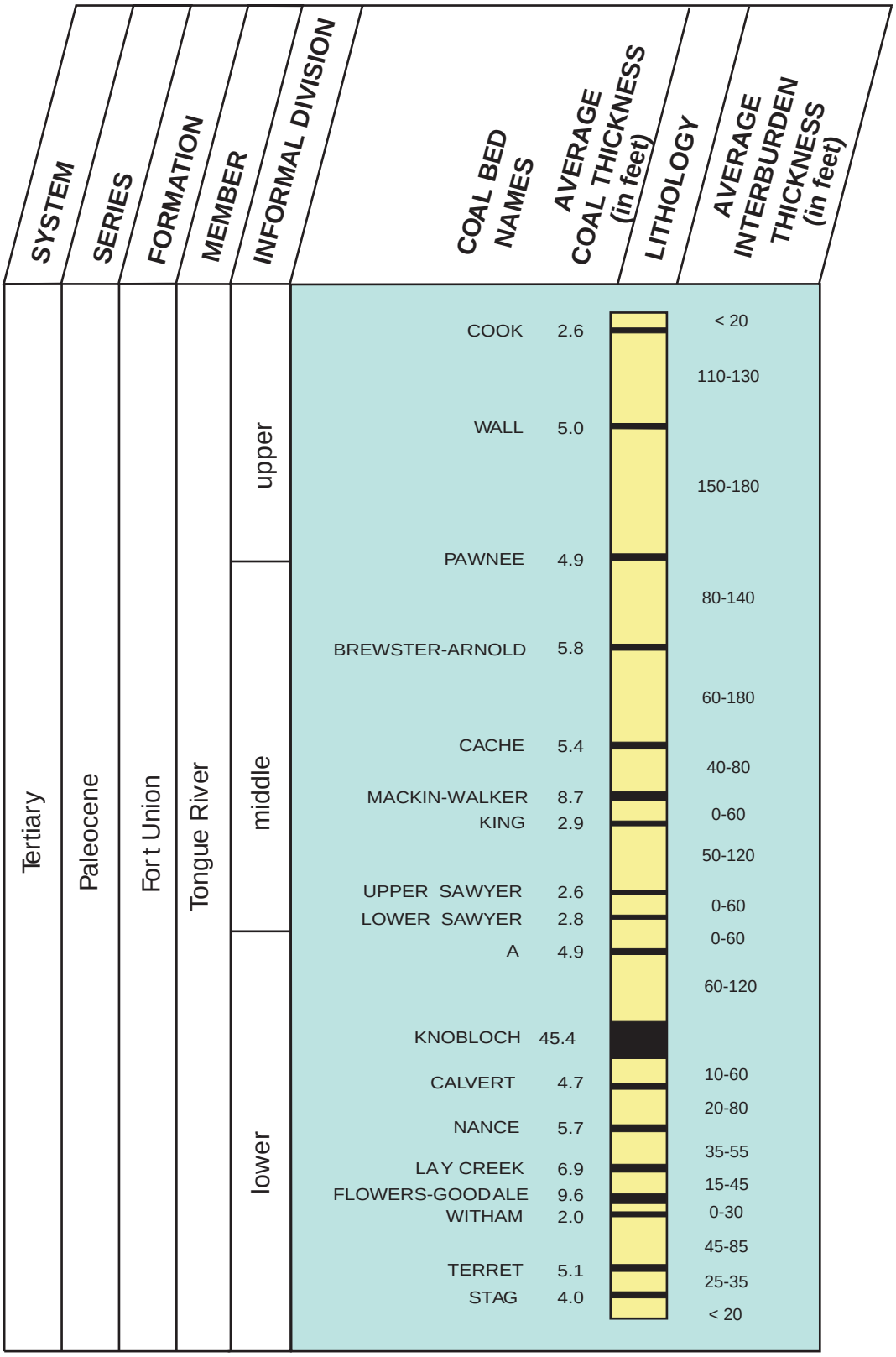


Figure PAR-11. Generalized composite stratigraphic section for the Willow Creek quadrangle. Rocks between the coal beds are sandstone, siltstone, shale, claystone, and clinker.

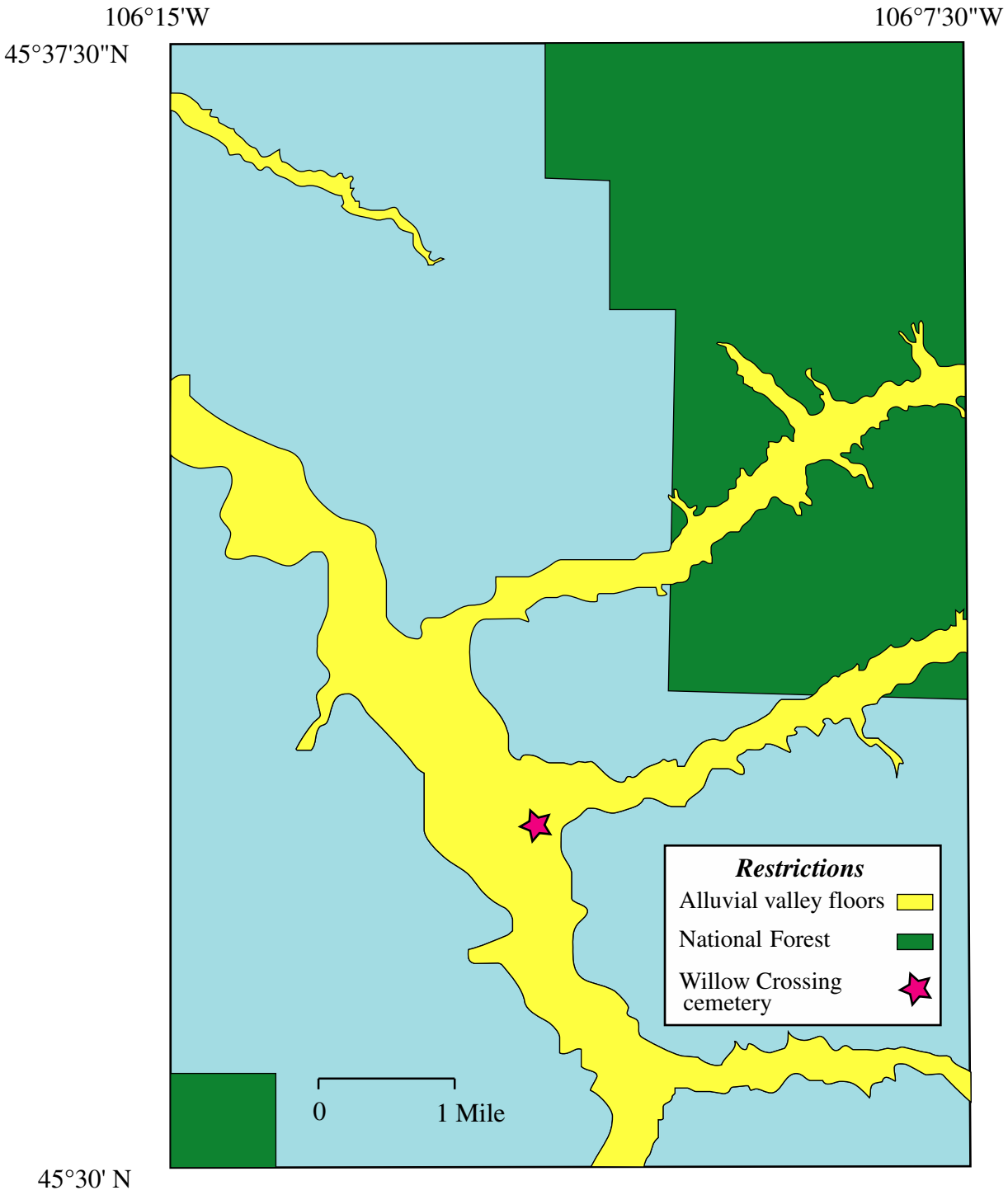


Figure PAR-12. Type 1 restrictions in the Willow Crossing quadrangle. These areas are not available for surface mining because of land-use or technologic restrictions.

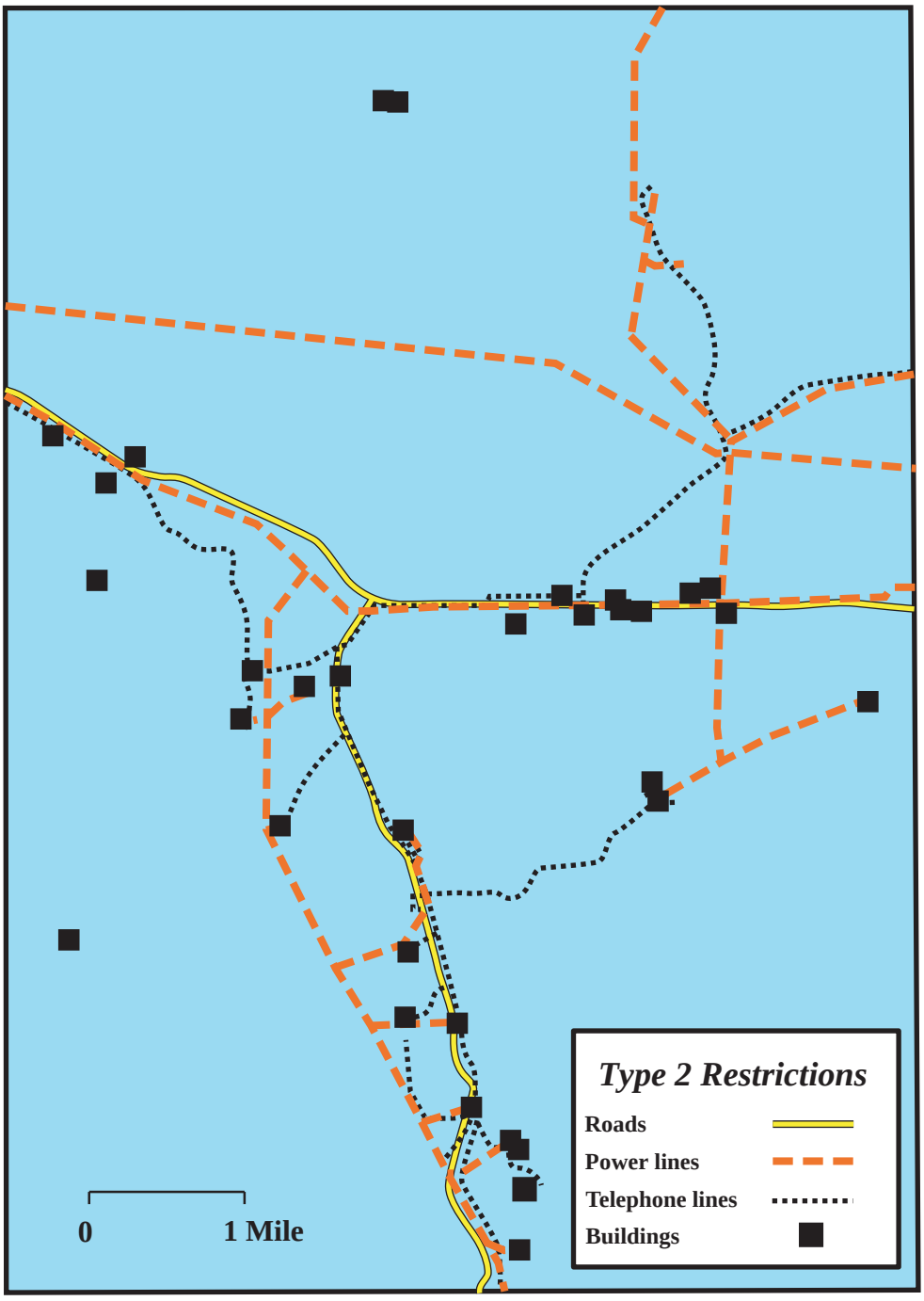


Figure PAR-13. Type 2 restrictions in the Willow Crossing quadrangle. These land-use restrictions encompass both unsuitable areas and multiple-use areas where mitigation would be necessary in order to mine.

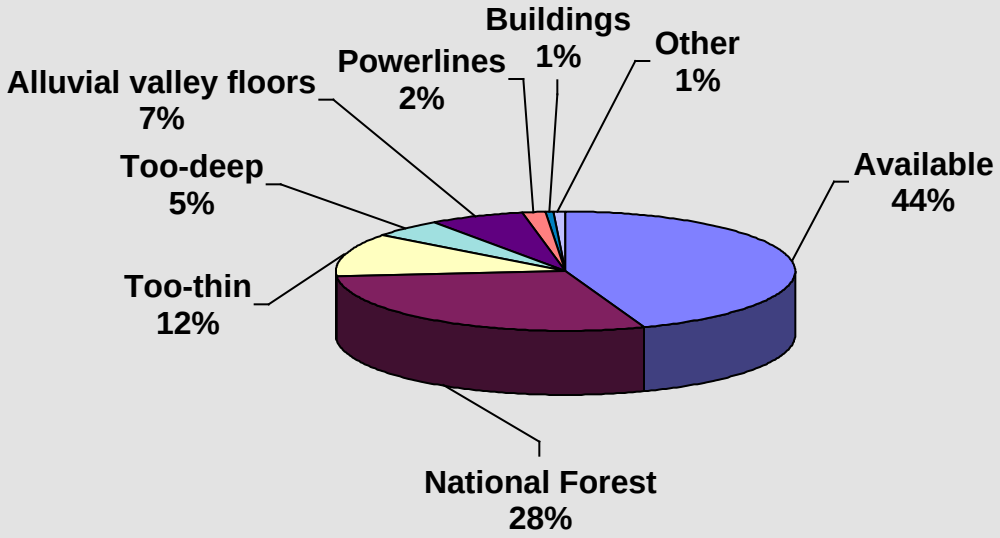


Figure PAR-14. This chart shows the percentage of the original coal resource that is contained in each mining restriction and the percentage that is available. Total unavailable coal in the Willow Crossing quadrangle is 2.4 billion tons.

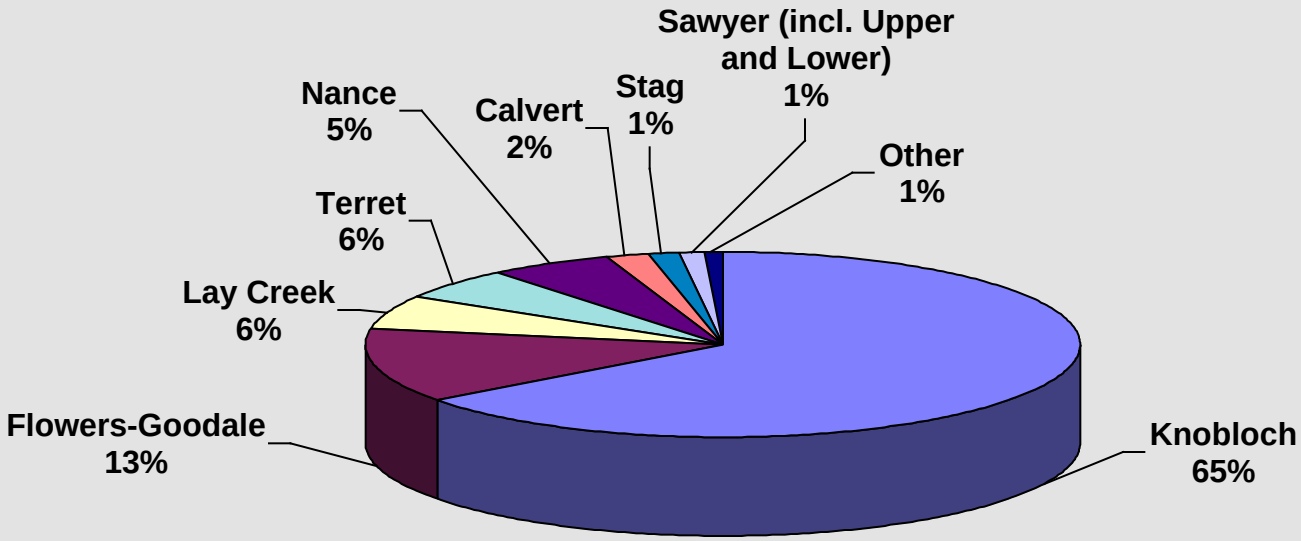


Figure PAR-15. This chart shows the percentage of the total available resource contained in each coal bed. The total available resource in the Willow Crossing quadrangle is 1.9 billion tons.

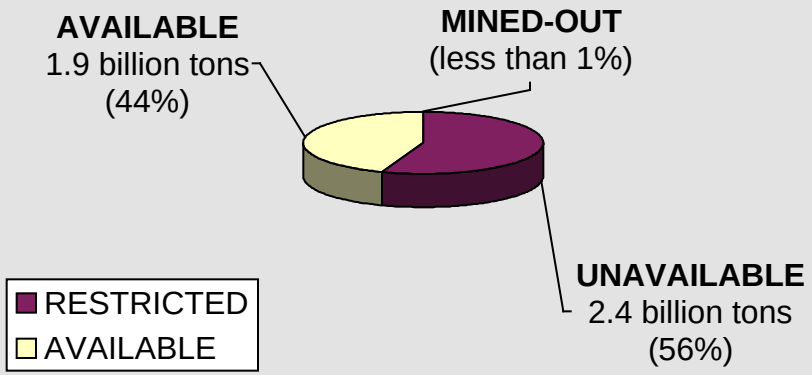
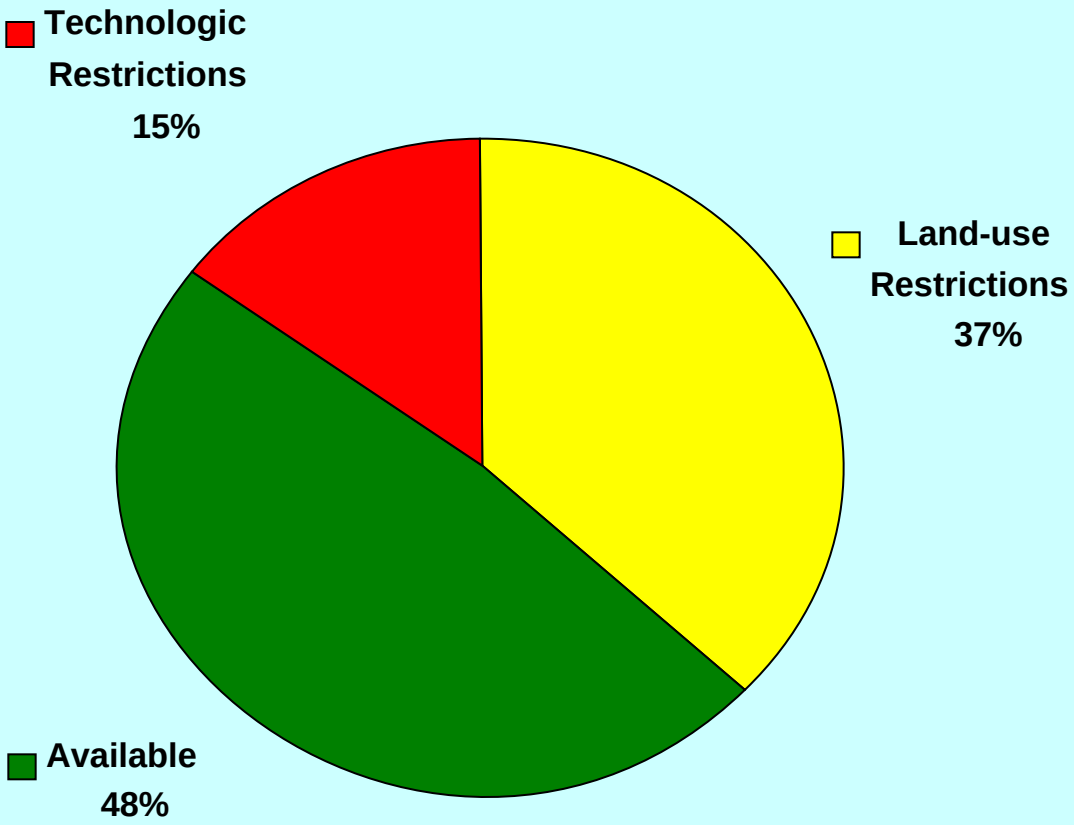


Figure PAR-16. Results of the availability study of the Willow Crossing quadrangle (using Type 1 and Type 2 restrictions).

Original Coal: 4.3 Billion Tons



Land-use Restrictions	**37 %**
Technologic Restrictions	**15 %**
Available	**48 %**

Figure PAR-17. Results of Willow Crossing coal availability study (using Type 1 restrictions).

Table PAR-2. Classification of restraints to coal mining in the Willow Crossing quadrangle. Type 1 restrictions are unlikely to be mitigated, while Type 2 restrictions are commonly mitigated so that mining can proceed

TYPE	CATEGORIES	
	TECHNOLOGICAL	LAND-USE
1	COAL THICKNESS	
1	OVERBURDEN THICKNESS	
1		ALLUVIAL VALLEY FLOORS
1		NATIONAL FOREST LANDS
1		CEMETERIES
2		INHABITED BUILDINGS
2		TELEPHONE LINES
2		POWER LINES
2		ROADS

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Table PAR-3. Summary of tonnages for original, mined-out, remaining, restricted, and available coal resources in the Willow Crossing quadrangle (in thousands of short tons; rounded to whole tons)

COAL BED	ORIGINAL	MINED-OUT	REMAINING	RESTRICTED	AVAILABLE
Cook	12	0	12	12	0
Wall	131	0	131	131	0
Pawnee	2,268	0	2,268	2,268	0
Brewster-Arnold	9,657	0	9,657	9,657	0
Cache	13,337	0	13,337	13,337	0
Mackin-Walker	35,086	0	35,086	35,086	0
King	10,580	0	10,580	10,312	268
Upper Sawyer	13,415	0	13,415	11,232	2,183
Sawyer	72,689	114	72,575	58,595	13,980
Lower Sawyer	20,383	0	20,383	15,787	4,596
A	55,321	0	55,321	39,403	15,918
Knobloch	1,973,875	0	1,973,875	730,787	1,243,088
Calvert	235,873	0	235,873	197,975	37,898
Nance	346,735	0	346,735	242,067	104,669
Lay Creek	364,679	0	364,679	251,451	113,228
Flowers-Goodale	556,163	0	556,163	303,231	252,932
Witham	91,928	0	91,928	91,928	0
Terret	281,505	0	281,505	173,994	107,511
Stag	237,587	0	237,587	210,785	26,802
TOTAL	4,321,223	114	4,321,110	2,398,037	1,923,073