GEOLOGICAL SURVEY CIRCULAR 743

Land and Natural Resource Information and Some Potential Environmental Effects of Surface Mining of Coal in the Gillette Area, Wyoming

LAND AND NATURAL RESOURCE INFORMATION AND SOME POTENTIAL ENVIRONMENTAL EFFECTS OF SURFACE MINING OF COAL IN THE GILLETTE AREA, WYOMING

Wyodak-Anderson coal bed exposed in south pit of Wyodak mine, about 5 miles (8 km) east of Gillette, Wyo. The coal is about 90 feet (27 m) thick, and the overburden is less than 50 feet (15 m) thick. View is to the south. Photograph by D. W. Moore.

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By W. R. Keefer and R. F. Hadley

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CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the nearest whole number consistent with the values for the English units.

To convert English units	*Multiply by*	*To obtain Metric units*
acres	4.047×10^{-3}	square kilometers (km^2)
acre-feet (acre-ft)	1.233×10^{-3}	cubic hectometers (hm^3)
feet (ft)	3.048×10^{-1}	meters (m)
gallons (gal)	3.785	liters (l)
inches (in.)	2.54	centimeters (cm)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
pounds (lbs)	2.2046	kilograms (kg)
tons (short)	9.072×10^{-1}	metric tons or tonnes (t)

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ABSTRACT

Campbell County, along the east margin of the Powder River Basin in northeastern Wyoming, contains more coal than any other county in the United States. The principal deposit is the Wyodak-Anderson coal bed. The bed is 50–100 feet (15–30 meters) thick over large areas, lies less than 200 feet (60 meters) deep in a north-south trending strip nearly 100 miles (161 kilometers) long and 2–3 miles (3–5 kilometers) wide, and contains an estimated 15 billion tons (13.6 billion metric tons) of subbituminous, low-sulfur coal that is presently considered to be accessible to surface mining. Extensive mining of this deposit has the potential for causing a variety of environmental impacts and has been a matter of much public concern and debate in recent years.

An integrated program of geologic, hydrologic, geochemical, and related studies by the U.S. Geological Survey in central Campbell County provides basic information about the land and its resources, including (1) characteristics of the landscape, (2) properties of rocks and surface materials, (3) depth and thickness of coal, (4) streamflow, (5) depth to ground water, (6) quality of ground water, (7) sediment yield, (8) concentrations of trace elements in soils, rocks, coal, vegetation, and water, and (9) current land use. The data are used to analyze and predict some of the potential environmental effects of surface mining, such as the extent of land distrubance, nature and degree of landscape modification, and disruption of surface-water and ground-water systems. Advance knowledge and understanding of these and other problems are useful in the planning and regulation of future leasing, mining, reclamation, and related activities.

INTRODUCTION

One of the principal areas being considered for significantly expanded coal production in the Western United States is the eastern Powder River Basin in northeastern Wyoming (fig. 1). Campbell County, for which the city of Gillette is the county seat, contains more coal than any other county in the nation. Although development in the area has been minimal to date, current proposals call for the opening of several large new surface mines. These proposed activities, which have the potential for causing a variety of environmental impacts, clearly indicate the need for sound land-use planning, resource management, and environmental controls if the projected new development of coal is to proceed in the best public interest. Accordingly, many Federal, State, and local government agencies, as well as private organizations and institutions, are focusing considerable attention on Campbell County and adjacent areas in efforts to achieve this important goal. (For example, see Breckenridge and others, 1974.) Because the Federal Government is involved in many of the proposed actions, an environmental-impact statement has been prepared and issued on the eastern Powder River Basin (U.S. Department of the Interior, 1974).

A series of maps and other reports, published during the period 1973–76, presents some of the results of a broad program of integrated geologic, hydrologic, geochemical, and related studies being conducted by the U.S. Geological Survey in a 1,500-mi^2 (3,900-km^2) area surrounding the city of Gillette (Shown, 1973; U.S. Geological Survey, 1973, 1974, 1975; Denson and others, 1973; Keefer and Schmidt, 1973; Denson and Keefer, 1974; King, 1974; Frickel and Shown, 1974; Hadley and Keefer, 1975; Connor and others, 1976). Preliminary results of some of the Gillette area studies are also incorporated in the environmental-impact statement on the eastern Powder River Basin (U.S. Department of the Interior, 1974; see, for example, pages I–224, I–471, VI–66, and VI–72). Each of the published items contains an important element of information about the land, water, and (or) coal resources. The purposes of the present report are to summarize the data shown in the published maps and reports, as well as unpublished data from

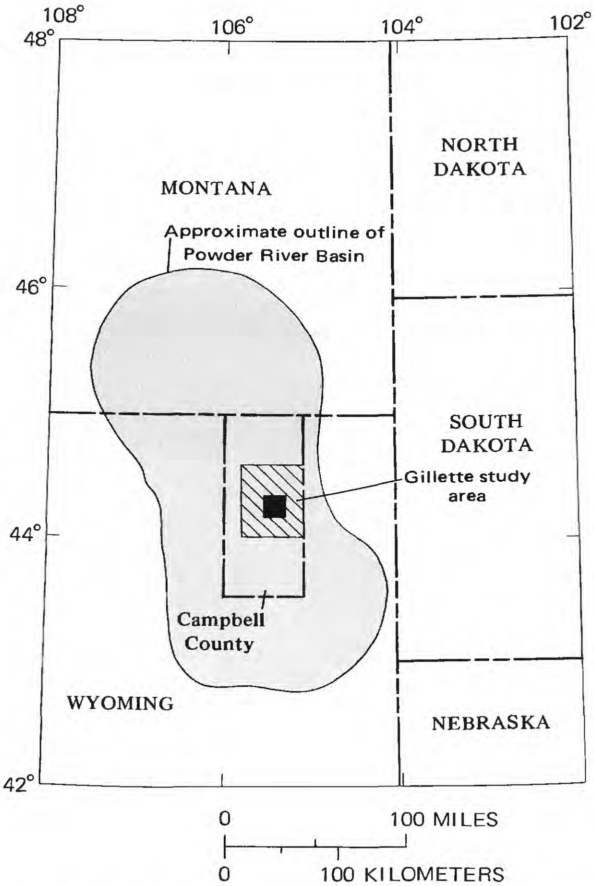


FIGURE 1.—Index map of the Powder River Basin and adjacent areas, showing location of the Gillette study area (cross hatched) and the four-township area (solid square) used to illustrate several sections of this report.

investigations still in progress, and to demonstrate how the different elements of information, used singly or in various combinations, can be applied to evaluations of some of the environmental effects of large-scale surface mining as related to land and water. Major emphasis is given to providing advance knowledge and understanding of potential problems that should be taken into account in the planning and regulation of future leasing, mining, and reclamation activities.

Because of the large areal extent of the Gillette study, only a 144-mi² (375-km²) four-township area surrounding the city of Gillette will be used to illustrate most sections of this report (solid square, fig. 1; fig. 3). The small scale of the maps (1 : 125,000; 1 inch equals approximately 2 miles; 1 cm equals 1.25 km) also has necessitated generalization of some of the data.

ACKNOWLEDGMENTS

The preparation of this report would not have been possible without the assistance and cooperation of many colleagues from the U.S. Geological Survey. Special thanks and acknowledgments are given the following individuals for contributions in advance of publication of the results of their own respective studies: F. R. Shawe (coal and post-mining terrain data); L. M. Shown (sediment-yield data); D. A. Coates, D. S. Fullerton, and V. S. Williams (surficial sediments and landform data); and V. E. Swanson and J. R. Hatch (coal-chemistry data). In addition, the Gillette area investigation benefited materially from areal and regional geologic, hydrologic, coal resource, geochemical, and related studies in various parts of the Powder River Basin by B. M. Anderson, F. A. Branson, J. J. Connor, N. M. Denson, J. H. Dover, R. B. Ebens, J. A. Erdman, G. L. Feder, D. G. Frickel, G. L. Galyardt, S. L. Grazis, P. T. Hayes, G. H. Horn, J. R. Keith, B. H. Kent, N. J. King, E. R. Landis, B. E. Law, G. C. Lusby, H. E. Malde, W. J. Mapel, E. J. McKay, R. F. Miller, D. W. Moore, E. M. Schell, and R. R. Tidball. G. B. Glass, Wyoming Geological Survey, contributed several samples of coal, the analyses of which are incorporated in the appropriate section of this report.

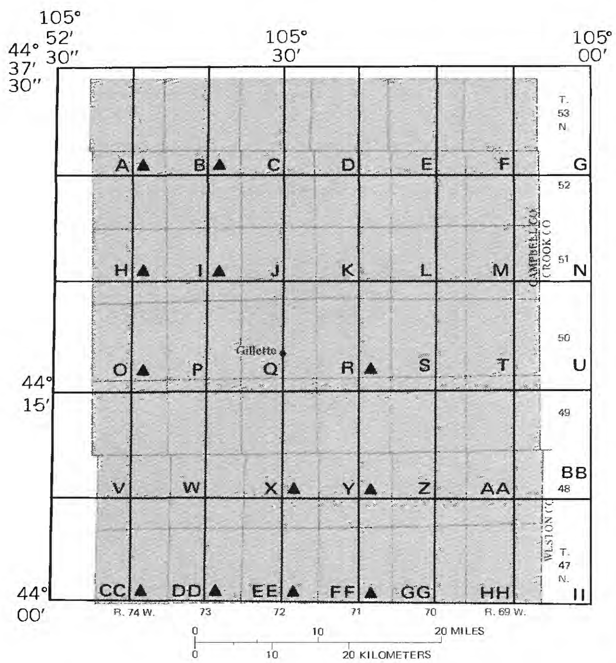
LAND AND NATURAL RESOURCE INFORMATION

TOPOGRAPHY AND LANDFORMS

Topographic maps, in the form of 7½-minute quadrangles at a scale of 1 : 24,000 (1 inch equals 2,000 feet; 1 cm equals 240 m), are available for all of the Gillette study area (fig. 2). These maps, showing detailed configuration and elevation of the land surface and cultural and surface-drainage features, are the principal base maps for compiling and recording land and resource information. Another series of topographic maps, at a scale of 1 : 100,000 (1 inch equals approximately 1.57 miles; 1 cm equals 1 km), are available for displaying regional information. The Gillette study area is included within the Gillette 1 : 100,000 quadrangle; the base map for the four-township area around the city of Gillette (fig. 3), at a scale of 1 : 125,000 (1 inch equals approximately 2 miles; 1 cm equals 1.25 km), was reduced from this 1 : 100,000 quadrangle map.

The terrain of the Gillette area is flat to moderately rolling. The most prominent topographic features are narrow isolated ridges, hills, and buttes, the tops of which are capped by erosion-resistant red and purple clinker beds. (Clinker is the hard-baked and fused material from rocks that were directly above a burning coal bed, as well as the noncombustible materials within the coal.) Extensive burning of coal, triggered chiefly by natural causes during prehistoric times, has been a common occurrence in the Gillette area. The effects of this widespread burning have had a profound influence on the erosional history of the region, as is now evident in the appearance of the landscape.

Figure 3 characterizes the landscape to be seen in the vicinity of Gillette. Such a landform map can be used for a variety of planning purposes. It shows the areal distribution of different types of terrain, indicates general slope conditions, and provides a measure of the amount of erosion that has presently taken place. Landscape characteristics are also an indication of the relative ease or difficulty involved in restoring mined lands to their approximate original contour—that is, the pre-mining surface configuration of the land, not necessarily the pre-mining elevation. Highly dissected badland topography, for example, could not be restored after mining to anything approaching its original shape, whereas gently rolling, moderately dissected terrain would be less difficult to duplicate. Surface-mine spoils in areas where the original slopes are other than flat or gentle would be especially susceptible to increased erosion unless careful terracing and revegetation measures are taken. The delineation of flood plains and adjacent low terraces along streams is of special importance because satisfactory restoration of these kinds of features and attendant hydrologic systems is particularly difficult to achieve (National Academy of Sciences, 1974, p. 44–45); for this reason, sponsors of Federal strip-mining legislation (for example, H. R. 25 in 1975 and H. R. 9725 in 1976) have included provisions that seek to restrict mining on alluvial valley floors. Alluvial valley floors, as defined in general terms, are those features underlain by unconsolidated stream-laid deposits for which available water is sufficient for subirrigation or flood irrigation agricultural activities. The map unit labeled "stream terraces and flood plains" in figure 3 includes alluvial valley floors as thus defined.



EXPLANATION

- A Truman Draw
- B Wildcat, Kent, 1976
- C Calf Creek, McKay and Mapel, 1973
- D Weston SW
- E Long Tree Creek
- F Adon
- G Flag Butte
- H Twentymile Butte
- I Oriva NW, geologic map called Townsend Spring, McLaughlin and Hayes, 1973 (1974)
- J Rawhide School, Mapel, 1973
- K Moyer Springs
- L Green Hill
- M Rozet NW
- N Rozet NE
- O Jeffers Draw
- P Oriva, Law, 1975
- Q Gillette West
- R Gillette East
- S Fortin Draw, Law, 1974
- T Rozet
- U Rozet SE
- V Scott Dam
- W Four Bar J Ranch
- X Appel Butte
- Y The Gap, Galyardt, 1974a
- Z Coyote Draw, Galyardt, 1974b
- AA Coon Track Creek
- BB Whitetail Creek NE
- CC Double Tanks
- DD Pleasantdale, Grazis, 1974b
- EE Scaper Reservoir, Grazis, 1974d
- FF The Gap SW, Grazis, 1974a
- GG Saddlehorse Butte, (formerly Kicken Creek), Grazis, 1974c
- HH Whitetail Creek
- II Whitetail Creek SE

FIGURE 2.—Index to 7½-minute topographic quadrangle maps and areas for which geologic maps have recently been published or released in open file. Letter(s) in lower right corner of each quadrangle refers to list given above. Solid triangle in lower left indicates that geologic map is available (reference given in list).

GEOLOGY

The Fort Union Formation of Paleocene age (53 to 65 million years ago) and the Wasatch Formation of Eocene age (38 to 53 million years ago) form the surface rocks throughout the Gillette study area. The areal distribution of these units over some parts of the area is shown on several recently published geologic quadrangle maps. (See fig. 2.) Both formations are characterized by interbedded soft sandstone, siltstone, shale, and carbonaceous shale in various shades of brown and gray. Both also contain coal beds, but the coal beds are notably thicker and more numerous in the Fort Union than in the Wasatch (figs. 4, 5). Disagreement exists as to the precise position of the contact between the two formations because of similar rock types and because a thick zone of clinker masks the contact in many

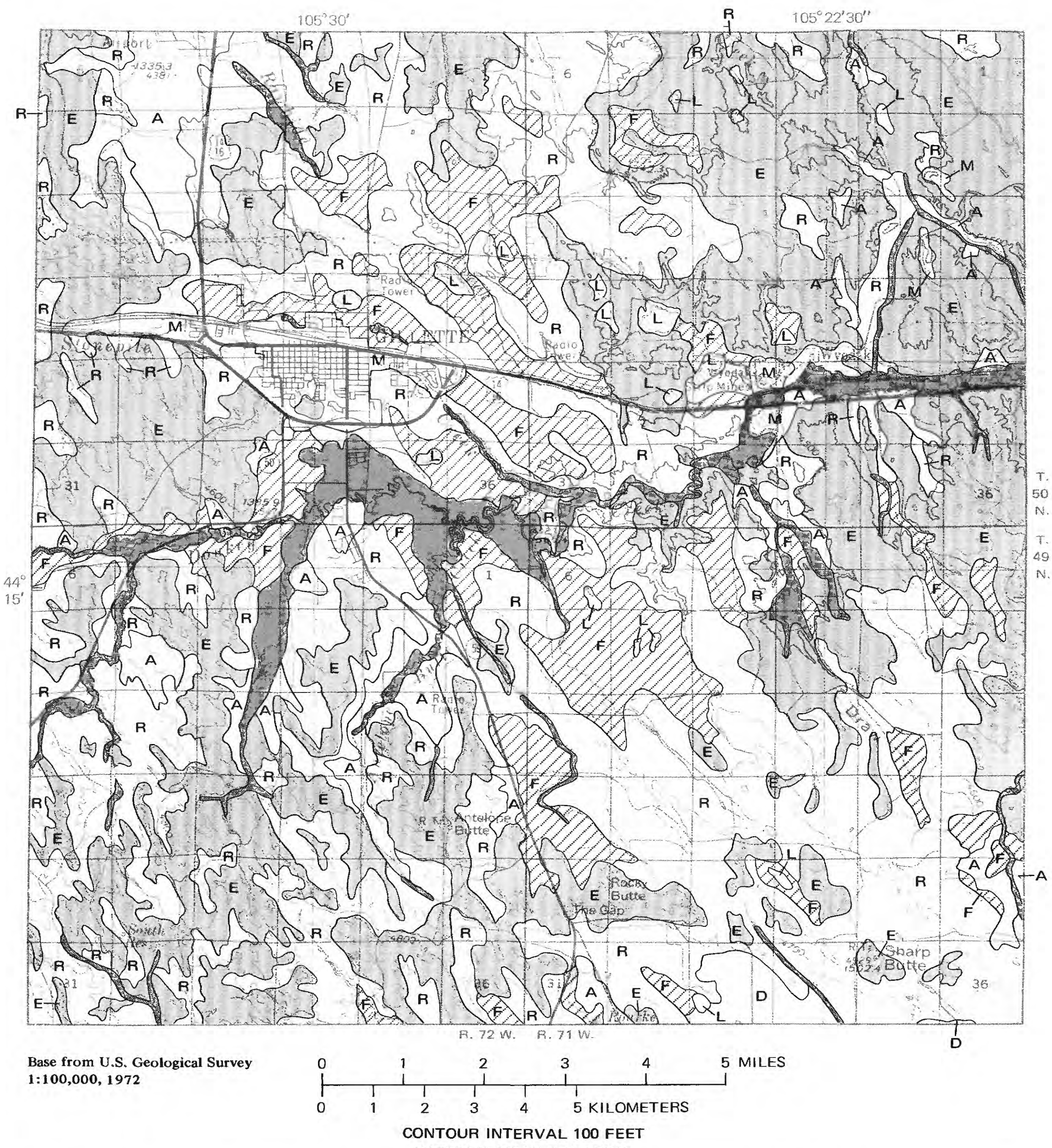


FIGURE 3.—Map showing landforms, Gillette and vicinity four-township area. Generalized from written communication by D. S. Fullerton and V. S. Williams, 1976.

places. In general, however, the formation boundary is considered to lie at or somewhat above the top of the Wyodak-Anderson coal in surface exposures (near line marking approximate eastern limit of Wyodak-Anderson coal deposit in fig. 4), but lies at higher stratigraphic horizons in drill holes to the west (perhaps above the Smith coal bed as shown in fig. 5).

Structurally, the Gillette study area lies along the east margin of the Powder River Basin, where the

EXPLANATION

Stream terraces and floodplains — Nearly level land formed by stream-deposited alluvium, and benches formed adjacent to streams by erosion

L Playas — Beds of ephemeral lakes and ponds

F Flat lands — Including alluvial plains formed from slopewash. Land with slopes generally less than 4 percent

A Alluvial fans — Fans or aprons of alluvium deposited by ephemeral streams; slopes generally 3–15 percent

D Dune fields — Areas of hummocky, low-relief topography formed by deposition of windblown sand and silt. Dunes are now inactive

R Rolling hills — Lands formed by erosion but not deeply incised by streams; slopes greater than 4 percent

E Rough and broken terrain — Lands moderately to highly dissected by stream erosion (some badlands); conical hills, mounds, knobs, knolls, buttes, and ridges formed primarily by erosion of resistant clinker beds; slopes 5–100 percent

Modified lands — Land modified to the extent that its original form cannot be determined

rocks dip westward toward the basin interior at a very slight angle (commonly less than 1°). However, detailed mapping and plotting of coal beds indicate that the strata locally are folded into a series of gentle northwest-trending anticlines and synclines. (See figs. 6, 14.)

Because of the generally soft, nonresistant character of the Fort Union and Wasatch strata and their ready susceptibility to weathering and erosion, large parts of the Gillette area are covered by a mantle of unconsolidated residuum and soil ranging in the thickness from a few inches to several feet. A mapping program was begun in 1975 to describe and classify these surficial deposits systematically. Primary emphasis is placed on the relation of active geologic processes to recent landforms. Interpretative studies of these processes may be used to predict how future mining, industrial, and agricultural activities may be affected by alteration or disturbance of the present landscape and, conversely, how the landscape may react to these modifications.

The mapping and related studies of surficial deposits are still in progress. Preliminary results, however, indicate that much of the landscape in the Gillette area—especially in the uplands—is relatively stable and that erosion is minimal. In an environment that receives limited precipitation and has a short growing season, this natural balance may be difficult to maintain or restore if disrupted.

COAL RESOURCES

Detailed geologic mapping and the examination of records from numerous drill holes indicate that the Fort Union and Wasatch Formations in the eastern Powder River Basin locally contain a dozen or more coal beds of potential economic interest (Denson and others, 1973). The combined thickness of these beds is 100 feet (30 m) or more over large areas, and in several places exceeds 200 feet (60 m; fig. 4). The sequence of coals penetrated by a well drilled about 6 miles (10 km) northwest of Gillette is shown in figure 5.

The bulk of the coal in the Gillette study area is too deeply buried to be considered for extraction by surface mining methods. However, across extensive tracts of land, a few beds are close enough to the ground surface to be reached by modern surface mining equipment.[1] One such bed is the Wyodak-Anderson[2], which, in terms of total volume, is the largest single coal deposit presently known in the United States and is a primary target for extensive exploitation in the coming years. (See frontispiece.)

The Wyodak-Anderson coal occurs either in a single layer, or in a group of closely spaced layers, and is 50–100 feet (15–30 m) thick over large areas of the eastern Powder River Basin (fig. 7; Denson and others, 1973; N. M. Denson, J. H. Dover, and L. M. Osmonson, oral commun., 1976). The potentially strippable tract, lying between the outcrop or "burn line"[3] on the east and the 200-foot (60 m) overburden line on the west, occupies a strip nearly 100 miles (160 km) long and 2–3 miles (3–5 km) wide through Campbell County and northern Converse County (Keefer and Schmidt, 1973); it contains an estimated 15 billion tons (13.6 billion metric tons) of subbituminous coal that is presently considered to be accessible to surface-mining. Specific delineation of this strippable tract (fig. 4) is an essential first step in

[1]For purposes of this report, coal beds less than 200 feet (60 m) below the land surface are arbitrarily placed in the strippable category; however, no economic limits with regard to depth have yet been established in the region. In the case of the Wyodak-Anderson bed, the strippable coal zone as outlined in figure 7 includes coal that in places lies at depths somewhat greater than 200 feet (60 m) because of local irregularities in topography.

[2]For purposes of this report, the Wyodak and Anderson coal beds are considered to form a single continuous coal unit, although the thick Wyodak bed, as exposed in the Wyodak mine, 5 miles (8 km) east of Gillette, may split westward into both the Anderson and Canyon beds (Denson and others, 1973).

[3]In many places the Wyodak-Anderson coal is not present in surface exposures, and the east edge of the strippable coal zone has been arbitrarily mapped as the boundary between clinkered rock and unclinkered rock. Scattered drill data indicate that some coal may be present locally beneath the clinker.

acquiring the necessary information for comprehensive resource evaluation, land-use planning, and environmental-impact analysis. The remainder of this report focuses primarily on that part of the tract that occurs within the four-township area surrounding the city of Gillette (figs. 6, 7).

Results of analyses performed by the U.S. Bureau of Mines, Forrest E. Walker, chemist-in-charge, Pittsburgh, Pa., on 10 samples collected from the Wyodak-Anderson coal bed within and adjacent to the Gillette study area are as follows (analyses reported as percentages on the as-received basis):

Proximate analyses			Ultimate analyses		
	Mean	*Range*		*Mean*	*Range*
Moisture	24.7	10.4–29.9	Hydrogen	6.5	5.6–6.8
Volatile matter	33.5	31.5–40.9	Carbon	51.7	47.7–58.8
Fixed carbon	36.2	31.2–40.3	Nitrogen	.9	.7–.9
Ash	4.6	4.2–9.0	Oxygen	34.8	24.9–38.8
			Sulfur	.5	.3–.9
			Ash	5.6	4.2–9.0

The average heat value of the 10 samples analyzed is 8,950 British Thermal Units (BTU) per pound (range 8,180=10,280 BTU), and the apparent rank of the coal is subbituminous B. Computations based on this value and the low average sulfur content (0.5 percent) indicate that if all the sulfur in the average Wyodak-Anderson coal were converted to sulfur dioxide fumes upon combustion, 1.12 pounds (0.5 kg) of sulfur dioxide would be created per million BTU (the maximum allowable by National Air Quality standards is 1.2 pounds (0.54 kg) per million BTU). In practice, however, a certain proportion of the sulfur remains in the coal ash and does not become part of the stack effluent.

GEOCHEMICAL DATA

Knowledge of the distribution and concentration of chemical elements in the natural environment is of prime importance in efforts to predict, measure, and interpret changes in existing conditions. For example, redistribution of elements in landscape materials, which could result from coal exploitation and related industrialization could be detrimental, or in some instances beneficial, to future uses of the affected land and to the quality of ground water and surface water. Geochemical studies and sampling programs are being conducted in many parts of the Powder River Basin, and analyses are being made of soils, plants, rocks (including coal), and surface and ground water. The primary objective of these investigations is to determine the geochemical properties of each of these materials, both locally and regionally, as a basis for establishing baselines in advance of the large-scale modifications that are now anticipated. Special attention is being given to concentrations of trace metals (such as arsenic, mercury, and selenium) and other potentially harmful substances that could cause problems if not detected and treated accordingly. Some of the results of the geochemical sampling and analytical program are given in table 1.

As may be seen in table 1, few trace-element concentrations in the coal exceed the concentrations found in the surface and near-surface soil and rock materials of the Powder River Basin (mercury and selenium are exceptions), nor do they exceed the average concentrations found in rocks of the Earth's continental crust (boron, mercury, and selenium are exceptions). It should be noted that the coal may yield some, or all, of a few given elements to the atmosphere upon burning, whereas the other materials listed in table 1 are not likely to be burned. Also, surface and near-surface sandy materials to depths of 6.6 feet (2 m) show little significant variation in trace-element composition in the few localities that were sampled. Available geochemical data on overburden rocks, based on analyses of several different rock types, show a relatively wide range of concentrations for many elements, with the higher values for some elements noticeably exceeding those found either in the Wyodak-Anderson coal or in surface and near-surface materials.

Data on the concentrations of trace elements in ground water are still accumulating, and no reliable baselines have yet been established. However, the analysis of one sample of water from the Wyodak-Anderson coal bed, collected from the working face of the Belle Ayr mine (mine location in fig. 4), indicates that the chemical content is similar to that for ground water from noncoal aquifers in the Fort Union Formation (U.S. Geological Survey, 1974, p. 34).

LAND AND COAL OWNERSHIP

One of the most controversial issues involved in the expansion of coal development in the West is that dealing with the separation of surface ownership and mineral ownership. In many of the coal-rich areas of the Rocky Mountain and Northern Great Plains regions, much of the land surface is owned by private and State interests, whereas the mineral rights (including coal) are owned by the Federal

Government (that is, the general public). This circumstance, which has caused virtually irreconcilable conflicts in many cases, stems from the fact that by the year 1910 Federal statutes governing homesteading on the public lands had been modified to the extent that subsequent homesteads would receive title to the surface but not to the underlying coal (U.S. Government, 1968). The modified statutes also reserved to the Federal Government the right to prospect for and mine the coal. In the Gillette area, as elsewhere, much land was acquired by private interests as a result of the Stock Raising Homestead Act of 1916, giving rise to the present widespread separation of land and coal ownership. (See U.S. Geological Survey, 1973; Breckenridge and others, 1974; and various land and mineral ownership maps issued by the U.S. Bureau of Land Management.)

Ownership patterns for the area surrounding the city of Gillette, typical for the eastern Powder River Basin, are shown in figure 8. The outlines of the zone

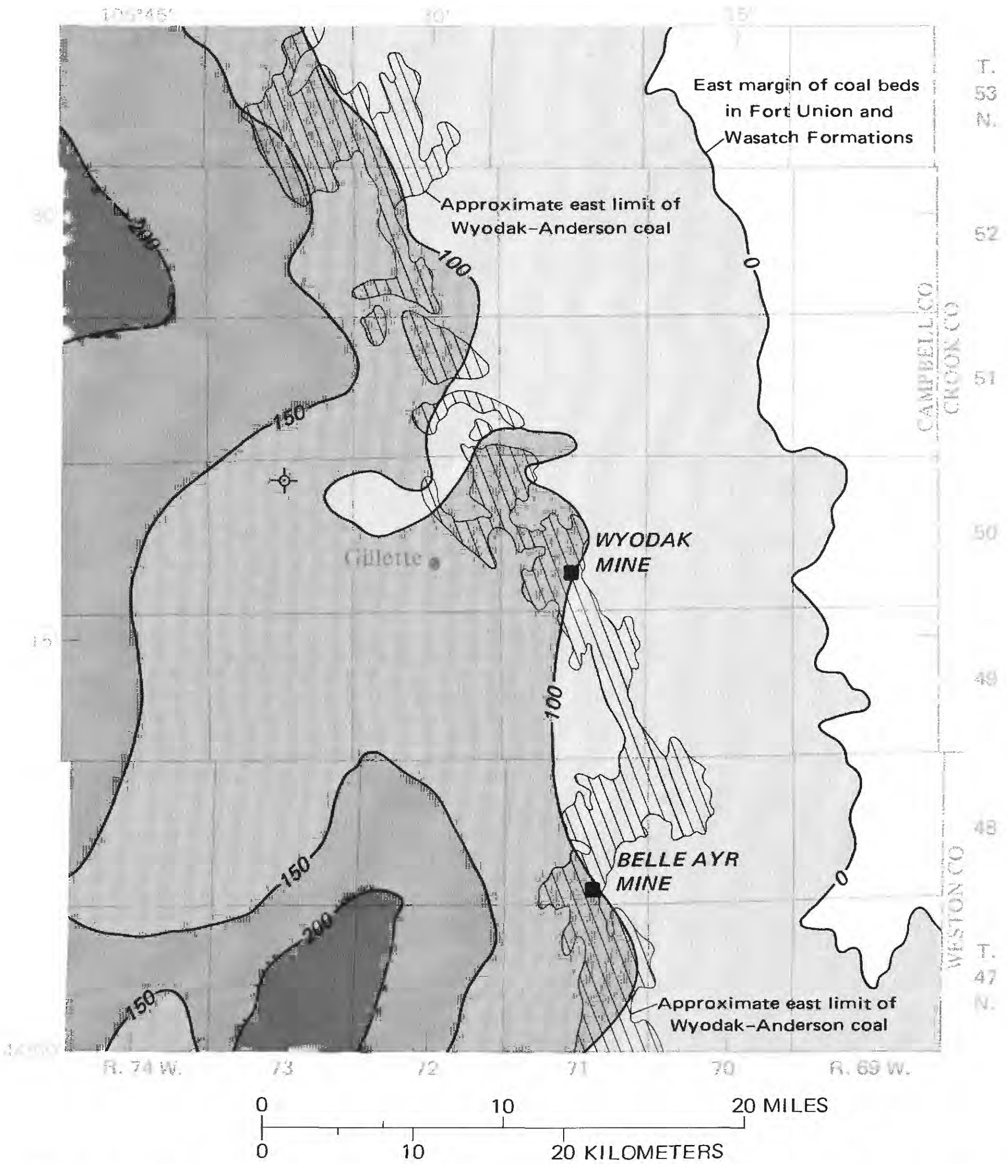


FIGURE 4.—Map of Gillette study area, showing areas where the Wyodak-Anderson coal bed lies less than 200 feet (60 m) below the ground surface. Labeled lines indicate total thickness of all coal beds in the Fort Union and Wasatch Formations, in feet. Oil well symbol in T. 50 N., R. 73 W., is location of well shown in figure 5. Information is based on Denson and others, 1973; and Denson and Keefer, 1974 (modified by F. R. Shawe).

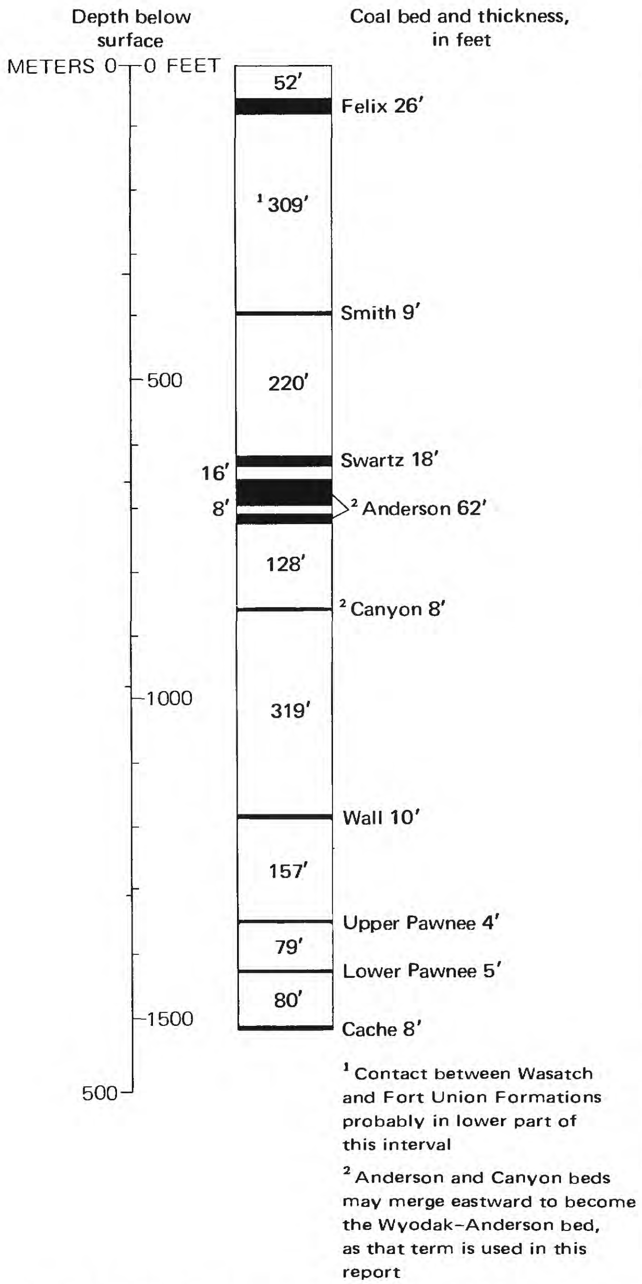


FIGURE 5.—Coal beds penetrated by McCulloch Oil Corp. Federal No. 2-3 well, sec. 3, T. 50 N., R. 73 W. (location plotted in fig. 4). Based on information from Denson and others, 1973.

underlain by strippable coal of the Wyodak-Anderson bed are drawn on this map to emphasize the problems inherent in separate ownership.

CURRENT LAND USE

Land in the Gillette area is used principally for agricultural purposes. Most of the acreage is occupied by rangeland; lesser amounts are utilized for the cultivation of hay and small grains in support of ranching operations. Figure 9 shows current land uses in the four-township area surrounding the city of Gillette. Although the predominance of agriculture is illustrated in figure 9, agriculture is not entirely typical of the region because somewhat more than the usual amount of land near Gillette is given over to dryland farming and to urban and commercial development.

Surface mining of coal represents a land use that conflicts with the more traditional uses. The outline of the strippable coal zone of the Wyodak-Anderson bed is superimposed on the current land-use map (fig. 9) to indicate where, and to what extent, conflicts may arise if the coal is extracted from this particular tract. The kinds of information shown on this map are especially important when advance decisions have to be made with regard to land-use priorities.

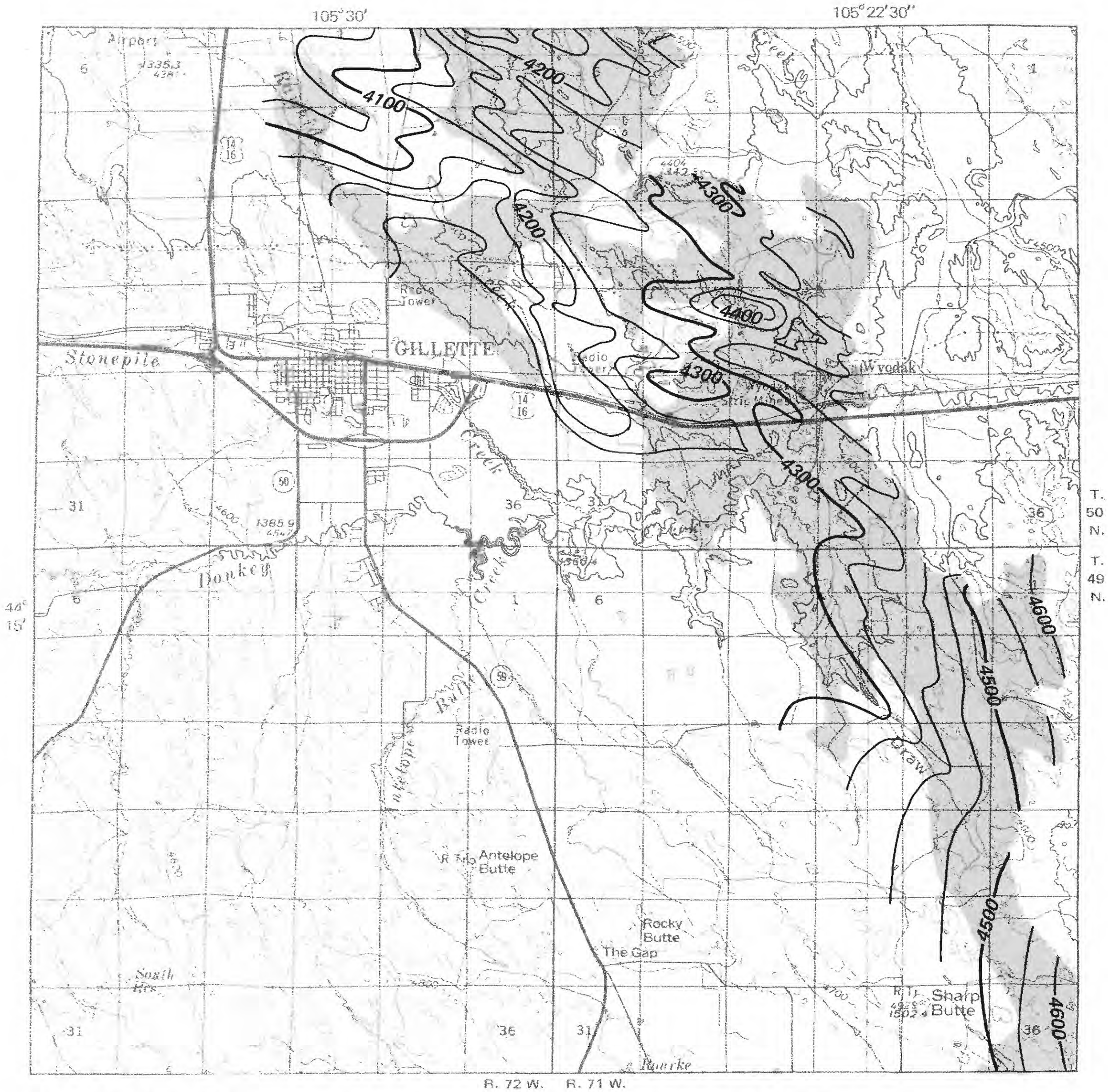
SURFACE WATER

Most of the streams in the Gillette study area (fig. 17) are ephemeral, being dry much of the year and flowing only in response to spring snowmelt or rainstorms large enough to produce runoff. The average annual precipitation at Gillette is 14 inches (36 cm). One stream, Donkey Creek, exhibits characteristics of both ephemeral and perennial streams. It is perennial in the sense that parts of the channel contain water throughout the year—in pools with little or no discernible flow. However, like that of ephemeral streams, most of the flow of Donkey Creek results from snowmelt or rainstorms.

The primary use of surface water in the study area is for flood irrigation of hayfields along valley floors. Small reservoirs for livestock water and erosion control also withhold significant amounts of streamflow in some tributary basins. Surface water, however, does not make up a very large part of the total water available in the study area. The average annual runoff from the area is about 0.25 inches (0.63 cm) or 13.3 acre-ft/mi^2; in the four-township area surrounding Gillette, this amounts to approximately 2,000 acre-feet.

GROUND WATER

The aquifers considered in this report lie at depths less than 500 feet (153 m). Water from this shallow system, which includes both alluvial and bedrock aquifers, is used primarily for domestic and livestock use, whereas water for municipal or industrial use is derived from deeper aquifers. Ground water occurs under water-table conditions in the alluvial aquifers but is generally under confined, or artesian, conditions in most bedrock aquifers (King, 1974). The map in figure 10 is based on measurements of water-level elevations in wells that have been completed in the shallow ground-water aquifers in the area surrounding the city of Gillette. Although the shallow ground-water system is a composite of several aquifers, it is considered as a single inte-



Base from U.S. Geological Survey
1:100,000, 1972

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 6.—Structure contours drawn on base of Wyodak-Anderson coal, Gillette and vicinity (F. R. Shawe, written commun., 1976). Contour interval is 50 feet (15 m); datum is mean sea level; hachures point toward areas of lower elevation. Strippable coal zone, Wyodak-Anderson coal deposit, is shown by shading.

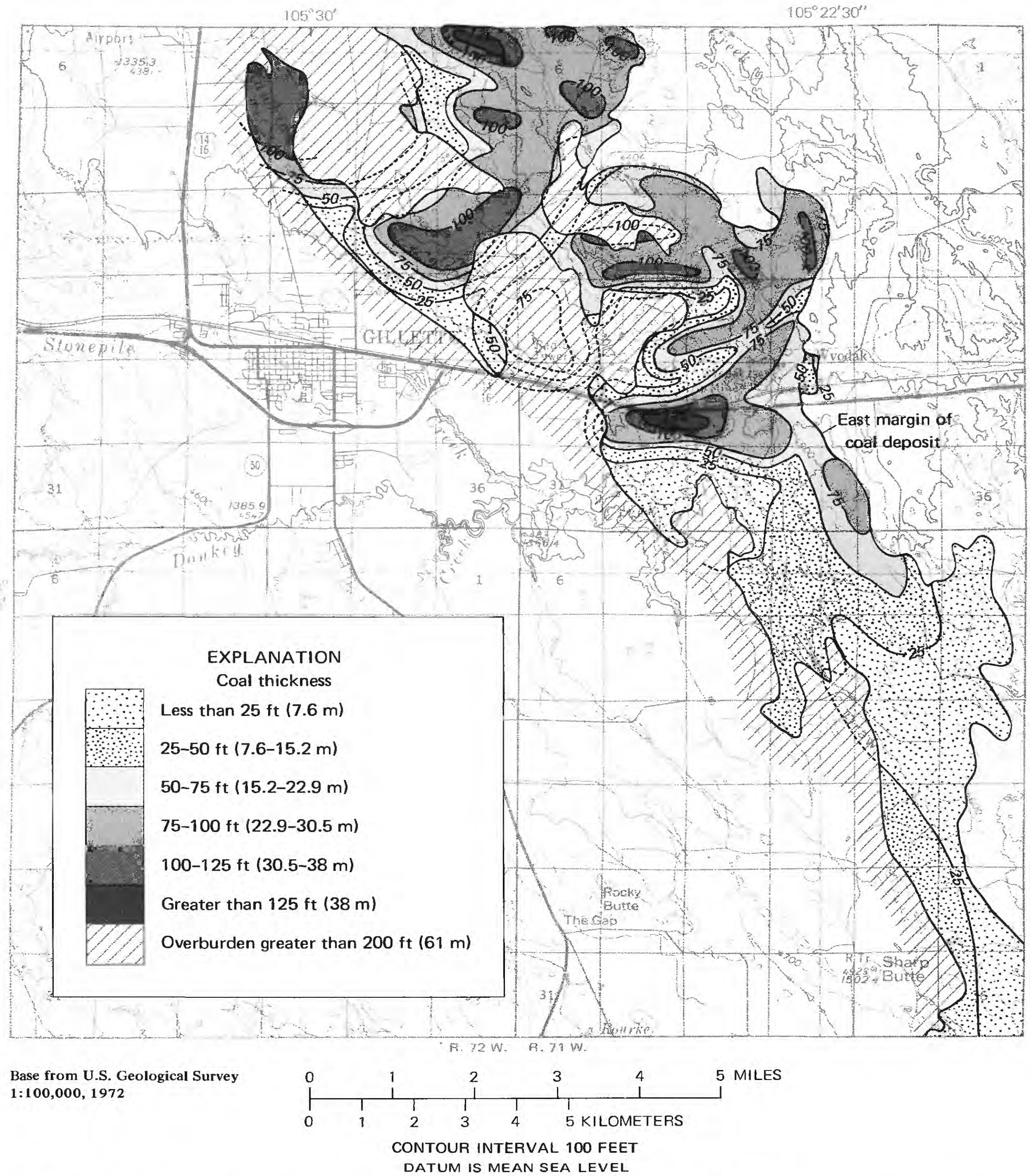


FIGURE 7.—Outline of strippable coal zone, Wyodak-Anderson coal deposit, showing thicknesses of coal (F. R. Shawe, written commun., 1976).

grated system because most wells either are uncased or have been perforated to take advantage of ground-water yields from most, if not all, of the aquifers penetrated. Hence, the water levels in these wells, as contoured in figure 10, reflect the approximate top of the zone of saturation of the shallow ground water system (N. J. King, oral commun., 1976). In a later section of this report which discusses the potential effects of surface mining on ground-water levels, a distinction is made regarding the behavior of water

TABLE 1.—*Concentrations of trace elements in Wyodak-Anderson coal, surface soils, near-surface soils and rocks, overburden rocks, and sagebrush in the Powder River Basin*

[Analyses performed in U.S. Geological Survey laboratories. Symbol < indicates concentration is less than the value shown. Leaders (...) indicate no available data. Asterisk(*) indicates elements generally considered to be of environmental concern. All values are in ppm]

Element	Wyodak-Anderson coal[1] (reported on whole-coal basis)		Sagebrush ash (*Artemisia tridentata*)[2]		Surface and near-surface materials[3]						Overburden rocks[7]	Average concentrations in rocks of the Earth's continental crust[8]
					Depth: 0-1 inch (0-2.5 cm)[4]		Depth: 6-8 inches (15-20 cm)[4]		Depth: 3.3 feet (1 m)[5]	Depth: 6.6 feet (2 m)[6]	Depth: 10-166 feet (3-35.5 m)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Range	Range	Range	
Antimony*--	0.3	<0.1-.7	--	--	1.2	--	1.1	--	0.4-.9	0.9-1.0	1.6-2.9	0.2
Arsenic*---	1.9	<1-4	--	--	7.2	--	8.2	--	4-5	2.6-8.6	3-70	1.8
Barium-----	300	150-500	580	150-1,500	770	500-3,000	760	300-1,500	500-700	700	300-1,000	425
Beryllium--	.2	<.15-.7	--	--	.96	<1-1.5	1.11	<1-1.5	<1-1	<1	<2-3	2.8
Boron------	30	20-50	280	200-500	31	<20-70	28	<20-70	<20-20	<20-20	<30-50	10
Cadmium*---	.1	<.1-.12	6.8	1.3-30	--	--	--	--	--	--	<1-2.5	.2
Chromium---	5	1.5-50	21	5-150	48	20-100	52	20-100	20-30	20-30	30-100	100
Cobalt-----	2	<.5-3	2.6	<1-6	6.7	<3-10	7.5	<5-20	<3-5	5	<5-20	25
Copper*----	13.2	3.3-51	--	--	16	3-30	18	5-50	7	7-20	10-60	55
Fluorine*--	47	30-200	--	--	--	<400-2,200	--	<400-1,200	--	--	260-840	625
Gallium----	2	1-20	--	--	13	7-20	14	7-20	10	10-15	10-30	15
Lanthanum--	5	<5-20	--	--	--	--	34	<30-70	<30	<30-30	<50-70	30
Lead*------	4	<1.5-8.2	65	<30-150	18	10-30	18	10-100	15	15	<25-30	12.5
Lithium*---	2.5	<.5-49	12	2-48	22	11-35	25	24-47	9-15	12-21	11-50	20
Manganese--	50	10-200	530	300-1,500	280	70-1,000	250	100-700	30-200	100-150	--	950
Mercury*---	.14	.05-.29	--	--	.022	.01-.04	.025	.01-.04	.01-.02	.02-.03	.02-.15	.08
Molybdenum-	.5	.3-1.5	11	<7-30	--	<3-20	--	<3-5	<3-5	<3-5	<5-7	1.5
Nickel-----	5	2-15	17	<10-30	15	<5-30	16	<7-50	5-10	7-10	7-100	75
Niobium----	1.5	<1-20	--	--	7.2	<10-10	7.2	<10-10	<10-10	<10	<10-15	20
Scandium---	2	.7-15	--	--	8.2	<3-15	8.7	<3-15	3-5	5-7	<5-15	22
Selenium*--	1.5	.3-6.7	.68	.08-4.8	.20	--	.14	--	<.1-.3	<.1	<.1-1.4	.05
Silver-----	--	--	--	<1-1	--	--	--	--	--	--	--	.07
Strontium--	70	20-200	700	150-1,500	180	50-500	180	100-500	100-150	150	70-200	375
Thorium*---	1.5	<1.5-7.9	--	--	9.6	5.3-15	9.8	5.6-15	8.4-9.8	6.7-9.7	7.3-18.3	9.6
Titanium---	500	150-5,000	1,100	200-2,000	--	--	--	--	--	--	--	5,700
Uranium*---	.8	<.2-3.2	.72	<.4-3.5	3.1	1.7-7	3.2	2.2-7	2.2-2.4	2.0-2.2	2.3-6.9	2.7
Vanadium---	20	5-150	39	<15-70	80	30-150	92	50-150	30-70	50-70	30-150	135
Ytterbium--	--	--	--	<2-3	1.9	1-5	1.9	1-5	1	1	<2-3	3
Yttrium----	3	<1-7	--	<20-30	17	10-50	18	10-30	10	10	15-30	33
Zinc*------	7.5	2.1-25	430	200-800	62	28-93	64	25-104	28-35	32-49	30-375	70
Zirconium--	15	5-150	64	20-150	160	70-500	150	70-300	70-150	70-100	70-500	165

[1]Based on analyses of 15 samples from Wyodak mine and 11 samples from Belle Ayr mine. (See mine locations, figure 4.) Data compiled by J. R. Hatch and V. E. Swanson; analyses performed by Claude Huffman, Jr. (chemist-in-charge), A. J. Bartel, L. A. Bradley, G. T. Burrow, E. J. Fennelly, J. Gardner, W. D. Goss, P. Guest, J. C. Hamilton, A. W. Haubert, A. E. Hubert, R. E. McGregor, V. M. Merritt, Jr., H. G. Neiman, D. R. Norton, R. L. Rahill, F. N. Ward, and R. A. Zielinski (U.S. Geological Survey). For additional information, see Glass (1975).

[2]Based on analyses of samples from 48 localities within the Powder River Basin. Data compiled from Connor, Keith, and Anderson (1976); U.S. Geological Survey (1974, 1975).

[3]Data compiled from Connor, Keith, and Anderson (1976); U.S. Geological Survey (1974, 1975).

[4]Based on analyses of samples from 48 localities within the Powder River Basin.

[5]Based on analyses of samples of sand and clayey sand from three localities near Gillette. A single number indicates that the same value was obtained at each locality.

[6]Based on analyses of samples of sandstone from two localities near Gillette. A single number indicates that the same value was obtained at each locality.

[7]Based on analyses of 22 rock samples from 4 core holes in the eastern Powder River Basin; compiled from data in Department of Interior, 1974, p. I-182c-I-182e.

[8]From Taylor (1964).

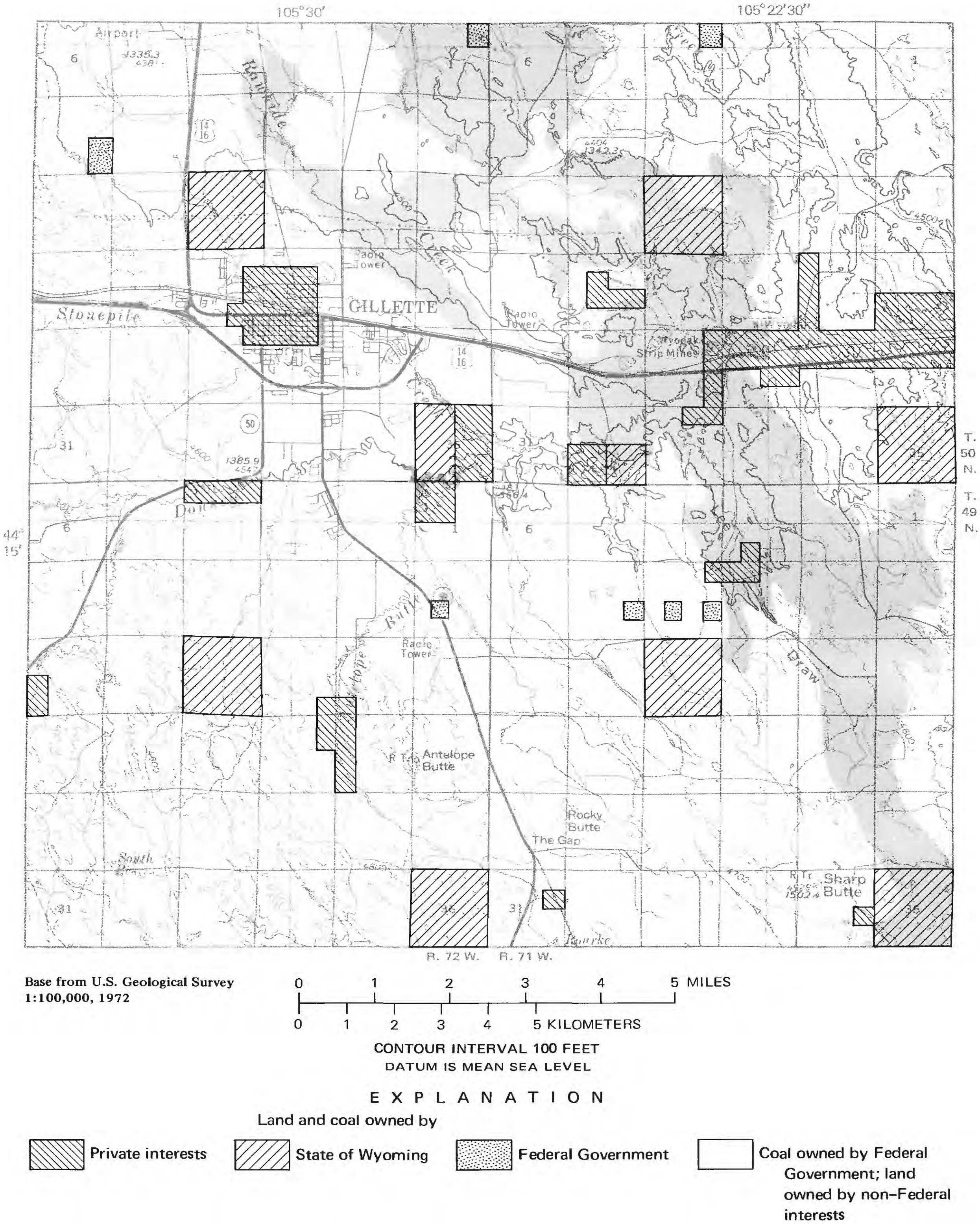


FIGURE 8.—Land and coal ownership, Gillette and vicinity. From U.S. Geological Survey, 1973. Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area.

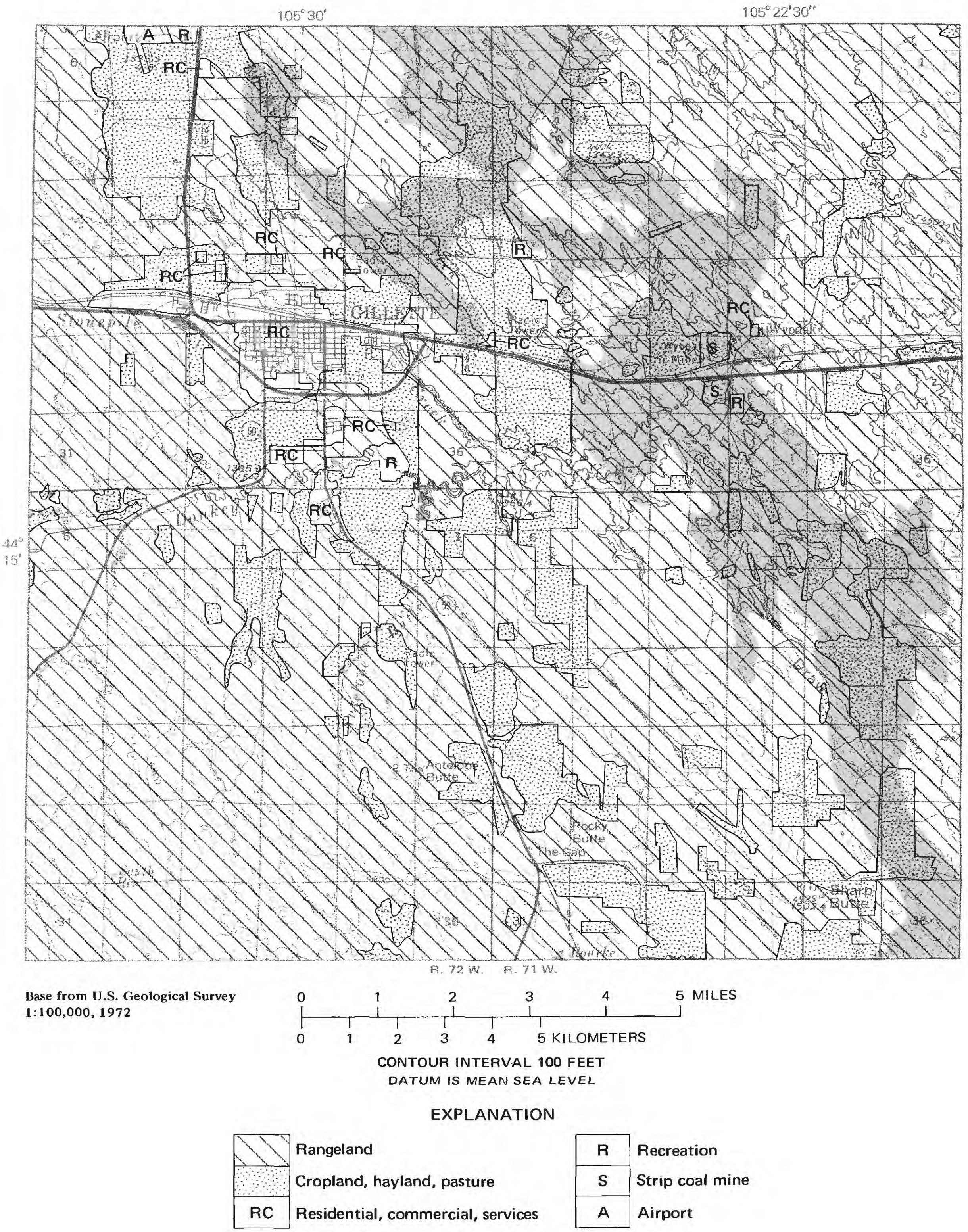


FIGURE 9.—Land use map, Gillette and vicinity, 1970. (From Shown, 1973.) Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area.

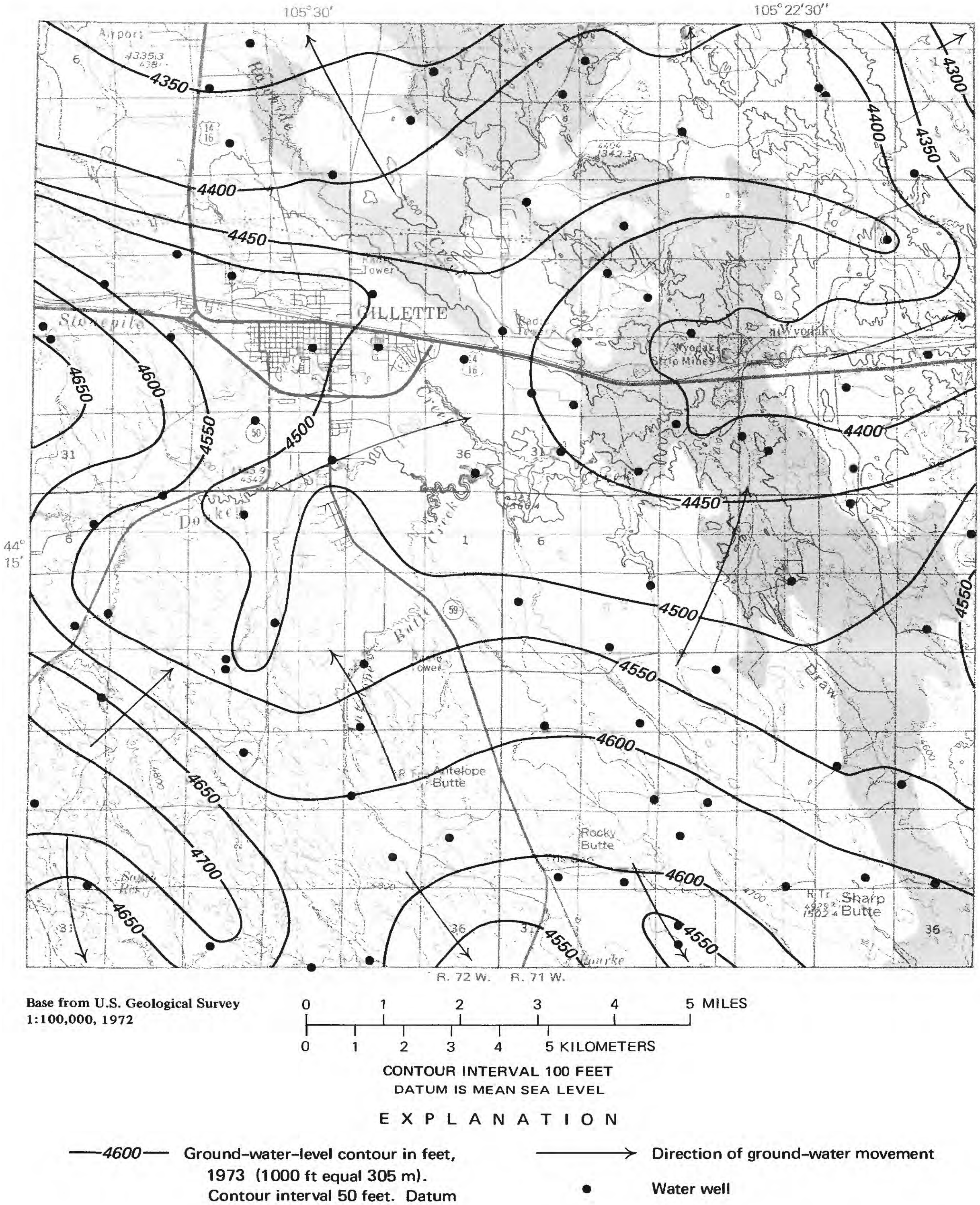


FIGURE 10.—Level and direction of ground-water movement, Gillette and vicinity. (From King, 1974.) Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area.

levels in tightly cased wells that bottom in different aquifers having different potentiometric surfaces. (See fig. 15.)

The bedrock aquifers in the shallow ground-water system generally exhibit similar water-bearing characteristics. All are composed largely of interbedded sandstone, siltstone, mudstone, and shale; all contain one or more coal layers. Sandstone generally yields water to wells in areas where the sandstone is saturated, with the water yield depending primarily on the permeability of the saturated rock. In contrast, siltstone, mudstone, and shale are relatively impermeable and yield little or no water to wells. Coal beds generally are sufficiently fractured to be good aquifers. Thin coal beds of limited areal extent will yield limited amounts of ground water; however, thick coal beds of broad areal extent may yield 10–100 gallons (38–380 liters) per minute.

In the central part of the four-township area surrounding the city of Gillette (fig. 10), ground water moves generally toward the channel of Donkey Creek. Ground-water divides occur near the south and north edges of this area. In the more permeable aquifers, the slope of the water level is generally about 10–25 feet per mile (2–5 m/km). In aquifers having low permeability, the slope may exceed 100 feet per mile (19 m/km). The spacing of the contours in figure 10 provides some indication of the transmissivity of the shallow aquifers.

A generalized map of ground-water quality in shallow aquifers is shown in figure 11. This map was prepared from measurements of specific conductance (electrical conductivity) of water samples from wells (King, 1974). Specific conductance is controlled by, and is therefore an index of, the dissolved-solids content of the water. Figure 11 shows comparatively well defined areal patterns of water quality at depths of 0–500 feet (0–153 m). These patterns probably reflect lithologic changes within the underlying bedrock units.

EROSION AND SEDIMENT YIELD

Upland erosion and stream-channel erosion generally are not serious problems in the Gillette study area, which lies astride a relatively undissected upland in the upper parts of the Little Powder and Belle Fourche River watersheds. The only major stream crossing the area is Donkey Creek, a tributary of the Belle Fourche River.

In order to estimate sediment yield on a regional basis under present land use, surveys were made of several small reservoirs of the type commonly used for storing water for livestock. The sediment accumulations in these reservoirs are direct indicators of the erosion conditions and sediment yield from upland areas during the life of the structure, and the information can be used to establish reliable estimates of long-term sediment yield.

The study area was divided into four broad landform types based chiefly on interpretations of aerial photographs and on generalizations of landform information shown in figure 3; sediment-yield data from reservoirs were then extrapolated to areas exhibiting similar landform and erosion characteristics. The combined landform and sediment-yield information was used to construct the source-area sediment-yield map shown in figure 12.

Under present land use, most of the area underlain by strippable coal (fig. 12) has an estimated annual sediment yield of 0.05 to 0.25 acre-ft/mi^2, and along the channel and flood plain of Donkey Creek it is probably less than 0.05 acre-ft/mi^2. These are low sediment yields for semiarid rangeland, but, as discussed earlier, most of the uplands in the Gillette area are undissected, and the vegetation cover is good. The potential for increased sediment yield is large if the vegetation cover is greatly reduced and slopes are steepened by surface disruptions associated with mining.

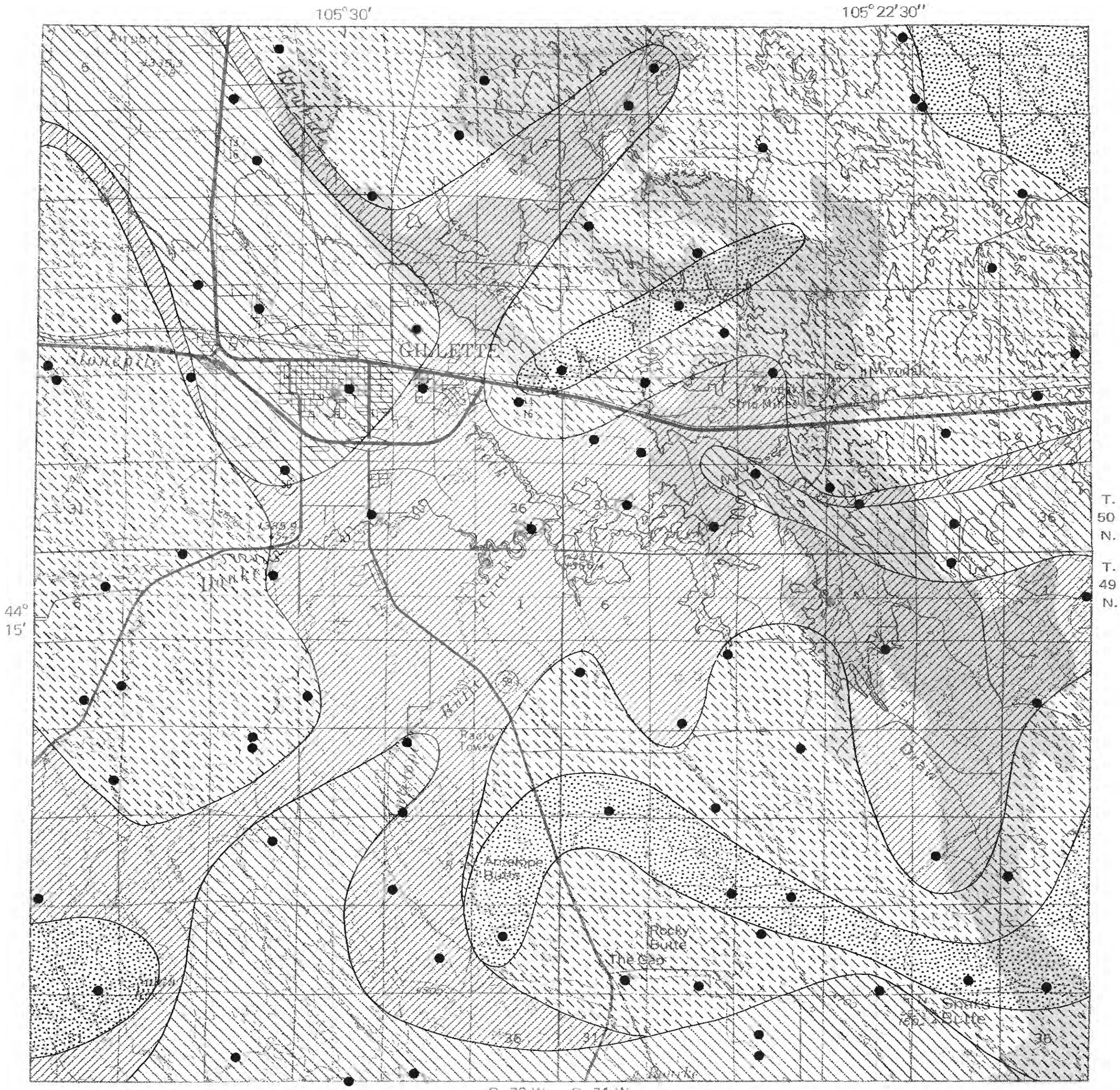
SOME ENVIRONMENTAL IMPACTS OF SURFACE MINING

LAND DISTURBANCE AND TOPOGRAPHIC CHANGES

Surface mining of coal cannot be accomplished without disturbing the land surface; the acreages involved depend primarily on the tonnages and thicknesses of the bed being mined. The following table shows the extent of land disturbance that will occur with the mining of different tonnages of coal from the Wyodak-Anderson deposit in the eastern Powder River Basin, assuming 90-percent recovery.[4] The

Tonnage (millions of short tons) / Average coal thickness	Extent of land disturbance (acres)		
	15	50	100
1	42	13	6
5	209	63	31
10	417	125	63
25	1,043	313	156

[4]The nationwide average for recovery of coal from surface mines is approximately 70 percent. However, in many western surface mines recovery of thick coal beds may exceed 90 percent.



Base from U.S. Geological Survey
1:100,000, 1972

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

- Generally suited for most domestic uses
- Marginal for most domestic uses and for lawn and garden irrigation; good for livestock use
- Undesirable for most domestic uses; fair for livestock use
- Unsuitable for most domestic uses; generally suitable for livestock use
- ● Water well

FIGURE 11.—Water quality in wells and springs, Gillette and vicinity. (From King, 1974.) Areal patterns of water quality based on approximate dissolved-solids content of water samples. Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area.

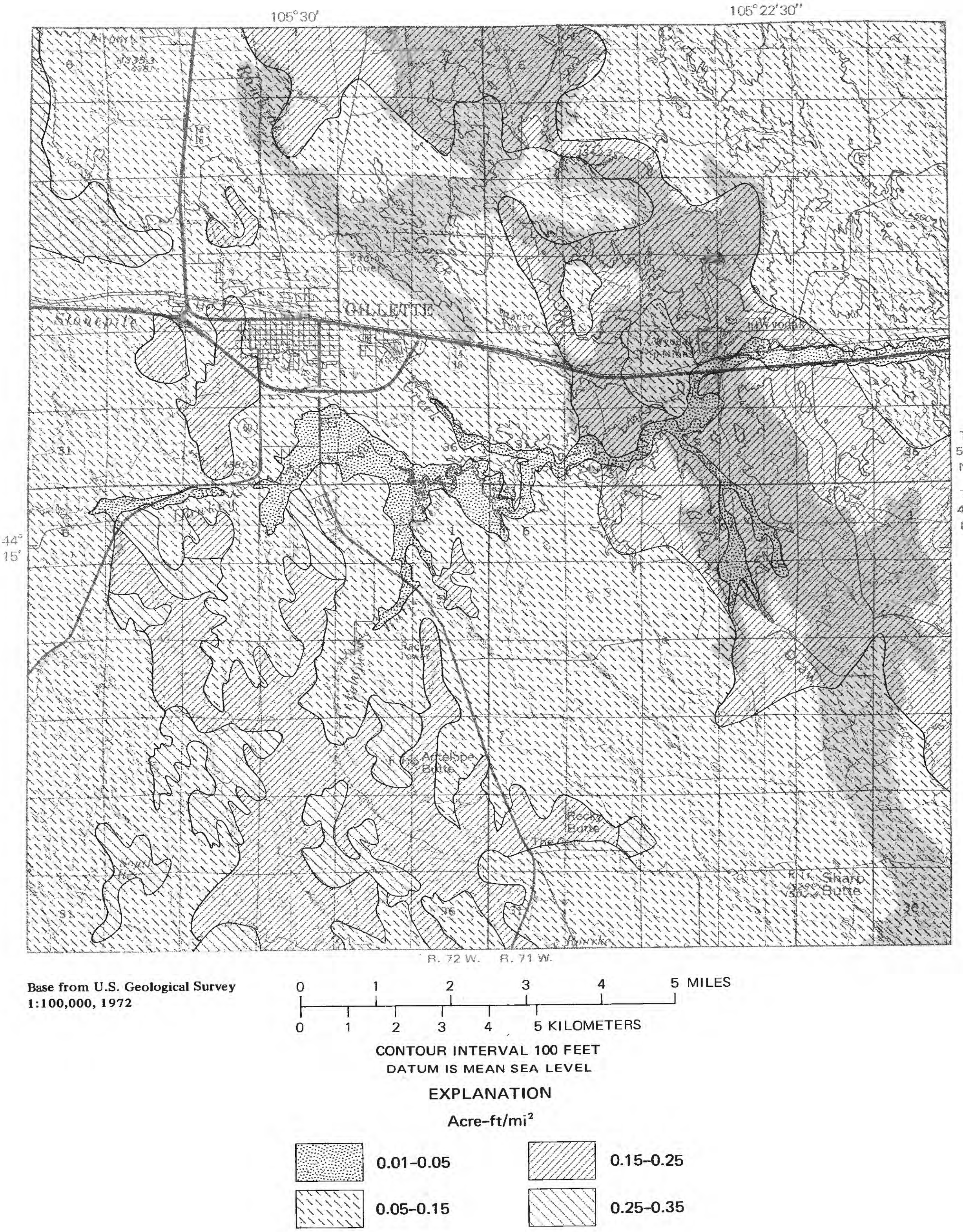


FIGURE 12.—Map of Gillette and vicinity showing estimated annual source-area sediment yields, 1975 (L. M. Shown, written commun., 1976). Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area.

calculations are based on the fact that an acre-foot of subbituminous coal (a bed with an area of 1 acre and a thickness of 1 foot) contains 1,770 short tons (1.607 metric tons).

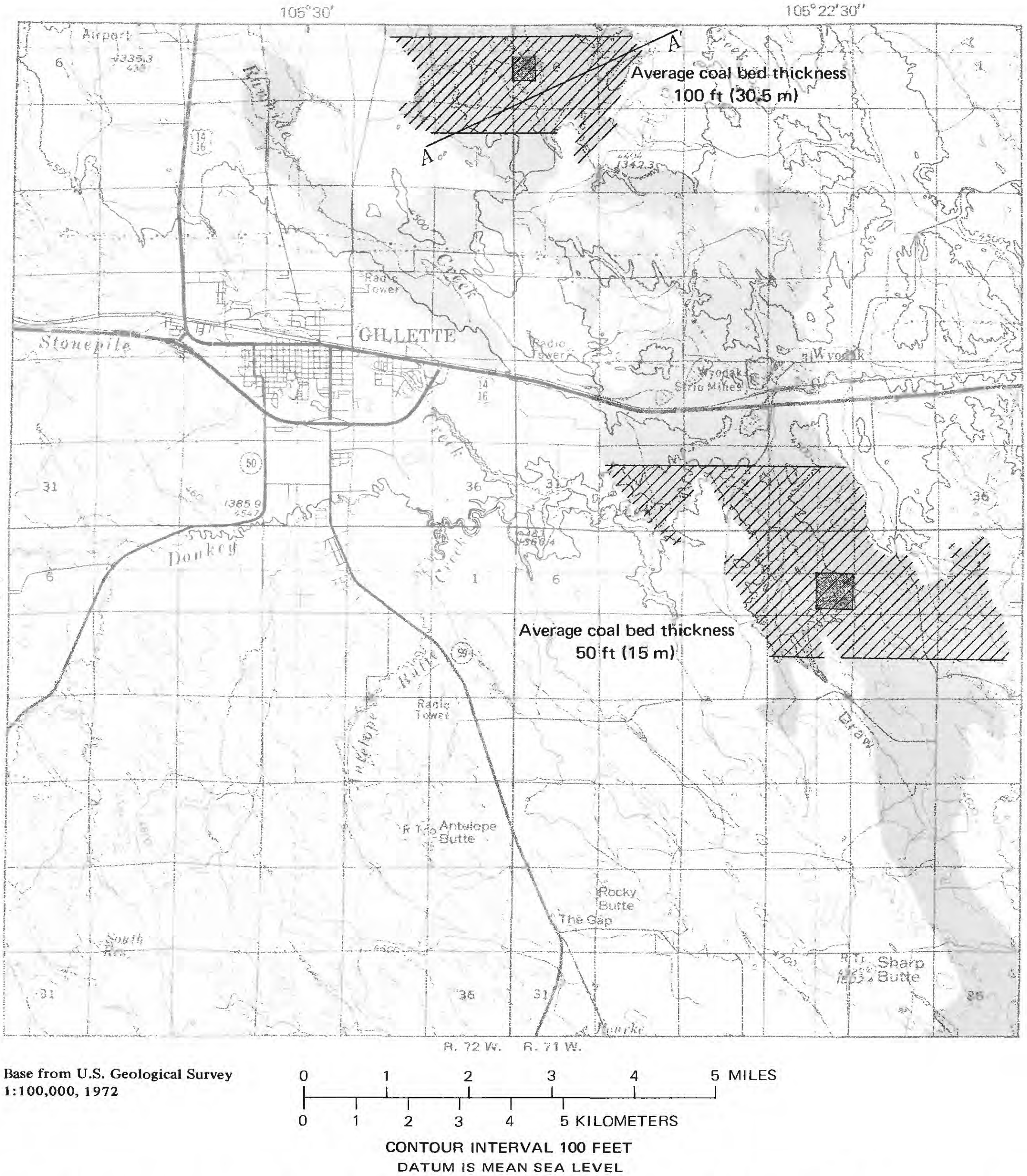


FIGURE 13.—Map showing extent of land disturbance involved in surface mining of coal deposits that average 50 (15 m) and 100 (30 m) feet thick, assuming 90 percent recovery. Dark squares indicate acreages involved in mining 10 million tons (9.1 million metric tons). Patterned areas (including dark squares) indicate tracts that would be disturbed in mining 350 million tons (320 million metric tons). Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area. Line labeled *A–A'* shows location of cross section.

Relating the figures given in the above table to surface mining operations in the eastern Powder River Basin, it is assumed, for purposes of discussion, that a given mine has been designed to produce 10 million short tons (9.1 million metric tons) annually over a period of 35 years, for a total of 350 million short tons (318 metric tons). If this amount were extracted from a tract where the underlying Wyodak-Anderson bed averages 100 feet (30 m) in thickness, the area involved, assuming 90 percent recovery, would be 2,188 acres (about 3.4 mi^2). If the coal bed averages 50 feet (15.3 m) in thickness, the area of disturbance would be doubled. Map views of these two hypothetical mine areas, plotted with respect to assumed average coal thicknesses within the strippable coal zone of the Wyodak-Anderson bed, are shown in figure 13. It should be emphasized, however, that at no time would open pits probably occupy more than a small fraction of the areas of disturbed lands plotted in figure 13. At some predetermined stage in most surface mining operations, reclamation will begin, with spoil materials being graded and reclaimed at about the same rate as overburden is removed from new mining cuts. In addition to the acreages involved in actual mining operations, a few hundred adjacent acres will be occupied by associated surface facilities, including railroad trackage.

The degree to which the topography of an area will be altered by surface mining depends upon many factors; most important are the depth and thickness of the coal being mined (figs. 6, 7) and the manner in which the overburden is replaced in the mined-out pits. Overburden expands as the earth materials are broken up during mining; hence, overburden takes up more space where it is dumped than it did before being disturbed. The expansion factor ("bulking") differs according to the kinds of rock involved, but it is common for soft sandstone and shale, as are found in the Gillette area, to increase 20 to 25 percent in volume. Thus, where coal 20–25 feet (6–8 m) thick is overlain by 100 feet (30 m) of overburden, little change would occur in the average elevation of the land surface when the overburden has been returned to the mined-out pits. For the same amount of overburden, a lesser thickness of coal would result in a higher land surface, and a greater thickness of coal would result in a lower land surface. Figure 14 shows, in cross-sectional view, some of the changes in topography that might result from surface mining in areas where the Wyodak-Anderson bed is 100 feet (30 m) thick over a large part of the strippable coal zone. Note that the replaced overburden probably will undergo some compaction in ensuing years.

Advance knowledge of how the landscape will

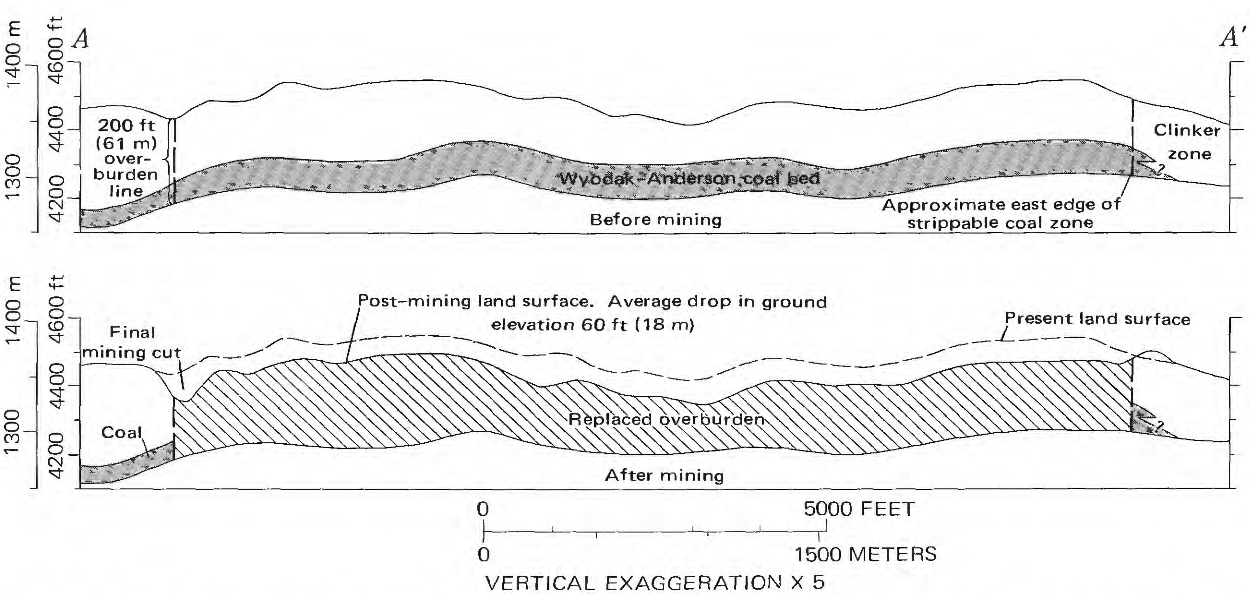


FIGURE 14.—Cross section showing potential changes in topography resulting from surface mining (location of section shown in fig. 13). Lower cross section is based on the assumption that overburden is replaced on a cut-by-cut basis with 200-foot-wide (60-m-wide) cuts, spoils are smoothly graded, high walls are graded to 3:1 slopes, and overburden expands 20 percent.

likely appear after being surface-mined is important for purposes of reclamation, land-use planning, and environmental-impact evaluation. This is especially true for the Gillette area, where the strippable coal is thick in comparison to overburden and where major modifications of the existing terrain are expected for large tracts of land (fig. 14). Maps showing simulated post-mining terrain—in essence, maps depicting the shape of the land surface as it will look after mining and reclamation—are being prepared for those parts of the Gillette study area that are underlain by strippable coal of the Wyodak-Anderson deposit. The maps are constructed by combining data on coal thickness, structure contours (figs. 6, 7), and present-day topography; they are based on assumptions that coal will be extracted and overburden replaced according to a specified set of mining and reclamation practices (such as those listed in the caption for fig. 18). These maps can be used to evaluate a variety of environmental impacts, such as determining the extent of potential disruption of the surface-drainage system and predicting changes in erosion and sediment-yield patterns. (See, for example, fig. 18 and the discussion on environmental impacts relating to surface drainage.) Identification of these and other problems will assist in all stages of planning of mining and reclamation activities.

POTENTIAL EFFECTS ON GROUND-WATER LEVELS

Some of the effects on ground-water levels that may result from surface mining of coal in the Gillette area can be inferred from the ground-water data shown in figure 10 and from the structure contour map (fig. 6). The combined information indicates that nearly everywhere along the strippable zone of the Wyodak-Anderson coal deposit the depth of mining will exceed the depth to ground water and thereby disrupt the shallow ground-water system. The potential effects are illustrated by the block diagrams in figure 15 and the map in figure 16.

On block diagram *A* (fig. 15), the ground-water level marked by the solid line (labeled "water table") represents the level of saturation, or potentiometric surface, in the discontinuous sandstone aquifers overlying the coal. The dashed line represents the potentiometric surface, or the level to which water will rise, in tightly cased wells that bottom in the coal-bed aquifer or deeper aquifers. Both water levels slope eastward to points of discharge along the stream that traverses the right (east) edge of the diagram.

Block diagram *A* (fig. 15) illustrates ground water conditions for an area where surface mining has not yet begun. Six water wells are shown that represent a variety of conditions based on well data collected throughout the Gillette study area (King, 1974). Well 1 is completed in a discontinuous sandstone aquifer; the overburden above the Wyodak-Anderson coal is about 550 feet (170 m) thick. The well is 120 feet (37 m) deep, and the water level is 60 feet (18 m) below the land surface. Well 2 is completed in the Wyodak-Anderson coal and is 520 feet (160 m) deep. The water level—that is, the potentiometric surface of the coal-bed aquifer—stands 130 feet (40 m) below the land surface. Well 3 is completed in a discontinuous sandstone aquifer at a depth of 540 feet (165 m). This aquifer is partially confined and underlies the Wyodak-Anderson coal. Well 4 is completed at a depth of 200 feet (60 m) in a discontinuous sandstone aquifer above the coal. The water level stands 40 feet (12 m) below the land surface. Well 5, completed in the same aquifer as well 4, is 120 feet (37 m) deep, and the water level is 40 feet (12 m) below the land surface. The overburden above the Wyodak-Anderson coal at well 5 is only 140 feet (43 m) thick. Well 6 is east of the surface outcrop of the coal and is completed in a discontinuous sandstone aquifer. The well is 120 feet (37 m) deep, and the water level is 10 feet (3 m) below the land surface. All these wells are used for domestic or livestock water and yield moderate amounts of water, generally less than 50 gal/min (190 l/min).

In block diagram *B*, a hypothetical surface mining operation has been imposed on the ground-water system. The overburden has been removed to a depth of 200 feet (60 m) and the Wyodak-Anderson coal, having a thickness of 100 feet (30 m), has been mined. The inferred impact on the shallow aquifers after the removal of the overburden and coal is based on the assumptions that (1) the Wyodak-Anderson coal-bed aquifer will be dewatered to the level of the pit floor, and (2) the overlying aquifers will be drained to the lowest point on the high wall where they are exposed, instead of to the stream channel near the east edge of the block. As a consequence, the water table probably will be lowered appreciably near the open pit, and wells 4 and 5 will be dewatered. Well 1 is far enough west of the mining operation that the water level probably will be lowered only slightly.

The potentiometric surface of the coal-bed aquifer will be lowered as in well 2 and graded to the bottom of the open pit. Because of the continuity and fracturing in the coal, however, the lowered potentiometric surface should maintain a fairly constant gradient to the east. Well 3, which is completed in an aquifer below the coal bed, also will be affected, although to a lesser extent than well 2. Water could

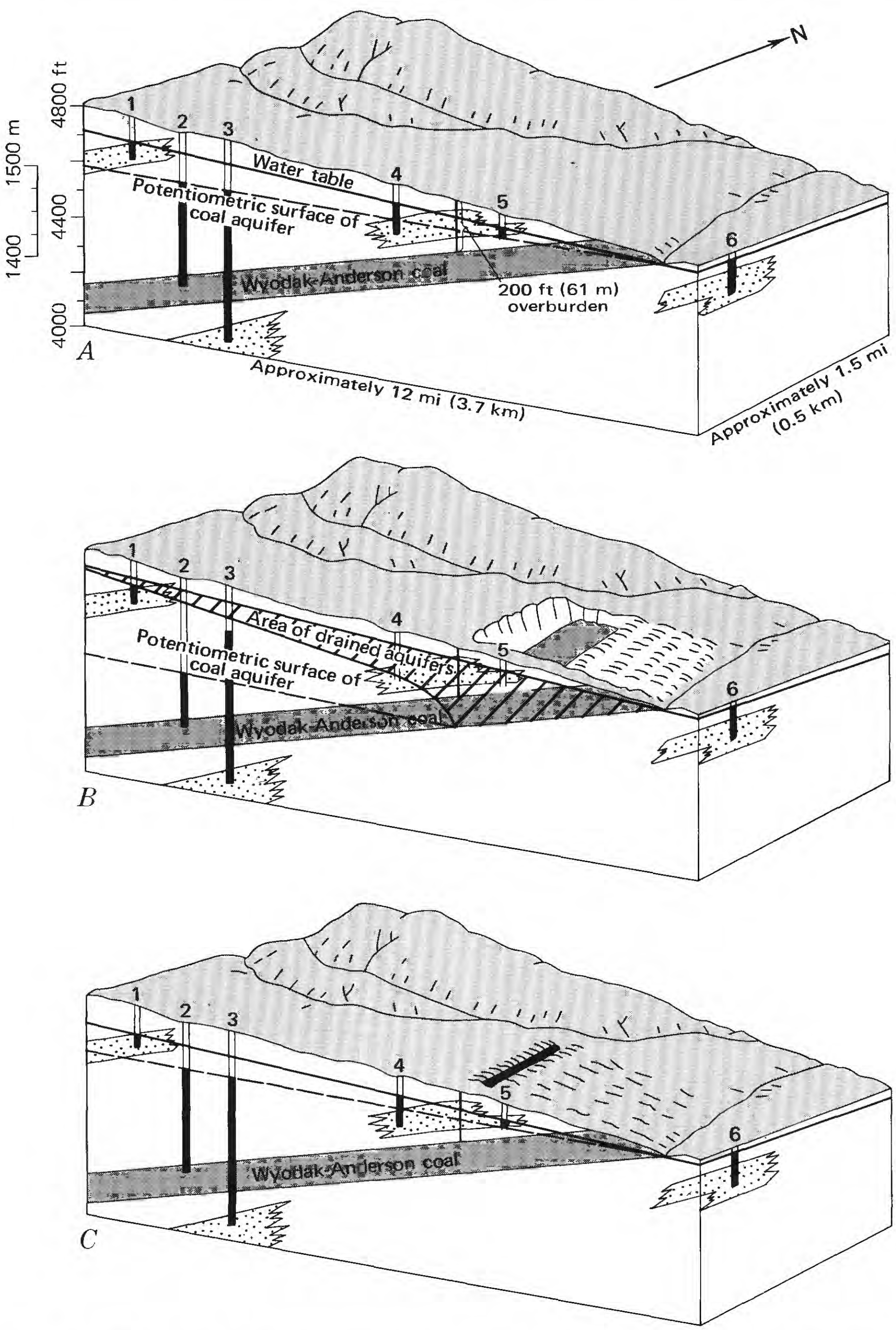
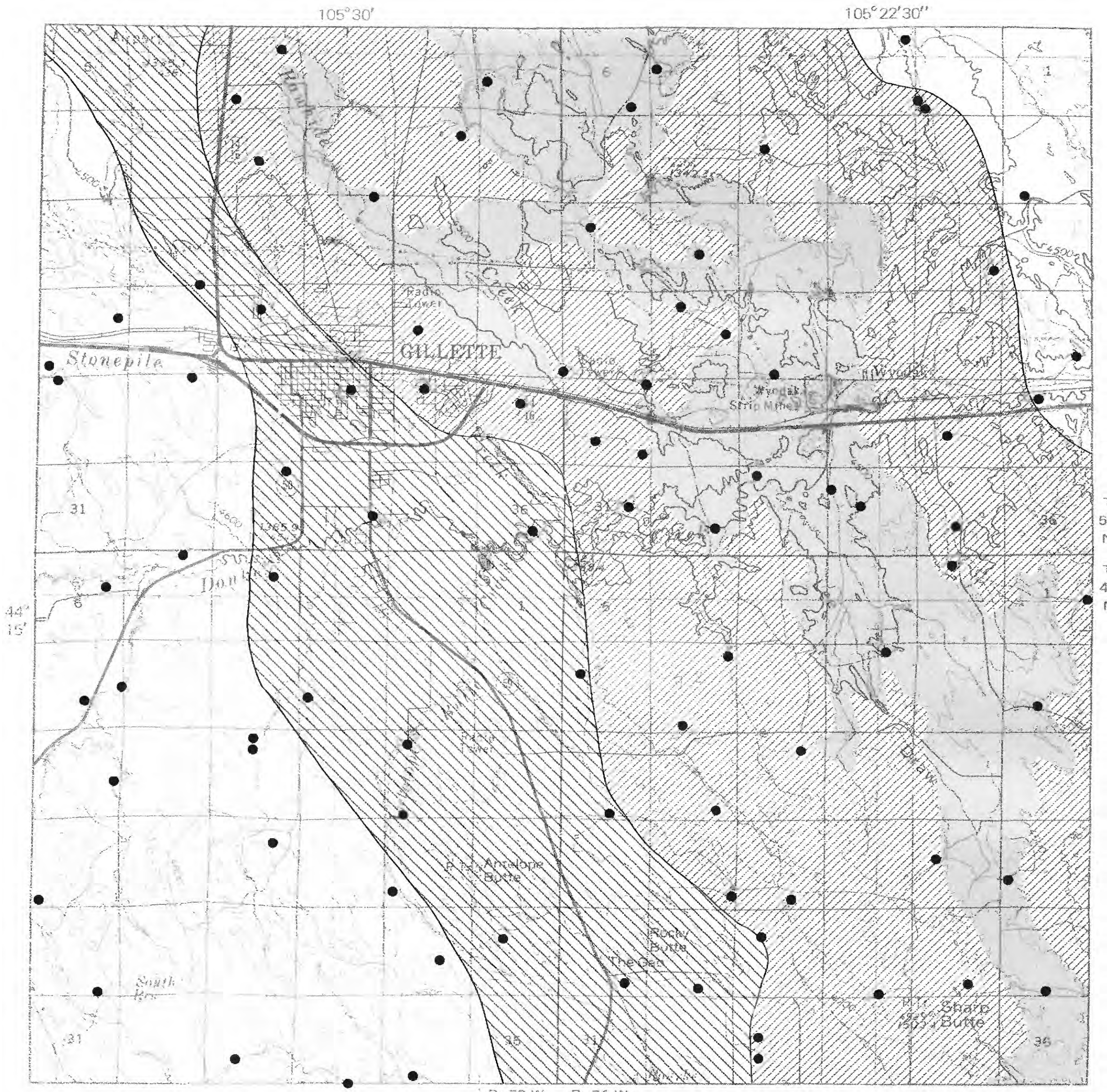


FIGURE 15.—Idealized block diagrams showing potential effects of mining on shallow aquifers. From Hadley and Keefer (1975). *A*, Ground-water levels before mining (water levels in numbered wells explained in text). *B*, Inferred changes in ground-water levels caused by removal of 200 feet (60 m) of overburden and 100 feet (30 m) of coal. *C*, Inferred recovery of ground-water levels after completion of mining and rehabilitation of mined area.



Base from U.S. Geological Survey
1:100,000, 1972

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

- Area where all aquifers above base of Wyodak-Anderson coal will be drained in the vicinity of mining operations
- Areas where aquifers less than 200 ft (61 m) deep will be moderately affected; water levels may be lowered appreciably
- Areas where wells in the Wyodak-Anderson coal will be moderately affected; shallower aquifers will not be affected appreciably
- Areas where shallow aquifer system probably will be little affected by mining of the Wyodak-Anderson coal down to the 200-foot (61 m) overburden line
- ● Water well

FIGURE 16.—Potential effects of surface mining on ground water, Gillette and vicinity. (Modified from Hadley and Keefer, 1975.)

possibly move upward in well 3 and enter the coal bed because of the lowering of the point of discharge of the coal-bed aquifer to the base of the high wall, which, in turn, lowers the water level in this well.

Well 6, which is east of the coal outcrop, may be affected by the mining operation to a small extent. The stream channel to which the water level in this well is graded will be dewatered, and there will be a general lowering of the potentiometric surface that may also lower the water level in well 6.

The longevity of the described impacts on ground-water levels requires further study. However, inferences can be made as to what will happen if the overburden is returned to the mined-out pits and if the topography is properly reshaped. Block diagram *C* illustrates the topography as it may appear after rehabilitation of the mine shown in block diagram *B*. In time, the overburden will become saturated, the point of discharge of ground water will again rise to the stream-channel level on the east edge of the block, and water levels in the discontinuous sandstone aquifers and the coal-bed aquifer west of the mine will perhaps return nearly to pre-mining altitudes.

The map in figure 16 shows the strip in the Gillette study area that has potential for surface mining of coal and also the areas adjacent to this strip where shallow aquifers may be affected. However, it should be noted that the inferred impacts on shallow aquifers probably will be confined to areas that lie within only a few miles of an individual mine. Also, if water levels are lowered in domestic and livestock wells so that they are no longer productive, it may be feasible to deepen the wells either in the same aquifer or to a deeper aquifer.

POTENTIAL CHANGES IN SURFACE-DRAINAGE PATTERNS

The potnetial changes in topography, which were discussed in the section on land disturbance and topographic changes, will also cause disruption of surface drainage. Figure 17 shows the present drainage pattern in the four-township area surrounding Gillette; all streams are ephemeral except Donkey Creek. The ephemeral channels, however, also carry flood flows to the Belle Fourche and Little Powder Rivers.

Donkey Creek is the only stream that flows entirely through the Gillette area (fig. 17). It flows generally eastward across, and nearly perpendicular to, the strippable tract of the Wyodak-Anderson coal. At the present time, there is only one surface mine—the Wyodak mine about 5 miles (8 km) east of Gillette—in the valley of Donkey Creek, but streamflow is not materially affected as a result of the stream being diverted around the mine pit.

Figure 18 shows potential changes in surface-drainage patterns near Gillette, based on the extraction of all coal from the Wyodak-Anderson deposit between the outcrop or burn line on the east and the 200-foot (60 m) overburden line on the west, according to the mining and reclamation practices outlined in the figure caption. Because the coal is 75 to more than 100 feet (23 to more than 30 m) thick over much of this area (fig. 7), the ground surface will be lowered appreciably and extensive closed depressions may be created. Restoring and maintaining through-flowing drainage ways, therefore, will be difficult, and water flowing in stream channels that are intersected by mining may become permanently impounded, unless measures are taken to insure proper outflow. Other problems of equal importance are those relating to gullying along stream courses upstream from the high walls and to increased erosion and sediment yield both inside and outside the mined-out area. The potential for stream-channel disruption must therefore be recognized and planned for on a site-by-site basis, as well as regionally, in the pre-mining stages of surface mine development. The technology for stabilizing stream-gradient breaks by using engineering structures is available and should be applied wherever necessary in the reclamation planning.

POTENTIAL GEOCHEMICAL CHANGES

The greatest potential for change in the chemical makeup of surface materials stems from the substitution of overburden rocks for surface soils following strip mining (U.S. Geological Survey, 1975, p. 5). This potential may be minimized by the removal, stockpiling, and subsequent return of existing surface and near-surface soils and rocks as topdressing on mine spoils. As indicated in table 1, the few localities in which these materials have been sampled show little change in geochemical properties from the surface downward to 6 to 7 feet (about 200 cm).

One inevitable result of surface mining, however, is that still more deeply buried, relatively unaltered rocks will be brought closer to the land surface in many places and subjected to the natural cycle of leaching, weathering, and erosion. Although available analyses on overburden rocks (table 1) indicate higher concentrations of some trace elements as compared with concentrations in surface and near-surface materials, conclusions have been reached (Department of the Interior, 1974, p. I–182b and I–182f) that (1) when the higher values for the samples that were analyzed are averaged with those of other samples from the same core, their significance is minimal; (2) none of the elements occur in abnormally greater amounts than are present in similar rock types throughout the United States; and (3) the presence of toxic trace elements (those indicated with an asterisk in table 1) serves as a

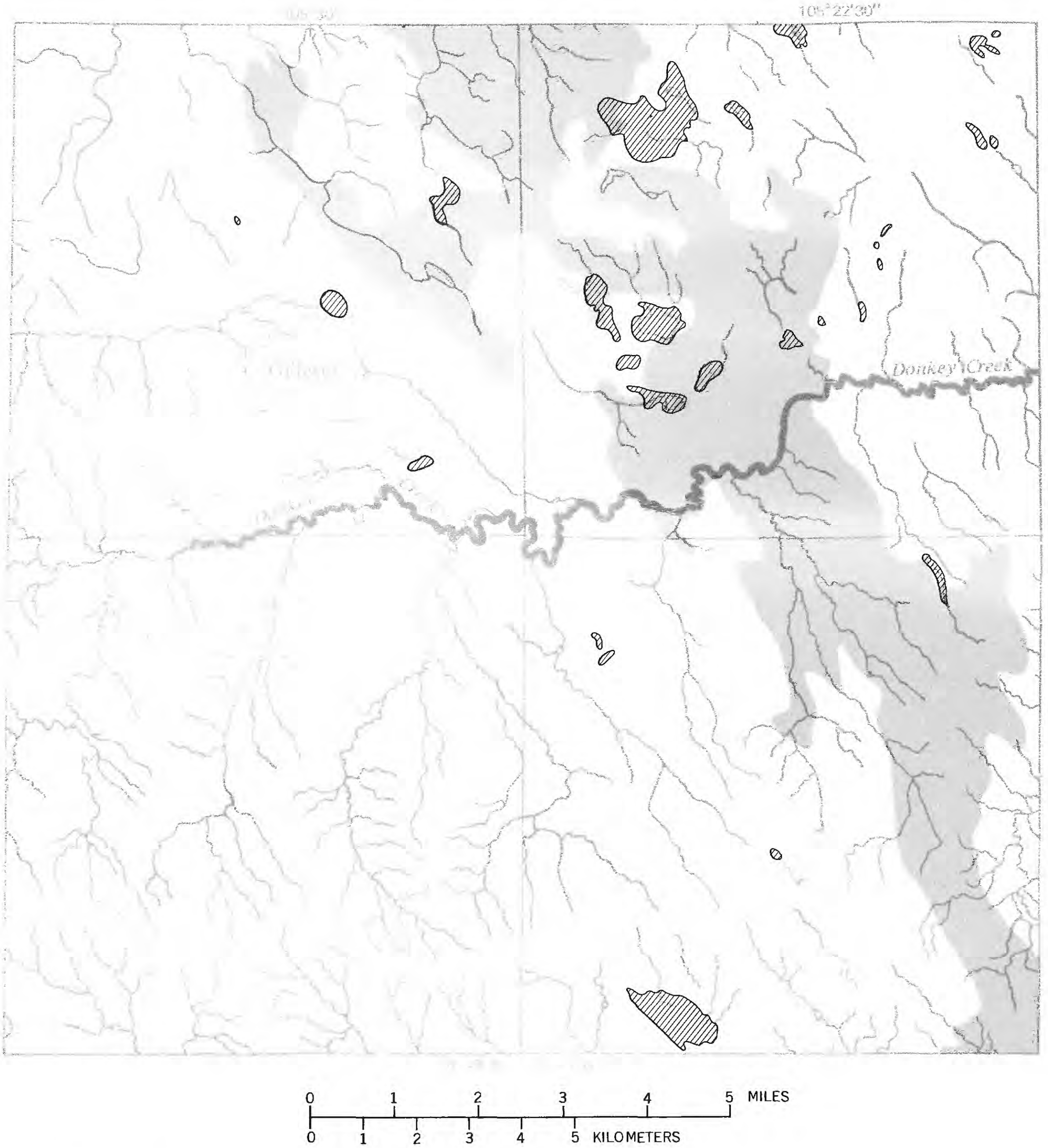


FIGURE 17.—Present surface drainage, Gillette and vicinity. Closed topographic depressions shown by patterned areas. Strippable coal zone, Wyodak-Anderson coal deposit, shown by shaded area. All drainage is intermittent except part of Donkey Creek shown as heavy line.

warning of a potential pollutant or contaminant but does not necessarily indicate that toxic concentrations would result from the oxidation and leaching of overburden materials. Few oxidation

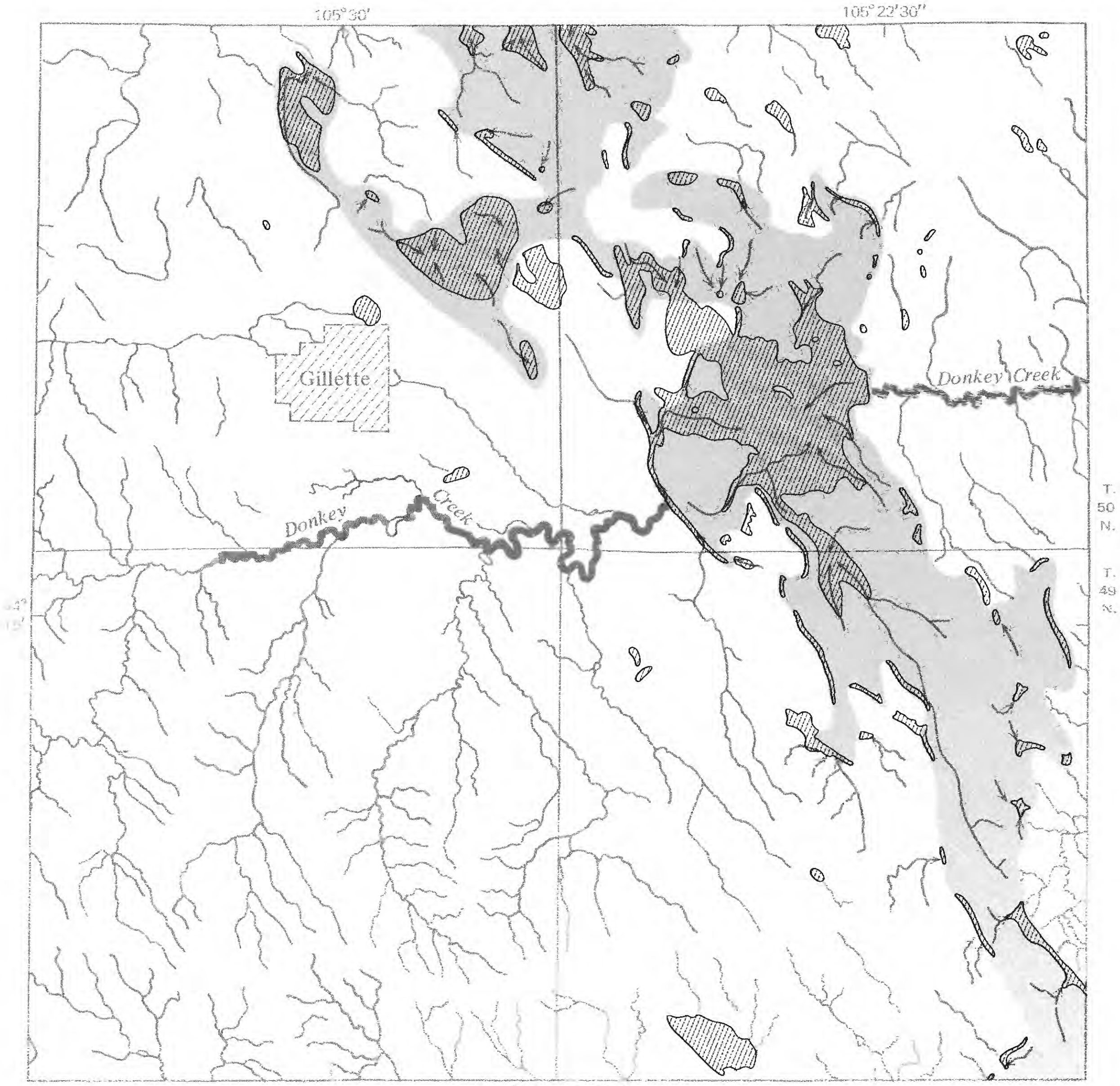


FIGURE 18.—Reconstructed surface drainage, Gillette and vicinity, if all coal is extracted from the strippable zone of the Wyodak-Anderson deposit according to the following assumed methods of mining and reclamation: 1, Overburden is replaced on a cut-by-cut basis as mining proceeds from east to west on 200-foot-wide (60-m-wide) north-south trending panels; 2, spoils are smoothly graded; 3, high walls are graded to 3:1 slopes; 4, overburden swells 20 percent; and 5, no attempt is made to reestablish through-flowing drainage. Topographic depressions marking areas of internal drainage within the mined-out tract are shown by pattern. Arrows indicate direction of streamflow. Based on a detailed reconstruction of the post-mining terrain by F. R. Shawe. All drainages are intermittent except parts of Donkey Creek shown as heavy line.

and leaching tests, however, have yet been conducted for overburden rocks in the eastern Powder River Basin.

Energy conversion plants—especially those involving combusiton of coal, such as steam-powered electrical generating plants—may cause chemical changes in surface materials through fallout from stack emissions. Few generalizations, however, can be made with regard to emissions resulting from the burning of any given coal, such as the Wyodak-Anderson, because individual power-plants vary widely in their operating procedures. For example, coal may be burned at a higher temperature in one plant than in another, thereby producing a larger volume of volatile (gaseous) materials. Nevertheless, certain elements (such as arsenic, fluorine, mercury, and selenium) are highly volatile and may become parts of the stack effluent under a wide range of conditions, whereas other elements (such as uranium, barium, and zinc) are largely nonvolatile and concentrate in the remaining ash. Thus, it is necessary to sample and test each plant individually, even though the same source of fuel is being used.

Of interest to the present investigation are geochemical studies conducted near the 750-megawatt Dave Johnston power-generating plant in the southern part of the Powder River Basin, approximately 100 miles (160 km) south of Gillette. The results of a sampling and analytical program there show that the concentrations of some trace elements (antimony, arsenic, selenium, strontium, vanadium, and uranium) in near-surface materials and sagebrush decrease significantly with distance downwind (eastward) from the plant. Although geochemical baseline data were not available prior to the construction and operation of the generating plant, the distribution pattern of these trace elements is believed to have been influenced by its presence, perhaps through stack emissions (Connor and others, 1976, p. 56; U.S. Geological Survey, 1975, p. 57). Note, however, that the coal being used in the dave Johnston plant is not from the Wyodak-Anderson deposit.

At mine-mouth electrical generating plants, the captured bottom ash and fly ash are usually returned to the mined-out coal pits and buried. Such ash is generally less stable chemically than overburden rock and is subject to leaching by ground water. Studies therefore need to be made to determine the least environmentally damaging effects of ash disposal. In fact, the possible constructive use of this ash—for example, in manufacturing concrete blocks or for use as road metal—should not be overlooked.

RECLAMATION POTENTIAL OF SURFACE-MINED LANDS

Today, surface mining is generally viewed as only a temporary use of the land; after that use the affected land is expected to be returned to some use commensurate with its former condition and productivity. Reclamation is now prescribed by laws and regulations in many States and by the Federal Government. (See Imhoff and others, 1976.) The degree to which a given tract can be reclaimed after surface mining, however, is difficult to determine except through observation of actual reclamation results. Although it is a common practice to think of reclamation primarily in terms of reestablishing soil and vegetation on mine spoils (for example, Department of Interior, 1974, p. I-78–I-79), this is only a part of the process. A complex array of many critical factors—geologic, hydrologic, geochemical, topographic, biologic (in addition to revegetation), climatic, economic, and social—must be considered in comprehensive evaluations of reclamation potential and of procedures that are best to follow in achieving reclamation goals.

As part of its investigations in the Gillette area, the U.S. Geological Survey is studying the reclamation potential of lands across, and adjacent to, the strippable zone of the Wyodak-Anderson coal deposit. The inherent attributes of land and water are fundamental to a determination of reclamation potential, hence the need for many of the kinds of data and interpretations that are discussed in this report. The results of the reclamation-potential study are incomplete and are not summarized in the present report.

SUMMARY

Surface mining inevitably causes disturbances of natural land features and environmental conditions. In the foregoing pages we have presented a sequence of maps and descriptive materials that show existing conditions of land, water, and coal resources in a representative area of the eastern Powder River Basin, Wyo. These data have led to interpretations and predictions concerning some of the potential impacts of surface mining in that area, and to the recognition of certain problems that require special consideration in the planning and regulation of future leasing, mining, and reclamation activities. Further study is needed to determine whether the identified impacts are long-term or only short-lived and the extent to which they may be mitigated by proper mining and reclamation practices. Nevertheless, the kinds of data assembled in this report emphasize the importance of evaluating all aspects of resource development as they relate to the protection of the environment.

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