Chapter 3

Western Surface Mining and Reclamation

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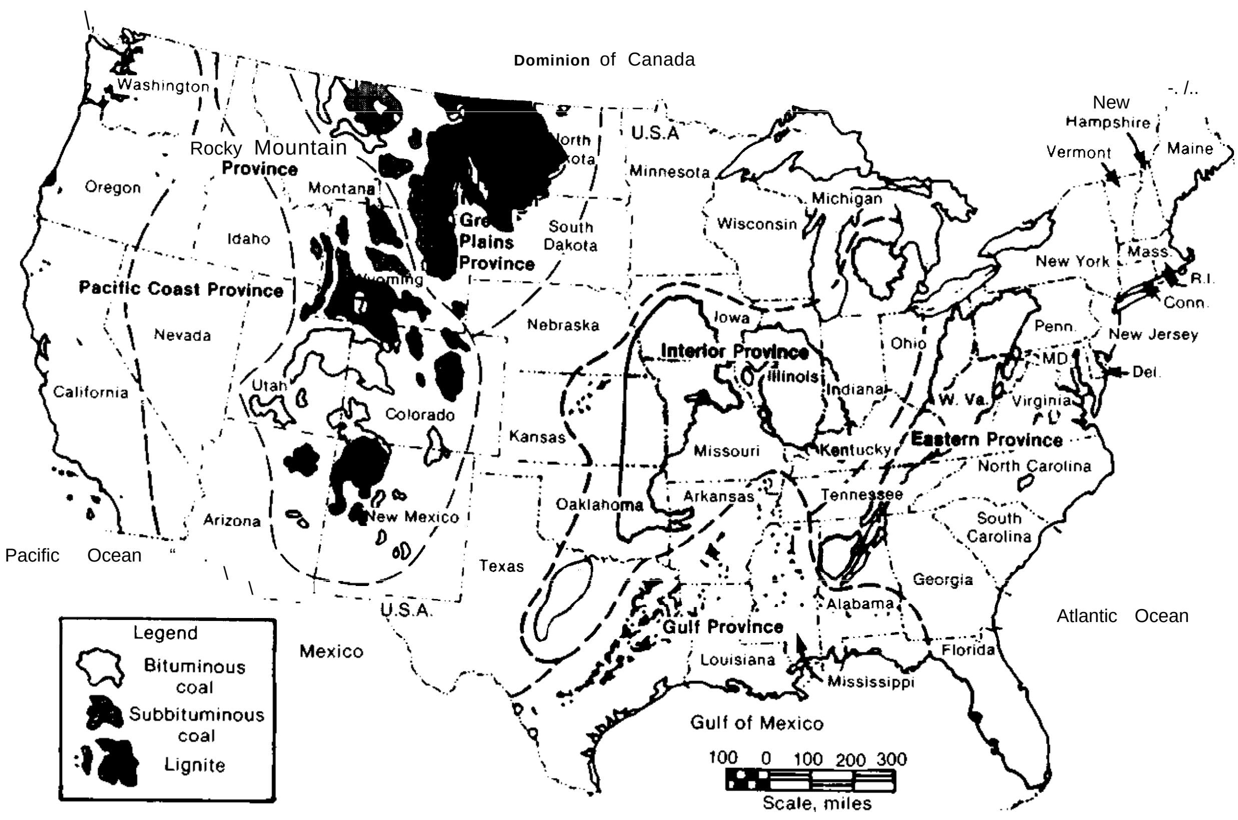
Western Surface Mining and Reclamation

INTRODUCTION

Slightly over half of U.S. coal reserves are located in the Northern Great Plains and Rocky Mountain Coal Provinces of the Western United States (see fig. 3-1) (4). The Federal Government owns between 50 and 60 percent of the coal reserves in the six major Federal coal States (Colorado, Montana, New Mexico, North Dakota, Utah, and Wyoming) (6). In 1983, these States produced 208.9 million tons of coal, or approximately 27 percent of total U.S. production (3). With the exception of mines in Utah and portions of Colorado, most Western coal is produced by surface mining methods (see table 3-1).

The coal-bearing areas in the Western United States are notably distinct from the rest of the country for their relatively small amount of available water, their shallow soils and high erosion rates, and their patterns of land and mineral ownership. Furthermore, within the West, coal mining operations differ greatly from one another due to the diversity of terrain, climate, and land use. The terrain varies from the rolling plains of the Fort Union region of western North Dakota and eastern Montana, to the high rugged mountains of Colorado, to the arid deserts of southwestern Wyoming and northern New Mex-

Figure 3-1.—Generalized Coal Provinces of the United States



SOURCE U S Bureau of Mines, adapted from USGS Coal Map of the United States, 1960

Table 3-1.—1982 Production From Western Coal Mines (thousands of tons)

State	Number of surface mines[a]	Surface production	Percent of total	Number of underground mines[a]	Underground production	Percent of total	Total production
Arizona	2	12,364	100%0	0	0	0%	12,364
Colorado	19	11,696	64	30	6,621	36	18,317
Montana	6	27,890	100	0	0	0	27,890
New Mexico	9	19,233	96	3	711	4	19,944
North Dakota	10	17,855	100	0	0	0	17,855
Utah	0	0	0	21	17,029	100	17,029
Wyoming	29	107,085	99	3	1,276	1	108,361
Total	73	196,123	88	57	25,637	12	221,760

[a]Includes some temporarily inactive mines as well as new mines that have not yet reached full production.

SOURCE: Office of Technology Assessment, from 1984 Keystone Coal Industry Manual.

ice. The climate ranges from cold and subhumid in the north, to hot and dry in the San Juan region of New Mexico. Annual precipitation can vary by as much as 50 percent among mines within a region, and by as much as 10 percent even between mines located within 2 or 3 miles of each other (see fig. 3-2).

The nature of the coal resource contributes to the differences among Western surface mines, and between Western mines and those in other parts of the United States. Western coal varies from the lignite of western North Dakota and eastern Montana, with seams from 2 to 50 feet thick, to the bituminous and sub-bituminous coals of Wyoming with seams up to 150 feet thick. Stripping ratios may be as high as 12:1 (cover/coal) or as low as 1:2 (16).

Finally, in the Western United States the Federal Government owns a substantial portion of the surface overlying coal resources as well as the majority of the mineral rights (see table 3-2). As a result, much Western coal must be leased from the Department of the Interior before it can be mined (see ch. 4). In areas where the government owns the coal but not the surface (split estate lands) and where ownership is in a "checkerboard" pattern, coal leasing and development can become complicated. [1]

This chapter describes the environmental and technical context for Western surface mining and reclamation, including the regional ecology and mining and reclamation methods. Chapter 4 outlines the institutional and regulatory context.

[1]A detailed discussion of leasing in split estate and checkerboard areas may be found in reference 5, pp. 124-129.

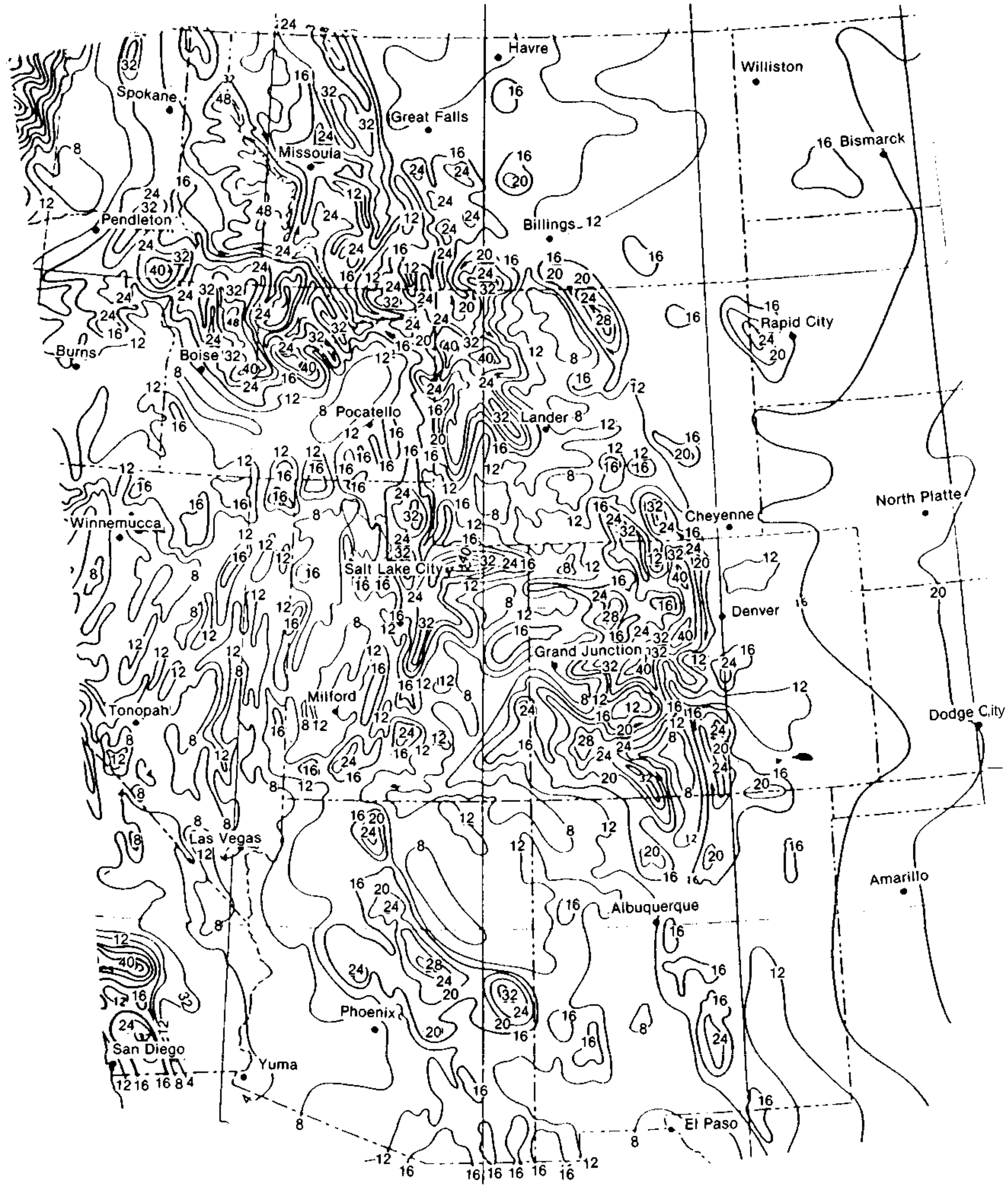
THE WESTERN ENVIRONMENT

In general, Western surface mined lands must be reclaimed with less than one-third as much rainfall as mined lands in Appalachia and the Midwest. Droughts are common in the West, and precipitation frequently occurs in short, intense storms with the potential to cause severe erosion. Temperatures fluctuate widely, and high summer daytime temperatures can dry out soil and seeds quickly.

In all the Western coal lands, evaporation exceeds precipitation. The ratio of evapotranspiration to precipitation ranges from 2:1 in the Fort Union region to 6: 1 in the San Juan River region. The evaporation rates in the region vary from 48 to 64 inches per year in the northern coal regions, and generally increase to a high of 80 to 96 inches in the southern reaches of the San Juan River region (9). Low rainfall and high evaporation create moisture stress throughout the Federal coal areas.

Furthermore, **organic matter accumulates slowly in arid and semiarid Western soils, and the resulting soil profiles have limited capacity for holding moisture, although the moisture content usually is sufficient to sustain plant growth for 3 months of the year (9). In much**

Figure 3-2.— Mean Annual Precipitation for the Western Coal Region States



SOURCE U S Department of Commerce, *Climatic At/as of the United States, 1988*

Table 3.2.—Ownership of Surface and coal Resources in Five Western Coal Management Regions[a] (in acres)

Region	Federal surface/ Federal coal[b]	Percent of total	Federal surface/ non-Federal coal[b]	Percent of total	USFS surface/ Federal coal	Percent of total	USFS surface/ non-Federal coal	Percent of total	State surface/ Federal coal	Percent of total
Fort Union:	31,680	1.0 %	2,260		2,890		0		14,320	—
North Dakota .	800	– d	0		2,890	·	0	—	3,640	—
Montana	30,880	2.5%	2,260		0	—	0	—	10,680	1.0%
Power River:	584,331	9.5%	1,891	—	490,501	7.9%	8,160	—	45,608	1.0%
Montana	193,430	10.3%	60	—	434,515	23.1%	3,120	—	21,190	1.1%
Wyoming.	390,901	9.8%	1,831	—	55,986	1 ,4%	5,040	—	24,418	1.0%
Green River-Hams Fork:	1,179,740	43.9%	4,840		2,220	—	640	—	6,012	—
Wyoming.	1,124,370	51 .8%	960	—	160	—	0	—	2,732	—
Colorado	55,370	10.8%	3,880	1 .0%	2,060	—	640	—	3,280	1.0%
Uinta-Southwestern Utah:	765,630	45.5%	6,640	—	384,270	22.9%	**1,040**	—	4,680	—
Colorado	230,730	40.8%	2,680	—	94,980	16.8%	0	—	0	—
Utah . .	534,900	47.9%	3,960	—	289,290	25.9%	1,040	—	4,680	—
San Juan River:	1,219,770	48.4%	27,040	1.1%	62,650	2.5%	3,140	—	27,190	1.1%
Colorado	34,470	12.6%	120	—	55,620	20,3%	3,140	—	2,910	1.1%
New Mexico ... .,	1,185,300	52.8%	26,920	1 .2%	7,040	—	0	—	24,280	1.1%

Table 3.2.—Ownership of Surface and Coal Resources in Five Western Coal Management Regions[a] (in acres) —Continued

Region	State surface/ non-Federal coal	Percent of total	Private surface/ Federal coal	Percent of total	Private surface/ non-Federal coal	Percent of total	Other surface/ Federal coal[c]	Percent of total	Other surface/c non-Federal coal	Percent of total	Total coal resource
Fort Union:	111,080	3.0%	1,205,740	32.2%	2,263,470	60.4%	91,580	2.4%	27,450	1 .0%	3,750,470
North Dakota ...	44,600	1.8%	711,160	28.3%	1,643,250	65.4%	79,860	3.2%	26,170	1 .0%	2,512,370
Montana	66,480	5.4%	494,580	40.0%	620,220	50.1 %	11,720	1 .0%	1,280	—	1,238,100
Powder River:	473,099	7.7%	3,814,722	61 .7%	720,166	11 .6%	70,837	1 .2%	32,203	—	6,185,532
Montana	107,980	5.8%	1,046,895	55.8%	443,560	23.6%	2,470	·	2,960	—	1,877,651
Wyoming .	365,119	9.2%	2,767,827	69.5%	276,606	6.9%	68,367	1 .7%	29,243	—	3,985,338
Green River-Hams Fork:	102,764	3.8%	330,575	12.3%	1,029,655	38.3%	29,648	1 .1%	160	—	2,686,254
Wyoming, ., ., ...	57,134	2.6%	56,235	2.6%	912,860	42.0?40	17,883	1 .0%	40	—	2,172,374
Colorado ., ., .,	45,630	8.9%	274,340	53.3%	116,795	22.7%	11,765	2.3%	120	—	513,880
Uinta-Southwestern Utah:	74,590	4.4%	285,410	1 7.0%	143,290	8.5%	15,320	1 .0%	400	—	1,681,270
Colorado	8,190	1 .5%	180,070	31 .9%	44,360	7.9%	4,160	1 .0%	0	—	565,170
Utah	66,400	6.0%	105,340	9.4%	98,930	8.9%	11,160	1 .0%	400	—	1,116,100
San Juan River:	160,620	6.4%	273,570	10.9%	183,220	7.3%	430,080	17,1 %	133,500	5.3'YO	2,520,780
Colorado	22,220	8.1 %	68,950	25.2%	84,840	31 .0%	680	—	1,120	—	274,060
New Mexico ...	138,400	6.2%	204,620	9.1 %	98,380	4.4%	429,400	19.1 %	132,380	5.9%	2,246,720

[a]Includes Known Recoverable Coal Resource Areas (KRCRAs) defined as of March 1978
[b]Includes BLM-administered and other public domain lands, excluding National forest lands
[c]Includes Bankhead-Jones acquired lands, Federal withdrawn lands (e g military reservations), and Indian lands
d·· _ ·· indicates less than 1 percent

SOURCE Bureau of Land Management, *Final Environmental Statement Federal Cod Management Program, 1979*

of the West, rates of natural erosion are among the highest in the country, and soil frequently is lost to flash flooding and hillslope erosion. Vegetative succession also is a slow process in the West due to climatic severity. A disturbed site in the Eastern United States may revegetate itself naturally in 5 to 10 years, but decades or centuries may be needed for natural revegetation in the West (9).

The Fort Union Region*

The Fort Union Coal Region in northeastern Montana and western North Dakota (see fig. 3-3) lies in the Missouri Plateau of the Great Plains Coal Province, which extends from the Missouri Coteau westward *to* the Rocky Mountains. The land consists of rolling prairie and grasslands with isolated coniferous forests and badlands, and occasional buttes and mesas. The region has relatively deep fertile soils formed from glacial till, and the primary land uses are grazing and agriculture, including hay, feed grains, and various types of wheat. In 1983, there were 11 operating surface mines in the North Dakota portion of Fort Union (seven of which incorporate Federal coal), and one in Montana, These mines produced a total of approximately 18.7 million tons of lignite (1 6). All of the coal is used locally for electricity generation or synthetic fuels production.

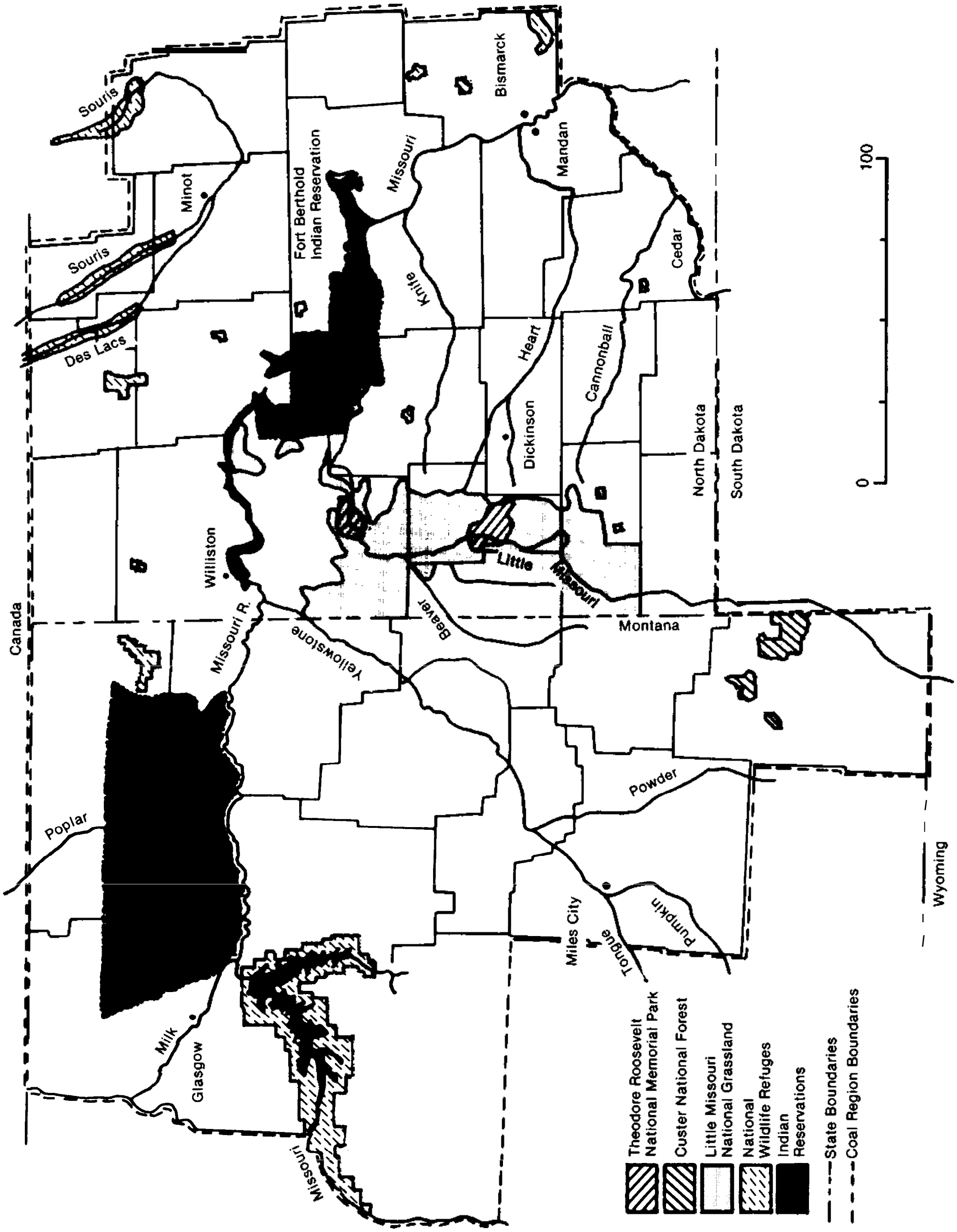
The Fort Union region is characterized by a semiarid continental climate, with an average of about 15 inches annual precipitation, most of which occurs in late spring and early summer. Snowfall averages about 33 inches per year. This is a region of climatic extremes, and temperatures

'Unless otherwise indicated, the material in this section is adapted from references 9 and 10.

Photo credit: Office of Surface Mining

Due to the relatively harsh climate, soils, and other conditions in the Western coal regions, it may take decades for a disturbed site to revegetate naturally.

Figure 3-3.—Fort Union Coal Region



SOURCE: Office of Technology Assessment.

vary widely on an annual, seasonal, and daily basis. The Rocky Mountains modify the prevailing westerly flow of air masses from the North Pacific, but there are no topographical barriers to modify the cold, dry air masses from the polar regions, or the warm, moist air masses from the tropical areas to the south.

Most of the usable surface water in the region occurs in the Yellowstone and Missouri Rivers and the Missouri's reservoir system. Both agriculture and livestock grazing rely heavily on irrigation from these rivers. Surface water also is used for municipal and industrial water supplies. Groundwater is distributed more evenly over the region in deep aquifers, but is not as readily available in as much quantity as surface water. Groundwater is used for domestic, livestock, municipal, and some irrigation water supplies.

Native prairie areas, wetlands (prairie potholes), and woody draws populated with native trees and shrubs are the primary wildlife habitats. The prairie potholes, on the Central Flyway, are part of the primary waterfowl production area of North America.

The Powder River Region[3]

In many respects, the Powder River region (see fig. 3-4) in southeastern Montana and northeastern Wyoming is similar to the adjacent Fort Union region. As with Fort Union, the Powder River region belongs to the Great Plains physiographic province and is part of a broad basin between the Black Hills on the east, the Laramie Mountains to the South, the Bighorn Mountains on the West, and the Cedar Creek anticline in Montana on the North. The region is within the drainage basin for the Missouri River and its tributaries, including the Powder and Yellowstone Rivers.

In 1983, there were 18 active surface mines in the Wyoming portion of the Powder River Coal Region (16 incorporating Federal coal) with 6 under development, and 7 active mines in the Montana portion (6 with Federal coal), and 4 under development. In that year, these mines produced about 121.3 million tons of coal (16). The region also contains valuable oil and gas and uranium deposits, as well as other minerals such as iron and trona.

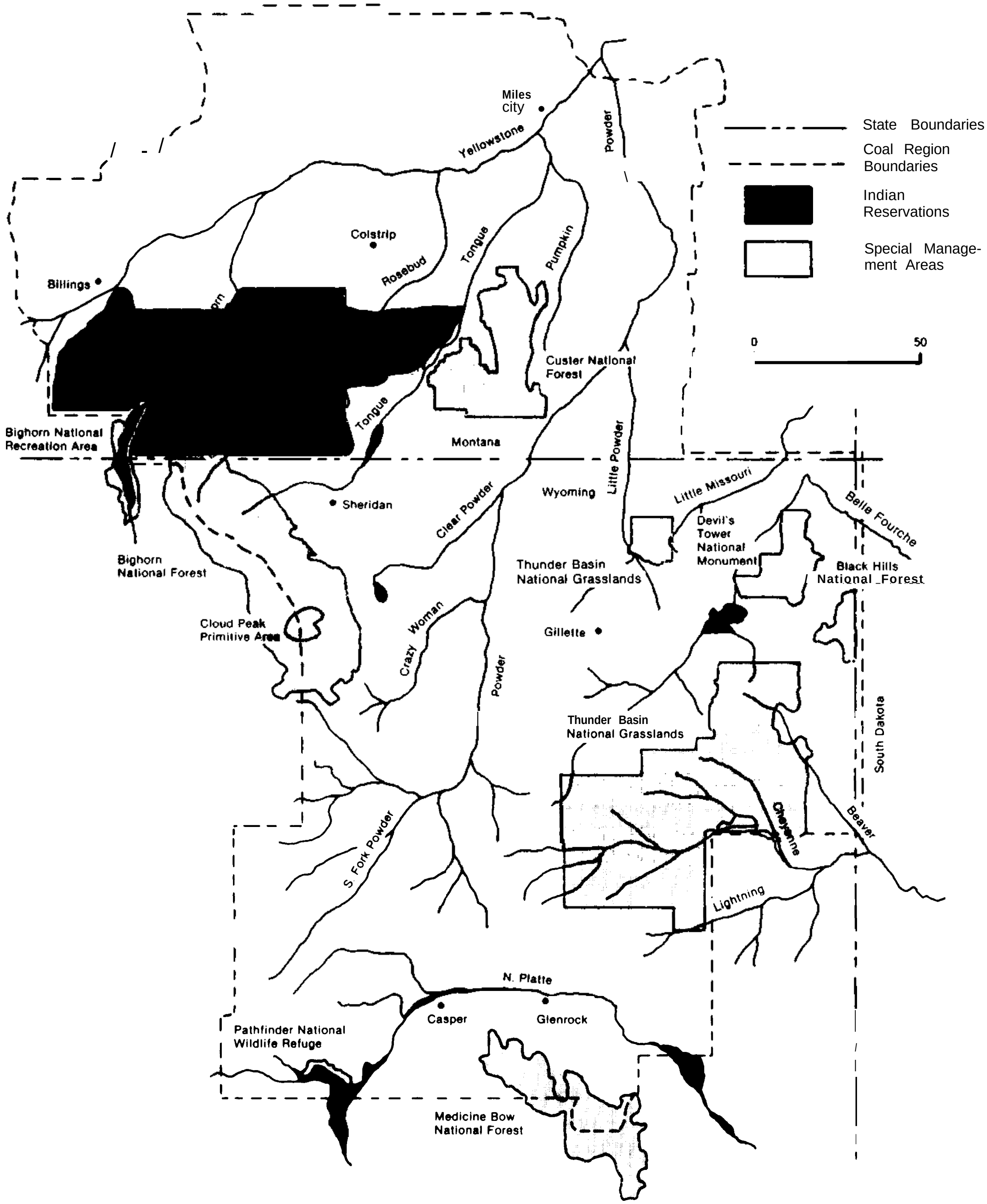
The topography of the powder River region varies from relatively steep high open hills with heavily wooded escarpments in the northern part; to gently sloping plains and tablelands in the central area, with badlands breaking the steep slopes adjacent to major drainages; to rolling grass-covered prairie in the southern portion, with conspicuous scoria knobs and erosion escarpments separated and dissected by broad stream valleys. The predominant vegetation types are those typical of rangeland, characterized by low-growing shrubs and herbaceous plants adapted to the semiarid condition of the region. The sagebrush and grassland are broken by patches of coniferous forest (primarily ponde rosa pine) in the northern portions of the region, and by deciduous trees (mainly cottonwoods) in riparian areas. As in Fort Union, big game, smaller mammals, raptors, and game birds abound, with the region being part of the Central Flyway for migrating waterfowl.

The area is semiarid with wide annual temperature variations between summer and winter. The region is particularly subject to cold air invasions from the north, although during the winter warm chinook winds blow from the south and west. Maximum precipitation usually occurs in the spring and early summer, with frequent but very light rain showers and occasional heavy cloudbursts that cause flooding. Droughts are common. Even when annual precipitation is higher than average, it may not occur during the critical period of the growing season.

Streams originating in the plains areas tend to be ephemeral (flow only as a result of direct runoff), while streams rising in the Bighorn Mountains and Black Hills usually are perennial, with sustained base flows from groundwater inflow. The numerous stock-water reservoirs and spreader systems on many of the small tributaries result in appreciable depletion of water through evaporation and seepage. The major uses of the surface waters include storage for consumption by livestock, irrigation of hay crops along the base of the Bighorn Mountains and in the North Platte

3Unless otherwise noted, the material in this section is adapted from references 4, 9, and 11.

Figure 3-4.—Powder River Coal Region



SOURCE: Office of Technology Assessment.

River drainage, and for municipal water supply systems. Groundwater from shallow aquifers is the principal source of domestic and livestock supplies, and is used extensively for waterflooding in secondary oil recovery. Many of the aquifers have too high dissolved solids or sodium content for use for irrigation or human consumption.

Green River= Hams Fork Region[4]

The Green River-Hams Fork Coal Region is in northern Colorado and southern Wyoming and includes the Green and Yam pa River basins, as well as the Hanna basin, Great Divide basin, Red Desert, and portions of the geologically complex Overth rust Belt (see fig. 3-5). In 1983, there were 14 active surface mines (1 O with Federal coal) and 2 under development in the Wyoming portion of the region, and 12 active surface operations (6 Federal coal) and 2 under development in the Colorado portion, producing approximately 7 to 8 million tons and 18 million tons, respectively. There also are a number of underground mines in the region. The coals range from sub-bituminous to high volatile bituminous, with seam thicknesses varying from 1 foot to over 30 feet (1 6).

The Green River-Hams Fork region is topographically diverse, ranging from the low mountain ranges, rolling hills, and broad alluvial valleys of the Yam pa coal field; to the sagebrush-covered high plains and rimrock of the Hanna Basin; to the mountains and valleys formed by linear folds and faults in the Overthrust Belt. The predominant vegetation type is sagebrush and associated shrubs such as greasewood and saltbush. Evergreen and aspen forests may be found in the higher elevations, and deciduous trees along the river drainages, with some stretches of open grassland. Livestock grazing is the most extensive land use in the Green River-Hams Fork region, with some cropland (primarily hay) along river bottoms where irrigation water is available.

The region has a semiarid continental climate characterized by dry air, clear skies, little precipitation, high evaporation, and large diurnal temperature changes. Annual precipitation in surface mining areas varies from about 7 inches per year in southwestern Wyoming to around 26 i riches in the high plateaus of Colorado. Thunderstorms can occur almost daily in the summer, and blizzards or extremely frigid conditions are not uncommon during the winter months.

The region contains the upper parts of seven river basins and a portion of the Great Divide basin, which has no drainage to either ocean. The North Platte River drains areas east of the Continental Divide, while the Colorado, Green, Little Snake, White, and Yampa Rivers drain west of the divide. Surface water is used for irrigation of cropland, for livestock and wildlife, and to meet industrial and municipal demands. Groundwater may be found at varying depths throughout the area, and many of the coal beds are potential aquifers. The predominant uses of groundwater are for livestock and ranch wells, with some wells supplying oil drilling operations.

In general, the Green River-Hams Fork region provides excellent habitat for big game animals, which summer i n the aspen and conifer habitats of the higher elevations and winter at lower elevations in mountain shrub and sagebrush areas. In some areas, winter density of elk is 50 per square mile. Game birds, especially grouse, are common, as are eagles and other raptors. Wild horses also may be seen throughout the region.

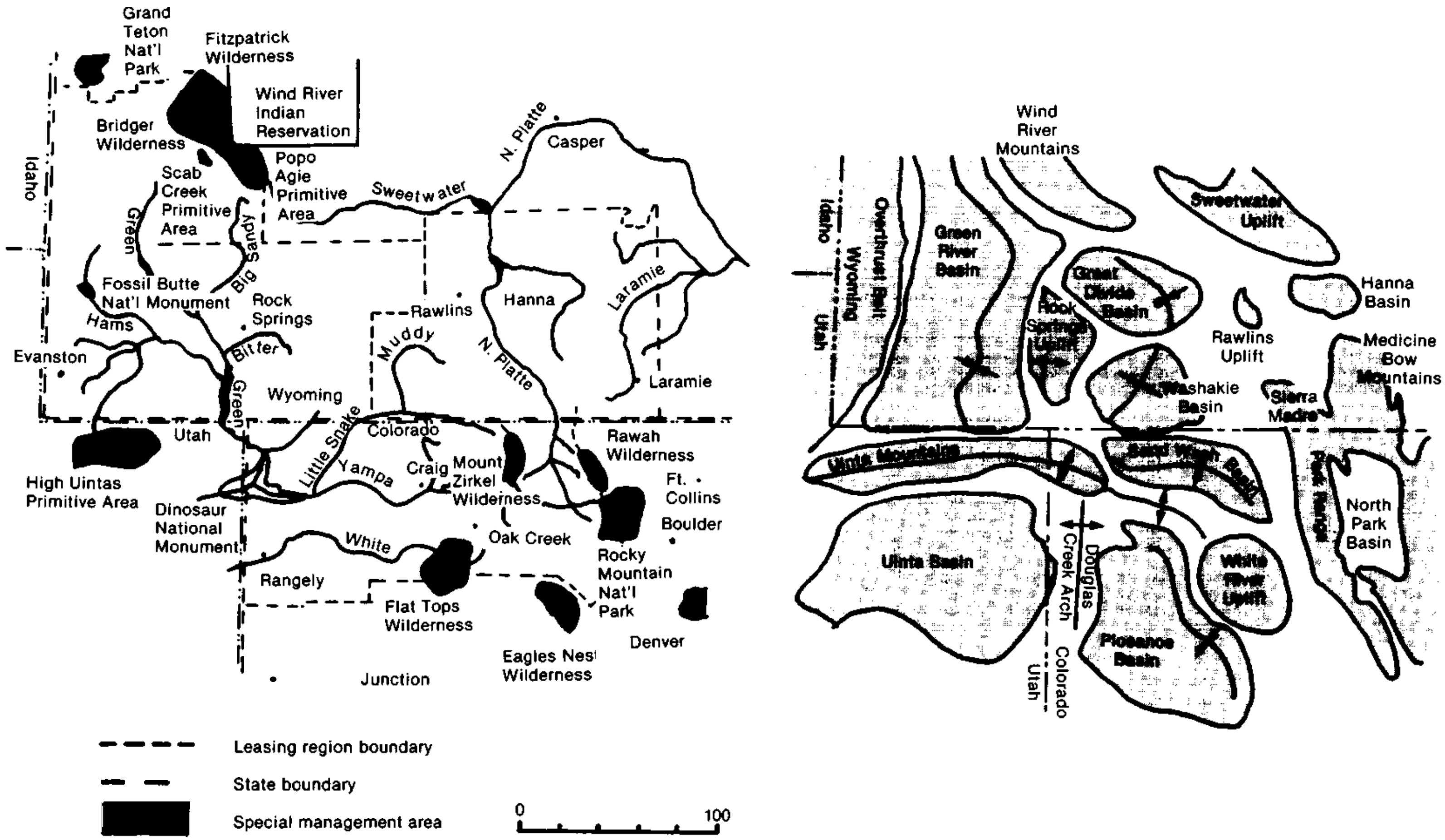
The San Juan River Region[5]

The San Juan River Coal Region is in the Colorado plateau, encompassing northwestern New Mexico and part of southwestern Colorado, including the Four Corners area (see fig. 3-6). It is essentially a high plateau, with low mesas, buttes, and badlands, occasionally cut by deep canyons formed by streams. The basin is surrounded by mountain ranges: the San Juans to the north, San Pedro Mountain and the Naciementos to the east, the Zunis on the south, and the Chuska Mountains to the west, with altitudes ranging from 5,000 to 7,500 feet. The Federal Government owns or manages much of the surface, including National Forest, Bureau of Land Management,

[4]Unless otherwise indicated, the material in this section is adapted from references 8 and 9.

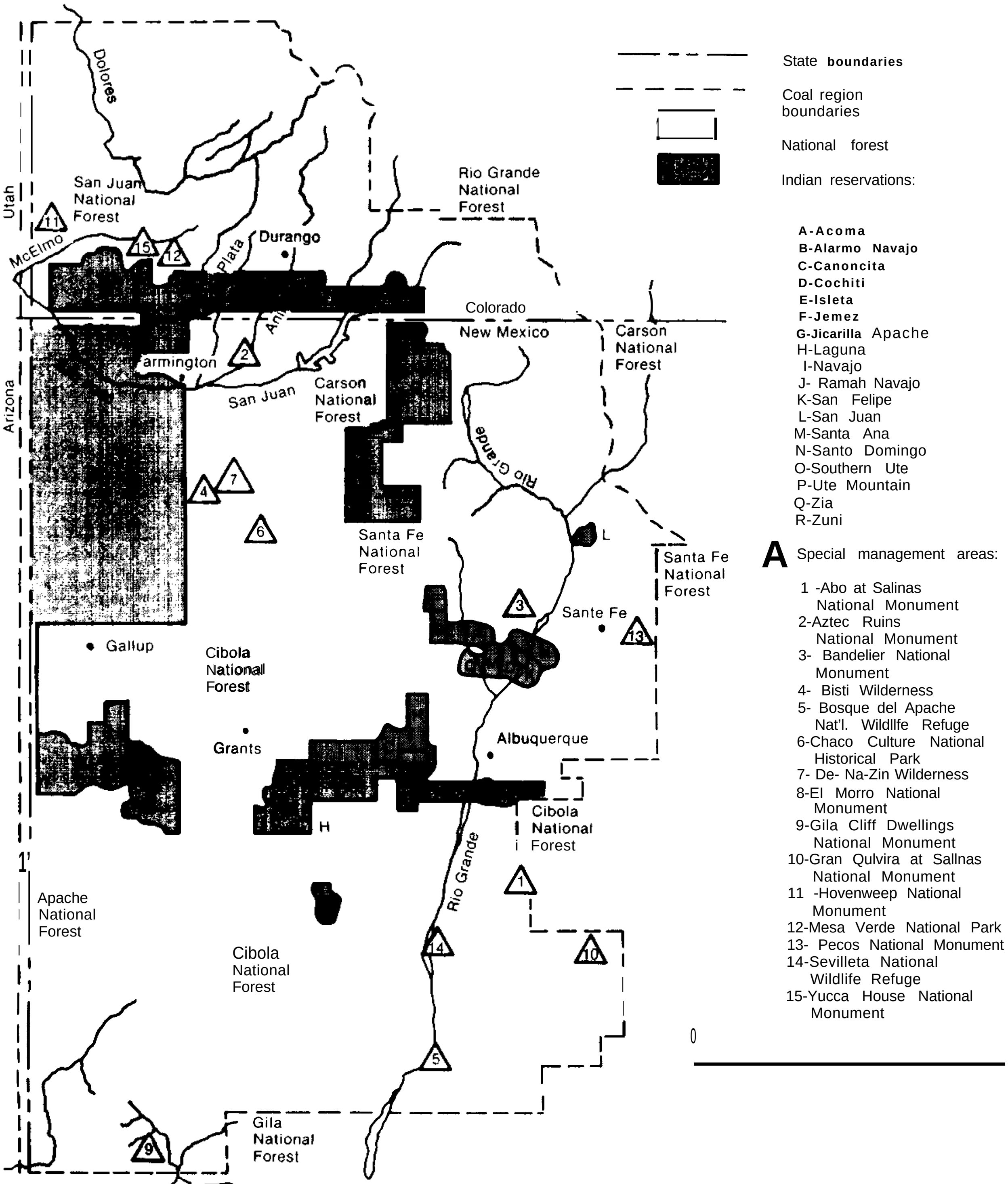
[5]Unless otherwise noted, the material in this section is adapted from references 4, 7, and 9.

Figure 3-5.—General and Tectonic Maps of Green River-Hams Fork Coal Region



SOURCE: U.S. Department of the Interior, Bureau of Land Management, *Draft Environmental Impact Statement, Green River—Hams Fork. Round II* (Washington, DC: U.S. Printing Office, August 1983).

Figure 3-6.—San Juan River Coal Region



SOURCE: Office of Technology Assessment

and Tribal lands. In 1983, there were 10 active surface mines in the New Mexico portion of the region (5 incorporating Federal coal, including Tribal coal), with 4 under development. The Colorado portion of the region has one active surface mine with Federal coal and four with private coal. The region's surface mines produced approximately 20.3 million tons of coal in 1983 (1 6).

The region lies south of the major storm belt from the Pacific across the Rockies, and has a semiarid to arid climate. Annual precipitation averages less than 10 inches, although the higher elevations may receive as much as 20 inches due to greater snowfall. Summer rainfall is primarily from intense local thunderstorms that frequently cause flash flooding. Daily high-low temperatures show a large variation, and potential evaporation exceeds normal precipitation by a factor of 6 or more.

The San Juan is the major river draining the region. Surface waters in the region generally have high concentrations of suspended sediment, especially during the floods associated with spring snowmelt and summer thunderstorms, The primary use of surface water is for irrigation. Groundwater generally is of good quality where it is available, and is used for livestock and domestic consumption, as well as in support of coal and uranium mining. The heaviest groundwater pumping occurs around Gallup, New Mexico, where withdrawals for coal and uranium mining and for municipal use exceed the natural replacement to the aquifers.

The principal vegetation types include grassland and grassland-shrub at the lower elevations, pinon-juni per up to 7,000 feet, and conifer forest above 7,000 feet. Livestock, dryland farming (primarily in Colorado), and irrigated farming along water courses are important land uses, along with energy development (coal, oil and gas, uranium). Many of the grassland-shrub areas in the region have been severely overgrazed by livestock.

WESTERN SURFACE MINING TECHNIQUES

Surface mining is the oldest and least expensive method of mining coal in the United States and currently is used to obtain about half of total U.S. coal production. Due to the nature of the Western coal resource, which has a relatively low Btu value and generally is near the surface, surface mining is the predominant method in that part of the United States, accounting for around 80 percent of regional production (see table 3-1). The techniques now practiced in Western surface mining operations have been developed to maximize recovery of the coal (which often occurs in multiple seams) with machinery that ranges from simple tractors equipped with backhoes, to very large electric shovels and draglines.

In general, surface mining involves exposure of the coal seam by removal of the overlying soil and rock material (overburden). The overburden is stored in spoil piles until needed to backfill the pit after the coal has been extracted. **Due to the size of Western surface mining operations, where mines producing 5 to 10 million tons per year are typical, and mines producing 10 to 20 million tons per year are not uncommon, the scale of the equipment is correspondingly larger than that in the East and Midwest. Shovel and dragline bucket capacities range from 40 to 115 cubic yards, and haul trucks have gross weights up to 220** tons. The larger scale of mining and operational considerations resulting from the topography and other factors also necessitate the use of mining methods different from those in the East.

***Area or open-pit mining* is the method most commonly used to extract Western coal. Large open pits are developed to expose the coal, using a variety of equipment.** The pit advances as coal is extracted, and the mined-out portions are backfilled. The size and shape of the pits, and the way in which the overburden is stored temporarily ("spoiled") and the pit backfilled, are a function

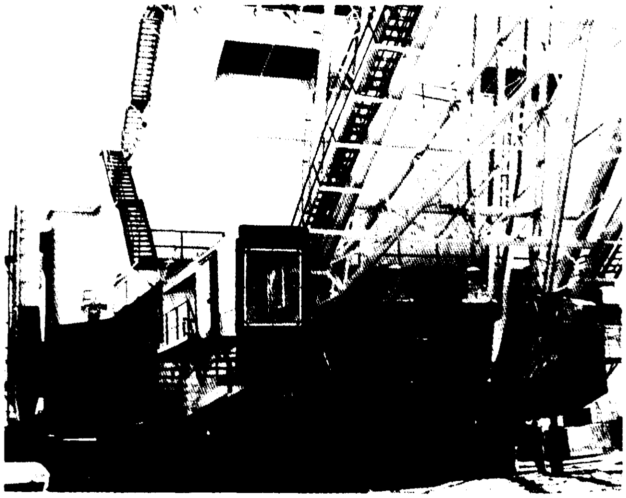


Photo credit: Jenifer Robison, OTA staff

Due to the large size of Western surface coal mines, where annual production may be as high as 15 to 20 million tons per year, the scale of the equipment is correspondingly larger than that used in the East and Midwest.

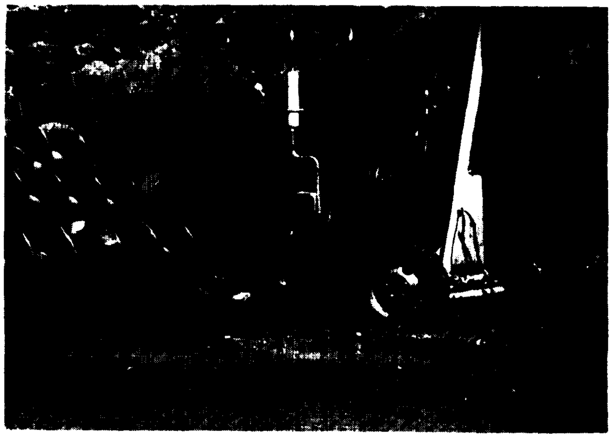


Photo credit: Jenifer Robison, OTA staff

Auger mining is used in some Western coal areas to recover additional coal when the overburden becomes too thick for exposure of the entire seam to be economical.

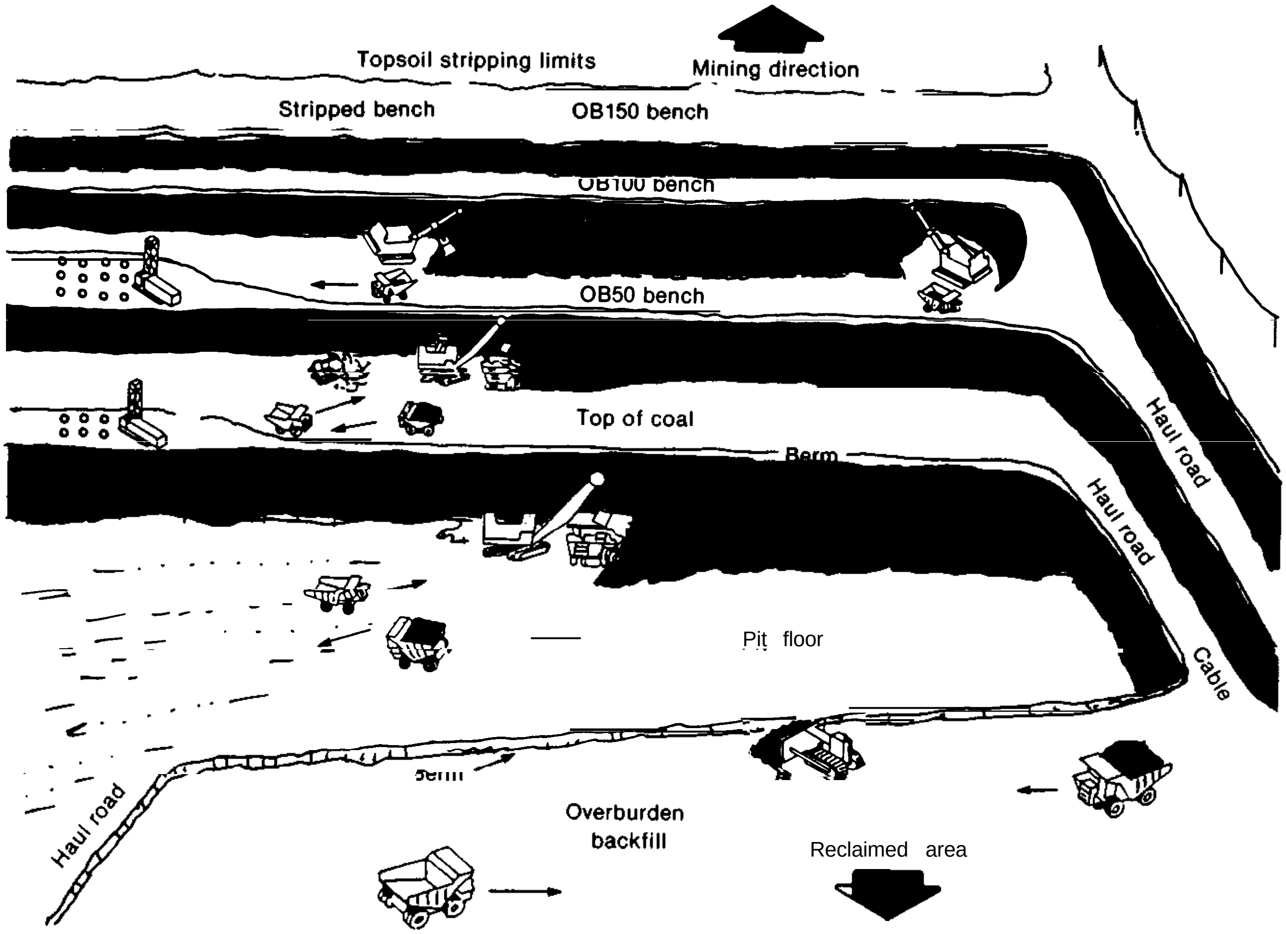
of the attitude, thickness, and number of the coal seams, and of the equipment selected (see fig. **3-7).** Longer dragline booms and the development of multiple-bench operations enable Western mines to reach coal buried under overburden **200** feet thick or more, and methods have been proposed for mining to stripping depths of over **500** feet (see fig. **3-8).**

In contrast, common Eastern mining methodologies include contour and auger mining. Contour mining is used in hilly areas, as in much of Appalachia, where a coal seam outcrops on the side of a hill. The mine begins at the outcrop and proceeds along the contour of the bed in the hillside, until the ratio of overburden to coal becomes too great for surface mining to be feasible. At that point auger mining, where huge drills are driven horizontally up to **200** feet into the coal seam, is used to recover additional coal (see fig. 3-9). These mining methods are not useful on the broad, flat plains that overlie most Western coal. They are, however, used to a limited extent at some of the small mines in hilly terrain in Colorado and New Mexico, and to recover some of the steeply dipping coal in Wyoming.

SURFACE MINE IMPACTS AND RECLAMATION

Surface mine reclamation may proceed in parallel with or independently of excavation. With parallel reclamation, the overburden from an active area is placed in the area of the previous cut, and then backfilled, graded, and compacted (if necessary). At the same time, topsoil is hauled from a newly disturbed area and applied directly to the recontoured overburden without stockpiling. This method avoids expensive double handling of the overburden, and is the general practice (after the initial cut) at larger Western operations. Where parallel reclamation is not feasible, the topsoil from an active area is stockpiled and the overburden accumulated in spoil piles until these materials are needed to fill a mined-out pit. At that time, the overburden is backfilled and graded to postmining contour, and then the topsoil is hauled to the recontoured area, graded, and prepared for seeding and planting. **While Western surface mine reclamation can be rela-**

Figure 3.7.—Area or Open-Pit Mining



SOURCE: Thunder Basin Coal Co.

tively straightforward, the wide range of hydrologic, soils, vegetation and other conditions that may be encountered, and the extensive regulatory requirements imposed under Federal and State reclamation laws, also can make it an extremely complicated process.

This section reviews the reclamation methods or techniques currently in use at mines in the Western United States. Special reclamation situations are illustrated with examples, highlighted in boxes, from Western mines whose permit applications were reviewed for this assessment. The permitting process and the data and analyses used to develop a mining and reclamation plan are discussed in detail in chapters 4 through *6.* Subsequent chapters address the the criteria and analytical techniques used to evaluate the success of reclamation, special reclamation tech-

redi Ut

p g m g a d re amat ac m
p m g wa d e g w h p p ed a ead
m ed area e e 2 re e reg aded a ea
g p pared rec amat o regro d 3) re
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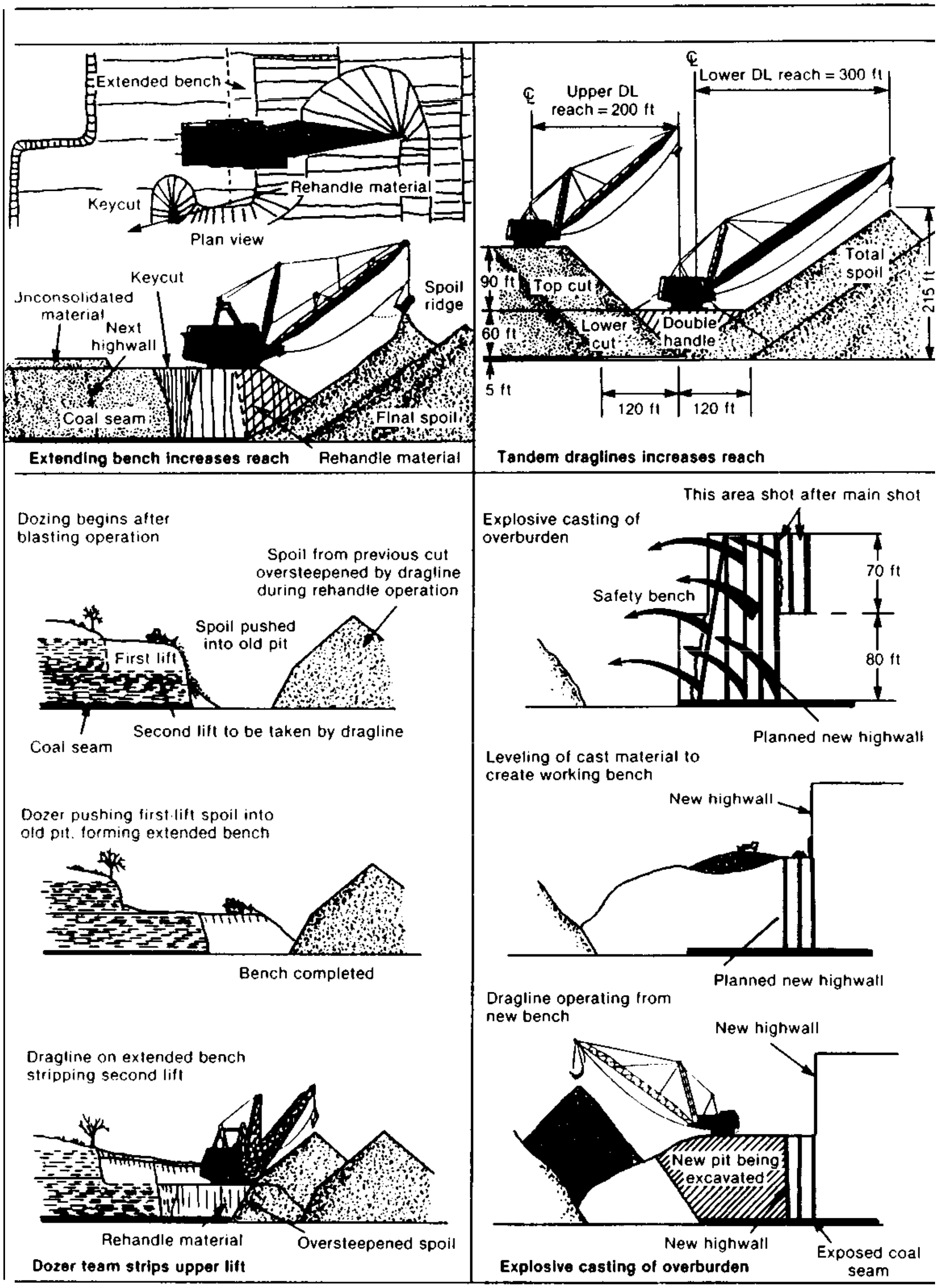
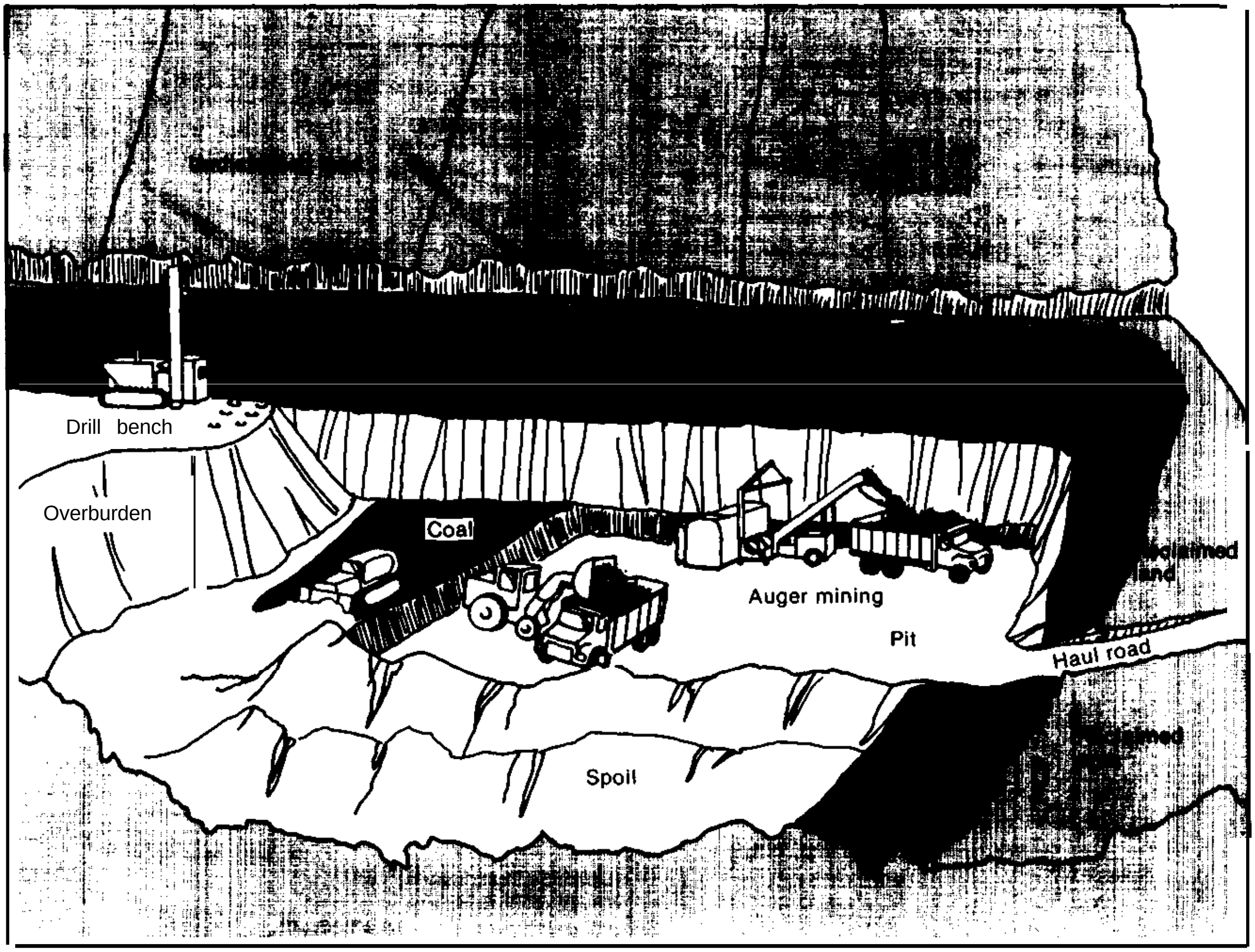
d rbed d bad a d bac g d

Figure 3-8.— How To Help Draglines Reach Deeper Seams



SOURCE Nicholas P Chironis, “Improved Mining Methods and Larger Equipment Reach Deeper Seams,” Coal Age, July 1984



SOURCE: Office of Technology Assessment.

niques and issues, and technological innovation and research in reclamation methods.

Soil and Overburden

The methods used to salvage and redress topsoil and to handle overburden vary widely among mines, depending on the physical and chemical characteristics of the soil/overburden and the configuration of the mine. For soil handling, a system is developed for each mine, using the baseline soil inventory **in the permit application as a guide, in order to salvage the right amount of topsoil from the appropriate areas (see** chs. **5 and 6 for further discussion of soil inventories and salvage plans). The topsoil usually is salvaged with large machines called scrapers, but deep soils may be salvaged with truck and shovel equipment. Similarly, each mine will handle overburden differently, depending on its physical and chemical characteristics. After the overburden is drilled and blasted, it is removed either with a dragline** *or* **electric shovel and truck.**

Characterization

Soil is ranked as suitable or unsuitable for salvage according to chemical or physical criteria that affect revegetation success. These criteria are established by the State regulatory authority and reflect characteristics of climate, vegetation,

[6] Unless otherwise noted, the material in this section is adapted from reference 12.

and geology of the mining regions in that State (see ch. *6,* table 6-4). These criteria, methods of data collection, and suitability determination are discussed in chapters 5 and *6.* All suitable materials normally are salvaged for use in reclamation (unless the suitable soil is very deep), and unsuitable materials are spoiled with the overburden (see "Overburden Handling, " below). As discussed in chapter 8, salvaging very deep soils without special handling (e. g., two lifts; see below) and without regard to the biological viability of the soil can make revegetation more difficult. If sufficient topsoil is not available, a suitable topsoil layer must be reconstructed from overburden or interburden materials (see examples from Western mining situations illustrated in boxes 3-A and 3-B).

Overburden also is ranked as suitable **or unsuitable, the goal being to ensure that overburden material in contact with redressed soil and within the root zone will not be deleterious to soil development and plant growth.** The delineation of deleterious overburden is governed by criteria (shown in table **6-3)** often referred to as "suspect levels." Overburden material that tests above those levels is considered potentially "toxic" (defined as "chemically or physically detrimental to biota" in the Federal regulations) and must be specially handled to protect groundwater and/or covered with sufficient benign material to protect vegetation (see box 3-B). The methods for identifying and handling unsuitable and toxic materials are discussed in chapters 6 and 8.

Overburden Handling

The overburden on a site usually has both deleterious and benign zones, although the overburden on some sites may be all benign or even all deleterious. If all of the overburden is benign, the spoil can be backfilled without special handling. Where some or all of the overburden has deleterious qualities, the mine plan must ensure that revegetation and postmining surface and groundwater quality will not be adversely affected (see box 3-H, below). This requirement often is satisfied with a permit stipulation that the top 4 to 8 feet of the recontoured spoil must be tested for unsuitable characteristics prior to replacement of the topsoil. Otherwise, the unsuitable material must be rehandled and buried in the pit or spoil piles (see box 3-C), covered with suitable spoil (usually 4 feet or more in thickness) from an adjacent area, or treated (e.g., liming acid spoil).

Special handling of overburden can be accomplished much more easily in a truck and shovel

Box 3-A.—Use of Overburden as a Topsoil Substitute[1]

The regulations in all five of the study-area States allow the use of supplemental overburden material in addition to, or in place of, existing topsoils when the supplemental material can be shown to be as good or better than the existing topsoil. Although such a situation is extremely rare, at one mine the premining soils inventory showed most of the site to consist of badlands or shale barrens, and all of the surface materials were determined to be unsuitable for use as topsoil in reclamation. A sandstone stratum (clayey sandstones or siltstones with sodium adsorption ratios—SARs—of 32 to 38) over 10 feet thick in the overburden was proposed for use as an alternative topdressing material. The material is stockpiled separately from the remainder of the overburden, and redressed like topsoil. Salvage operations try to maximize the use of the coarser textured materials with clay contents less than about 25 to 30 percent. A permit stipulation requires the material to be redressed in two lifts to a total depth of 14 to 18 inches; in practice, each lift has a depth of 8 to 10 inches, resulting in a total depth of 16 to 20 inches. The first lift will be disked into the underlying spoil to minimize formation of a textural barrier. The operator has established a research plot to evaluate use of the sandstone as an alternative topdressing material. Several different treatments of soil thickness (0 to 18 inches), number of lifts, erodibility, and disking are being investigated, as well as the effects of the high sodium content on the physical characteristics of the spoil.

[1]See case study mine M in reference 12.

Box 3-B.Obtaining Sufficient Topdressing for Unsiutable Overburden[1]

Overburden characterization at a mine in New Mexico indicated that essentially all of the overburden is deleterious due to high SAR and clay content. The Federal regulations require "appropriate depth of cover" over toxic materials, but at the time of permitting, the State progam did not have a definition of "toxic." The operator contended that non-saline, sodic spoils (materials with high sodium relative to calcium and magnesuim, but low total sodium and other salts) are not toxic to adapted species. During permitting, the operator argued that 4 feet of cover are not available onsite that native species are adapted to the conditions, and that codification of the topdressing was not a concern. Subsequent research conducted by the operator supported the latter contention, but it was challenged by the regulatory authority, which imposed a permit stipulation that required a soil monitoring plan. To enable the operator to obtain additional volumes of cover, the regulatory authority relaxed the suitability criteria, based on the natural soil chemistry, to *allow* use of saltier, more sodic materials. Based on the relaxed criteria, subsequent vOlume calculations showed 11.2 inches of topdressing to be available. The regulatory authority contended that 11.2 inches would be insufficient due to the high SAR, and required 18 inches. A regolith (weathered bedrock) **study also was required by the regulatoryauthority to delineate additional suitable material.The study found two isolated bodies of regolith that could provide about 6 inches more cover, for a total of almost 18 inches. Over most of the mined area, topsoil and subsoil will be redressed to a depth of 18 inches in two lifts of 4 inches and 14 inches, respectively. In areas of benign spoil, two 4-inch lifts will redress topsoil to a depth of 8 inches.**

[1]See case study mine L in reference 12.

Box 3-C.-Special Handling of Unsuitable Material[1]

A dragline operation in the eastern Powder River basin is mining two seams with a gray shale interburden that has a high clay content. When the mine was first permitted under a pre-SMCRA State law, high clay contents were considered unsuitable, and the regulatory authority did not allow the interburden to be spoiled in such a manner as to be found on the surface of the regraded spoil. This required very expensive double handling of the spoil in order to make room deep in the overburden spoil for the interburden. In the early 1970s, research on copper:molybdenum ratios in yellow and white sweet clover (molybdenum accumulators) growing on the site showed ratios (i.e., high molybdenum relative to copper) suspected to be capable of causing molybdenosis in cattle. Subsequent sampling of the overburden and spoil at this mine showed molybdenum concentrations still above suspect levels, and the requirement for double handling was retained when the mine was permitted under the permanent regulatory program. Permit stipulations required recontoured spoil sampling and a special study of the molybdenum problem. That study, conducted from 1979 to 1982, found that "segregation of the interburden material did not have a statistically significant effect on the molybdenum content or copper:molybdenum ratios of the seeded plant species, when compared to vegetation grown on the mixed interburden area." As a result of this and other findings, the company requested that the requirement to bury the interburden be eliminated. Based on the regulatory authority's understanding that the interburden would be buried to a considerable degree over much of the remaining area to be mined, on the condition that the company submit a regraded spoil/vegetation sampling and analysis program, and on the condition that problem spoil materials detected in that program would be removed and/or buried, the regulatory authority granted the request in 1984. If spoil samples indicate unsuitable pH, salinity, or SAR, the area would be rehandled. If molybdenum is high (above 6 ppm), the spoil will be rehandled or covered; if it is above the suspect level (between 2 and 6 ppm), vegetation transects will be monitored on the revegetated surface. If molybdenum levels in the forage become a problem for grazing animals, the affected area will have to be completely reconstructed.

[1]See case study mine C in reference 10.

operation than with a dragline. The top bench (40 to 50 feet), which is less likely to have deleterious qualities because it is at least partially weathered, usually is placed on top of the spoil during recontou ring in a truck and shovel operation. With a dragline, however, overburden material closer to the bottom of the stripping depth is more likely to end up on top of the recontoured spoil where it will be subject to oxidation. An inefficient modified dragline swing that increases the likelihood of undesirable material being buried, or expensive double handling may be required to prevent this occurring. With either type of equipment, the situation can become more complex if strata exhibit parameters that are deleterious both to revegetation and to groundwater quality (e.g., selenium), or exhibit multiple deleterious parameters (e.g., overburden exhibiting both a high SAR and high nitrates; see "Groundwater, " below).

Under SMCRA and the State programs, the overburden must be backfilled and graded to the approximate original (premining) contour unless specifically exempted due to excess or thin overburden. The design of the recontou red surface must have slopes that will provide a stable postmining landscape that is subject to neither excessive erosion nor deposition, and is compatible with the postmining land use. As discussed in chapter 8, however, recontou ring to the approximate original contour may be impossible in some instances (e. g., removal of bedrock outcrops).

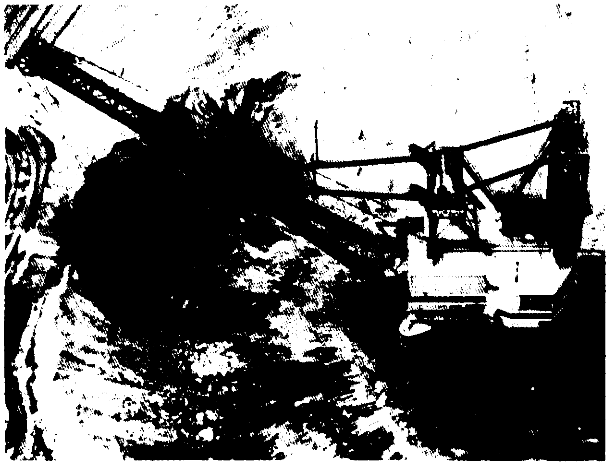


Photo credit: Office of Surface Mining

Special handling of potentially deleterious overburden material can be accomplished more easily with a shovel, because the benign upper bench is more likely to be spoiled on top during backfilling and recontouring.

Photo credit: Jenifer Robison, OTA staff

With a dragline, overburden material closer to the bottom of the stripping depth is more likely to end up on top of the recontoured spoil, where it will be subject to oxidation, enhancing its potential for deleterious effects on revegetation.

Some subsidence has occurred on recontoured surfaces in Colorado, Montana, North Dakota, and Wyoming. For example, at one mine in Montana, a depression about 4 feet deep, 50 feet wide, and 200 feet long has formed; a long area parallel to dragline spoils has subsided leaving a 1-foot high scarp; and a few cracks several hundred feet long have appeared. Over the long term, there is a potential for subsidence in dragline operations, where the mine floor becomes covered with thin strata of coarse rubble composed of wasted coal and boulders that collect at the bottoms of spoil ridges. These rubble zones can become confined aquifers postmining, and there is a possibility that, over the long term, the rubble will break down in the water, leaving a void that could cause subsidence (14).

After final grading, the recontoured spoil is prepared for topsoiling, typically by ripping with a chisel plow to alleviate compaction, prevent a spoil/soil barrier from forming, and prevent the soil from slipping on the spoil surface.

Soil Handling

Salvaged soil may be stockpiled until it is needed for reclamation, or it may be hauled directly to an area being reclaimed, depending on the timing of the mining and reclamation. Rehandling stockpiled topsoil is expensive, and the combined haul distance from salvage to stockpile and then to reclamation area may be farther than directly from salvage area to reclamation area. Moreover, soils that have been stockpiled for more than about 2 years deteriorate biologically due to decreases in the viability of seeds, roots, and microbiota, increasing the difficulty of revegetation (see ch. **8).**

Soil is handled in either one or two lifts. The latter requires that surface materials (usually A and B horizons) be segregated from subsurface (usually C horizon), and then redressed with the topsoil (A and B) over the subsoil (C). As a result, the more organically rich and biologically active materials are concentrated on the surface of the reconstructed soil, rather than being mixed with the less rich subsoil. This is an especially important consideration for very deep soils. The Montana and North Dakota programs both require two lifts, as does the Colorado program in **some** instances. Even in areas of thin soils, however, operators are beginning to appreciate the benefits derived from a two-lift system, and the procedure is being adopted more and more when the potential reclamation advantages outweigh the additional operational cost.

As an area or open-pit mine progresses, two lifts may be combined with direct hauling. In this case, topsoil from a small strip of land is first salvaged and stockpiled temporarily. Subsoil from that strip is picked up and applied to a backfilled area in the process of being reclaimed. Topsoil from the next strip is then picked up and applied over the redressed subsoil. This continues to the end of the salvage area, when the temporarily stockpiled topsoil is placed over the last band of redressed subsoil. **The combination of two lifts with direct hauling methods may provide the best species diversity in revegetation at mines with deep soils because it simultaneously preserves the biologically active materials and replaces them on the surface.** Where topsoil operations are contracted out, or where there is a dedicated fleet of reclamation equipment, this method is implemented more easily than at operations where scrapers are shared between topsoil operations and pit operations.

Box 3-D.—Soil Reconstruction for Reestablishing Ponderosa Pine[1]

The reestablishment of ponderosa pine is a sophisticated mine reclamation problem requiring special soil reconstruction. The ponderosa pine occurs only on scoria knobs and resistant sandstone ridges; the mining process removes the substrate condition on which they depend. Their reestablishment requires the reconstruction of a thick layer of coarse, loose scoria or very gravelly soil over a compacted layer of spoil, and preferential planting on north-facing slopes, to obtain a substrate that is well drained but sufficiently moist to enhance early establishment. The compacted spoil creates a barrier to soil moisture movement and thus leaves a moist zone within reach of the roots. The coarse, loose material provides rapid infiltration. At one mine, soils taken from ponderosa pine stands are clinker-type soils, and will be replaced over compacted spoil in two lifts. The subsoil and topsoil will be applied loosely and ripped to reduce compaction. Mulch or herbicides have been used to reduce competition from herbaceous species, but winter predation by rodents and deer is a continuing problem. Containerized nursery stock grown from local seed has proven most effective, with an 80 to 90 percent survival rate. The oldest plantings (1978) have resulted in ponderosa pines 2 to 3 feet tall. Current densities are about 500 stems/acre. The Montana regulatory authority recently asked the mine to establish seedling tree densities of 1,000 per acre in order to provide a closed tree canopy for wildlife. Such densities would not be achieved from volunteer growth for over 30 to 50 years, but probably will be difficult to establish due to increased competition among the pines. To reduce the potential for competition problems, the operator plans to interplant in older areas of pine reestablishment.

[1]See case study mines C in reference 12 and MT-1 and MT-2 in reference 13.

Federal regulations require that topsoil be redressed in a uniform thickness, consistent with the postmining land use. During premine planning, the volume of available soil is calculated and divided by the area to be redressed to get the average thickness of topsoil (see ch. 6). As discussed in chapter 8, however, **allowing non-uniform topsoil replacement may facilitate direct hauling and may provide greater vegetative diversity.** In the Western States, only the Montana legislation specifically mentions special reconstruction of soils with non-uniform depths as an alternative reclamation technique, although this method has been or will be permitted on a case-by-case basis at several mines in other parts of the study region (see boxes 3-B, and 3-O).

There are numerous methods of preparing the redressed topsoil for seeding and planting, and of preventing erosion. These include contour furrowing, ripping on the contour, surface pitting, disking, terracing, and mulching. For particular postmining land uses or unusual revegetation problems, special soil reconstruction methods are employed (see boxes 3-D, 3-G and 3-K). The redressed surface soil may be tested for fertilizer requirements prior to seeding (see "Revegetation," below).

Surface Water[7]

Surface water reclamation may involve both mitigation of impacts to water quantity and quality during mining, and restoration of the surface water hydrologic regime after mining is completed. Discharges from active mining or reclaimed areas to local streams may increase levels of total suspended solids (TSS) and total dissolved solids (TDS). Changes in postmining groundwater quality also can affect surface water quality where groundwater systems discharge to surface streams. Moreover, surface mining can either increase the water quantity in local streams due to discharges from the mine, or decrease flow due to impoundments and drawdowns.

Water Quality

Although current mining regulations do not specifically distinguish between perennial and ephemeral streams when establishing effluent limitations from point sources, the potential impacts from surface mining are very different for the two types of streams. The potential for increasing sediment loads in ephemeral streams is slight, due to their naturally high sediment levels during runoff events. Impacts on perennial streams can be significant, however, including increases in TSS due to accelerated erosion resulting from removal of the vegetative cover, stripping of topsoil, and construction of stockpiles, tipples, roads, and other facilities. In addition, increases in TDS levels in perennial streams may be caused by discharges of pit water or by the movement of groundwater through replaced spoils to discharge areas in perennial stream channels (see "Groundwater," below).

Effluent limitations for TSS are established under the Clean Water Act and SMCRA (see ch. 4). As discussed in chapter 8, **sediment control ponds generally are considered the best available control technology for meeting the TSS standards, although the effectiveness of alternative controls currently is being investigated.** Where sediment control ponds are used, they are classified as point sources and must be designed to meet effluent standards for runoff equal to or less than that resulting from a lo-year 24-hour precipitation event.[8] The effluent standards for point sources include limitations for pH, total iron, and total manganese, as well as TSS. To ensure that these standards are met, ponds are designed to store the entire 10-year 24-hour runoff volume. The water stored in such ponds is released gradually after it has been detained long enough to meet the effluent standards for point sources.

The principal control for TDS in Western surface mining is to ensure that soil and overburden materials containing soluble ions (primarily salts) are buried in such a manner that they will

[7]Unless otherwise noted, the material in this section is adapted from reference **14.**

[8]A 1()-year 24-hour precipitation event is the maximum amount of rain that could fall within *24* hours with a probable recurrence interval of once in 10 years, as determined by the National Weather Service.

not reach surface receiving waters (or groundwater) in concentrations in excess of the applicable standards.

A 1981 assessment of the cumulative TDS impacts from all anticipated mining and agricultural development on the Tongue River of southeastern Montana indicated that, even with intensive mining, the dissolved solids concentrations in the study area would not increase substantially, nor would they reach levels unfit for irrigation water (1 5). That assessment found that the Tongue River tributaries could experience significant increases in TDS, but the major tributaries already have dissolved solids concentrations considered unsuitable for irrigation. A similar cumulative impact assessment of the Yampa River and its tributaries found that the effects of mining are greatest during periods of low flow when high TDS loads due to groundwater discharge are not diluted by surface runoff. As in the Tongue River study area, impacts to the smaller perennial streams in the Yampa basin are expected to be the greatest, and could adversely affect the suitability of these waters for irrigation during average-to-low flows.[9]

Water Quantity

Individual mines have little impact on the quantity of surface water supplies in the Western States. The water that is used at a mine for dust control, coal preparation, etc., generally is drawn from aquifers below the coal being mined, and supplemented by water interrupted by the pit and water stored in sediment ponds. The drawdowns created by an individual mine seldom substantially impair the yields of nearby wells or flows in perennial streams. The disruption in surface-water supplies caused by the cumulative drawdown of several mines concentrated in one area is discussed in chapter 6. Additionally, water storage in sediment control ponds can decrease streamflows when the cumulative impacts of several mines within a drainage basin are considered (see ch. 8).

Unlike experiences in the East, mine discharges are seldom a problem in Western mining operations. In the semiarid Western environment, shallow aquifers likely to be intersected by the mine pit often are of limited extent, or are seasonal. Thus the volume of continuous or seasonal discharges from surface mines is small and easily borne by local stream channels capable of holding flows from much larger volume precipitation events. The low volume of these discharges also relieves the potential for impacts to water quality of the receiving streams.

Occasionally, some of the large mines in the Powder River basin have temporarily produced very large discharges from scoria bodies (cindery rock strata) breached during facilities construction or mining. For example, in 1976, a mine in this area pumped 6,000 gpm for several days from a saturated scoria pod encountered during excavation for a coal preparation plant. Discharge of this water into the Little powder River, an intermittent stream, significantly altered the flow until the scoria was dewatered.

Restoration of Surface Drainage Systems

Replacement of an erosionally stable surface drainage system is critical to the long-term success of surface mine reclamation. Although not specifically addressed in SMCRA, regulatory authorities use the general legislative provisions for water quality protection, minimum disturbance to the hydrologic balance, and erosion control to require operators to include designs for the restoration of surface drainage systems in their perm it applications (see ch. 6). A detailed hydraulic analysis of each restored channel also is required to ensure that postmining runoff velocities will not cause erosion. If the velocities are erosive, engineered controls such as riprap may be used, but States discourage the long-term use of engineered structures in permanent reclamation designs because they require maintenance after runoff events (see boxes 3-E and 3-F).

The extent to which mining affects surface drainage characteristics depends on factors such as stripping ratio, areal extent of mining, and mining methods. Mines that cover large areas or contain relatively small watersheds often must reconstruct entire drainage basins. The ultimate goal is to develop topographic characteristics that produce a system in equilibrium with respect to erosion and sediment transport (see ch. 6). Where

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[9] The data and methodologies for these cumulative assessments are discussed in chs. 5 and 6.

Box 3-E.—Reconstruction of a Surface Drainage on an Excess Spoil Disposal Area[1]

A mine permitted pre-SMCXA is constructing a fill area for excess spoil disposal within a surface drainage. Incised valleys in the area of the mine generally are narrow, V-shaped, and about 250 to 500 feet deep, with valley wall gradients of 40 to 100 percent. When completed, the valley fill will contain approximately 54 million cubic yards of overburden with an average slope of 3:1 (horizontal to vertical). The face will be topsoiled and revegetated, and mulching and contour furrows in conjunction with benches will be used to control erosion. The drainage being filled with spoil contained an ephemeral stream that drained to perennial streams downstream of the permit area. The stream channel has been relocated on the north side of the fill, with drainage from the face of the fill collected by ditches that slope gradually in the direction of the restored stream channel. The channel empties into a sedimentation pond at the bottom of the fill. The restored channel was designed to accommodate the 100-year runoff event based on the ultimate maximum drainage area when reclamation is complete+ The restored channel will be completely lined with riprap due to potentially erosive velocities (6 feet per second) during the design event.

[1]See case study mine Q in reference 14.

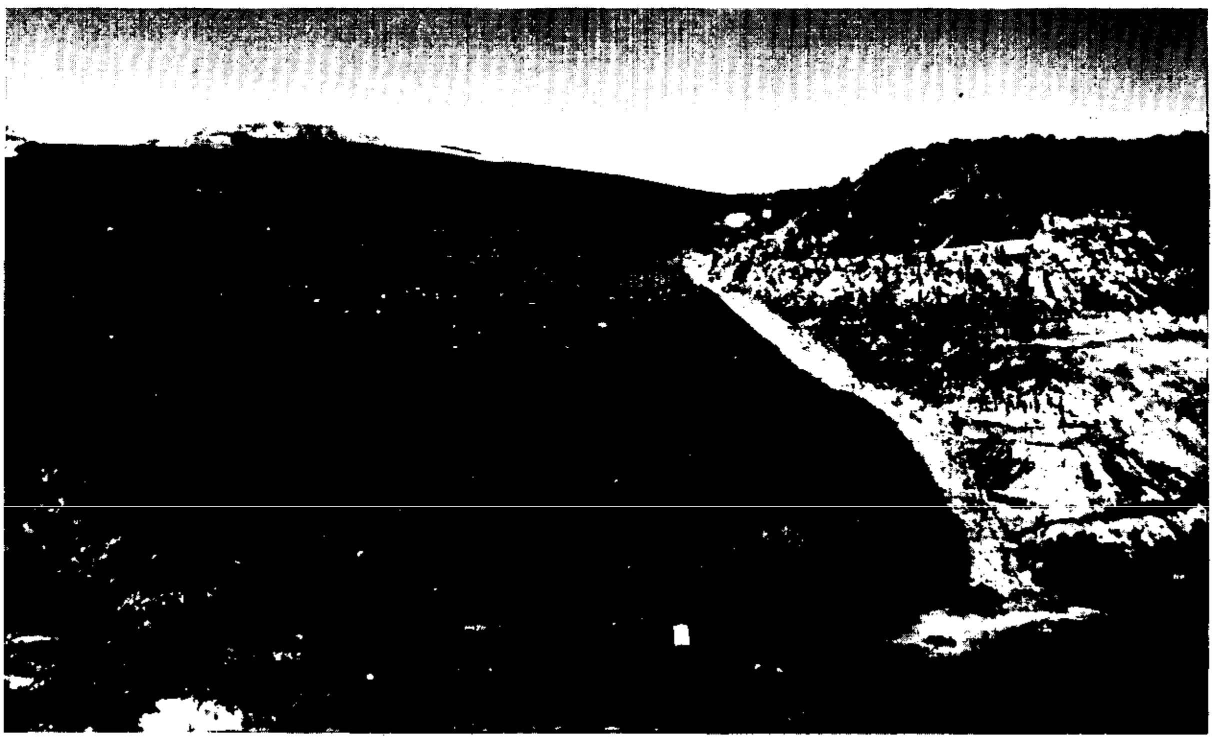


Photo credit: Colowyo Coal 00.

This excess spoil disposal area oocupies a former stream valley. Note the cross-slope channels draining into the reconstructed drainage (right center), which is lined with riprap and drains into a sedimentation control pond (lower right).

Box 3-F—Design and Construction of a Permanent Diversion[1]

Surface water restoration at a mine in New Mexico includes a permanent diversion for the major arroyo draining the permit area, sized for the 25-year 24-hour precipitation event. The arroyo is ephemeral above the permit area, intermittent below, and drains into a perennial river about 0.75 miles south of the mine. Prior to construction of the diversion, the operator analyzed sediment transport and deposition, and runoff volumes and peak flows for various precipitation events. The diversion channel was then sized to provide a transport capacity approximately 3 percent greater than the sediment discharge of the arroyo. The diversion channel is riprap-lined for most of the length, and includes two riprap drop structures. The construction, operation, and maintenance of the diversion in this arid area will provide valuable information for the design of reconstructed surface drainages postmining. In 1981 (after the original design was permitted), the Federal and State regulatory authorities concluded that the design should include criteria to ensure the diversion would be in equilibrium with the stream channels above and below. To accomplish this, the channel was redesigned to maintain the existing channel gradients, maintain subcritical flows during a 100-year 24-hour storm, maintain TSS levels throughout the diversion length, hold the minimum bankfull capacity of the undisturbed up- and downstream channels, and allow the riprap structures to adjust to the existing hydrologic regime. Construction was completed in 1983. Since then, one major precipitation event has occurred with a flow less than 3 feet in depth; it resulted in 4- to 5-foot deep cuts over 150 to 200 feet of the east bank of the diversion. The regulatory authority attributed the erosion to the lack of riprap on the east bank and along the entire bottom of the diversion. A monitoring program has been developed to provide evaluation criteria for the diversion, and to ensure that excessive erosion does not occur, and that the diversion and mined areas remain stable. The operator is developing a mitigation plan for excessive erosion. A continuing uncertainty is the stability of the riprap during runoff events.

[1] See case study mine R in reference 14.

the stripping ratio is high, the postmining topography often will very nearly duplicate premining topography, and it may be possible to restore the premining surface drainage system to its approximate original configuration. Provided that the premining erosional stability of the drainage system was not dependent on geologic features that are removed during mining, such as bedrock outcrops, restoration of stream channels may simply be a matter of restoring premining channel slopes, cross sections, and bed form.[10]

In other **areas, such as the Powder River basin, low stripping ratios may preclude restoration** of a drainage system to its original configuration. In these areas, entire drainage systems must be built on the restored surface, based on a complete quantitative analysis of the geomorphology of the premining and postmining drainage basins. Where the overburden is extremely thin (relative to the coal seam thickness), it may be difficult to establish any surface drainages, and permanent topographic depressions may remain.

In cases where mining removes only a segment of a stream channel, restoration involves duplication of the undisturbed channel with no abrupt changes in slope as well as nonerosive slopes (see box 3-F). If necessary to achieve acceptable slopes, channels and flood plains are reconstructed in a winding configuration ("sinuosity") to spread the change in elevation over a longer distance. If the channel is alluvial, special attention must be paid to the size and gradation **(size** composition) of the bed material in order to maintain the sediment transport rate and ensure channel stability. For channels stabilized with vegetation, the ability of the bed and bank to support a viable vegetation community is the critical factor.

Special surface water restoration techniques may be used in innovative or unique reclamation situations. These include channel reconstruction through natural scouring and deposition processes, engineered reconstruction of winding

[10] Bed form includes channel bed characteristics such as particle size gradation for alluvial channels, or the presence of perennial sod-forming grasses for stabilized channels.

Photo credit: Jenifer Rob/son, OTA staff

At this Wyoming mine, a small drainage basin was reconstructed with a winding drainage proceeding from the upper center of this picture to the lower left. Millet was planted to stabilize the topsoil until the appropriate season for applying the permanent seed mix.

drainages, and restoration of wetlands (box **3-G). in these situations, the criteria** for evaluating the success of the reclamation become extremely important (see ch. 7).

Groundwater[11]

Surface coal mining affects groundwater resources both during and after mining in ways that vary with the mining method, the extent and scale of mining, and the characteristics of the hydrogeological system. **Mining activities can lower water tables and reduce groundwater quality, either of which could result in impacts to the existing ecological system** (ch. **6** discusses the analytical techniques used to predict these impacts). Surface mining regulations require the operator to monitor groundwater characteristics for at least 1 year prior to the start of mining, in order to establish a baseline against which the impacts of mining can be measured (see chs. 4 and 5).

Groundwater Quantity

Shallow aquifers in coal seams and overburden strata in the Western States provide water for both stock and domestic uses from wells that typically

[11] Unless otherwise noted, the material in this section is adapted from reference 14.

Box 3-G.—Reconstruction of Wetlands[1]

A North Dakota lignite mine permit area contained 15 wetlands prior to mining. The operator surveyed the landowners to determine their preferences about which wetlands to restore, to what land use they should be restored, and which wetlands to eliminate. Based on the results of this survey, 2 of the wetlands will not be disturbed, 10 will be eliminated, 3 will be reconstructed to be hydrologically equal to their premining condition, and 2 new wetlands will be designed based on areal hydrologic data. Definition of the premining chemical and physical characteristics of the wetlands was difficult because many of these characteristics vary widely over time and with climatic conditions. Premining vegetation was surveyed in the three wetlands to be reconstructed, and the geology of the wetland basins and their soil types were identified. A postmining basin shape was designed to provide both the vegetative diversity desirable for wildlife use and adequate water storage to minimize the probable downstream hydrologic consequences. Based on the design water depths and the basin configuration, the operator expects a vegetational succession of aquatic plants that ultimately will provide cover for water-nesting birds as well as nesting and foraging for other birds and mammals. Because of the unique nature of this restoration, OSM stipulated that the operator develop standards for reclamation success. These standards are based on an assessment of water quality and quantity, vegetation community patterns indicating levels of diversity, and wildlife use patterns. Revegetation appears relatively easy to accomplish, due in part to the ability of many wetland plant species to spread from rootstock or cuttings. Native vegetation plugs from nearby wetland areas are transplanted. The operator also appointed a Wetlands Advisory Committee that will review all monitoring data, conduct onsite inspections, and make recommendations to the operator on restoration techniques and criteria for success. It is unclear what action will be taken if the advisory committee or the regulatory authority determines that wetlands are not restorable.

[1] See case study mines: A in reference 12; C in reference 14; ND-2 in reference 13; and A in reference 1.

yield 5 to 10 gpm, a flow rate insufficient for irrigation. Exceptions are wells developed in the alluvial aquifers of major streams, such as the Tongue and Missouri Rivers, where much larger yields are possible. In any case, State water laws and the Federal and State regulatory programs require the mine operator to replace the water supply or to otherwise compensate the owner for the water lost if mining activities dewater any nearby wells to the extent that they are no longer usable.

During and after mining, aquifers in the overburden and coal are destroyed and replaced by mine spoils. Usually the coal seam itself would have been the only shallow aquifer of any significance. Tests conducted on wells developed in postmine spoils in several Western mining areas suggest that the spoils will be at least as capable of transmitting water as were the coal seam aquifers that have been removed.

Mining method, which together with lithology determines the swell factor (the ratio between the volume of postmining spoils and premining overburden) in the replaced spoils, partially influences the degree to which an aquifer's premining hydraulic characteristics are restored postmining. Swell factors range from **5** to 10 percent for small scraper mines, 10 to 15 percent for truck-and-shovel mines, and 20 to 30 percent for dragline operations. There is a general correlation between increase in postmining volume and an increase in porosity and hydraulic conductivity. For permit approval, the operator is required to evaluate both the sources and the rate of recharge to the postmine spoil aquifer (see ch. 6).

Spoils aquifer recharge and groundwater discharge to surface waters are affected by postmining surface topography. At thin overburden mines, for example, postmining topography may be lower than the premining surface, and unless the backfill is sealed to create a confined aquifer, a lake or swamp could form on the surface. At a mine in Wyoming, where modeling showed the potential for the postmining water table to be approximately 10 feet below the surface, the postmining topography will be designed with small stream channels **at least 10 feet deep to drain surface water, intercept the water table, and keep** the majority of the surface from being saturated (see also box 3-H).

Groundwater Quality

Mining breaks up shales and sandstones and exposes fresh mineral surfaces for leaching, which will affect the quality of the water that flows through these materials. Because groundwater flows toward the pit during mining, there is little opportunity for any contaminants introduced by mining to affect offsite areas, and impacts to groundwater quality *during* mining are minimal (see ch. 6, figs. **6-1A, B).**

The greatest potential for groundwater quality impacts occurs ***after*** mining, when groundwater saturates the spoil and returns to a steady-state groundwater flow pattern (fig. 6-1 C). Water quality is expected to be degraded in the resatu rated spoils until they have been leached by sufficient volumes of water to establish a chemical equi-

Box 3-H.—Burial of Unsuitable Spoil so as To Prevent Groundwater Contamination[1]

At a mine in Montana, the postmining TDS concentrations in the groundwater in resaturated spoils are around 1.5 times greater than in the premining aquifers. The principal constituents in the spoils groundwater are magnesium and sulfate, although lead and nickel concentrations also are higher in the groundwater of reclaimed areas than in undisturbed areas. The higher TDS levels are attributed to elevated concentrations of these elements in the overburden and interburden. As a result, the operator has committed to burial of interburden below at least 8 feet of suitable spoil material, but above the postmining water table and away from reconstructed drainages. Protection of postmining groundwater quality is further provided in the permit application by plans to construct spoil surfaces that are well drained by channels. With this design, the precipitation falling on reclaimed spoil surfaces will be less likely to infiltrate the spoils deeply, and therefore less likely to leach the undesirable chemical constituents into the groundwater system.

[1]See case study mine F in reference 14.

librium between incoming water and soluble constituents in the spoil material. **Over the long term, however, groundwater quality is still predicted to be suitable for the majority of postmining land uses.**

The soluble constituents primarily responsible for elevated TDS levels are the salts of sodium, calcium, and magnesium, as well as sulfate and bicarbonate. The worst impacts on postmining groundwater quality could result from placement of unoxidized sodic and sulfide-rich sediments near the surface—above the water table—where water from surface infiltration could contact these sediments en route to the groundwater table. In this situation, surface infiltration must be limited to prevent adverse impacts to groundwater quality (box 3-H). While acid-mine drainage has long been a problem in the Eastern united States, it is just beginning to be recognized in Western mines (see box 3-I), where the overburden is much more likely to be high in carbonate minerals (calcite and dolomite) with a high buffering capacity (see ch. 8).

The principal reclamation technique to control TDS and other groundwater contamination is special handling of the overburden (i. e., selective placement or mixing). At present, however, researchers are divided in their opinions on the technique for the burial of overburden in mine spoils in order to minimize impacts to groundwater systems.

When wastes (e.g., fly ash or scrubber waste from powerplants) are buried in the pit, concerns about groundwater quality increase. Soluble metals in the coal can be concentrated in the ash and, under certain conditions, mobilized by groundwater. As with other chemically unsuitable spoil materials, special handling is required in burial of utility wastes. A mine in New Mexico buries fly ash, bottom ash, and scrubber sludge in low permeability mine spoils below the postmining water table (see box 6-F), while a mine in northwestern Colorado is required to dispose of utility wastes in dry mine spoils above the postmining water table (see box 3-J).

At the Wyodak Mine near Gillette, Wyoming, thin overburden conditions necessitate disposal of fly ash beneath the postmining water table.

Box 34.-Handling of Acid-Forming Material[1]

The overburden and coal seam at a Powder River basin mine have layers of carbonaceous material containing pyritic and organic sulfur that can produce acids when oxidized. The regulatory authority was concerned about incorporating this material in spoil below the postmining water table because of the possibility of producing acidic groundwater. Analysis of the acid-base potential of the carbonaceous materials (see ch. 8) indicated that the materials would pose no hazards to groundwater quality. The carbonaceous material will be mixed with highly basic spoils to dilute the acid-producing potential of the backfill. The top of the regraded backfill must consist of suitable material, as demonstrated by sampling and analysis of the top 4 feet, which can include carbonaceous materials in low concentrations.

[1]See **case study** mine M in reference 14.

Due to concerns about the permeability of the spoils, the Wyoming DEQ requires that the ash material be encapsulated in compacted clay cells to minimize impacts to groundwater quality. Chemical analysis of the ash, column-leaching studies of the ash and ash-overburden mixtures, and accelerated-aging studies of the compacted clay liners were required to document that this disposal method would minimize groundwater quality degradation (see ch. 6 for further discussion of these analytical techniques).

Alluvial Valley Floors[12]

Alluvial valley floors (AVFS), as defined in SMCRA, are “the unconsolidated stream-laid deposits holding streams where water availability is sufficient for subirrigation or flood irrigation agricultural activities” (sec. 701). In the Western United States, SMCRA prohibits surface coal mine operations that would interrupt, discontinue, or preclude farming on AVFS significant to agriculture, unless the acreage to be disturbed is so small as **to** have a negligible impact on farming. The Act also prohibits mining that would materially

[12]Unless otherwise noted, the material in this section is adapted from reference 14.

Box 3-L—Disposal of Powerplant Waste in the Mine Pit[1]

Groundwater quality concerns about disposal of fly ash, bottom ash, and scrubber sludge at a mine in northwestern Colorado arose when column-leach studies indicated that water percolating through the waste could produce leachate concentrations of aluminum, barium, chromium, sulfate, boron, and molybdenum in excess of the Environmental Protection Agency's primary and proposed secondary drinking water standards and recommended limits for irrigation water. The premining water quality in the main aquifer in the area was classified as poor for domestic use and good for irrigation and livestock use. The aquifer will be removed in the northern limits of the mine, and at the end of mining the exposed portion of this aquifer at the northern pit highwall will be in direct contact with the spoils. If contamination occurs, water from the [illegible] could [illegible] the aquifer and seven bedrock wells and two alluvial wells might be affected. [illegible] the results of the column leaching studies, the regulatory authority stipulated in the permit that [illegible] be buried above the projected postmining water table, and certain areas of the [illegible] be used for utility waste disposal. Under this disposal plan, the only source of water [illegible] the waste is infiltration and deep percolation of precipitation. From the results of a [illegible] concluded that during a typical year no deep percolation through the spoils from precipitation infiltration will occur. Moreover, based on historical weather data and the [illegible] rate of approximately 1.6 cm/yr, the operator calculated that from 500 to 1,000 years would be required for percolating water to reach the waste. In addition, the analysis suggested that little of the percolating water ever would contact the waste because the water would flow down the path of least resistance [illegible] the spoil material, which is 10 to 100 times more permeable than the waste, would provide a path for the percolating water.

[1]See case study mine P in reference 14.

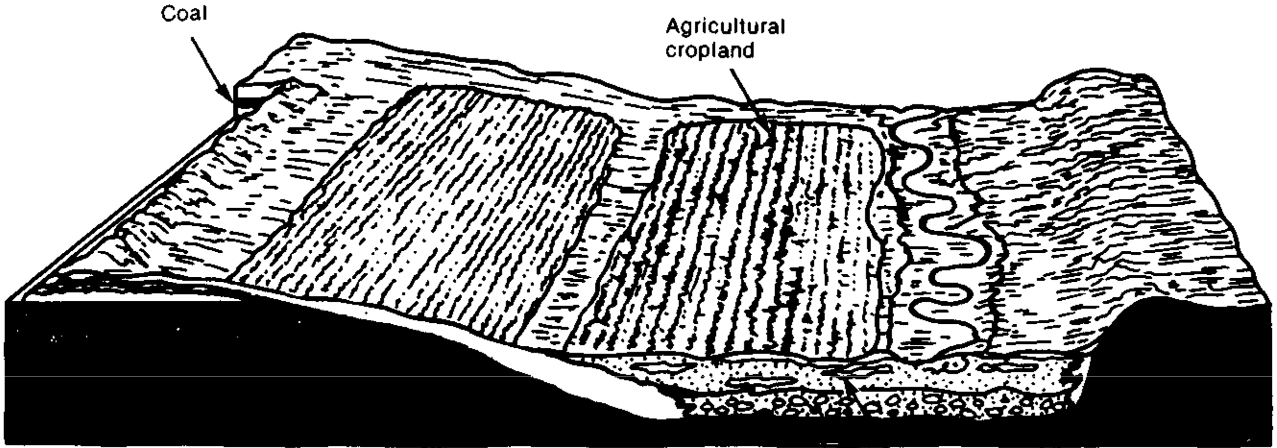
damage the quantity or quality of surface or groundwater systems that supply AVFS significant to farming. Where mining is allowed, either because the AVF is not significant to agriculture or because the area to be disturbed is very small, SMCRA imposes special reclamation standards to preserve or restore the essential hydrologic functions of the AVF. A special monitoring system also is required for all AVFS from the onset of mining until all bonds have been released. Figure 3-10 presents a stylized diagram of an AVF.

The hydrologic functions unique to AVFS include the collection, storage, and regulation of flow that results in water being usefully available from the stream or alluvial aquifer in quantities sufficient for agricultural purposes. As yet, no AVFS have been mined and finally reclaimed under SMCRA. However, several plans for AVF restoration have been approved by the regulatory authorities. These plans focus on channel and floodplain geometry and erosional stability, and on alluvial aquifer depth, thickness, and water storage and transmitting capabilities. Thus AVF restoration combines some of the more rigorous design aspects of surface and groundwater restoration discussed previously (see box 3-K),

Design of the restored channel and floodplain is essentially the same as described under "Surface Water," above, except that the drainage basin must be of sufficient size to sustain the premining surface water irrigation capability. This usually is not a problem, because drainage basins large enough to contain an AVF in the semiarid West normally are much larger than a mine area. Moreover, topography adjacent to the AVF typically is flatter after mining, increasing its value for irrigation.

The simplest plan for restoration of an alluvial aquifer is to salvage and replace alluvial materials present in the undisturbed valley. These materials ordinarily range from very fine-grained deposits near the surface to coarser-grained sands and gravels at the base of the deposit. Often there are fine-grained sequences mixed within other layers. Due to mixing, salvage and replacement of these materials may not restore the premining hydraulic properties of the material. There-

Figure 3-10.—Stylized Diagram of an Alluvial Valley Floor



SOURCE Dollhopf, Wendy, Goering, and Hedsberg, "Hydrology of a Watershed With Subirrigated Alluvial Materials in Crop Product ion," Montana Agricultural Experiment Stat Ion Bulletin 715, 1979.

Box 3-K.—Techniques for Restoring the Essential Hydrologic Functions of an AVF[1]

A mine in the Powder River basin has an AVF not significant to farming running through the center of the permit area. The majority of the AVF acreage lies adjacent to an intermittent stream, and minor acreages adjoin small ephemeral tributary channels. Subirrigated areas were found to cover about 10 percent of the unconsolidated stream-laid deposits. Artificial flood irrigation currently is not practiced within the area to be affected by mining, but over 100 acres of land adjacent to the intermittent stream has suitable soil quality, water quality and quantity, and topography to be potentially flood-irrigable. The operator will employ special measures to restore subirrigation along the reclaimed portion of the intermittent stream. All coarse-textured alluvial deposits found along the intermittent stream will be salvaged and stockpiled separately, and subsequently replaced in the reconstructed channel so as to facilitate subirrigation and hydrologic communication between the reconstructed and undisturbed portions of the stream. Reclamation also will attempt to extend subirrigation to an 80-foot-wide reclaimed low flow channel. The AVF area also received discharge from the premining coal and overburden aquifers, which helped to maintain the groundwater levels in the valley floor and thereby helped support subirrigation. The operator is placing a compacted clay soil layer beneath the restored alluvial aquifer in order to isolate the restored alluvial system hydraulically from the remainder of the spoils, and thus help to shorten the time for subirrigation to be reestablished. Subirrigation and hydraulic communication between the reconstructed and undisturbed portions of the intermittent stream will be promoted by the placement of a 10-foot thick layer of coarser-grained alluvial material beneath 2 feet of suitable topsoil, above 10 feet of suitable overburden, and above the compacted clay soil layer in the 80-foot wide reconstructed active low flow channel. Separate overburden stockpiles have been established for suitable alluvial material to ensure that a sufficient amount will be available for channel reconstruction. Reestablishment of subirrigation will be demonstrated by the extent and variation of plant species, along with other hydrologic indicators of restoration of the alluvial water levels.

&e case study mine J in reference 14.

fore alternate materials, such as sandy overburden, may be used in AVF reconstruction. Most AVF restoration plans include a compacted layer beneath the replaced alluvium to minimize loss of streamflow into the spoils. In addition, this layer should help speed up restoration of the essential hydrologic functions of the alluvial system by making its restoration relatively independent of that of the adjacent spoils (see box 3-K).

Revegetation[13]

The goal of revegetation at Western surface coal mines is to reestablish plant communities similar to the premining vegetation (as determined by baseline vegetation maps and quantitative data for all land-use categories), except where the postmining land use is different from the premining use, or where the premining vegetation was of poor quality and thus represents an unacceptably low standard for revegetation. The range of natural vegetation within the study region is broad, with a concomitant variation in the permitting process and subsequent approaches to revegetation. The desert grasslands of northwestern New Mexico, for example, present significantly different revegetation problems from the mountain brush in northwestern Colorado, the mixed prairie in northeastern Wyoming, the ponderosa pine woodlands of southeastern Montana, and the woody draws along drainages in North Dakota. Plant communities along drainages are especially important in much of the region, because the moister conditions frequently support greater vegetation densities and diversities than drier uplands, and may foster plant and animal species not found elsewhere.

Once the redressed topsoil has been graded and prepared for revegetation (see discussion of "Topsoil Handling," above), the area is seeded and planted with species appropriate for the postmining land uses—primarily native species for rangeland and wildlife habitat. The timing of seeding and planting is determined by site-specific moisture and climatic conditions, as well as vegetation types (see below). The seed mixes generally are chosen by the operator in consultation with the regulatory authority, and are specified in the approved permit. The seeds may be applied through broadcast or drill methods. Shrubs and trees can be established from nursery stock, including bare-root and containerized stock; from planted or in-situ seeds; or from onsite transplants. In some areas, special management practices may be used to promote revegetation success (see discussion below and in ch. 8).

The site-specific factors that affect revegetation include soil texture, depth, and alkalinity; site elevation, slope, aspect, and wind exposure; and precipitation and temperature patterns and ranges. Plant-available moisture, as determined by the amount, form, and seasonal distribution of precipitation, is usually the primary limiting factor for plant growth and successful revegetation. As discussed at the beginning of this chapter, seasonal precipitation varies widely in the study area, with annual averages at most mine sites ranging from approximately 7 or 8 inches to 16 or 18 inches (fig. 3-2). Plant-available moisture usually is at a maximum in late spring to early summer for most of the study area, but peaks in mid to late summer in the San Juan River region.

The combined patterns of plant-available moisture and temperature determine whether cool season plants, which carry out most of their growth before or after the heat of summer, or warm season plants, which start and accomplish their growth at warmer temperatures, are dominant. In either case, the maximum period of growth coincides with the maximum precipitation. In general, cool season species are dominant in the central and northern portions of the study region, and warm season species prevail in the southern reaches.

Special Management Practices

A variety of special management practices may be used to promote revegetation success and meet performance standards. These may range from relatively common agricultural practices adapted for mined land reclamation, such as mulching, irrigation, and fertilization; to direct-haul topsoiling; to innovative techniques to reduce interspecies competition, enhance woody plant density, improve grassland quality, and pro-

[13] Unless otherwise indicated, the material in this section is adapted from reference 13.

mote landscape diversity. The use of any of these practices will depend on site-specific conditions and the postmining land use, as well as on mining methods.

As discussed above, direct ***haul topsoil*** **provides an organically rich and biologically active medium for revegetation, which dramatically improves the establishment of planted and volunteer species.** As a result, superior lifeform (i.e., shrubs, forbs, grasses) and species diversity can be obtained within a relatively short time. In areas with deep soils of suitable chemical and physical parameters, the benefits of direct haul topsoil may be enhanced with the use of two lifts (see ch. 8).

Mulch **conserves soil moisture and aids erosion control, and has long been an integral part of surface mine revegetation.** Historically, the most common mulching materials have been straw or hay. Although these materials are effective in erosion control, they often are difficult to anchor in windy areas, and the usual anchoring technique of crimping the straw into the soil may cause more soil moisture to be lost through wicking than it conserves. Considerable nitrogen also is tied up in the decomposition of the mulch. Furthermore, straw or hay mulches tend to include seeds of undesirable species, and the resulting weed infestations can cause serious competition with the planted species. Those native hay mulches that have proven to be relatively weed-free can include desirable native seeds that otherwise may be hard to obtain. Reliable sources of native hay are scarce at many mines, however.

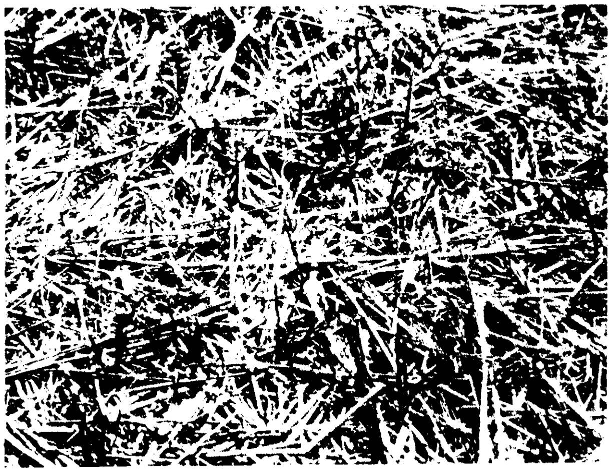


Photo credit: Office of Surface Mining

Straw or hay mulch can conserve soil moisture and aid in erosion control until revegetation is established. Here, grass may be seen coming up through the mulch.

Alternative approaches include the use of mulch created onsite and "stubble" mulch. Mulch derived from shredded native vegetation ("live mulch") has shown good results in promoting woody plant density and diversity at one mine in northwestern Colorado, where the climatic and other conditions for revegetation are the most favorable in the study region (see box 3-L). This promising technique is now being tried in the more arid conditions of northwestern New Mexico.

For stubble mulch, a cover of small grain (e.g., wheat, barley, millet) is drill-seeded in the spring to retard wind and water erosion. The following

Box 3-L.—Creating Mulch From Native Vegetation

A mine in northwestern Colorado "creates" mulch before topsoil removal by treating woody areas with a tractor-mounted shredder that leaves a residue of finely chopped woody biomass on the soil surface. The shredder can operate in the aspen woodlands, producing as much as 77 tons of mulch per acre. This technique allows complete topsoil salvage in areas where woody plants formerly were uprooted and removed by bulldozers. The uprooted plants had substantial amounts of the uppermost (and most valuable) soil layers left attached to the root system. This rich soil and accompanying root material were lost as the plants were hauled away for disposal. Areas treated by this mulching technique have shown substantial woody-plant regeneration by root sprouting, resulting in far better densities than previously achieved through seeding and planting. Moreover, after topsoil removal and replacement on the reclaimed surface, sufficient organic debris remains on the surface to function as a mulch, and the regulatory authority has approved this innovative "live" mulching in lieu of other traditional mulching methods at this mine (see also box 8-B).

See case study mine CO-1 in reference 13.

fall, the grain "nurse" crop, which may be mowed to prevent seed production, is present as standing dead straw, and the perennial seed mix is interseeded between the rows of remaining stubble. During the winter, the stubble enhances snow retention, and as a result, the perennial seed mix germinates and grows in a more favorable environment than if the stubble were not there. On at least one mine, grain crops have been grown for several years, and the stubble disked into the soil in hopes of enhancing organic-matter content prior to seeding the perennial mix.

Early concern about revegetation success in areas with less than 10 inches of annual precipitation led to the imposition of *irrigation* require ments in a number of mine permits. Irrigation can ensure consistent and predictable plant establishment, especially in the Southwest where precipitation is less effective in promoting plant growth because it occurs later in the year and under warmer conditions, resulting in more precipitation loss by evaporation. However, vegetation growth developed under irrigation normally experiences a substantial dieback when the irrigation is withdrawn. Moreover, in such low-precipitation areas, irrigation water of acceptable quality is likely to be difficult to obtain (see box 3-M).

Box 3-M.—Supplemental Irrigation[1]

At a mine in southwestern Wyoming with annual average precipitation of 7 inches, a permit stipulation required irrigation to ensure successful revegetation. The streams in the mine area are all ephemeral, and available surface water derived from runoff is likely to be of poor quality due to the combination of intense rainfall, low natural vegetation density, erosive soils, unstable stream channels, and extremely transient, highly peaked streamflows. As a result of the poor quality of water available at the site, the permit stipulation also required the operator to develop a less salty irrigation water supply or demonstrate that the existing water quality would not damage soils or vegetation. No better water source became available, and use of the surface water on test plots showed deleterious salt buildup. While both the search for better water and studies of the effects of salinization continued, revegetation was attempted without the use of supplemental irrigation. Results to date show values of cover and production roughly comparable to the established performance standards based on premining vegetation. Based on monitoring data for unirrigated revegetation areas, the regulatory authority granted relief from the permit stipulations for the duration of the 5-year permit, but irrigation requirements could be reinstated at the time of permit renewal.

[1]See case study mine I in reference 14 and WY-3 in reference 13.

Vegetation developing slowly under dryland conditions may reach the same level of cover and production in the long run as irrigated areas. A mine in northwestern New Mexico that receives as little as 6 to 8 inches average annual precipitation uses irrigation for 2 years after seeding as part of its standard reclamation practice. On part of another mine in the same area owned by the same company, an experimental area without irrigation has been initiated and will be monitored to determine the relative success of revegetation with and without irrigation.

***Fertization* of revegetated areas has diminished steadily because pasture species dependent on high fertilizer rates have been removed from seed mixes, and because experience has indicated that nitrogen fertilizers encourage vigorous growth of weeds and the more aggressive native grasses, to the detriment of less aggressive natives, including woody plants.** At most sites, performance standards can be met through other management practices, and the enhanced short-term production and cover resulting from fertilization are not needed for long-term revegetation success.

A number of steps maybe taken to *reduce interspecies competition* between aggressive cool season grasses and the various shrubs, forbs, and warm season grasses that frequently are unable to survive beyond germination. Two commonly used planting remedies are to reduce the relative proportion of cool season grasses in the seed mix in order to offset their competitive advantage, and to use two-staged or two-phased planting for temporal separation in the establishment of aggressive and less aggressive species. Two-staged or two-phased planting was first practiced at a mine in southeastern Montana, where warm season grasses plus forbs and shrubs are planted in prepared topsoil, and then given one to three growing seasons to become established before interseeding with cool season grass species. Alternatively, sequential drill-seedings at an angle to one another provide a slight—but apparently effective-spatial separation of aggressive and less aggressive species. Another successful approach is to plant both cool and warm season species during the warm season to reduce the competitive advantage of cool season grasses, and then use supplemental irrigation to maximize the growth of warm season species. Also, lower total planting rates associated with direct haul topsoiling typically have improved the establishment of less aggressive species.

***Revegetation of woody plants* in sufficient density and diversity to meet performance standards is a continuing concern in the West, especially in areas where woody plants are important winter browse for big game.** Loss of newly established shrubs to wildlife is a continuing problem, However, monitoring and other revegetation data at a number of mines in Wyoming suggest that shrub densities of one stem per square meter over 10 percent of the area (the proposed standard in Wyoming) can be realized in the early years of reclamation using direct seeding combined with one of the methods for reducing competition discussed above. In general, the greatest success has been achieved with four-wing saltbush. Other shrubs valuable as browse have had variable success, and big sagebrush has proven especially difficult to establish at many sites (see ch. 8). Planting of nursery stock and onsite transplants of mature shrubs may be too expensive and results too poor at some mines for large-scale use of these techniques, unless supplemented with direct haul topsoiling, which can provide a valuable source of seeds or rootstock ("propagul es") for shrub volunteers. In addition, as noted above, mulch created from shredded native woody vegetation has shown promise as a propagule source in northwestern Colorado, although its effectiveness in other parts of the study regions has yet to be demonstrated. Several mines in northwestern Colorado also are transplanting shrub and tree pads directly with a front-end loader, which may provide volunteer growth later in the liability period.

Several special management techniques are being used on *upland grasslands* in the Northern Great Plains to improve lifeform and species diversity, seasonality (particularly warm season grass establishment), and vigor. In the Northern Plains, grasslands comprised of highly productive species may become stagnant and less productive if excess litter (decayed organic matter) accumulates, because litter ties up nutrients and can promote disease. Grazing is one technique for breaking up the litter and incorporating seeds and organic matter into the soil. Burning also can increase nutrient availability temporarily and hasten breakdown of the litter. Grazing, burning, haying, and application of herbicides may improve diversity (including seasonality) when the timing and intensity of these practices decrease the advantage of cool season grasses and "weeds. "

Wildlife[14]

Techniques or practices to alleviate surface coal mining impacts to wildlife include mitigation techniques during mining as well as habitat restoration postmining. A mine operator will select a set of techniques in consultation with the regulatory authority and relevant wildlife agencies (e. g., U.S. Fish and Wildlife Service—FWS, State Fish and Game agencies), given the baseline data **on species occurrence, distribution, and abundance, habitat preference, and reproductive success, and on habitat or habitat features considered limiting or critical to the survival or maintenance of a particular species population (see** ch. ***5).*** Important terrestrial habitats in the study region include raptor nest sites, critical big game winter range, sharp-tailed and sage grouse breeding grounds, bald eagle winter concentration areas, and sand hill-crane nesting habitat, as well as habitat for threatened and endangered species. Aquatic habitat potentially

[14]Unless otherwise noted, the material in this section is adapted from reference 1.

Table 3.3.—Selected Mitigation Techniques Listed by General Category[a]

Avoidance	Operational	Habitat replacement/enhancement	Offsite enhancement
–Preserve vegetation patches[b]	–Restrict speed limits on access and haul roads	–Topographic manipulation	–Controlled burning
–Preserve important habitat[b]	–Compatible location of roads	• undulating surface	–Fertilizing[c]
–Buffer zones	–Underpasses/overpasses for roads and conveyors	• surface depressions	–Seeding
–Temporal avoidance during critical periods or times	–Raptor-safe powerlines	• drainage reconstruction	–Shrub thinning or crushing
–Visual barriers	–Compatible fence design or lay-down fence for big game	• microtopographic features	–Elimination or reduction in livestock grazing
–Protect migration corridors	–Employee wildlife awareness programs	–Establish/enhance impoundments	–Impoundments[b]
–Stagger operations to avoid disturbing large tracts of habitat concurrently	–Hunting and fishing allowed/ not allowed	–Rock piles/boulders	–Strutting ground relocation
	–Prohibit firearms in vehicle	–Transplant shrubs/trees	–Relocate raptor nests[b]
	–Monitoring	–Establish shrub patches	
		–Establish interspersion/edge concept with vegetation reestablishment	
		–Establish shelterbelts/riparian vegetation	
		–Direct application of topsoil	
		–Attain shrub density standards	
		–Brush piles[c]	
		–Implant dead trees for snags[c]	
		–Stream habitat reconstruction	
		–Improve land management practices	
		–Nesting structures	
		–Leave/modify highwalls[b]	
		–Relocate raptor nests[b]	
		–Relocate sage grouse strutting grounds	
		–Special studies/research	
		–Perch sites[c]	
		–Gallinaceous guzzlers[c]	
		–Vegetation species selection	

[a]For detailed descriptions and discussions of these techniques, please refer to the list of selected references in reference 1.
[b]Legal, technological, and/or economic constraints limit the extent to which these practices may be employed.
[c]Temporary techniques that require maintenance beyond installation.

SOURCE: Cedar Creek Associates, "Wildlife Technologies for Western Surface Coal Mining," contractor report to OTA, August 1985,

affected by surface coal mining consists mostly of small wetlands, stockponds, perennial streams, and ephemeral drainages.

Under SMCRA, operators must, to the extent possible using the best technology currently available,[15] minimize adverse wild life and habitat impacts. The Federal regulations add provisions related to endangered species, bald and golden eagles, wetlands and habitats of unusually high value, and specify design standards for features such as powerlines, haul roads, and fences.

Mitigation Techniques

There are four general categories of techniques for mitigating wildlife impacts from surface coal mining: habitat replacement/enhancement, avoidance techniques, operational techniques, and off site enhancement. Table 3-3 summarizes he measures more commonly employed at Western surface coal mines for each of these categories.

***Habitat replacement and enhancement* during reclamation comprise the greatest number of wildlife mitigation measures. All mining operations give some consideration to wildlife** in planning revegetation and other reclamation activities. Where wildlife habitat is the primary postmining land use, or where sensitive or protected species will be disturbed, wildlife habitat replacement or enhancement may be complex and extensive (see box 3-N). For those portions of the mine site where the primary postmining land use is wildlife habitat, SMCRA requires that plant species for revegetation be selected based on their proven nutritional value, their use as cover, and their ability to support and enhance

[15] In this context, "best technology currently available" is defined in the Federal regulations as "equipment, devices, systems, methods, or techniques which will minimize, to the extent possible, disturbances [of] and adverse impacts on fish, wildlife, and related environmental values, and achieve enhancement of those resources where practicable. "

Box 3-N.—Habitat Replacement and Enhancement Techniques

The premining surface at a mine in northeastern New Mexico was managed specifically for big game, primarily elk and mule deer. The primary postmining land use will be wildlife habitat, as specified by the surface owner, who maintains a strong economic interest in resident big game herds. Other big game animals present include black bear and mountain lion. Several years ago, the operator entered into a cooperative agreement with the surface owner for extensive monitoring of the big game herds, in order to determine the effects of mining on game populations, and to design appropriate mitigation efforts. Subsequently, this monitoring has been expanded to include nongame animals and fish in order to obtain an overall picture of the wildlife ecology of the area. The operator has collected extensive telemetry and mapping information from radio-collared big game animals, and has analyzed the quality of nearby habitats, presence or absence of suitable habitat for given species, animal distance from the operation, and wildlife's ability to adapt to mining. To date, these efforts indicate use by mule deer and elk of reclaimed areas adjacent to the active mining operation. Wildlife mitigation measures implemented at the mine comprise specifically designed techniques and alternate reclamation practices to improve habitat components beneficial to wildlife. The site-specific designs include: 1) construction of rock piles placed randomly within reclaimed areas as shelter and escape cover for small animals and as perch sites for birds and raptors; 2) formation of brush piles to provide habitat analogous to rock piles; 3) fencing of the permit area to exclude livestock that could compete for forage, trample riparian vegetation, and compact streamside soils; 4) replacement of tree-cavity nesting habitat (nest boxes) for kestrels; 5) fertilization of offsite habitats to improve forage production for big game; 6) education of mine personnel about the effect of wildlife harassment; and 7) introduction of stocked fish in mine-area ponds as a "barometer" of water quality and to provide prey for fish-eating predators. Alternate reclamation practices involve: 1) leaving a short stable highwall that resembles natural rock outcrops and bluffs and adds topographic diversity, 2) redistribution of soils to place thin rocky soils on slopes and thicker soils on ridgetops and valley bottoms to encourage plant diversity, 3) targeting earlier successional plant communities in the seed mix to promote habitat diversity and forage production, and 4) reestablishment of shrubs and trees in configurations beneficial to wildlife, such as travel lanes and mixing of types for edge effects.

[1] See case study mine G in reference 1.

habitat. In addition, the selected plants must be grouped and distributed in a manner that optimizes edge effect, cover, and other benefits to wildlife.

Operators also must avoid disturbing, enhance where practicable, restore, or replace wetlands and vegetation along rivers, streams, and ponds, as well as other habitats of unusually high value for fish and wildlife (e.g., cliffs supporting raptor nests, wintering and nursery areas, breeding areas, etc.). At some mines, this may involve manipulating the postmining topography to obtain landscape diversity (see ch. 8), or recreating special wildlife habitat areas such as sage grouse strutting grounds (see box 3-Q, below), woody draws (box 3-O), and wetlands (box 3-G). For other land uses, however, mitigation efforts often are limited to measures such as planting groups of trees or shrubs to break up blocks of land and to diversify habitat types for birds and other animals. Rockpiles and other surface features beneficial to wildlife often are replaced postmining.

Avoidance techniques **range from disallowing mining to preserving small patches of important habitat, to maintaining or establishing visual barriers or buffer zones between mining operations and sensitive wildlife habitat.** Avoidance measures also can be temporal—for example, prohibiting blasting or mining near breeding areas during the breeding season. In areas where habitat removal is imminent, temporal avoidance only postpones removal during important wildlife seasonal activities, and therefore the benefits usually are short-term unless the habitat is restored following mining. Avoidance requirements may be imposed prior to leasing as a result of application of the unsuitability criteria (see ch. 4),

Box 3-Q.—[illegible] of Woody Draws[1]

Reestablishment of woody draws involves deciduous tree and shrub communities in both Montana and North Dakota. One mine in North Dakota is [illegible] woody draws with subcategories of mixed deciduous woodland, tall shrubland, and low shrubland (see table 3-4). Because these species [illegible] moisture, the restoration process at the mine begins with the creation of topographic features to retain moisture [illegible] or [illegible]. [illegible] parts of the [illegible] moisture [illegible]. The special handling of soils to return those with proper water-holding qualities is practiced sometimes, but is difficult in North Dakota where regulations require return of topsoil to the surface owner. [illegible] has been grown in a nursery [illegible] when feasible. The mine installs approximately 2,700 transplants per acre [illegible]-type planters. Heavy mulch ([illegible] tons/acre of slough-grass hay or wood chips) is used to control herbaceous competition and [illegible].

[1] See case study [illegible].

Table 3-4.—[illegible] Standards for Woody Draw [illegible] at a Mine in North Dakota

Species planted	Plants/acre	Performance standard
Mixed deciduous woodlands:		
Willow	135	3,7[illegible] plants/acre of
Boxelder	270	which 1,215 are trees
Green ash	810	and 2,430 are shrubs;
Cottonwood	405	all species planted
Burr oak	135	must be present; for
Aspen	135	each species, at least
Native plum	270	50% of the number
Chokecherry	270	planted must be
Serviceberry	135	present.
Round-leaved hawthorn	135	
Tall shrub type:		
Native plum	[illegible]	[illegible] plants/acre;
Silver buffaloberry	135	all species
Serviceberry	540	planted must be
Chokecherry	540	present; for each spe-
Round-leaved hawthorn	540	cies, at least 50% of
Red osier dogwood	135	the number planted
Bristly gooseberry	135	must be present.
Low shrub type:		
Silverberry	540	10,[illegible] plants/acre; all
Western wild rose	1,080	species planted must
Snowberry	1,080	be present; for each
		species, at least 50%
		of the number planted
		must be present.

SOURCE: [illegible] Contractor Report to OTA, [illegible].

or during permitting based on the wildlife impact assessments included in the permit application package.

Avoidance of important habitats or patches of vegetation can be important **for maintaining natural sources of wildlife and vegetation for reinvasion into reclaimed areas.** However, the importance of these areas as wildlife habitat during mining may be limited if the areas are small or isolated by large tracts of disturbed land. Moreover, operational, cost, and full coal recovery considerations often limit an operator's ability to avoid important habitats.

As experience is gained with wildlife responses to mining in the West, less emphasis has been placed on avoidance measures. For example, during the late 1970s and early 1980s, wildlife biologists believed that all eagles were extremely sensitive to human activity, especially during breeding or fledging seasons. As a result, it was standard practice for coal leasing and permitting agencies to require an undisturbed buffer zone around active eagle nests. Recent research has shown, however, that some eagles may be much more tolerant of nearby disturbances from mining than expected, and that in some cases nests can be moved without adverse impacts on the eagle population (see box 3-P; see also ch. 9, box 9-A).

***Operational mitigation techniques* may involve the education or regulation of mine personnel, as well as modifications in mine operations or mine plan structures designed to reduce the potential for adverse impacts. Specific techniques include lowering speed limits on access and haul roads to reduce the potential for road-kills, designing and locating roads and other structures so as not to interfere with wildlife movement, conducting employee wildlife awareness programs, or making powerlines raptor-safe (see fig.** 3-1 1).

***Offsite enhancement* measures usually focus on modifying habitats to increase their value to targeted species, or constructing new habitats offsite to replace those to be disturbed by mining (see box** 3-Q), **and are used to mitigate projected wildlife impacts resulting from disturbance or removal of mine-area habitats.** Providing alternate raptor nest sites (e.g., rockpiles), improving surface-water resources, eliminating livestock grazing, and thinning of overly dense shrub stands are examples of offsite enhancement techniques. In other instances, these practices may be undertaken to protect newly established vegetation from wildlife. Surface ownership of, and land use practices on, adjacent areas are the primary factors (other than cost) determining the extent to which offsite enhancement measures are implemented.

Box 3-P.-Relocating Golden Eagle Nests[1]

Wildlife studies at a mine in southern Wyoming documented at least four active golden eagle nests in mine highwalls scheduled to be reclaimed. Nearby mining and reclamation activities apparently had no adverse effects on the eagle pairs, and all four nests successfully fledged young. In 1982, the operator, FWS, the Wyoming Department of Game and Fish, and the Wyoming regulatory authority initiated a cooperative effort to formulate the best technique for relocating two of the highwall-nesting golden eagle pairs. Artificial nesting platforms were built near the active nests, and fledglings were moved from the nests to the platforms to lure the adults to the new nest sites. As additional active eagle nests were established on highwalls in subsequent years, nest relocations have been attempted by moving young to nearby natural rimrock areas or to artificially established boulder nest sites. Most relocations were successful and a monitoring program was instituted to evaluate continued nesting on the platforms.

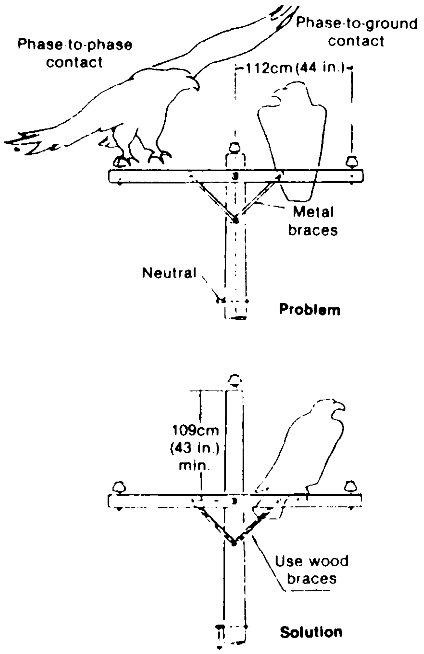
[1]See case study mine D in reference 1.

Box 3-Q.-Creationreation of a Sage Grouse Strutting Ground[1]

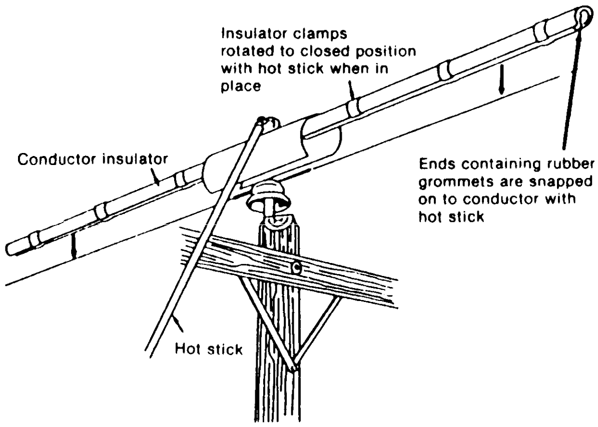
At a mine in southeastern Montana, the path of future mining was expected to disturb a known sage grouse strutting ground (lek). Baseline studies were performed to analyze the sage-grouse habitats and fidelity to the breeding ground. A new sage grouse strutting ground was created offsite by clearing an area on relatively high ground that was surrounded by suitable sage grouse habitat—primarily sagebrush 5 to 30 inches high with an average cover of 14 to 25 percent, intermixed with forbs. Decoys and tapes of male sage grouse "booming" were used to induce birds to use the relocated strutting ground. Experimental studies strongly indicate successful transfer of fidelity from the old ground to the new ground. Documented decreases of breeding activity at the old lek correlate highly with increases at the new offsite area.

[1]See case study mine C in reference 1.

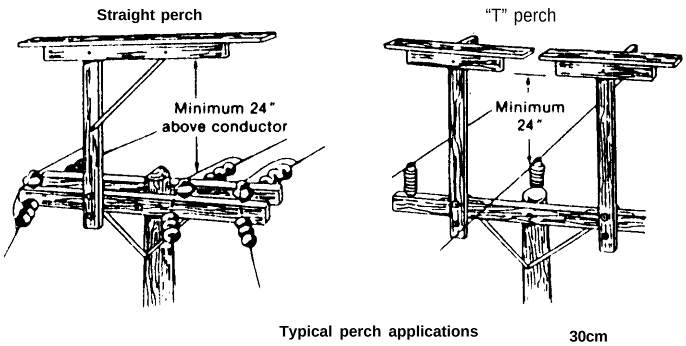
Figure 3-11.—Designs for Raptor-Safe Powerlines

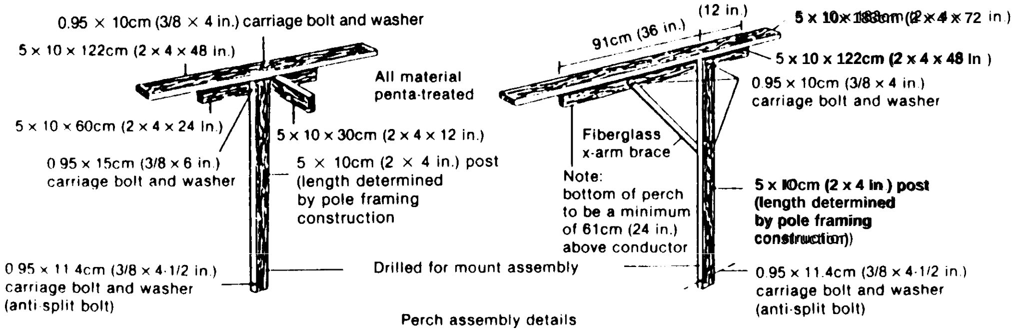


Vertical separation of the center and two outside conductors precludes the electrocution hazard on one type of pole



Protective conductor insulation cover for installation on poles used by raptors as an alternative to pole reconstruction





Artificial perches mounted above existing poles as an alternative to Pole modification (suitable primarily for tree-less areas) and perch assembly details.

SOURCE: U.S. Department of the Interior, Fish and Wildlife Service, Practices for *Protecting and Enhancing Fish and Wildlife on Coal Surface-Mined Land.*

Photo credit: Colowyo *Coal Co.*

Thinning dense shrub stands on an undisturbed portion of the mine site during the winter stimulates new spring growth attractive to browsers such as elk, thus reducing wildlife use of revegetated areas.

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