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Strip-Mining Techniques To Minimize Environmental Damage in the Upper Missouri River Basin States

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STRIP-MINING TECHNIQUES TO MINIMIZE ENVIRONMENTAL DAMAGE IN THE UPPER MISSOURI RIVER BASIN STATES

by

Franklin H. Persse[1]

ABSTRACT

To meet escalating energy requirements, substantial increases in production from the strippable coal and lignite deposits in eastern Montana, western North Dakota, and northeastern Wyoming already have occurred, and further expansions are expected at least until the year 2000. Such production, attributable largely to rising demand for low-sulfur coal, must be accomplished with a minimum of adverse effects on the environment. Information on geology, climate, and current land use in the Upper Missouri River basin is presented in the Bureau of Mines review as a guideline to what operators may expect during and after mining. Proven methods of protecting the air and water from pollution and of restoring mined land for other uses are described, and untried methods of land reclamation, some with equipment yet to be manufactured, are discussed as possible means of maintaining aesthetic values in the basin.

Costs incurred to protect the environment are part of the production cost and thus are borne by the ultimate consumer. Unit production costs are less for the thick coal and lignite deposits of the basin than for the thinner but higher Btu coal deposits of the Eastern and Midwestern United States. Precise comparisons of environmental protection costs between mines in such disparate areas cannot be made, because of differences in physical conditions, accounting procedures, and other variables.

INTRODUCTION

Strip mining is an efficient and safe method of extracting a near-surface mineral deposit. Too often in the past, however, no attempt was made to restore mined land; toxic minerals were exposed that caused water pollution, and the barren area was a source of dust and subject to erosion. Consequently, strip mining became almost synonymous for wasted land having a potential for polluting air and water. Although trends are changing as efforts are intensified to prevent air and water pollution and to reclaim strip-mined land, technology to minimize environmental damage has not kept pace with the advances in overburden removal and mineral recovery.

[1]Mining engineer.

Increased demand for low-sulfur coal and lignite found in eastern Montana, western North Dakota, and northeastern Wyoming thus has aroused public concern about the effect of mining on the environment in this region. The Bureau of Mines has published data on known strippable reserves of coal and lignite in the Upper Missouri River basins; impacts of environmental policies on its coal, lignite, and water; and projections of water required for converting coal and lignite to electric power and to synthetic gas or liquid fuels. Expansion of mining activity indicates the desirability of extending environmental studies to those techniques that could improve methods and reduce costs for curtailing air and water pollution and for reclaiming strip-mined land.

The techniques described were culled from a review of related literature or assembled by personal inquiry and onsite examination of reclamation work. Some of the methods and equipment discussed are those currently in use; others would require modification of existing techniques and equipment, or development of entirely new systems.

Trade periodicals and other literature have described methods or techniques for reclaiming land after it has been mined. Such exchanges of ideas have resulted in improvements in mined-land reclamation and have lowered its cost. This work cites possibilities for further improvements and reductions in costs through advance planning and incorporating mined-land reclamation into the mining method.

ACKNOWLEDGMENTS

The author acknowledges the cooperation of the many individuals who provided helpful information, including employees of AMAX Coal Co., Belle Ayr mine; Big Horn Coal Co., strip mine No. 1; Cobusco, Inc.; Decker Coal Co., Decker mine; Marion Power Shovel Co., Inc.; Pacific Power and Light Co., Dave Johnston mine; Western Energy Co., Colstrip mine; and the Black Hills Power and Light Co., Wyodak mine.

GENERAL INFORMATION

The Upper Missouri River basin, as defined for this study and shown in figure 1, is that region upstream from Pierre, S. Dak., drained by the Missouri River and its tributaries. Strippable deposits of coal and lignite lie in the central part of the region. Figure 2 shows the approximate locations of the deposits and the boundary of the coal- and lignite-bearing region.

Although the lignite-bearing area extends into six counties of South Dakota, overburden thickness and other data necessary to determine if any strippable deposits exist were unavailable.

Production is expected to increase manyfold over current output because of the ever-increasing demand for low-sulfur fuel, the decreasing supply of natural gas and petroleum, and the thick beds and vast reserves of coal and lignite in the Upper Missouri River basin. Output for 1990, in the tributary Powder River basin portion alone, has been projected as high as 793 million

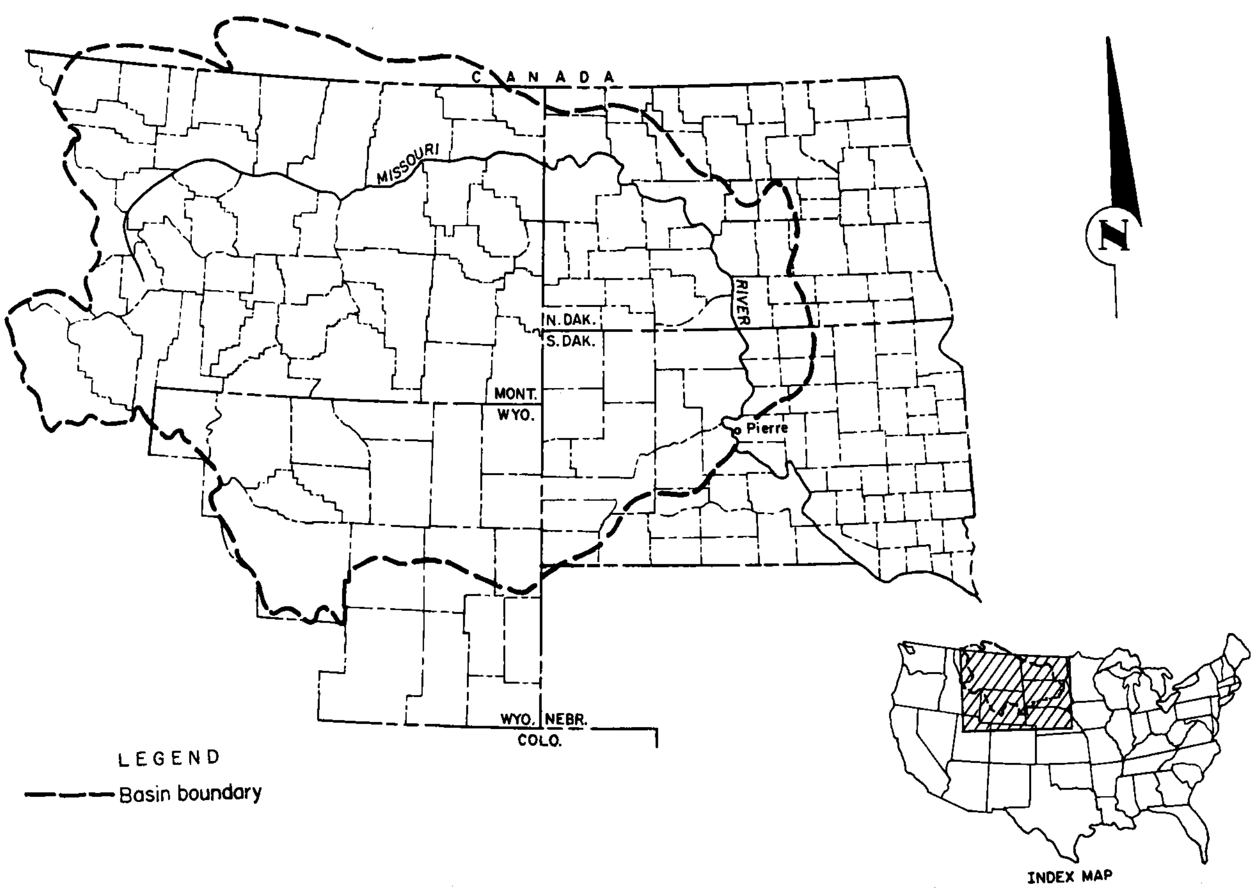

FIGURE 1. - Upper Missouri River basin.

tons (12).[2] Coal and lignite production of this magnitude will have considerable impact on the economy.

Few trade centers exist in the Upper Missouri River basin. Billings, Mont. (1970 Standard Metropolitan Statistical Area (SMSA) population, 87,367), is the only primary-wholesale-retail center.[3] Bismarck-Mandan, N. Dak. (combined 1970 population, 45,796), Minot, N. Dak. (1970 population, 32,290), and Rapid City, S. Dak. (1970 population, 43,836), are secondary-wholesale-retail centers.[4] Casper, Wyo. (1970 population 39,361), just south of the

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[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

[3]A primary-wholesale-retail center has more than 100 wholesale establishments, and all of the following wholesale functions: automotive supplies, bulk oil, chemicals and paint, drugs, dry goods, apparel, electrical goods, groceries and food, tobacco and beer, lumber and construction materials, hardware, industrial and farm machinery, paper, plumbing, heating, air-conditioning equipment, and professional service equipment.

[4]A secondary-wholesale-retail center has more than 50 wholesale establishments and at least 10 of the wholesale functions listed in footnote 3.

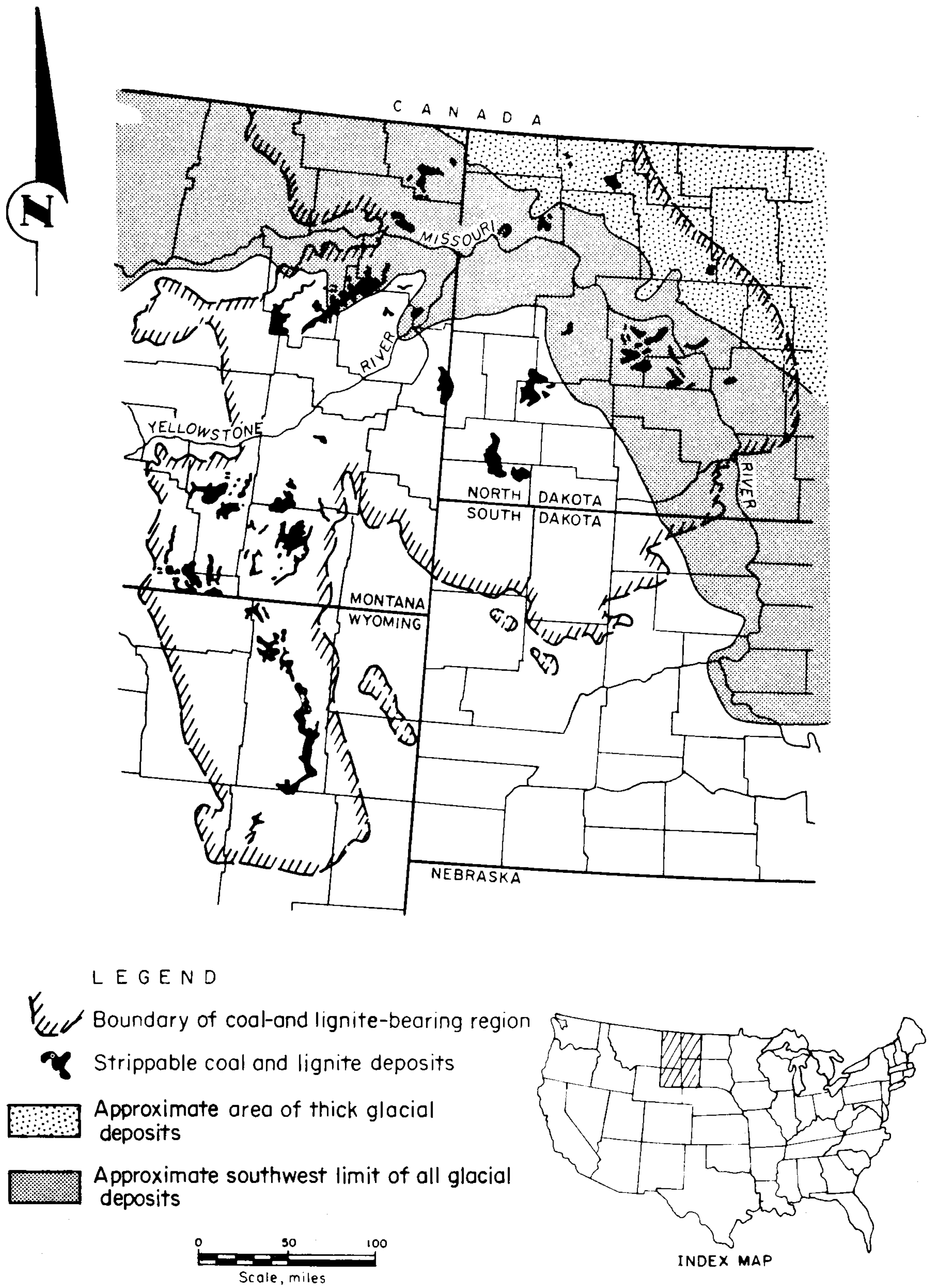

FIGURE 2. - Coal- and lignite-bearing area and strippable deposits in the Upper Missouri River basin.

Upper Missouri River basin, is also a secondary-wholesale-retail center supplying much of the needs of the Wyoming portion. Complete shopping centers[5] in Montana are limited to Miles City and Glendive (1970 population, 9,023 and 6,305, respectively); in North Dakota they include Dickinson and Williston (1970 population, 12,045 and 11,280, respectively); and in Wyoming they are Gillette and Sheridan (1970 population, 7,194 and 10,856, respectively). Metropolitan wholesale and retail centers[6] closest to the region are the Denver, Colo., SMSA and the Minneapolis-St. Paul, Minn., SMSA. The region is served by four airlines, four railroads, and a network of interstate, primary, and secondary highways. Agriculture, the dominant industry, is the principal source of income.

Geology

All known strippable coal and lignite deposits in the Upper Missouri River basin, formed during Tertiary time, are commonly referred to as the Williston and Powder River basin coalfields. All strippable deposits in Montana are in the Tongue River Member of the Fort Union Formation. In the Wyoming portion of the basin, all deposits except three are in the Tongue River Member of the Fort Union Formation. The three exceptions are found in the Wasatch Formation of Eocene age. Descriptions of the strippable coal and lignite deposits in Montana are presented in Bureau of Mines Preliminary Report 172 (2), and those of North Dakota and Wyoming may be found in Bureau of Mines Information Circulars 8537 (13) and 8538 (16). Table A-1 lists each deposit and a reference that describes its geology in detail.

Strippable coal and lignite deposits in the Upper Missouri River basin are overlain by various sedimentary formations. The overburden often includes soil, alluvium, clay, shale, clinker, sandstone, siltstone, conglomerate, limestone, leonardite, and coal or lignite that is either too thin to mine or of a poor quality. Interbedding is common; concretionary structures, generally ferruginous, sometimes overlie the coal or lignite. Glacial drift occurs in the northern part of Montana and in the northern and eastern part of the lignite-bearing area of North Dakota (fig. 2).

Partings within the coal or lignite beds can include--singly or in combination--clay, shale, carbonaceous shale, bone, bony coal, sandstone, and limestone. Intervals between coal or lignite beds usually consist of sedimentary rock formations similar to those in the overburden.

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[5]A complete-shopping center has nine or more of the following retail functions: sporting goods, family shoe store, florist, radio and TV store, tires-batteries-accessories, paint, glass and wallpaper, music store, children's wear, heating and plumbing equipment, antique or secondhand store, stationery, women's accessories, camera shop, and photographic studio.

[6]A metropolitan wholesale-retail center has more than 500 wholesale establishments, and over $1 billion annually in both wholesale and retail sales.

Climate (3)

Climate in the coal- and lignite-bearing region of the Upper Missouri River basin is semiarid; weather conditions are influenced by location, relief, and proximity to the Rocky Mountains. The strippable deposits of coal and lignite lie between 43° and 49° north latitude; altitudes range from a high of about 5,800 feet above mean seal level near the School-Badger deposit in Converse County, Wyo., to a low of less than 2,000 feet at many of the deposits in North Dakota.

Precipitation is irregular, normally ranging between 12 and 16 inches annually; the greatest part falls as rain from April to September. Temperature also varies widely for different locations within the basin, but the normal range is from subfreezing in the winter to the low 70's in July. Tables B-1 through B-3 show norms (mean precipitation and temperatures) by climatological stations and divisions. Extreme temperatures range from subzero to over 100° F. Examples of the norms, means, and extremes, as recorded at Miles City, Mont., Bismarck and Williston, N. Dak., and Sheridan, Wyo., are shown in table B-4.

To minimize any impact on the mine or the environment from adverse weather, historical climatic data should be considered when planning a mine-drainage system. A daily log of weather at the minesite can be helpful in avoiding effects of adverse weather during the various phases of operation.

Current Land Use

Considered on the basis of either area or gross annual income, land in the Upper Missouri River basin is used predominantly for agriculture. Such agriculture is principally dry-land farming and ranching, producing mostly small grains and cattle. Cultivated lands generally are limited to the flood plains and benches of the larger valley, whereas the higher lands, ridges, and butte areas are utilized for grazing. Oil and gas production, utilizing a minimal amount of surface area, provides additional revenue that currently is second in magnitude only to that from agriculture. Land use by the petroleum and mining industries usually is of relatively short duration. After the mineral is extracted, the land is returned to agricultural or other permanent uses. During the period of oil and gas production, land adjacent to the wells and storage tanks or traversed by pipelines can be cultivated or used for pasture. The time frame of land use for strip mining is similar. A mine plant may occupy a few acres of land for 20 to 40 years, but the area then can be reclaimed and restored to its original or another use within 5 years or less.

One difference between reclaimed strip-mined land and undisturbed land is that improved wildlife habitat and recreational areas can be developed with only a small additional expenditure when land is being reclaimed; similar improvements on undisturbed land can be difficult to justify and finance. Currently, many coal and lignite mining companies are reclaiming mined land for use as wildlife habitat; pasture often is a secondary use.

AIR-QUALITY CONSIDERATIONS

Strip coal and lignite operations must meet the same emission and ambient air standards as all other industries. In addition, they must comply with safety requirements established by the Federal Coal Mine Health and Safety Act of 1969 (P.L. 91-173). Emission and ambient air standards for particulate generated at working places are generally met when dust is suppressed to comply with the limits set in the regulations authorized by P.L. 91-173. When an exception occurs, dust can be suppressed by spraying water upon the source; chemical sprays should be available, however, when the temperature is subfreezing.

Upper Missouri River basin coals and lignites have two inherent advantages over coal from many other regions: (1) Deposits now being mined do not contain enough foreign material to require cleaning with air or water so that no air separators or thermal dryers are used, and (2) the high moisture content of the fuel tends to suppress dust at the tipple so that allowable ambient and emission limits usually are not exceeded. The present trend in tipple construction is to enclose the coal or lignite from the time it is dumped into the tipple hopper until it is loaded on the train. Such a system prevents air contamination and protects the coal from weather.

Potential sources of dust in a semiarid climate are unvetegated spoil, working areas cleared of vegetation, and unsurfaced or graveled roads. Wind erosion and vehicular travel cause particulate to become airborne; unless it is controlled, any or all of the allowable limits can be exceeded. Suppression by sprinkling with water is the common practice for roads and other areas where vehicles travel; however, because it is now unlawful to pollute the ambient air, or to allow the concentration of respirable dust to exceed 2 milligrams per cubic meter of air at the working places, it may be necessary to suppress dust from unvegetated spoil and working areas. Dust from such sources can be suppressed or reduced in various ways. Probably the first method that comes to mind is use of a water spray or rotary irrigation system, which would not be difficult or expensive at operations producing ample mine water. Other means, such as applying chemicals or chiseling the surface, must be used where water is scarce. Regardless of the method used to prevent air pollution, the cost may be reduced when the exposed areas are kept to a minimum.

Fortunately, because most of the strippable coal and lignite deposits in the Upper Missouri River basin are not forested, air pollution problems from burning unmarketable timber and other organic waste are minor. Where a waste disposal problem exists and burning is prohibited, preplanning often would permit pushing such waste over the highwall after coal or lignite has been removed so that it will be buried beneath spoil from the next cut.

WATER-QUALITY CONSIDERATIONS

A successful coal or lignite strip mine requires water for its operation. Except for drinking water, an adequate supply normally can be obtained from the mine-produced ground water and surface runoff from the property. The term "ground water" in this report is used broadly to mean all water below the ground surface (15). Mine-produced ground water and that from precipitation (meteoric water) falling within the working area is commonly referred to as mine water. Surface runoff is water that has not passed below the land surface during its journey to the outlet of the drainage area considered.

Both mine water and surface runoff must be controlled in and near the working area. Diversion and pumping are the common methods of control. Mine water and the surface runoff resulting from meteoric water falling on the mine property often are stored for mine use. Watercourses across the mine property are generally diverted around the working area to protect the mine and the rights of others downstream. Such diversions, usually including much of the meteoric water from the mine property, must be done in a manner that will not impair water quality or quantity. However, meteoric water falling on the mine property could be prevented from entering a watercourse if necessary to avoid pollution or to retain such water for mine use. Figure 3 shows the average annual runoff in the Upper Missouri River basin. In normal years, such volume would not pose a problem, but the mine operator must consider exceptional years and establish controls for maximum runoff.

To determine whether diversion of a water course would cause pollution, water samples should be taken for subsequent comparisons along the original watercourse from the point of proposed diversion to the point of reentry before any such diversion is made. The period of sampling should be at least 1 year and at intervals frequent enough to determine seasonal and storm-caused variations. If possible, samples should be taken before and after each rainstorm or snow melt. In addition, streamflow and precipitation should be measured at each sample point and correlated with streamflow hydrographs and recorded precipitation extremes and normals from the closest stations. Analyses of the water samples should provide 10 determinations (1) used as parameters by the Environmental Protection Agency (EPA): (1) pH, (2) temperature, (3) dissolved oxygen (DO), (4) bacteria, (5) radioactivity, (6) turbidity, (7) color, (8) taste and odor, (9) solids, and (10) toxic substances. If the mine is within a State that requires additional parameters, such as biochemical oxygen demand (BOD), nitrogen and phosphorus (plant nutrients), oil, grease, scum, bottom deposits, pesticides, and specific conductance, these determinations also must be included.

A soil profile should be taken along the proposed diversion route, and analyses should be made to determine whether mineralization, organic matter, or other constituents of the soil would contaminate the diverted water beyond the specific limits set for the watercourse. Enough soil samples to represent the surface runoff area of the mine property should be taken and analyzed in the same manner. If potential pollutants are found along the diversion route and cannot be avoided by a change in route, a conduit should be used, or the diversion channel should be lined with an impervious material. Should diversion of the surface runoff on the mine property cause pollution, such water must be gathered, impounded, and treated before its release into a watercourse.

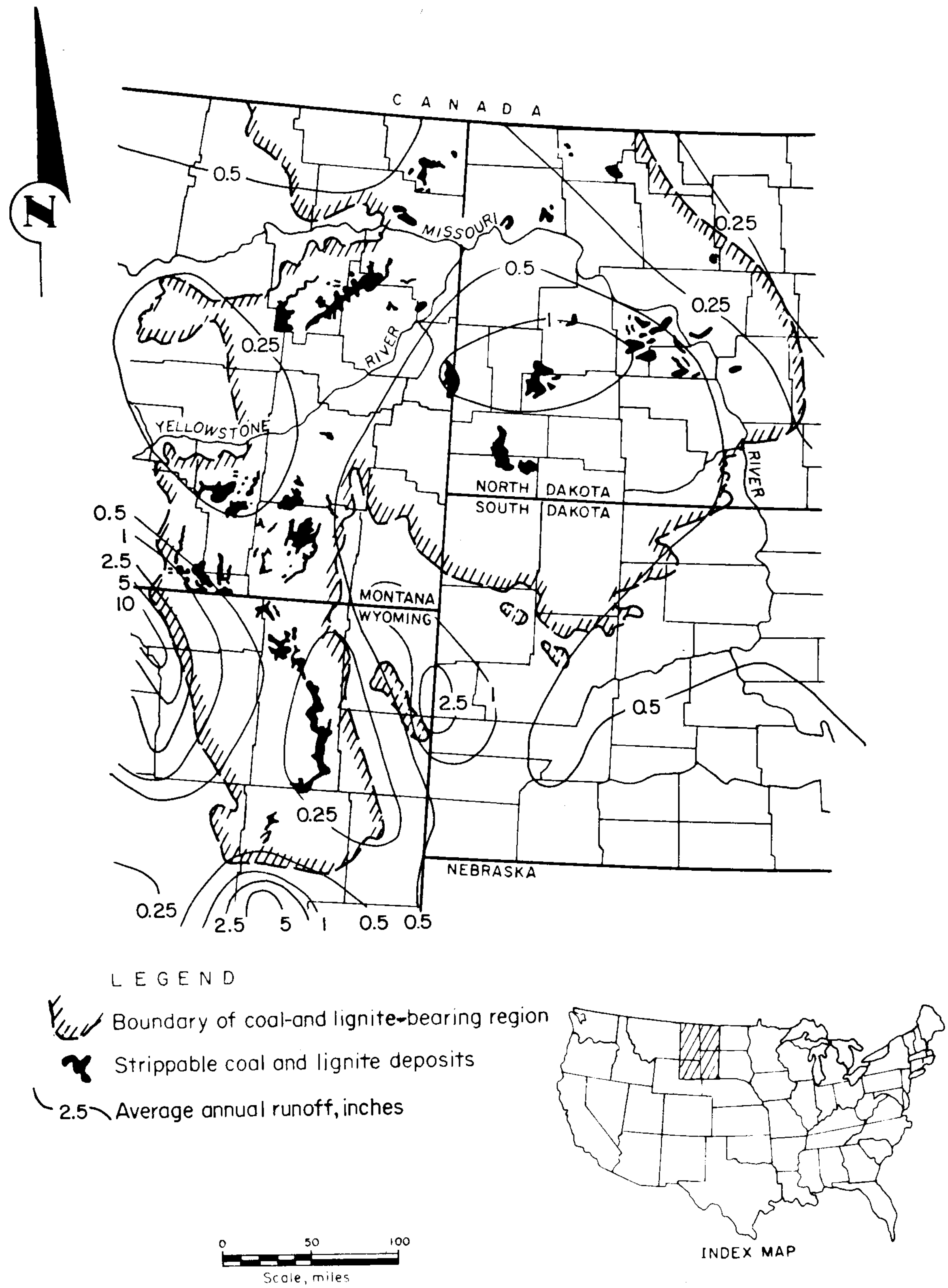

FIGURE 3. - Average annual runoff from the Upper Missouri River basin.

Determining what the quality of mine water will be before the mine becomes operational requires more than analyses of ground-water samples. Before the overburden and the coal or lignite are disturbed, and the mine floor exposed by the mining process, ground water is contained only in permeable formations; once mining has begun, both ground water and meteoric water are in contact with materials in all formations. Such formations often contain minerals that could contaminate the mine water. Two methods cited for estimating mine-water quality follow:

1. Samples of ground water taken from exploratory drill holes can be percolated intermittently through samples of overburden, coal or lignite, and floor material taken from the same drill holes. (Intermittent percolation allows chemical and physical changes to take place similar to what would occur naturally during mining.) Analyses of such water samples, made after they have percolated for a period similar to that during mining operations, should be fairly representative of the actual mine water.

2. A calculated or theoretical analysis could be obtained by a complete analysis of each horizon of overburden, coal or lignite, and mine floor. Then the chemical and physical reactions and interactions are calculated that could take place with continuous or intermittent contact with ground water and with ground water diluted with meteoric water.

Either of the described methods or any other technique that would disclose all possible contaminants should indicate the treatment required before use or disposal of the mine water. If treatment is required, the type of facilities may be determined from such data. The size of treatment facilities would depend upon the quantity of mine water to be treated, which can be estimated by test pumping the same exploratory holes used for quality samples. Meteoric water should be added in estimating the total quantity of mine water. Because the quantity of mine water is directly related to precipitation, it will fluctuate from year to year and with the seasons of the year. If mine water is to be stored, the reservoir capacity should be designed for maximum input and minimum outflow.

A vast amount of data on both quality and quantity of Upper Missouri River basin ground and surface water is available in published and unpublished reports of Federal and State agencies and others. A general knowledge of water composition for any particular area may be obtained from such reports. They should be used, however, only to supplement the data gathered at the specific site of operation because water from different sources often may be quite different in composition. For example, two adjoining wells differing only 10 feet in depth or two wells of the same depth but 200 feet apart will not necessarily yield the same quality of water (10).

The following general characteristics, however, apply to almost all of the surface and ground water that would be encountered in the operation of a coal or lignite strip mine in the Upper Missouri River basin:

1. Both surface and ground water are basic; pH commonly ranges between 7.1 and 8.0, and is occasionally as low as 6.8 or as high as 8.2.

2. Enough dissolved solids are present in such water to classify all of it as hard, but the degree of hardness varies greatly. Hardness can be carbonate, noncarbonate, or both. (Aquifers containing soft water generally are deeper than those exposed when coal or lignite is strip mined.)

3. Coal and lignite beds are often aquifers; however, because of organic matter within the beds, the water frequently is brown and has a disagreeable taste.

4. Surface water, especially in the Powder, Heart, and Grand Rivers, contains enough sediments to cause high turbidity. Erodible shales and sandstones over which the water flows are the sources of the sediments.

5. Because of high alkalinity, much of the water is classified only as "permissible," as defined by Wilcox's classification of irrigation water (18).

The presence of impurities, however, does not mean the water is polluted. All water, either raw or after treatment, contains impurities; only when specific limits are exceeded is water considered polluted. Water impurities can be classified according to six groups, not independent of each other: (1) Dissolved mineral matter, (2) dissolved gases, (3) turbidity and sediments, (4) color and organic matter, (5) taste and odor, and (6) microorganisms. For example, water-hardening bicarbonates are formed by the action of water containing dissolved carbon dioxide on such minerals as limestone, marble, magnesite, and dolomite; the growth of organic matter, promoted by nitrates, frequently imparts objectionable tastes and odors; and decayed organic matter reduces the dissolved oxygen and discolors the water. Actions and reactions within and between the groups are almost endless; many of these are described by Nordell (10).

Whether the water is consumed at the mine, used in an affiliated plant, or discharged into a watercourse, its use determines the treatment required. Water uses at the mine include suppression of dust, irrigation, coal washing, and impoundment in final cut. At a mine-mouth plant, water is used for cooling and other industrial purposes. If waste water is discharged into a stream, the ultimate use probably will be one of nine designated uses of a typical watercourse: (1) Public water supply--after complete treatment, (2) public water supply--after disinfection, (3) shellfish harvesting, (4) water-contact recreation, (5) fish propagation and wildlife, (6) agriculture water supply, (7) industrial water supply, (8) navigation, and (9) treated-waste transportation (1). Standards have been set by each State for each applicable use in accordance with the Federal Water Pollution Control Act of 1972.

In the Upper Missouri River basin, a great quantity of mine water is used to suppress dust on access and haul roads, and a lesser quantity for dust suppression at the working places. Some operations would not have enough mine water and surface runoff combined for dust suppression needs. For these operations, the supply must be supplemented by additional water, or the dust must be suppressed chemically. Other operations having a surplus of mine water over that required to suppress dust should store and use it to irrigate the reclaimed land. Irrigation at the time of planting and during dry periods until plants are established has improved survival rate on test plots in southwestern Wyoming (8). Surplus mine water may be used either for makeup water in a closed circuit at those mines where coal is washed to obtain a marketable product, or as industrial water in a mine-mouth plant. If all of the mine water cannot be consumed at the mine or mine plant, it usually must be disposed of in a watercourse.

Ordinarily, mine water used to suppress dust does not require treatment unless it is so corrosive that it would damage the equipment used for application, a condition that is very unlikely for water in the Upper Missouri River basin. Unless the sodium content is excessive, mine water used for irrigation would not require any treatment other than precipitation of solids in a storage reservoir. When sodium is applied to the soil in irrigation water, it reacts with certain clay minerals and causes unfavorable physical conditions. The soil deflocculates when wet and becomes sticky and impervious; upon drying, the soil forms large cracks and hard clods that not only make it difficult to work but restrict penetration by roots and thus limit the water supply of plants. Chemical changes also occur, resulting in the formation of carbonate (black) alkali. When irrigating is to be done with mine water high in sodium cations and carbonate anions, gypsum can be spread over the soil before planting. This application will precipitate the carbonate anion as calcium carbonate, allowing the soluble sodium sulfate to leach from the soil. Use of mine water for irrigation in the Upper Missouri River basin would be inadvisable if the total concentration (dissolved solids) and the percent sodium or the concentration of boron exceeded the limits for irrigation water. Permissible limits for total concentration, expressed in terms of electrical conductivity and percent sodium are shown in table 1; boron concentration limits appear in table 2. Mine water exceeding these limits would not benefit plant growth; moreover, treatment to render it permissible would be too expensive. Treatment of mine water used for washing coal normally would consist of removing only suspended inorganic solids by settling. However, if fine particles, which do not settle readily, are present, the addition of a coagulant may be required. Filtering after coagulating and settling generally would not be necessary. Treating the effluent from a coal-washing plant can be eliminated by using a closed circuit and adding mine water only for makeup.

TABLE 1. - Permissible limits for electrical conductivity and percent sodium in irrigation water

Rating	Water classification, grade	Electrical conductivity, micromhos per cm	Sodium,[1] percent
1	Excellent...........	<250	<20
2	Good.................	250 to 750	20 to 40
3	Permissible..........	750 to 2,000	40 to 60
4	Doubtful.............	2,000 to 3,000	60 to 80
5	Unsuitable...........	>3,000	>80

[1]Sodium percent is the percent of sodium cations of the total alkali and alkali earth cations.

Source: Wilcox (18, p. 27).

TABLE 2. - Permissible limits for boron in irrigation water

Rating	Water classification, grade	Sensitive crops, ppm	Semitolerant crops, ppm	Tolerant crops, ppm
1	Excellent......	<0.33	<0.67	<1.00
2	Good...........	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
3	Permissible....	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful.......	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable.....	>1.25	>2.50	>3.75

Source: Wilcox (18, p. 27).

At a mine-mouth plant, mine water could be used for cooling or boiler makeup; however, either use would require treatment by one or more of the following processes: (1) coagulation, settling, and/or filtration, (2) cold lime, (3) sodium cation exchange, (4) two-stage cold lime and sodium-cation exchange, (5) demineralization, (6) acidizing, (7) iron and manganese removal, and (8) the use of chlorination, copper salts, and polyphosphates. These processes are described by Nordell (10).

Water can be discharged into a watercourse only after a Government permit is obtained. The Federal Water Pollution Control Act of 1972, replacing the permit program under the River and Harbors Act of 1899, establishes a national system of permits that eventually will be under State authority to control discharges. Until authority is transferred to the individual State, EPA will issue such permits. Each permit limits pollution by specifying which substances and the quantity of each can be discharged and how cleanup requirements must be achieved. The new water law requires that any permit issued to an industry insure compliance with the best practicable control technology currently available for a particular industry, that it limit or prohibit toxic discharges, and that new facilities be required to install the best demonstrated control technology and standards that protect water quality. Interim authorization may be granted to States to operate the permit program before receiving final approval, if EPA determines that the State program will carry out the purpose of the law.

Concern has been expressed that pumping mine water to dewater the projected coal and lignite mines in the Upper Missouri River basin would pose serious problems regarding water quality. Some concern is justified, and precautions, as stated heretofore, must be taken to prevent degradation of water quality. Although a high coal and lignite use of 763 million tons annually by 1990 has been projected for the Powder River basin portion (12) of the Upper Missouri River basin, the area of coalbeds that would be open below the water table at any one time would be relatively small. The total known strippable reserves in the Upper Missouri River basin underlie an approximate area of only 550 square miles. This area is less than 0.5 percent of the lands underlain by coal or lignite and less than 1 percent of the total areas of the counties that contain strippable coal or lignite deposits. Mining these deposits at the projected high rate of production would open less than 20 square miles annually during the peak production years; only about

2 square miles would be open at any given time. It is reasonable to expect to encounter some water at almost all of the mines, but only a few mines will be excavated below the water table; these mines may have a surplus of water that cannot be consumed at the mine or mine-mouth plant. If necessary, surplus water can be treated to assure that the water discharged will not impair the quality of the receiving watercourse.

Ground water remaining after mining has been completed may be sufficient to fill the final cut. A lake thus formed could be used for recreation, or its water could be utilized for irrigating adjacent lands or for industrial purposes in a nearby plant. When a final cut is left open to create a lake, the supply of water must at all times be ample to maintain a surface level at least 2 feet above the exposed coal or lignite in the highwall. If such a water supply is not assured, the exposed coal must be sealed with earth. A minimum of 2 feet of earth is required.

ARCHEOLOGICAL SURVEY

Before a mining and reclamation plan is approved, it is mandatory in many States to submit a statement that an archeological survey will be conducted in advance of mining. Particulars vary for the different States; in general, however, and depending upon what is found, the artifacts are removed and preserved. Under certain circumstances an area may have to be set aside as a historical site.

A simple way for a mining company to meet such requirements is to contract its survey to a recognized archeological foundation and thus avoid any controversy after an area is mined. Archeological foundations are generally affiliated with universities.

MINED-LAND RECLAMATION

For at least the next 50 years, surface mining is expected to be the principal method of producing coal and lignite in the Upper Missouri River basin. Land from which coal or lignite is recovered no longer can be left in an as-mined condition; it must be reclaimed, and the reclamation program should be planned simultaneously with mining. A plan must be submitted and approved by the State or Federal Government before a permit to mine can be issued. Although called a reclamation plan, it is a mining plan that incorporates reclamation of the mined land and implies that the cost of reclamation must be considered a part of the mining cost borne by the coal or lignite consumer. Therefore, cost reduction can be achieved only by reducing the total production cost.

Techniques for removing overburden and coal have been improved continuously since the days of horse- or mule-drawn scrapers. Almost every innovation and increase in equipment size has reduced mining costs, permitting thinner and deeper beds to be mined profitably. However, the use of large bucket-wheel excavators, coal haulers, draglines, and shovels has raised the subsequent reclamation cost for grading spoil to a rolling topography or flat surface, because as the pit width increases, both the quantity of spoil and the distance it must be moved increase. Figure 4 illustrates graphically that increases in mean haul distances are proportional to increases in pit width; figure 5 shows that the quantity of spoil also is increased as the pit width is increased.[7]

Because reclamation costs are a part of the cost of mining and because improvements in mined-land reclamation have lagged in comparison with improvements in mining, the greatest potential for further reducing production cost is betterment of mined-land reclamation. It must be done, however, by developing lower cost operational combinations, which require planning. Planning data should include all possible information about the surface, subsurface, and climate. Surface data should include topography, type of soil, vegetation, land use before and after mining, and surface-water quality and quantity. Much of the essential subsurface data can be provided from detailed logs and samples taken at each development drill hole from the surface to below the lowest coal or lignite seam to be mined. An awareness of the details of local geological and climatic conditions is also necessary. Depending upon many factors, mining and mined-land reclamation costs are variable. Table C-1 lists some of these factors and indicates how a change in one can affect others.

Land Use

Land use after mining should be determined before mining is begun, and it need not be the same use that preceded mining. Subsequent use generally will be determined by the owner and/or lessee with the approval of the State and may be one or a combination of the following: Cultivated farm land, forest, pasture, recreation area, fish and wildlife habitat, and building or industrial sites. Life expectancy for strip mines is usually 20 years or more, and restricting the use of an entire coalfield to mining only would be costly. To help defray such cost, the area yet to be mined and that which has been completely reclaimed can be used for other purposes; however, use of land within the active mine area for anything other than mining is an unsafe practice and should be avoided. Animals and unauthorized people must be prevented from entering the active mine area, including any spoil area that is undergoing reclamation. Wildlife is difficult to restrict, however, and browsing can be detrimental to establishing plant growth on the graded spoil. Unless the vegetation on reclaimed spoil is to be annual farm crops, access should be denied until the plants are well established. The period required for mining and reclaiming the mined land, including establishing plants, averages about 5 years.

Direction of Mining

Topography of the field and the pitch of the coal or lignite seam generally determine the direction of mining, an important factor. Water

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[7]Although figures 4 and 5 are illustrative of all variations in surface slope, coal- or lignite-seam pitch, and spoil angle of repose, the curves as drawn are specifically for a level surface and flat coal or lignite seam, and for an angle of repose for spoil whose tangent is 0.8.

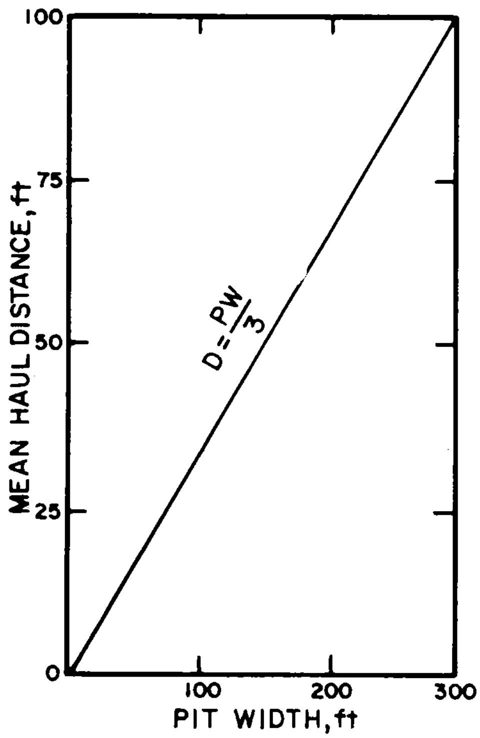

FIGURE 4. - Effect of pit width on spoil haul.

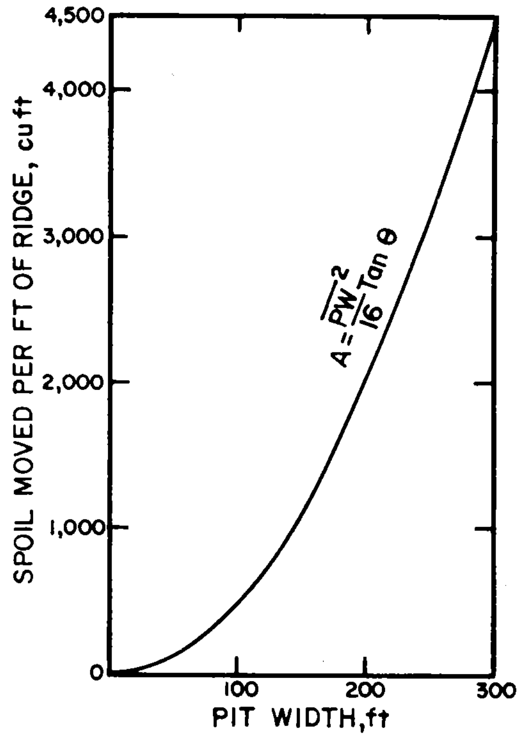

FIGURE 5. - Effect of pit width on quantity of spoil moved.

NOTE.–

D = mean distance spoil is hauled from ridge to valley.

PW = pit width.

A = end area of spoil moved from ridge to valley.

Tan θ = tangent of the angle of repose for spoil.

Formulas shown on figures are for leveling spoil; they apply only where both the original ground and coal or lignite seam are level.

diversion routes, haul and access routes, reservoir locations, powerline locations, mine development, and the sequence of mined-land reclamation all depend on the direction of mining.

Water Control

Water control is necessary for preventing flooding the working areas, for eliminating erosion and pollution, for mine and/or mine-plant use, and for the safety of miners and the public. Methods of control have already been described. Water storage is part of water control; reservoirs that are properly positioned, sized, and constructed can prevent flooding the mine and downstream areas and polluting watercourses. The pollution factor may require treating water impounded in a reservoir. Reservoirs built for flood protection can be designed to retain a conservation pool for recreation, but if so used, they should be away from the working area so that recreationists will not be endangered. Final cuts often are used as reservoirs, reducing reclamation cost and adding recreational and aesthetic value to reclaimed land. Land on which a reservoir has been constructed solely for a mining operation often must be returned to its original use when mining is terminated. By preplanning, the reservoir can be so located that water can be diverted to a final cut, minimizing the reclamation cost.

Roads

The next step, after establishing the direction of mining and the pattern for water diversion, is to select routes for roads (haul, access, and fire), railroads, and electric transmission lines. Because haul roads and railroads are expected to last at least the life of the mine, cut-and-fill slopes should be vegetated to prevent erosion and to increase the aesthetic value. Topsoil, when available from the roadway and box cut, should be conserved for use on such slopes. Other overburden from the box cut should be used as borrow for both haul roads and railroads to reduce the area of undisturbed land occupied by spoil. Access roads are constantly relocated until mining is terminated; then they usually are obliterated. Thus, the land access roads occupy is reclaimed as the spoil is reclaimed. Where fire lanes are required on the reclaimed spoil, cut-and-fill slopes should be minimal; however, if they exist, they should be covered with topsoil and vegetated.

Electric-Power Transmission

Currently, it is necessary to beautify or screen and camouflage electric-power transmission lines and towers when they can be observed from a highway or inhabited area between the mainline substation and the mine area. This assumption is based upon the thesis that lines and poles within the mine area are no more detrimental to scenery than any other segment of the operation and that they are removed when mining is terminated. Details of how electric-power transmission lines may be beautified can be found in a recent publication (17).

Refuse Disposal

Disposal of refuse must be done in a manner that will not pollute air or water and will not contaminate or blight the land with litter. All refuse could be buried beneath or within the spoil, but for some items other disposal methods should be considered. A large mine and its associated mine-mouth plants will generate numerous waste items that can be recycled, reused, or sold. Waste paper and waste-paper products have some salvage value when properly separated. Unmarketable timber and other heavy vegetation that must be cleared from the land before mining could be shredded and composted, then used on the reclaimed spoil. Generally, land clearing will amount to removing 10 or 20 trees per acre, most of which could be transplanted with a front-end loader. Such reclamation may be done when the front-end loader is not required for its assigned task; thus, this part of land reclamation can be accomplished with little additional cost. Other wastes, such as glass, metal, petroleum products, and plastics could be separated and shipped to a secondary-recovery plant appropriate for each waste. Where leonardite is associated with lignite, such leonardite can be recovered for use and/or sale as a soil conditioner. Large amounts of dirty coal or lignite, bone, toxic materials, and preparation plant refuse can be buried beneath or within the spoil. However, small bits and pieces of coal and lignite, when spread on the surface in amounts up to 1 ton per acre, can benefit the calcareous soil of the Upper Missouri River basin (4). Fly and bottom ash generated at a mine-mouth plant is a waste product that can be marketed for various uses, including soil conditioning; however, the supply is expected to exceed the demand in the Upper Missouri River basin. Therefore, planning is necessary for disposal of at least a part of the total amount that will be generated. Such disposal must be accomplished in a way that prevents environmental contamination. Dumping the ash in a pit bottom and covering it with spoil will prevent air pollution, but some environmentalists have expressed concern that certain trace minerals contained in the ash might contaminate the ground water if the pit bottom is below the water table. To date, there is no evidence to substantiate this concept.

Requirements

The principal requirements of Federal and many State regulations for strip-mined land reclamation are conserving and replacing topsoil, grading spoil to specifications for a designated land use, removing or burying all debris and toxic refuse, vegetating the spoil, and avoiding pollution of air and water. Reclamation requirements vary depending upon the administrative agency, land use, location, and climate. To minimize any confusion or conflict between regulations of State and Federal agencies, operators may safely conclude that the strongest regulations usually are the ones enforced.

During the past decade, each State in the Upper Missouri River basin has enacted laws that make mandatory the reclamation of land disturbed by surface mining.

Reclamation rules and regulations are guidelines for planning and executing a reclamation program; those pertaining to strip mining of coal are the basis of the techniques suggested in this study. Some of the coal-mine-reclamation techniques discussed, however, could be adapted for spoil generated by other surface-mining operations.

Minimum grading requirements in the Upper Missouri River basin are that spoil must be graded to rolling topography with slopes of 20 percent or less that are traversible by farm machinery.

An axion, "the better the soil the better the crop," applies to spoil as well as to land that has not been strip-mined. To improve the surface of spoil, Upper Missouri River basin States and the Federal Government now require that topsoil be removed before mining and then replaced after the spoil has been graded. Selective stripping of overburden other than topsoil is required when topsoil is of insufficient thickness to warrant removal, or when certain strata of the overburden will not support vegetation and must be buried. Although such practice increases the cost of overburden removal, it decreases the chance of unsatisfactory vegetation of the reclaimed spoil.

Equipment

Not all equipment is adaptable to selective overburden removal. Prime movers of overburden in use include one or a combination of the following: Bucket-wheel excavator, dragline, bulldozer, front-end loader, scraper, shovel, shovel and front-end loader or truck, and, according to C. W. Livingston (7), explosives. Scrapers, the most adaptable for removal and deposition of topsoil or a formation selected for its soil characteristics, are not suitable for removing boulders or blasted rock. Except for removing topsoil, the use of scrapers as prime movers at large operations is limited. The same holds for bulldozers and front-end loaders. Each has its place, but bucket-wheel excavators, draglines, or shovels can strip a coal or lignite seam for a fraction of the cost using scrapers, bulldozers, or front-end loaders.

Although shovels and trucks or front-end loaders have not been commonly used for removing overburden at coal or lignite strip mines, such a method is used at the Belle Ayr mine in Campbell County, Wyo. The method, called quarry-type mining by the operator, is included here because it may become the dominant method used to mine the 60- to 80-foot-thick coalbeds in the Powder River basin.

To perform this type of surface mining, the mine area was first divided into 40-acre tracts. The initial or box cut was made on two adjacent tracts that were away from the outcrop. Overburden from the box cut was removed with a shovel and trucks and spoiled on land underlain with coal that will be mined later. Coal recovery began when overburden removal from the first cut was completed; box-cut spoil was temporarily vegetated. By the time overburden removal from the third tract began, enough of the 70-foot-thick coalbed had been mined from the first tract to allow spoiling in the first tract. Overburden from successive tracts is spoiled in the same manner. Any parting encountered during mining is buried. When mining is completed, 80 acres of spoil will have been handled twice, but land that did not produce coal will remain undisturbed.

Preliminary tests at the Belle Ayr mine indicate a condition that seems favorable to mining and reclaiming the mined land. All of the overburden is soil material, but that near the surface has a greater alkaline content than the remainder of the overburden. Therefore, unless further testing disproves initial results, the topsoil can be mixed with the remaining overburden to provide a better growing media than the original topsoil.

Overburden spoiled in the mined-out pit is graded to the approximate relief of the land before it was mined. When mining terminates, sometime in the 21st century, the mined area will have an appearance similar to that before mining was begun except that it will be about 70 feet lower in elevation. (Swell of spoil is almost nil.)

Experimental planting on spoil is being done to determine the best procedure. Various future uses of reclaimed land are being considered, including water recreation, because it is believed that the surface runoff and water from the coal seams will form a lake in the lower portion of the lowered land.

Using shovel or front-end loaders and truck for overburden removal offers advantages for reclaiming the spoil. If necessary, topsoil can be removed and spread upon graded spoil with only a slight increase in cost over that of removing it with the remainder of the overburden. Also, if necessary, a selected formation within the overburden can be removed and spread upon the spoil surface. Spoil can be dumped from trucks so that only a small amount of grading is necessary. For mining thinner coal seams, such a mining method would not be as economical as the overcast technique commonly used.

When explosives are used to remove overburden from a seam of coal or lignite, some portion of the overburden, up to 40 percent, will remain on the coal or lignite. This portion must be removed with mechanized equipment, such as a bucket-wheel excavator, cable excavator, dragline, or shovel. The equipment most likely to be used normally deposits spoil in ridges. Therefore, methods of grading spoil removed by explosives would be similar to those currently used for grading spoil ridges.

Grading

Present methods of grading spoil are costly and, coupled with all other costs of protecting the environment, will lead to higher prices for strip-mined coal and lignite. Improved grading methods thus would tend to minimize price increase. A better method devised for one operation, however, would not necessarily be the best method for all operations. Various methods should be examined to determine which one is the most economical for a particular operation. A good approach is to prepare a cost estimate for all schemes that could possibly be adapted to the operation, and then compare the individual estimates for both present and long-range cost.

Topsoil covering the area to be occupied by the first few cuts must be stockpiled. When mining has progressed sufficiently, topsoil can be removed from the highwall side of the cut and be placed directly on graded spoil. This procedure both reduces the cost of handling the topsoil and prevents killing many beneficial soil organisms that would die in a stockpile.

Scrapers are commonly used to remove topsoil from the highwall side of the pit and to spread it on graded spoil. Because haul distances around the ends of the pit can become excessive, pit crossings can be constructed to minimize the distance; however, each one constructed means additional cost. The lesser the grade of the pit crossing, the greater the construction cost; steep grades, however, increase the cost of equipment operation.

Criteria for Estimating Topsoil Removal

Although minimizing the cost of moving topsoil depends upon many variables, an estimate can be obtained from using the following four: (1) Length of haul, (2) number of pit crossings, (3) optimum grade for the equipment, and (4) number of equipment units. One method of estimating such a cost follows:

1. Select scraper and bulldozer sizes.

2. Assume a maximum haul distance.

3. Calculate the number of equipment units required to move the quantity of topsoil necessary to keep up with the progress of mining.

4. Establish a construction-cost curve for pit crossings of various grades.

5. Construct a cost curve for hauling topsoil over various grades.

6. Using the two curves, determine the optimum grade of a pit crossing.

7. Estimate the construction cost of a pit crossing of optimum grade using data represented by step 4.

8. Estimate total cost for loading, hauling, and spreading all topsoil within the area of the maximum haul (step 2), including pit-crossing construction and maintenance cost.

9. Estimate cost per cubic yard of moving topsoil.

10. Repeat steps 2, 3, 7, 8, and 9, using various haul distances, but less than the maximum, until the least cost is estimated.

Alternatives in Equipment Selections

Scrapers

Opening a new mine or a new area of an existing mine requires stockpiling topsoil from the area to be occupied by the box-cut spoil and the first few cuts. The haul distance is minimized by removing, hauling, and depositing topsoil normal to the centerline of the cuts, forming a large windrow of topsoil just beyond the area to be occupied by the box-cut spoil. Scrapers are best suited for this job. Topsoil could be removed from a wide area to reduce the number of pit crossings to be constructed. However, such practice would expose excess land susceptible to wind and water erosion, creating a great potential for air and water pollution. Such a procedure also would tend to destroy soil organisms because of the increased depth of topsoil in the stockpile and the length of time it is stored. For these reasons, plus the adverse aesthetic effects, some States have limited the area exposed or denuded at any one time to as little as two ridges behind the pit opening. A good rule to follow would be to remove and stockpile topsoil only from the width along the proposed pit sites that is sufficient to accommodate the orderly progress of mining and land reclamation. An additional disadvantage of removing topsoil too far in advance of overburden removal is that during the winter months exposed overburden freezes to a greater depth, thus making excavation more difficult and costly.

Scrapers are the best equipment for moving and stockpiling the initial topsoil where the latter is of minimal thickness and where dilution and contamination with other materials are to be controlled. Other types of equipment may be used where a greater thickness of topsoil is present and dilution and contamination from surface formations are not as important.

All methods should be costed for the particular mine to determine which is most economical. As a "rule-of-thumb" guide in strip mining coal, haul distances generally are too long for bulldozers or front-end loaders and too short for trucks.

An alternative to using scrapers for removing and stockpiling topsoil from the area to be occupied by the box-cut spoil and the first few cuts is to use the same dragline or shovel that is to be employed for overburden removal. For example, a dragline with a dumping radius of 225 feet could remove a strip of topsoil nearly 900 feet wide and stockpile it along one side by making only one trip each way over the strip. On the trip down, it could remove topsoil along a width of about 450 feet, depositing it atop the topsoil yet to be removed. On the return it would rehandle the topsoil overcast on the trip down plus another width of 450 feet, depositing all of the topsoil along one side of the cleared area. Topsoil could be stockpiled similarly by a shovel; however, because a shovel cannot dig as far away from itself as a dragline, the width of the topsoil removed in making a trip the length of the strip would be greatly reduced. Consequently, a shovel would require more trips and more rehandling of the topsoil than would a dragline. A bulldozer should work with either a dragline or a shovel to clean up bucket spillage and to windrow areas of thin topsoil.

After mining has progressed across the area from which the initial topsoil is removed, the topsoil still in place between the highwall and the limits of mining can be removed from the undisturbed land and placed directly on graded spoil, thus eliminating stockpiling, rehandling, and destruction of soil organisms. Such a method means a longer haul for placing the stockpiled topsoil; however, because such topsoil will remain in the stockpile until mining is completed, the topsoil then would be placed on graded spoil from the last cuts. Either scrapers or trucks loaded by a shovel or front-end loader would be necessary to remove and place the stockpile topsoil because the haul could be lengthy. Scrapers are not recommended for hauls exceeding 1 mile (9).

Mines that have been worked without salvaging topsoil and now find salvage necessary can remove and place topsoil directly on spoil previously graded, thus eliminating stockpiling. Spoil from the last few cuts cannot be covered, however, unless adjoining undisturbed land has sufficient topsoil to allow partial robbing. Removal of topsoil by scraper should be restricted to areas reasonably free of large rocks, boulders, or stumps. Although most large rubber-tired scrapers can handle solid pieces of material up to 24 inches, such material may damage the scraper and result in high maintenance costs. Large boulders may be encountered in topsoil within a glaciated area; large rocks should be expected occasionally in the unglaciated area of the Upper Missouri River basin. Stumps will be found in forested areas, but should not be troublesome if such areas are properly cleared. All methods for removing and replacing topsoil should be analyzed to determine the lowest cost technique for a particular operation.

Large dual-engine scrapers, now being used for grading spoil, do not replace bulldozers but are used to form a rolling surface after a bulldozer strikes the peaks and ridges to a sufficient width for the scrapers to travel. An experienced operator can load the scraper near the ridge top, deposit material in the valley bottom, and move spoil at a faster rate than can be accomplished with a bulldozer. The spoil, however, must be relatively free of large rocks and boulders, a condition often found in the Upper Missouri River basin where this method is now being used.

If topsoil is meager or lacking, overburden horizons should be analyzed to determine which one has the greatest potential for plant growth. Then, stripping should be done to place the selected material atop the graded spoil.

Bucket-Wheel Excavators

Bucket-wheel excavators remove such materials as earth, clay, sand, and soft shale efficiently, but as the hardness of the material increases, the cost of maintenance also goes up and efficiency declines. The degrees of material hardness that requires using other methods of excavation is a matter of operator judgment. Rock can be excavated by a bucket-wheel excavator if it shows good fragmentation when blasted. However, excavation of material containing stumps, large roots, or boulders too large for the bucket should be avoided.

Bucket-wheel excavators could be used as a means of reducing mined-land reclamation costs at those mines in the Upper Missouri River basin having overburden consisting of soft materials. The greatest potential for low-cost, mined-land reclamation would be at those deposits southwest of the glaciated area shown in figure 2. A bucket-wheel excavator was tried at the Glenharold mine near Stanton, N. Dak., but later was replaced with a dragline (11).

A bucket-wheel excavator could remove all of the overburden from coal or lignite, or it could be used in tandem with a dragline or shovel, as shown in figure 6, to remove only near-surface material. Whether a bucket-wheel excavator is used for removing all or only a part of the overburden, it can be operated so that either topsoil or a selected formation of the overburden will be atop the graded spoil. Furthermore, if a telescoping discharge conveyor is used, spoil can be cast and placed relatively free of peaks and ridges, thus minimizing grading.

Where topsoil is thick enough to be removed directly by the wheel, a separate pass is made removing only the topsoil. Dimensions of the excavation would be the depth of the topsoil, the width of the pit at the surface, and the length a predetermined distance along the cut--probably the distance that can be completely excavated in one shift. Excavated topsoil would be moved across the pit by the bucket-wheel excavator and placed atop graded spoil from a previous cut. After topsoil is excavated the desired distance, the machine would backtrack to the starting point and begin excavating the remaining overburden and casting it into the adjoining cut.

When topsoil is too thin to form a bank for the wheel to work against, it should be dozed or bladed into a windrow beyond the line of highwall for that cut. Then, after the bucket-wheel excavator completes its cut to top of rock, coal, or lignite, the topsoil can be pushed over the highwall against the toe of the cut to be picked up and placed atop graded spoil by the bucket-wheel excavator. Should it be necessary to top the spoil from a selected horizon within the overburden, all overburden above the selected horizons first would be excavated a predetermined distance. The machine then backtracks, excavating the selected horizons, and deposits this material on spoil from the previous cut. After returning to the starting point, the bucket-wheel excavator again proceeds forward, excavating the remaining overburden.

If the bucket-wheel excavator is not equipped with a telescoping conveyor, spoil may be manipulated from a single pit width in two or more ridges rather than in a single ridge. Such emplacement reduces the cost of grading spoil to a rolling topography or a smooth surface by lessening both the quantity of spoil to be moved and the distance it must be moved in the grading operation.

A large capital investment is required for a bucket-wheel excavator, an outlay that might not be justified for moving only topsoil. The investment could be justified, however, if use of the bucket-wheel excavator included excavating all or part of the overburden. Then the prorated cost for removing, hauling, and placing topsoil, coupled with a reduced grading cost, should be less than that using bulldozers for grading and scrapers for handling the topsoil.

Draglines

Draglines are the principal prime movers of overburden at coal and strip mines currently operating in the Upper Missouri River basin. One reason is that a dragline, in a single pass, can move overburden a considerable

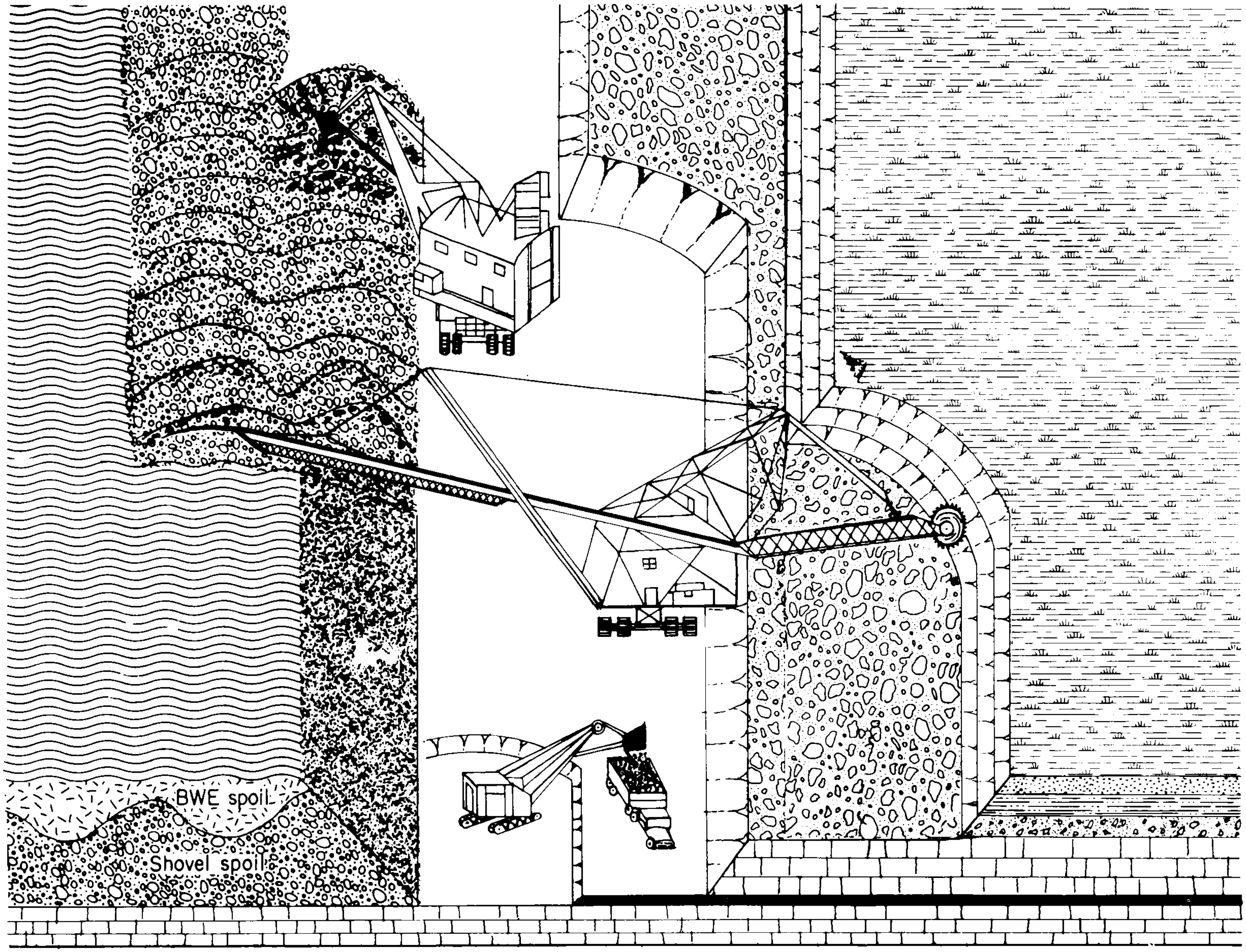

FIGURE 6. - Tandem stripping with bucket-wheel excavator and shovel.

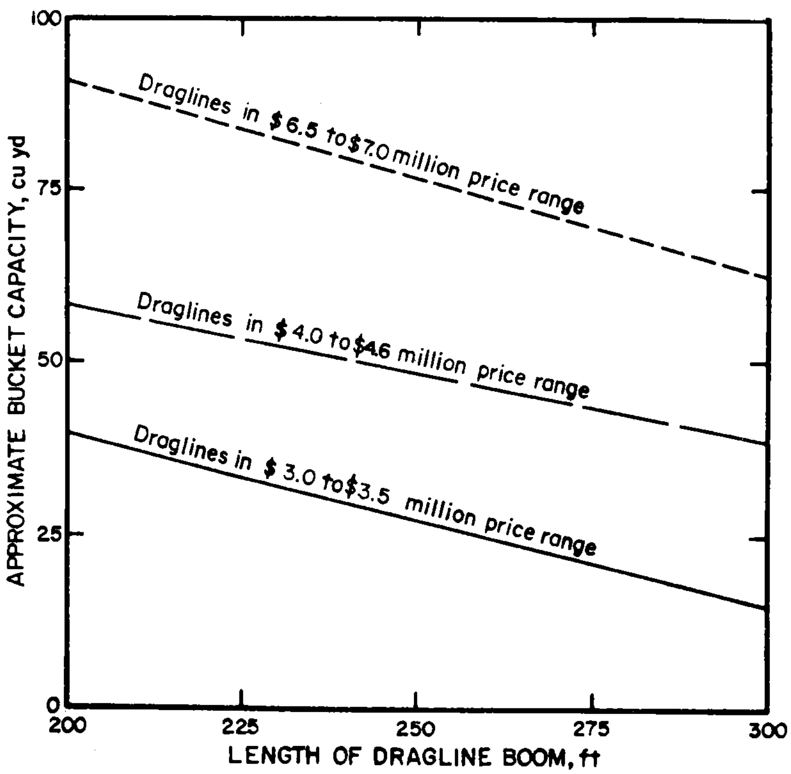

FIGURE 7. - Relationship of dragline-bucket capacities to length of boom.

distance for a small cost. However, the distance is dependent upon length of boom or dumping radius. For a given machine, increasing the boom length decreases the quantity of overburden that can be moved with each pass. Boom lengths versus bucket capacities are shown on figure 7 for draglines in three 1973 price ranges. A long boom is essential in thick overburden and wide pits in order to reduce the quantity of overburden that must be rehandled.

Many factors--depth of overburden, width of pit, angle of highwall, angle of repose, etc.--determine the distance that overburden must be moved to allow removal of the coal or lignite. A dragline generally is capable of digging to a depth greater than its ability to deposit spoil and prevent it from rolling back into the cut. When such conditions present a problem, a second or rehandle dragline normally is used on the spoil to move part of the overburden twice. The stripping dragline on the highwall deposits overburden into the cut; part of this spoil is picked up by the rehandle dragline and moved farther away. The rehandle dragline can reduce costs by placing the spoil so that additional grading is virtually eliminated. Also, with two machines, topsoil can be removed from the highwall side of the cut and placed within the cut by the stripping dragline; then topsoil can be removed from the cut and spread upon the graded spoil by the rehandle dragline. Topsoil must be carefully placed in and removed from the cut to minimize dilution or contamination by materials from other horizons. Figure 8 depicts how two draglines could work in tandem, moving both topsoil and overburden, and minimizing haul distance and cost.

Under favorable conditions, one dragline can strip the overburden from a single seam of coal or lignite, cast the spoil so that the surface meets grading specifications, and spread topsoil upon the graded spoil. The following hypothetical data illustrate such favorable conditions:

Variables	Dimensions
Thickness of overburden........feet..	Not to exceed 60
Thickness of coal or lignite....do...	Not to exceed 30
Slope of highwall...................	1/2 to 1
Slope of spoil......................	5 to 4
Width of pit..................feet..	100
Dumping radius of dragline......do...	275
Pitch of seam and slope of ground....	Nearly level
Swell factor........................	1.25

Although any significant change in the conditions stated could eliminate the possibility of a single-machine operation, other combinations of conditions are possible. An increase of one dimension, however, normally would require a corresponding decrease in another.

A longer boom is required for a dragline capable of performing stripping, grading, and placing topsoil than for one that, under the same conditions, would only cast spoil in ridges. Enough additional length is necessary to increase the dumping radius to approximately three-quarters of the distance across the pit. A longer boom decreases bucket capacity, which would reduce the quantity of overburden stripped during a given period. Such a reduction would range from approximately 20 percent for large machines to more than 50 percent on smaller ones. Additional reduction in the quantity of overburden removed during a given period would result from the extra time needed for placing (not casting) that quantity of spoil (about 10 percent) required to grade the spoil surface and for removing and spreading topsoil. One dragline capable of stripping and grading the spoil would not eliminate the use of grading equipment. A dozer or a grader would be needed occasionally for catchup work, but this would not compact the spoil as much as it would be compacted if a bulldozer did all of the grading. Whether or not such a

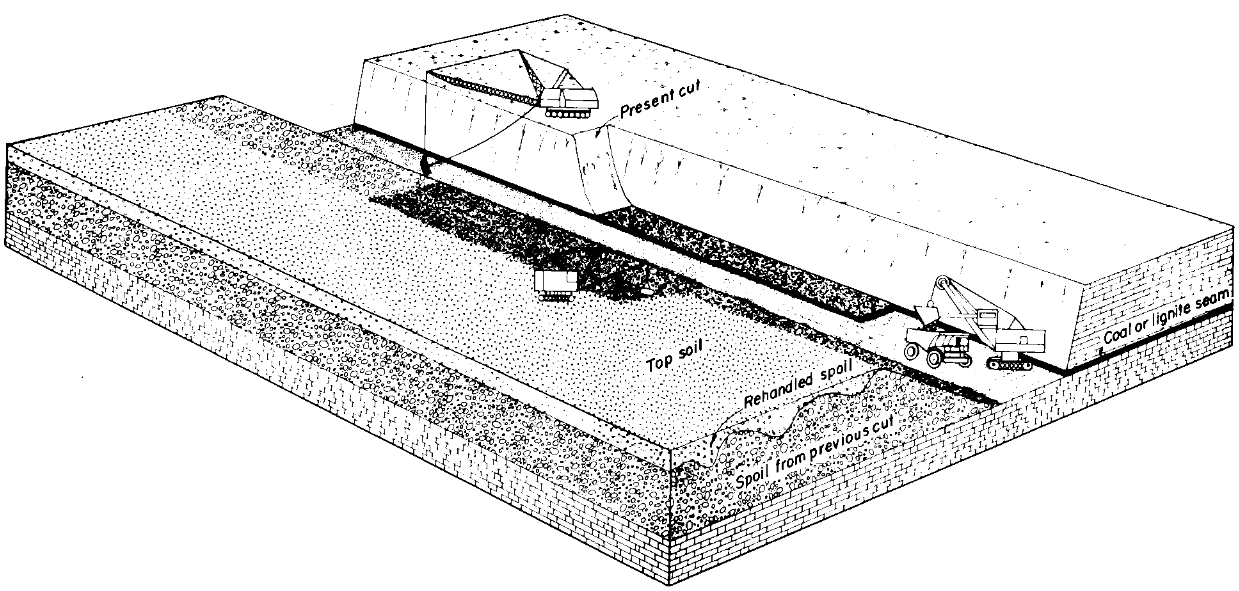

FIGURE 8. - Two draglines operate jointly, one stripping and one rehandling the spoil.

method can reduce costs of grading spoil and salvaging topsoil, where the latter is thick enough to salvage, would require careful study for each operation.

Mining more than one seam of coal or lignite requires stripping the overburden from the top seam, followed by the alternate removal of coal or lignite seams and partings or intervals between, until all recoverable coal or lignite has been mined. Stripping the overburden from the top seam could be accomplished with either a dragline or shovel, but if topsoil is to be cast across the pit, a dragline should be used. A second or rehandle dragline atop the spoil would be used to remove partings or intervals between the seams and to grade the spoil. Often, however, partings and intervals between seams are less likely to support plant growth than near-surface formations in the overburden. When this condition exists, one method of disposing of the undesirable material is to use a sequence of mining that places the spoiled overburden far enough away from the toe of the bottom coal or lignite seam to allow the parting and/or interval material to be cast into the pit bottom or on the slope of the spoil so it will be covered by spoiled overburden from the present or next cut. Part of the overburden spoiled by the stripping shovel or dragline may require rehandling to allow sufficient space for the spoiled parting or interval material to be placed below the surface. The rehandle dragline also can be used for spreading topsoil on the graded surface if such topsoil is cast across the pit.

Mining multiple coal or lignite seams in this manner would require the second dragline to shuttle back and forth atop the spoil to remove material between the seams. Such maneuvers would increase spoil compaction considerably over that incurred in a one- or two-seam operation requiring the second dragline to pass only once. Unless the pattern for mining the coal or lignite deposit is a complete or nearly complete circuit (around a hill or valley returning to or near the starting point), downtime for both draglines will result when the end of the strip is reached. This costly delay arises because removal of overburden from the next strip cannot begin until all coal or lignite is removed from the present strip.

Conveyors

A dragline working in tandem with a conveyor system is another possible method, but of limited application, for grading spoil simultaneous with mining coal or lignite. All overburden and topsoil would be removed by the dragline; all but the topsoil and that quantity of selected overburden needed to form the final grade of the spoil would be cast to the spoil bank by the dragline. Topsoil and selected overburden would be transported to the spoil bank by conveyor. The conveyor system would consist of a self-propelled hopper, feeder, and inclined conveyor extending to the top of the spoil where it would discharge onto a self-propelled horizontal conveyor capable of swinging 180°.

A conveyor system for grading spoil and placing topsoil is limited to handling overburden of relatively uniform thickness in which at least one horizon, free of large rocks or blocky material, can be selectively excavated to form the graded surface of the spoil. The system would be best suited to a situation where the top of the graded spoil did not exceed the elevation of the exposed coal or lignite seam by more than 60 feet. Overburden thickness should not vary more than 30 feet because of the fixed length of the inclined conveyor. The system need not be designed to handle particles in excess of 6 inches in the largest diameter because large rocks and boulders should not be placed on the surface of the spoil. If the overburden contains much oversize material, an alternate method should be used. A conveyor system should be suitable for thick coal seams, such as the Dietz in Big Horn County, Mont., the Roland-Smith in Campbell County, Wyo., or the Healy in Johnson County, Wyo. Depending upon the size and type of spoil material to be handled by the conveyor, the maximum angle at which the inclined conveyor can operate ranges from 16° to 22°. Therefore, placing spoil higher than 60 feet above the elevation of the exposed coal or lignite would require conveyor spans of excessive lengths, which would be both costly to construct and maintain and difficult to operate.

A conveyor system could be used in lieu of a rehandle dragline, but it is not recommended because of the excessive length required for each span. For example, overburden 150 feet thick could be removed from a coal or lignite seam 20 feet thick, but the pit width and each conveyor span, two horizontal and one inclined, could be as much as 300 feet long. Such a conveyor system would have to be designed for handling blocky material, large rocks, and boulders, as well as the topsoil and finer material for grading the spoil surface. Any given operation should be costed for both a conveyor system and a rehandle dragline before a definite decision is made. The main advantage to using a conveyor system for grading spoil and placing topsoil would be in reducing spoil compaction; only that area occupied by the traveling supports of the horizontal conveyor atop the spoil would be compacted. This small area could be plowed if necessary.

Stripping Shovels

Where a stripping shovel is the prime mover of overburden, additional equipment is necessary if topsoil is to be salvaged and spread on the graded spoil. Grading could be done with bulldozers; topsoil could be removed and spread with scrapers, possibly an economical method where a rehandle dragline is not required. If a rehandle dragline is necessary, the stripping shovel can make two passes to uncover the coal or lignite. On the first pass, the shovel removes only topsoil and casts it into the pit bottom where it is picked up by the rehandle dragline and spread upon graded spoil. On its second pass, the shovel removes the remaining overburden casting it into the pit. Then the dragline atop the spoil rehandles the necessary quantity of the cast overburden, using it to grade the spoil surface. Such a method should be used only where topsoil is thick enough to fill or nearly fill the shovel bucket on each swing and where dilution from subsurface material will not be harmful to vegetation. Disadvantages include (1) walking the shovel out and into the pit at the end of each cut, (2) compacting the spoil to a greater degree by the extra pass the rehandle dragline must make to retrieve and spread topsoil, and (3) using a large and costly shovel to remove the small quantity of topsoil. A study is recommended for each operation to determine whether this or another method of salvaging topsoil is the best.

At some operations, a small long-boomed shovel used only to remove topsoil might be advantageous. It would eliminate walking the stripping shovel out of and into the pit and would reduce the operating expense incurred by using the stripping shovel to remove topsoil.

With few exceptions, a shovel used for selective overburden removal is not as efficient as other types of equipment because it usually requires ramping up and down between the lifts of overburden to be separated, a time-consuming and hence costly procedure. One exception arises when conditions permit use of a method similar to that employed in uncovering two seams of coal with a stripping shovel working with its crawlers on the bottom seam (6). Once a pit is established, a large stripping shovel with its eight crawlers atop a coal or lignite seam can excavate overburden in two lifts and spoil it so that the overburden originally near the surface remains near the surface. Such placement is often advantageous, keeping materials of strata near a coal or lignite seam, which are detrimental to plant life, away from the surface or near surface. If necessary, this same procedure could be used to place the lower lift of overburden in the upper part of the spoil. Limitations are that the lower lift must be just above the coal or lignite seam and must not exceed 30 feet in thickness (fig. 9).

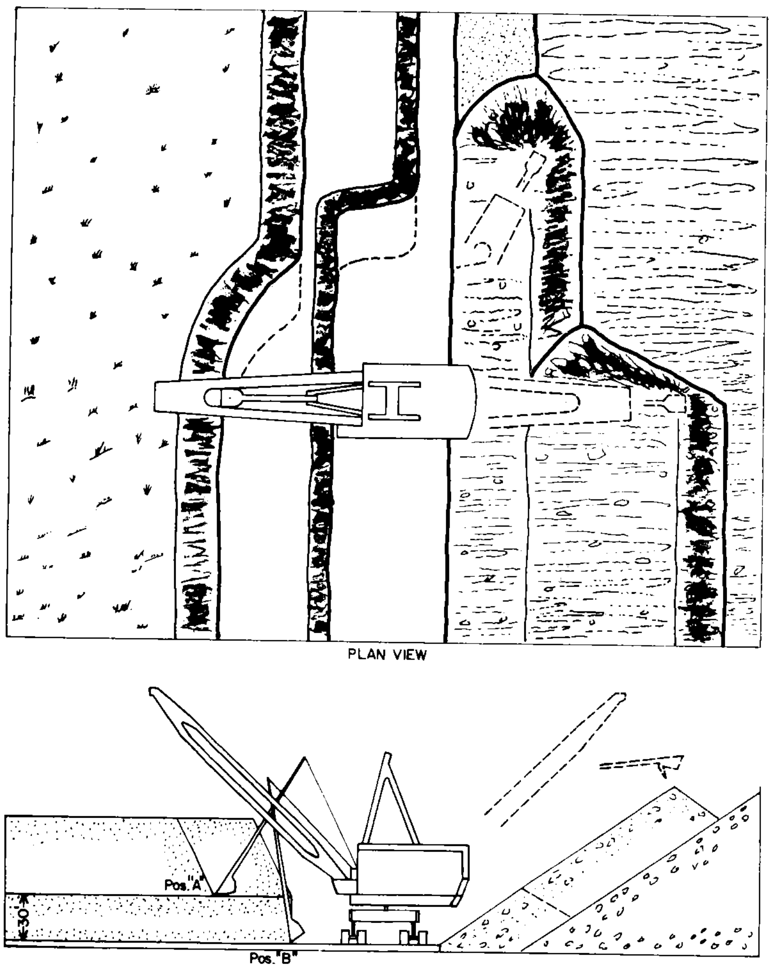

FIGURE 9. - Removing overburden selectively with a shovel.

A shovel normally must work in tandem with a bucket-wheel excavator, a conveyor system, or a rehandle dragline to keep the operations of casting and grading spoil abreast. The items of equipment listed are not the only selections for grading spoil cast with a shovel, nor are the schemes and equipment previously described the only alternatives for grading dragline spoil. For example, many operations currently grade spoil with a bulldozer--a costly method. Also, the many trips back and forth on the spoil ridge greatly increase spoil compaction. Because spoil can be graded by numerous methods using various types of equipment, probably a lower cost solution ultimately will be reached by methods not yet discovered or with equipment yet to be designed, if the trend in earthmovers over the last 30 years is any indication. Size and bucket capacity of draglines and shovels seem to have reached a plateau; the effort now is concentrated on methods and equipment to improve mined-land reclamation. Although forthcoming advancements must remain speculative, their objectives clearly are to prevent or minimize increases in the total cost of producing surface-mined coal and lignite by developing efficient methods of mined-land reclamation.

Crawler Tractors

Crawler, track-type tractors equipped with a dozing blade are capable of moving large quantities of spoil. Their effectiveness can be increased by working two tractors in tandem with only one operator; a blade designed especially for flattening spoil peaks and ridges is attached to the foremost of the two tractors. However, the cost per acre is high, and the graded spoil often is compacted to the point of restricting or preventing water penetration and plant growth. Efficiency is reduced because energy is lost to friction between the spoil being moved and the material over which it is moved. Hence, minimizing compaction and increasing efficiency are two points to consider when devising methods for grading spoil.

A two-tractor method being tried utilizes a giant dozer blade fitted to one tractor. The second tractor supplies additional traction and power, assisting to pull the first tractor. Although the method requires two operators, preliminary indications are that it is more economical than operating two single bulldozers (5).

Dragline Versus Tractor

A dragline atop the spoil would not compact as great an area as a bulldozer; hence, a smaller area would require subsequent plowing. If the dragline is not required to assist the stripping machine in rehandling spoil or in moving and spreading topsoil, the area compacted by the tub and shoes or crawlers could be further reduced by one-half or more by grading two or more ridges at once, depending upon the operating radius of the dragline and pit width. A dragline can further reduce compaction of spoil over which it passes by agitating the spoil with its bucket, thereby eliminating plowing before planting. Once the bucket is loaded, energy expended to overcome friction between the moving spoil and that over which it is moved also would be less when a dragline is used instead of a bulldozer. The steel bottom of a dragline bucket incurs less friction when in contact with the ground; furthermore, this friction is reduced to zero when the bucket is lifted above the surface. Moreover, a raised bucket does not compact soil over which it passes.

Possible Equipment Innovations

Untried methods of grading spoil with machinery not yet manufactured are too speculative for serious attention; whatever improvements are devised probably will be adapted from modifications of earthmoving machines currently manufactured. In general, an improved machine would operate either from a position on the spoil ridge to be graded, propelling spoil into the valley on one or both sides, or from a position on previously graded spoil, pulling spoil from the adjoining ridge into the intervening valley. Such a machine would travel on either rubber-tired wheels or crawlers; the latter would be preferable for traction and weight distribution.

To minimize spoil compaction, a machine should form the specified grade by making only one pass on each ridge. The traveling mechanism should have a large area of contact with the suface of the spoil for a low weight distribution per unit of area. Additional reduction in compaction can be achieved by plowing (ripping) that area compacted by the traveling mechanism. Plowing can be accomplished by a ripper mounted on a tractor; the ripper should contain at least three teeth, one in the center and one mounted behind each track to lessen the compaction created by the tractor. Alternatively, but requiring more power for operation, rippers could be mounted at the rear of the spoil-grading machine. Eliminating a tractor and its operator would reduce costs, but the disadvantages of grading and plowing with the same machine may offset the cost advantage.

Numerous possibilities exist for constructing a device to grade spoil, using current material-handling principles. A machine that would travel upon the spoil ridge to be graded might resemble a bucket-wheel excavator, a continuous miner or excavator, or a trenching machine. Each would have a means of conveying the spoil excavated from the ridge for placement in an adjoining valley on a specified grade.

Modified Bucket-Wheel Excavator

A bucket-wheel excavator modified to grade spoil would be similar in size to those now used for loading sand gravel. Main differences are that the boom and discharge conveyor would be long, and that the conveyor should swing, telescope, or both. Length of the boom should be at least one-quarter of the pit width, the minimum swing must be 180°, and the boom should discharge from either side. Although such a machine should be used only in spoil relatively free of large rocks, boulders, and stumps, the boom should be strong enough to push an occasional oversive rock or boulder into the valley for burial. The discharge conveyor should be capable of placing spoil any place from the end of the cut to the center of the fill. If spoil is cast only in one direction, the conveyor must be of a length to place spoil on the opposite side of the valley fill.

Replacing the bucket wheel at the end of the boom with a fragmenting device similar to that on a continuous miner permits handling spoil containing large pieces that, if left on the surface, would deter traversing with farm machinery. Such large pieces, however, should be soft enough to be broken by the bits of the miner.

A machine that resembles a continuous excavator or reclaimer equipped with an extra-long conveyor is another possibility for grading spoil ridges; such ridges, however, should not contain large rock, boulders, or stumps. The conveyor must be able to swing and/or telescope to allow placing the spoil properly. If such a machine were limited to the size of the largest continuous excavators currently in operation, it would take 6 to 10 passes to grade an average ridge of spoil. A machine large enough to grade a ridge of spoil in one pass is possible; however, a complete design analysis would be needed to determine whether the expense, weight, power requirement, etc., are practical. A machine of adequate size could be designed so that only one long conveyor, capable of shuttling from one side to the other, would be required. The shuttling action would eliminate need for a telescoping conveyor; however, a shuttle conveyor cannot be used unless the machine is large enough to remove all of the ridgetop in one pass. Spoil compaction resulting from multipasses of a small machine should not be appreciably greater than that created by a large machine making one pass. The use of either should compact the spoil less than a bulldozer would.

Hoes and Gradalls[8]

Hoes (backhoes, pullshovels, dragshovels, etc.) and Gradalls are another type of excavating equipment that, with modifications, would have potential as a tool for grading or possibly rehandling and grading spoil. The modifications required for hoes mainly would be to increase the length of the handle and boom and the capacity and shape of the bucket. A hoe, so modified, offers two possible advantages over a dragline: (1) A better finished grade could be accomplished by constructing the bucket wider but not as deep as a conventional bucket, and (2) limited ripping or plowing of a compacted area could be accomplished by attaching teeth to the bucket. A possible disadvantage, to be determined by a design analysis, is that the extended boom and handle may require more power, and hence more weight, than a dragline of comparable capacity. Hoes can be operated either hydraulically or with cables as a matter of preference. Draglines are cable operated only.

A Gradall can be described as a hydraulically operated, push-and-pull excavator that possesses versatility for many small jobs. As presently manufactured, the Gradall is much too small to grade spoil. If it were possible to englarge this machine to have an operating radius of at least 100 feet and handle an allowable load in the range of 50,000 to 70,000 pounds, it would be efficient for grading spoil. Various tools besides a bucket, such as a ripper or a blade, easily attached to or detached from a Gradall boom, could be used to prepare spoil for topsoil placement or planting. Under certain conditions, an enlarged Gradall also could rehandle and spread topsoil excavated by a stripping dragline.

Tower Excavators

A tower excavator (cable excavator) is any cable-operated excavator working a bucket between a head structure and a tail anchor spaced hundreds of feet apart. The track cable, upon which the bucket travels, is slackened to lower the bucket for digging and is tightened to elevate the bucket for

[8]Reference to a specific company or brand name is made for identification only and does not imply endorsement by the Bureau of Mines.

travel. Dumping, accomplished when a dump sheave on the traveler block strikes a dump button having a fixed position on the track cable, usually is done just in front of the head structure. A tower excavator as currently constructed would have limited usefulness in grading spoil because it can dump only over that point where the traveling block strikes the dump button. Thus, use would be restricted to filling the final cut. Then after the final cut is filled, a bulldozer or other equipment would still be necessary to grade the dumped spoil. If, however, a tower excavator were modified so a loaded bucket would be pulled in both directions and dumped anywhere along the track cable, it could be used for grading spoil. The head structure or tail anchor would travel upon previously graded spoil, atop the highwall or in the pit bottom. The traveling surface between the highwall and pit bottom should be where it would interfere the least with other phases of mining. Whether the head structure or the tail anchor traveled on previously graded spoil would be optional, but an operator could view the grading operation better if the head structure were so positioned. An exception would be that when filling the final cut the head structure should travel atop the highwall. A modified tower excavator could stockpile topsoil or remove it from stockpile and spread it on the graded spoil. It could also remove topsoil in place on the highwall side and spread it over graded spoil. Without modification it could remove and stockpile topsoil from the first few cuts, and it could remove topsoil from the highwall side and deposit in a pile or ridge on the spoil side.

Establishing Vegetation

The last step in reclaiming strip-mined land is to cover the spoil with vegetation. How, what, when, and where the vegetation is to be established should be ascertained before mining begins. Determining factors include land use, physical and chemical soil characteristics, climate, plant species, and the mined-land reclamation law. In the Upper Missouri River basin, reclaimed land is used mainly for wildlife habitat, pasture, and cultivated crops; however, such additional uses as recreation and forest cannot be overlooked.

Reclaimed land to be cultivated should be relatively flat for ease of tilling and reducing the possibility of water erosion. Except for land irrigated by flooding, a gently rolling topography is beneficial because it tends to catch and retain more moisture and is less prone to wind erosion than a flat surface. Land reclaimed to rolling topography for use as wildlife habitat and pasture could support trees for a forest crop and also be used for recreation. If a permanent source of water exists, hunting, fishing, and water sports could be included. Rolling topography offers many advantages over a smooth surface, including limited protection for domestic and wild animals; more moisture retained in the swales to provide an increased plant survival and development rate and in turn better forage; less wind and water erosion, hence less stream pollution; and catch basins, formed intentionally or unintentionally in the swales. Such basins often retain runoff from spring and early summer storms that can benefit both animals and nearby trees, shrubs, and grasses.

The amount and type of preparation required before planting depend upon several factors, including land use, topsoil replacement, physical and chemical characteristics of the graded spoil surface, and fertilization requirement.

How the land will be used after reclamation should be determined before mining starts so that spoil can be graded and surface prepared according to the planned use. For example, if large rocks or boulders are present within 6 to 12 inches of the surface, removal would be necessary for land to be used for cultivated crops, but removal normally would not be critical for use as wildlife habitat, pasture, or forest. A mechanical rock picker is a good method of removal. Burial beneath the spoil is the easiest method of disposal, unless the rocks or boulders can be used.

Although topsoil replacement is a controversial added expense, it is required in most States and on Federal land administered by the Bureau of Land Management. Some authorities claim fertilizers and mulch applied to graded spoil will produce vegetation at least equal to that produced where topsoil is replaced and at less expense. This claim, neither proved nor disproved, could apply to some spoil, but it is doubtful that it would apply to all. The Montana Agricultural Experiment Station, Bozeman, Mont., is conducting specific tests on vegetating spoil with no topsoil versus spoil covered with topsoil. Figure 10 shows an experimental area after one growing season at

FIGURE 10. - Topsoil versus no topsoil test plots at Pit No. 6, Western Energy Co., Colstrip, Mont.

Colstrip, Mont., using a variable depth of topsoil on a 3-to-1 slope. Even numbered plots (2, 4, and 6) were planted on the raw spoil; plots 1, 3, 5, and 7 were covered with 4, 8, 8, and 2 inches of topsoil, respectively.

In the Upper Missouri River basin, both physical and chemical characteristics of the spoil--especially the spoil surface--depend upon the constituents of the overburden and specifically those of the particular horizons or mixture of horizons that become the surface of the graded spoil. The dominant physical characteristic, in general, will be glacial boulders within the glaciated area. South and west of the glaciation, overburden can vary from a sandy loam to sandstone and shale.

Moisture, temperature, and exposure affect the physical and chemical properties of the spoil and the plant life it supports. Moisture available to plants is usually sparse in the semiarid climate; the benefits depend upon when and how precipitation occurs. High temperature evaporates moisture; low temperature (below freezing) prevents it from entering the ground. Temperature of the ground varies with exposure to the sun and wind and in turn increases or decreases evaporation from the ground surface and transpiration from plants. The never-ending cycle weathers and leaches the ground surface and enhances or destroys vegetative growth. The effect is shown in figure 11 by the thick growth on the trench bottom and on the slope facing northeasterly (left), and the spares growth opposite where warm rays of the sun strike the slope facing southwesterly (right).

One outstanding chemical characteristic common to topsoil and spoil in the Upper Missouri River basin is that both are generally basic; often the topsoil contains a greater concentration of salts than the underlying formations. Such generalizations, however, cannot be relied upon. Data from soil and range analyses and climatological observations are essential aids in determining the need for soil treatment and the species to be planted at a particular site. Alkali topsoil and/or spoil that contains enough exchangeable sodium to reduce or prevent plant growth can be treated by adding soluble calcium or magnesium salts, then removing the sodium by leaching. Where high-calcium (hard) water is available, alkali removal can be accomplished in one step; if not, gypsum or other soluble calcium salt can be applied to the soil before leaching. Another possible characteristic of the topsoil and/or spoil in a semiarid climate is a saline-alkali nature (soil that contains an excess of both soluble salts and exchangeable sodium). Diagnosing and improving such soil is explained by Richards (14).

Both soil and topsoil in the Upper Missouri River basin generally lack nitrogen, but some quantities of phosphate and potassium are often present. Analyses of topsoil and/or spoil are indicators of the fertilizing necessary; however, the results of field experiments are the best guides to determine the amount of each kind to be applied. Such experiments are made by dividing an area of spoil into test plots, then applying various amounts and types of fertilizers.

Regardless of the ultimate land use, the preferred method of seeding is with a drill. It provides uniform seed distribution at the proper depth

FIGURE 11. - Comparison of a northeasterly slope (left) with one that faces southwesterly (right). The southwest-facing slope receives more sun and therefore loses more moisture; plant growth is much weaker than on the other slope.

without damage to the seed. Cost, size, and species of plants, quantity to be planted, and personal preference seem to be the main factors determining what method will be used for planting trees and shrubs. Seeding and planting are seasonal, generally performed in spring or fall; therefore, the advantages and disadvantages of contracting this phase of strip-mined land reclamation should be considered. Usually mine workers are not farmers, but instructing them in seeding and planting could be psychologically sound and could prevent a bulldozer operator or a truck driver from using reclaimed land for a short-cut. Most mine employees who take part in reclaiming the land take pride in it.

Revegetating spoil in the Upper Missouri River basin, beginning about 30 years ago, has accelerated greatly in the last decade. Much of the planting has been experimental, and from these experiments better vegetation of spoil is developing. Several publications, listed table C-2, describe some of the progress that has been made.

Whether irrigating planted spoil in a semiarid climate during the first one or two growing seasons is beneficial or detrimental is another point of controversy, but one that can be settled by experimentation. Where the supply of mine water is sufficient, sprinkler irrigation can cover a circle one-quarter mile in diameter in a single setting on flat terrain; this method should be tried even though the land will not be irrigated in its ultimate use. The effort would not be a complete loss should the vegetation not survive after irrigation terminates. Legumes, such as alfalfa, would supply nitrogen to the soil; both legumes and grasses would provide green manure for a better survival and growth of indigenous species.

SUMMARY AND CONCLUSIONS

A fixed cost for protecting the environment in any area or region would be extremely difficult to determine because of the many variables in mining and the differences of opinion as to what costs should be included for environmental protection. Such costs, regardless of their distribution, are part of the total cost of producing coal or lignite and are ultimately paid by the consumer. Therefore, to be competitive, the mine operator must protect the environment in the best possible way for the least possible expenditure. Mining must be done by methods that cause minimal damage so that necessary repair is minimal. Mined-land reclamation must be done both to satisfy mandatory requirements and to obtain public acceptance. Such operations may be difficult and costly in the beginning but should pay out as a long-term investment.

Many actions taken to protect the environment can prove beneficial elsewhere. Curtailing dust will extend machinery life. Diverting and settling water to prevent pollution can prevent flood damage and improve working conditions. Reclaiming the mined land suppresses dust, reduces the potential of erosion, improves the appearance of the mine, and retains mined land on the tax roll for future use.

The semiarid climate of the Upper Missouri River basin necessitates suppression of dust for the well-being of both men and machinery, and for public benefit. With a few exceptions, no changes in the methods used to suppress dust were required by the enactment of air-pollution-control laws. Additional curtailment of airborne particulates may be required at working places for compliance with the Federal coal mine health and safety regulations. Dust generated from the coal or lignite should constitute little if any problem because of the high moisture content; the dry overburden, however, may cause limits to be exceeded. Mine employees curently are wearing detectors to determine whether they are exposed to excessive amounts: more than 2 milligrams of particles 5 microns (micrometers) or less in size per cubic meter of air.

In the Upper Missouri River basin, preventing water pollution at coal and lignite operations generally would include diverting surface water from the working area by a means that would not increase sedimentation or dissolved salts; testing all discharge water for purity; measuring all water entering and leaving the mine area; and constructing a settling basin for mine water and other water containing sediments that are to flow into a watercourse. No acid water would flow from the mining area, but dissolved salts could be excessive. Should such a condition occur, some method of preventing salt contamination or partial removal of the salt to reduce its concentration would be necessary. Should washing the coal or lignite at a preparation plant be required, which would seldom happen in this region, a closed system is recommended. Processes for preventing water pollution could vary considerably for each operation, but water pollution prevention in the Upper Missouri River basin should be relatively simple compared with areas where treatment of acid water is required.

Reclamation of the strip-mined land in the Upper Missouri River basin will require a greater annual expenditure than that for preventing pollution of air or water. The reclamation cost per million Btu of energy recovered from the thick deposits (25 feet or more) will be less than in other parts of the Nation; however, incorporating land reclamation with removal of overburden so that material with the greatest potential for establishing plant life becomes the surface of the reclaimed spoil may increase the total production cost. Such reclamation techniques can be beneficial in other ways, however, making possible faster release of bonds, quicker restoration of the mined land for other uses, and improved aesthetic values. Similar benefits also may be realized by mulching, fertilizing, and irrigating.

Strip mining is a one-time productive use of the land. Reclamation readies such land for other productive uses, fulfilling the responsibility of seeing that productive use continues just as it would if the land were never mined.

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APPENDIX A.--GEOLOGIC REFERENCES

TABLE A-1. - Geologic references to strippable coal and lignite deposits in the Upper Missouri River basin

County and deposit	Authors	Publication
	MONTANA	
Big Horn:		
Decker.............	Baker, A. A........	The Northward Extension of the Sheridan Coal Field. U.S. Geol. Survey Bull. 806-B, 1929, 67 pp.
Hanging Woman Creek	.....do............	Do.
Kirby..............	.....do............	Do.
Roland.............	.....do............	Do.
Smith..............	.....do............	Do.
Custer:		
Foster Creek.......	Brown, A., Culbertson, W. C., Dunham, R. J., Kepferle, R. C., and May, P. R.	Strippable Coal in Custer and Powder River Counties, Montana. U.S. Geol. Survey Bull. 995-E, 1954, pp. 151-197.
Do...............	Gilmour, E. H., and Williams, L. A.	Geology and Coal Resources of the Foster Creek Coal Deposit, Eastern Montana. Mont. Bur. of Mines and Geol. Bull. 73, June 1969, 9 pp.
Pine Hills.........	Brown, A., et al...	See Foster Creek, Custer County, Mont.
Pumpkin Creek......	.....do............	Do.
Sand Creek.........	.....do............	Do.
Dawson:		
North Fork Thirteen Mile Creek.	Culbertson, W. C...	Three Deposits of Strippable Lignite West of the Yellowstone River, Mont. U.S. Geol. Survey Bull. 995-H, 1954, pp. 293-332.
McCone:		
R..................	Collier, A. J., and Knechtel, M. M.	The Coal Resources of McCone County, Mont. U.S. Geol. Survey Bull. 905, 1939, 80 pp.
Do...............	Matson, R. E.......	Strippable Coal Resources, McCone County, Mont. Mont. Bur. of Mines and Geol. Bull. 78, Prelim. Rept., May 1970, 13 pp.
S..................	.....do............	Do.
Powder River:		
Broadus............	Warren, W. C.......	Reconnaissance Geology of the Birney-Broadus Coal Field, Rosebud and Powder River Counties, Mont. U.S. Geol. Survey Bull. 1072-J, 1959, pp. 561-585.

TABLE A-1. - Geologic references to strippable coal and lignite deposits in the Upper Missouri River basin--Continued

County and deposit	Authors	Publication
MONTANA--Continued		
Powder River (Con.):		
Foster Creek.......	Brown, A., et al...	See Foster Creek, Custer County, Mont.
Moorhead...........	Baker, A. A........	See Decker, Big Horn County, Mont.
Do...............	Matson, R. E.......	Strippable Coal in the Moorhead Coal Field, Mont. Mont. Bur. of Mines and Geol. Bull. 83, May 1971, 18 pp.
Otter Creek........	Warren, W. C.......	See Broadus, Powder River County, Mont.
Pumpkin Creek......	Brown, A., et al...	See Foster Creek, Custer County, Mont.
Sand Creek.........	.....do...........	Do.
Sonnett............	Warren, W. C.......	See Broadus, Powder River County, Mont.
Do...............	Matson, R. E., Dahl, G. G., Jr., and Blumer, J. W.	Strippable Coal Deposits on State Land, Powder River County, Mont. Mont. Bur. of Mines and Geol. Bull. 69, August 1968, 81 pp.
Richland:		
Breezy Flat........	Brown, A., et al...	See Foster Creek, Custer County, Mont.
Fox Lake...........	.....do...........	Do.
Roosevelt:		
Fort Kipp..........	Great Northern Railway Co., Mineral Research and Development Department.	The Fort Kipp Lignite Deposit, Northeastern Mont. Rept. 26, March 1966, 63 pp.
Lanark.............	.....do...........	Lignite Drilling Program, Williston Basin, North Dakota and Montana. Rept. 1, 1955, 26 pp.
Rosebud:		
Birney.............	Warren, W. C.......	See Broadus, Powder River County, Mont.
Colstrip...........	Kepferle, R. C.....	Selected Deposits of Strippable Coal in Central Rosebud County, Mont. U.S. Geol. Survey Bull. 995-I, 1954, pp. 333-379.
Greenleaf-Miller Creek.	.....do...........	Do.
Hanging Woman Creek	Baker, A. A........	See Decker, Big Horn County, Mont.
Poker Jim O'Dell Creek.	Warren, W. C.......	See Broadus, Powder River County, Mont.

TABLE A-1. - Geologic references to strippable coal and lignite deposits in the Upper Missouri River basin--Continued

County and deposit	Authors	Publication
	MONTANA--Continued	
Rosebud (Con.):		
Rosebud Creek.....	Pierce, W. G.......	The Rosebud Coal Field, Rosebud and Custer Counties, Mont. U.S. Geol. Survey Bull. 847-B, 1936, pp. 43-120.
Sheridan:		
Coalridge..........	Beckly, A. L.......	The Culbertson Lignite Field, Valley County, Mont. U.S. Geol. Survey Bull. 471-D, 1912, pp. 319-358.
Medicine Lake......	.....do............	Do.
Reserve............	.....do............	Do.
Wibaux:		
Four Buttes........	May, P. R..........	Strippable Lignite Deposits in the Wibaux Area, Montana and North Dakota. U.S. Geol. Survey Bull. 995-G, 1954, pp. 255-292.
Wibaux.............	.....do............	Do.
	NORTH DAKOTA	
All lignite deposits.	Brant, R. A........	Lignite Resources of North Dakota. U.S. Geol. Survey Circ. 226, 1953, 78 pp.
Do.................	Leonard, A. G., Babcock, E. J., and Love, L. P.	The Lignite Deposits of North Dakota. N. Dak. Geol. Survey Bull. 4, 1925, 240 pp.
Billings:		
Dickinson..........	Northern Pacific Railway Co., Geology Div.	Preliminary Evaluation of Dickinson Lignite Field, Billings, Dunn, and Stark Counties, N. Dak., May 1963, 6 pp.
Bowman:		
Bowman-Gascoyne....	Kepferle, R. C., and Culbertson, W. C.	Strippable Lignite Deposits, Slope and Bowman Counties, N. Dak. U.S. Geol. Survey Bull. 1015-E, 1955, pp. 123-182.
Burke:		
Niobe..............	Armstrong, C. A....	Geology and Ground Water Resources of Burke and Mountrail Counties, N. Dak. N. Dak. Geol. Survey Bull. 55, pt. 2, 1969, pp. 185-191.
Noonan-Kincaid.....	.....do............	See Niobe, Burke County, N. Dak., pp. 243-246.

TABLE A-1. - Geologic references to strippable coal and lignite deposits in the Upper Missouri River basin--Continued

County and deposit	Authors	Publication
NORTH DAKOTA--Continued		
Burleigh:		
Wilton.............	Kume, J., and Hansen, D. E.	Geology and Ground Water Resources of Burleigh County, N. Dak. N. Dak. Geol. Survey Bull. 42, pt. 1, 1965, 111 pp.
Do..............	Randich, P. G......	Geology and Ground Water Resources of Burleigh County, N. Dak. N. Dak. Geol. Survey Bull. 42, pt. 2, 1965, pp. 228-229.
Dunn:		
Dickinson..........	Northern Pacific Railway Co.	See Dickinson, Billings County, N. Dak.
Dunn Center........	Clayton, L.........	Preliminary Geologic Map of Dunn County, N. Dak. N. Dak. Geol. Survey Misc. Map 11, August 1968.
Golden Valley:		
Beach..............	May, P. R..........	See Four Buttes and Wibaux, Wibaux County, Mont.
McLean:		
Washburn...........	Smith, C. C........	The Washburn Lignite Field, North Dakota. U.S. Geol. Survey Bull. 381-A, 1908, pp. 19-29.
Mercer:		
Beulah-Zap.........	Benson, W. E.......	Geology of the Knife River Area, North Dakota. U.S. Geol. Survey Open File Rept., 1953, 323 pp.
Hayden.............	.....do............	Do.
Renner's Cove......	.....do............	Do.
Stanton............	.....do............	Do.
Oliver:		
Stanton............	Johnson, W. D., Jr., and Kunkel, R. P.	The Square Buttes Coal Field, Oliver and Mercer Counties, N. Dak. U.S. Geol. Survey Bull. 1076, 1959, 91 pp.
Center.............	.....do............	Do.
Slope:		
Bowman-Gascoyne....	Kepferle, R. C., et al.	See Bowman-Gascoyne, Bowman County, N. Dak.
Stark:		
Dickinson..........	Northern Pacific Railway Co.	See Dickinson, Billings County, N. Dak.
Ward:		
Niobe..............	Armstrong, C. A....	See Niobe, Burke County, N. Dak.
Velva..............	Andrews, D. A......	Geology and Coal Resources of the Minot Region, North Dakota. U.S. Geol. Survey Bull. 906-B, 1939, pp. 43-84.

TABLE A-1. - Geologic references to strippable coal and lignite deposits in the Upper Missouri River basin--Continued

County and deposit	Authors	Publication
	NORTH DAKOTA--Continued	
Williams:		
Avoco.............	Great Northern Railway Co., Mineral Research and Development Department.	The Avoco Lignite Deposit, Williams County, N. Dak. Rept. 27, April 1966, 65 pp.
Do..............	Herald, F. A.......	The Williston Lignite Field, Williams County, N. Dak. U.S. Geol. Survey Bull. 531-E, 1913, pp. 91-157.
M. & M............	Great Northern Railway Co., Mineral Research and Development Department.	Lignite Drilling Program, Williston Basin, North Dakota and Montana. Rept. 1, 1953-55, 5 pp.
	WYOMING	
Campbell:		
Clear Creek........	Olive, W. W........	The Spotted Horse Coalfield, Sheridan and Campbell Counties, Wyo. U.S. Geol. Survey Bull. 1050, 1957, 83 pp.
Wyodak............	Dobbin, C. E., and Barnett, V. H.	The Gillette Coal Field, Northeastern Wyoming. U.S. Geol. Survey Bull. 796-A, 1927, pp. 1-64.
Spotted Horse......	Olive, W. W........	See Clear Creek, Campbell County, Wyo.
Converse:		
Dry Cheyenne.......	Winchester, D. E...	The Lost Spring Coal Field, Converse County, Wyo. U.S. Geol. Survey Bull. 471-F, 1912, pp. 472-515.
School Badger......	Shaw, E. W.........	The Glenrock Coal Field, Wyoming. U.S. Geol. Survey Bull. 341-B, 1909, pp. 151-164.
Johnson:		
Lake De Smet.......	Mapel, W. J........	Geology and Coal Resources of the Buffalo-Lake De Smet Area, Johnson and Sheridan Counties, Wyo. U.S. Geol. Survey Bull. 1078, 1959, 148 pp.
Do..............	Mapel, W. J., Gill, J. R., and Schopf, J. M.	A Thick Coal Bed Near Lake De Smet, Johnson County, Wyo. U.S. Geol. Survey Circ. 228, 1953, 47 pp.
Sheridan:		
Acme-Kleenburn.....	Taff, J. A.........	The Sheridan Coal Field, Wyoming. U.S. Geol. Survey Bull. 341-B, 1909, pp. 123-150.
Clear Creek........	Olive, W. W........	See Clear Creek, Campbell County, Wyo.

APPENDIX B. - TEMPERATURE AND PRECIPITATION

TABLE B-1. - Mean temperature and precipitation in eastern Montana, by climatological stations and divisions[1]

Divisions and stations	Temperature (° F) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Northeastern:													
Circle 7 N	13.1	16.5	27.3	42.8	54.1	62.0	70.0	67.8	56.9	45.5	29.6	20.5	42.2
Culbertson	9.5	13.4	25.5	42.6	54.9	62.6	70.5	68.2	57.2	45.3	27.9	17.5	41.3
Frazer	8.1	12.4	25.8	43.1	55.2	62.8	71.2	68.7	57.5	45.4	27.7	16.7	41.2
Glasgow WSO	9.8	13.6	26.7	43.4	55.1	62.3	70.7	67.8	56.7	45.4	28.2	17.7	41.4
Glendive	15.2	18.7	30.5	46.5	58.4	66.3	74.7	72.0	60.8	48.8	32.5	22.6	45.6
Haxby 18 SW	16.1	19.0	28.9	43.8	55.1	62.7	71.8	69.5	58.5	47.7	31.8	23.0	44.0
Jordan	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lustre 4 NNW	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Medicine Lake 3 SE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Poplar	9.4	13.8	26.5	44.2	56.2	63.9	71.6	69.2	58.4	46.3	28.7	17.6	42.2
Savage	12.8	16.6	28.2	44.4	56.3	64.3	72.0	69.5	58.7	47.0	30.3	20.4	43.4
Vida	12.6	15.8	26.6	43.3	55.2	62.5	71.2	69.2	58.2	46.7	29.7	20.5	42.6
Average	10.8	15.3	26.2	43.0	55.1	62.7	70.9	68.4	57.5	45.9	28.8	18.5	41.9
Southeastern:													
Baker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Colstrip	21.6	24.5	32.4	44.8	55.1	63.5	72.6	70.5	59.8	48.6	34.4	26.8	46.2
Ekalaka	17.9	20.8	28.8	43.1	54.4	62.8	71.6	69.8	58.7	47.0	31.1	23.7	44.1
Mildred	15.5	19.0	29.8	44.8	56.4	64.7	73.5	71.1	59.6	47.7	31.7	22.4	44.7
Miles City FAA Airport	16.5	20.3	30.9	45.7	57.4	65.6	75.3	72.6	61.0	49.0	32.6	23.2	45.8
Plevna	14.7	17.4	27.2	42.7	54.3	62.6	71.5	69.7	58.4	46.4	30.0	21.1	43.0
Average	17.8	21.5	30.4	44.4	55.4	63.6	72.6	70.4	59.7	47.8	32.2	23.8	44.9
Confidence limits[2]	3.2	2.8	1.5	1.2	1.2	0.9	0.8	0.7	1.1	1.3	1.7	2.1	0.7

Divisions and stations	Precipitation (inches) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Northeastern:													
Circle 7 N	0.27	0.22	0.34	0.91	1.45	2.93	1.84	1.22	0.93	0.63	0.34	0.25	11.33
Culbertson	.34	.29	.42	.94	1.60	3.36	1.79	1.49	1.08	.76	.45	.32	12.84
Frazer	.47	.41	.69	1.09	1.48	3.19	1.59	1.35	1.04	.67	.46	.38	12.82
Glasgow WSO	.48	.41	.56	1.01	1.49	2.98	1.33	1.49	.96	.64	.47	.45	12.27
Glendive	.39	.39	.62	1.03	1.60	3.17	1.73	1.48	.90	.71	.41	.30	12.73
Haxby 18 SW	.43	.36	.67	1.12	1.62	3.26	1.32	1.37	1.10	.74	.50	.41	12.90
Jordan	.34	.29	.52	.91	1.38	2.46	1.22	1.05	.79	.64	.37	.34	10.31
Lustre 4 NNW	.28	.24	.37	.81	1.38	2.93	1.74	1.60	.99	.55	.31	.22	11.42
Medicine Lake 3 SE	.31	.29	.36	.92	1.55	3.30	2.04	1.48	1.06	.69	.47	.30	12.77
Poplar	.30	.30	.46	.87	1.47	3.19	2.21	1.54	.93	.64	.38	.29	12.58
Savage	.40	.31	.54	1.18	1.61	3.30	2.09	1.54	1.10	.66	.42	.26	13.41
Vida	.75	.64	.85	1.32	1.70	3.42	1.91	1.36	1.10	.88	.71	.60	15.24
Average	.40	.35	.52	.96	1.53	3.09	1.84	1.49	1.00	.68	.43	.35	12.64
Southeastern:													
Baker	.38	.33	.59	1.04	1.67	3.24	1.81	1.37	1.04	.72	.37	.29	12.85
Colstrip	.58	.60	1.00	1.64	2.26	2.94	1.23	1.22	1.19	1.22	.66	.59	15.13
Ekalaka	.40	.35	.62	1.11	1.95	2.96	1.90	1.39	1.01	.74	.45	.34	13.22
Mildred	.38	.31	.56	1.05	1.80	2.84	1.64	1.34	.89	.77	.45	.33	12.36
Miles City FAA Airport	.44	.37	.65	1.06	1.73	2.71	1.34	1.24	.96	.87	.43	.37	12.17
Plevna	.39	.35	.58	1.14	1.68	2.95	1.74	1.22	.97	.80	.41	.33	12.60
Average	.43	.39	.70	1.17	1.88	2.81	1.48	1.17	.95	.88	.52	.41	12.79
Confidence limits[2]	0.15 p	0.14 p	0.18 p	0.23 p	0.27 p	0.32 p	0.28 p	0.25 p	0.29 p	0.25 p	0.19 p	0.17 p	0.24 p

NA Not available.

[1]Normals for the period 1931-60. Divisional normals may not be the arithmetical average of individual stations published because additional data for shorter period stations are used to obtain better areal representation.

[2]In the absence of trend or record changes, the chances are 9 out of 10 that the true mean for temperature or precipitation will lie in the interval formed by adding and subtracting the listed values from the means for any station in the State. Because of the wider variation in mean precipitation, the corresponding monthly means and annual mean must be substituted for "p" in the precipitation data to obtain mean precipitation confidence limits.

NOTE. - Figures and letters following a station name, such as 3 SE, indicate distance in miles and direction from the U.S. Post Office.

Source: Cordell, G. V., Jr. Climates of the States, Climate of Montana. National Oceanic and Atmospheric Administration Environmental Data Service, Climatography of the United States No. 60-24, March 1971, 21 pp.

TABLE B-2. - Mean temperature and precipitation in western North Dakota, by climatological stations and divisions[1]

Divisions and stations	Temperature (° F)													Precipitation (inches)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Northwest:																										
Crosby	6.0	10.3	21.5	39.7	52.9	60.7	68.5	65.7	55.0	44.0	25.8	13.8	38.7	0.36	0.34	0.62	0.79	1.64	3.29	2.13	1.85	1.09	0.83	0.40	0.41	13.75
Foxholm 7 N	7.3	11.4	22.6	41.0	54.2	62.1	69.6	67.3	56.9	45.5	26.6	14.4	39.9	.50	.36	.77	1.19	1.84	3.52	1.98	2.10	1.24	.78	.57	.41	15.26
Kenmare	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.50	.49	.83	1.07	1.86	3.52	2.25	1.90	1.36	.80	.53	.46	15.57
Mohall	5.3	9.4	21.2	40.4	54.0	61.9	69.1	66.8	56.4	44.7	25.5	12.6	38.9	.50	.47	.89	1.31	2.01	4.01	2.55	2.18	1.42	.83	.58	.44	17.19
Newtown	6.0	9.3	20.6	41.3	53.4	61.7	69.4	67.0	56.1	44.6	26.6	14.6	39.2	.50	.44	.57	1.21	1.66	3.61	1.97	1.68	1.22	.74	.60	.39	14.59
Parshall	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.40	.31	.47	1.15	2.02	3.54	2.41	1.67	1.44	.72	.49	.28	14.90
Portal	4.1	8.2	19.4	39.5	52.7	60.7	68.2	65.3	55.1	43.3	24.5	11.8	37.7	.43	.44	.67	.83	1.88	3.78	2.10	2.27	1.24	.75	.47	.44	15.30
Wildrose	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.54	.48	.69	.90	1.63	3.26	1.80	1.85	1.13	.76	.45	.48	13.97
Williston WB City	10.0	13.5	26.5	42.9	54.6	63.0	70.9	68.1	57.2	45.5	28.3	15.7	41.3	.49	.46	.75	1.07	1.66	3.59	2.13	1.41	1.21	.77	.58	.54	14.66
Average	6.3	10.5	21.4	40.5	53.2	61.2	69.0	66.5	56.0	44.6	26.0	13.6	39.1	.46	.42	.67	1.09	1.90	3.59	2.15	1.94	1.28	.77	.50	.40	15.17
Southwest:																										
Bowman Court House	14.8	17.7	26.5	42.7	54.2	62.2	71.1	68.8	60.4	46.5	30.0	21.2	43.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dickinson Exp Station	10.7	13.9	23.9	41.3	53.1	61.4	69.8	57.1	56.4	44.8	27.9	17.5	40.7	.48	.45	.76	1.36	2.01	3.98	2.00	1.76	1.13	.88	.55	.32	15.68
Hettinger	15.2	18.3	27.0	43.5	55.0	63.5	72.0	72.5	59.1	47.1	30.8	21.3	43.8	.37	.29	.72	1.25	2.11	3.47	1.98	1.82	1.13	.83	.36	.23	14.56
Marmarth	14.9	18.7	28.0	44.4	55.5	63.6	72.1	69.1	58.3	46.6	30.1	20.6	43.5	.56	.45	.80	1.12	1.92	3.59	1.92	1.65	1.00	.92	.45	.38	14.76
Mott	13.6	17.1	26.6	43.5	55.0	63.4	71.8	69.1	58.9	46.8	29.9	19.8	43.0	.43	.41	.79	1.07	1.90	3.65	1.97	1.55	1.27	.68	.44	.30	14.46
New England	14.3	17.4	27.0	43.0	54.8	63.4	72.1	69.4	58.7	46.2	30.2	19.9	43.0	.63	.59	1.11	1.51	1.88	4.00	2.39	1.58	1.15	.85	.52	.38	16.59
Richardton Abbey	12.9	16.1	25.5	42.7	54.4	62.6	70.8	68.8	58.7	47.2	29.6	19.2	42.4	.56	.55	1.05	1.46	2.02	3.99	2.59	1.79	1.14	.83	.82	.36	17.16
Trotters 6 SE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.54	.44	.75	1.05	1.84	3.01	2.06	1.68	1.16	.74	.54	.38	14.19
Average	13.7	17.2	26.0	42.8	54.3	62.5	71.0	68.7	58.1	46.5	29.7	19.8	42.5	.50	.46	.85	1.33	1.95	3.77	2.11	1.76	1.18	.86	.49	.32	15.58
South-Central:																										
Bismarck WB Ap	9.2	12.7	26.7	43.1	54.8	64.3	72.1	69.3	58.5	45.7	28.4	15.5	41.7	.36	.43	.76	1.39	1.94	3.33	2.33	1.50	1.43	1.00	.53	.40	15.40
Carson No. 2	11.8	15.1	25.4	42.8	54.8	52.4	71.7	69.4	59.0	46.8	29.3	18.6	42.4	.53	.55	1.11	1.41	2.36	3.87	2.09	1.51	1.34	1.02	.55	.35	16.69
Fort Yates	12.1	16.5	27.9	44.9	56.7	65.4	73.1	70.5	60.4	48.1	30.9	19.1	43.8	.39	.45	.80	1.37	2.10	3.58	2.01	1.74	1.18	1.12	.36	.25	15.35
Linton	10.1	14.7	26.7	44.3	56.6	65.1	72.8	70.9	60.3	47.4	29.3	16.8	42.9	.40	.39	.72	1.36	2.05	4.09	2.47	1.85	1.43	1.10	.40	.31	16.57
Mandan Exp Station	9.4	13.0	24.6	42.9	55.2	63.9	71.8	69.2	58.9	46.6	28.3	16.2	41.7	.50	.48	.90	1.42	1.95	3.78	2.33	1.76	1.34	.92	.59	.37	16.34
New Salem 1 S	11.0	14.5	25.0	42.6	54.6	63.1	71.1	68.9	58.9	46.7	28.8	17.6	41.9	.45	.48	.81	1.29	2.02	3.54	2.21	1.80	1.30	.76	.47	.30	15.43
Average	10.9	15.2	25.6	43.5	55.5	64.0	71.9	69.7	59.4	47.3	29.4	17.7	42.5	.44	.47	.83	1.32	2.06	3.89	2.26	1.85	1.36	1.01	.50	.32	16.31
West-Central:																										
Dunn Center 2 SW	10.4	14.2	24.1	40.8	53.1	61.4	69.5	66.5	55.4	44.9	27.8	17.7	40.5	.43	.39	.65	1.26	1.99	3.85	2.34	1.97	1.24	.81	.46	.27	15.66
Garrison	8.3	12.4	23.7	41.6	54.2	62.8	70.4	67.7	57.4	45.2	27.0	15.0	40.5	.59	.54	.75	1.27	2.05	3.48	2.35	1.82	1.27	.78	.62	.44	15.96
Max	6.0	10.0	21.3	40.2	53.2	62.1	69.7	67.1	56.1	43.9	25.4	13.2	39.0	.45	.40	.73	1.25	2.19	3.98	2.66	2.16	1.30	.72	.59	.36	16.79
Washburn	10.2	14.4	25.6	43.6	55.9	64.3	72.0	69.2	59.2	47.1	28.9	16.9	42.3	.40	.40	.69	1.32	1.75	3.69	2.35	1.78	1.32	.82	.49	.32	15.33
Watford City	11.2	15.5	25.6	43.0	55.1	62.9	71.4	68.9	58.0	46.5	29.0	17.7	42.1	.61	.55	.85	1.33	1.85	3.58	2.36	1.55	1.25	.96	.56	.49	15.94
Average	8.8	12.7	23.6	41.8	54.1	62.3	70.1	67.7	57.1	45.6	27.2	15.7	40.6	.47	.44	.75	1.30	2.01	3.79	2.38	1.93	1.36	.83	.55	.36	16.17
Confidence limits[2]	3.1	3.1	1.6	1.4	1.5	1.2	1.1	0.8	1.1	1.4	1.7	2.2	0.7	0.11	0.11	0.17	0.31	0.49	0.69	0.50	0.36	0.39	0.19	0.17	0.09	1.27
Comparative data[3]	10.2	14.1	26.0	41.8	51.4	61.9	68.1	65.7	55.9	43.5	29.2	14.8	40.2	0.46	0.40	0.66	1.21	2.50	3.49	2.21	1.82	1.32	1.02	0.48	0.50	16.07

NA Not available.

[1]Averages for the period 1931-55, except for stations marked WB which are "normals" based on 1921-50. Divisional means may not be the arithmetical average of individual stations published, since additional data from shorter period stations are used to obtain better areal representation.

[2]In the absence of trend or record changes, the chances are 9 out of 10 that the true mean will lie in the interval formed by adding and subtracting the listed values from the means for any station in the State.

[3]These data are the mean temperature and average precipitation for Dickinson experiment station, North Dakota, for the period 1906-30 and are included in this publication for comparative purposes.

NOTE. - Figures and letters following a station name, such as 6 SE, indicate distance and direction from the U.S. Post Office.

Source: Bavendick F. J. Climate of the State, North Dakota. Weather Bureau, Climatography of the United States No. 60-32, October 1959, 16 pp.

TABLE B-3. - Mean temperature and precipitation, by stations, for two climatological divisions in northeastern Wyoming[1]

Divisions and stations	Temperature (° F)													Precipitation (inches)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Powder, Little Missouri, and Tongue Drainage:																										
Midwest	24.0	27.3	33.9	45.2	54.6	64.0	73.3	71.2	61.1	49.9	35.3	27.8	47.3	0.59	0.58	1.07	1.65	2.23	1.67	1.18	0.70	1.00	0.97	0.65	0.55	12.84
Nine Mile Creek	21.8	25.2	31.4	43.2	52.2	60.9	70.6	69.1	58.8	47.7	33.0	25.8	45.0	.52	.43	.93	1.63	2.07	1.77	1.06	.69	.99	.78	.74	.56	12.17
Rockypoint 2 NE	19.2	22.1	28.7	42.5	52.7	61.4	71.4	69.7	58.9	47.3	31.7	23.3	44.1	.89	.75	1.33	1.94	2.59	3.39	1.38	1.09	1.34	.95	.84	.72	17.21
Sheridan WB Ap.	20.1	23.2	31.6	43.5	52.9	61.4	70.6	68.6	57.9	46.6	33.1	24.0	44.5	.75	.61	1.37	2.26	2.64	2.60	1.38	.82	1.45	1.27	.93	.67	16.75
Sheridan Fld. Sta.	19.6	22.4	30.2	44.1	54.1	62.0	71.6	69.8	58.9	47.7	32.7	24.1	44.8	.55	.62	1.22	2.00	2.81	2.86	1.41	.89	1.43	1.18	.70	.51	16.18
Average	20.3	23.5	29.5	40.4	51.1	59.5	68.9	67.0	56.8	46.3	32.4	24.7	43.4	.62	.55	1.18	1.89	2.41	2.56	1.34	.92	1.29	1.01	.77	.57	15.11
Belle Fourche Drainage:																										
Colony	21.7	24.3	30.7	45.0	55.3	64.2	74.2	72.0	61.4	49.6	34.6	26.1	46.6	.55	.45	.93	1.66	2.23	3.29	1.41	1.15	1.26	.83	.67	.47	14.90
Gillette 2 E.	21.9	25.0	30.9	43.3	52.9	61.3	72.2	70.2	59.9	48.7	33.8	26.1	45.5	.70	.50	1.15	1.71	2.31	2.51	1.27	.86	1.17	.72	.73	.64	14.27
Sundance	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.74	.62	1.14	1.70	2.55	3.38	1.66	1.09	1.38	.99	.78	.69	16.72
Average	20.6	24.1	29.4	42.7	52.5	61.2	71.0	69.2	58.6	47.7	32.7	24.5	44.5	.64	.56	1.03	1.80	2.56	2.96	1.58	1.15	1.33	.89	.73	.49	15.82
Confidence limits[2]	2.6	2.3	1.4	1.4	1.1	1.1	0.7	0.6	1.0	1.4	1.7	1.9	0.6	0.19 p	0.17 p	0.19 p	0.31 p	0.31 p	0.37 p	0.28 p	0.30 p	0.37 p	0.33 p	0.25 p	0.19 p	0.28 p

NA Not available.
[1]Averages for the period 1931-55, except for stations marked WB which are "normals" based on 1921-50. Divisional means may not be the arithmetical average of individual stations published because additional data from shorter period stations are used to obtain better areal representation.
[2]In the absence of trend or record changes, the chances are 9 out of 10 that the true mean for temperature or precipitation will lie in the interval formed by adding and subtracting the listed values from the means for any station in the State. Because of the wider variation in mean precipitation, the corresponding monthly means and annual mean must be substituted for "p" in the precipitation data to obtain mean precipitation confidence limits.

NOTE. - Figures and letters following a station name, such as 2 NE, indicate distance in miles and direction from the U.S. Post Office.

Source: Lowers, A. R. Climate of the States, Wyoming. Weather Bureau, Climatography of the United States No. 60-48, February 1960, 16 pp.

TABLE B-4. - Normals, means, and extremes from four climatological stations in the Upper Missouri River basin

Month	Temperature (° F) Normal Daily maximum	Temperature Normal Daily minimum	Temperature Normal Monthly	Temperature Extremes Record highest	Year	Temperature Extremes Record lowest	Year	Normal degree-days[2]	Precipitation (inches) Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hours	Year	Snow, ice pellets[1] Mean total	Maximum monthly	Year	Maximum in 24 hours	Year	Relative humidity (percent) 5:00 a.m. MST	11:00 a.m. MST	5:00 p.m. MST	11:00 p.m. MST	Wind Mean hourly speed	Prevailing direction	Fastest mile Speed	Direction	Year	Percent of possible sunshine	Mean sky cover sunrise to sunset[3]	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog[4]	Temperatures Max. 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below
MILES CITY, MONT., MUNICIPAL AIRPORT																																										
(6)	(7)	(7)	(7)	33		33		(7)	(7)	33		27		27		30	30		17		10	10	10	10	21	14					18	18	18	18	33	21	20	18	26	26	26	26
J	27.4	5.6	16.5	62	1953	-37	1969+	1504	0.44	0.96	1965	0.08	1961+	0.42	1944	6.2	14.7	1949	7.5	1964	72	69	68	72	9.2	NW	NA	NA	NA	NA	6.8	6	8	17	8	2	0	1	0	18	31	12
F	31.8	8.7	20.3	66	1961	-37	1939	1252	.37	1.30	1959	.08	1954+	.77	1952	5.6	19.0	1949	6.5	1952	81	72	70	78	9.3	NW	NA	NA	NA	NA	7.0	5	8	15	7	2	0	2	0	13	28	8
M	42.3	19.4	30.9	83	1943	-27	1947	1057	.65	1.83	1950	.07	1959	.61	1944	5.4	17.8	1967	5.0	1957	79	63	55	74	10.5	NW	NA	NA	NA	NA	6.9	5	8	18	8	2	(8)	1	0	8	27	4
A	58.6	32.8	45.7	91	1952	7	1954	579	1.06	2.82	1969	.10	1952	1.36	1947	3.4	16.6	1967	10.5	1947	78	54	47	69	11.6	NW	NA	NA	NA	NA	6.8	5	8	17	8	2	1	1	(8)	1	16	0
M	70.6	44.1	57.4	99	1964	15	1954	276	1.73	5.33	1955	.24	1958	2.39	1955	.5	8.6	1967	2.0	1953	77	49	44	66	10.9	SE	NA	NA	NA	NA	6.5	6	10	15	10	(8)	4	1	1	(8)	3	0
J	78.5	52.6	65.6	104	1961	32	1951+	99	2.71	9.78	1944	.84	1961	2.71	1964	.1	2.0	1950	2.0	1950	78	47	41	66	10.1	SE	NA	NA	NA	NA	5.5	8	10	12	12	(8)	8	(8)	4	0	(8)	0
J	90.2	60.4	75.3	109	1960	41	1945	6	1.34	4.58	1948	.22	1959	2.02	1962+	.0	.0	-	.0	-	70	39	31	54	9.4	SE	NA	NA	NA	NA	4.0	15	12	4	8	0	8	(8)	16	0	0	0
A	87.5	57.7	72.6	110	1949	35	1966	6	1.24	4.00	1951	T	1967	1.65	1943	.0	.0	-	.0	-	63	36	27	47	9.5	SE	NA	NA	NA	NA	4.0	15	11	5	6	0	6	(8)	15	0	0	0
S	75.2	46.7	61.0	105	1950	20	1942	174	.96	4.67	1941	T	1960	2.67	1941	.1	3.0	1941	.7	1950	73	48	39	61	9.7	NW	NA	NA	NA	NA	5.1	10	10	10	7	0	2	(8)	3	0	1	0
O	62.4	35.5	49.0	93	1963+	9	1942	502	.87	3.20	1946	T	1965+	1.38	1953	1.4	12.6	1949	3.8	1946	72	48	44	62	9.6	SSE	NA	NA	NA	NA	5.4	12	8	11	5	(8)	(8)	1	(8)	(8)	11	0
N	43.5	21.7	32.6	75	1965+	-23	1955	972	.43	1.33	1964	.02	1953+	1.18	1957	3.8	14.6	1955	8.0	1964	78	64	62	74	9.7	SSE	NA	NA	NA	NA	6.6	7	7	16	6	2	(8)	1	0	6	26	2
D	33.6	12.8	23.2	69	1939	-31	1951	1296	.37	1.78	1968	.02	1957+	.50	1941	5.2	18.0	1968	7.0	1958	76	70	69	75	9.6	SSE	NA	NA	NA	NA	6.5	7	8	16	7	2	(8)	2	0	15	30	7
Yr	58.5	33.2	45.8	110	Aug 1949	-37	Jan 1969+	7723	12.17	9.78	June 1944	T	Aug 1967+	2.71	June 1964	31.7	19.0	Feb 1949	10.5	Apr 1947	75	55	50	66	9.9	SE	NA	NA	NA	NA	5.9	101	108	156	92	13	30	10	39	61	173	32

NOTE. - Foregoing means and extremes are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest tempertature 111° F in July 1901; lowest temperature -49° F in February 1899; minimum monthly precipitation 0.00 in August 1899 and earlier; maximum precipitation in 24 hours 3.74 inches in May 1908; maximum monthly snowfall 35.3 inches in March 1894; maximum snowfall in 24 hours 28.0 inches in March 1894.

Month	Temperature (° F) Normal Daily maximum	Temperature Normal Daily minimum	Temperature Normal Monthly	Temperature Extremes Record highest	Year	Temperature Extremes Record lowest	Year	Normal degree-days[2]	Precipitation (inches) Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hours	Year	Snow, ice pellets[1] Mean total	Maximum monthly	Year	Maximum in 24 hours	Year	Relative humidity (percent) 5:00 a.m. MST	11:00 a.m. MST	5:00 p.m. MST	11:00 p.m. MST	Wind Mean hourly speed	Prevailing direction	Fastest mile Speed	Direction	Year	Percent of possible sunshine	Mean sky cover sunrise to sunset[3]	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog[4]	Temperatures Max. 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below
BISMARCK, N. DAK., MUNICIPAL AIRPORT[9]																																										
(6)	(10)	(10)	(10)	18		18		(10)	(10)	18		18		18		18	18		18		18	18	18	18	18	8	18			18	18	18	18	18	18	18	18	18	18	18	18	18
J	20.1	-1.8	9.2	54	1942	-44	1950	1730	.36	1.24	1952	.02	1940	.67	1952	7.2	16.9	1950	7.9	1952	77	77	71	75	10.2	NW	54	W	1953+	54	6.6	8	7	16	8	3	0	1	0	23	31	18
F	23.3	2.1	12.7	62	1954	-34	1944	1464	.43	1.03	1952	.12	1954	.63	1951	6.0	12.7	1948	8.7	1951	80	79	71	76	10.5	WNW	54	NW	1953	56	6.6	6	8	14	7	2	0	1	0	20	28	13
M	36.7	16.6	26.7	81	1946	-31	1948	1187	.76	2.84	1950	.21	1947	1.30	1950	8.7	29.7	1950	13.5	1950	82	83	68	70	11.7	WNW	65	NW	1941	57	6.8	5	9	17	9	3	(8)	2	0	14	30	6
A	54.6	31.6	43.1	92	1952	- 2	1954	657	1.39	3.05	1948	T	1952	1.54	1948	3.1	11.3	1950	8.7	1942	76	83	53	51	13.0	NNW	63	W	1955	57	6.6	6	10	14	7	1	1	(8)	(8)	1	18	(8)
M	67.3	42.2	54.8	98	1941	19	1944	355	1.94	4.40	1953	.31	1952	1.88	1944	.9	10.3	1950	5.7	1950	72	79	49	47	12.8	E	61	NW	1945	59	6.4	7	11	13	9	(8)	4	1	1	0	4	0
J	76.3	52.2	64.3	99	1956+	33	1950+	116	3.33	8.29	1947	1.24	1949	3.25	1947	T	T	1943	T	1943	80	81	55	54	11.9	WNW	66	NW	1953	61	6.1	8	10	12	12	0	8	1	2	0	0	0
J	85.5	58.6	72.1	107	1949	39	1945	29	2.33	4.18	1949	.87	1953	1.78	1954	.0	.0	-	.0	-	79	85	52	49	9.9	E	72	W	1946	75	4.6	12	13	6	10	0	11	1	9	0	0	0
A	83.3	55.2	69.3	109	1941	37	1950	37	1.50	5.05	1944	.32	1940	2.06	1951	.0	.0	-	.0	-	76	85	50	47	10.0	E	72	S	1944	71	4.8	13	11	7	9	0	9	1	7	0	0	0
S	72.0	44.9	58.5	103	1948	16	1942	227	1.43	3.91	1941	.02	1948	1.99	1941	.3	4.1	1942	4.1	1942	75	84	50	50	10.6	WNW	49	NW	1954	64	5.4	11	9	10	7	(8)	3	1	3	0	2	0
O	58.5	32.9	45.7	95	1953	6	1942	598	1.00	2.34	1947	.07	1952+	1.24	1947	1.4	7.6	1946	4.9	1946	75	82	52	56	10.4	WNW	54	NW	1954	60	5.7	10	9	12	6	1	1	1	(8)	1	14	0
N	38.3	18.5	28.4	73	1953	-19	1940	1098	.53	2.56	1944	.08	1942	.99	1944	4.6	14.7	1955	6.6	1955	80	82	67	73	11.0	WNW	65	NW	1947	47	6.6	7	7	16	6	2	0	1	0	9	28	3
D	25.5	5.5	15.5	60	1949	-36	1951	1535	.40	.91	1951	T	1944	.38	1950	4.7	12.0	1950	7.6	1950	79	80	70	75	9.7	WNW	61	NW	1956	49	6.7	7	6	18	7	1	0	1	0	18	31	10
Yr	53.5	29.9	41.7	109	Aug 1941	-44	Jan 1950	9033	15.40	8.29	June 1947	T	Apr 1952+	3.25	June 1947	36.9	29.7	Mar 1950	13.5	Mar 1950	78	82	59	60	11.0	WNW	72	W	July 1946+	59	6.1	100	110	155	97	13	37	12	22	86	186	50

NOTE. - Foregoing means and extremes are from the existing or comparable location(s). Annual extremes have been exceeded at prior locations as follows: Highest termperature 114° F in July 1936; lowest temperature -45° F in February 1936 and earlier date(s); maximum monthly precipitation 9.90 inches in June 1914; maximum precipitation in 24 hours 3.76 inches in June 1914; maximum monthly snowfall 31.0 inches in November 1896.

TABLE B-4. - Normals, means, and extremes from four climatological stations in the Upper Missouri River basin--Continued

WILLISTON, N. DAK., POST OFFICE[9]

Month	Temperature (° F): Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Extremes: Record lowest	Year	Normal degree days[2]	Precipitation (inches): Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hours	Year	Snow, ice pellets[1]: Mean total	Maximum monthly	Year	Maximum in 24 hours	Year
(6)	(10)	(10)	(10)	41		41		(10)	(10)	41		41		41		41	41		41	
J	19.8	.2	10.0	55	1944	-40	1935	1705	.49	1.51	1943	.04	1940	.55	1953	5.7	17.0	1954	6.5	1943
F	23.2	3.7	13.5	66	1932	-50	1936	1442	.46	1.24	1930	T	1934	.60	1951+	4.8	13.7	1948	6.6	1951
M	36.0	17.0	26.5	79	1946	-29	1948	1194	.75	2.18	1920	.06	1930	1.22	1920	6.6	18.2	1936	8.6	1936
A	54.0	31.8	42.9	91	1952+	- 3	1954+	663	1.07	2.45	1948	T	1931	1.55	1918	3.4	14.9	1923	10.6	1947
M	66.2	42.9	54.6	99	1934	15	1945	360	1.66	4.69	1927	.08	1917	2.94	1925	.8	11.2	1927	9.2	1927
J	73.9	52.1	63.0	108	1931	31	1951	138	3.59	7.88	1944	.57	1918	3.06	1932	T	T	1943	T	1943
J	83.5	58.2	70.9	110	1936	37	1934	29	2.13	6.07	1928	.36	1917	2.10	1938	.0	.0	-	.0	-
A	81.2	54.9	68.1	108	1949	35	1934+	42	1.41	5.06	1947	.20	1949	1.60	1927	.0	.0	-	.0	-
S	69.7	44.6	57.2	101	1948	17	1928	261	1.21	3.62	1954	.02	1948	1.96	1951	.2	2.8	1926	2.6	1942
O	57.0	34.0	45.5	92	1957	- 2	1919	605	.77	2.11	1932	T	1944	1.47	1953	2.2	11.0	1919	8.8	1938
N	37.3	19.3	28.3	70	1916	-20	1921	1101	.58	1.37	1922	T	1949+	.95	1922	3.8	11.5	1940	8.0	1940
D	24.8	6.6	15.7	63	1939	-33	1916	1528	.54	2.11	1933	.03	1944	.74	1918	5.3	21.2	1933	5.8	1929
Yr	52.2	30.4	41.3	110	July 1936	-50	Feb 1936	9068	14.66	7.88	June 1944	T	Nov 1949+	3.06	June 1932	32.8	21.2	Dec 1933	10.6	Apr 1947

Month	Relative humidity (percent): 5:00 a.m. MST	11:00 a.m. MST	5:00 p.m. MST	11:00 p.m. MST	Wind: Mean hourly speed	Prevailing direction	Fastest mile: Speed	Direction	Year	Percent of possible sunshine	Mean sky cover sunrise to sunset[3]	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog[4]	Temperatures Max.: 90° and above	32° and below	Min.: 32° and below	0° and below
(6)	16	41	40	41	30	30	38			41	16	41	41	41	41	41	41	41	41	41	41	41
J	74	74	67	69	6.8	W	38	W	1933	51	6.7	9	8	14	8	2	0	1	0	23	31	15
F	75	76	67	69	7.1	W	37	SE	1932	58	7.0	8	8	12	6	2	0	1	0	19	28	12
M	79	79	64	64	8.2	NW	43	W	1953	60	7.0	9	10	12	7	2	0	1	0	12	29	4
A	68	77	49	47	8.8	SE	38	W	1950	63	6.6	9	10	11	7	1	1	(8)	(8)	2	15	(8)
M	67	74	45	42	8.7	SE	45	W	1952	66	6.5	10	11	10	9	(8)	3	(8)	1	(8)	4	0
J	75	79	50	47	8.1	SE	56	E	1952+	66	6.7	10	11	9	12	0	8	(8)	2	0	(8)	0
J	71	78	45	41	7.0	SE	60	W	1946	79	4.7	15	12	4	9	0	9	(8)	8	0	0	0
A	67	77	44	39	6.9	SE	46	W	1937	75	5.0	15	11	5	8	0	6	(8)	6	0	0	0
S	70	80	47	45	7.3	SE	38	NW	1933	66	5.8	12	9	9	7	(8)	2	1	1	(8)	2	0
O	70	79	52	53	7.5	SE	40	W	1951+	60	5.9	11	11	9	5	1	(8)	1	(8)	1	13	(8)
N	78	79	66	69	7.4	W	53	NW	1933	48	6.8	8	8	14	6	1	0	1	0	10	27	2
D	77	76	69	71	6.8	SW	47	NW	1956	48	7.0	9	8	14	7	2	0	1	0	19	31	10
Yr	73	77	55	55	7.6	SE	60	W	July 1946	64	6.3	125	117	123	91	11	29	7	18	86	180	43

NOTE. - Foregoing means and extremes are from the existing or comparable location(s). Annual extremes have been exceeded at prior locations as follows: Maximum monthly precipitation 8.84 inches in June 1901; maximum precipitation in 24 hours 4.16 inches in May 1893; maximum monthly snowfall 26.6 inches in April 1896.

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Month	Temperature (° F): Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Extremes: Record lowest	Year	Normal degree days[2]	Precipitation (inches): Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hours	Year	Snow, ice pellets[1]: Mean total	Maximum monthly	Year	Maximum in 24 hours	Year
(6)	(10)	(10)	(10)	17		17		(10)	(10)	17		17		17		17	17		17	
J	32.8	7.4	20.1	70	1953	-30	1951	1392	.75	1.70	1948	.15	1952	.88	1948	9.7	22.9	1949	8.3	1946
F	35.7	10.7	23.2	73	1951	-31	1949	1170	.61	2.68	1955	.10	1941	1.10	1955	11.9	35.0	1955	11.0	1955
M	43.3	19.9	31.6	76	1943	-20	1955	1035	1.37	3.26	1946	.42	1941	2.25	1946	15.6	36.8	1954	13.3	1946
A	56.0	30.9	43.5	87	1946	2	1945	645	2.26	4.53	1948	.80	1952	3.84	1948	9.0	39.6	1955	26.7	1955
M	65.9	39.8	52.9	95	1948	13	1954	387	2.64	4.94	1956	.67	1940	2.04	1956	1.8	11.0	1943	7.3	1954
J	74.9	47.9	61.4	100	1940	27	1951	161	2.60	9.54	1944	1.07	1956	3.44	1944	.2	3.2	1951	3.2	1951
J	86.1	55.0	70.6	106	1954	40	1943	27	1.38	3.48	1952	.13	1953	2.28	1948	.0	.0	-	.0	-
A	84.4	52.8	68.6	105	1949	38	1952	41	.82	2.00	1945	.07	1940	1.71	1943	.0	.0	-	.0	-
S	72.9	42.8	57.9	100	1940	26	1955+	239	1.45	3.08	1951	.26	1952	1.33	1947	.5	3.2	1941	3.2	1941
O	60.8	32.4	46.6	89	1953	8	1941	578	1.27	2.11	1946	.08	1944	1.38	1953	3.9	10.9	1949	7.8	1949
N	45.7	20.5	33.1	76	1949	-18	1955	957	.93	2.23	1942	.15	1951	.86	1942	8.5	24.0	1942	12.0	1942
D	36.5	11.5	24.0	71	1941	-24	1944	1271	.67	2.03	1955	.23	1957+	.54	1946	8.8	27.6	1955	6.3	1955
Yr	57.9	31.0	44.5	106	July 1954+	-31	Feb 1949	7903	16.75	9.54	June 1944	.07	Aug 1940	3.84	Apr 1948	69.9	39.6	Apr 1955	26.7	Apr 1955

Month	Relative humidity (percent): 5:00 a.m. MST	11:00 a.m. MST	5:00 p.m. MST	11:00 p.m. MST	Wind: Mean hourly speed	Prevailing direction	Fastest mile: Speed	Direction	Year	Percent of possible sunshine	Mean sky cover sunrise to sunset[3]	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog[4]	Temperatures Max.: 90° and above	32° and below	Min.: 32° and below	0° and below
(6)	17	17	17	15	17	9	17	17		17	14	17	17	17	17	14	17	17	17	17	17	17
J	73	62	66	71	7.7	NW	73	NW	1946	57	6.6	7	9	15	8	3	0	1	0	12	31	9
F	74	61	64	73	8.0	NW	70	W	1957	60	6.6	6	9	13	9	4	(8)	1	0	9	28	5
M	77	59	61	74	9.1	NW	65	SW	1955	61	6.8	5	9	17	12	5	0	1	0	7	29	4
A	77	48	46	70	10.0	NW	66	NW	1947	59	6.6	6	8	16	11	3	1	1	0	1	16	0
M	79	48	48	71	9.3	NW	71	NW	1946	56	6.7	5	11	15	13	(8)	6	(8)	(8)	(8)	4	0
J	81	49	48	74	8.7	NW	66	SW	1952	61	5.8	8	11	11	11	(8)	10	(8)	1	0	(8)	0
J	72	36	35	62	7.5	W	73	W	1947	76	3.9	15	12	4	7	0	10	(8)	12	0	0	0
A	70	35	32	58	7.5	NW	72	NW	1945	74	4.1	14	12	5	7	0	8	(8)	11	0	0	0
S	73	40	39	64	7.8	NW	66	NW	1945	67	4.8	12	10	8	8	(8)	3	(8)	2	(8)	2	0
O	73	44	47	66	7.7	NW	66	NW	1947+	65	5.3	11	9	11	7	1	(8)	(8)	0	(8)	14	0
N	75	57	65	73	8.2	NW	84	SW	1949	54	6.4	6	9	15	8	3	0	1	0	4	27	1
D	73	61	68	71	7.7	NW	63	NW	1955	52	6.6	6	9	16	8	4	0	1	0	9	30	4
Yr	75	50	52	69	8.3	NW	84	SW	Nov 1949	63	5.9	101	118	146	109	23	38	6	26	42	181	23

NOTE: - Foregoing means and extremes are from the existing or comparable location(s). Annual extremes have been exceeded at prior locations as follows: Lowest temperature -41° F in December 1919; minimum monthly precipitation T in November 1939 and earlier dates; maximum precipitation in 24 hours 4.41 inches in July 1923; maximum monthly snowfall 42.6 inches in April 1927.

NA Not available. + Also on earlier dates, months, or years. T Trace, an amount too small to measure.
[1]Sleet was included in snowfall totals beginning with July 1948.
[2]Degree-day totals are the sums of the negative departures of average daily temperature from 65° F. Below zero temperatures are preceded by a minus sign (-).
[3]Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.
[4]Heavy fog reduces visibility to ¼ mile or less.
[5]Cordell, G. V., Jr. Climates of the States, Climate of Montana. National Oceanic and Atmospheric Administration Environmental Data Service, Climatography of the United States No. 60-24, March 1971, 21 pp.
[6]Length of record, years.
[7]Climatological standard normals (1931-60).
[8]Less than ½ unit.
[9]Bavendick, F. J. Climate of the States, North Dakota. Weather Bureau, Climatography of the United States No. 60-32, October 1959, p. 8-9.
[10]Normal values are based on the period 1921-50, and are means adjusted to represent observations taken at the present standard location.
[11]Lowers, A. R. Climate of the States, Wyoming. Weather Bureau, Climatography of the United States No. 60-48, February 1960, p. 9.

APPENDIX C.--LAND RECLAMATION

TABLE C-1. - List of major factors, fixed and variable, for planning a strip-mining operation and its land reclamation

Factors	Affected or determined by--
Land use	Surface owner and/or lessee. Regulation. Water quality and quantity. Aesthetics.
Direction of mining	Topography. Pitch of coal or lignite seam.
Water control	Quality and quantity. Contamination potential. Mine use. Use after leaving mine property. Aesthetics.
Water storage	Quality and quantity. Mine use. Use after leaving mine property. Treatment, if required. Aesthetics.
Roads (access, haul, fire lanes, and railroads).	Topography. Overburden thickness. Coal or lignite seam(s) thickness. Classifications of subgrade materials. Aesthetics.
Electric power transmission	Topography. Aesthetics.
Refuse disposal	Type refuse. Depth of water table.
Reclamation requirements	Law. Topography. Land use. Overburden type. Climate. Aesthetics.
Pit width	Equipment size and type. Reclamation requirements. Overburden thickness (depth). Mine-safety requirements.
Equipment (size, type, and quantity).	Annual output. Overburden thickness and type. Reclamation and mine-safety requirements. Preference. Coal or lignite seam(s) thickness.

TABLE C-2. - List of publications describing progress made in establishing vegetation on strip-mined land in the Upper Missouri River basin

States and authors	Publication
Montana:	
Hodder, R. L., and Sindelar, B. W.	Coal Mine Land Reclamation Research, Decker, Mont., Progress Report 1971. Mont. State Univ. Agr. Exp. Station, Res. Rept. 21, April 1972, 29 pp.
Hodder, R. L., Sindelar, B. W., Buchholz, J., and Ryerson, D. E.	Coal Mine Land Reclamation Research, Western Energy Co., Colstrip, Mont. Progress Report 1971. Mont. State Univ. Agr. Exp. Station, Res. Rept. 20, March 1972, 45 pp.
Hodder, R. L., Ryerson, D. E., Mogen, R., and Buchholz, J.	Coal Mine Spoils Reclamation Research Project, Western Energy Co., Colstrip, Mont. Mont. State Univ. Agr. Exp. Station, Res. Rept. 8, 1970, 56 pp.
Hodder, R. L., and Sindelar, B. W.	Progress in Reclamation Research in Montana. Mont. State Univ. Agr. Exp. Station, Misc. 11, April 1972, 12 pp.
Hodder, R. L......	Revegetation Methods and Criteria for Bare Areas Following Highway Construction. Mont. State Univ. Animal and Range Sciences Dept., July 1970, 97 pp.
Hodder, R. L., and Sindelar, B. W.	Tubelings--A New Dry Land Technique for Roadside Stabilization and Beautification. Mont. State Univ. Agr. Exp. Station, Res. Rept. 18, March 1972, 19 pp.
Montana and North Dakota:	
Gwynn, T. A.......	Reclaiming Strip-Mined Land by Establishing Game Management Areas, a Progress Report. Knife River Coal Mining Co., Bismarck, N. Dak., July 15, 1966, 27 pp.
North Dakota:	
Gwynn, T. A.......	Reclaiming Strip-Mined Land in North Dakota by Establishing Game Management Areas. Knife River Coal Mining Co., Bismarck, N. Dak., Jan. 1, 1965, 41 pp.
Gwynn, T. A.......	Report of the Land Reclamation Task Force, North Central Power Study. March 1971, 30 pp.
Carlson, C. G., and Laird, W. M.	Study of the Spoil Banks Associated With Lignite Strip Mining in North Dakota. N. Dak. Geol. Survey Misc. Series 24, 1964, 28 pp.
Wyoming:	
May, M., Lang, R., Lujan, L., Jacoby, P., and Thompson, W.	Reclamation of Strip Mine Spoil Banks in Wyoming. Univ. Wyo. Agr. Exp. Station, Res. 51, September 1971, 32 pp.[1]

[1]Experiments were made outside the Upper Missouri River basin.

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