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Evaluation of the Environmental Effects of Western Surface Coal Mining

Volume I

Interagency Energy/Environment R&D Program Report

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May 1979

EVALUATION OF THE ENVIRONMENTAL EFFECTS OF WESTERN SURFACE COAL MINING
Volume I

by

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Contract No. 68-03-2226

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the pollutional impact on our environment and even on our health often requires that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

An evaluation of the surface coal mining methods presently used in arid and semi-arid regions of the western United States and a description of the effects that those methods have on the environment are presented in this volume. In addition, recommendations on how those methods might be altered to reduce both long-term and short-term environmental effects are presented. For further information, contact the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
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ABSTRACT

The objectives of this project were to describe and evaluate the methods presently used for surface mining of coal in the western United States, to identify and evaluate the effects that use of those methods have on the environment, and to recommend ways in which the methods might be altered to reduce both long-term and short-term environmental damage.

This was accomplished by statistical analysis of comprehensive production and reclamation data for all 44 western surface mines active or under development in 1975, and through qualitative evaluations based on personal interviews of state and Federal reclamation specialists and field surveys of nine mines during three seasons of the year.

On a regional basis, the short-term environmental damages caused by western surface coal mining in 1975 and 1976 were deemed to be neither severe nor extensive. There are, however, areas in which current or projected concentration of large-scale surface coal mining activities could produce serious local effects in both the short- and long-terms. Additionally, there are regional uncertainties regarding the long-term severity and extent of certain potential environmental damages.

There appears to be one significant way in which current mining methods may need to be altered to reduce environmental damage. It is modification of operating practices to enable more selective removal of overburden and placement of spoil, particularly where multiple seams are mined. This would include not placing high-sodium clays and shales on spoil surfaces and preventing the placement on pit floors of materials high in soluble minerals or trace elements.

This report was submitted in fulfillment of Contract No. 68-03-2226 by Mathtech, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from June 25, 1975, to April 30, 1977, and work was completed on June 3, 1977.

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ACKNOWLEDGMENTS

The guidance and assistance of Mr. S. Jackson Hubbard, Project Officer, are gratefully acknowledged, particularly in allowing the latitude necessary to place the problem in its proper perspective.

Field surveys and assessments of the environmental impacts of mining activities at those mines were conducted by Hittman Associates of Columbia, Maryland under subcontract to Mathematica. Peter Briggs and Thomas Mills were the principal project participants for Hittman.

Mr. James E. Biller, Mining Engineering Consultant, helped greatly during conduct of the field survey and analysis of modified mining methods. Dragline and bucket wheel excavator operating alternatives, production analyses, and cost analyses were prepared by Mr. Wilbur A. Weimer, retired Vice President of Engineering for Peabody Coal Company, and now an independent mining consultant.

The cooperation of mining company personnel in allowing unlimited and repeated access to their mining and reclamation operations, and in providing extensive information, was invaluable. Listed below are the names and affiliations of some of the people who helped:

- Consolidation Coal Company (Glenharold Mine): Buddy Beach, David Kirtz, Richard Huscka.
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- Kemmerer Coal Company (Elkol and Sorenson Mines): Gus Tuason, Louis Engstrom, James Brophy.
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- Montana Bureau of Mines and Geology:
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  Richard Hodder, Bernard Jensen.

- U.S. Bureau of Land Management:
  Ron Kuhlman (Denver).

- U.S. Department of Agriculture, Forest Service, SEAM Program (Billings):
  Grant Davis.

Finally, while much of this report is based on information provided by the foregoing people, all conclusions are those of the authors.

SECTION 1

INTRODUCTION

Rapid growth since 1969 of production of western coal by the surface mining method has aroused public interest in the possible environmental, social, economic, and political effects not only of mining, but also of coal transportation, conversion, and utilization. This report addresses the environmental effects of mining -- particularly the physical effects.

In recent years, doubts over the feasibility of adequate reclamation of mined lands in arid and semi-arid western climates have been voiced. Some have questioned the feasibility of revegetating mined lands; others believe that groundwater systems may be disrupted or that groundwater will be contaminated by mining. Additional uncertainties, such as those concerning the effects of mining on air quality, persist as well.

Historically in other parts of the country, particularly in Appalachia, it has been concluded that reclamation as an add-on-technology, appended to existing mining methods, would not be adequate to prevent severe and extensive environmental damage. Instead, basic modification of the mining methods themselves, to incorporate reclamation-related practices, has been shown to be necessary. The purpose of this study was to detail the environmental damage which results from the mining methods currently being utilized.

SECTION 2

CONCLUSIONS

On a regional basis, the short-term environmental damages caused by western surface coal mining in 1975 and 1976 were deemed to be neither severe nor extensive. This is due not only to unique features of the western environment, such as gradual topography and virtual absence of acid overburden strata, but also to stringent reclamation laws, organizational changes at the mines, and commitment by mining companies of the resources needed for adequate reclamation. The relatively low rate of land disturbance by present western surface coal mining activities is also a factor.

These general conditions notwithstanding, however, there are areas in which current or projected concentration of large-scale surface coal mining activities could produce serious local effects in both the short- and long-terms. Additionally, because there has not yet been a "long-term" in western surface coal mining as currently practiced, there are uncertainties regarding the long-term severity and extent of certain potential environmental damages. For example, for the region as a whole, there is uncertainty regarding the feasibility of permanently restoring mined lands to pre-mining productivity levels.

Based on available information, though, it now appears in general that mined lands can be adequately revegetated with species suitable for erosion control and planned post-mining land uses, so long as the best available topsoiling material is salvaged (as it is at 96 percent of the active mines), and proper techniques for seedbed preparation, seeding, and amendment are used. Time will tell whether additional procedures, such as irrigation (infrequently used at present), will be needed to guarantee long-term vegetation success. There are notable exception to this such as the very arid areas located in the southwestern portions of the United States.

The potential effects of mining on groundwater quantity and quality appear to be local ones, since indications are that the aquifers disturbed by mining are shallow and generally discontinuous. Mining activities have in some cases caused dewatering of wells located close to the mines, but an apparently effective remedy has been for the mining companies to drill deeper wells. Additionally, there are uncertainties regarding the long-term effects of mining on local groundwater quality. If current research indicates that there are problems, it may prove to be necessary on site-specific bases to remove and place overburden materials selectively as a means of minimizing degradation of the quality of local groundwater supplies.

The effects of mining activities on air quality have not yet been widely assessed, so that no conclusions have been drawn about the need for, or lack of need for, control measures to reduce fugitive dust emissions.

Other kinds of environmental damages, such as creation of closed surface depressions, erosion, and mineralization of surface waters, could possibly be fairly serious local problems if adequate preventive technology was not brought to bear. But in general, the technology is available; it is being used; and it costs relatively little on a per-ton basis where the thickness of the coal exceeds about six meters (20 feet).

The predominant mining methods presently used in the west are dragline stripping of single and multiple coal seams. There appears to be one significant way in which those methods may need be altered to reduce environmental damage. It is modification of operating practices to enable more selective removal of overburden and placement of spoil, particularly where multiple seams are mined, to prevent placement of high-sodium clays and shales on spoil surfaces, or to prevent placement on pit floors of materials high in soluble minerals or trace elements.

It is desirable to devise mining equipment or methods that would enable placement of topsoiling materials directly on graded spoils by the main stripping machine.

It is also desirable to identify and evaluate alternative means for minimizing the effects of mining on groundwater quality and quantity, particularly where alluvial valley floors are to be mined. This would be a logical supplement to research now being conducted to assess the effects of mining on aquifer systems.

SECTION 3

RECOMMENDATIONS

Extensive research is currently being conducted to assess the magnitudes of the environmental effects of western surface coal mining, and to identify and evaluate means for mitigating those effects. The research recommendations presented in this report are intended to supplement the current research program.

It is recommended that the Environmental Protection Agency sponsor a symposium on selective overburden and spoil placement techniques used or proposed for use in dragline stripping situations. In this regard, it is desirable that symposium material be prepared by and for mine engineering and operating personnel rather than by and for contract researchers, and that participation of midwestern mine personnel as well as those in the west be solicited. Emphasis should be placed on practical aspects, including information requirements, methods used in advance of mining to identify desirable and undesirable strata, operating practices used to enable dragline operators to identify the various strata, management techniques used to ensure that dragline operators follow plans, overburden removal and spoil placement techniques, production and cost characteristics, alternatives considered, and operational performance and problems.

It is further recommended that consideration be given to conduct of laboratory or field studies to determine the effects of selective removal and placement practices on required topsoil replacement depths, revegetation success, and water quality.

Consideration should also be given to conduct of a study to identify and evaluate alternative methods for minimizing the effects of mining on groundwater quantity and quality, both during and after mining. This would be a logical supplement to the research projects now being conducted to assess groundwater effects.

Finally, with industry cooperation, an analysis of the feasibility, costs, and effectiveness of bucket wheel excavators for overburden removal at large mines in North Dakota should be considered. Use of such a system may enable placement of topsoil by the main stripping machine directly on graded spoil surfaces.*

*A bucket wheel excavator was at one time used at a North Dakota mine for removal of overburden and interburden and mining of three coal seams from one machine position. This application was considered unsuccessful primarily because mining of the coal by the bucket wheel excavator resulted in unacceptably high ash content in the coal.

SECTION 4

BACKGROUND, OBJECTIVES, SCOPE

BACKGROUND

Recent rapid development of the thick, shallow, low-sulfur coal reserves of the western United States -- initially stimulated by increased demand for low-cost, low-sulfur coal -- has aroused public interest in the possible social, economic, and environmental effects of western coal mining, transportation, conversion, and utilization. The feasibility of reclamation of surface-mined lands in arid and semi-arid western regions, for example, has repeatedly been challenged, most notably by the Sierra Club in a suit brought against the U.S. Department of Interior to slow or stop surface mining of Federally owned coal in the eastern Powder River Basin. Although the injunction won by the Sierra Club in that suit has since been lifted by the U.S. Supreme Court, thereby permitting the opening of several large mines in eastern Wyoming, skepticism over reclamation feasibility persists. This is manifested not only by the numerous surface coal mining and reclamation research projects now being conducted in the region, but also by the determination of the people in states like Montana to control the rate of growth of coal production.

But, environmental concerns notwithstanding, the social and economic effects of mining, transportation, conversion, and utilization of coal are also important. For example, it is probably fair to state that opposition to construction and operation of the Four Corners (New Mexico) and Colstrip Units 3 and 4 (Montana) power plants was far greater than the opposition to the mines from which those power plants are supplied. Such opposition, motivated in part by concern over air pollution, was intensified by the fact that, although the coal is mined and burned in-state, the electricity is transmitted to out-of-state users.

The transportation, conversion, and utilization of coal may entail the use of large quantities of water, whether for coal slurry pipelines, water-cooled power plants, or coal gasification plants. To many people in the arid west, this prospect is alarming at best. Additionally, in the case of coal gasification, the spectre of huge gasification plants looming on quiet, rural western horizons, is sufficient to unnerve the local populace.

There are many more examples; the effects of rapid population growth are the most notable of those. They include overcrowded schools, increased taxes and, overall, a kind of shattering of the rural tranquility. Grace Lichtenstein of the New York Times put it this way:

> "In recent years, Gillette [in northeastern Wyoming] has exhibited many symptoms of the trailer-lined energy boom town that is scarring the Western landscape -- inflated rents, mobile homes on dirt strips, overcrowded schools, crime and mental health problems. The one local car rental agency charges premium rates for cars with 75,000 miles on them. Liquor stores outnumber groceries." [1]

The focus of the present study was the environmental impacts of western surface coal mining as practiced during 1975 and 1976, but it is clear that a balanced perspective on this subject can be achieved only in the context of other types of impacts, other activities associated with coal development, and other uses of land.

STUDY OBJECTIVES

The purposes of this study were threefold:

- To evaluate, qualitatively, the surface coal mining methods presently used in arid and semi-arid regions of the western United States.
- To describe and evaluate the effects that those methods have on the environment.
- To recommend ways in which those methods might be altered to reduce both short-term and long-term environmental damage.

SCOPE OF STUDY

The study included current surface coal mining and reclamation methods and equipment used in the states of North Dakota, Montana, Wyoming, Colorado, New Mexico, and Arizona. Social and economic aspects, and other phases of coal development and utilization were considered to be within the scope where necessary to provide needed perspective.

STUDY METHODOLOGY

The methodology used to achieve study objectives was basically a qualitative one involving the following tasks:

- Compilation of a comprehensive inventory of information on climate, topography, geology, mining methods, and reclamation practices for all western surface coal mines active during 1976 or planned for opening prior to 1980. This inventory is documented in an accompanying volume.

- Statistical classification and analysis of inventory data to determine, quantitatively, the frequency of occurrence of various physical and technological conditions.

- A survey of literature on mining methods, reclamation practices, and environmental impacts, with emphasis on research studies and environmental impact statements recently completed or currently in progress.

- Personal interviews of state and Federal government personnel responsible for regulation of reclamation of surface coal mines.

- A field survey of nine surface coal mines. Each mine was visited during three different seasons of the year.

Regarding the personal interview phase of the project, an attempt was made to identify consensuses of opinion regarding the magnitudes of the environmental impacts caused by surface coal mining in the region. This was generally possible, although individual differences of opinion were encountered. In one state, for example, a reclamation specialist, an ecologist by training, indicated his opinion that surface mining destroys soils that may have required hundreds of years for development. He felt that current methods for salvaging and replacement of topsoil were not effective, for two reasons. First, he indicated, the various soil horizons are mixed during removal of soil by scraper prior to main stripping. Secondly, he felt that the fertility of the soil was destroyed during the period in which the soil remained stockpiled prior to replacement on graded spoil surfaces.

In the same state, another reclamation specialist, a soils scientist, stated that mining and reclamation as practiced in that state improved the overall plant-growing medium. He felt that topsoil salvaging and replacement as currently practiced was an effective reclamation practice, that stockpiling of soil for relatively long periods of time had little effect on soil fertility, and that breaking up of the clay hardpan normally near the surface in many western mining areas was a beneficial effect.

The foregoing opinions were weighed by members of the study team in light of reclamation performance observed at the nine field survey mines. Judgments regarding the effectiveness of the reclamation practices were then made.

The nine field survey mines each were visited during October 1975, January 1976, and April 1976. In each instance, mining and reclamation personnel at the mines were interviewed. Additionally, mining operations, reclamation operations, and areas in various stages of reclamation were observed and photographed. In all instances, members of the field survey team were allowed unlimited access to all parts of the mines.

The principal field survey investigators were a hydrologist and a mining engineer. On various occasions, these individuals were also accompanied by a biologist, a geological engineer, and a mechanical engineer.

Average annual production for the field survey mines was 1,250,000 tons per year. The mines included the following ones:

- Two area lignite mines located in semi-arid areas.
- Three area mines located in semi-arid areas. One of those was in Colorado, where the coal seams pitched moderately.
- Two open pit coal mines, one located in an arid area, the other in a semi-arid area.
- Two area coal mines located in an arid area.

SYNOPSIS OF SUBSEQUENT SECTIONS

Major environmental issues and impacts associated with western surface coal mining are identified in the next section. This is accomplished after describing the growth and structure of the mining industry, the environmental setting, and the impacts of other phases of coal development and other land uses.

Section 6 contains a classification and description of current mining and reclamation practices. Relationships between mining methods and reclamation performance are emphasized. Statistics describing the frequency of use of various mining and reclamation practices are also presented in this section, as are assessments of the effectiveness of current reclamation practices.

Possible means for improving reclamation performance or reducing the costs of achieving current reclamation results through modification of mining equipment or methods are discussed in Section 7.

SUMMARY

The recent growth of surface coal mining activity in the western United States has aroused interest not only in the environmental effects of the mining operations themselves, but also in the social, economic, and environmental effects of coal transportation, conversion, and utilization. Thus, although the focus of the present study was the environmental impact of mining, related issues are discussed in this report to provide needed perspective.

The basic purposes of this study were to evaluate the surface coal mining methods currently used in the western United States, to describe and evaluate the effects that those methods have on the environment, and to recommend ways in which the methods might be altered to reduce both short-term and long-term environmental damage.

The study included current surface coal mining operations in North Dakota, Montana, Wyoming, Colorado, New Mexico, and Arizona. Evaluation of mining and reclamation equipment and methods was within the scope of the study.

The approach taken to achieve study objectives was basically a qualitative one, involving judgments made by study team personnel on the basis of information gathered from literature surveys, personnel interviews of government and industry mining and reclamation specialists, and field surveys of nine western surface coal mines in three different seasons of the year.

SECTION 5

ISSUES AND IMPACTS

INTRODUCTION

In evaluating the environmental effects of western surface coal mining and identifying research needs in that area, it is important first to identify the major issues associated with development of strippable western coal reserves, to differentiate between apparent issues and real ones, and to identify the factors underlying the real issues. Additionally, prior to any discussion or evaluation of mining methods and reclamation practices, it is desirable to define the types, potential extent and potential severity of the environmental effects of surface coal mining in the region. These objectives are accomplished in the present section.

First, the general setting for coal development is described. Next, the factors that have caused concern over development of strippable western coal reserves are identified. The physical, institutional, and technological factors that affect the potential extent and severity of environmental damages are then discussed, and types of environmental effects are classified as insignificant or potentially significant.

THE GENERAL SETTING FOR DEVELOPMENT

Development of the vast strippable coal reserves of the western United States is taking place in sparsely populated agricultural and ranching areas located in arid and semi-arid climates. These three regional factors -- population density, land use, and climate -- more than any others, have greatly influenced public attitudes toward development of strippable coal reserves in the region.

Although, because productivity in western surface coal mining is very high, the effects of mine employment on population density in areas other than Campbell County, Wyoming, Colorado's Yampa Basin, and the Beulah/Stanton area of North Dakota (where very rapid growth in mining is now occurring) are generally small, the effects on population of associated activities, such as construction of mine-mouth power plants, may be large.*

*Average direct employment in 1975 was 87 employees per mine. Total direct employment in the six-state area was approximately 4,000 employees for 45 surface coal mines.

The climate in western surface coal mining areas is arid or semi-arid, with average annual precipitation ranging from 18 centimeters (seven inches) in northwestern New Mexico to 51 centimeters (20 inches) in western North Dakota. In such a setting, any land use that affects surface or groundwater quantity or quality in any potentially adverse way will be viewed critically by many people. This is particularly true of groundwater (aquifer) systems.

The predominant land use in western surface coal mining areas is grazing of cattle and sheep. In fact, as shown in Table 1, 97 percent of the area disturbed by mining in 1975 was used for grazing of cattle or sheep prior to mining. Coal mining is a relatively new land use, at least on present and projected scales, and there is naturally some skepticism over the compatibility of the existing land uses with this new use.* Additionally, the new land use brings with it new kinds of people, with economic, educational, political, and social backgrounds different from those of the native ranchers and farmers. The result is a kind of cultural shock for natives and newcomers alike.

Although there has been surface coal mining activity in the region for the past fifty years, it was not until the early 1970's, when the boom in western surface coal production began, that the foregoing factors came into play in an important way.

TABLE 1. FREQUENCY OF OCCURRENCE OF PREMINING LAND USES AT MINES ACTIVE OR UNDER DEVELOPMENT IN 1975

Predominant Premining Land Use	Frequency of Occurrence at Mines in 1975	
	Percent of Acres	Percent of Mines
Cropland or Hayland	3	11
Grazing of Cattle or Sheep	97	89
Wildlife Habitat	Negligible	Negligible

*The importance of this kind of skepticism is illustrated in another part of the country by the public relations campaign sponsored by a major coal company to popularize the slogan, "Cows, Coal, and Corn are Compatible."

FACTORS AFFECTING PUBLIC ATTITUDES TOWARD DEVELOPMENT OF STRIPPABLE COAL RESERVES

As a further means of presenting the issues surrounding western surface coal mining, an elaboration of the foregoing discussion is presented next.

The Growth of Mining

For the three decades preceding 1969, total western surface coal mine output remained fairly constant at 1.8 million metric tonnes (two million tons) annually. Since 1969, as shown in Figure 1, production growth has been truly startling, increasing at an average annual compound rate of 30 percent, from 14.5 million metric tonnes (16 million tons) in 1969 to 68 million metric tonnes (75 million tons) in 1975. At this rate, annual production doubles roughly every three years. By 1985, it is conservatively forecast that regional production will have reached 318 million metric tonnes (350 million tons) annually, resulting in an annual mining disturbance of approximately 6,962 hectares (17,203 acres).* At the same time, as illustrated in Figure 2, the relative importance of underground coal mining, at least in the next decade, will continue to decline. For 1985, for instance, it is estimated that surface mining will account for nearly 95 percent of total western coal production.

Geographically, production comes from most of the strippable coal reserves areas shown in Figure 3, but, as shown in Figure 4, the majority (approximately two-thirds) of actual 1975 and forecasted 1980 regional production is accounted for by two states -- Wyoming and Montana. The latter Figure also shows that production growth between the years 1975 and 1980 will occur in all states individually.

Historically, in the eastern and midwestern surface coal mining regions of the United States, rapid growth in surface coal mining coupled with a lack of stringent reclamation laws underlay the extensive environmental damage that resulted. The damage was widely and graphically publicized. Thus, in 1969, when growth in western mining began in earnest, it is understandable that the average citizen in the west envisioned thousands of miles of eroding, unstable, unsightly spoil banks; exposed highwalls; and heavily sedimented and acidified streams.

Markets for Western Coal

As though the perceived environmental costs of mining were not bad enough, there appeared to be few in-state benefits to counterbalance those costs. On a regional scale, the employment effects of mining were not seen to be large. State severance taxes on coal were small. Worse still, much of the coal was not to be used to provide energy for in-state

*This estimate is based on the actual 1975 average for the region of 20,345 tons per acre.

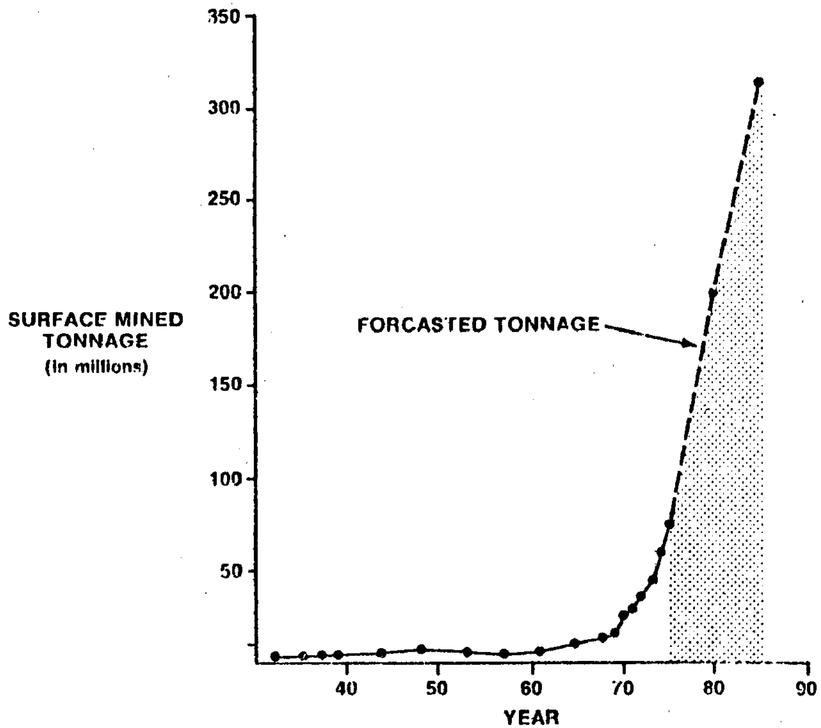

Figure 1. Trends in Surface Coal Mine Production in the Western United States

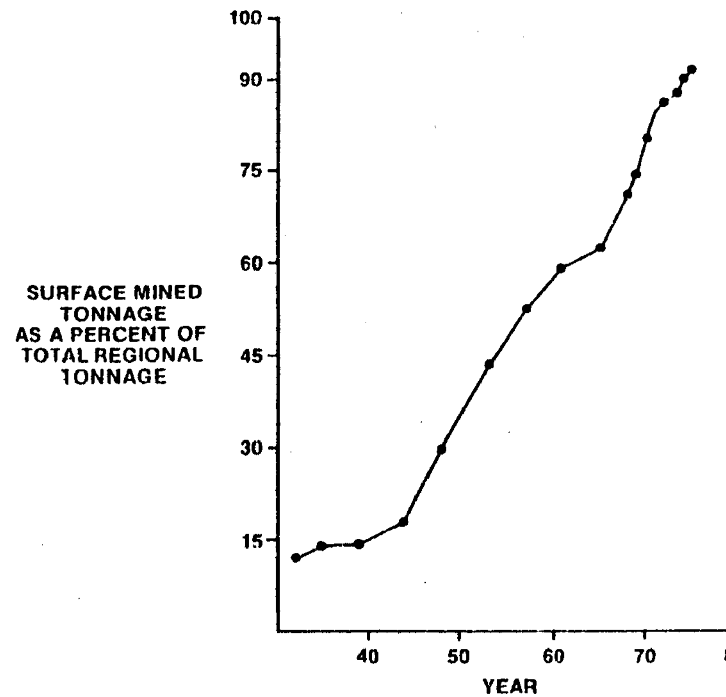

Figure 2. Trends in Production Share for Surface Coal Mining in the Western United States

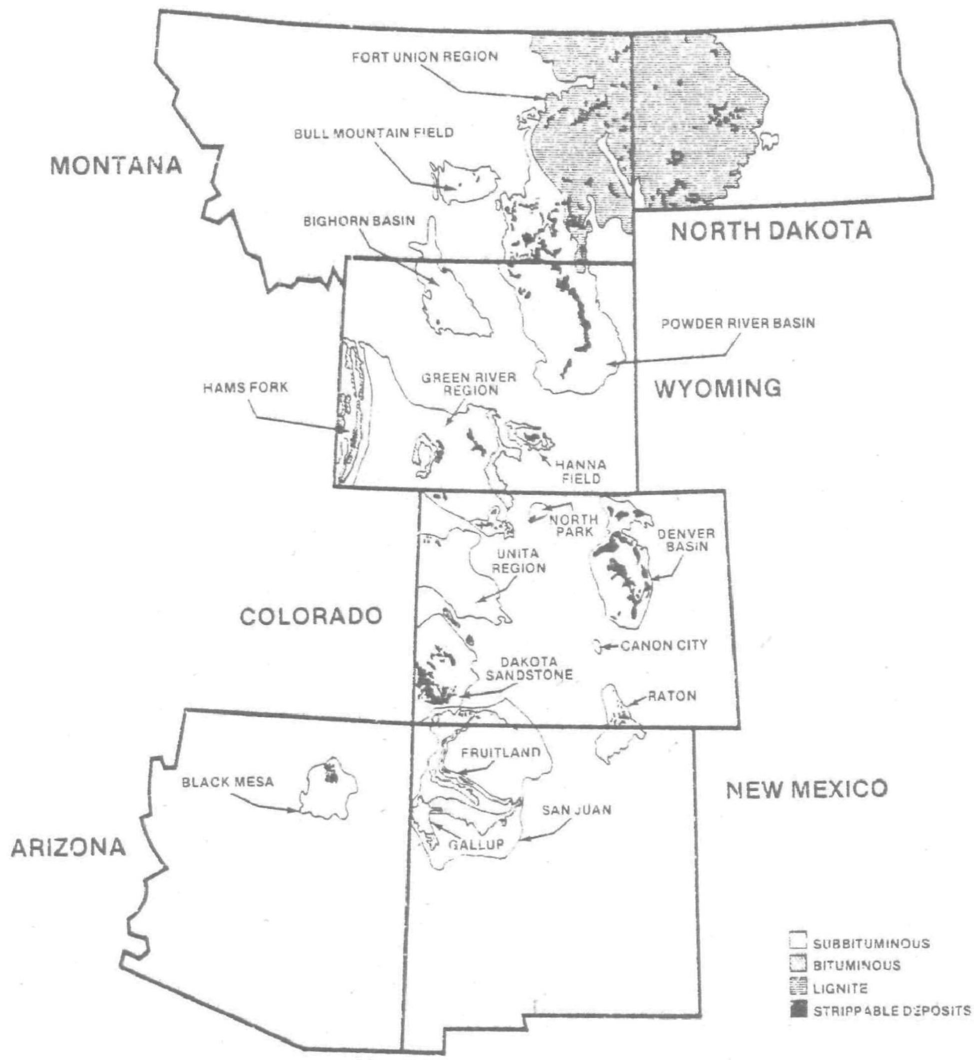

Figure 3. Strippable Coal Reserves of the Western United States*

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*Small amounts of strippable coal are present in Utah, but are not shown in this Figure.

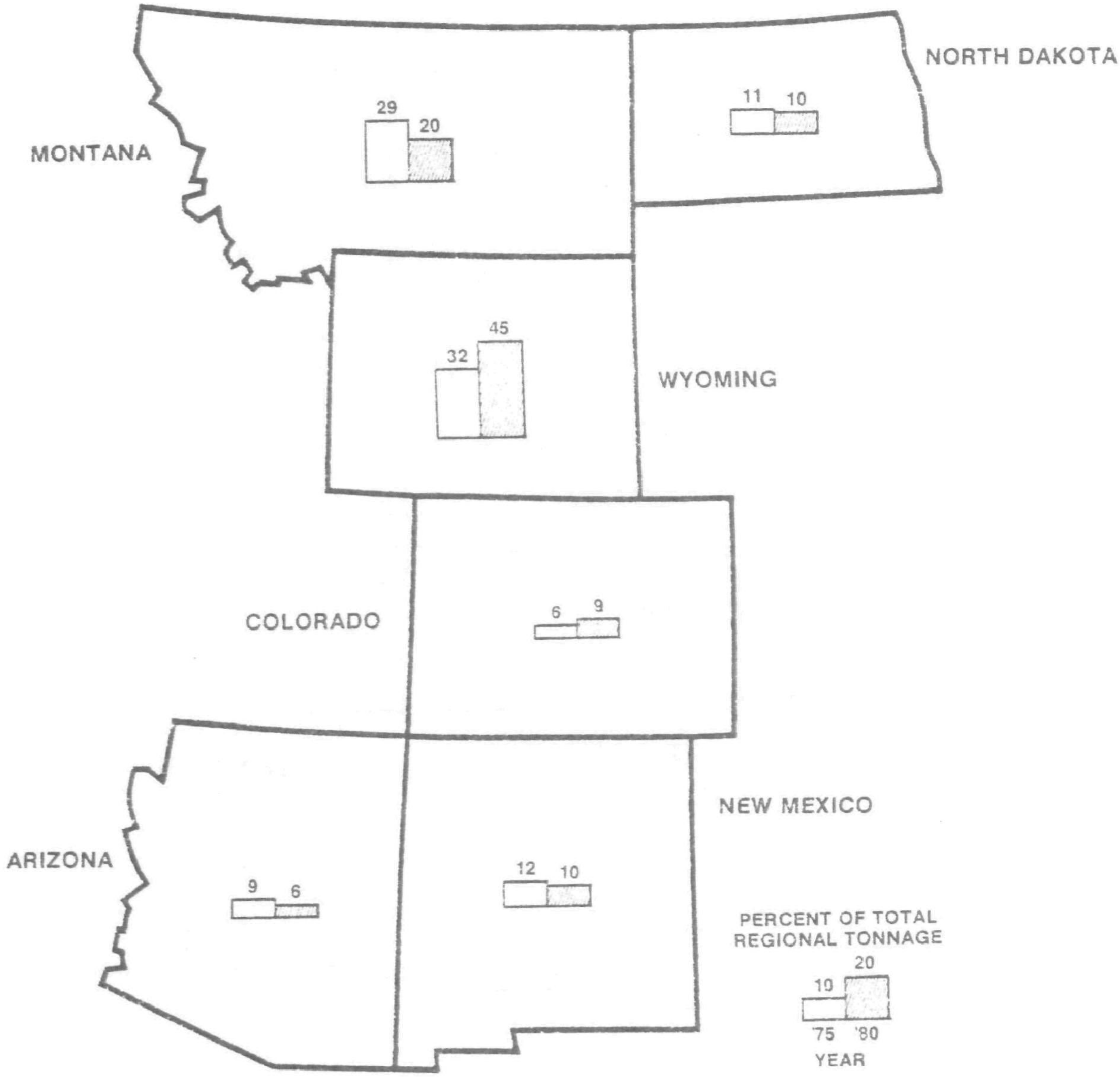

Figure 4. Current and Forecasted 1980 Surface Coal Mine Production Percentages for the Western United States

residents. In fact, as shown in Table 2, more than half of the coal that was surface-mined in the region during 1975 was exported from the region. The export percentages for Wyoming and Montana, the two largest producing states, were 74 and 95 percent, respectively.

Figure 5 shows the states of final destination for coal that was surface-mined in Wyoming during 1975. Most of the market areas were in the midwestern United States. The export picture for Montana was similar.

The transportation of coal both within and out of the region has associated social, economic, and environmental effects. Existing railroad track is insufficient to meet projected transportation demand, thus new track must be constructed. Some ranches will be split in the process. Additionally, existing transportation patterns may be disrupted. Coal slurry pipelines are proposed; water will be required to operate them. Although, as shown in Figure 6, new railroad track requirements are relatively small on a regional scale, several new coal slurry pipelines, to Oregon, Arkansas, and Texas, are proposed. The associated impacts are perceived by some as potentially severe.

Coal Conversion and Utilization

The foregoing export patterns do not tell the whole story because much of the coal that is not exported is (or will be) converted to electricity or gas which, in turn, will be exported from the states. For example, as

TABLE 2. NET EXPORTS OF COAL SURFACE-MINED IN THE WESTERN UNITED STATES DURING 1975 (ACTUAL) AND 1980 (FORECASTED)

State	Net Exports as a Percent of Total Surface Coal Mine Production	
	1975	1980
Arizona	50	(10)*
Colorado	(42)	7
Montana	95	91
New Mexico	8	32
North Dakota	27	17
Wyoming	73.5	66
REGIONAL	53	52

*Parentheses indicate net imports.

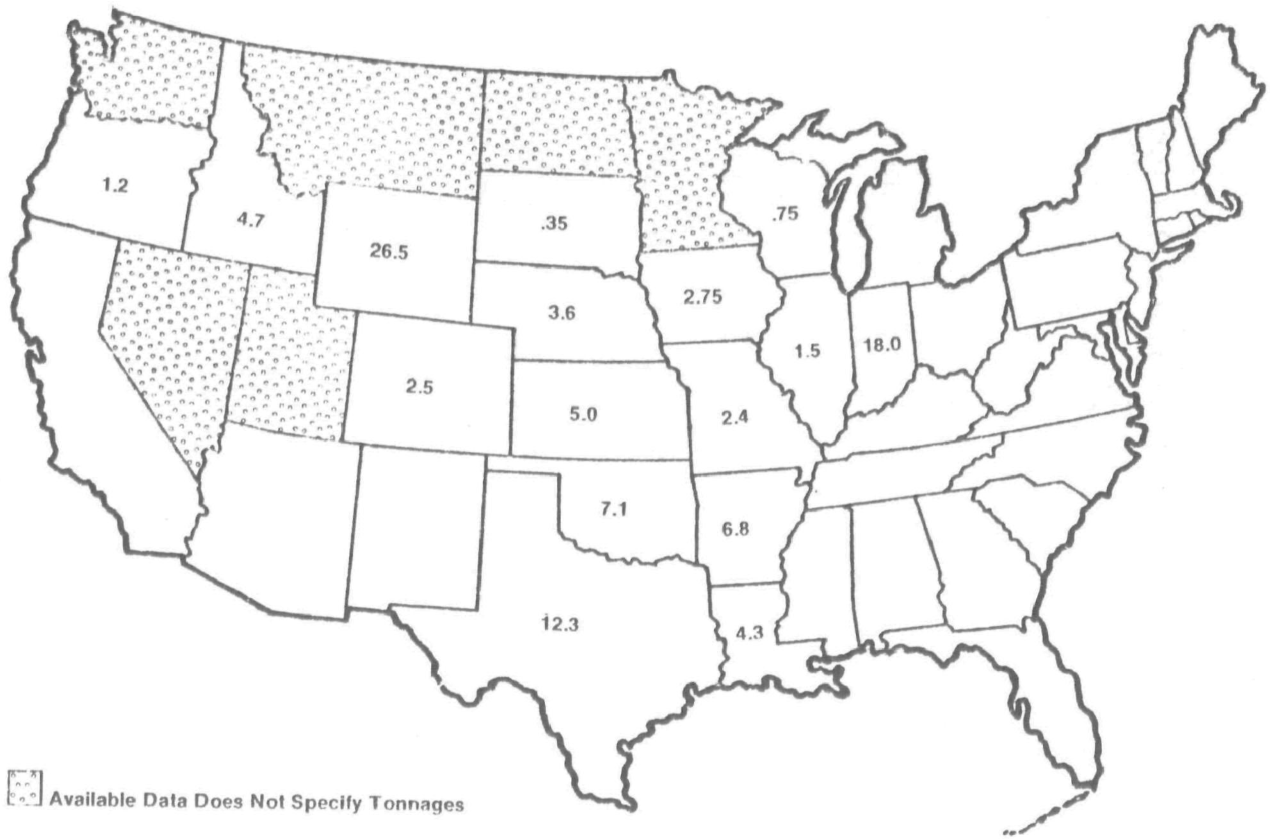

Figure 5. Geographic Distribution of Coal Surface-Mined in Wyoming During 1975

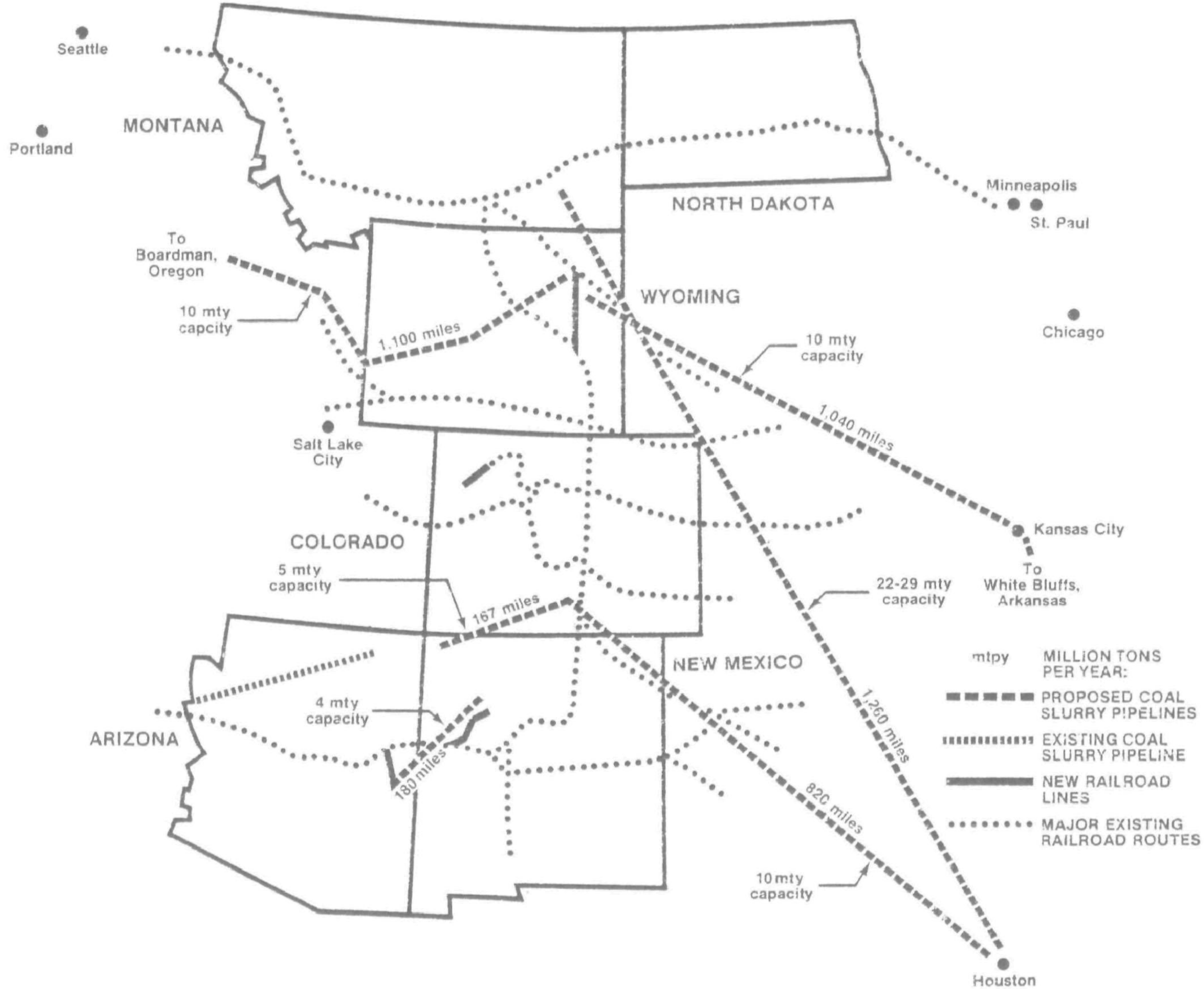

Figure 6. Existing and Proposed Railroad Lines and Coal Slurry Pipelines in the Western Region

shown in Table 3, 95 percent of the electricity generated in new coal-fired power plant units planned for construction in Wyoming and North Dakota is dedicated to out-of-state consumers. In such cases, although construction and operation of the power plants will yield in-state economic benefits, it will also cause adverse social and environmental effects. Additionally, in many areas, especially those that are particularly scenic, the construction of large transmission towers and long lines may fuel local opposition.

Similarly, the construction and operation of coal gasification plants, and the transmission of gas, although economically beneficial in many respects, will cause social and environmental disruptions. The use of water, mentioned earlier, is perceived by some as a major disadvantage of the plants, although aesthetic and air quality considerations also come into play.

In total at the present time, ten coal gasification plants are planned for construction in the six-state region. The locations of those proposed plants, along with the locations of planned new coal-fired plants and additions to existing power plants, are shown in Figure 7.

TABLE 3. CAPACITY OF COAL-FIRED STEAM ELECTRIC POWER PLANTS DEDICATED TO OUT-OF-STATE CONSUMERS

State	Percent of Installed Capacity Dedicated to Out-of-State Consumers		Percent of Planned New Capacity Dedicated to Out-of-State Consumers
	1975	1980	
Arizona	Not determined	Not determined	Not determined
Colorado	8	10	10
Montana	30	37	50
New Mexico	93	Not determined	Not determined
North Dakota	55	79	95
Wyoming	80	85	95
REGIONAL (Approximate)	71	60	Not determined

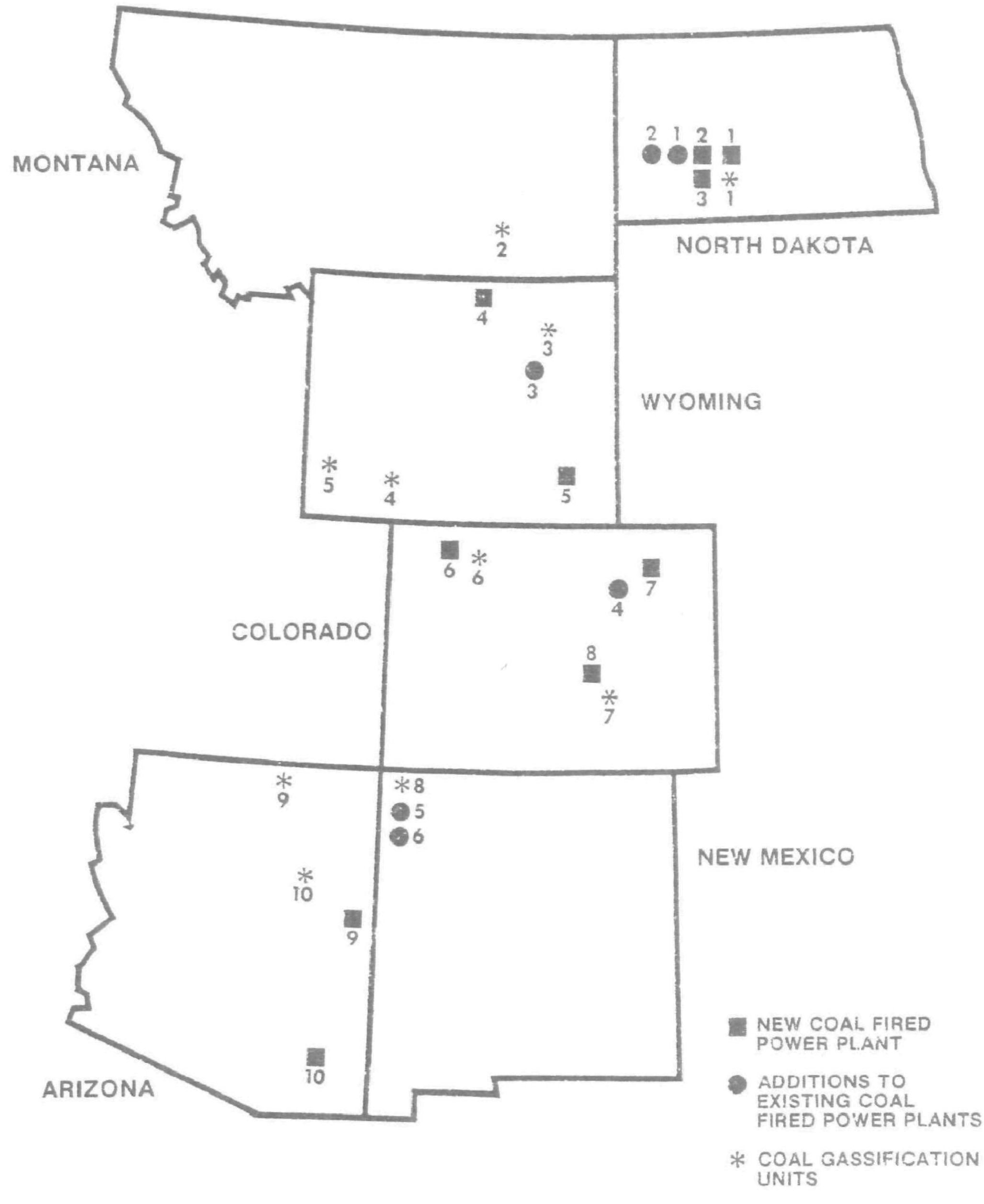

Figure 7. Locations of Planned Coal Gasification Plants and Coal-Fired Power Plants

PREVIEW OF MINING AND RECLAMATION TECHNOLOGY

The types, potential extent, and potential severity of the environmental effects caused by surface coal mining are dependent primarily upon three factors: the physical characteristics of the mine site, the mining technology, and the reclamation technology. In order to provide a backdrop for discussion of physical factors and their relationships to environmental effects, a brief preview of frequently used mining and reclamation technologies is presented next.

Mining Technology

The predominant mining technology used in the west during 1975 was stripping of single and multiple coal seams using a single walking dragline as the prime stripping machine.* A simplified representation of the operating procedures used in the single seam case is shown in Figure 8. First, the initial or box cut is opened, generally parallel to the coal seam cropline or burn line. Prior to actual overburden removal, in all western states but North Dakota, the overburden is drilled and blasted. Blasting may cause ground vibration, air shock, noise, and dust. Additionally, both drilling and blasting cause emission of fugitive dust.

Subsequently, working from a position on or near the original ground surface, box cut overburden is removed and spoiled by the dragline onto the natural ground adjacent to the cut. The height of the box cut spoil pile, which depends on the width and depth of the box cut and the natural repose angle of the spoil, usually ranges between 30 and 50 feet. The permanent topographic change that results may degrade the appearance of the area, and may also affect water table levels after mining.

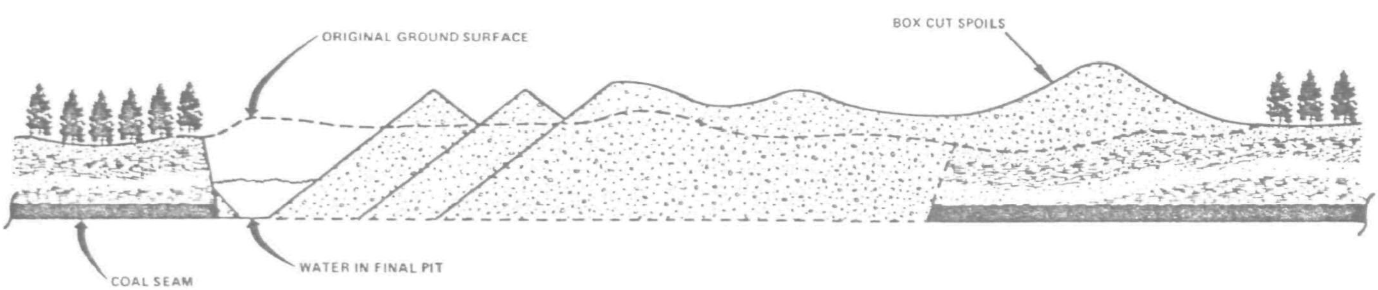

Figure 8. Section View of Results of Single Seam Dragline Stripping

*Henceforth, the term "mining" will mean surface coal mining and the term "west" will mean the surface coal-producing areas of the western United States.

Additionally, the outslope of the spoil pile, which is initially 35 to 40 degrees from the horizontal, drains externally; that is, surface runoff from the outslope enters natural drainageways external to the actual mining operation. Since, immediately after spoil placement at least, the outslope is long, steep, and unvegetated, erosion and sedimentation may result.

If the overburden or coal seam carried groundwater prior to mining, groundwater will be intercepted by the box cut and may collect in the pit. Possible effects include lowering of the water table and sedimentation or chemical degradation of the water that enters the pit. Since, for production reasons, pit water is usually pumped out to external drainageways or storage basins, surface water quality might also be affected.

After the box cut has been completed and coal has been loaded out, a second cut is made roughly parallel to the first one. Excavated overburden is placed by sidecasting it into the adjacent open cut to rest at its natural angle of repose. This topographic change, from rolling terrain to steep-sided piles, might degrade land use if nothing was done about it. Moreover, since overburden strata that were originally nearest the coal are usually placed on or near the surfaces of the spoil piles, the chemical quality of surface water that comes in contact with the spoil may be affected. Groundwater, if initially present in the overburden or coal, will eventually flow through this spoil.* Minerals or toxic chemicals in the spoil may then dissolve in the groundwater. Further, since the topography and permeability of the spoil is or may be different than that of the overburden, rates of percolation and runoff of surface water may be altered, thereby possibly changing the physical and chemical characteristics of the water. It is notable, however, that sedimentation of external surface waters is not a problem even potentially at this stage, since the spoils from the second and subsequent cuts drain internally.

After removal of overburden from the cut, coal is loaded into off-highway trucks, which haul the coal on dirt- or rock-surfaced roads to a loading facility. Coal loading, haulage, and unloading generates dust.

Stripping and loading procedures in subsequent cuts are similar to those used in the second cut. When the overburden becomes too deep for profitable stripping, or a property boundary is reached, stripping ceases. Overburden excavated from the last cut is placed in the open second-to-last cut; thus the last cut would remain open permanently if special efforts were not made to fill it.

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*It has been assumed here that the water table will return to approximately the original level after mining has been completed.

Reclamation Technology

Clearly, in the absence of use of special preventive procedures, western mining, both during and after actual conduct of mining operations, would adversely affect land use, water quality, and air quality both on and off the mine site. Special procedures are generally used, however.

Prior to mining, for example, drainage diversion ditches or impoundments are constructed to reduce the amount of surface water that will enter the active pit. Although used primarily for production reasons, this practice is usually environmentally desirable. Additionally, sediment control basins are constructed "below" mining operations.

In order to reduce noise and ground vibration, millisecond delays are used in blasting of overburden. The total weight of explosive detonated at a given instant is determined by using a formula developed by the U.S. Bureau of Mines.

Bulldozers are used to reduce the steepness of the box cut spoil outslopes so that surface runoff and erosion will be reduced. Terraces may be constructed on the outslope as an additional erosion-control measure. Salvaged topsoil may or may not be spread on the slopes of the box cut spoil piles and, whether or not topsoil is used, the slopes will be seeded, generally with a mixture of native and introduced grasses. Fertilizer and mulch may also be used.

In the second and subsequent cuts, special procedures may be used to avoid placement of undesirable materials either below the water table or near spoil surfaces. Angle-of-repose spoil piles are graded by dozer to a topography suitable for the planned post-mining land use. Salvaged topsoil is generally spread on graded spoils, and topsoiled areas are seeded, fertilized, and mulched. They may also be irrigated, although this is not a common practice. Restoration of suitable topography and revegetation both have dual purposes; they reduce erosion and sedimentation and improve post-mining land use potential. The final cut, in some states, will be partially filled after mining. Production- or safety-related practices, such as watering of haul roads, also are environmentally beneficial. They may also be needed to reduce fugitive dust emissions.

The purpose of use of the foregoing practices is to maintain satisfactory air and water quality on and off the mine site during and after mining, and to restore the land to productive use after mining. The effectiveness of those practices is dependent not only on the quality of reclamation efforts but also on the physical characteristics of the mine site, the topic of the next section.

PHYSICAL CHARACTERISTICS OF THE REGION

Climate, topography, geology, hydrology, and land uses differ in many important respects among the three major surface coal mining regions of the United States -- east, central, and west. Some characteristics of the western region are environmentally desirable; others are not.

Climate

The climate in western mining areas is arid to semi-arid with average annual precipitation ranging between 18 centimeters (seven inches) and 51 centimeters (20 inches).* The distribution of average annual precipitation at surface coal mines active in the region during 1975 is shown in Figure 9. Much of the precipitation is snow. When it does rain, the rain often falls during infrequent, intense thunderstorms. Surface runoff is high. Because the precipitation is infrequent, soil moisture content is generally low. Even if the soil moisture was high, it still might not be available at the proper time for seed germination and plant growth.

High summer temperatures, wind, and low average humidity cause rapid evaporation of water from the ground. Water is also lost by plant transpiration. Wind, another climatic factor, carries water vapor from the site of evaporation or transpiration, thereby increasing evapotranspiration potential. Wind also may pick up fine soil particles, resulting in loss of soil and increases in particulates suspended in the air.

As shown in Figure 10, the altitude at western mines ranges between 305 meters (1,000 feet) and 2,440 meters (8,000 feet), and averages 1,545 meters (5,070 feet). The growing season at these altitudes is relatively short; 60 to 120 days is a typical range. Additionally, the numbers of vegetative species available for reclamation at such altitudes may be very limited.

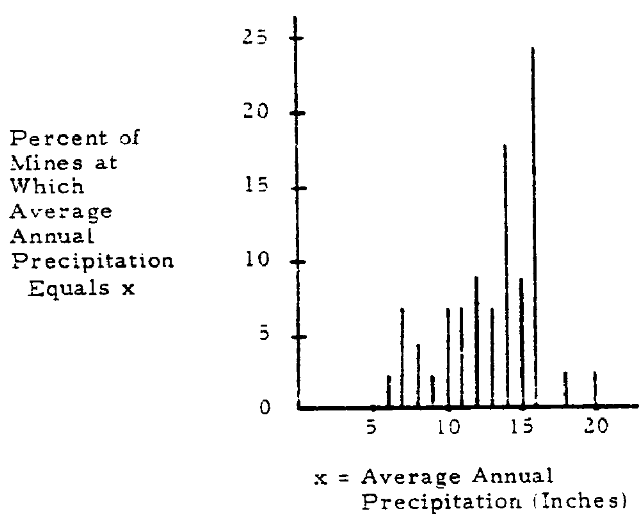

Figure 9. Distribution of Average Annual Precipitation at Western Mines

*Arid regions are those in which average annual rainfall is 30 centimeters (12 inches) or less. From a reclamation standpoint, extremes of annual precipitation may be more relevant than averages.

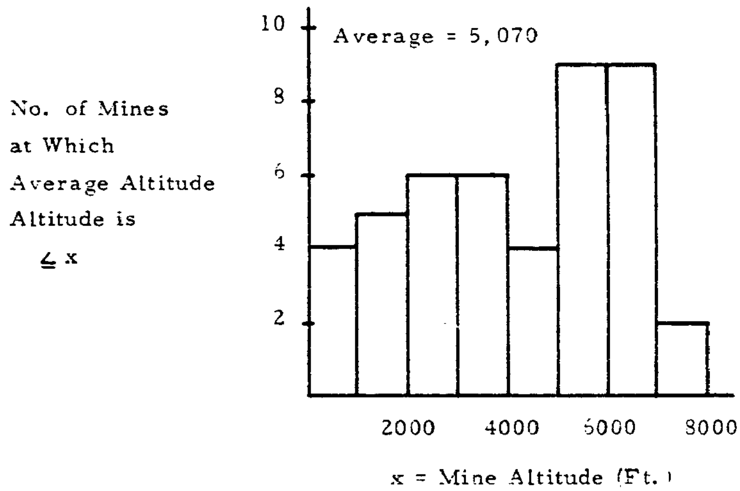

Figure 10. Histogram of Average Altitudes at Western Mines

The relevance of the foregoing is in part that revegetation of mined areas may be difficult. Fugitive dust may be troublesome. Preservation of shallow aquifer systems may assume special importance. On the other hand, pit flooding is relatively infrequent, undesirable spoil materials need not be buried too deeply (e.g., by more than several feet) to protect against leaching, and erosion may be potentially less troublesome than in areas of heavy precipitation.*

Topography

Approximately 70 percent of the acreage disturbed by western surface coal mining during 1975 was characterized by gently rolling topography. The remainder was characterized by either flat or hilly topography. There were few if any mountainous areas, such as those typical of central Appalachian surface mining areas.

Western topography is generally desirable from an environmental standpoint. First, restoration of approximate original contours, although possibly costly, is not too difficult. Additionally, because the west is naturally characterized by sharply contrasting landforms -- with buttes and mesas rising out of vast plains areas, and landforms often changing at fence lines -- it is relatively easy to blend reclaimed topography with adjacent undisturbed topography.

The combination of low rainfall and gradual topography is also desirable because, in some cases, erosion problems are potentially less serious than those in the eastern United States, where rainfall is heavy and topography is steep.

*The potential for erosion is also greatly dependent upon soil characteristics, however.

Soils

Most of the soils in western mining areas are residual soils, derived over long periods of time from the underlying rock strata. A common rule of thumb in such cases is that 100 years are required for formation of one inch of soil. The other two types of soils sometimes present in western mining areas are alluvial soils -- those carried to their present location by water -- and glacial soils -- those developed from glacial drift. The occurrence of these latter two types of soils, although possibly frequent in some locales, is infrequent on a regional scale.

Western residual soils are typically sandy or clayey, relatively infertile, often highly erodible, and sometimes high in salts. The sandy soils have low moisture-holding capability, whereas the clay soils tend to be very hard when dry. Additionally, clays tend to grip the water molecules so tightly that plants cannot use the water in the soil.

Nonetheless, although western soils are often inferior to those, for example, in the midwestern United States, they are frequently the best plant-growing media available in strip mine reclamation; that is, they are usually superior to underlying overburden materials. This fact underscores the importance of salvaging and replacement of topsoiling materials, usually surface soils.

Overburden

Western overburden usually consists of clays and interbedded shales and sandstones. The shales are often weakly consolidated. Massive sandstone, such as that common in the eastern United States, is uncommon in the west. Limestone and slate in the overburden are also uncommon. Glacial drift is found in parts of the lignite fields of North Dakota and northeastern Montana, but it occurs very infrequently on a regional scale.

When placed as spoil, the shales tend to weather fairly rapidly to clay-sized particles. Where the shale is high in exchangeable sodium -- indicated by sodium adsorption ratios (SAR) greater than about ten -- the weathered material will become poorly permeable, thereby impeding revegetation attempts. In fact, until fairly recently, revegetation failures due to permeability problems were not uncommon in North Dakota and parts of Montana and Wyoming, where high-SAR shales and clays frequently occur in the overburden or in the interburden separating coal seams.

Sandstones, if placed on spoil surfaces, also tend to weather fairly rapidly, although less rapidly than shales, producing a droughty condition.

Most often, the color of surface spoil materials is light gray or light brown. This is desirable because dark-colored spoil materials, such as those often found in other parts of the country -- western Kentucky is a good example -- cause excessively high surface temperatures during the growing season. This may inhibit seed germination and plant growth.

Overburden and spoil materials in the west are almost always basic. The acid-producing pyritic and marcasitic overburden frequently associated with high sulfur coal in the midwestern United States is rare in the west. This factor, coupled with low precipitation, means that surface coal mining in the west will rarely if ever cause acid mine drainage. On the other hand, the overburden may contain high proportions of soluble salts that might dissolve in surface water or groundwater that passes over or through spoiled overburden. Dissolution of trace elements in surface water and groundwater is another potential problem, although trace element pollution has not been widely reported.

In sum, the chemical problems related to overburden in other parts of the country, especially acid mine drainage, may not be major problems in the west, although there is little hard data to refute or support this assertion. Physical problems related to failure of spoil materials to weather quickly -- such as is the case in Illinois, for example, if limestone is placed on spoil surfaces -- are not particularly troublesome in the west. In contrast, however, a physical problem -- impermeability of spoil surfaces -- is a characteristic of many western mining operations. Thus a need for selective placement of undesirable overburden materials, namely high-SAR shales and clays, exists in the west, just as it does in other parts of the country, although for different reasons.

Vegetation

The predominant types of native vegetation in western mining areas are long grasses, short grasses, and shrubs. The long grasses provide fairly dense cover and protection from erosion, but in many cases, long grass areas have been converted to production of wheat. Vegetative density in short grass and shrub areas is generally less than that in long grass areas. Additionally, extensive grazing of such areas has frequently resulted in a change of vegetative species mixes, with less palatable species such as sagebrush predominating. This has resulted in reduction in land productivity and increases in runoff and erosion. In fact, in some cases, environmental impact statements are required where Federally owned lands are to be grazed.

Surface Water

The minor streams of the region are predominantly ephemeral; that is, they flow only during snowmelt and rainfall. These streams contribute little to perennial water bodies. Indeed, the quality of surface waters flowing in perennial water bodies in the region is relatively poor, a condition resulting from heavy natural sediment loads and high concentrations of sulfates, bicarbonates, and dissolved solids. [2-15]

The implication here is that the potential effects of mining on surface water quality, whether physical or chemical, do not appear to be great. At least, they seem to be of lesser concern to state regulatory personnel and mining company reclamation personnel than are other potential problem areas. Possible adverse effects on water quality, due to evaporation of surface water impounded on mine sites are also considered to be of lesser importance.*

Groundwater

At the present time, in the authors' opinion, one of the major remaining uncertainties regarding the environmental effects of western surface coal mining concerns the effects on groundwater quantity and quality. This is an emotional and fairly complex area of concern, and one in which it is fairly easy to fuel the flames of protest.

There are, in the west, three types of aquifers of interest: glacial, alluvial, and rock aquifers. Glacial aquifers are composed of unconsolidated sand and gravel deposits associated with the glacial drift overlying bedrock. These kinds of aquifers occur only in parts of North Dakota and Montana, but even there, their extent is limited because proportionately very little of strippable western coal reserves are overlain by glacial drift. Alluvial aquifers, which consist of unconsolidated sand and gravel deposited on floodplains in modern geologic times and deposits that filled preglacial river valleys, are important sources of water in the region. They generally lie along major rivers and act as storage for those rivers. Any significant disruption of the alluvial aquifers might affect the quantity and quality of the surface waters that flow in the rivers. Some western mines are located in floodplains but unless the scale and location of mining changes drastically in relation to forecasts, the potential effects of mining on alluvial aquifers may not be large in a regional sense, although local effects may be significant.

Rock aquifers consist primarily of sandstones, limestones, and coal seams. Unlike many sandstones, the coal has relatively low porosity. Fractures serve as the primary conduits for groundwater in coal seams. The result is that yields from coal seam aquifers are usually small. In fact, in mining areas during 1975, the average yield from wells which derived their water from overburden or coal was less than 3.7 liters per minute (seven gallons per minute). In all cases but one, the well water was used for domestic purposes and stock watering. In general, the important non-coal rock aquifers are located below current stripping depths, with water tables typically found at depths of 50 to 150 meters below the ground surface. Those kinds of aquifers will not normally be affected by mining.

Nonetheless, shallow aquifers, which can be important water sources for stock watering and domestic purposes, are affected by mining. In 1975, for example, this was true at 65 percent of the mines in the

*It should be noted that high levels of total dissolved solids in western surface waters and groundwater continue to be of concern to some environmental specialists. Although agriculture is currently a major cause of this problem, they believe that large-scale surface coal mining may also ultimately be a problem-source.

region. Since many people in rural areas draw well water from these shallow aquifers, the effects of mining on the quantity and quality of well water are of legitimate concern.

It is known, for example, that water levels in wells located within a few kilometers of active mining operations have been lowered by three to six meters (10 to 20 feet). Although the water table may rise to approximately its original level after mining and reclamation have been completed, the drawdown of the water table during mining is an effect that should be mitigated in some way.* Means for doing so are described and evaluated later in this report. For perspective, however, the following is noted here. A review of mining and reclamation plans in the region revealed that no more than 10 or 20 wells or springs are usually affected by any single mining operation. At the present time, there are about 28 mines at which shallow aquifers are disrupted in some way. Therefore, on a regional scale, possibly 400 wells or springs may be affected during the production periods of mines that are currently active. This number will of course increase as the scale of mining increases.

Lowering of the water table is not the only consequence of concern; replacement of coal or rock aquifers by less permeable or more permeable spoil may permanently alter rates of groundwater flow and storage. Scientific research projects currently in progress should shed light on this soon. One such project, recently completed at strip mines in the Powder River Basin, indicates that spoils placed by dragline are generally as permeable as the shallow sandstone aquifers in the area, but that spoils placed by scraper or truck are not as permeable. [16]

Degradation of the quality of groundwater that passes through spoils is another possible problem caused by mining. In some areas, this potential problem is not viewed with much concern, because the natural quality of the groundwater in shallow aquifers is poor before any mining disturbance takes place. In others, it is known that mining has changed groundwater quality. Considerable amounts of data, now becoming available as a result of groundwater monitoring and modeling by coal companies, state agencies, and Federal contractors, should help in determining whether or not problems exist.

Summarizing, mining may affect groundwater in shallow aquifers by lowering the water table, reducing the rate of flow, or changing the chemical quality of the water. Because, prior to mining, the groundwater in those aquifers is often low in yield and poor in quality, and because the aquifers are frequently discontinuous, the regional effects of current mining activities are not viewed as highly significant. In certain locales, of course, the effects could be significant.

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*If the aquifer that was disturbed was a confined aquifer, the original water table may not "recover" after mining.

Land Use

Although there are many different uses of western land, the pre-mining land use for almost all of the land that has been or is being mined in the west is grazing of cattle, sheep, and horses. This is a desirable feature from mining and reclamation standpoints. One reason is the relative ease with which a suitable topography can be restored after mining. Restoration of positive drainage from the mine site is not too difficult where the original rolling topography is restored. This is not always the case when a relatively flat topography suitable for farming is restored. Differential settling of spoils presents far fewer problems on land reclaimed to grazing than on that reclaimed to row-crop or feed grain production. Vegetative species used for revegetation can be native rangeland grasses which, once established, should require relatively little maintenance for grazing purposes.

Summary: Potential Environmental Problems

Summing up, in a relative sense, it is felt that lowering of water tables, reduction of aquifer yields, chemical changes in groundwater, inability to establish adequate long-term vegetation, and emission of fugitive dust are the potential problems associated with western mining at present. This is not to suggest that they are actual problems on a regional scale -- that issue is discussed later in this report -- but rather to suggest that other types of physical and chemical effects are less significant. Those latter effects include aesthetic degradation, landslides, and acid mine drainage. Sedimentation of surface waters does not appear to be a problem on the present scale of mining, although some believe that the projected mining growth could change this. Biological and socioeconomic effects were not evaluated.

FURTHER PERSPECTIVES

It was stated earlier in this section that the extent and magnitude of the environmental damages caused by mining are dependent on three things: the physical characteristics of the mining area, the mining method, and the quality of reclamation efforts. This latter factor, the quality of reclamation efforts, cannot be discussed fully merely by describing reclamation practices. There are important institutional and technological factors that come into play. The major ones are discussed below. Since public attitudes toward western mining -- which surely have had a great influence on the kinds of research planned or in progress -- were in part formed on the basis of knowledge of past environmental damages in the eastern coalfields of the United States, the format for the subsequent discussion is a contrast of factors in each geographic region.

Industry Structure

In the east, both the mines and mining companies are small, on the average. As shown in Figure 11, average annual production for eastern mines has remained fairly constant at 50,000 metric tonnes (55,000 tons) for over thirty years. As a result, mine lives are short; six to twelve

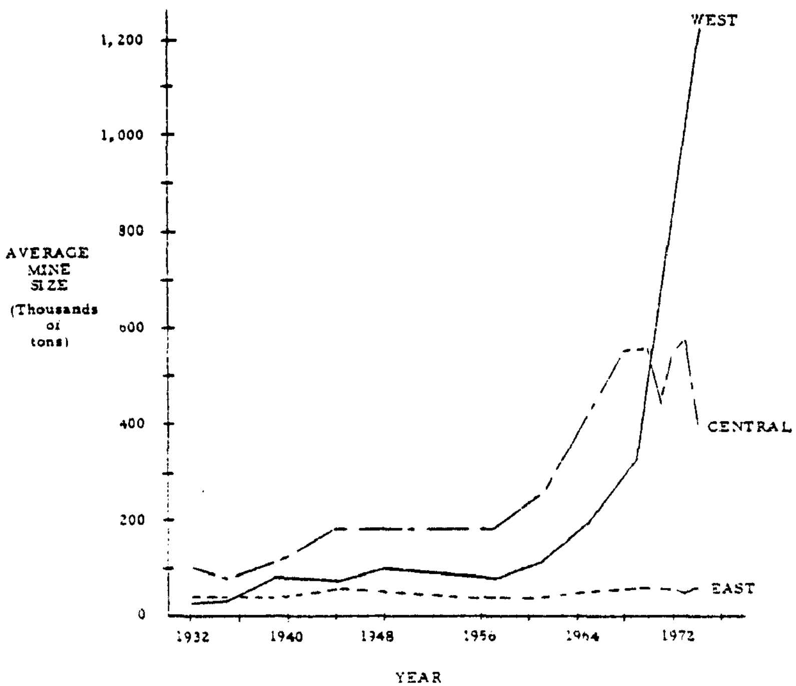

Figure 11. Regional Trends in Average Surface Coal Mine Size

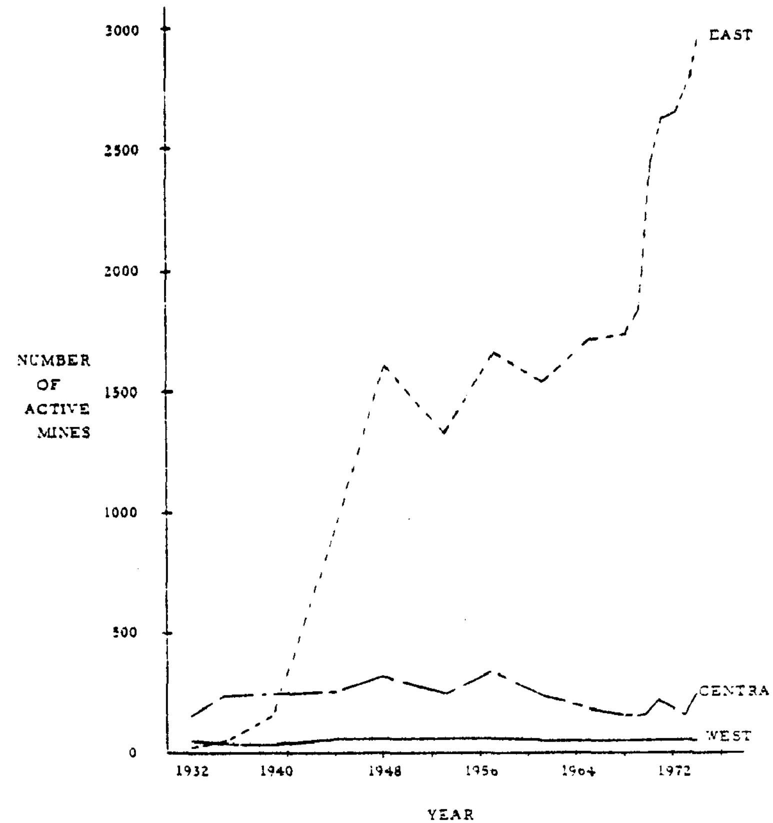

Figure 12. Regional Trends in the Number of Active Surface Coal Mines

months is common. Capital requirements for an average mine are relatively low; approximately $1.5 million capital is required to open a mine that will produce 91,000 metric tonnes (100,000 tons) per year. The equipment used is mobile and multipurpose. It can be used for highway construction work as readily as for strip mining.

These characteristics have several important effects. The first of these is that there are many mines, the number of active mines having increased, as shown in Figure 12, from 1,500 in 1960 to over 3,000 in 1973. This is an average of about 450 mines in each of the eastern states. The sheer volume of mining operations taxes the ability of state reclamation agencies to effectively administer reclamation laws. Additionally, because capital requirements are fairly low, many new mine operators enter the market when coal prices rise, as has been the case over the past several years. Some of these operators lack expertise in reclamation technology. Many of the companies have neither engineers nor reclamation specialists. Bankruptcies are not uncommon. When this happens, the environment may suffer.

Things are vastly different in the west. There are and have been relatively few active mines. The number has remained fairly steady at about 50 for 30 years. This is an average of about eight mines per state, a figure that does not tax the administrative capability of state reclamation agencies.

Although western production has increased dramatically in the past decade, this increase has resulted not from an increase in the number of mines, but rather from an expansion of the capacities of existing ones. In 1976, the average annual production for western mines was 1.45 million metric tonnes (1.6 million tons). Operation of such mines requires not only huge capital investment, but also considerable engineering and reclamation expertise. The mines are long-lived; 27 years is the average remaining life of mines now active. The coal companies are large and well-established. Many are wholly owned subsidiaries of public relations-conscious power companies.

Under such circumstances, it is not surprising that the coal companies have made a commitment to reclaim the land, if only to avoid jeopardizing a $20 to $50 million capital investment. This commitment, coupled with resident reclamation expertise, often means good reclamation.

Reclamation Laws

The reclamation laws in the west are fairly new. In drafting those laws, the experience of reclamation agencies in midwestern and eastern states weighed heavily. As a result, western reclamation laws are generally comprehensive and stringent. Since the coal industry was until recently not a major economic factor in the west, the lobbying that often proved effective in other regions was not effective in the west. Good laws, coupled with the quality of enforcement possible when there are only ten or so mines in a given state, translated into effective reclamation, at least insofar as current knowledge and technology is concerned.

An additional factor is the extensive ownership of western coal by the Federal government. This means, under the National Environmental Policy Act, that comprehensive, detailed environmental impact statements must be prepared before the coal can be mined. Such statements may require several man-years to prepare.

Disturbed Acreage and Land Use

At present, the acreage disturbed annually by western mining is less than that disturbed annually by eastern mining. There are two reasons for this. First, western coal is much thicker than eastern coal. In 1975, for example, the average total thickness of the coal seams mined in the west was 11.9 meters (39 feet), whereas for the east the average was 1.5 meters (five feet).* Other things being equal, this means that approximately 25,000 metric tonnes of coal are produced per hectare disturbed (67,860 tons per acre) in the west, but only 3,300 metric tonnes of coal are produced per hectare disturbed (9,000 tons per acre) in the east.**

Other things are not equal, however, since for a given coal seam thickness, the acreage disturbed by the typical one-cut contour methods used in the east is approximately 60 percent greater than the corresponding acreage when area mining methods are used. This is offset by the fact that, on the average, the heating value of western coal is only about 65 percent as great as that of eastern coal. Overall, though, even on the basis of heating value, roughly seven and one-half times fewer hectares are disturbed per metric tonne of western coal than in the east.

Another factor is the premining productivity of western lands. This is depicted in Figure 13 which shows that the premining stocking rates at mines active in 1975 ranged between 4 and 48 hectares (10 and 120 acres) per animal unit year, and averaged 25 hectares (62 acres) per animal unit year. In 1975, about 1,458 hectares (3,605 acres) were disturbed by mining. This caused a temporary productivity loss of only 58 animal unit years of grazing for the six-state region. Even if coal production tripled or quadrupled and several years were required to return the land to full or near-full productivity, the loss of grazing capacity in the west would still be small. Of course, since large-scale surface coal mining and reclamation are relatively new in the west, there are still doubts that productivity can be restored in the long run.

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*Total coal seam thickness is defined as the total thickness of all seams mined in a given pit.

**Western coal: 1,740 tons per acre-foot. Eastern coal: 1,800 tons per acre-foot. Only the acreage directly disturbed by overburden removal is included in this example.

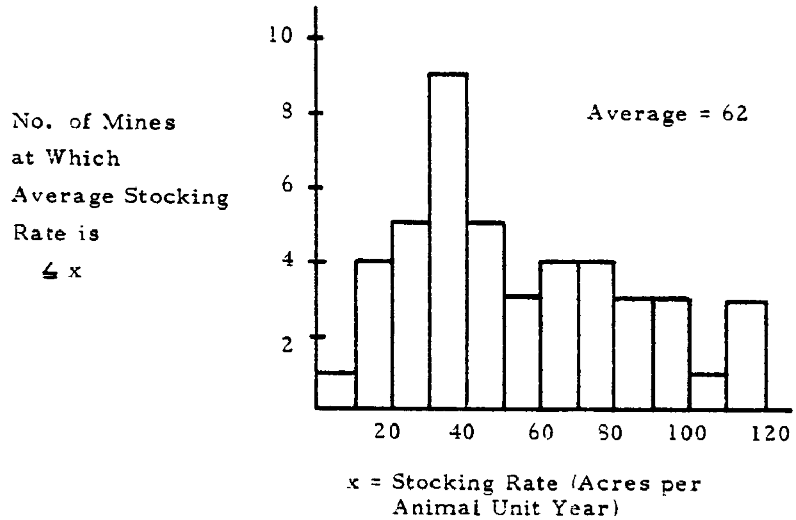

Figure 13. Histogram of Premining Stocking Rates at Western Mines

Mining and Reclamation Costs

In 1976, the average stripping ratio at western mines was 4.5 cubic yards of overburden per ton of coal mined. The corresponding average for the east and midwest was approximately 16:1 cubic yards per ton. [17] If overburden removal costs per cubic yard of overburden were the same in all regions, this would imply that western costs on a tonnage basis would be only 28 percent as great as those in the east and midwest. Of course, this cost difference is reflected in the coal prices which, for steam coal in 1976, averaged about $5 per ton f.o.b. mine in the west versus $17 per ton f.o.b. mine in the east.

An additional effect of the difference in coal seam thicknesses is the disproportionate effect of reclamation cost increases among the regions. For example, a $1,000 per acre reclamation cost increase would on the average be equivalent to 1.4 cents per ton in the west and 11 cents per ton in the east. Stated another way, the average cost increase on a per-ton basis would be 0.28 percent of the selling price in the west, but 0.64 percent of the selling price in the east.

Reclamation Research

Reclamation research was being conducted at 71 percent of the 45 western mines active in 1976. The types and frequencies of research activities are summarized in Table 4. Revegetation research is common. Experiments are being conducted to evaluate alternative vegetative species, irrigation procedures, various topsoiling depths, and water harvesting techniques. In many cases, the mining companies themselves are conducting or paying for the conduct of this research.

TABLE 4. FREQUENCY OF OCCURRENCE OF RECLAMATION RESEARCH AT WESTERN MINES IN 1976

Subject of Research	Percent of Mines at Which Research is Being Conducted*
Revegetation	69
Hydrology	31
Overburden Analyses	18
Spoil Grading	7
Mining Method	4

*Percentages total to more than 100 percent because two or more types of research are being conducted at some mines.

Exposed Highwalls

In typical eastern contour mining situations, the predominant situation in the east, only one cut is made; thus every cut is a final cut, resulting in a final highwall, whether it is eventually buried or not.* At the typical western mine, many cuts are made, but only one (per pit area) is a final cut. Thus the length of exposed highwalls in the west is far smaller than that in the east. This is aesthetically desirable.

*The exception is mountaintop removal mining, a method in which no final highwalls are left.

SECTION 6

CURRENT MINING AND RECLAMATION SYSTEMS

INTRODUCTION

The purposes of this chapter are to describe and evaluate the mining and reclamation practices most frequently used in the west during 1975 and 1976. Ways in which environmental considerations have influenced or should influence mining practices are emphasized. Mining and environmental problems are identified.

Many different types of mining situations occur in the west; it is neither necessary nor desirable to discuss all of them. Rather, the different situations have been classified in accordance with a series of physical and technological parameters, and the frequency of occurrence of each class of situations has been determined. Only those which occurred frequently are discussed.

CLASSIFICATION OF MINING SITUATIONS

The choice of mining methods and equipment is dependent on many economic, physical, and technological factors. In classifying the various mining situations into groups with common production or environmental characteristics, however, the following four factors (parameters) are felt to be sufficient:

- Mining method
- Number of coal seams mined per pit
- Main stripping equipment
- Spoil placement method

Mining Method

The area method of mining, used at 82 percent of western mines, accounted for 97 percent of the acreage disturbed in 1975. In this method, overburden is removed in fairly long and roughly parallel strips, each averaging about 43 meters (140 feet) in width, with overburden from a given cut being hauled, pushed, or cast into the adjacent open cut. A typical cut and spoil pile are shown in Figure 14.*

The open pit method of coal mining is an infrequently used method in which spoil is hauled from the pit by trucks and placed in a permanent storage area outside the pit. Although the maximum pit depth in area mining is currently about 45 meters (150 feet), an open pit may be as much as 305 meters (1,000 feet) deep. Because of the great depths, the highwalls in open pits are benched, giving the pits the terraced appearance shown in Figure 15. A large permanent spoil "mesa" shows in the foreground of that Figure. Unlike area mining, when open pit mining is completed a large hole remains; there is no backfilling.

Modified open pit mining, although infrequently used at present, is a method that will be widely used in the eastern Powder River Basin of Wyoming where the coal seams are very thick. It is similar to area mining in that spoil is placed back in the open cut, but more similar to open pit mining in that spoil is hauled and the cuts are not long and narrow. Additionally, although spoil is placed back in the open cut, a

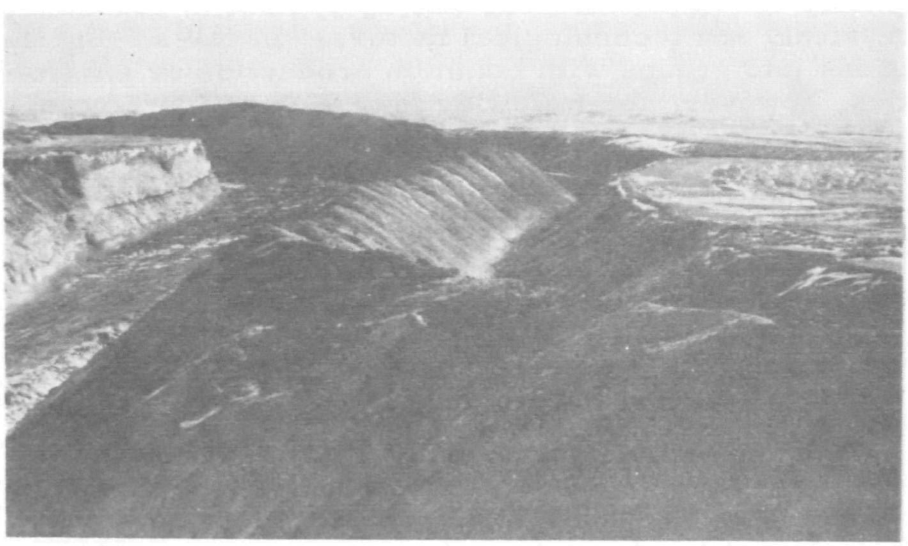

Figure 14. Photograph Showing Area Mining Site

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*Spoils to the right of the angle-of-repose spoil pile in the photograph have been graded to approximate original contour.

Figure 15. Photograph Showing an Open Pit Coal Mine

permanent depression in the land surface usually remains after mining. This is because the coal is often much thicker than the overburden where the method is used.

Number of Coal Seams Mined Per Pit

Multiple seam mining, defined as the mining of two or more seams in one pit (or highwall), accounted for about half of the acreage disturbed by western mining in 1975. Single seam mining accounted for the remaining acreage. A unique environmental feature of multiple seam mining is that the interburden separating two coal seams is often chemically or physically undesirable and must be buried in the spoil to prevent subsequent spoil revegetation failures.* From a production standpoint, multiple seam mining is more complex than single seam mining.

Stripping Equipment

Three kinds of stripping equipment are used in the west. These are sidecast equipment, construction equipment, and open pit (truck and shovel) equipment.

*In some states, the interburden material must be placed above the water table in addition to below the spoil surface.

Sidecast equipment, which includes draglines and stripping shovels, is equipment that is used to remove overburden and place it in the adjacent open cut by sidecasting. Stripping shovels are rarely used in the west at present nor will they be widely used in the future. Draglines are widely used, having accounted for 88 percent of the acreage disturbed by western mining in 1975.

Two characteristics of dragline stripping are notable from an environmental standpoint. One is that spoils are cast to rest at their natural angle of repose; thus the spoil piles require grading by other equipment to restore approximate original contours. The second is that it may be difficult to place spoil materials selectively, particularly where multiple seams are mined. Draglines are used only in the area method of mining, never in open pit or modified open pit mining.

Construction equipment consists of dozers, end loaders, scrapers, and relatively small spoil haulage trucks. These kinds of equipment are rarely used in the west. When they are used, it is usually to supplement dragline production. The equipment has production drawbacks compared to draglines, in that operating costs are fairly high and production capacity is fairly low. On the other hand, construction equipment has desirable environmental characteristics. Approximate original contours can be restored as part of the spoil placement process and spoil materials can be placed selectively.

Open pit equipment consists of loading shovels and spoil haulage trucks. The loading shovels are used to excavate overburden and load it into trucks.* The trucks haul and place the excavated material. Although the operating costs for truck and shovel stripping are higher than those for dragline stripping, they are lower than the corresponding costs for construction equipment. Additionally, fairly large rates of production can be achieved with truck and shovel systems. Moreover, they have the same environmental advantages as construction equipment. Truck and shovel equipment, shown in Figure 16, is presently used primarily in conjunction with the open pit and modified open pit mining methods.

Use of Spoil Segregation Techniques

Spoil segregation refers to selective placement of spoil to place undesirable materials below spoil surfaces or above the water table or both. As indicated earlier, adequate spoil segregation can be difficult to achieve where draglines are used for overburden removal and spoil placement, but should not be difficult where construction or open pit equipment is used. This practice, which accounted for 39 percent of 1975 western production, is the principal way in which western mining and reclamation operations can be integrated.

*Loading shovels differ greatly from stripping shovels.

Figure 16. Photograph Showing Truck and Shovel Stripping Combination

Classification of Mining Situations

A summary of the frequencies of occurrence in 1975 of the values of the foregoing parameters is presented in Table 5. The Table shows that area mining accounted for 97 percent of the acreage disturbed by western mining in 1975. Single and multiple seam mining occurred with roughly equal frequency. Draglines were by far the most widely used type of stripping equipment. According to coal company mining and reclamation plans, spoil segregation was practiced at 40 percent of the mines active in 1975.

A classification of western mining situations based on the foregoing parameters is shown in Figure 17. Alternative measures of the frequency of occurrence of each situation are shown on the right side of that Figure. Although 13 different mining situations are depicted, only five occurred with sufficient frequency to warrant attention in this report. Those five situations and their associated production percentages are summarized in Table 6. Dragline area mining of single coal seams without spoil segregation, for example, accounted for roughly one-third of 1975 strip pits and disturbed acreage. In total, dragline stripping situations, including single and multiple seams, both with and without spoil segregation, accounted for 69 percent of the strip pits, 83 percent of the tonnage, and 88 percent of the acreage disturbed by western mining in 1975.

TABLE 5. FREQUENCY OF OCCURRENCE OF PARAMETER VALUES IN 1975

Parameter	Parameter Value	Percent of 1975 Acres	Percent of 1975 Mines
Mining Method	Area	97	82
	Modified Open Pit	1	15
	Open Pit	2	3
No. of Coal Seams Mined Per Pit	Single	51	37
	Multiple	49	63
Stripping Equipment	Dragline	88	70
	Truck and Shovel	5	15
	Construction	7	15
Use of Spoil Segregation Techniques	No	61	60
	Yes	39	40

TABLE 6. PRODUCTION PERCENTAGES FOR THE FIVE MOST FREQUENTLY OCCURRING WESTERN SURFACE COAL MINING SITUATIONS

Rank	Mining Method	Number of Seams	Main Stripping Equipment	Spoil Segregation?	Percent of ...			
					Pits	1975 Tonnage	1975 Acres	Maximum Tonnage
1	Area	Single	Dragline	No	34	23	30	16
2	Area	Single	Dragline	Yes	11	25	11	18
3	Area	Multiple	Dragline	Yes	11	20	24	11
4	Area	Multiple	Dragline	No	13	15	23	11
5	Modified Open Pit	Multiple	Truck & Shovel	Yes	3	4	1	12
TOTAL	--	--	--	--	72	87	89	68

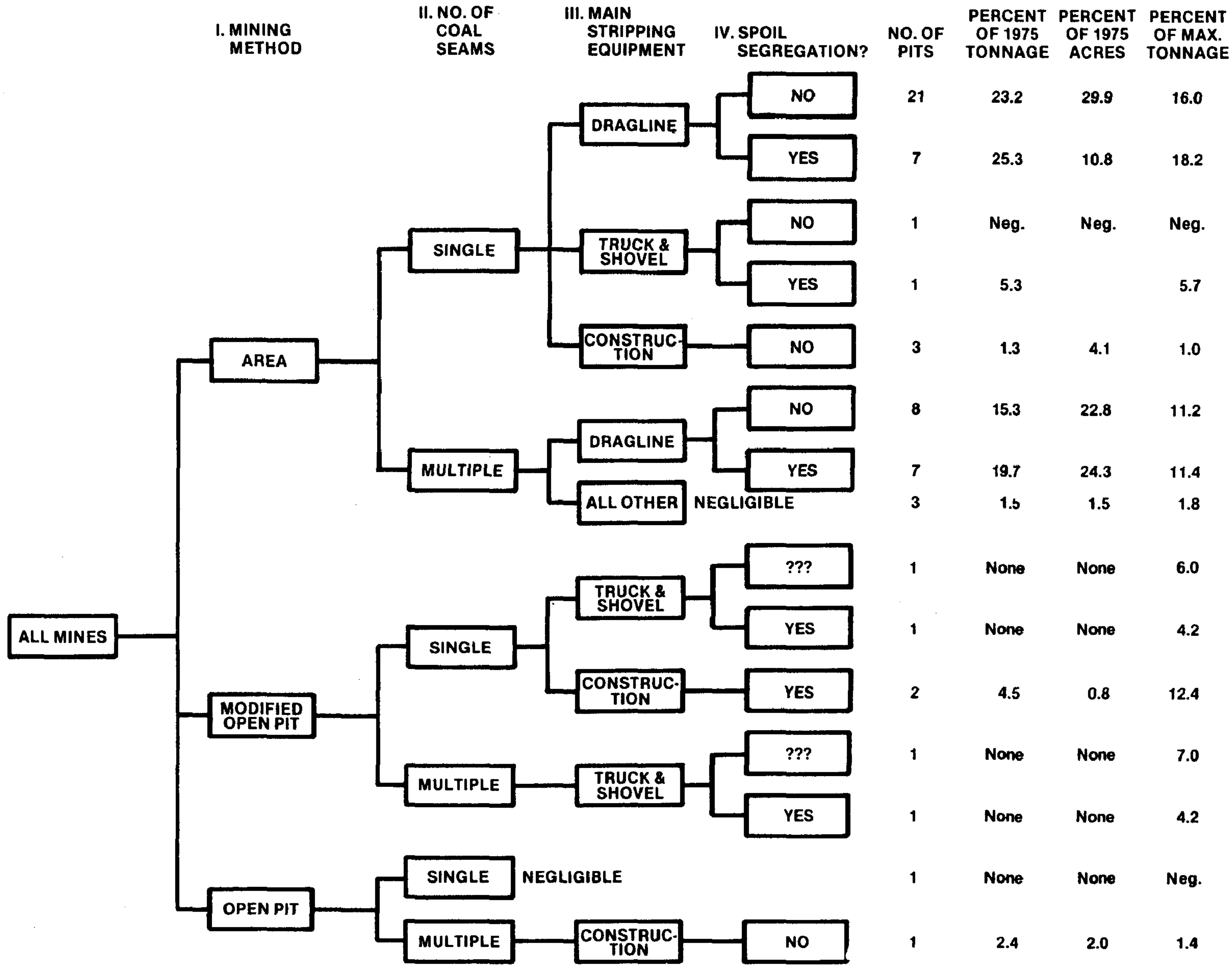


Figure 17. Classification of Western U.S. Surface Coal Mining Situations

TABLE 7. RANKING FACTORS FOR THE FIVE MOST FREQUENTLY OCCURRING WESTERN SURFACE COAL MINING SITUATIONS

Mining Method	Number of Seams	Main Stripping Equipment	Spoil Segregation?	Rank, Based on Percent of ...				Overall Rank
				Pits	1975 Tonnage	1975 Acres	Maximum Tonnage	
Area	Single	Dragline	No	1	2	1	2	1
Area	Single	Dragline	Yes	4	1	4	1	2
Area	Multiple	Dragline	Yes	3	3	2	4	3
Area	Multiple	Dragline	No	2	4	3	5	4
Modified Open Pit	Multiple	Truck & Shovel	Yes	6	6	8	3	5

A ranking of the top five situations, based on a composite of the various frequency measures, is presented in Table 7. Area mining of a single coal seam using a single dragline without and with spoil segregation, respectively, ranked first and second. Area mining of multiple coal seams using a single dragline with and without spoil segregation, respectively, ranked third and fourth. Finally, modified open pit mining of multiple seams with spoil segregation ranked fifth. This is not because the situation occurred frequently in 1975, but rather because it will occur fairly frequently by the early 1980's.

The foregoing five mining situations are discussed in this chapter. Dragline systems receive special emphasis, particularly with regard to ways in which production and reclamation practices can be integrated. Briefly, this refers to the practices of selectively placing spoil and choosing pit geometries that minimize the time lag between spoil placement and spoil grading.

MINE PLANNING

Planning of new western mines requires several years. Frequently the first step is to obtain a prospecting lease on a property. Exploration drilling is then conducted to determine the general characteristics of the coal seams, including depth, thickness, dip, heating content, sulfur content, ash content, moisture content, and, in some parts of the west, sodium content. In this phase the spacing of core drill holes is generally about one mile. Ordinarily only the coal is cored at this stage. If preliminary analysis indicates that mining is feasible, markets for the coal will be sought and a mining lease will be obtained. If surface ownership differs from coal ownership, attempts will be made to lease or purchase surface rights.

Subsequently, a detailed mapping program will be undertaken. The property will be drilled on 1/4 to 1/2 mile centers and, for some holes, the overburden as well as the coal will be cored. Overburden stratigraphy will be analyzed to estimate overburden drilling, blasting, removal, and placement costs. Additionally, some overburden samples will be artificially weathered in a laboratory and tests will be conducted to determine the plant-growing potential of the various overburden strata. The overburden will also be analyzed chemically and physically to determine those materials which must be placed selectively as spoil to comply with state and Federal reclamation laws.

Various maps will be developed. One type of map will show lines of equal overburden depth (isopachs). Others will show lines of equal stripping ratio, coal seam thickness, heating value, and sulfur content. The latter types of maps, depicting the characteristics of the coal on an areal basis, are particularly important where multiple coal seams are to be mined. This is because the characteristics of the coal seams may vary considerably, and blending of coal from two or more seams may be required to meet sales contract requirements. Blending may also be required where only one seam is mined as well, because the characteristics of a given seam may vary significantly over the mining property. In North Dakota, for example, the sodium content of the coal is sometimes troublesome. Near the coal seam outcrop, the sodium content is frequently low because much of the sodium has been leached out. In deeper overburden, the sodium content is typically higher. In such cases, it may be necessary to work two or more pits simultaneously, so that coal from the various pits can be blended to keep the average sodium content within contract limits.

The total strippable coal reserves will then be reestimated with increased accuracy made possible by the detailed drilling program. For a given area, the strippable reserves are dependent primarily on the selling price and thickness of the coal, the overburden depth, and the coal recovery percentage. Based on estimated coal selling prices and mining costs, a recovery line is defined. This line shows the estimated location of the final highwall, that is, the line of maximum strippable overburden depth. Of course, during the life of the mine, economics may change, usually resulting in redefinition of the recovery line and thus the strippable coal reserves and the estimated mine life.

Once the reserves, overburden depths, and stripping ratios have been estimated, alternative mining equipments will be evaluated. Limits on the total allowable capital investment for equipment are usually set in accordance with a rule of thumb which states that the total capitalization should not exceed $1.11 per metric tonne (one dollar per ton) of strippable reserves. Thus, for example, the total capitalization for an area underlain by 45 million metric tonnes (50 million tons) of strippable coal should not exceed 50 million dollars if the foregoing rule is used. Limits on total capitalization imply limits on equipment capacity and thus on rates of coal production. Those limits affect markets for the coal and the coal selling price.

Selection of main stripping equipment, the so-called prime movers, receives major emphasis. Draglines are widely favored as prime movers in the west today because, for a given rate of production, the unit ownership and operating costs for a dragline are lower than those for alternative types of equipment. Required overburden removal capacities for the dragline are determined by multiplying the required rate of coal production by the stripping ratio. For example, if the required rate of production is 1.8 million metric tonnes (two million tons) of coal per year and the average stripping ratio is 2.72 bank cubic meters of overburden per metric tonne of coal (three bank cubic yards per ton), then the required stripping capacity would be 4.9 million cubic meters (six million cubic yards) per year.* The dragline bucket size necessary to provide this capacity is dependent on the operating schedule, overburden type, and machine availability. The overburden in part determines cycle times, spoil swell factors, and bucket fill factors, which influence production capacity. Typical planning factors are shown below:

- Scheduled operations: 720 hours per month
- Machine availability: 75 percent
- Cycle time: 60 seconds
- Spoil swell factor: 30 percent
- Bucket fill factor: 85 percent

Application of those factors results in an estimated production of 200,000 cubic meters (260,000 cubic yards) of overburden per year per cubic meter of dragline bucket capacity. Thus, in the foregoing illustration, a dragline with a bucket capacity of 17.6 cubic meters (23 cubic yards) would be required.

In practice, determination of required equipment capacity is complicated by the fact that, because mining usually begins along the coal seam cropline where the overburden is shallow, the average stripping ratio increases steadily as mining progresses. This means that required equipment capacity will be greater in the later years of mining than in early ones. Accordingly, a stripping machine sized to meet early year production requirements will be too small to meet those in later years. Conversely, a machine sized to meet later year requirements will have excess capacity in early years.

Although there is no set rule for resolving this problem, common practice appears to be to size the machine to meet production requirements in early years, and then to purchase additional equipment in later years. The primary alternative is to purchase a machine capable of

*In this simplified illustration, it has been assumed that there is no appreciable spoil rehandle.

meeting maximum production requirements and then to use it only one or two shifts per day in the early years of mining.

The problem of selection of equipment capacity is compounded if the rate of coal production itself will increase over the life of the mine. Then the required rates of overburden removal increase as a result of both increasing stripping ratio and increasing coal production. This situation occurs most notably in Wyoming's eastern Powder River Basin where, because the coal is very thick, one company may have mining rights to billions of metric tonnes of strippable coal -- too much for which to find a market all at one time. As a result, production rates at a given mine will increase as new markets for the coal are found. This necessitates the use of a flexible stripping system whose capacity can be increased in the required increments.

This can be difficult where the prime movers are draglines, particularly since the present lead time for purchase of new machines is seven years; thus an alternative choice has frequently been made in the eastern Powder River Basin. The choice is truck and shovel stripping equipment. The equipment is proven, readily available, and can be augmented in small increments by adding trucks and shovels. The disadvantage of this alternative is that it is more costly to operate than draglines, a factor that may not be too significant when the coal is 30 meters (100 feet) thick, but is very significant otherwise. It is notable in this regard that the average thickness of individual seams mined in western areas other than the eastern Powder River Basin was 6.7 meters (22 feet) in 1975.

The implication here is that draglines will continue to dominate the western mining scene for the foreseeable future. This is but another reason for the strong emphasis on dragline mining situations in this report.

Additional equipment that must be selected includes that for topsoil removal, coal loading, coal haulage, and spoil grading, amendment, and seeding. Specifications for materials handling, maintenance, and office facilities are also defined at this stage. These decisions, although important, are not too relevant from an environmental standpoint.

Initial mining and reclamation plans will also be developed during the planning phase. The mining plan will typically show the sequence and geometry of stripping cuts, the methods used for overburden removal and spoil placement, and the approximate locations of drainage control facilities, coal haulage roads, and coal loading facilities.

In preparation of reclamation plans and environmental impact statements, several kinds of environmental surveys and analyses are generally conducted. These include, but are not limited to, the following:

- Overburden analyses.
- Soil surveys to determine topsoiling materials that are suitable for placement on the surfaces of graded spoils.

- Hydrologic surveys to determine the premining characteristics of surface water and groundwater in the mining area.
- Vegetation surveys to determine the types and densities of native vegetative species prior to mining.
- Archeological surveys to identify historically significant archeological features that should be preserved.
- Wildlife surveys to determine the types and numbers of wildlife that inhabit the mining area.

Reclamation plans include specification of at least the following kinds of procedures:

- Drainage control procedures, which may include stream diversions, above-highwall diversion ditches, impoundments, culverts under haul roads, and ditches alongside haul roads.
- Topsoil salvaging procedures, including depths of topsoil removed and replaced, locations of topsoil stockpiles, and ages of stockpiles at the time of placement of topsoil on graded spoils.
- Spoil segregation procedures to selectively place undesirable spoil materials during the mining process.
- Erosion and sediment control procedures including terracing, contour ditching, and construction and maintenance of sediment basins.
- Procedures for grading of spoil piles to restore approximate original contours. The plans usually include maps showing the topography after grading.
- Seeding and spoil amendment procedures including types and densities of vegetative species to be used, methods and times of year for seeding, and amounts of fertilizer, lime, gypsum or other spoil amendments to be used.
- Procedures for reducing the height and slope of the final highwall.
- Procedures to minimize noise, ground vibration, and air shock resulting from overburden and coal blasting.
- Procedures to control fugitive dust emissions.

After all necessary permits and licenses have been obtained, planning has been completed, a market for the coal has been defined, and financing has been obtained, mine development can begin. It includes purchase and assembly of equipment and construction of facilities and haul roads.

MINE OPERATING PROCEDURES

Operating procedures for frequently occurring mining situations are described below in more-or-less chronological order.

Drainage Control Practices

At 31 percent of the mines active or under development in 1975, intermittent stream courses that originally crossed planned pit areas were diverted to prevent surface water from entering strip pits. An apparent tendency in such cases is to straighten the stream beds thereby increasing the hydraulic gradient, possibly accelerating erosion of stream banks. This phenomenon was observed at one of the nine field survey mines.

Above-highwall diversion ditches were constructed at 71 percent of the mines active or under development in 1975 as a means of reducing the amount of surface runoff that entered strip pits. Generally those ditches were placed at or near the perimeters of the mining areas to eliminate the need to reconstruct the ditches as mining progresses. Although erosion of the ditches is a potential problem, it did not appear to be an actual one. This is because the gradients of the ditches are controlled to some extent, the ditches are often naturally vegetated, and rainfall, although sometimes intense, is infrequent. Figure 18 shows a typical diversion ditch. After mining has been completed, the ditches are revegetated as part of the reclamation effort. A reclaimed ditch is shown in Figure 19.

The ditches usually empty onto undisturbed ground. Headcutting at the ditch outfalls, shown in Figure 20, had occurred at two of the field survey mines where no attempt had been made to dissipate the energy of the outflow. At other mines, effective means had been devised to prevent headcutting. One of those, shown in Figure 21, was construction of a shallow rock-lined catch basin at the outfall of the ditch.

At some mines, small earth dams were constructed across natural drainageways to impound surface runoff and prevent it from entering strip pits or crossing haul roads. Those impoundments were generally deemed to be effective in controlling runoff. Potentially, however, they could have adverse effects on the water budget, due to increased evaporation of impounded water, and on surface water quality. But losses to the water budget due to the impoundments were deemed to be insignificant. Some grab samples taken from the impoundments were salty, however.

Figure 18. Photograph Showing a Typical Drainage Diversion Ditch

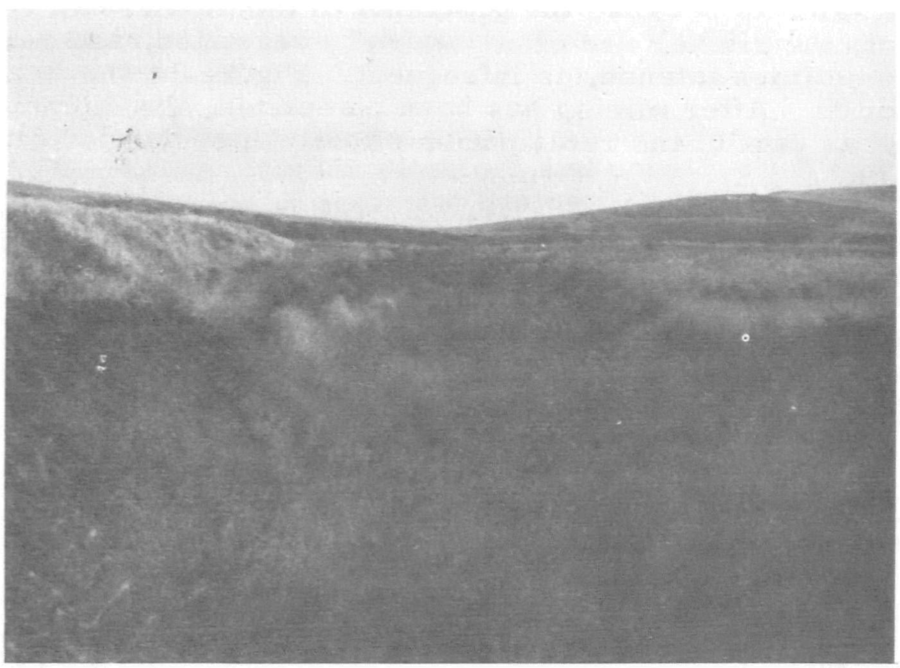


Figure 19. Photograph Showing a Revegetated Diversion Ditch

Figure 20. Photograph Showing Headcut at Outlet of Drainage Diversion Ditch

Figure 21. Photograph Showing Rock-Lined Outlet of Drainage Diversion Ditch, Used to Prevent Headcutting

Sediment basins were used at 87 percent of the mines active or under development in 1975. Although many of the basins at the field survey mines were shallow, they appeared to be effective. The conclusion is that sediment is being controlled adequately at the field survey mines. Some on-site sedimentation was observed, however.

Drainage treatment facilities, commonly used in other parts of the country, are not used in the west. This is taken to imply that chemical treatment of mine area discharge is not needed.

Of course, despite efforts to prevent water from entering strip pits, some surface water or groundwater usually does enter the pits. In such cases, water is pumped from the pits and discharged onto natural ground, or into drainage diversion ditches, or is routed through plastic tubing to sediment basins. Pit water was pumped at 82 percent of the mines active in 1975. In other parts of the country, particularly in midwestern acid areas, water that is pumped out of the pit must be treated to settle iron and reduce acidity. This is not required in the west because there are few acid areas. Of course, as pumped, the water may be heavily sedimented or high in soluble salts or trace elements. Sediment appears to be settled out in basins. At some mines there is no indication that pit discharge is chemically undesirable; in fact the water is used at some mines to irrigate reseeded spoil areas. At others, it appears that water quality has been changed.

Drainage at haul roads is controlled in the following three ways at most western mines:

- By installing culverts under the roads wherever the roads cross natural drainageways.
- By constructing and maintaining roadside ditches that carry runoff from the roads.
- By crowning the roads to divert surface runoff to the roadside ditches.

At the field survey mines, culverts, ditches, and crowning were used and appeared to be adequate.

A summary of the frequencies of use of the foregoing drainage control practices is presented in Table 8. An overall evaluation of the effectiveness of those practices is also presented.

Topsoiling Practices

Salvaging of topsoiling material was used at 96 percent of the western mines active in 1975. Typically, topsoil is removed by scrapers about one to six months ahead of overburden removal. In some northern areas, topsoil is not removed during winter months but in other areas it is removed year-round. The average depths of topsoil that were removed were determined from the premining soil surveys, and ranged from 10 to

TABLE 8. FREQUENCY OF USE AND EVALUATION OF DRAINAGE CONTROL AND TREATMENT PRACTICES USED DURING 1975

Drainage Control Practice	Frequency of Use of Practice in 1975		Overall Evaluation
	Percent of Acres	Percent of Mines	
Stream Diversion	12	31	Some stream bank erosion due to increased hydraulic gradient
Drainage Diversion Ditches	55	71	Effective, but headcutting at outfall of ditch should be prevented
Impoundments	No Data	No Data	No data
Sediment Basins	72	87	Appear to contain most or all sediment on-site
Drainage Treatment	1	2	Apparently not needed, but current research will provide resolution
Pump Water From Pits	89	82	No apparent significant adverse effects

122 centimeters (four to 48 inches) during 1975, as depicted in Figure 22. For the region as a whole, the average depth was 33 centimeters (13 inches). Figure 23 shows two scrapers removing topsoil. Figure 24 shows topsoil being piled by a dozer for subsequent loading into trucks. In North Dakota, topsoil and subsoil are removed separately. At most mines in other states, either only topsoil is saved, or topsoil and subsoil are removed and stockpiled together.

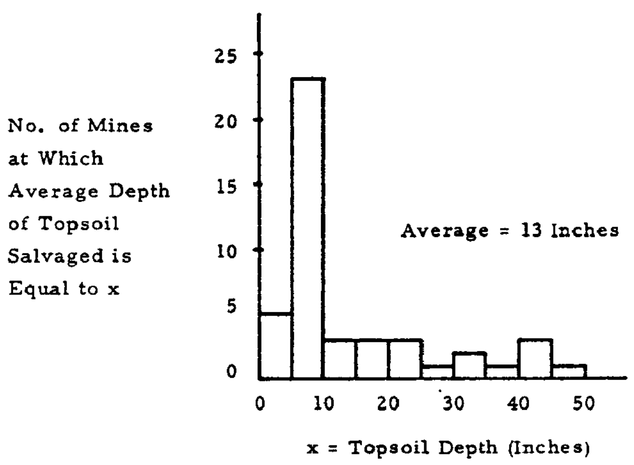


Figure 22. Histogram of Average Topsoil Salvaging Depths

Figure 23. Photograph Showing Scrapers Removing Topsoil

Figure 24. Photograph Showing Topsoil Removal by Dozer

At 96 percent of the mines active in 1975, some topsoil was temporarily stockpiled prior to placement on graded spoils. There are several reasons for this. One is that in the early years of mining there are only small acreages of graded spoil upon which to spread the topsoil. This is particularly true where topsoil is removed well in advance of overburden removal -- a practice that may expose large areas to wind erosion. Another is that it is not always desirable to place topsoil during winter months, when seeding is not done and wind erosion may occur. In general, however, it is desirable to place topsoil without stockpiling because a transplant effect may occur. This could be accomplished if topsoil was transferred across the active pit by the prime mover, a practice which is not feasible under current technology, but in some cases could be done if the prime mover was a bucket wheel excavator.

Transport of topsoil around the active strip pits to graded spoil areas can be costly, particularly where the pits are long. Typical costs range from \$0.33 to \$0.66 per cubic meter of topsoil (\$0.25 to \$0.50 per cubic yard). In some cases, to reduce costs, spoil bridges are constructed across the pits.

Wind and water erosion of stockpiled topsoil is a potential problem, and in some instances an actual one. Seeding of stockpiles to reduce water erosion is an effective but infrequently used practice -- during 1975, it was used at only 22 percent of the active mines. Where not used, erosion was observed to occur, as shown in Figure 25. The vegetation on the stockpile in that Figure is volunteer.

Figure 25. Photograph Showing Erosion on Topsoil Stockpile

The percentage of topsoil that is stockpiled varies from mine to mine and year to year. Thirty to fifty percent appears to be a representative figure.

Some time after stockpiling, usually six to 24 months, the topsoil is spread by scraper on graded spoils. Figure 26 shows topsoil replacement by scraper. Figure 27 shows an area that has been topsoiled, adjacent to an area that has not. The topsoiled area is at the right of the Figure.

In recent years, some ecologists have expressed concern that presently used topsoil salvaging practices may not be adequate. Their concerns are twofold. The first is that mixing of the various horizons may "contaminate" the A-Horizon material. The second is that stockpiling of topsoil for long periods of time may reduce or destroy the fertility of the soil. Field observations suggest that those concerns are unfounded in the short-term at least. At all of the field survey mines, vegetative density on topsoiled and seeded areas was good to excellent. Of course, through refinement of topsoiling salvaging techniques, it might be possible to reduce the time required to establish a given vegetative density on reclaimed areas, but, allowing for the apparent success of current practices, those refinements do not appear to be critical.

The frequencies of use and evaluations of topsoil salvaging practices are summarized in Table 9.

Overburden Drilling and Blasting

In North Dakota where the overburden consists of clays, soft shales and, in some areas, glacial drift, blasting of overburden is not required. At most mines in the other states, the overburden is drilled and blasted prior to excavation. Blasthole drill diameters at the field survey mines ranged between 19 and 27 centimeters (7-1/2 and 10-5/8 inches). Holes are generally drilled on 6 x 6 or 7.6 x 7.6 meter (20 x 20 or 25 x 25 foot) centers. Holes are typically loaded with bulk ANFO. Ordinarily, the overburden does not require hard blasting; typical powder factors range between 0.12 and 0.33 kilograms per cubic meter of overburden (0.2 and 0.55 pounds per cubic yard). This is much less than the 0.6 kilogram per cubic meter (one pound per cubic yard) average in the eastern United States. Frequently, where draglines are the prime movers, overburden is blasted only in the keycut. At some mines where loading shovels are used for overburden removal, the breakout force of the shovels is sufficient to remove overburden without blasting.

At the field survey mines, overburden is drilled three to six months in advance of stripping. Holes are usually loaded and shot within ten days after drilling. These practices appear to be unique to the west. In the midwestern and eastern United States where rainfall is fairly heavy, overburden blastholes are usually drilled only a few shifts ahead of stripping and the holes are loaded and shot within a few hours after drilling. This is because surface runoff or shallow groundwater may cause clogging of the blastholes.

Figure 26. Photograph Showing Topsoil Replacement by Scraper

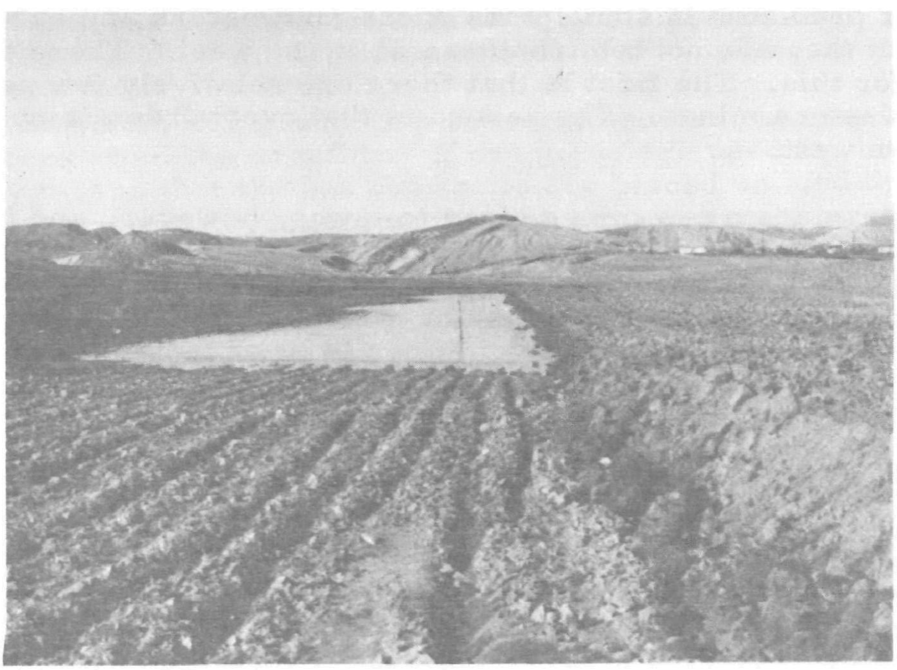


Figure 27. Photograph Showing An Area That Has Been Topsoiled

TABLE 9. FREQUENCY OF USE AND EVALUATION OF TOPSOIL SALVAGING PRACTICES

Activity	Frequency of Use		Remarks
	Percent of 1975 Acres	Percent of 1975 Mines	
Topsoil Removal and Replacement	94	96	Scrapers used extensively.
Topsoil Stockpiling Prior to Placement on Graded Spoils	94	96	Includes 65 percent of mines at which stockpiling will be done "if necessary". Usually it is necessary in the early years of mining.
Use of Special Measures to Control Erosion on Topsoil Stockpiles	15	22	Excludes 36 percent of mines at which erosion control measures will be used "if necessary".

Blasting of overburden can have adverse environmental consequences, primarily noise, ground vibration, and air shock. These effects are major problems in some parts of the midwestern and eastern United States, but they are not too troublesome in the west. There are two reasons for this. The first is that there are relatively few people living close to western mines. The second is that overburden is not blasted too hard in the west.

There are a few mines close to towns, however, and two procedures are used at those mines to minimize the environmental effects of blasting. The first is to delay the shots by row so that the amount of explosive detonated at a given instant is less than or equal to an amount determined by the U.S. Bureau of Mines to be acceptable. The second is to replace primercord detonators with electrically wired blasting caps. Primercord is a cord made of explosive material which is lain on the surface of the overburden connecting the blastholes. Ordinarily several hundred meters of primercord will be exposed on the surface of the ground for any given shot. The cord is detonated by a blasting cap and then detonates caps buried in each hole. Since the primercord is itself an explosive and is on the surface, its detonation usually makes a lot of noise. The alternative is to use electrical wire running to the caps in the blastholes. Detonation of the buried caps makes relatively little noise. Thus the substitution of electric caps for primercord is an effective noise-reducing technique.

Some researchers have made the claim that overly hard blasting of overburden may result in excessive amounts of fines in the shot material, thereby causing permeability problems when the material is placed as spoil. This potential problem does not appear to occur in practice. Blasting costs can be a fairly large component of total overburden removal costs and western mine operators are careful not to blast the overburden any harder than necessary.

There have been some complaints on the part of ranchers living near mines that blasting has caused wells or springs to dry up. In some cases, it has been determined that blasting could not have been the cause of the problems. In others -- the Absolaka mine is an example -- it has been determined that blasting has disrupted groundwater systems.

Drilling and blasting may also cause emission of fugitive dust. Neither the magnitude nor the extent of this potential problem was evaluated as part of this study.

Box-Cutting Procedures

The first step in the actual stripping process is to open the box cut. This cut is usually made along or near and roughly parallel to the coal seam cropline, where the overburden is shallow. In dragline stripping situations, the dragline rests on or near the natural ground surface, as shown in Figure 28, to excavate the box cut overburden. Excavated material is sidecast onto the natural ground adjacent to the box cut as shown in Figure 29. Where shovels and trucks are used to open the box cut, the spoil need not be stacked next to the cut and in practice it usually isn't. Generally, regardless of the equipment used, the box cut spoils are placed on areas that are not underlain by strippable coal; in dragline stripping this would be immediately outside of the coal seam cropline.

On occasion, for production reasons, the box cut may be opened fairly far back from the cropline. If draglines are used for box-cutting, this usually means that the box cut spoils are placed on land that is underlain by strippable coal. Consequently, the box cut spoils must eventually be moved to enable mining of the underlying coal. In such cases, mine operators may be reluctant to grade and seed the box cut spoil piles because they will be redisturbed. This is a minor environmental disadvantage of opening the box cut with a dragline back from the coal seam cropline.

Where the box cut overburden is fairly shallow, as is usually the case, box-cutting with shovels and trucks costs more than box-cutting with draglines. As a result, where shovels and trucks are the major overburden removal and spoil placement equipments, small draglines are often used to open the box cuts. They are also used for auxiliary work such as ditch-digging. On the other hand, where draglines are the prime movers, it is very unlikely that shovels and trucks would be used to open the box cuts. Rather, the prime mover or a small auxiliary dragline would be used.

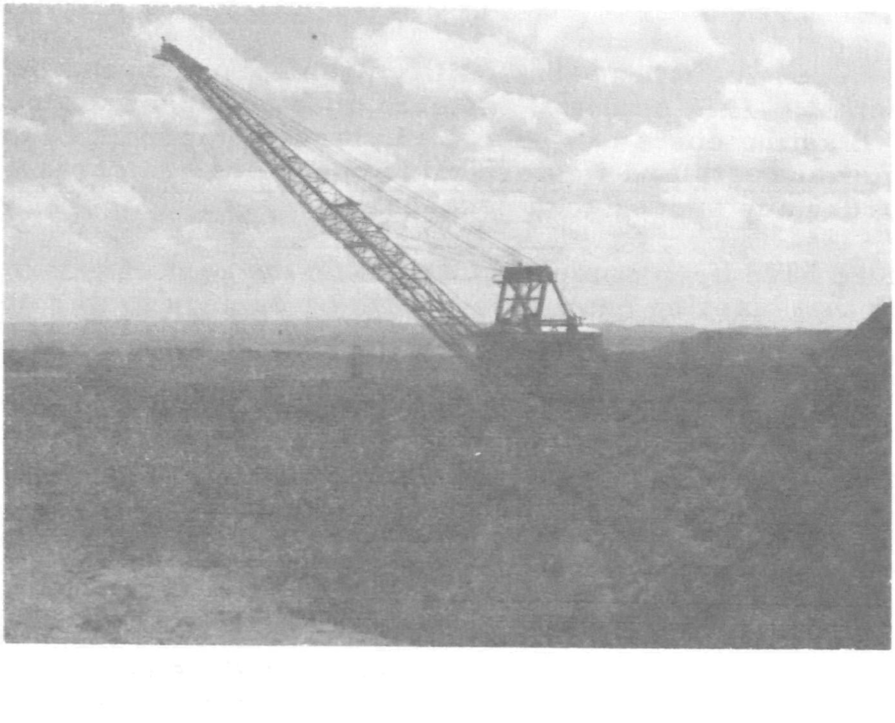


Figure 28. Photograph Showing Dragline Excavating Box Cut Overburden

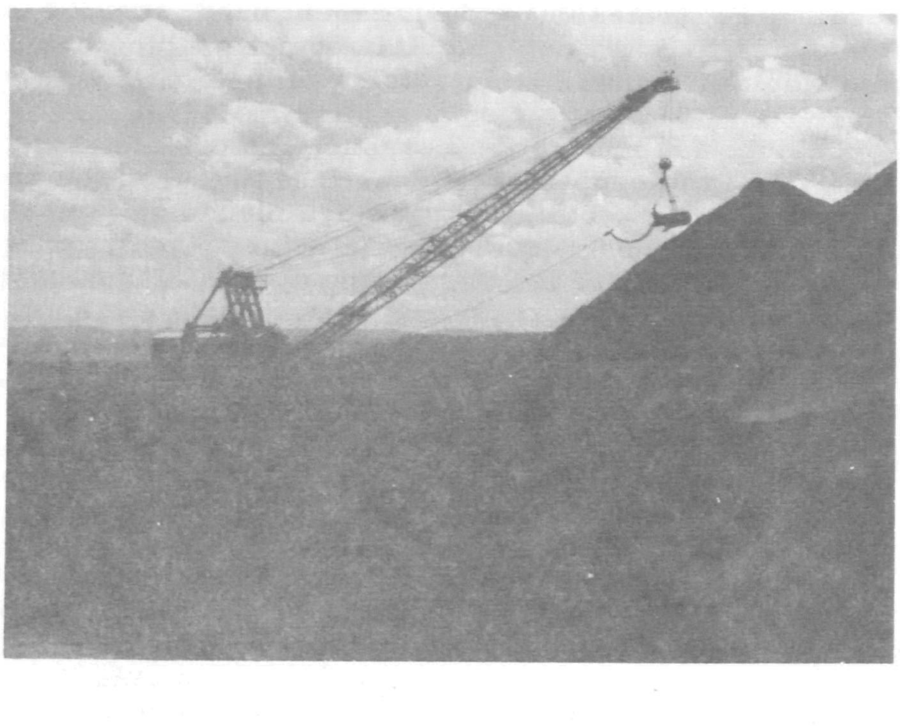


Figure 29. Photograph Showing Dragline Placing Box Cut Spoils

There are three situations in which box-cutting costs for draglines could be fairly high. One is where the box cut overburden is deep and spoil rehandle is required, either because a borrow pit is required or because box cut spoil must be placed on both sides of the cut as shown in Figure 30. The second is the case where the coal seam pitches steeply down from the cropline. In this case, standard practice is to open the box cut as wide as possible to allow for progressive narrowing of subsequent cuts to reduce overall spoil rehandle and maximize the amount of coal that can be recovered by stripping.

The third case is that in which two or more coal seams are to be mined in a given pit. In such cases, if a dragline is used to open the box cut and the overburden is fairly deep, it may be difficult or costly to open up to both seams in the box cut. This is environmentally relevant in states like Montana where the law requires that all seams which are economically recoverable be mined. One purpose of this law is to prevent redisturbance of reclaimed areas to recover lower lying seams, the mining of which may become economically feasible in later years.

Single Seam Dragline Stripping Procedures

The most common mining situation in the west in 1975 was stripping of a single seam using a single dragline as the prime mover. Several alternative operating procedures were used, depending on the overburden depth and the chemical and physical characteristics of the overburden. Each procedure is discussed in succeeding paragraphs.

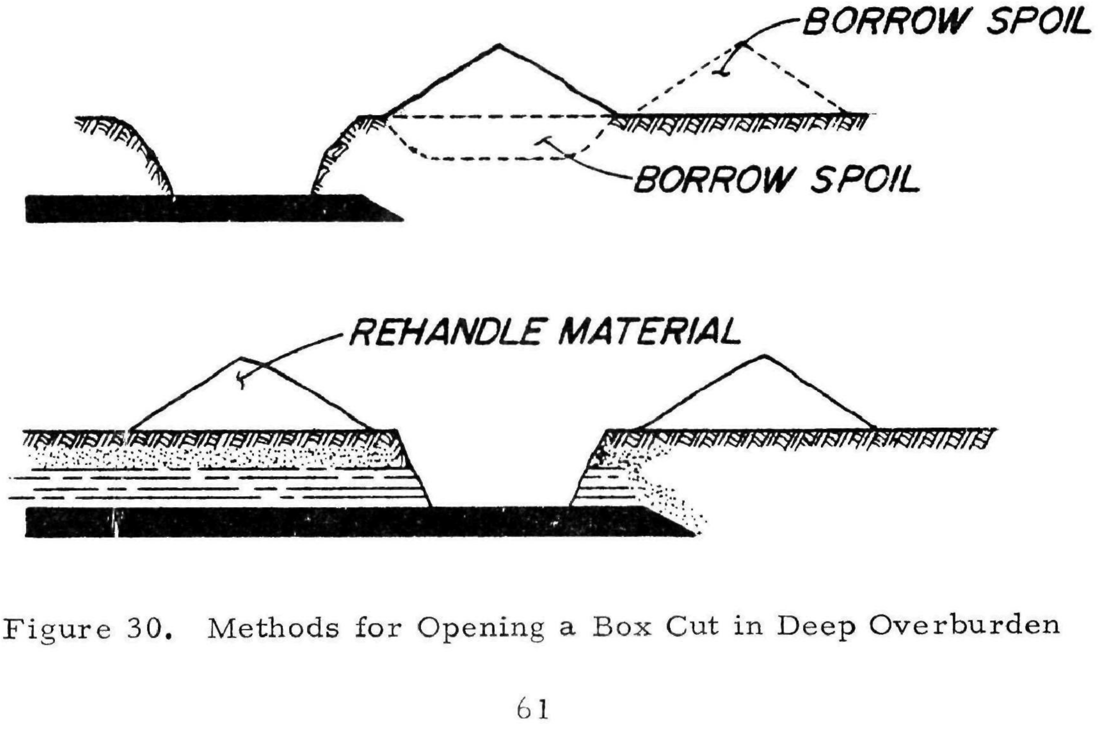


Figure 30. Methods for Opening a Box Cut in Deep Overburden

One-Lift, One-Pass Stripping Without Spoil Rehandle --

The least complex and most frequently occurring single seam dragline mining situation is one in which the dragline rests on or near the natural ground surface and overburden is removed in one lift and one pass in each pit.

In each cut the dragline is centered over the keycut, a narrow trench made to establish the new highwall. This is shown in position #1 in Figure 31. From that position, the keycut material is cast into the adjacent open cut. Eventually, if the dragline was not moved from the keycut position, the resulting spoil pile would become so large that the toe of the spoil would ride up the existing highwall above the top of the coal seam, thus necessitating subsequent spoil rehandle to enable recovery of all the coal. In order to prevent this, the dragline is moved sideways out toward the open cut to enable casting of the remaining spoil at an increased distance from the existing highwall. The resulting working position for the dragline is shown as position 2 in Figure 31.

After digging out a complete block, called a digout or move, the dragline is moved to the new keycut position to begin the next digout. Overburden handling procedures on this digout are similar to those on the previous one. When the end of the pit is reached, the machine is usually deadheaded (moved without excavating any overburden) back to the opposite end of the pit to begin the next cut.

The primary operating decision variables in this case are the width of the pit and the length of the digout. The choices of pit width and digout length affect both production costs and spoil grading costs. As the pit is narrowed, for example, the swing time and thus the overall cycle time for the dragline will be reduced. In theory, of course, the pit could be narrowed so far that swing angles would become so small that the dragline bucket could not be hoisted the required distance during the time required for the loaded swing. If this were to happen, narrowing the pit might increase cycle times and reduce productivity. In practice, however, this situation probably would rarely occur because the minimum pit width is dictated by safety considerations or the operating room required for coal loading and haulage equipment. At western mines, where electric shovels are used for coal loading, the minimum pit width in practice is 30 meters (100 feet). Where front end loaders are used for coal loading, this can be reduced to 27 meters (90 feet). Under such circumstances, where the dragline operates on or near the natural ground surface, overall cycle times are usually determined by swing rather than hoist times.

Intangible factors also affect the minimum practical pit width. For example, if the pit is deep and narrow, people may not want to work in it. In fact, at some surface coal mines in Australia, union contracts require a minimum pit width of 43 meters (140 feet). In the United States, a good rule of thumb is that the pit should be at least as wide as it is deep.

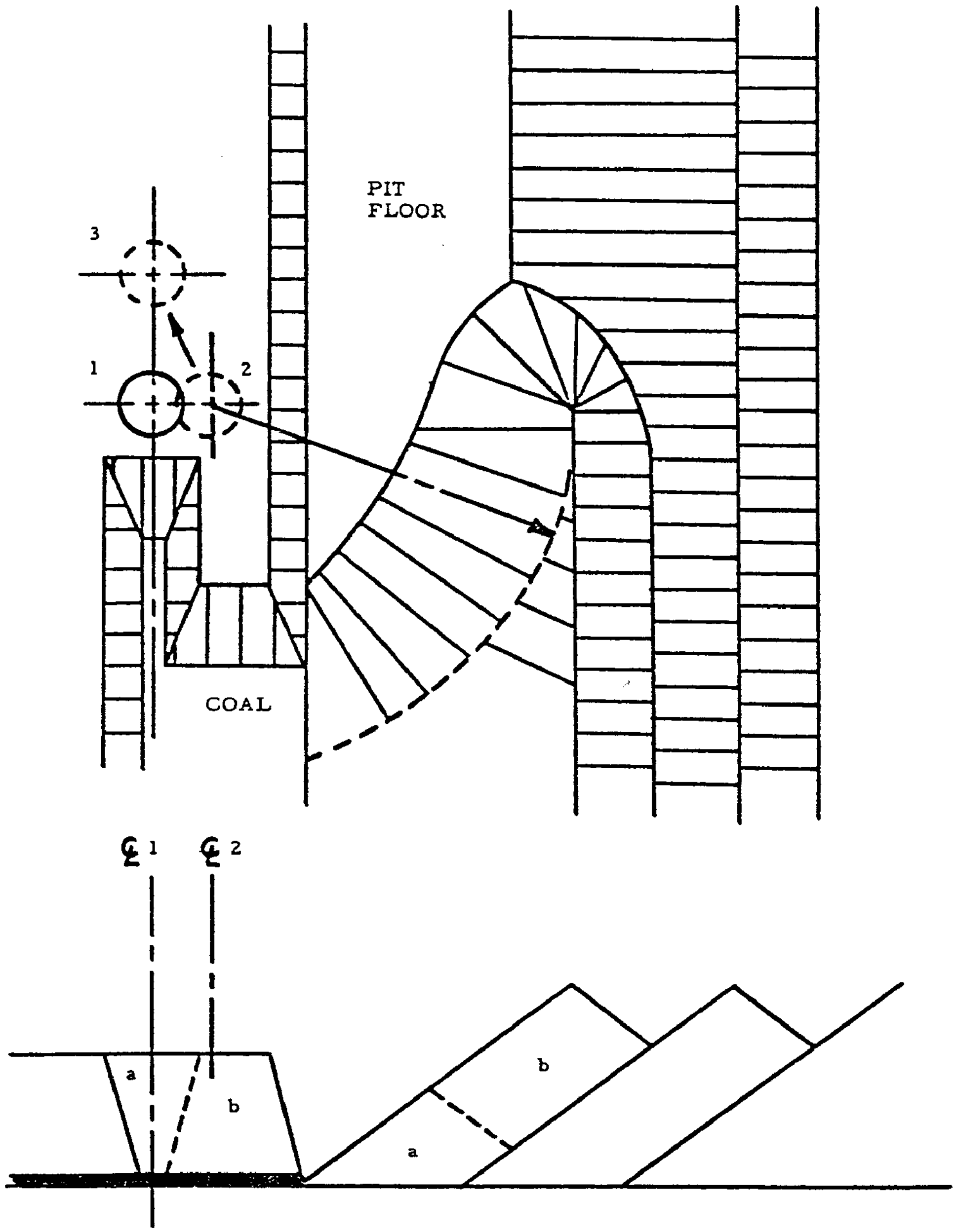


Figure 31. Plan and Section Views Showing Dragline Keycutting Procedures

The possible effect of this rule on pit widths can be gauged by considering the average overburden depths at western mines. As shown in Figure 32, those depths ranged between six and 55 meters (20 and 180 feet), and for the region as a whole averaged 24 meters (80 feet). Since 30 meters (100 feet) is the minimum width dictated by working room requirements for coal loading and haulage equipment, it would appear that the foregoing rule affects minimum pit widths only where overburden depths exceed 30 meters (100 feet). But for overburden that deep, production factors usually dictate that the pits be fairly wide. In 1975, the average width of dragline pits at western mines was 43 meters (140 feet).

The reason for emphasis on pit widths in this situation is that time lags between spoil placement and spoil grading can be reduced, and spoil grading costs as well as overburden handling costs can also be reduced by narrowing the pit.* Grading costs decrease as the crest-to-crest spacing of the spoil piles decreases. That spacing, in turn, is identical to the pit width. It has been estimated, for example, that per-acre grading costs for spoils with 27 meter (90 foot) crest-to-crest spacing are roughly half of the costs for grading of spoils with 37 meter (120 foot) crest-to-crest spacing. [19] The reason for this cost difference is illustrated in Figure 33, which shows that the width and depth of the vee between adjacent piles increases as the crest-to-crest spacing of the piles increases. Since spoils are graded by pushing spoil from the crests into the vee, decreasing the width and depth of the vee decreases the amounts and distances that spoil must be moved to achieve a desired final contour.

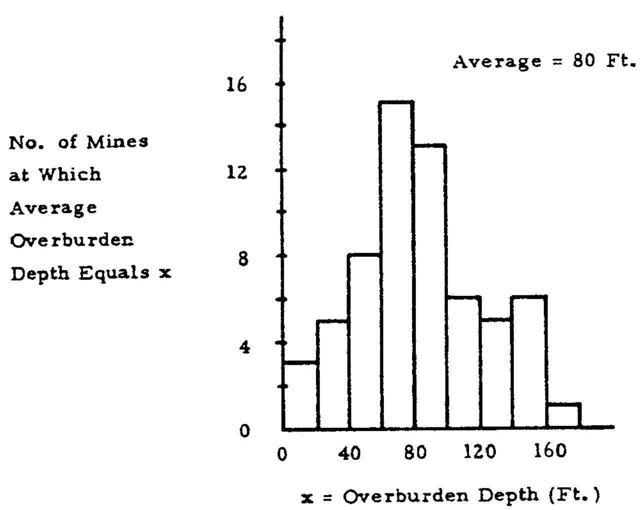
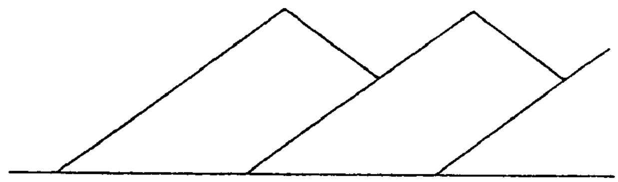
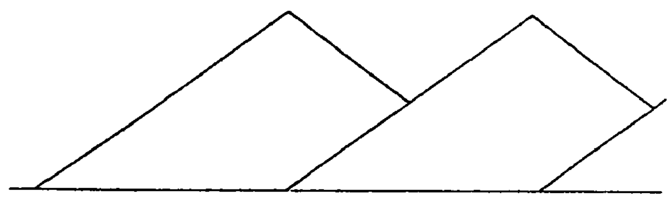


Figure 32. Histogram of Average Overburden Depths

*This applies only to the no-rehandle situation under discussion.



Crest-to-Crest Spacing: 90 feet



Crest-to-Crest Spacing: 120 feet

Figure 33. Comparison of Spoil Piles with 27 Meter (90 Foot) and 37 Meter (120 Foot) Crest-to-Crest Spacing

At one western mine in 1975, for instance, pit width was 120 feet and spoil grading costs were estimated to be $3,954 per hectare ($1,600 per acre). The average coal seam thickness was 4.6 meters (15 feet), yielding a grading cost of 5-1/2 cents per metric tonne of coal (six cents per ton). It is estimated that narrowing the pit to 27 meters (90 feet) would result in a grading cost reduction of 2-3/4 cents per metric tonne (three cents per ton) of coal produced.

This modest decrease in grading costs must be balanced against the increased non-productive dragline walking time and possible decrease in spoil stability that may result when the pit is narrowed. The former effect results from the fact that, for a given area to be mined, the number of pits and dragline digouts required increases as the pit width is decreased. This in turn increases the non-productive movement time for the dragline. Additionally, as the pit is narrowed, the base of the spoil pile is also narrowed and, although spoil instability is not a major problem at western mines, the stability of the spoil pile may be decreased.

Coal recovery percentages are also affected by the choice of pit width in that, in each pit, a wedge or "fender" of coal is usually left in place at the toe of the spoil pile, as shown in Figure 34, either to buttress the spoil toe or because clean coal cannot be loaded near the spoil toe. The height and width of the wedge depend on the coal seam thickness and the position of the spoil toe. If the pit is narrow, it may be possible to keep the spoil toe low on the coal seam in the highwall as shown in the top section view in Figure 34. The height of the coal wedge would then be correspondingly low. For a given overburden depth, as the pit is widened, the spoil toe will generally ride higher on the coal in the highwall, necessitating

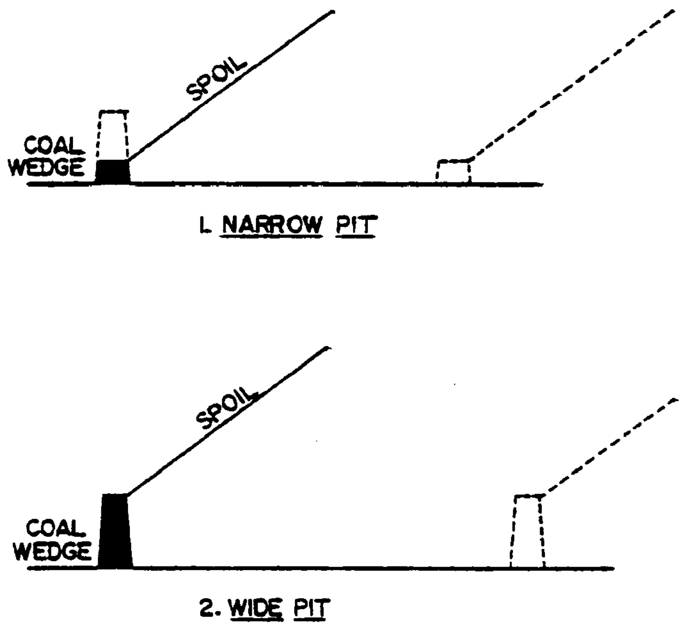


Figure 34. Section View Showing Coal Wedge

a higher coal wedge. Of course, although in a given pit the size of the wedge may increase as the pit width is increased, the number of pits and thus the number of wedges decreases.

Operators of western mines generally estimate losses of coal in wedges as a function of the pit widths. An example is a mine in Montana at which the average coal seam thickness is 4.6 meters. The average coal loss for a pit width of 33.5 meters (110 feet) is 1.7 percent; for a pit width of 45.7 meters (150 feet) it is 2.3 percent. The higher within-pit coal losses for the wider pits are counterbalanced to some extent by the reduction in total number of pits required.

Most mine operators are interested in finding ways to reduce the losses in coal wedges. In fact, in Montana, this is required by law. One solution, observed in use at a field survey mine, is to use a backhoe to recover the coal wedge after the main part of the seam has been loaded out by shovel. The left-hand side of Figure 35 shows the appearance of an area from which the coal wedge has been removed. The wedge is still in place at the right-hand side of that Figure.

The length of the digout also affects production and spoil grading costs. If the digout is long, the spoil is placed in conical piles and the resulting spoil ridge line as viewed from the highwall is undulating. In such cases, before spoils can be graded by pushing material into the vee's between adjacent spoil piles, dozers must be used to create a fairly level spoil crestline from which they will subsequently work to push material into the vee's. Nonetheless, some mine operators prefer long digouts

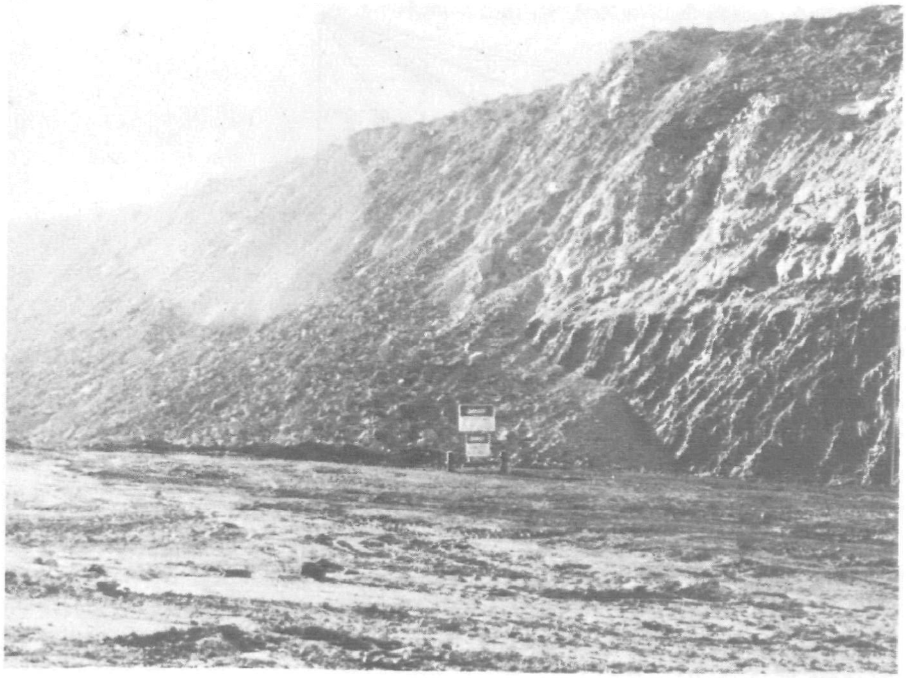


Figure 35. Photograph Showing Removal of Coal Wedge and Subsequent Collapse of Spoil

because they reduce the total number of digouts required and the non-productive sideways and diagonal movement of the dragline.

The alternative is to shorten the digout so that, rather than being placed in conical piles, the spoil is placed so that the crestline is fairly even, similar to the crestline for spoils placed by a stripping shovel. In this case, it is fairly easy to construct a road on the crestline from which spoil will be pushed into the vee's. Although use of the shorter digout does therefore reduce spoil grading costs, total non-productive sideways and diagonal movement time for the dragline is increased.

This latter disadvantage is frequently offset to some degree by a decrease in digging time for the dragline. This is because, although the bucket can usually be filled in two or three bucket lengths, conventional practice is to continue pulling the bucket in to the machine fairleads to tip the bucket upward before hoisting, thus preventing material from spilling from the bucket when it is hoisted. This practice is depicted in Figure 36. By shortening the digout, the average distance that the filled bucket is dragged before hoisting is reduced; thus overall cycle times are also reduced. In one instance known to the authors, the digout was shortened to reduce spoil grading costs and dragline productivity increased by two percent.*

*Use of a patented device known as the Miracle Hitch enables hoisting of the loaded bucket at any point without substantial spillage, thereby eliminating the practice of dragging the filled bucket into the fairleads before hoisting.

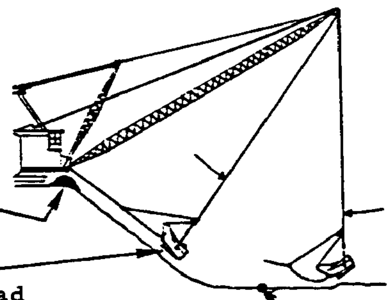


Figure 36. Section View Showing Dragging of Filled Bucket Before Hoisting to Prevent Spillage

The foregoing discussion has illustrated some interrelationships between pit width and digout length on one hand and spoil grading costs and timeliness on the other. It may be possible through consideration of those relationships in choosing pit widths and digout lengths to "integrate" mining and reclamation decisions. Overall, however, the effects of those choices on reclamation performance are seen to be modest, particularly where the coal seams being mined are thick.

There is another, potentially more significant way to integrate mining and reclamation practices, however. It involves selective removal of overburden and placement of spoil materials to ensure that the "best" spoil materials are placed on or near spoil surfaces, or below the water table, if any exists above the pit floor. In conventional practice, where special spoil placement methods are not used, overburden materials are inverted on the spoil piles. Thus surface overburden materials are placed near the pit floor and overburden materials nearest the coal seam are placed on the surfaces of the spoil piles. This is frequently undesirable from an environmental standpoint.

One reason is illustrated in Figure 37 which shows the sodium adsorption ratio (SAR) vs. overburden depth for a core drill sample from a surface coal mine in North Dakota. In this case, the SAR value increases with overburden depth and reaches the critical value of ten at a depth of about six meters (20 feet). The SAR value for the overburden stratum immediately above the coal seam is 45, indicating that significant permeability, and, therefore reclamation problems would result if the material was placed on the surfaces of the spoil piles, as would be the case if selective placement procedures were not used -- and often in practice they are not. In fact, old unvegetated orphan spoils in several of the western states are testimony to the spoil permeability and vegetative cover problems that have resulted from placement of high-SAR materials on spoil surfaces.*

*There are also old orphan spoils which have a good cover of volunteer vegetation but in some cases the spoils resulted from stripping of shallow overburden which may not have had high SAR values.

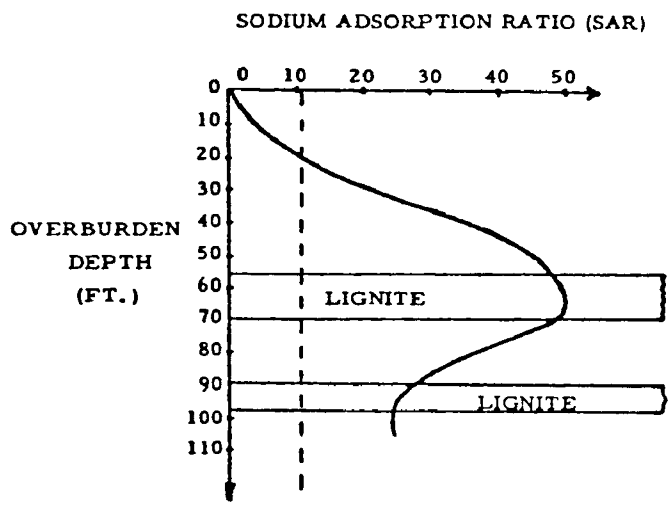


Figure 37. SAR Analysis of Core Drill Sample From North Dakota Mine

Of course, to a great degree, potential revegetation problems due to impermeable surface spoil materials are reduced through spreading of topsoil on spoil surfaces, but the topsoil depths required to prevent contact of plant roots with the underlying impermeable spoil layer may be fairly large. In North Dakota, for example, the law requires replacement of up to 1-1/2 meters (five feet) of topsoil to prevent occurrence of this problem. In Montana, undesirable spoil materials must also be buried under a minimum of 1-1/2 meters of acceptable material. In such instances, selective placement of spoil materials could result in a reduction of necessary topsoil replacement depths. Although selective spoil placement practices in dragline stripping situations are not widely used in the west, they are widely used in the midwestern United States, indicating that such practices are both technologically and economically feasible.

One method for ensuring that the overburden strata immediately above the coal seam are buried in the spoil pile is illustrated in Figure 38 which depicts stripping of 27 meters (90 feet) of overburden by a dragline with a 72 meter (235 foot) boom at 30-1/2 degrees and a 23 cubic meter (30 cubic yard) bucket. It has been assumed that the lowest six meters (20 feet) of the overburden consist of undesirable material which must be buried in the spoil.

An operational procedure that can be used to achieve this objective is as follows. First, after removal of 1-1/2 meters (five feet) of topsoil by scraper, the top 20 meters (65 feet) of the overburden are excavated and cast into the open pit at an average swing angle of 82 degrees from the digging position. Next, the lowest six meters of the overburden are excavated, and the boom is swung through an average angle of 120 degrees to place the material ahead of the main spoil pile near the pit floor. This procedure is known as leading the spoil.

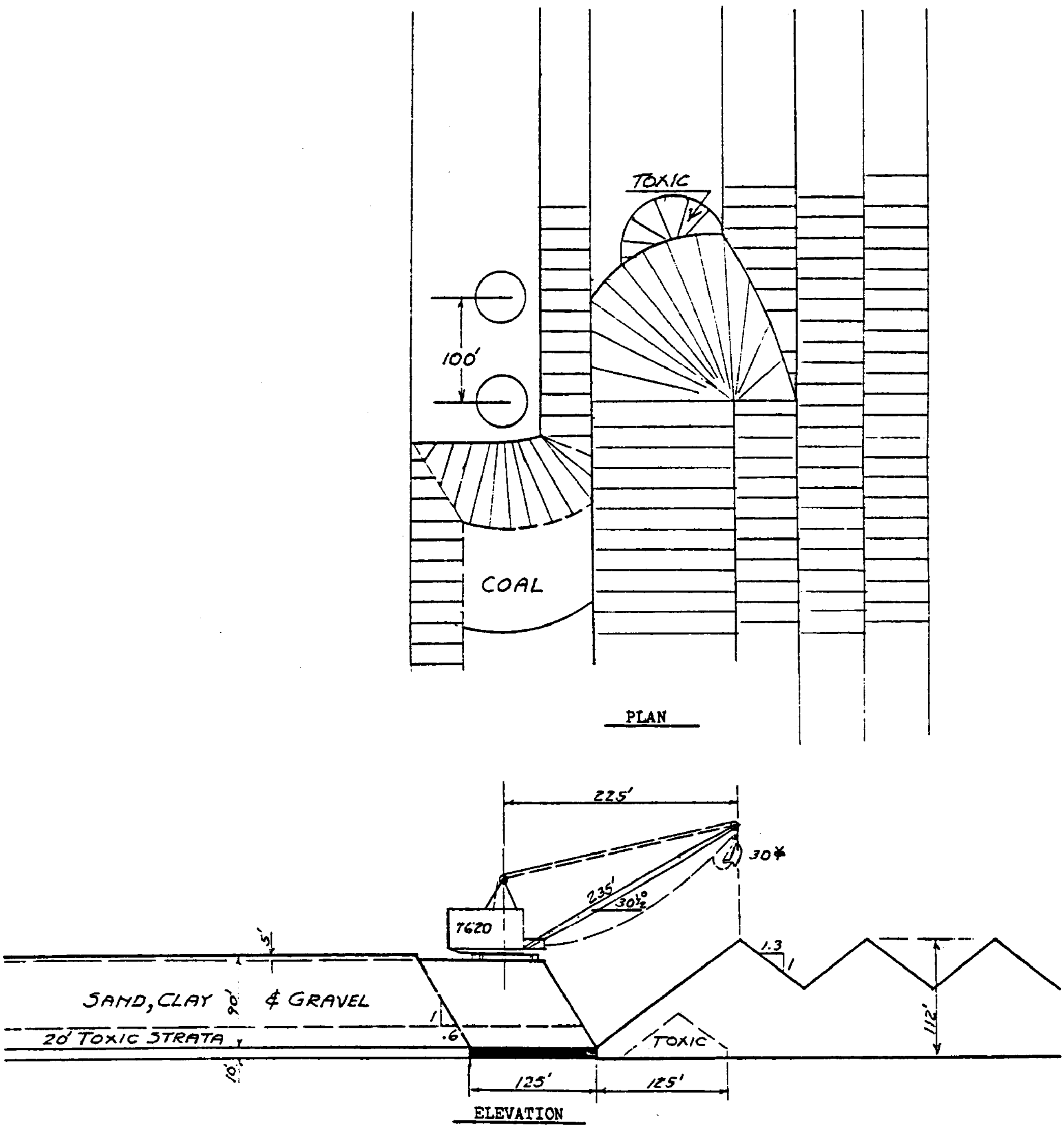


Figure 38. Illustration of Selective Spoil Placement Procedure in Single Seam Dragline Stripping Situation

Selective digging of the undesirable overburden material results from a digging procedure known as layer loading, a practice in which overburden is excavated by dragging the bucket parallel to the overburden strata. This practice is not only feasible, it is also desirable from a production standpoint because it minimizes digging time. An exception is digging of sandstone strata, in which case layer loading may be difficult.

The foregoing selective spoil placement procedure, although both feasible and desirable, has an adverse effect on dragline productivity. This is because the swing angle required to lead the undesirable spoil material is greater than that which would be required if the selective placement procedure was not used. A production estimate for the selective placement case is shown in Table 10. Assuming a three meter (10 foot) coal seam, the estimated average annual production in 18 to 27 meters of overburden (60 to 90 feet) cover is one million metric tonnes (1,125,000 tons) of coal.*

TABLE 10. PRODUCTION SUMMARY FOR SELECTIVE SPOIL PLACEMENT ILLUSTRATION

Walking Dragline (Marion 7620) 235' boom with a 30 cubic yard bucket, cut 125' wide in 90' overburden cover and a 100' digout.

Component	Swing Angle	Swings Per Hr.	Bank Cu. Yds. Bucket Carry	Bank Cubic Yards	Time Hours
Topsoil (Move by scrapers)				2,315	
Sand, Clay & Gravel	82°	62	21.6	30,093	22.47
Toxic Strata	120	57	21	9,260	7.73
Total				41,668	
Moved by dragline				39,353	
Operating time for a 100' digout 80%					30.20
Delays 20%					7.55
Scheduled time					37.75
Cubic yards per digging hour					1,303
Cubic yards per month (576 hours)					751,000
Cubic yards per year (bank)					9,007,000
Mining ratio (cubic yards per ton)					10
Tons per year					900,000
Tons per year at 60' cover overburden (ratio = 6.67)					1,350,000
Annual average tons in 60' to 90' cover					1,125,000

*In this example, 27 meters (90 feet) has been assumed to be the maximum overburden depth.

Estimated costs for this case are presented in Table 11. Highlights from that Table are summarized below:

- Capitalization: $10 million.
- Stripping and grading cost: $1.09 per metric tonne ($1.20 per ton).
- Total mine operating costs: $2.23 per metric tonne ($2.46 per ton).
- After-tax income: $0.32 per metric tonne ($0.35 per ton).
- After-tax net cash flow: $0.72 per metric tonne ($0.80 per ton).

The effect on production of use of the selective placement procedure is shown in Table 12. If all spoil was placed non-selectively, the average swing angle for the dragline would be 85 degrees, where, in contrast, the average for the selective placement case was 91 degrees. This reduction of swing angle would result in a two percent increase in the amount of overburden moved and coal exposed each year. Overall stripping costs per unit of coal produced would also decrease, in this example from $1.09 per metric tonne ($1.20 per ton) to about $1.07 per metric tonne ($1.18 per ton). Thus the estimated incremental cost to selectively place overburden in this case is roughly two cents per metric tonne of coal produced. Based on an average stripping ratio of 6.7 cubic meters per metric tonne (eight cubic yards per ton), this is equivalent to an incremental overburden removal cost of much less than one cent per meter (one cent per cubic yard).

The cost of moving topsoil has been reported by operators of western mines to be $0.37 to $1.11 per cubic meter ($0.25 to $0.85 per cubic yard) of topsoil replaced.* Thus, in the present example, if selective spoil placement would enable reduction of required topsoil replacement depths, reclamation costs might also be reduced.

Of course the foregoing example is just one of many possible situations. For example, at one mine at which the average overburden depth is 24 meters (80 feet), soil and overburden analyses indicated that the top six meters (20 feet) of the overburden excluding topsoil were the least desirable of all the materials in the bank. Burial of such material in the spoil presents no problem unless, to prevent possible contamination of groundwater, the materials cannot be placed on or near the pit floor. Even in this case, however, the required placement of high bank (or low bank) overburden materials in the middle of the spoil profile is

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*The upper end of the cost range generally applies where topsoil salvaging is contracted.

TABLE 11. COST ESTIMATE FOR SELECTIVE SPOIL PLACEMENT EXAMPLE

Walking Dragline	(M 7620)
Cubic yards moved per year in 60' to 90' overburden	9,000,000
Tons of coal produced annually, 10' seam @ 90% recovery	1,125,000
Average Mining Ratio	8.00
CAPITAL COSTS	
1- Walking dragline, 235' boom, 30 cu. yd.	$ 5,300,000
1- Coal loader (M 151)	900,000
1- Cat. 992B, F.E.L.	200,000
2- Cat. D8 dozers + 1 Cat. 633C scraper	450,000
1- Cat. 16 patrol grader	125,000
3- Coal haul trucks (120 ton)	450,000
1- Coal dump hopper, crusher and car mover	400,000
1- Railway lead and hold yard	500,000
1- Building and miscellaneous equipment	1,675,000
Total	$10,000,000
MINE OPERATING COSTS	PER TON
Stripping	
Labor	$0.52
Repairs and Supplies	0.32
Power	0.16
Reclamation	0.20
Total	1.20
Coal loading and shooting	0.10
Coal hauling (2 miles)	0.12
Crushing and loading RR cars	0.10
Supervision and office	0.16
Administration and general	0.06
Western Miners Union royalty	0.40
Interest on one-half of the capital costs	0.18
Miscellaneous	0.14
TOTAL	$2.46
SALES REVENUE ($0.35 per mm BTU)	$4.25
Royalty	0.25
REALIZATION NET	$4.00
Mine Costs	2.46
	1.54
Depreciation	-0.45
Depletion	-0.40
Net for income taxes	0.70
North Dakota income tax 4%	0.03
Federal income tax	0.32
INCOME PER TON	$0.35
Add back	0.45
NET CASH FLOW	$0.80

TABLE 12. PRODUCTION SUMMARY FOR NON-SELECTIVE SPOIL PLACEMENT ALTERNATIVE

Walking Dragline (Marion 7620) 235' boom with a 30 cubic yard bucket, cut 125' wide in 90' overburden cover and a 100' digout

Component	Swing Angle	Swings Per Hr.	Bank Cu. Yds. Bucket Carry	Bank Cubic Yards	Time Hours
Topsoil (Move by scrapers)				2,315	
Sand, Clay & Gravel	85°	61.5	21.5	39,353	29.54
Total				41,668	
Moved by dragline				39,353	
Operating time for a 100' digout 80%					29.54
Delays 20%					7.38
Scheduled time					36.92
Cubic yards per digging hour					1,332
Cubic yards per month (576 hours)					767,000
Cubic yards per year (bank)					9,205,000
Mining ratio (cubic yards per ton)					10
Tons per year					920,000
Tons per year at 60' cover overburden (ratio = 6.67)					1,380,000
Annual average tons in 60' to 90' cover					1,150,000

feasible and can often be achieved without appreciable cost increase. It may be costly, however, where the dragline operates from a position on or near the natural ground surface. In such cases, it would be advisable to revise operation procedures so that the dragline operates from a bench, as described next.

Two-Lift, One Pass Stripping Without Rehandle --

In some cases it is impossible or undesirable to work the dragline from the top of the ground, so instead the machine works from a bench that is cut some distance below the ground surface. There are several possible reasons for operating from a bench. One is to keep the dragline at a constant elevation above the coal even though the terrain may be rolling. Another, particularly applicable in glaciated areas, is to provide a working surface for the dragline on bedrock. In wet weather, this reduces problems that might otherwise result from walking a large dragline through mud. A third reason is to prevent casting of unconsolidated surface overburden materials on the pit floor. This is sometimes necessary to minimize spoil instability problems.

At large mines, the dragline is usually used to cut its own bench. The operating procedure involves making two overburden lifts in one pass of each pit. First, working from the machine-supporting bench, the overburden beneath the bench is excavated and spoiled in conventional fashion. Then the bench for the next pass -- not the next digout -- is excavated to the side of the bench from which the dragline operates. This is accomplished by turning the boom in the direction of the next pit, as shown in the left-hand portion of Figure 39, and excavating overburden above the dragline bench. Then, as shown in the right-hand portion of Figure 39, the boom is turned through 180 degrees and the spoil is cast on top of the existing spoil pile.*
An artist's conception of this procedure is shown in Figure 40.

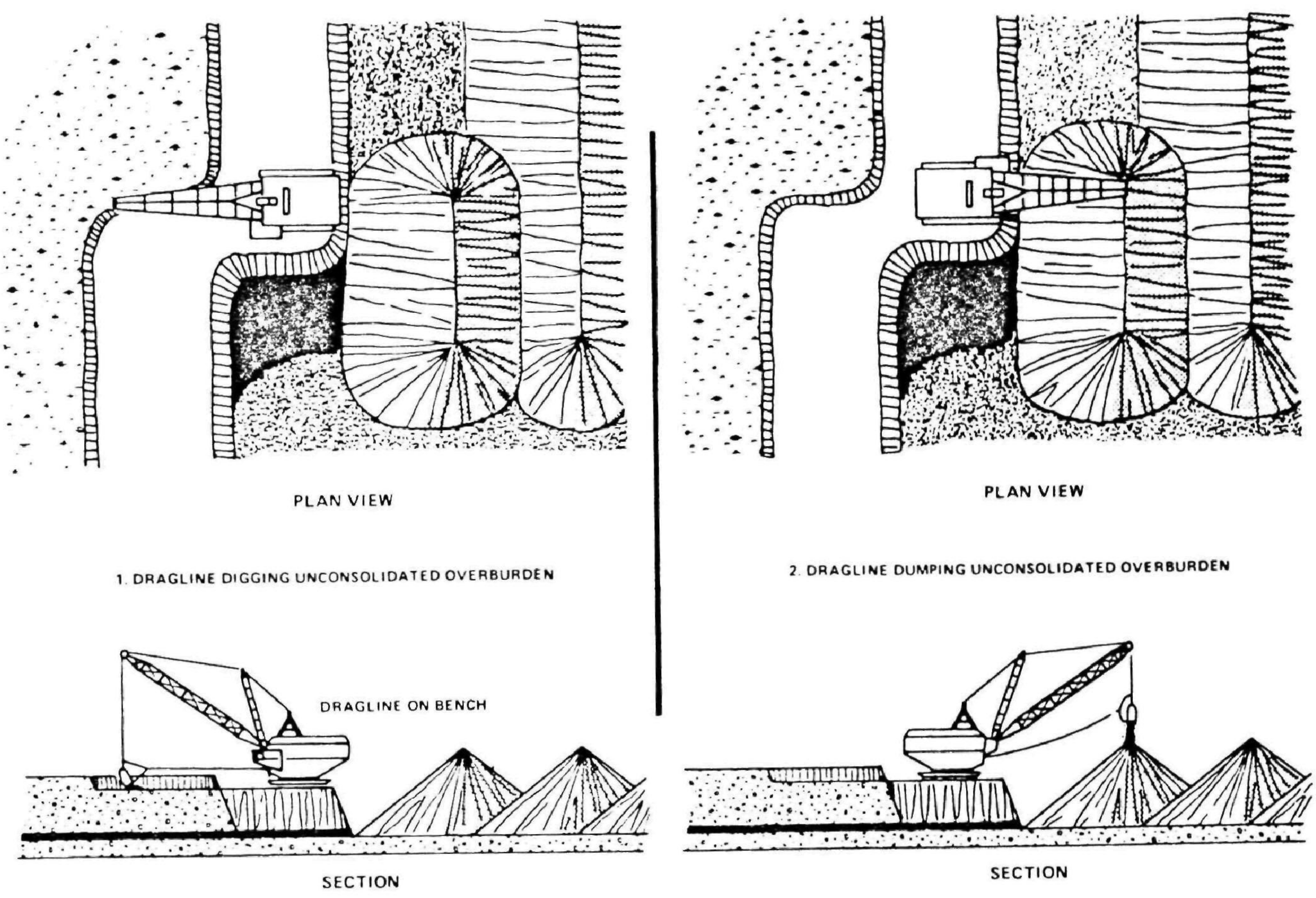


Figure 39. Plan and Section Views Showing Side-Benching Procedure

*In practice the average swing angle in this operation is usually about 135 degrees.

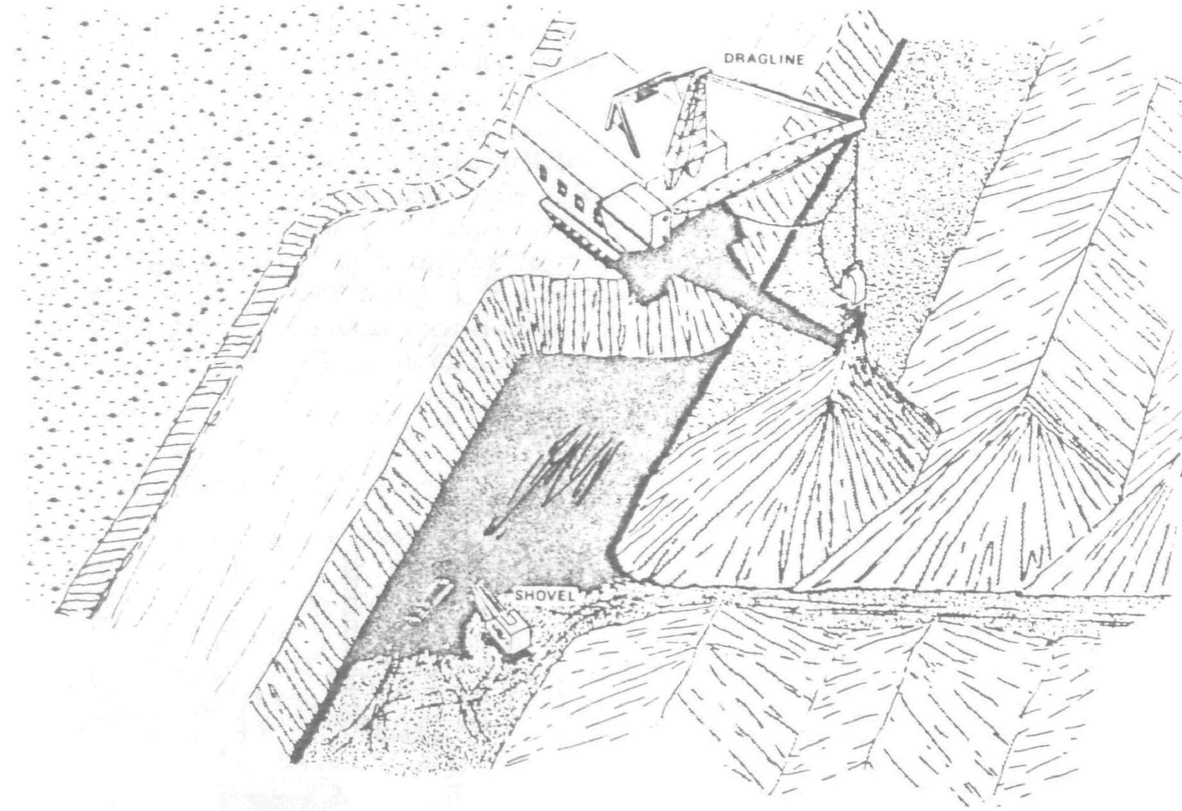
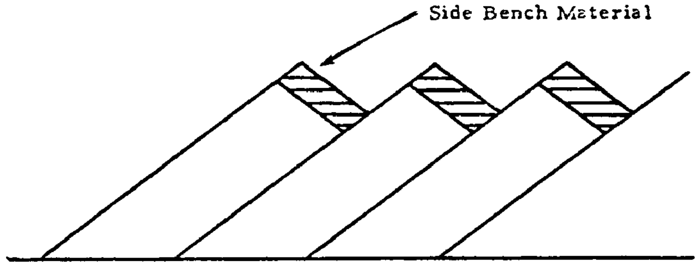


Figure 40. Artist's Conception of Side-Benching Procedure

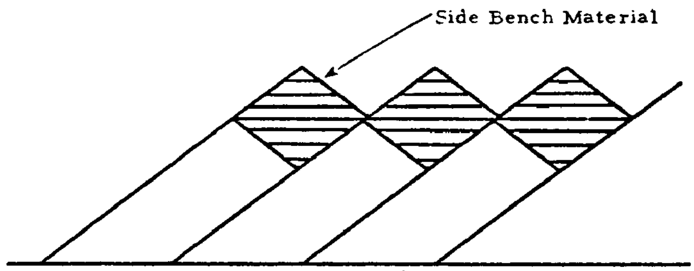
The bench from which the dragline operates is called the established bench; the bench which is cut to the side for the next pass is called the side bench. The side bench is used extensively for production reasons at mines in the midwestern United States but is infrequently used at western mines. This is because in the west precipitation is low and soils are shallow. Thus problems with spoil instability and movement of draglines through deep mud are infrequent. But although, historically, the side bench method has evolved principally as a solution to production problems, it also has environmental advantages that may make it desirable for more widespread use in the west.

Where the surface overburden materials are better plant-growing media than lower bank materials, the advantage is that the former materials can readily be placed on the surfaces of the spoil piles. In fact, in the midwestern United States this is one of several reasons for the successful revegetation efforts that characterize parts of the region. There is a potential drawback, however, in that the underlying spoil materials, which may be undesirable, are sometimes exposed during grading of the spoil piles. A case where this might happen is illustrated in the top half of Figure 41 which shows the appearance of side bench spoils for a situation in which the overburden depth is 30 meters (100 feet) and the bench depth is three meters (10 feet). In this instance, it is likely that spoil materials immediately underlying the side bench spoil



1. Overburden Depth = 100 feet

Bench Depth = 10 feet



2. Overburden Depth = 100 feet

Bench Depth = 30 feet

Figure 41. Comparison of Spoil Profiles in Two Side-Benching Situations

will be exposed during spoil grading. In practice, however, this potential problem can be remedied by rehandling of spoil materials by the dozers during grading to ensure that the side bench materials remain on the surface after grading.

Another possible solution, shown in the lower half of Figure 41, is to make the dragline bench deeper to increase the depth of the side bench materials on the spoil piles. In this illustration, it is virtually impossible to expose the underlying spoil materials during grading.

The potential reclamation advantages of the deeper dragline bench notwithstanding, however, many mine superintendents are opposed to its use. There are several reasons for this. One is that the swing angles required for placement of side bench materials are very large. Thus, for a given overburden depth, the deeper the bench, the greater the average swing angle on each digout. Additionally, although all draglines were once used in this manner, many dragline operators dislike digging overburden high above the bench. Further, if the bench is very deep, it may be difficult to fully load the bucket during the side-bench digging cycle. One reason for this is the fact that, when the bucket is dropped from above onto the surface of the overburden, a procedure known as "chopping," the bucket jaw plates hit the surface before the teeth; thus bucket penetration may be poor. A typical bucket is shown in Figure 42. It is seen in that Figure that the jaw plates protrude far beyond the teeth.

A second reason for difficulty in filling the bucket in overhead digging is that some of the material to be excavated moves out ahead of the bucket and falls down onto the dragline bench. This phenomenon, called "chasing the dirt," in combination with reduced bucket penetration in chopping, often means that bucket fill factors are lower in side-benching than in conventional digging.

Where the overburden is not extremely deep or spoil rehandle is not required, or both, there are few production advantages to offset the foregoing disadvantages. As a result, if the side bench is not required for production reasons, and in the west it often is not, then mine operators will be very reluctant to use the method, or, if they do use it, they'll carry the bench high in the bank, thus minimizing potential reclamation advantages. For reasons presented later in this section, deep overburden or the necessity to rehandle spoil may soften this reluctance.

In the situations discussed thus far, it has been assumed that surface overburden materials beneath the topsoil are best for placement on spoil surfaces and that the strata immediately above the coal seam are the worst. This is not always the case. At one mine, for example, the top six meters (20 feet) of a total of 24 meters (80 feet) of overburden have been determined to be the least desirable materials for placement either

Figure 42. Photograph Showing a Typical Dragline Bucket

on spoil surfaces or on the pit floor. Thus it is necessary to place the surface overburden materials in approximately the middle of the spoil profile. This is an unusual situation and, at first glance, one for which there may not be a simple solution.

But there is one. It involves working the dragline from a bench six meters (20 feet) below the ground surface. Then, on a given digout, a depth of about 12 meters (40 feet) of overburden is excavated below the bench by layer loading and is cast onto the floor of the adjacent cut. This is the material shown as #1 in Figure 43. Next the side bench is cut from the top six meters (20 feet) of overburden and the material is cast onto the existing spoil. Finally, the remaining six meters (20 feet) of overburden below the bench, that is, immediately above the coal, are excavated by layer loading and cast on top of the side bench spoils. In this manner, the side bench material is buried in the middle of the spoil pile.

If in addition it was necessary to keep the three or so meters of overburden immediately above the coal from being placed on the top of the spoil piles, this too could be accomplished by leading that material ahead of the main spoil and placing it low in the spoil profile.

Summarizing, in single seam dragline stripping, it is generally possible to achieve the required degree of spoil placement control if the side bench procedure is used. Use of those procedures is more costly than use of conventional sidecasting procedures. To the best of the authors' knowledge, although it would be a fairly straightforward task, no one has tried to determine those costs for a range of operating situations.

Single Seam Stripping With Spoil Rehandle --

It is desirable in surface mining to handle overburden materials only once. In practice, where draglines are used to strip deep overburden, rehandling of some material, typically 20 to 30 percent of the bank material, is sometimes required. The need to rehandle spoil affects the choice of pit width and digout length, and often affects the capability to selectively place spoil material, usually for the better.

The maximum depth of overburden that can be excavated and sidecast without the necessity for subsequent spoil rehandle is a function of the operating procedure, the dragline dumping radius, the spoil repose and highwall angles, and the amount of swell of the spoil. A mathematical expression of that function is given below for the case in which the dragline operates from the surface of the ground:

$$d = \frac{e - 0.25\, w}{\cot \phi + (1+f) \cot \theta} \qquad (1)$$

where

d = maximum depth of overburden that can be excavated and spoiled without rehandle (meters).

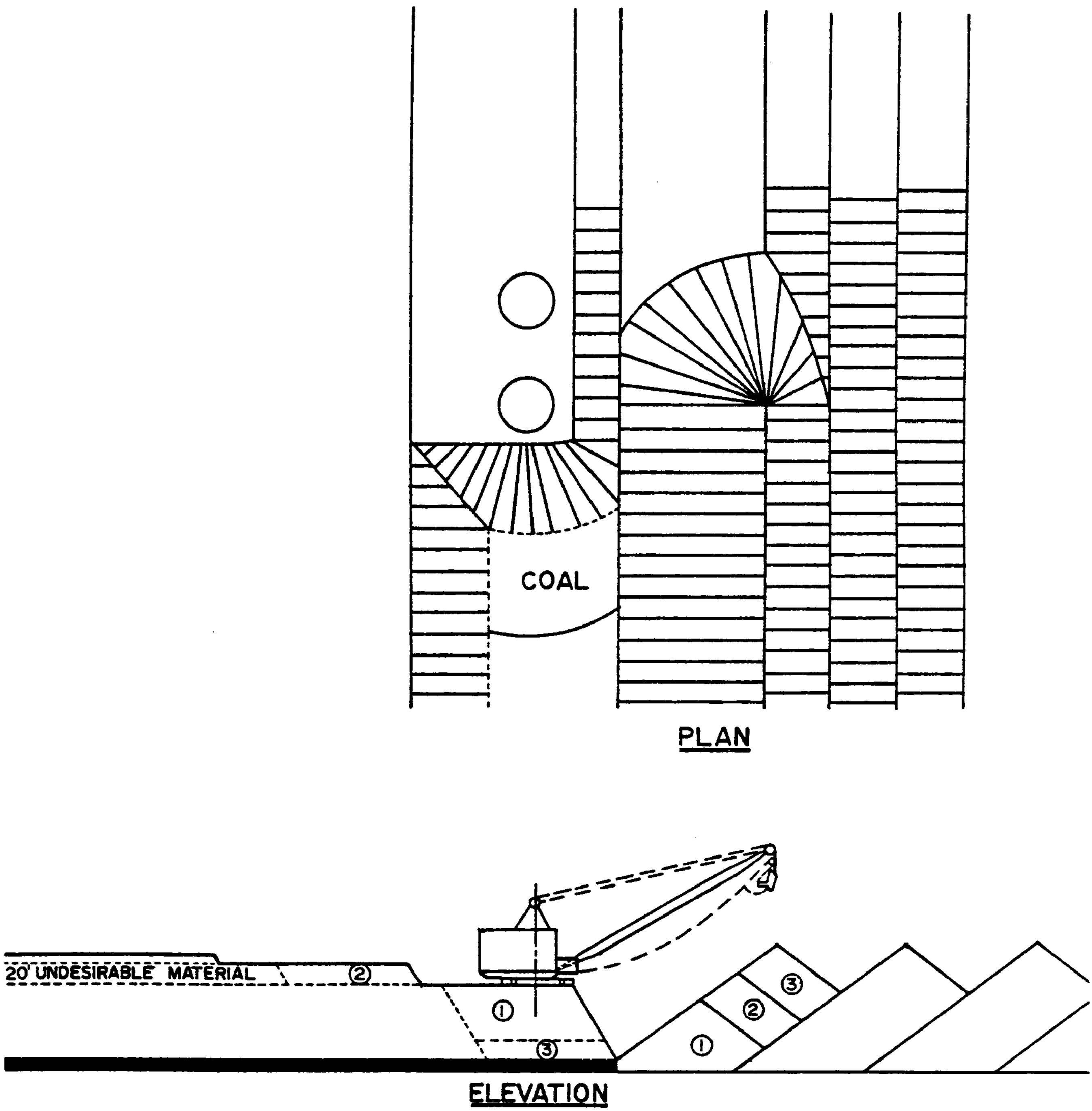


Figure 43. Procedure to Bury Surface Overburden Strata in Middle of Spoil Profile

e = effective spoil radius of the dragline, defined below (meters).

w = pit width (meters).

ϕ = angle of the highwall from the horizontal (degrees from horizontal).

θ = natural repose angle of the spoil from the horizontal (degrees from horizontal).

f = swell fraction for the spoil (decimal).

The effective spoil radius of the dragline is defined as the horizontal distance from the top edge of the highwall to the crest of the final spoil pile, when the dragline is positioned as close to the highwall edge as possible. Generally this is a position in which the rim of the dragline tub is about three meters (10 feet) from the edge of the highwall. Mathematically, the following expression applies:

$$e = r - a - 3 \text{ meters (10 feet)} \tag{2}$$

where

r = dragline dumping radius; the horizontal distance from the centerline of the tub to the centerline of the point sheave (meters).

a = the radius of the tub (meters).

In the west in 1975, the following averages applied:

- Overburden depth: 24 meters (80 feet).
- Pit width: 43 meters (140 feet).
- Effective spoil radius: 61 meters (200 feet). This corresponds in practice to a boom length of about 79 meters (260 feet).
- Spoil swell factor: 0.30.
- Highwall angle: 75 degrees from horizontal.
- Spoil repose angle: 37 degrees from horizontal.

The maximum no-rehandle depth for these conditions is approximately 25 meters (83 feet). Figure 44 is a graph showing the general relationship between maximum no-rehandle depth and dragline boom length.*

*The graph shows theoretical values for which pit curvature and variations in overburden depth within a given pit have not been considered.

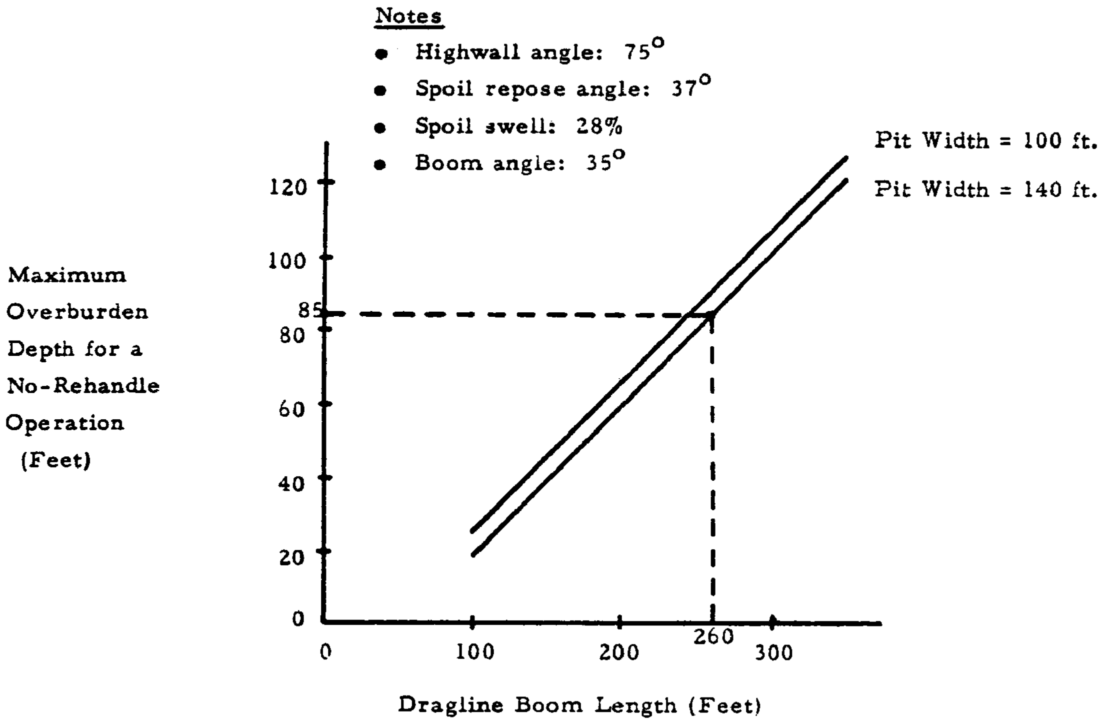


Figure 44. Maximum No-Rehandle Depth vs. Dragline Boom Length

In practice, because mining usually begins along the coal seam cropline in shallow overburden, average overburden depth increases steadily from cut to cut. When the maximum no-rehandle depth is reached, the pit is generally narrowed to increase that depth. In the preceding example, for instance, narrowing the pit from 43 meters to 27 meters (140 feet to 90 feet) would increase the maximum no-rehandle depth from 25 meters (83 feet) to 27 meters (89 feet). When the pit has been narrowed to its practical minimum, the toe of spoil is allowed to ride up the highwall to the top of the coal seam. This procedure further increases the maximum no-rehandle depth.

Eventually, however, it becomes necessary at most mines to extend the effective spoil radius of the dragline to enable stripping of still deeper overburden. The method used to accomplish this, known as the extended bench method, was patented by Weimer and Mullins in 1941. A typical extended bench procedure is depicted in Figure 45. Working from an established bench, the first activity on the digout is to dig the keycut. But instead of casting the keycut spoils at relatively small swing angles as in conventional practice, the keycut spoils are swung at an angle of about 130 degrees from the digging position, and cast against the existing highwall in the open cut. This spoil, which is then leveled by dozers, extends the dragline bench out into the open cut. Eventually, on each digout, the dragline will be moved out sideways onto this extended (spoil) bench to complete the digout. This includes excavation or rehandle of the extended bench material from the previous digout. The rehandle material,

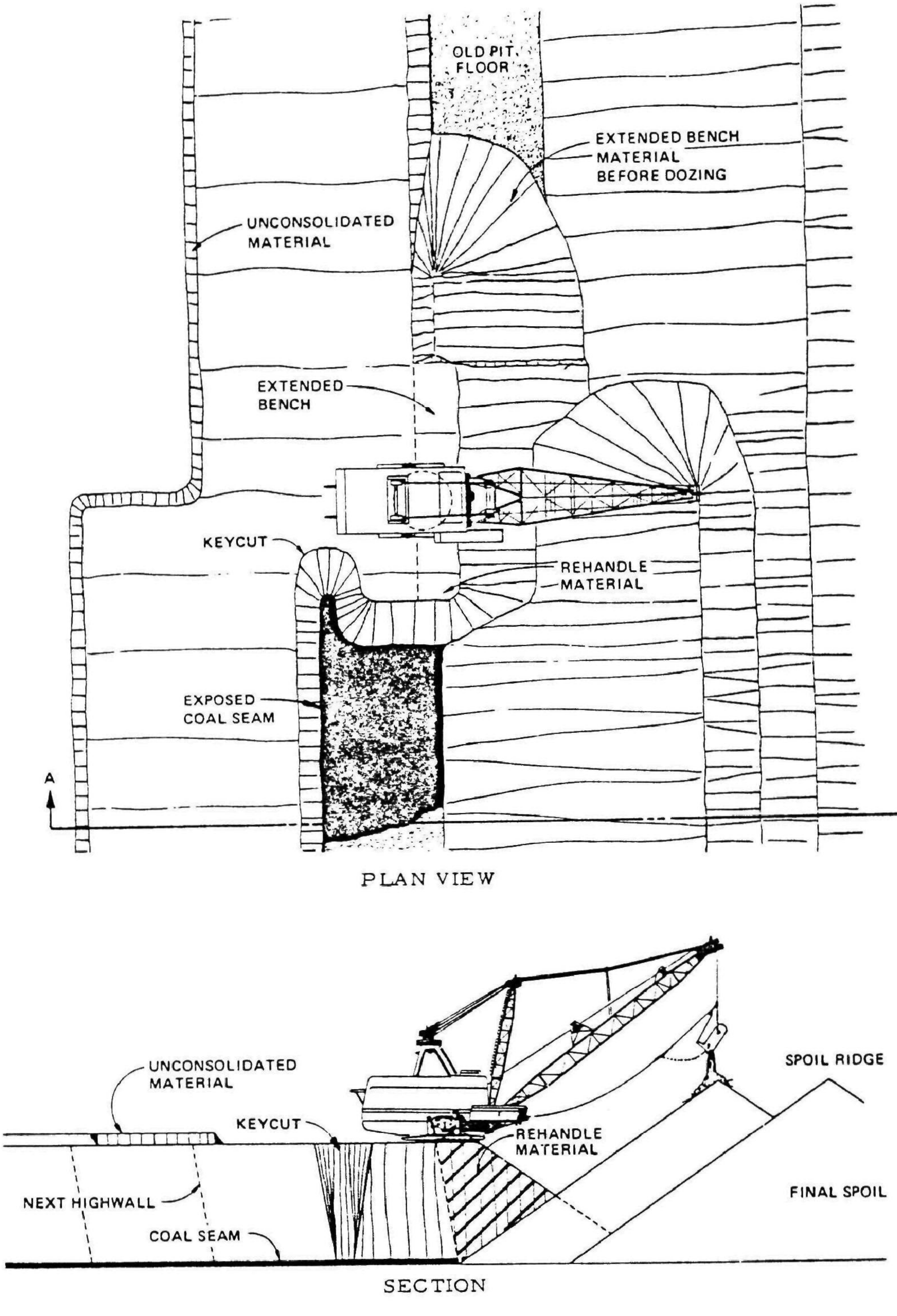


Figure 45. Method Used to Extend the Dragline Bench

shown cross-hatched in Figure 45, is the last material handled on each digout, so it always becomes the surface spoil material.

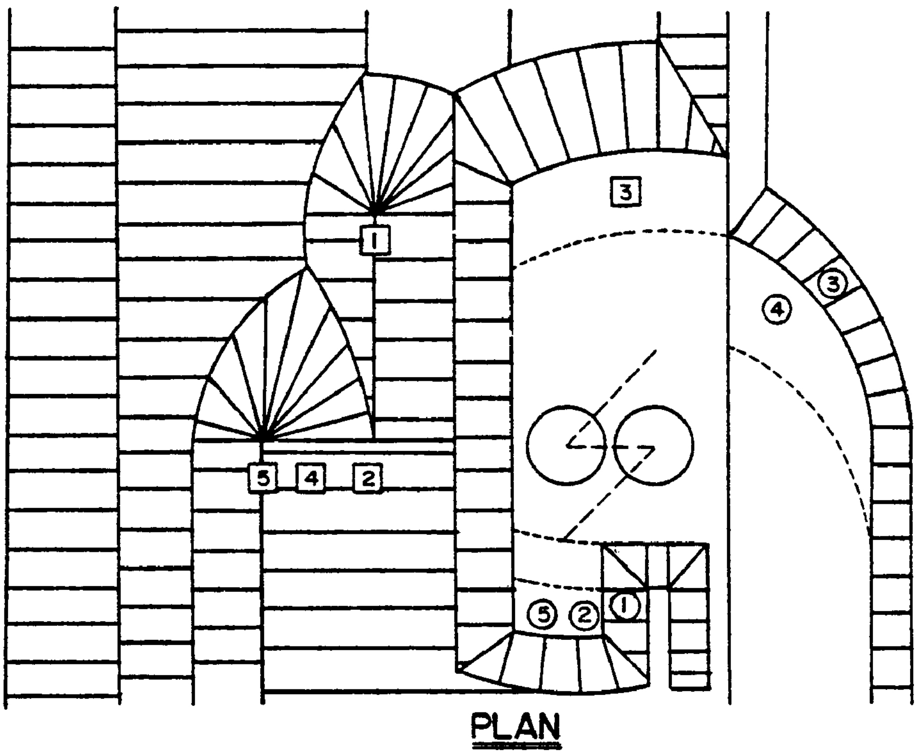
The environmental relevance of the extended bench method, which is a one-pass, two-lift method, is that overburden can be excavated and spoil placed very selectively through proper choice of the bench depth and the material used to extend the bench. In practice, for reasons presented previously, many mine superintendents prefer shallow (high) benches. This preference may not always be optimal, either from production or environmental standpoints. Additionally, although standard practice in the west is to use keycut material to extend the bench, use of other material would sometimes be better as a means of achieving reclamation objectives. Briefly, the recommended practice would be to determine the best material for placement on the surfaces of the spoil piles and then to use that material to extend the bench.

An example of a procedure proposed for use at one mine involves mining of a single coal seam by removal of 38 meters (125 feet) of overburden using a large walking dragline. In this case, maximum overburden depth for no rehandle is 27 meters (88 feet) with a 46 meter (150 foot) pit width. The overburden consists of clay and hard shale. Spoil must be placed selectively in two ways. First, the spoil placed on the pit floor as the first activity in the digout must be the hard shale, which is lower bank material. This is because placement of incompetent clay materials on the pit floor as the spoil pile base would probably result in instability of the pile after additional spoil had been placed on top of the clay. The second requirement is that the top 7.6 meters (25 feet) of the overburden be placed on the tops of the spoil piles.

Plan and section views of the pit are shown in Figure 46. The operating procedure is as follows. The dragline works from an established bench which is 15 meters (50 feet) below the ground surface, roughly at the interface of the clay and shale strata. On each digout, material below the bench is excavated conventionally. Side bench material, above the elevation of the established bench, is dug by chopping, as previously described.

The first activity on each digout is to make the keycut below the bench. Since all of the keycut material is competent hard shale, it is suitable for placement on the pit floor. This is accomplished by swinging the keycut material through an angle of about 120 degrees from the digging position and placing it on the pit floor, ahead of the main spoil pile. The keycut spoil thus forms the spoil-stabilizing "buckwall". It is not used to extend the bench, rather the toe of the keycut spoil pile intersects the bottom of the coal seam at the highwall. Next, the remaining overburden below the elevation of the bench is excavated and cast on top of the buckwall.

The third activity on each digout is to dig ahead and to the side and excavate surface overburden materials by digging above the bench. Those materials, shown as #3 in Figure 46, are used to extend the dragline bench. The swing angles required in this phase are fairly small because the boom is swung counterclockwise from the bank to the extended bench.



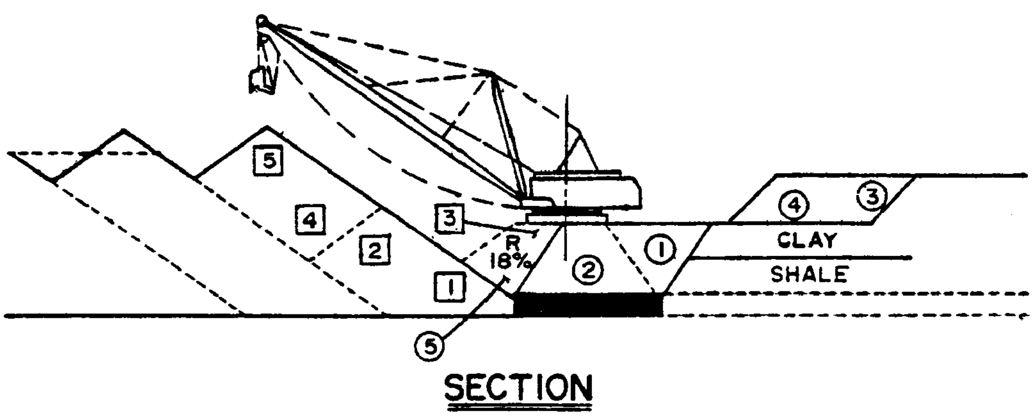


Figure 46. An Extended Bench Procedure with Selective Spoil Placement

Subsequently the remaining side bench material, #4 in Figure 46, is excavated and cast on the main spoil pile.

As the last activity on each digout, the dragline is moved sideways onto the extended bench for that digout, and the extended bench material from the previous digout is excavated and cast onto the top of the spoil pile. This material was originally the surface overburden material. The rehandle percentage in this example is 18 percent.

A production estimate for this example is presented in Table 13. The effect on production of the swing angles required for various components of the digout can be guaged from the swings per hour for each component. In this case, for the bench depth shown, 18 percent rehandle would be required regardless of the spoil placement method used. Rehandle in this case is thus necessitated by overburden depth, not by reclamation requirements.

TABLE 13. PRODUCTION ESTIMATE FOR EXTENDED BENCH PROCEDURE WITH SELECTIVE SPOIL PLACEMENT

Extended Bench Method Using Walking Dragline (B-E 2570), 335' boom @ 35° with 110 cu. yd. bucket, pit 150' wide by a maximum of 125' overburden cover and 100' digout.

Component	Swing Angle	Swings Per Hr.	Bank Cu. Yds. Bucket Carry	Bank Cubic Yards	Time Hours
(1) Keycut to Buckwall	125°	50	56	10,416	3.72
(2) Lower lift to spoil	80	58	59	31,250	9.13
(3) Surface to Bench	60	70	81	12,543	2.21
(4) Upper lift to spoil	140	53	81	15,235	3.55
				69,444 - 82%	18.61
(5) Rehandle to Spoil	70	70	99	15,296 - 18	2.21
				84,740 - 100%	
Operating time for a 100' digout			(75%)		20.82
Delays - Variable due to many conditions			(25%)		6.94
Scheduled time			(100%)		27.76
Cubic yards per digging hour					4,070
Cubic yards moved per month (540 hours)					2,198,000
Bank cubic yards moved per month					1,802,000
Bank cubic yards moved per year					21,163,000
Ratio at overburden of 125'					4.6
Tons per year					4,600,000

The foregoing examples were intended to illustrate that, contrary to folklore, selective removal of overburden and placement of spoil can be accomplished in very deep overburden where a dragline is the prime mover. In some cases, however, the ability to place surface overburden materials on the surfaces of the spoil piles may be contingent upon the use of a fairly deep bench. This may be resisted by mine operators because of the large swing angles required for casting of side bench materials and the need to chop out overburden above the bench.

In deep overburden, however, where spoil rehandle is required, the deep bench has certain notable advantages. The major one is that, for a given operating situation, the rehandle percentage decreases as the bench is deepened. This is illustrated in Figure 47 for a situation in which average overburden depth is 30 meters (100 feet). As the Figure shows, if the bench depth is six meters (20 feet), the rehandle percentage is 30 percent. Deepening the bench to 50 feet reduces the rehandle to 14 percent.

An additional advantage of the deep bench in deep overburden is the improved position of the dragline for digging strata below the bench. For a given dragline and type of overburden strata, there is an optimal digging depth. Below that depth, productivity declines somewhat because of difficulties in filling the bucket when digging far below the bench. This is illustrated in Table 14, which shows the effect of bench height on productivity for several swing angles. [20] The reason for difficulties in filling the bucket is that the vertical component of the drag force increases as the digging depth increases. Beyond some optimal depth this is undesirable because the vertical force becomes so large that it tends to pull the bucket out of the bank before the bucket has been fully loaded.

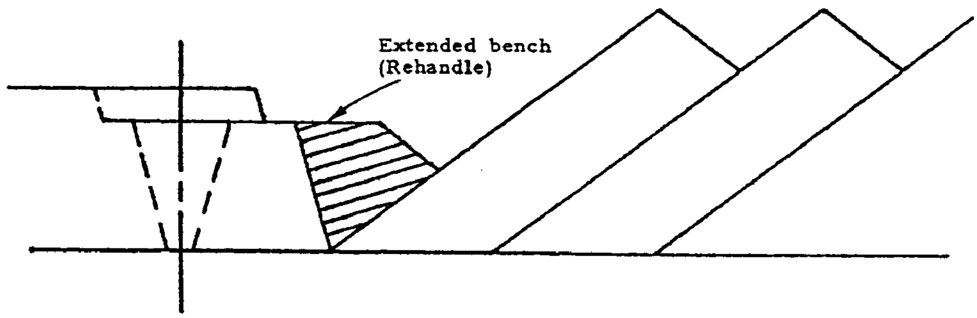
In a specific situation, the advantages and disadvantages of different bench depths must be weighed. Often, the disadvantages of the deep bench will outweigh its advantages. On the other hand, there are some situations in which a fairly deep bench, about one-third to one-half of the distance from the surface of the bank to the coal, appears to be the best choice. An example is the case where the upper half of the bank consists of unconsolidated material and the lower half consists of material that is hard to dig, such as sandstone or limestone.

In light of the apparent reclamation advantages of the deeper bench, if selective overburden removal and spoil placement capability is needed on a large scale in deep western stripping, then a systematic evaluation of the effects of bench depth on productivity and reclamation performance might be warranted.

Multiple Seam Dragline Stripping Procedures

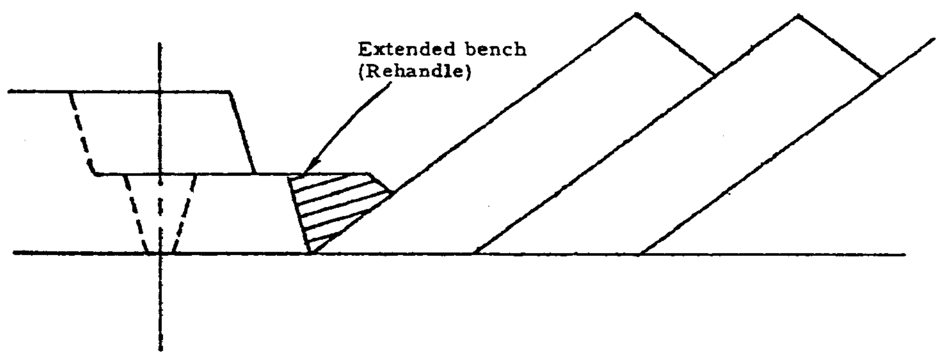
Mining of two or more coal seams in a given pit accounted for roughly half of the acreage disturbed by western mining in 1975. Most often these situations involved uncovering of two coal seams by a single dragline. From a production standpoint, multiple seam mining is more complex than single seam mining and much could be said here about

HIGH BENCH (30% REHANDLE)



1. 100 foot overburden depth, 20 foot bench depth.
Rehandle = 30%

DEEP BENCH (14% REHANDLE)



2. 100 foot overburden, 50 foot bench depth.
Rehandle = 14%

Figure 47. Comparison of Spoil Rehandle Percentages for Two Bench Depths

TABLE 14. EFFECT OF BENCH HEIGHT AND SWING ANGLE ON DRAGLINE OUTPUT [20]

Percent of Most Favorable Cut Depth	Swing Angle							
	30°	45°	60°	75°	90°	120°	150°	180°
20	1.06	0.99	0.94	0.90	0.87	0.81	0.75	0.70
40	1.17	1.08	1.02	0.97	0.93	0.85	0.78	0.72
60	1.24	1.13	1.06	1.01	0.97	0.88	0.80	0.74
80	1.29	1.17	1.09	1.04	0.99	0.90	0.82	0.76
100	1.32	1.19	1.11	1.05	1.00	0.91	0.83	0.77
120	1.29	1.17	1.09	1.03	0.985	0.90	0.82	0.76
140	1.25	1.14	1.06	1.00	0.96	0.88	0.81	0.75
160	1.20	1.10	1.02	0.97	0.93	0.85	0.79	0.73
180	1.15	1.05	0.98	0.94	0.90	0.82	0.76	0.71
200	1.10	1.00	0.94	0.90	0.87	0.79	0.73	0.69

current operational procedures and ways in which they can be improved. But from the standpoint of the effect of western mining on the environment, only two differences between single and multiple seam mining are relevant and significant. They are the following:

- Frequently the interburden material separating two coal seams is physically or chemically undesirable and must be buried in the spoil to ensure successful reclamation. This is the case, for example, where the interburden has a high sodium adsorption ratio.

- In cases in which spoil rehandle is not required for production reasons, it may be difficult or costly to bury the interburden material.

Three alternative multiple seam mining methods are used at western mines. The choice of method is dictated by overburden, interburden, and dragline characteristics. Each involves making two passes in a given pit, one to uncover the top seam and the second to uncover the bottom seam. The methods differ primarily in the position of the dragline on the second pass of each pit. That position in turn is determined by the dumping radius and dumping height of the dragline in relation to requirements imposed by the overburden and interburden depths.

Multiple Seam Stripping Without Rehandle --

The most desirable situation from a production standpoint, although often least desirable from an environmental standpoint, is one in which two seams are stripped without appreciable spoil rehandle. The procedure, as used at a particular western mine several years ago, is illustrated in Figure 48. On the first pass, the dragline works from the natural ground surface and overburden is excavated and cast conventionally, exposing the upper coal seam. The coal is loaded out fairly closely behind the stripping operation.

After this first pass of the pit, the dragline is deadheaded back to the opposite end of the pit -- the end from which the upper coal seam has been loaded out -- and is moved down a ramp to the top of the interburden. Now the second pass begins, with interburden materials excavated conventionally and cast on top of the spoil pile that resulted from first-pass stripping. This exposes the lower coal seam, which is loaded out close behind the interburden stripping operation. At the end of the pit, the dragline is ramped up to the ground surface and deadheaded back to the opposite end of the pit to begin the first pass in the next cut.

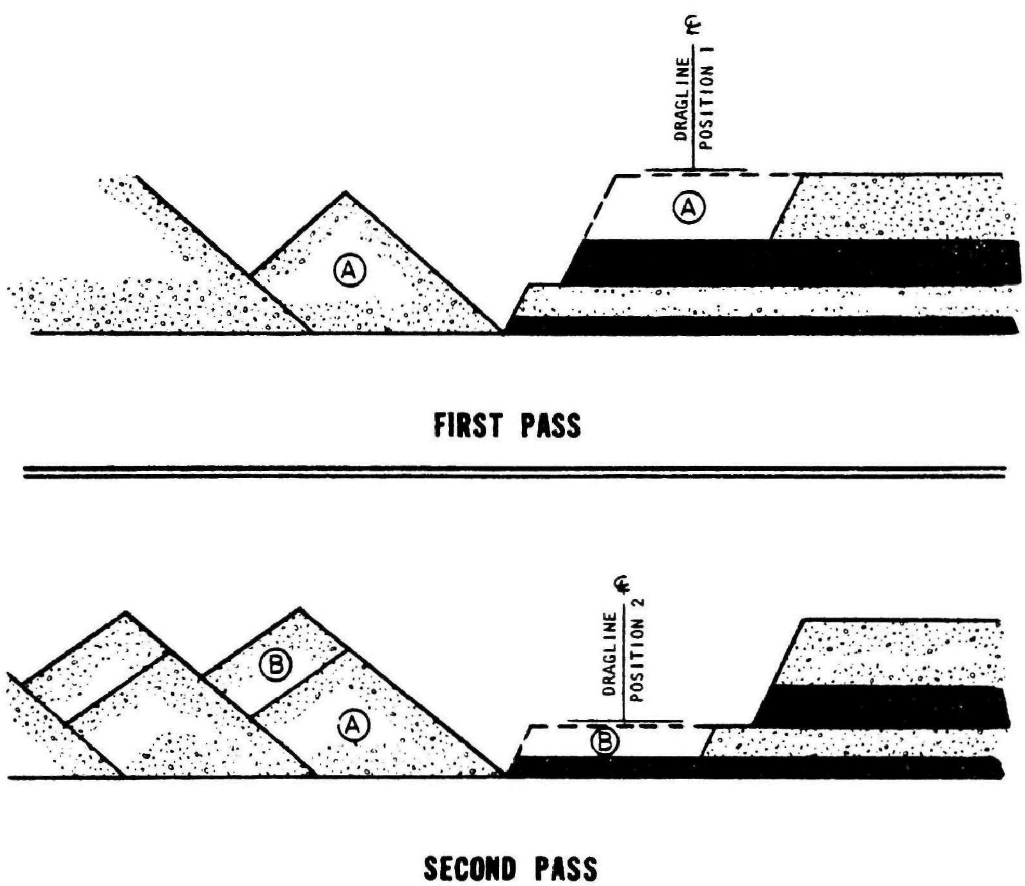


Figure 48. Multiple Seam Situation With No Spoil Rehandle

The feasibility of this method is dependent on the following two conditions:

- The dumping radius of the dragline must be sufficient to enable placement of all overburden and interburden materials without the use of an extended bench.
- The dumping height of the dragline must be sufficient so that, when the dragline is positioned on the interburden, it is possible to cast all interburden material on top of the spoil pile that resulted from the first pass.

In practice, it is rare for both of these conditions to hold true and, as a result, the operating method just described is rarely used. When it is, the interburden material always ends up on the top of the spoil piles. To the best of the authors' knowledge, there is no way to prevent this without incurring some spoil rehandle.

In the actual case under discussion, during the early 1970's, the interburden was placed on top of the spoil piles and, because of impermeability of the resulting spoil surface, revegetation failures were common. Subsequently, operating procedures were revised to enable burial of the interburden material in the spoil pile. The procedure, which is depicted in Figure 49, is as follows. On the first pass, on overburden, the material is deliberately cast in close to the lower highwall. Otherwise, the first pass operating procedure is identical to the method just described.

After deadheading and ramping down to a position on the interburden, the interburden is excavated and cast on top of the spoil pile which resulted from first-pass stripping. The last activity on each digout, however, is to rehandle a portion of the overburden material that had been cast in close to the lower highwall during the first pass, and to cast that material on the top of the spoil pile. If the rehandle material is deep enough on the angle-of-repose spoil piles so that the buried interburden material is not exposed during grading, then reclamation objectives will have been achieved.

Burial of the interburden material in this kind of situation can be costly since rehandle which would not have been required otherwise is required to meet reclamation requirements. If, however, spoil rehandle is required for production reasons, as in the situations discussed next, the effects of reclamation requirements on production costs may not be as great.

Extended Bench Stripping of Two Coal Seams --

When the dumping height of the dragline is sufficient to enable casting of all interburden materials on top of the spoiled overburden, from a dragline working position on top of the interburden, but the dumping radius is too small, then a two-pass extended bench method is used. The first pass on overburden is similar to that described in the preceding

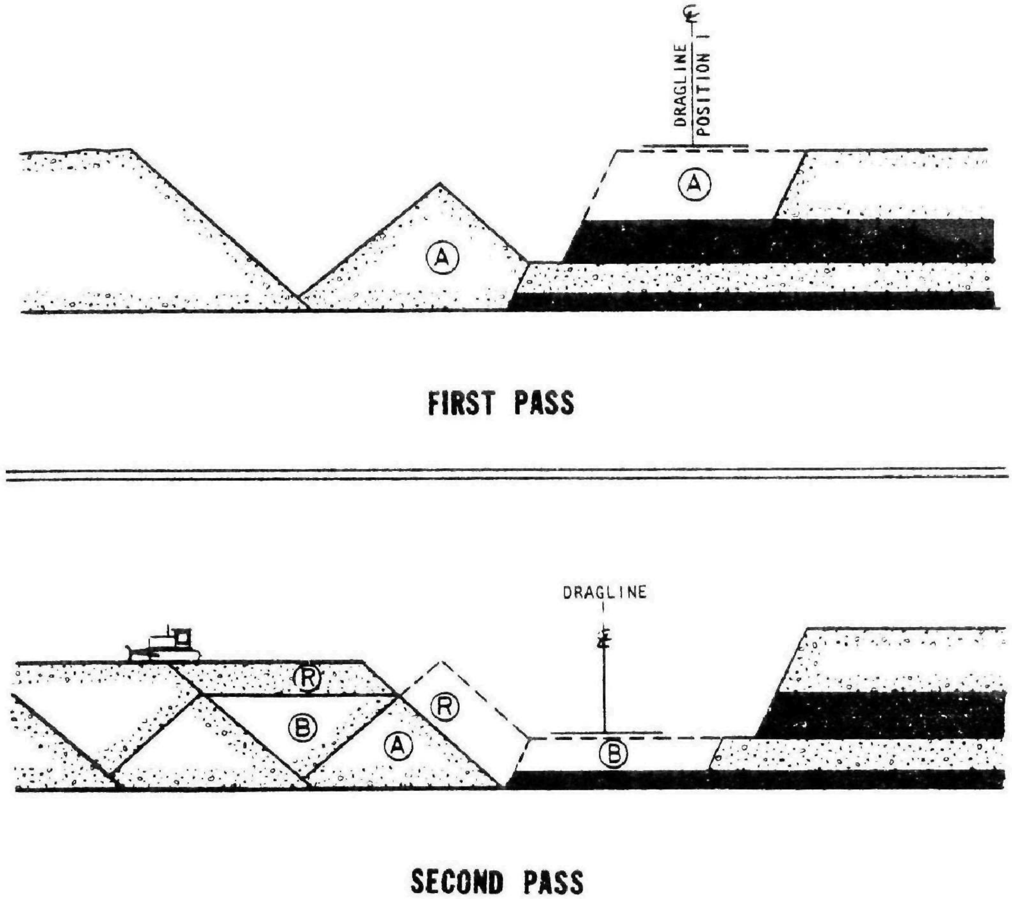


Figure 49. Multiple Seam Method With Rehandle to Enable Burial of Interburden Material

section. On that pass, some of the overburden material is cast in close to the lower highwall and, as shown in Figure 50, will subsequently be used to extend the bench for the second pass. Ultimately, the extended bench material will be rehandled and placed on top of the spoil piles.

After completion of the first pass, the dragline is deadheaded and ramped down onto the interburden as in the previous example. Interburden material is excavated and cast on top of the spoiled overburden. Eventually, on each digout, the machine will be moved out onto the extended bench to complete the digout. The last activity on each digout is to excavate the material that formed the extended bench for the previous digout, and to cast that material on the spoil pile. If this rehandle material is suitable for reclamation and it is deep enough on the angle-of-repose spoil piles so that the buried interburden material will not be exposed during grading, then reclamation objectives will have been achieved.

Spoil rehandle is always required in use of this extended bench method whether or not burial of the interburden material is required. But the amount of rehandle incurred might be increased substantially by a requirement for interburden burial. No specific data were determined for

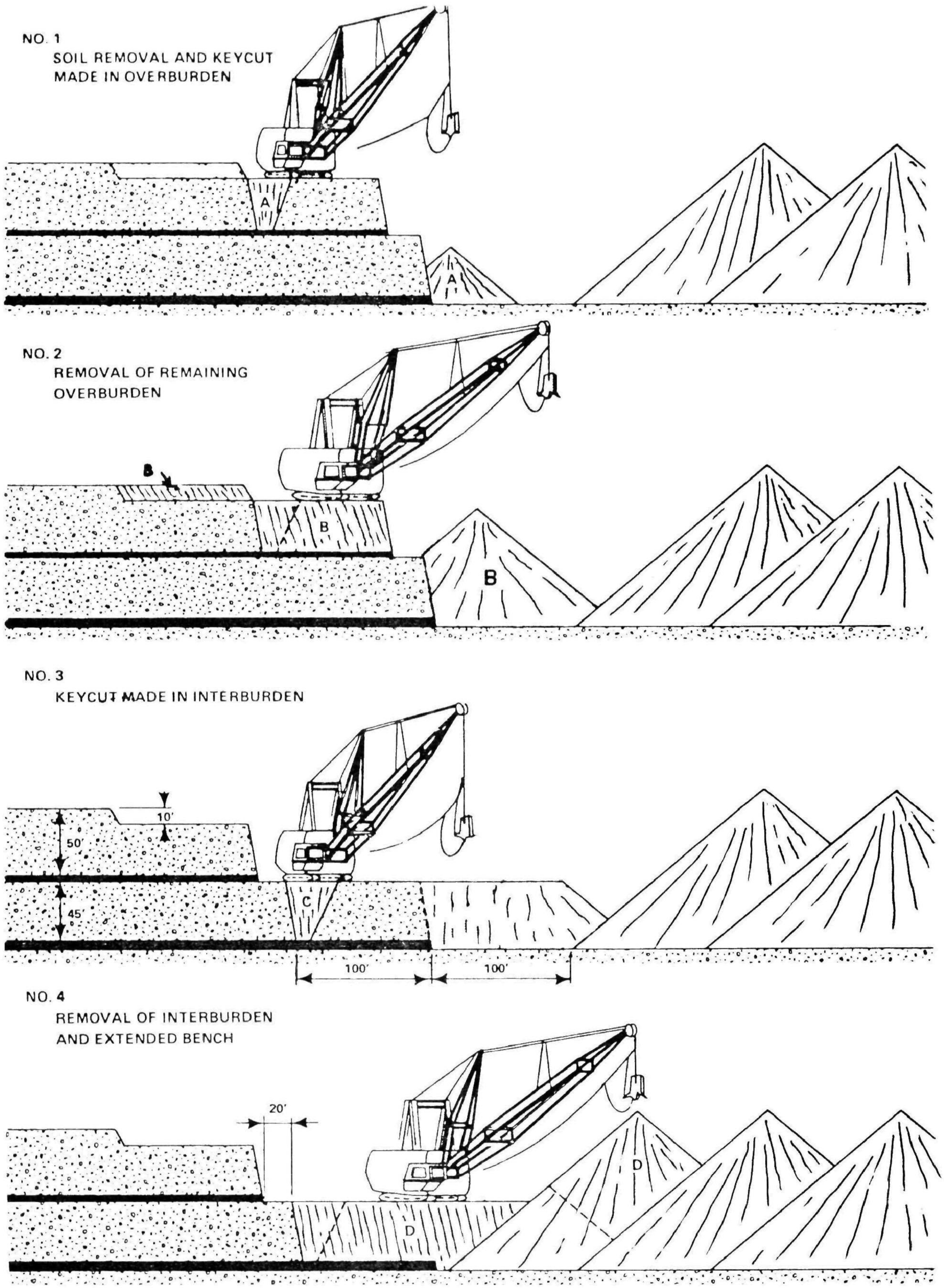


Figure 50. A Two-Pass Extended Bench Method for Stripping of Two Coal Seams

the west but for one midwestern mine at which acid interburden had to be buried and topsoil was not replaced, 15 percent rehandle was required for production reasons. In order to adequately bury the interburden and ensure that it stayed buried after spoil grading, the rehandle had to be increased to 40 percent.

The Horseshoe Method for Two-Seam Stripping --

Most frequently in practice, both the effective spoil radius and the effective dumping height of the dragline must somehow be extended to enable stripping of the lower seam. Extension of the effective dumping height is required when the dragline does not have sufficient height, when working from a second-pass position on the interburden, to cast all of the interburden material on top of the spoiled overburden pile. The operational solution to this problem is to increase the effective dumping height by raising the elevation of the bench from which the dragline will work when stripping the interburden.

Although there are two different ways to do this, only one is widely used. It is a two-pass method in which, on the first pass, the dragline operates from the ground surface or a shallow bench. Overburden is excavated conventionally and cast into the open pit at maximum effective range. This usually means that the toe of the spoil pile thus made will intersect the face of the lower coal seam at the highwall.

At the end of the pit, the dragline is moved over into the spoil pile that resulted from the first pass and is deadheaded in the spoil to the opposite end of the pit. During the deadheading operation the dragline, assisted by a dozer, is used to knock the tops off of the first-pass spoil pile and create a flat bench in the spoil pile. When the opposite end of the pit has been reached, the dragline remains on the spoil bench that has just been constructed and digs the interburden. (The upper coal seam has by this time been loaded out at this end of the pit.) The elevation of the machine on the spoil bench is roughly the same as the elevation of the surface of the natural ground, thus working from the bench in the spoil pile increases the effective dumping height of the dragline considerably as contrasted with a machine position on the interburden.

The interburden is excavated by underbench chopping, a procedure illustrated in Figure 51. Facing the highwall from a position across the pit on the spoil bench, the dragline bucket is dropped onto the surface of the interburden. Because the jaw plates on the bucket protrude beyond the teeth, bucket penetration in this chopping operation is generally poor. As the bucket is dragged toward the spoil pile for loading, some material rolls out ahead of the bucket and falls into the vee between the lower highwall and the spoil pile, thus bucket fill factors in this operation are fairly low. When the digging cycle has been completed, the bucket is hoisted and swung through an angle of about 135 degrees to cast the interburden materials on top of the spoil bench from the previous cut. The lower coal seam is loaded out behind the stripping operation.

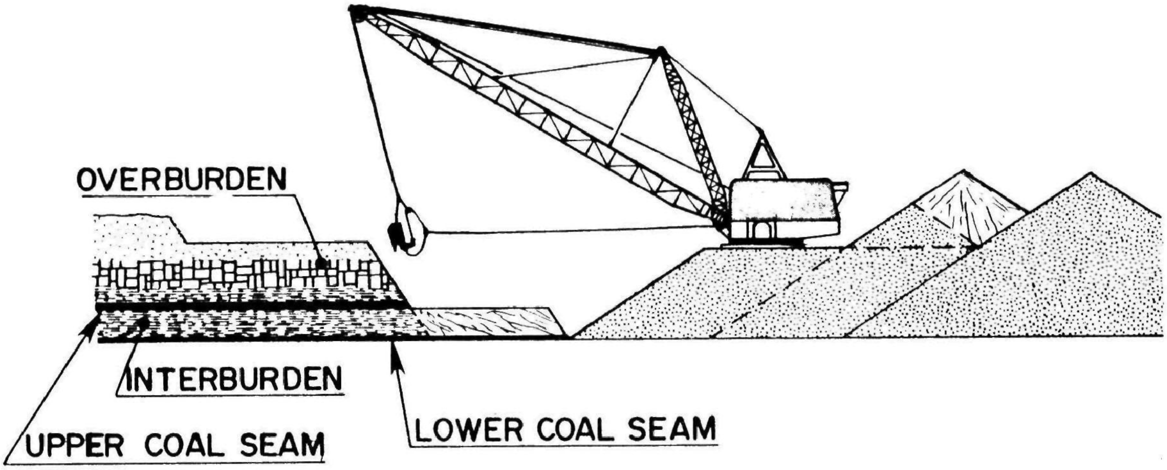


Figure 51. Removal of Interburden by Underbench Chopping

When the end of the pit is reached, the machine is moved to the overburden and is again deadheaded back to the opposite end of the cut to begin the first pass on the next cut. Generally excavation of the overburden cannot begin until all of the lower coal has been loaded out of the previous cut.

Dragline productivity in removal of the interburden depends on many site-specific factors, but is always lower than productivity in removal of the overburden. According to mine operators queried by the authors in a recent nationwide survey of surface coal mining operations, productivity in removal of interburden from a spoil bench ranges between 15 and 60 percent of the productivity for the same machine when used in conventional overburden removal and spoil placement, depending on on-site conditions. [17] A typical range for mine planning is 35 to 50 percent.

There are several reasons and partial remedies for the low productivity. One is the need to construct a bench in the spoil pile for the second pass in each pit. Another is the large average swing angle required for placement of interburden material. A third is difficulty in crossing inclines (coal haulage ramps) if the inclines enter the pit at other than the ends of the pit. This problem can be avoided by having only one incline and placing it at the end of the pit, but then the entire pit of lower coal must be loaded out before removal of overburden in a subsequent cut can begin.

A fourth reason is the low bucket fill factor in underbench chopping. Frequently the interburden is blasted very hard to raise the fill factor during chopping. Another partial solution is to use dozers and end loaders to keycut the interburden so that the dragline bucket can be dropped into the keycut to excavate the interburden. A further partial remedy, only conceptual at present, is to design a special chopping bucket for use during the interburden removal pass in each pit. This bucket might have longer teeth, hinged jaw plates, or a modified center of gravity, to improve penetration of the bank when chopping down from the spoil bench.

Environmentally, the method may not be good if the interburden is undesirable as a spoil surface material. This is because the interburden material is usually placed on the surfaces of the spoil piles.

At many mines, each of the three foregoing methods is ordinarily used at some time during the life of the mine. Initially, when the overburden is shallow, the two-pass method without appreciable spoil rehandle can be used. Later, as overburden depth increases, the two-pass extended bench method must be used to extend the effective spoil radius of the dragline on the second pass. Finally, when the overburden gets deep enough, the two-pass horseshoe method just described must be used to extend both the effective spoil radius and the effective dumping height of the dragline. For all three methods, particularly the last one, burial of the interburden material in the spoil pile may be difficult and costly. The magnitude of the problem has not been evaluated quantitatively, but it would be fairly easy to do so for a wide range of operating conditions.

One-Pass Stripping of Two Coal Seams --

It is in some cases possible to improve both productivity and selective overburden removal and spoil placement capability in two-seam mining through use of a novel one-pass method. As a rule of thumb, from a production standpoint, the method is superior to two-pass methods only for situations in which the coal seams are thin and the interburden depth is similar to or greater than the overburden depth. Such situations rarely occur in the west; thus the one-pass method is rarely, if ever, used there.

Nonetheless, selective removal of overburden and placement of spoil can be achieved fairly readily through use of one-pass methods, and they are illustrated here for that reason. The first illustration is a situation in which the effective spoil radius but not the effective dumping height of the dragline must be increased. It is the counterpart of the two-pass extended bench method, except that only one pass is made in each pit.

A characteristic of the one-pass extended bench method is that the dragline always works from a position on the interburden, never on the overburden. This eliminates the need to ramp the machine up and down at the end of each pit. The method is illustrated below for a situation in which the following three selective placement requirements must be satisfied:

- Competent interburden materials must be used to build the spoil-stabilizing buckwall.
- Interburden materials must be buried in the spoil pile.
- Surface overburden materials must be placed on the tops of the spoil piles.

It would be difficult or impossible to satisfy all three of these requirements if a two-pass method was used. The one-pass method shown in Figure 52 will work, however. As shown in that Figure, the

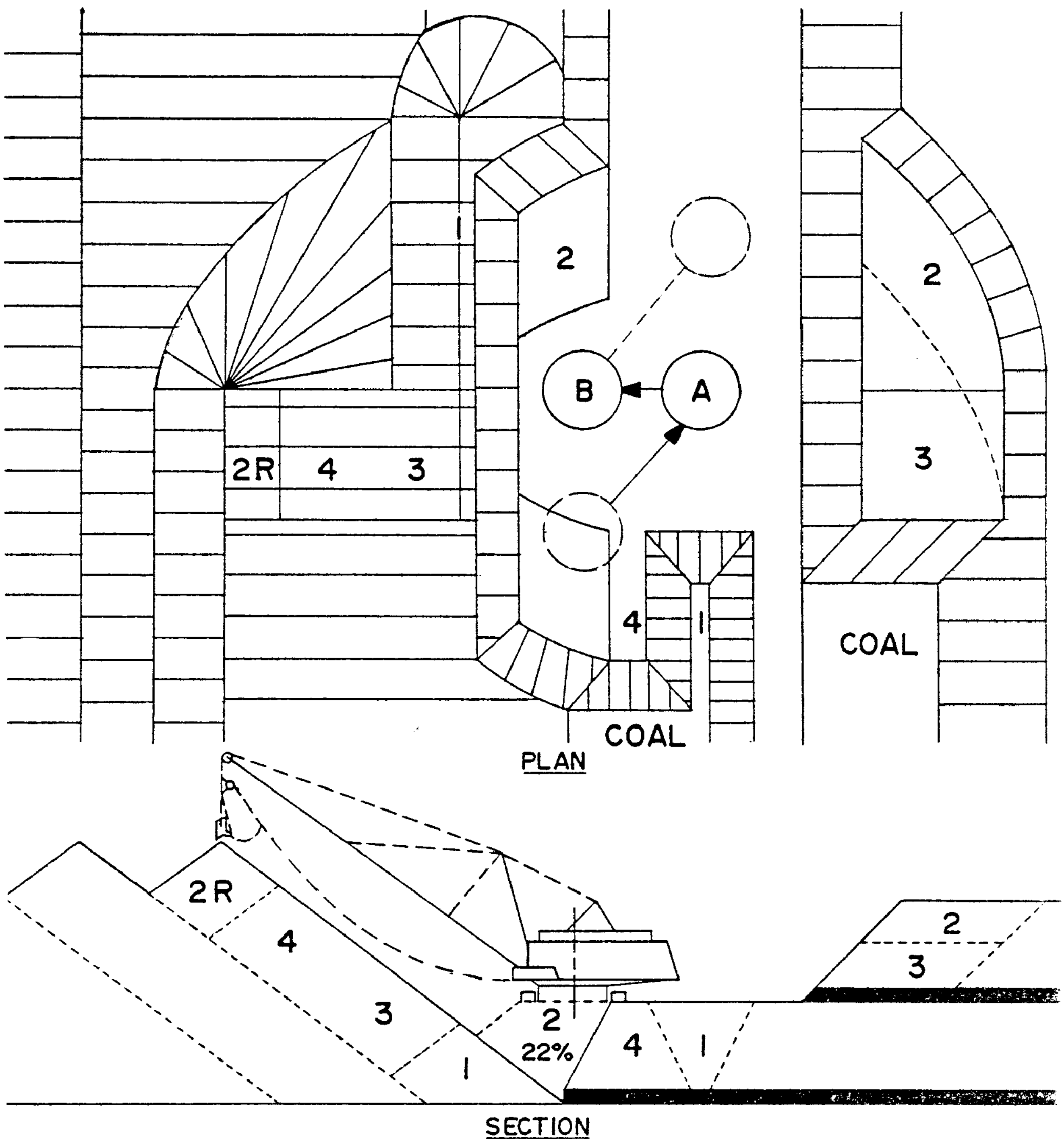


Figure 52. Single Pass Extended Bench Method for Stripping of Two Coal Seams

dragline is positioned on the interburden. The first activity on each digout is to dig a keycut in the interburden, subsequently swinging the keycut spoil through an average angle of 130 degrees to place the spoil on the pit floor, thereby forming the buckwall. Next, the top nine meters (30 feet) of the overburden are dug to the side and above the bench. These materials are cast against the lower highwall on top of the buckwall to form the extended bench for the next digout.

The third component of the digout involves above-bench digging of the remaining overburden, which is cast onto the main spoil pile. The remaining interburden is then dug conventionally, below the bench, and also is cast onto the main spoil pile.

Finally, on each digout, the dragline is moved out onto the extended bench and the material used to extend the bench for the previous digout is excavated and placed on top of the main spoil pile. This rehandle material came from the surface of the overburden.

The method is seen to be environmentally desirable for situations in which interburden materials are to be buried in the spoil and surface overburden materials are to be placed on the surfaces of the spoil piles. It also has certain production advantages over the two-pass method. These include the following:

- Elimination of underbench chopping.
- Elimination of ramping of the dragline up or down at the end of each pit.
- A fifty percent reduction in dragline deadheading.
- A spoil rehandle percentage identical to the two-pass method.

Unfortunately, the method also has a significant disadvantage, the one which would probably prevent its use in most western mining situations. It is the need to chop all overburden to the side and above the dragline bench. Most mine superintendents and dragline operators will resist this, particularly where the overburden is hard and deep. It is equivalent to working from a deep bench in one-pass stripping of a single seam.

Still, all things considered, the one-pass extended bench method for uncovering of two seams might be the best choice in the west where the following conditions hold:

- The average overburden depth is 12 meters (40 feet) or less.
- The overburden strata are not too hard.
- The thickness of the upper coal seam is three meters (10 feet) or less.

It is also possible to use a one-pass method in situations in which both the effective spoil radius and the effective dumping height must be increased to enable stripping of the interburden. The method is not discussed here. Suffice it to say that it has advantages and disadvantages similar to the one-pass extended bench method.

Truck and Shovel Stripping Systems

For reasons presented earlier in this section, loading shovels and spoil haulage trucks will be used for overburden removal and spoil placement at several large mines in the eastern Powder River Basin of Wyoming, where the coal is very thick. In general, although the operating costs of such equipment are higher than those for draglines, use of shovels and trucks enables very selective placement of spoil, better control of reclaimed topography, and grading of spoils concurrent with placement.

Overburden is excavated by loading shovels, generally in benches because of the limited digging height of the shovels and to make safe highwalls in deep overburden, and is loaded into haul trucks. The resulting spoil is then hauled to designated placement areas, usually to a mined-out portion of the active pit, and is dumped. As the spoil is placed, dozers are used to maintain a fairly level working place for the trucks, thus spoil grading is accomplished nearly concurrently with placement.

One possible drawback of this method of spoil placement is that the spoil materials are compacted fairly tightly. Where there is a water table above the pit floor, researchers have found that the resulting spoils may be less permeable than the original coal or soft sandstone aquifers. [16] Thus rates of groundwater flow through the spoil will probably be less than those in the original aquifers.

Because the coal is thick -- sometimes thicker than the overburden -- where shovels and trucks are used for stripping, the ground surface will usually be lowered appreciably by mining. (This is not a function of the stripping equipment, however, but rather depends on the depth of the overburden and the thickness of the coal.) Keefer and Hadley have speculated that lowering of the ground surface may result in creation of extensive closed depressions. [21] They further maintain that restoration and maintenance of through-flowing drainageways will be difficult and that water flowing in stream channels that are intersected by mining may become impounded unless measures are taken to ensure proper outflow. They also point out, however, that the technology for stabilizing stream-gradient breaks by using engineering structures is available.

Use of shovels and trucks for stripping in the foregoing kinds of situations is actually beneficial, because the reclaimed topography can be shaped more precisely than in cases where spoil is placed by dragline. An example of this is depicted in Figure 53, which shows projected reclaimed contours for both dragline and truck and shovel stripping systems.

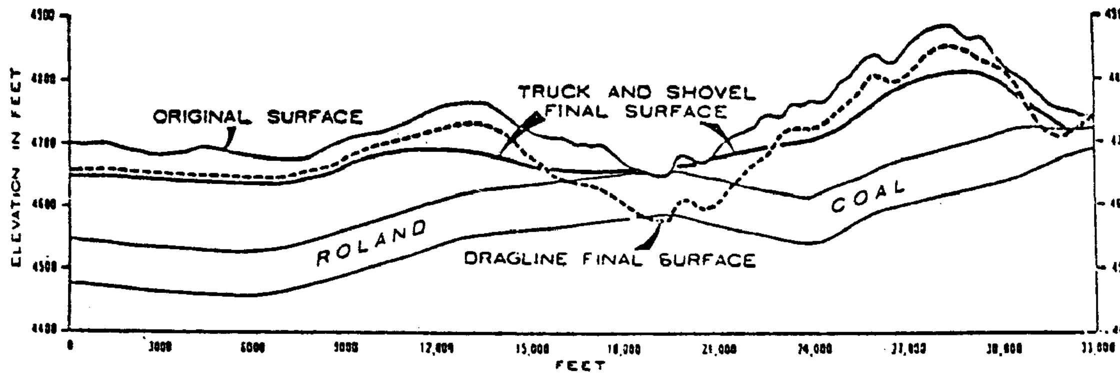


Figure 53. Comparison of Final Surface Contours for Dragline and Truck and Shovel Stripping Systems

A final environmental advantage of some truck and shovel systems is that it may be fairly simple to remove topsoil and subsoil separately. This may aid in revegetation efforts.

Coal Loading and Haulage

Although coal loading and haulage activities are of lesser environmental relevance than are overburden removal and spoil placement activities, they do cause some environmental impacts. The main ones are generation of fugitive dust, potential spoil grading delays, disruption of surface drainage patterns, and erosion of haul road surfaces.

The standard coal loading and haulage system is based on the use of electric shovels for coal loading and bottom-dump trucks for coal haulage. Prior to loading, because western coal is fairly thick, it is usually drilled and blasted. Similar to overburden blasting, this may cause generation of fugitive dust, such as that shown in Figure 54. It is not generally known if that dust is carried off of the mine sites.

After blasting, the coal is excavated by shovel and loaded into haul trucks. The trucks are then driven in the pit to the closest incline, up the incline to the main haul road network, and then to the loading facility. Truck traffic causes generation of fugitive dust. At most mines, the roads are periodically watered to maintain some safe level of visibility. This is the main dust suppression procedure used.

The design, location, and spacing of inclines into the pits are of interest from an environmental standpoint. This is because grading of spoils may be delayed near incline areas and because it may be difficult to backfill the inclines after completion of mining without leaving topographic depressions that adversely affect surface drainage patterns on reclaimed lands.

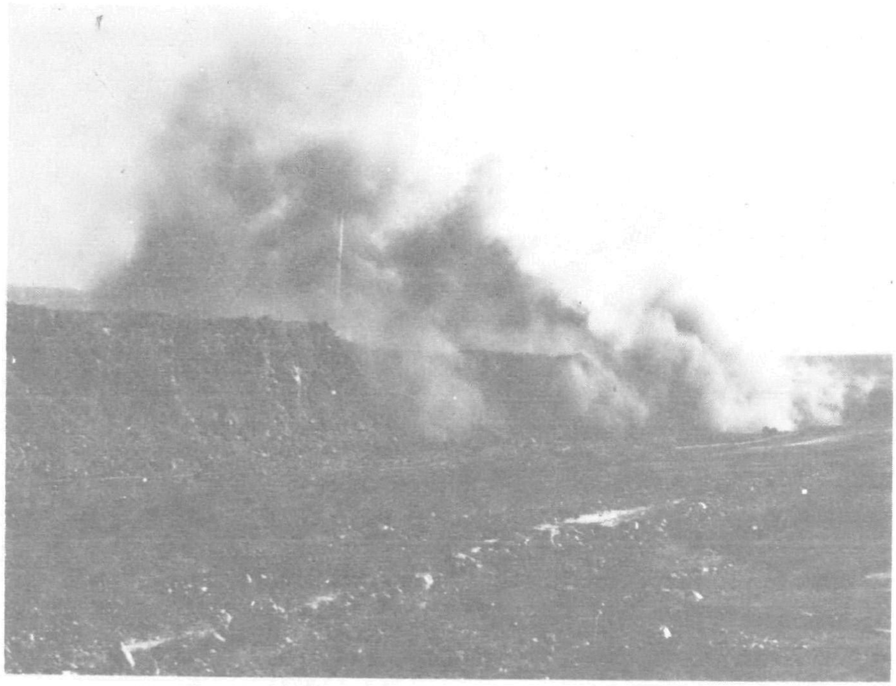


Figure 54. Photograph Showing Fugitive Dust Caused by Blasting of Coal

A typical incline is shown in Figure 55. Standard practice at many mines is to carry the inclines low in the spoil profile, maintaining a maximum grade of about eight percent into the pits. In single seam mining, the incline usually enters the pit at the level of the top of the coal seam. Where two seams are mined in a given pit, the incline enters at the elevation of the upper seam and an additional ramp, sometimes steeply graded, is constructed from the incline entrance down to the lower seam.

In addition to the fact that the incline is often carried low in the spoil profile, the spoil piles on either side of the incline are usually higher than the remaining spoil piles in a given pit. This is because the overburden materials that otherwise would have been placed in the opening left for the incline entrance must be stacked high on either side of the incline. The crest-to-crest spacing across the resulting spoil piles probably averages about 114 meters (375 feet). Grading cannot usually take place within this "band" so long as the incline is used for coal haulage out of the pit.

The average spacing of inclines at western mines in 1975 was 609 meters (2,000 feet). Delays in grading of 114 meter-wide strips along each incline can be significant. Additionally, where the inclines are very deep, it may be difficult to completely backfill them when they no longer are needed.

Figure 55. Photograph Showing Typical Pit Incline

As a remedy for this, many mining companies have made the following changes:

- The spacing of the inclines has been increased, thereby reducing the number of inclines for a given pit.
- The inclines are carried high in the spoil profile, and then brought down fairly sharply into the pit.

Where the inclines are carried high in the spoil profile, it is possible to backfill and grade them as mining progresses. Where there are two inclines in a given pit area, for example, one incline might be used while backfilling and grading are taking place on a section of the other.

These kinds of procedures are required by law in some states, and are sometimes used voluntarily in others. It would appear that their use increases coal haulage costs, but improves reclamation.

SUMMARY: INTEGRATION OF MINING AND RECLAMATION PRACTICES

Certain reclamation activities, such as drainage diversion and topsoil removal, take place in advance of stripping. Others are an integral part of the mining process, and yet others, still to be discussed, take place after stripping, coal loading, and coal haulage have been completed in a given pit area.

The phrase, "integration of mining and reclamation" has been widely publicized in recent years in debates over the need for, or lack of need for, new and more stringent reclamation laws. Indeed, in steep slope mining in central Appalachia, where reclamation is in large part a materials handling problem, the phrase has real meaning. Similarly, in acid areas of the midwestern United States, where exposure of toxic materials for even short periods of time may cause significant environmental damage, mining and reclamation should be integrated to prevent or minimize such exposure.

But things are different in the west. Although many words have been used in this report to describe ways in which mining and reclamation practices can be integrated, selective removal of overburden and placement of spoil is the principal way in which this need be accomplished. Nonetheless, various other ways have been proposed in the literature, so before moving on to a discussion of reclamation practices per se, a recap of actual and proposed methods for integration of mining and reclamation is presented.

Selective Overburden Removal and Spoil Placement

Several features of the western environment are relevant in this regard.

- Since there are few acid areas, reduction of the time lapse between spoil placement and spoil grading, say by narrowing or shortening the pits, may not yield significant environmental benefits. (In contrast, in acid areas such as those in southern Indiana or western Kentucky, these practices might yield very significant benefits.)

- Topsoil is salvaged and replaced at virtually all western mines. In some cases, this may reduce the need to selectively place spoil materials that will eventually be covered by the topsoil.

- Potential chemical contamination of groundwater is of greater concern in the west than in other parts of the country. This may impose unique selective placement requirements on western mining companies.

Unique requirements or not, however, observation of existing practices and analysis of proposed ones suggests that selective overburden removal and spoil placement can be accomplished at a cost. Preliminary analysis of several cases suggests that the cost may be fairly low. It might be worthwhile, therefore, to determine and publicize those costs for a wide range of operating conditions.

Moreover, in a given situation, there may be many ways to achieve a specified selective placement objective. Some will be less costly or more effective than others. The authors' field experience suggests that superintendents of mines in the midwestern United States have had more experience in developing cost-effective procedures than those in the west. If so, some "technology transfer" may prove beneficial. One way in which such a transfer might be accomplished is discussed in Section 7 of this report.

Narrow Pits and Short Digouts

It has previously been asserted in this section that, within limits, spoil grading costs and the time lags between spoil placement and grading can be reduced by narrowing dragline pits and shortening the digouts. For example, it has been shown in a previous report for one specific case that reduction of pit width from 43 meters (140 feet) to 27 meters (90 feet) would reduce the time lag between spoil placement and grading from 20 weeks to 13 weeks. At most western mines, this change of pit widths would also reduce spoil grading costs by several cents per ton. But these effects are not felt to be significant in the west, where the coal is thick and there are relatively few toxic overburden strata; thus research to determine environmentally best pit widths and digout lengths appears to be unwarranted.

Modified Incline Spacing and Design

Reduction of the number of inclines per pit and raising of the inclines in the spoil profile appear to be desirable practices from a reclamation management standpoint in that reclamation of the inclines can be made more-or-less concurrent with mining.

Dipline Mining

With the exception of a few mines in Colorado, the strip pits at western mines are oriented roughly parallel to the strike of the coal (perpendicular to the dip). Since groundwater in rock aquifers generally flows down-dip, opening of a long pit along the strike may result in interception of relatively large amounts of groundwater. Possibly, by orienting the pits parallel to the dip of the coal seam, and thus to the direction of groundwater flow, the amounts of groundwater intercepted by the active pits could be reduced.* After mining and reclamation had been completed, however, the net effects would be the same, regardless of the pit orientation.

The dipline mining concept does not appear to warrant serious consideration as a means of reducing the environmental impacts of mining, for the following reasons:

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*The effect of pit orientation on groundwater levels and flow rates is a matter of some speculation at present.

- Interception and drawdown of groundwater during mining may not be significantly affected by pit orientation.

- In most area mining situations, the dipline method has enormous economic disadvantages, related to the fact that deep overburden is encountered in every cut, including the first one. These disadvantages do not "average out" over the life of the mine.

Piling Spoil on the Highwall in the Final Cut

Frequently, during removal of overburden from the final cut, some spoil is piled on the highwall for subsequent use in burying the final highwall. This is a relatively minor way in which mining and reclamation practices can be integrated. It may result in achievement of reclamation requirements at least cost, but has the minor disadvantage that some land beyond the coal recovery line (final highwall) will be disturbed.

Retreat Mining

Retreat mining, a concept occasionally proposed for use in steep slope contour mining situations, is a method in which mining would begin at the permit boundary or coal recovery line and proceed back out to the coal seam cropline. It would involve first constructing coal haulage roads all the way to the expected location of the final highwall, and then mining or retreating back to the cropline. The purported advantage of the method is that it would enable concurrent reclamation of haul roads and other spoil areas which would never again be disturbed, by truck traffic or in any other way.

In the authors' opinion, such a method is unwarranted and impractical in most area mining situations for the following reasons:

- Adequate reclamation of inclines and haul roads can be achieved through use of practices already discussed.

- Opening of the box cut in very deep overburden along the recovery line would in most cases be technologically or economically infeasible, or both. Even it it was feasible, the resulting box cut spoil pile would be enormous in size.

- The recovery line, defined by the maximum depth of overburden that can be stripped profitably, changes greatly as the economics of mining change. For a mine which has a 30 year life, it is virtually impossible at the outset of mining to predict the locations of final highwalls.

- The economics of retreat mining would be disastrous. The equipment capacities required to meet production schedules in the early years of mining would be enormous. Not only that, the required equipment capacity would actually decrease over time. Additionally, the net cash outflows in the early years of mining would probably be so large as to make mining economically infeasible.

These enormous economic disadvantages coupled with questionable environmental advantages should be sufficient to lay this concept to rest.

Side Bench Stripping

As indicated earlier in this section, in single seam dragline stripping situations, cutting of a side bench by the dragline as the last activity on each digout enables placement of surface overburden materials on the surfaces of the spoil piles. This is a result that is often environmentally desirable and may cost relatively little. Thus, use of the method may sometimes be warranted even though possibly unnecessary from a production standpoint.

Blasting Delays

Use of blasting delays and electric caps in place of primercord are methods which are generally adequate, in the west, to reduce noise, air shock, and ground vibration to acceptable levels.

Tabular Summary

A summary and evaluation of ways in which mining and reclamation practices can be integrated in dragline stripping situations is presented in Table 15.

RECLAMATION PRACTICES

The final reclamation category in this discussion consists of those practices used in a given area after placement of spoils. The main purposes of these "post-mining" reclamation practices are to restore approximate original contours and revegetate the restored areas. The technology for doing so is fairly standard, much of it having been adapted from western agricultural practice.

The Organization for Reclamation

In past years, reclamation was the responsibility of production personnel at the mines. As a result, dual purpose equipment, that used for both production and reclamation, was used for production purposes as the need arose, often to the detriment of reclamation. The prime examples of resulting problems were grading delays caused by diversion of all operational dozers to production activities. Violations of grading regulations were not uncommon in past years.

TABLE 15. WAYS TO INTEGRATE MINING AND RECLAMATION IN DRAGLINE STRIPPING SITUATIONS

Mining Practice	Effect on Reclamation	Effect on Mining Productivity or Cost	Remarks
Selective Overburden Removal and Spoil Placement	May improve revegetation capability and reduce potential adverse effects on groundwater quality.	Productivity usually reduced because average dragline swing angle is increased.	Used at 40 percent of western mines in 1975.
Narrow Pit and Short Digout	Reduces time lag between spoil placement and grading. Reduces spoil grading costs.	Productivity may be increased or decreased depending on overburden and dragline characteristics.	Safety and other problems may result if pit is too narrow. Coal recovery decreases slightly as pit is narrowed.
Reduced Number of Inclines	Enables timelier spoil grading.	Increases coal haulage costs.	May also cause scheduling problems.
Carry Inclines High in Spoil Profile and Drop Sharply Into Pit	Enables timelier backfilling and grading of inclines.	Not known but may increase coal haulage costs.	Required by law in some states.
Dipline Pit Orientation	May reduce groundwater drawdown during mining.	Increases capital investment, reduces profitability, degrades cash flow pattern.	Rarely if ever used in practice except in Colorado where topography is unique. If used there, erosion problems may result.
Piling Spoil on Highwall in Final Cut	Reduces costs of backfilling final cut or reducing final highwall.	Probably minimal	Common practice in other parts of the country.
Retreat Mining	Enables complete back-filling of inclines concurrent with mining.	Felt to be economically infeasible.	Never used. Costs greatly outweigh benefits.
Placement of Side Bench Material on Spoil Surfaces	May reduce depth of topsoil required.	Productivity usually reduced because average dragline swing angle is increased.	Widely used in midwest, but infrequently used in west.
Blasting Delays for Overburden and Coal	Reduces noise, air shock, and ground vibration.	Not known, but may increase overburden removal costs.	Widely used

The first step taken at many mines to remedy this situation was to dedicate certain equipment to grading activities. Today, at about 60 percent of the western mines, some dozers are dedicated to grading and other reclamation activities. This has resulted in significant improvement in the timeliness of grading. Some minor problems persist, among them the fact that maintenance and repair of reclamation dozers is often given lower priority than maintenance and repair of production dozers; but, overall, dedication of equipment to reclamation has eliminated some past problems.

Another step taken by some companies was to create more-or-less autonomous reclamation organizations at the mines. Centralization of all reclamation activities under a reclamation superintendent has improved reclamation by reducing or eliminating possible conflicts between production and reclamation which frequently arose when both activities were administered by a single person.

Spoil Grading

Grading technology is largely standardized, involving the use of bulldozers to grade spoils and restore approximate original contours after placement of spoil. Grading costs per ton of coal are relatively low where the coal is thick.

In dragline stripping situations, grading is usually kept current to within two or three spoil ridges of the active pits, depending primarily on state or Federal reclamation regulations. It is not unusual, however, for grading to be kept current within one spoil ridge of the active pit. In fact, at some of the field survey mines, the spoil piles had been graded right up to the active pits.

The appearance of graded areas is generally excellent. Frequently, from a topographic standpoint, it is impossible to distinguish between areas that have been mined and those that have not. An example of such a case is shown in Figure 56. The area to the right of the road in that Figure has been mined and reclaimed. The area to the left was not disturbed by mining.

In general, surface drainage patterns at active mining sites are felt to be adequately restored by grading.* Often, new drainageways constructed on graded spoils are connected with natural drainageways at the boundaries of the mining operations. Of course, positive drainage from mining sites cannot be restored where the open pit mining method is used. Additionally, special care must be taken to restore adequate drainage in modified open pit mining situations, where the ground surface is lowered appreciably by mining.

*It should be noted that there are knowledgeable specialists who feel that restoration of surface drainage patterns may be one of the most critical problems facing western surface coal miners -- particularly with regard to stabilization of drainage channels over the final highwall.

Figure 56. Photograph Showing Reclaimed and Adjacent Undisturbed Areas

There may be occasional minor problems in grading during the spring, when the spoils are sometimes muddy, but the capacity of grading equipment appears to be large enough so that required grading timeliness can be accomplished even if no grading is done during wet periods.

Dozers are also used to grade the box cut spoils, but approximate original contours in box cut areas are restored at only 35 percent of the active mines. At the other mines, the outslopes of the box cut spoils are reduced to an average angle of about 15 degrees from the horizontal. This angle might be as high as 20 degrees. In the latter two cases, a spoil pile, such as that shown in Figure 57, remains and as such is a permanent topographic change. Some erosion generally occurs on the graded box cut piles.

Dozers are also used to reduce the height and slope of the final highwall and to partially backfill the final cut. Final cuts have been reached to date at very few western mines, but where they have been reached, one of two procedures has been used to reduce the final highwall. The first, mentioned previously, is to pile spoil on the highwall side of the last cut during the stripping process. After the coal has been loaded out, that spoil is pushed into the cut, thereby reducing the height and slope of the final highwall. The second is to use explosives to blast the final highwall down into the open cut. After blasting, dozers are used to do finish grading in the highwall area. The appearance of a reclaimed final cut at a western mine is shown in Figure 58. The final highwall in that cut was 24 meters (80 feet) high before reclamation.

Figure 57. Photograph Showing Graded Box Cut Spoil Pile

Figure 58. Photograph Showing a Reclaimed Final Cut

A minor disadvantage of the foregoing methods of reducing final highwalls is the disturbance of a narrow strip of land along the final highwall. Intuitively, however, it would seem that the acreage involved is but a small fraction of the total acreage disturbed by mining.

Even after reduction of the final highwall, a depression of swale will usually remain. If there was a water table above the elevation of the pit floor prior to mining, a shallow lake might form in that depression.

A tabular summary of grading practices is presented in Table 16. The Table shows that grading practices are widely used, generally with excellent results.

Revegetation and Erosion Control

Revegetation of mined areas has two purposes, control of erosion and return of the land to productive use. The vegetative species used for erosion control might not be productive in terms of the planned post-mining land use, which is usually grazing. Similarly, vegetative species suitable for grazing might not provide adequate erosion control, particularly during the initial years after seeding. A frequent solution to this potential problem is to seed both fast-growing annual grasses, suitable for early erosion control, and native species, suitable for the post-mining land use.

Several things are done before seeding. Common practice is to scarify the spoil surfaces prior to replacement of topsoil to ensure a good bond between the spoil and the soil. This is particularly important where the spoil surface is impermeable. An alternative sometimes used is to spread a few inches of topsoil on the spoil surface, scarify, then replace the remaining topsoil. Scarification is accomplished using a variety of farm implements and homemade devices.

Seed is usually sown by drill seeding. The rangeland type of drill is used at some mines and, in those cases, it apparently has worked very well. Drill seeding is usually done on the contour, although seeding up and down slopes was observed in occasional use at one field survey mine. In many cases, broadcast seeding is used in areas that are inaccessible to the drill; these are often areas that are fairly steep. Broadcasting is usually less successful than drilling, and many attribute this to the seeding method itself. One specialist, however, believes that broadcasting (at a double rate) should be more widely used because it enables seeding to be done at the proper times of year. In contrast, drill seeding during spring or fall may be delayed when the ground is muddy, resulting in seeding at other than optimal times. Hydroseeding has been tried at a few mines but, according to mine operating personnel, it failed because the water often made the surface of the spoil seal over. This occurred several years ago before topsoiling was required in some states. Aerial seeding, widely used at mines in the midwestern United States, is rarely used in the west.

Native species, required by regulation in some states, are widely used for revegetation in all states. Specialists generally agree that this is a good thing because the native species may persist without maintenance.

TABLE 16. FREQUENCY OF USE AND EVALUATION OF GRADING PRACTICES

Grading Activity	Frequency of Use		Remarks	Overall Evaluation
	Percent of 1975 Acres	Percent of 1975 Mines		
Restoration of Approximate Original Contour	97	96	Spoil grading required in all states.	Generally excellent from aesthetic, drainage, and land use standpoints. Occasional erosion problems on long unbroken slopes, but not a major problem overall.
Reduction of Outslope of Box Cut Spoil Piles	100	100	Approximate original contour restored at 35 percent of mines. Average maximum final grade at remaining mines is 27 percent (15 degrees).	Final grades are sometimes too steep for effective revegetation and erosion control, even if terracing is used.
Reduction of Highwall in Final Cut	74	82	Few impoundments permitted in final cuts. Approximate original contour required at 25 percent of mines. Average final grade of highwall at remaining mines is 33 percent (18-1/2 degrees).	Direct evaluation difficult because final cuts have been reached at very few mines. Observations at a few mines indicated excellent results.

Stocking rates on lands returned to grazing can be increased by as much as 15 times through use of introduced species, but annual fertilization and reseeding each decade would be required to maintain the land productivity. This is currently the range management procedure for "tame pasture" which is used for about one month each year during the spring calving period. The stocking rate for tame pasture might average about one acre per animal unit month as contrasted with an average of about 4-1/2 acres per animal unit month for rangeland. This evidences the well-known fact that grazing productivity can be increased through seeding of introduced grasses and legumes, but the range management requirements in such cases would probably be excessive for large acreages.

Several years ago, there was a widely publicized shortage of native seed supplies, brought on by rapidly increased demand for seed for strip mine reclamation. Although this shortage persists for many species, it has not resulted in widespread revegetation delays. Today, several companies are planning to grow their own seed. This is being encouraged by state reclamation personnel.

In almost all cases, requirements for amendments such as fertilizer or gypsum are determined by specialists whose services are retained by mining companies for that purpose. Amendments, mainly fertilizer, were used at 42 percent of the mines active in 1975. In the remaining cases, according to information provided by mining companies, tests had indicated that amendments were not needed.

Mulching, a practice employed at 24 percent of the mines active in 1975, is an effective means of conserving soil moisture and reducing erosion, if the mulch is used in sufficient quantity and is tacked or crimped into the soil so that it is not blown off by the wind. During the period of the field survey, for instance, operators of a mine located in a glaciated area started using mulch to reduce erosion on reclaimed areas. It appeared to be effective. Figure 59 shows sediment carried from reclaimed areas into roadside ditches prior to the use of mulch at that mine.

Terraces and ditches constructed on the contour are additional measures used to control erosion at 16 percent of the mines active in 1975. In general, however, these measures are not felt to be needed where mulching is used, except on long slopes. Terraces had been constructed on the outslopes of box cut spoils at a few mines, for example, but did not appear to have had any effect on erosion rates. On the other hand, contour ditches such as those shown in Figure 60 were effective in reducing erosion on long slopes in areas where the original topography was fairly steep.

Seeded areas were irrigated at only 16 percent of the mines active in 1975, and most of those were located in arid regions. The irrigation is used only for one or two growing seasons. Some problems with sealing of saline soils after wetting have occurred.

Figure 59. Photograph Showing Sediment Carried Into Roadside Ditch

Figure 60. Photograph Showing Contour Ditches Used to Reduce Erosion

The overall evaluation of revegetation and erosion control practices is good. Field observations at nine mines during three seasons of the year, coupled with information gathered from state and Federal regulatory personnel, indicate that mine spoils in the west can be revegetated to produce as good or better vegetative cover than the pre-mining cover. This is particularly true where topsoil is replaced and proper seedbed preparation, seeding, and amendment procedures are used. There is, however, still uncertainty regarding the long-term survival capability of vegetation on reclaimed lands.

Extensive revegetation research is now being conducted at western mines, as it should be; but the objectives of current research are mainly to reduce revegetation costs, decrease the time required to establish climax features, and increase post-mining land productivity.

A summary and evaluation of the revegetation and erosion control practices used at western mines during 1975 is presented in Table 17.

OTHER RECLAMATION-RELATED PRACTICES AND PROBLEMS

Insofar as the environmental effects of western surface coal mining are concerned, the trend seems clear. Initially, there was considerable skepticism over the feasibility of reclamation in general; many things were unknown, many questions were unanswered. But as information became available, and questions were answered, the answers usually indicated two things:

- The potential impacts were neither as severe nor extensive as had originally been anticipated.
- Reclamation is technologically and economically feasible.

There are still unanswered questions, however. What depths of topsoil are needed to ensure successful long-term vegetative growth? Will complex and interconnected aquifer systems be forever disrupted by mining? Is fugitive dust from mining operations a real problem? Will large sink holes appear in graded spoils years after grading? Some of these questions are legitimate ones, and research now in progress should provide answers.

An indication of the general areas of concern is given in Table 18, which shows potential environmental problems as identified by mining companies in their environmental impact statements and reclamation plans. The problems are termed potential ones because use of suitable reclamation techniques should often prevent them from becoming actual ones.

The potential problem condition most frequently cited was overburden or interburden materials that were clayey in texture and high in exchangeable sodium, as indicated by SAR values greater than ten. This

TABLE 17. FREQUENCY OF USE AND EVALUATION OF REVEGETATION AND OTHER EROSION CONTROL PRACTICES

Activity	Frequency of Use: Percent of 1975 Acres	Frequency of Use: Percent of 1975 Mines	Remarks	Overall Evaluation
Terracing of Graded Spoil Surfaces	34	16	Terracing and contour ditching should be more widely used.	Moderately effective in controlling erosion where used.
Spoil Amendment, Primarily Fertilizer	47	42	Not needed in all cases.	
Seeding			Broadcast used on areas inaccessible for drilling.	Broadcasting not felt to be as effective as drilling, although broadcasting at the right time of year may be more effective than drilling at the wrong time. Revegetation success generally good if proper seedbed has been prepared.
• Drill	44	71		
• Broadcast	5	7		
• Drill & Broadcast	51	22		
Mulching	28	24	Frequency of use is increasing.	An effective measure if crimping or tacking of mulch are used to prevent wind loss.
Irrigation	24	16		Appears to be very effective where used, although may cause sealing of high SAR clays.

TABLE 18. FREQUENCY OF OCCURRENCE OF POTENTIAL RECLAMATION PROBLEMS AS IDENTIFIED BY MINING COMPANIES

Problem Type	Frequency of Occurrence in 1975	
	Percent of Acres	Percent of Mines
Clayey, high SAR material in overburden or interburden	64	49
Fugitive dust	33	22
Sink holes	12	9
Sedimentation	10	9
High trace element concentrations	1	4
Chemical water pollution	0	0

condition occurred at half of the mines active in 1975. Means for preventing or minimizing the impermeability and attendant revegetation problems that could be caused by this condition have been discussed extensively in this report.

The second most frequently cited potential problem was wind erosion and fugitive dust. There are several mines at which fugitive dust appears to be a real problem. One is a large mine which is located right next to a town. During winter months in particular, coal dust is blown from large uncovered coal stockpiles toward the town. The state regulatory agency intends to require that the company monitor fugitive dust using high-volume air samplers.

In general, it is not known if fugitive dust is carried beyond the boundaries of mining properties. Research now in progress should shed some light on this question.

Some additional potential problems were cited by mining companies, but only infrequently. One is the possibility that sink holes will occur in graded spoils. Sink holes are surface depressions ranging from a few centimeters in diameter and depth, up to 10 meters in diameter and 15 meters in depth. To date, the problem, illustrated in Figure 61, appears to have occurred principally in orphan areas (ungraded spoils) where the spoil materials were high in sodium, primarily in North Dakota. These are typically areas that had been stripped by dragline without blasting of the overburden. As a result, large shale or clay "boulders" were placed in the spoil. It is possible that those boulders in combination with differential settling, weathering, and piping caused the subsidence (sink holes).

Figure 61. Photograph Showing Small Sink Hole in Orphan Sodic Spoil

To the best of the authors' knowledge, the sink hole problem has not yet occurred extensively in graded spoils. This doesn't necessarily mean that it won't. In fact, as a means of preventing occurrence of the problem, one company segregates large boulders during the stripping process.

Other infrequently cited potential problems included erosion, sedimentation, and high trace element concentrations in overburden strata. These do not appear to be significant problems on a regional scale, although severe erosion can occur on steep, glacial spoils, as shown in Figure 62. That Figure shows an isolated incident rather than a general condition, however.

There are also a handful of potential local problems. One is burial of power plant fly ash in the strip pits at captive mines. An example is shown in Figure 63. The fly ash is sometimes high in toxic trace elements such as boron, and some fear that burial of the fly ash in strip pits may result in chemical pollution of the groundwater. This potential problem was not studied as part of the current project.

A final comment applies to dewatering of wells during mining. Thus far, this has not occurred too frequently on lands not owned or leased by mining companies. Where it has occurred, mining companies have drilled deeper wells on affected properties. In every such case known to the authors, it has been possible to find lower-lying aquifers of

Figure 62. Photograph Showing Erosion on Steep Glacial Spoils

Figure 63. Photograph Showing Disposal of Fly Ash in a Strip Pit

yield and quality at least comparable to the groundwater in the aquifer that was dewatered.

SUMMARY

Mining of single and multiple coal seams by single draglines accounted for 68 percent of the strip pits, 83 percent of the tonnage produced, and 88 percent of the acres disturbed by western surface coal mining in 1975. Because of the actual frequency of occurrence of dragline stripping situations in 1975 and the forecasted frequency for 1980, those situations were emphasized in this study. Other situations, such as modified open pit mining of thick coal seams using loading shovels and trucks for overburden removal and spoil placement, occurred infrequently in 1975 and, although such situations will occur more frequently by 1980, they have received little emphasis in this report.

Procedures used to plan production and reclamation at western mines are sophisticated and thorough. The information gathered and analyses conducted to satisfy state and Federal reclamation regulations are extensive.

Prior to and during mining, adequate drainage control procedures are generally used. They include diversion of ephemeral streams that cross mining areas, construction of above-highwall ditches to divert surface runoff so that it does not enter strip pits, construction of earth dams across natural drainageways for the same purpose, construction of culverts under haulage roads and drainage ditches alongside the roads, crowning of haul roads to divert surface runoff to the ditches, and construction and maintenance of sediment basins. Although there are some occasional problems such as stream bank erosion in stream diversions, and creation of headcuts at outfalls of drainage diversion ditches, drainage control procedures were deemed effective overall. Diversion ditches are in general adequate in capacity, have suitable grades, and are adequately vegetated. Impoundment of surface water to prevent it from entering strip pits or crossing haul roads does not appear to have had a significant impact on water budgets or water quality. Sediment basins, although sometimes fairly shallow, appear to contain most or all sediment on site.

Topsoil was salvaged at 96 percent of the mines active in 1975. The depths of topsoil salvaged averaged 33 centimeters (13 inches). The soil is removed one to six months ahead of stripping, and some of it is stockpiled prior to replacement on graded spoils. Techniques for control of erosion on topsoil stockpiles were used at only 22 percent of the mines active in 1975, and wider use of such techniques appears warranted to reduce soil losses due to water erosion. Although direct replacement of topsoil without stockpiling appears to be desirable, at least during growing seasons, it is not always possible. Additionally, judging from the success of revegetation, claims that stockpiling destroys the fertility of the soil appear to be unfounded.

Drilling and blasting of overburden and coal do not appear to have caused significant environmental problems in the west, with the possible exception of emission of fugitive dust. There are several reasons for this, among them the low population densities in mining areas and the use of low powder factors in the relatively soft consolidated overburden that overlies strippable western coal. Where mines are located close to population centers, two techniques have been used to reduce noise, air shock, and ground vibration. One is to delay the shots so that the amount of explosive detonated at any given instant is less than or equal to an amount determined by the U.S. Bureau of Mines to be acceptable. The second is to replace primercord detonator with electric blasting caps to reduce blasting noise. Both of these techniques appear to have been effective and, overall, blasting is not felt to cause significant environmental impacts in the west.

There are many ways to integrate mining and reclamation practices in dragline stripping situations, but the only significant one in the west is selective removal of overburden and placement of spoil. This technique, planned for use at one-third of the dragline operations active in 1975, is needed for the following reasons:

- If special handling techniques are not used, overburden materials will be inverted on the spoil piles. Thus surface overburden strata will be placed on the pit floor, and the overburden strata immediately above the coal seam being mined will be placed on the surfaces of the spoil piles.

- Overburden or interburden at about half of the mines active in 1975 contained strata that were clayey in texture and high in exchangeable sodium, the latter factor indicated by a sodium adsorption ratio (SAR) greater than about ten. If placed on the surfaces of the spoil piles, as was often the case where selective placement procedures were not used, those materials soon become impermeable, increasing surface runoff and causing subsequent revegetation failures.

- Where there is a water table above the pit floor, placement on the pit floor of spoil materials high in soluble salts and trace elements may lead to mineralization or pollution of groundwater.

The objective in dragline stripping situations, therefore, should be to place the most desirable materials on the pit floors and on the surfaces of the spoil piles. This is generally possible at relatively low cost in single seam dragline stripping situations by using lead spoil principles and the side bench technique, neither of which appeared to be widely used in 1975. The problem is more difficult in multiple seam mining because two of the three prevailing multiple seam mining techniques result in placement of interburden materials, which are very often undesirable, on the surfaces of the spoil piles. Mine operators in the midwestern United States have had considerable experience in selective placement, however, and it is suggested that some means for "technology transfer" be devised.

The foregoing remarks are not meant to imply that better selective placement techniques are always needed to satisfy reclamation requirements, because, with topsoil replacement, they often are not. On the other hand, improvement in spoil placement control might enable reduction of the depths of topsoil required to achieve specified reclamation goals.

The design and spacing of inclines used to haul coal out of the strip pits have environmental relevance. Typical practice until recently was to space inclines about 457 meters (1, 500 feet) apart and to have them at the level of the pit floor for most of their length. This frequently resulted in spoil grading delays and made it difficult, from a management standpoint, to ensure that the inclines would eventually be completely backfilled. An apparently effective remedy, required by law in one state and sometimes used voluntarily in others, is to reduce the number of inclines used in a given pit area, and to keep them on top of graded spoil for as great a length as possible before dropping down to the level of the pit floor.

Economic considerations usually limit truck and shovel stripping systems to areas in which the coal is very thick. Such areas occur most notably in the eastern Powder River Basin of Wyoming. It is not reasonable to assume that trucks and shovels will come into widespread use in areas other than those in which the coal is very thick. Where used, however, such systems are environmentally superior to draglines in several respects in that they enable very selective placement of spoil, better control of reclaimed topography, and grading of spoils concurrent with placement. By the same token, though, the spoils are compacted more than spoils placed by dragline.

In dragline stripping situations, there are several additional ways to integrate mining and reclamation practices, but none of these is felt to warrant serious consideration. These include narrow pits, dipline mining, and retreat mining.

The organization for reclamation has been greatly improved at many mines through dedication of equipment to reclamation and centralization of reclamation activities under a reclamation superintendent. This has generally improved reclamation performance significantly.

Spoil grading was deemed to be good to excellent in all respects, including restoration of approximate original contours and adequate surface drainage patterns, appearance, control of erosion, and return of the land to productive use. Many mine superintendents would still like a cheaper means of grading, however. Additionally, there are specialists who feel that restoration of drainage patterns is one of the most serious problems facing western surface coal miners.

Revegetation success was generally felt to be good. In fact, the consensus of study team members and specialists interviewed during the course of the study is that, if proper spoil placement, topsoiling, seedbed preparation, seeding, amendment, and mulching techniques are used, it would appear that the vegetation on mined areas will be equal or superior in productivity to pre-mining vegetation. However, there are still some uncertainties regarding long-term revegetation success. Extensive revegetation research is now being conducted, but the primary objectives of those research activities are to reduce revegetation costs, reduce the time required to achieve climax conditions, and further increase land productivity.

Some questions remain unanswered, among them the following:

- What depths of topsoil are really needed to achieve specified revegetation objectives?
- Is fugitive dust from mining operations a significant problem on local or regional scales?
- What techniques can be used to minimize groundwater impacts in cases where they are potentially severe?
- Will sink holes (subsidence) occur extensively in graded sodic spoils?

SECTION 7

DISCUSSION OF RECOMMENDATIONS

SELECTIVE OVERBURDEN REMOVAL AND SPOIL PLACEMENT

A Symposium

It is recommended that the Environmental Protection Agency sponsor a symposium on the managerial, technical, and operational aspects of selective overburden removal and spoil placement in dragline stripping situations. The call for papers should be issued nationwide to enable some technology transfer from east to west, and possibly vice versa. The papers and presentations should deal with all aspects of selective removal and placement, including the following ones:

- Means used in advance of mining to identify desirable and undesirable spoil materials.
- Descriptions of planned operational procedures devised to enable selective removal and placement of undesirable materials.
- Actual operating procedures, including means for identification of undesirable materials by dragline operators, and management techniques employed to ensure that operators follow the plans.
- Operating problems.
- Adequacy of the procedures.
- Effects on production rates and costs.
- Alternative procedures considered.

Participation of both mine engineering and operating personnel would be essential to the success of such a symposium. Unfortunately, many of those people have neither the time nor the inclination to write or present technical papers. This could be remedied to some extent by appointing a select group of qualified individuals to survey mines at which selective removal and placement procedures are used, and to determine and document the needed information. The resulting document would then be reviewed by mining company personnel.

It would be essential that the symposium be a medium for exchange of practical information among practitioners. It would not be good if it turned out to be a progress report on environmental research.

Effectiveness of Selective Removal and Placement

It would be desirable to determine the effectiveness of selective overburden removal and spoil placement practices in terms of answers to the following questions:

- How does selective placement affect the amounts of topsoil that need to be replaced?
- How is the quality of groundwater and surface water affected?
- How is revegetation success affected?

In order to be useful, it would be necessary to obtain quick results for a wide range of conditions. This may not be possible; if it isn't, the project isn't worth doing.

MEANS FOR MINIMIZING GROUNDWATER IMPACTS

It may be worthwhile to conduct a study to identify and evaluate means for minimizing groundwater impacts. These might include selective overburden removal and placement, dipline mining, advance dewatering, deepening of wells on neighboring properties, and impoundments in final cuts, to name a few. The objectives of the study would be to describe alternatives and to present estimates of the costs and effectiveness of each alternative.

BUCKET WHEEL EXCAVATORS

Bucket wheel excavators can be used to excavate any overburden materials that do not require blasting. [22] Overburden does not generally require blasting at mines in North Dakota, thus bucket wheel excavators ("wheels") can in some cases be used there for overburden removal and spoil placement. Wheels cannot be used for overburden removal in most other western mining areas.

The interest here in these machines was motivated by attempts to devise overburden removal and spoil placement concepts that would have cost characteristics comparable to draglines, but also enable placement of topsoil by the main stripping machine directly onto graded spoils. This would appear to be a desirable mining and reclamation system.

In fact, it appears that use of a wheel would accomplish those objectives at some North Dakota mines. The operating procedure for a single seam case is shown in Figure 64. Working from a position on coal,

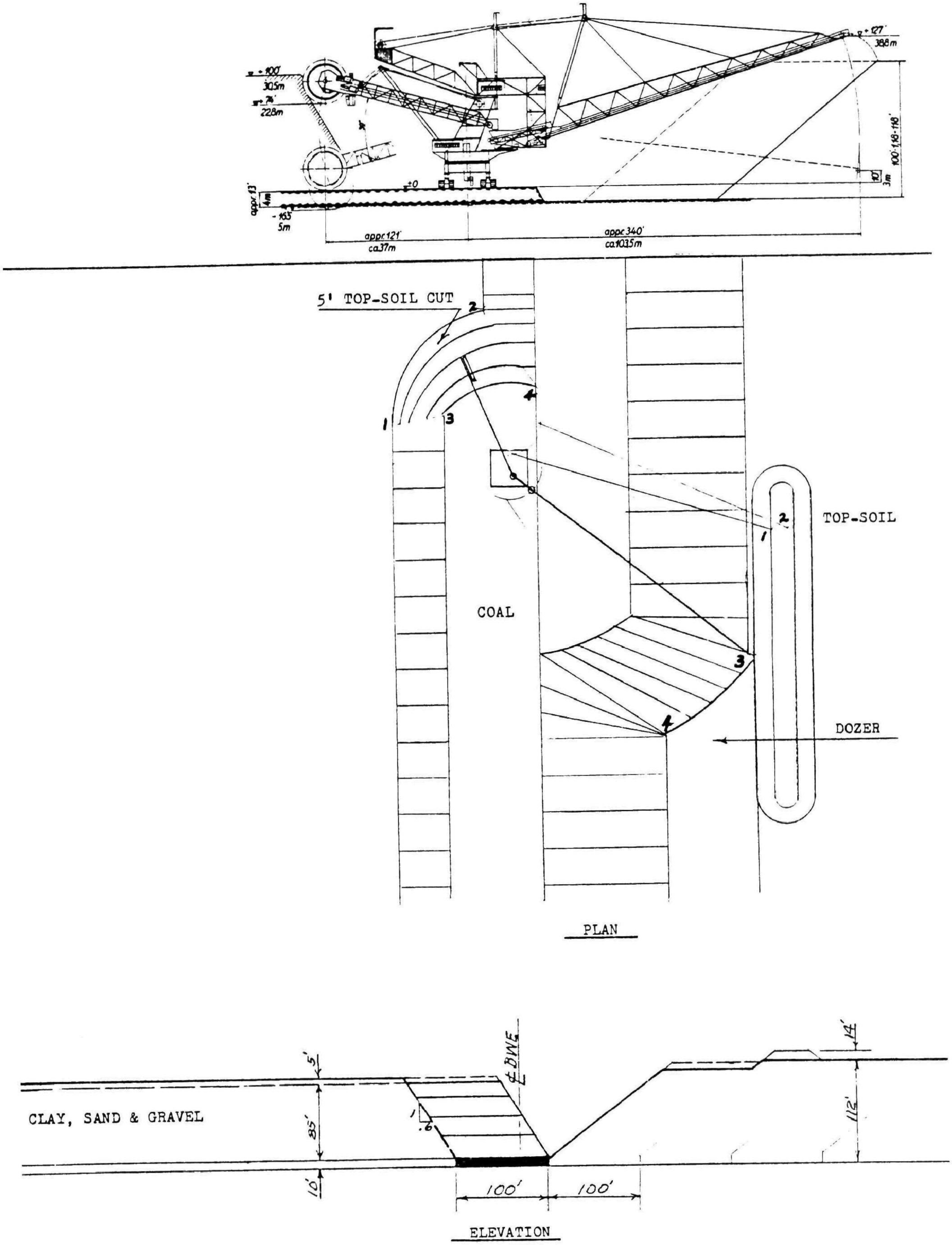

Figure 64. Operating Plan for Bucket Wheel Excavator

overburden would be excavated in lifts by the wheel and conveyed to the spoil pile via an articulated stacker. A dozer would work in the spoil leveling it as placed. After completing a given digout, the wheel would be advanced and topsoil for the next digout would be excavated. Now, however, the stacker would be swung in a counterclockwise direction, and the topsoil would be placed directly on leveled spoils from the previous pass (not the previous digout). This might be an excellent way to integrate mining and reclamation practices.

Additionally, if the rate of production was high enough, the wheel would actually be cheaper than a dragline of comparable capacity. This is shown in Table 19, which is a comparison of production rates and costs for dragline and bucket wheel excavator used under identical operating conditions where the coal seam is three meters (ten feet) thick and the overburden is 27 meters (90 feet) deep. For a given rate of production, 1.8 million metric tonnes of coal per year, total costs for the wheel are estimated to be 20 percent less than those for a large dragline.*

The wheel would have several disadvantages as well, among them the following:

- A large-capacity wheel would be required to operate in the typical overburden depths at western mines. This is because the long spoil dumping radius needed in, say, 25 meters of overburden can only be obtained

TABLE 19. COMPARISON OF MINING PLANS AND COSTS FOR DRAGLINE AND BUCKET WHEEL EXCAVATOR SYSTEMS

Stripping Machines		Annual		Annual Per Ton	
		Cubic Yards	Tons	Mining Cost	Earnings
Marion 7620	30 CY.	9,007,000	1,125,000	$2.46	$0.35
B-E 1370	60 CY.	16,000,000	2,000,000	2.30	0.42
BWE Krupp	20 CY.	16,848,000	2,105,000	1.85	0.66

The mining plans have been drawn and the costs estimated for the strip mining of the Gascoyne lignite deposits, Bowman County, North Dakota.

The costs estimates represents mining in the maximum overburden cover, approximately to a 90 foot recovery line.

*Details of production and cost estimates are presented in Appendix A.

on wheels with large capacity. Unlike draglines, it is not possible to buy a wheel with long reach and small capacity. This means that wheels are limited in use to situations in which large production capacity is needed.

- The presence of occasional sandstone lenses in the overburden, as is sometimes the case in North Dakota, might greatly complicate overburden removal by wheel.
- Unless special selective placement procedures were used, overburden materials beneath the topsoil would be inverted on the spoil piles.
- During North Dakota winters, the frost line at surface mines has averaged about 1.2 meters (four feet) deep in recent years. Frozen soil could not be excavated by the wheel.

All things considered, the wheel still might be a good choice for some large mines in North Dakota. Thus a study of the mining and reclamation characteristics of such a system should be considered.

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APPENDIX A

COMPARISON OF DRAGLINE AND BUCKET WHEEL EXCAVATOR PRODUCTION RATES AND COSTS

This Appendix contains the details of production and cost analyses of dragline and bucket wheel excavator stripping systems for a surface mining situation in North Dakota. Table A-1 shows the estimated production rate for a stripping situation involving a single dragline with a

TABLE A-1. PRODUCTION ESTIMATE FOR WALKING DRAGLINE (Marion 7620)

Component	Swing Angle	Swings Per Hr.	Bank Cu. Yds. Bucket Carry	Bank Cubic Yards	Time Hours
Topsoil	(Move by scrapers)			2,315	
Sand, Clay & Gravel	82°	62	21.6	30,093	22.47
Side Bench	120	57	21	9,260	7.73
Total				41,668	
Moved by Dragline				39,353	
Operating Time for a 100' Digout			80%		30.20
Delays			20%		7.55
Scheduled Time					37.75
Cubic Yards Per Digging Hour				1,303	
Cubic Yards Per Month (576 Hours)				751,000	
Bank Cubic Yards Per Year				9,007,000	
Mining Ratio				10	
Tons Per Year				900,000	
Tons Per Year at 60' Cover Overburden (Ratio = 6.67)				1,350,000	
Annual Average Tons in 60' to 90' Cover				1,125,000	

72 meter (235 foot) boom and a 23 cubic meter (30 cubic yard) bucket used to uncover a three meter (ten foot) coal seam overlain by an average of 23 meters (75 feet) of overburden cover. Estimated annual production is 1,020,000 metric tonnes (1,125,000 tons). Table A-2 shows a cost analysis for the same situation. Estimated total operating costs are $2.71 per metric tonne ($2.46 per ton).

Table A-3 shows the cost estimate for a larger dragline used under the same operating conditions. This dragline has a 79 meter (260 foot) boom and a 46 cubic meter (60 cubic yard) bucket. Estimated annual production in an average of 23 meters (75 feet) of overburden cover is 1,814,000 metric tonnes (2,000,000 tons). Total estimated operating costs are $2.54 per metric tonne ($2.30 per ton).

Estimated production rate for a Krupp Sch. Rs. 1500/5 · 30.5 bucket wheel excavator used in the same situation is 1,909,000 metric tonnes (2,105,000 tons) annually, as shown in Table A-4. The cost estimate, Table A-5, shows total operating costs of $2.04 per metric tonne ($1.85 per ton). Thus, for an annual production rate of 1,909,000 metric tonnes, the bucket wheel is the lower cost alternative.

TABLE A-2. COST ESTIMATE FOR WALKING DRAGLINE (Marion 7620)

CAPITAL COSTS	
1- Walking dragline, 235' boom, 30 cu. yd.	$ 5,300,000
1- Coal loader (M 151)	900,000
1- Cat. 992B, F.E.L.	200,000
2- Cat. D8 dozers + 1- Cat. 633C scraper	450,000
1- Cat. 16 patrol grader	125,000
3- Coal haul trucks (120 ton)	450,000
1- Coal dump hopper, crusher and car mover	400,000
1- Railway lead and hold yard	500,000
1- Building and miscellaneous equipment	1,675,000
Total	$10,000,000
MINE OPERATING COSTS	Per Ton
Stripping	
Labor	$0.52
Repairs and Supplies	0.32
Power	0.16
Reclamation	0.20
Total	1.20
Coal loading and shooting	0.10
Coal hauling (2 miles)	0.12
Crushing and loading RR cars	0.10
Supervision and office	0.16
Administration and general	0.06
Western Miners Union royalty	0.40
Interest on 1/2 of the capital costs	0.18
Miscellaneous	0.14
TOTAL	$2.46
SALES REVENUE ($0.35 per mm BTU)	$4.25
Royalty	0.25
REALIZATION NET	$4.00
Mine costs	2.46
	1.54
Depreciation	-0.45
Depletion	-0.40
Net for income taxes	0.70
North Dakota income tax (4%)	0.03
I.R.S.	0.32
EARNINGS PER TON	$0.35
Add back	0.45
CASH FLOW	$0.80

Strip mining with a walking dragline	(M 7620)
Cubic yards moved per year in 60' to 90' overburden	9,000,000
Tons coal produced annually, 10' seam @ 90% recovery	1,125,000
Mining Ratio	8.00

TABLE A-3. COST ESTIMATE FOR WALKING DRAGLINE (BE 1370)

CAPITAL COSTS	
1- B-E 1370, 260' boom, 60 cu. yd. bucket	$10,500,000
1- Coal loader B-E 195LR	1,160,000
1- Cat. 992B, F.E.L.	200,000
3- Cat. D8 dozers + 1- Cat. 16 patrol grader	575,000
4- Coal haul trucks	600,000
1- Coal dump hopper, crusher and car mover	400,000
1- Railway lead and hold yards	500,000
1- Building and miscellaneous equipment	2,065,000
Total	$16,000,000
MINE OPERATING COSTS	Per Ton
Stripping	
Labor	$0.33
Repairs and Supplies	0.32
Power	0.25
Reclamation	0.20
Total	1.10
Coal loading and shooting	0.10
Coal hauling (2 miles)	0.12
Crushing and loading RR cars	0.08
Supervision and office	0.10
Administration and general	0.05
Western Miners Union royalty	0.40
Interest on 1/2 of the capital costs	0.17
Miscellaneous	0.18
TOTAL	$2.30
SALES REVENUE ($0.35 per mm BTU)	$4.25
Royalty	0.25
REALIZATION NET	$4.00
Mine costs	2.30
	1.70
Depreciation	-0.40
Depletion	-0.40
Net for income taxes	0.90
North Dakota income tax (4%)	0.04
I. R. S.	0.44
EARNINGS PER TON	$0.42
Add back	0.40
CASH FLOW	$0.82

Strip mining with a walking dragline	(BE 1370)
Cubic yards moved per year in 60' to 90' overburden	16,000,000
Tons coal produced annually, 10' seam @ 90% recovery	2,000,000
Mining ratio	8.00

TABLE A-4. PRODUCTION ESTIMATE FOR BUCKET WHEEL EXCAVATOR

Scheduled hours per month	720
Operating time per month at 60%	432
Delay time per month at 40%	288
Cubic yards per digging hour	3,250
Bank cubic yards per month	1,404,000
Bank cubic yards per year	16,848,000
Mining ratio	10
Tons per year at 90' overburden	1,685,000
Tons per year at 60' overburden (Ratio = 6.67)	2,525,000
Annual average tons in 60' to 90' cover	2,105,000

Krupp bucket wheel excavator sch. rs. 1500/5 • 30.5
Cut 100' wide in 90' overburden
Direct topsoil excavation and placement by the bucket wheel excavator

TABLE A-5. COST ESTIMATE FOR BUCKET WHEEL EXCAVATOR

CAPITAL COSTS	
1- B.W.E, Sch. Rs. 1500/5 • 30.5 complete	$12,500,000
1- Coal loader (B-E 195LR)	1,160,000
1- Cat. 992B, F.E.L.	200,000
2- Cat. D8 + 1- Cat. 16 patrol grader	425,000
4- Coal hual trucks (120 ton)	600,000
1- Coal dump hopper, crusher and car mover	400,000
1- Railway lead and hold yards	500,000
1- Building and miscellaneous equipment	2,215,000
Total	$18,000,000
MINE OPERATING COSTS	Per Ton
Stripping	
Labor	$0.33
Repairs and Supplies	0.32
Auxillary equipment	0.04
Power	0.15
Total (including reclamation)	0.84
Coal loading and shooting	0.10
Coal hauling (2 miles)	0.12
Crushing and loading RR cars	0.08
Supervision and office	0.10
Administration and general	0.05
Western Miners Union royalty	0.40
Interest on 1/2 of the capital costs @ 8%	0.18
Miscellaneous	0.16
TOTAL	$1.85
SALES REVENUE	$4.25
Royalty	0.25
REALIZATION	$4.00
Mine costs	1.85
	2.15
Depreciation	-0.43
Depletion	-0.40
Net for income taxes	1.32
North Dakota income tax (4%)	0.05
I. R. S.	0.61
EARNINGS PER TON	0.66
Add back	0.43
CASH FLOW	$1.09

Strip mining with a bucket wheel excavator	
Cubic yards moved per year in 60' to 90' overburden	16,848,000
Tons coal produced annually, 10' seam @ 90% recovery	2,105,000
Mining ratio	8.00

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

This report is a companion volume to the report titled, "Evaluation of the Environmental Effects of Western Surface Coal Mining - Volume II: Mine Inventory." It describes and evaluates the methods presently used for surface mining of coal in the western United States, identifies and evaluates the effects that use of those methods have on the environment, and recommends ways in which the methods might be altered to reduce both long-term and short-term environmental damage.

This was accomplished by statistical analysis of comprehensive production and reclamation data for all 44 western surface mines active or under development in 1975, and through qualitative evaluations based on personal interviews of state and Federal reclamation specialists and field surveys of nine mines during three seasons of the year.

17. KEY WORDS AND DOCUMENT ANALYSIS

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