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THE ECONOMICS OF LAND RECLAMATION IN THE SURFACE MINING OF COAL: A CASE STUDY OF THE WESTERN REGION OF THE UNITED STATES

by

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ABSTRACT

This report presents the results of a comprehensive case study of land reclamation in the surface mining of coal. The study focuses on the arid Western region of the United States, encompasing all significant known reserves of strippable coal in the states of Montana, North and South Dakota, Wyoming, Colorado, New Mexico, Utah, Arizona, Washington and Alaska. The purpose of the investigation was to empirically examine Western reclamation requirements and procedures and to perform a comparative economic analysis of reclamation costs.

Local, state and federal laws, the principal means of controlling the reclamation efforts of the private mining industry, are carefully examined and evaluated. Within this framework of institutional control, the direct costs (i.e., the costs to the operator) of reclaiming "mined" lands are estimated. Other sources of surface disturbance (eg., transportation networks, storage facilities) are not examined in this study.

The analysis is based primarily on secondary sources of information. A limited field survey was conducted to provide corroborative evidence. Reclamation costs are derived, using an activity analysis approach and standard engineering cost schedules, for all major surface mines currently operating or planned for operation by 1980. Mine-specific costs are aggregated according to predefined coal production areas comprised of one or more counties, by state, and by subregions of several states, facilitating a comparative analysis of mining conditions, natural environments and institutional constraints.

The results of the analysis indicate that the earthwork handling requirements of recontouring and topsoiling typically account for 70 to 80 percent of total reclamation costs in the Western region. Consequently, the physical configuration of mining sites yields substantial variations in reclamation costs both within and among coal production areas. At the state and regional levels of aggregation, the influence of site-specific requirements, although not as pronounced, tend to overshadow the more subtle influences of reclamation law and enforcement standards.

The direct costs of current reclamation requirements and practices in the West range between $2,000 and $9,000 per acre of mined land. The average cost throughout the region is $3,500 per acre. On a per ton basis, estimates vary from a low of two cents to 34 cents, with an average for the region of about five cents per ton of coal mined. In terms of the impact of reclamation on market price, the range in costs account for as much as five percent at the upper limit, but average less than one percent of current western coal prices at mine-mouth.

The study concludes that, since the large-scale surface mining of coal is a relatively new phenomenon in the West, and due to the fragile natural environments of many potential development sites in the region, it would be premature to suggest that successful reclamation can be "purchased" at the reported costs.

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NOTICE AND DISCLAIMER

CHAPTER I

INTRODUCTION

A. STATEMENT OF THE PROBLEM

> "Let the sons, then, claim the kingdom they inherit, whatsoever the claim may cost. The day will and must come when through this vast deposit of easily accessible and marketable wealth, the wheels of industries will hum, the chimneys of factories will belch forth and cloud the sky by day and light it by night, and a half million artisans will find employment at good wages, build homes, rear children, clothe and educate them, and add ten thousand times ten thousand to the wealth, prosperity and contentment of this rich state.."

from
"Coal in Ward County"
North Dakota Magazine
December, 1906

Background

Adverse effects on the environment (and man) caused by massive surface disturbance in the surface mining of coal, other fuels and minerals are emerging national concerns. Surface-mined coal presently accounts for about 60 percent of the Nation's annual coal supply. At present levels of coal production, some 55,000 acres of land are disturbed annually by such mining. Increasing demand for energy resources, coupled with significant technological innovations in recovery and processing of

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coal, provide an incentive to stepped up surface mining, especially in the coal-rich western United States.

Approximately 1.3 million acres, nearly 2,000 square miles of land located primarily in the Eastern region, have been disturbed to date by surface mining [National Academy of Sciences, 1974]. The level of development necessary to achieve 1985 projections of coal production from the Western region would disturb as much as 90,000 acres (140 square miles) in that area [Northern Great Plains Resources Program Staff, 1974]. Orphaned land, i.e., previously mined, unreclaimed lands not covered under any pre 1977 reclamation law (either state or federal), is estimated at about 40 percent of total previous disturbance nationwide.

No accurate estimates are available for the monetary loss to the Nation that the unreclaimed lands represent. If it is assumed, for example, that annual income forgone and/or off-site pollution abatement costs amount to $25 per acre of unreclaimed land, an estimate of present total direct damages would be about $13 million annually. Fortune [1975] estimates public costs of a comprehensive, nation-wide reclamation program for these "orphaned" lands at $385 million (in 1976 dollars). In annual terms (discounted at 8 percent for 100 years), the direct costs amount to approximately $60 per acre or more than double the "assumed" benefits. Not knowing whether the assumed program benefits are high or low, it can be inferred from the existence of some 500,000 acres of orphaned land that the latter is probably the case. The belief that mined land reclamation is not justifiable on economic grounds has been an important disincentive to the systematic reclamation of mining disturbance in the past [Landy, 1976].

Issues of Public Concern

The long term consequences of surface mining in the West are not yet known, since only a small percentage of strip-mined lands have been successfully reclaimed. Earlier mining in the region has left some areas of land barren and unsightly -- a testament to fragile ecosystems and arid environments common to many Western states. Elsewhere in the Nation strip mining has left a history of polluted surface and ground waters, drastically altered topography, and glaring examples of diminished natural beauty of the landscape.

Failure to reclaim mined land can mean the permanent loss of its productivity for agricultural, recreational and other commercial purposes. In addition, significant external cost may result from unreclaimed mine sites, including: (1) erosion and related water quality degradation arising from steep slopes, uncompacted soils, and toxic substances, (2) the danger from collapse of highwalls and the subsidence of overburden materials, (3) the disruption of natural drainage networks at mine sites and the interference with groundwater aquifers and downstream water rights, and (4) the disruption of wildlife habitat including migratory and possibly endangered species.

Problems encountered in surface mined land reclamation are highly area-specific. In Appalachia, the problem is one of returning the land to its original contour in such a way that the harmful environmental and health effects of acid drainage, soil erosion and water runoff are avoided. In the broad expanse of the semi-arid West, the problem is basically one of revegetation.

Major factors influencing the success of reclamation efforts in the Western region are: (1) the chemical, hydrologic and physical characteristics of spoil materials as they affect fertility and erodability, (2) the climatic characteristics as reflected in the amounts and seasonal distribution of precipitation, length of the growing season, and evapotranspiration, (3) the availability of plant species suitable to the area and post-mining land uses, and (4) the form of technology and mining techniques employed in extracting and reclaiming the site. The physical factors of climate, soil and sparse vegetation combine to render revegetation a slow process in certain areas of the West, possibly involving a time frame measured in centuries [National Academy of Sciences, 1974].

Reclamation law and the administering institutional structures for enforcement and monitoring are relatively new in the West. In the absence of prior federal legislation, many Western states developed their own reclamation laws and enforcement policies. Because these laws are new and basically untested, there is considerable public interest in whether they will help or hinder reclamation efforts.

Policy Options

Reclamation can be defined broadly as a "transitional phase" in the continuing economic use of a natural resource [Leathers, 1976]. Although most concepts of reclamation imply returning disturbed sites as nearly as possible to their original condition (e.g., grazing to mining and back to grazing), the possibility of changing post-mining land use, given the existence of other alternatives, is worthy of careful consideration. For example, valleys and hills can be "created" from the mine spoils to simulate a natural beauty and variety that might otherwise be absent at the original site. In arid locales, irrigation might enhance the prospects for successful revegetation and add substantially to the reclaimed land values. Dry land cropping might replace rangeland in areas of ample rainfall and thus transform monocultures to a mixed land use base. Sanitary land fills, wildlife habitat, and residential uses are other examples which might be feasible alternatives in certain circumstances.

In nearly all cases three different courses of action can be considered: (1) restore the land (and related water resources) to achieve approximate pre-mining use and value; (2) reclaim the land to a level of use and value which exceeds its pre-mining history; and (3) sacrifice all or part of the land's future use and value. A sound economic evaluation of each option is made possible with the use of appropriate feasibility (or choice) criteria. Some of the more important criteria might include: (a) technical feasibility -- "What are the alternatives and costs?"; (b) efficiency criterion -- "How do costs compare with benefits?"; and (c) equity and distributional effects -- "What can be accomplished ... most efficiently ... for whom?"

A considerable amount of information is required, however, before a careful analysis of the problem and alternative approaches can be undertaken. Needed are criteria and guidelines for predicting reclamation potentials, limitations and costs for the various lands that are (and will be) subject to surface mining. Institutional arrangements and reclamation laws, which can either enhance or inhibit reclamation efforts, also require careful examination.

B. OBJECTIVE AND SCOPE OF STUDY

The principal objective of this study was to undertake a comprehensive economic analysis of surface-mined land reclamation in the arid Western region of the Nation. The Western region, as defined in this study, includes all major coal production areas that have been identified in the states of Montana, North and South Dakota, and Wyoming (the Northern Great Plains subregion); Colorado, Utah, New Mexico and Arizona (the Rocky Mountain subregion); and Washington and Alaska (the Pacific subregion). Coal production areas were delineated in terms of strippable reserves, and therefore selected portions of the above states with significant underground coal resources were omitted from the analysis. Maps of the study area are reproduced in Appendix A.

Further, the investigation focuses on mine-site disturbance, i.e., the area of land actually "mined" in the process of coal extraction. Although it is recognized that significant surface disturbance occurs in conjunction with the mining operation (for example, exploration, haul roads, coal storage and transportation facilities, equipment maintenance areas and the like), a careful examination of these sources was beyond the scope of the present study.

Specific Objectives

The substantive aspects of the problem were identified and examined within the context of several operational objectives. Specifically, the objectives were:

(1) to identify and evaluate the various institutional controls, laws and regulations which are currently being applied by the individual

state, local and federal governments to guide and control the reclamation efforts of the private mining industry;

(2) to identify appropriate technologic and economic variables which, in conjunction with coal and overburden characteristics and other engineering parameters, provide the basis for estimating the earthwork (recontouring and topsoiling) component of reclamation cost;

(3) to identify appropriate physical variables (e.g., geologic hydrologic, climatic, biotic and topographic aspects which influence the feasibility of successful revegetation) for use in formulating and evaluating response potentials and costs for the revegetation component of reclamation;

(4) to identify and estimate other components and costs, including off-site degradation abatement and unallocated overhead requirements; and

(5) to evaluate the cost estimates and the incidence of annual reclamation requirements within the perspective of different geographical and time frame considerations.

Approach

For the purposes of this study, the basic reclamation process was conceptually defined as several component activities: the engineering requirements of reshaping the spoils, topsoiling, and where required, backfilling and burying toxic substances; the revegetation requirements of seedbed preparation, planting and management of newly revegetated surfaces; and unallocated overhead activities, including premining planning, supervision, on-site diversion and runoff control structures, and environmental monitoring. Variations on the basic process are recognized in the form of different end-uses of reclaimed land and the attendant requirements that such alternative reclamation objectives would entail. The empirical analyses reported in this paper, however, emphasize basic reclamation practices.

Off-site externalities, (i.e. deleterious impacts which can be identified as a direct consequence of surface mining) require corrective action under present reclamation law and, therefore, the costs of abatement must also be considered an integral part of reclamation program costs. This study further distinguishes between direct and indirect costs, adopting the former measure which excludes the subsequent (indirect) effects of changes in market price [James and Lee, 1971].

A general mine-site evaluation technique, recently developed by the U.S. Forest Service, was a major element in the procedure for analyzing revegetation response potentials at the relevant coal development sites. The method utilizes extensive descriptive data, and brings together the important physical characteristics at each site to estimate revegetation potentials and costs.

The assessment of institutional controls (the promulgated rules and regulations) currently in use in the Western region was based primarily on available secondary sources of information. Pertinent data on the technological and biological aspects of reclamation was also obtained largely from secondary information. In addition to these sources additional data was obtained through a survey of randomly selected mine operators in the study area. Nine personal interviews were conducted, and although not comprehensive in scope, these responses were very useful as corroborative evidence.

C. ORDER OF PRESENTATION

The analyses and findings are reported in the same sequence as the operational objectives were outlined above. Chapter II reports the analysis of reclamation law, emphasizing the nature and effectiveness of current state programs. The analysis of reclamation requirements and costs is presented in the following three chapters: the engineering component (Chapter III), the revegetation component (Chapter IV), and other reclamation components along with estimates of total direct costs for the Western region (Chapter V). A concluding chapter (Chapter VI) reports the summary of findings and implications for public policy.

Chapter II

RECLAMATION AND THE INSTITUTIONAL ENVIRONMENT

A. INTRODUCTION

Emphasis in recent years on the Nation's capacity to become self-sufficient in energy production has caused concern about the potential impacts that would accompany a rapid development of the West's vast supply of strippable coal. Faced with uncertainties in the timing of coal development, and in the passage of Federal legislation on surface mine reclamation, the separate Western states have adopted their own method for dealing with the situation. The most important control measure adopted by the states has been surface mining reclamation laws.

This Chapter examines state reclamation law and other local, state, and federal institutional arrangements designed to encourage successful reclamation in the Western region. All Western states with the exceptions of Arizona and Alaska have newly enacted reclamation laws. As they are written and interpreted, however, the laws are not without problems. Because they are new and not well tested, state laws have come under criticism for being inconsistent, ambiguous, and otherwise unattainable in their stated objectives.

The approach followed in this study was to consider both the letter and the intent of the laws. This requires a careful examination of how the state laws are promulgated (rules and regulations) as well as implemented in actual practice. Other controls, including laws and regulations enforced by federal, state and local governments which have a bearing on reclamation and mining activities, are discussed in conjunction with the formal reclamation requirements.

B. LAW AND INSTITUTIONAL CONTROLS

The number of state programs designed specifically for strip mine reclamation in the United States has grown from one in 1939 to 39 in 1976. Thirty-three of these programs became effective just in the past six years, and the remaining 11 states are expected to have some form of reclamation legislation by 1980. New, comprehensive Federal legislation was passed only recently, in mid-1977. (See p. 28.)

In this section the pertinent reclamation laws, regulations, standards and regulatory procedures of the ten Western states are critically examined. Included with these are other non-state controls which are enforced by various federal agencies and local governments in conjunction with the state laws. Specific questions addressed in the analysis included such issues as: (a) How do requirements vary among the states?, (b) How does regulation enforcement responsibility differ?, (c) What are the consequences for failure to comply with the regulations?, (d) To what extent are allowances (variances) made in special situations?, (e) To what extent is reclamation coordinated with local land-use planning?, (f) What is the outlook for federal regulations and how will they modify state laws?

The descriptive material reported in this section draws heavily upon the recently published work of Doyle [1977], Imhoff and others [1976] and the Federation of Rocky Mountain States [1976]. Many attributes of present state law in the Western region are only briefly considered in this report for the sake of brevity.

Evolution of Reclamation Law

The first documented attempts to reclaim surface mined lands in the United States date back some fifty years to the experimental programs of several midwestern coal mining firms [Carter et al., 1974]. Reforestation proved successful in West Virginia, and in Indiana spoil banks were reclaimed to productive cropland at Meadowlark Farms near Terre Haute. The technical and economic feasibility to reclaim, and growing public concern over the damaging side-effects of surface mining, together provided the impetus for states to enact reclamation laws. Among the first states to have "written" rules and standards of compliance were: West Virginia (1939), Indiana (1941), Illinois (1943), Pennsylvania (1945), Ohio (1947), and Kentucky (1954).

The early state laws specifically addressed coal mining, and in most cases only revegetation and erosion control were required. State programs were expanded in scope and content in the late 1950's and early 1960's. In response to the new state and federal pollution control laws of the late 1960's, state reclamation laws were extended to other minerals and new standards were adopted to monitor (and regulate) all major activities that occur at a mine site. Consequently, the "environmental impacts" of surface mining now receive special attention in most state reclamation legislation.

Perhaps the most significant development in reclamation law of the 1970's has been the emergence of new programs that treat mining as an "interim" land use. Successful reclamation of mining disturbance to an "approved end-use" is of paramount importance in some recent state legislation. Examples of the interim use concept are found in the state laws of the Northern Great Plains and Rocky Mountain regions as well as in the laws of many states in the Midwest and Appalachia. Since interim use is only understood within the context of long-term planning, the concept implies an increasing involvement on part of all concerned parties in the decision-making process, including private firms, the local community, state and federal governments, and the tax-paying public.

Since the federal government owns the surface and mineral rights to a large proportion of the nation's land resource, some of which is underlain by strippable coal deposits, it is understandable that Federal laws have been passed to form the basis for regulating coal development and reclamation on land subject to federal coal leases.

However, as suggested in the following discussion, some provisions of state law could prohibit coal development on certain sites where reclamation is not possible, or perhaps delay or discourage coal development altogether. Accordingly, the new federal legislation has established procedures for resolving any potential conflicts between State and Federal law on both Federal and non-Federal land, based on the principle that the more stringent of the two laws shall prevail.

Review of Current State Programs

Key statutory provisions, rules and regulations embodied in the laws governing reclamation in the Western United States are summarized and compared in table 1. Several main headings are used in the table to facilitate the comparison of general provisions and requirements. The main headings include: stage of program development (columns 2-4), administration and coverage of the law (columns 5-8), specific reclamation requirements and standards (columns 9-18), requirements for land use planning (columns 19-22), special provisions (columns 23-27), state enforcement powers (columns 28-30), provisions for citizen participation (columns 31-34), and the conditions under which the operator is released from liability (columns 35-38). Each column describes a specific aspect of the reclamation program.

Stage of Development. The sequence of columns 2 through 4 denotes the normal progression of state legislation and follow-up administrative action. "Act(s)" refers to the enabling legislation whereas "rules and regulations" refers to the promulgation phase, i.e., providing specific direction and setting minimum levels of performance. With ample experience, rules and regulations can be extended to establish "technical guidelines" to be followed by the mine operators. As indicated in table 1, Montana is the only state in the West which has gone this far in its program development.

Surface mining reclamation laws are relatively new to the Western region. The first laws were enacted by North Dakota (1969), Washington (1970), and Montana and South Dakota (1971). Utah did not have a reclamation act until 1975, and Arizona and Alaska still do not have reclamation laws. Different state agencies are charged with administering the laws in each state. The administrative agency is the department of state government presently responsible for disseminating information, processing applications, issuing permits and monitoring performance. With the exceptions of North Dakota and New Mexico, where surface mined land reclamation only applies to coal, these state laws cover all mineral mining.

TABLE 1. COMPARATIVE ASPECTS OF STATE MINED LAND RECLAMATION PROGRAMS IN THE WEST, EFFECTIVE JULY 1, 1977.

State	STAGE OF PROGRAM DEVELOPMENT			STATE LAW			
	Act(s)	Rules and regulations	Technical guidelines	Title of Act(s) (Year Effective)	Administering agency(ies)	Mineral or commodity covered	Rules vary by mining method
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NORTHERN GREAT PLAINS REGION:							
MONTANA	X	X	X (Partial.)	(1) Montana Strip & Underground Mine Reclamation Act (1973), and (2) Open Cut Mining Act (1973), and (3) Montana Hard-Rock Mining Reclamation Act (1971); amended 1974-75.	Department of State Lands.	Act (1) Coal and uranium; Act (2) bentonite, clay, phosphate rock, scoria, and sand and gravel; Act (3) other minerals.	------------
NORTH DAKOTA	X	X	----------	North Dakota Century Code; Reclamation of Strip-Mined Land (1969); amended 1971, '73, '75.	Public Service Commission.	Coal----------------------	------------
SOUTH DAKOTA	X	X	----------	Surface Mining Land Reclamation Act (1971), as amended 1973-1976.	Department of Agriculture.	All minerals--------------	------------
WYOMING	X	X	----------	Wyoming Environmental Quality Act (1973); amended 1974-75.	Department of Environmental Quality.	All minerals--------------	Rules vary by soft rock mining or hard rock mining.

SOURCES: General references were Doyle [1977], Federation of Rocky Mountain States [1976], Dames and Moore [1976], Imhoff, et al. [1976], Energy and Environmental Analysis, Inc. [1976], National Academy of Sciences [1974] and Grim and Hill [1974].

Entry notation: "---" indicates no specific treatment of the topic in the Acts, although the subject matter may be addressed in the regulations, Administrative orders or in extant professional practices of that State. "X" affirms the existence of a requirement or program element, but does not provide enough detailed information to indicate the individual character of the State program. A.O.C. is an abbreviation for "approximate original contour."

1/ In addition to bonding, various fees for licenses and mining permits are levied on the mine operator. Since the amount of such fees are typically nominal, they are omitted here.

TABLE 1. ...Continued...

State	STAGE OF PROGRAM DEVELOPMENT			STATE LAW			
	Act(s)	Rules and regulations	Technical guidelines	Title of Act(s) (Year Effective)	Administering agency(ies)	Mineral or commodity covered	Rules vary by mining method
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ROCKY MOUNTAIN REGION:						
COLORADO	X	X	----------	Colorado Mined Land Reclamation Act (1973) as amended (1976).	Mined Land Reclamation Board, Department of Natural Resources.	All minerals excluding oil, gas and geothermal.	------------
NEW MEXICO	X	X	----------	New Mexico Coal Surface Mining Act (1972).	Bureau of Mines and Minerals.	Coal.	------------
UTAH	X	X	----------	Utah Mined Land Reclamation Act (1975).	Board and Division of Oil, Gas, and Mining, Department of Natural Resources.	All minerals excluding geothermal, oil and gas.	------------
ARIZONA	The State of Arizona applies standard reclamation requirements to State Lands as a condition of mineral leases. Arizona also contains Federal lands where reclamation requirements are a condition of mineral leases. Some local units of government use land-use controls (e.g., zoning) and activity permits (e.g., minerals proceeding) to encourage reclamation. In the absence of State Law, Federal lands are subject to federal regulations.						
	PACIFIC REGION:						
WASHINGTON	X	X	----------	Surface-Mined Land Reclamation Act (1970).	Department of Natural Resources.	All minerals.	Quarries are handled as special cases.
ALASKA	Mining in the State of Alaska is on Indian, Federal and/or State Lands; case-by-case State regulatory decisions and/or Federal coal leasing regulations apply.						

(Continued)

For the most part mining methods (column 8) are determined by economics and natural factors related to mineral extraction. However, in special cases the mining method has been influenced to a significant degree by reclamation requirements [Skelly and Loy, 1975]. These cases are generally limited to the Eastern region where the topography is more varied and mineral extraction often involves a combination of mining techniques. Kentucky and West Virginia, for example, have different rules governing the use of different mining techniques depending upon the particular natural features of a mine site [Doyle, 1977]. In the Western region, only the states of Washington and Wyoming have rules which vary by mining method, but these are usually limited to minerals other than coal.

Specific Standards and Requirements. State reclamation requirements have become fairly complex and comprehensive in a relatively short period of time. The required actions and standards of laws in the Western region are a clear demonstration of this. Within the general provisions of the Acts themselves, state enforcement agencies can (and do) issue orders, regulations, and guidelines and conduct licensing activities in the absence of specific rules and regulations [Carter *et al*., 1975]. Nonetheless, there is a trend in recent legislation for greater specificity in what is required of the mine operator and, in some cases, "how" he is to do it [Hansen, 1976].

All states with reclamation laws follow a similar procedure in examining a mine operator's credentials and plans, and in requiring a surety bond before a permit is issued. However, differences do exist in the specifics, such as time periods for renewal, number and amount

TABLE 1. ...Continued...

State	RECLAMATION--MAIN ACTIONS REQUIRED AND STANDARDS SET									
	Reclamation Bonding[1/]		Reclamation of Exploration Disturbance	Control water flow and quality	Conserve and replace topsoil	Backfill and grade	Reduce highwall or pitwall	Bury or neutralize toxic wastes	Revegetate for beneficial use	Other rules or remarks
	Amount	Release Time								
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	NORTHERN GREAT PLAINS REGION:									
MONTANA	Not less than $200 per acre with $2,000 minimum. Based on estimate of Reclamation costs.	Partial release upon approval of department; remaining bond will not be released prior to 5 years from initial planting.	As soon as possible. Topsoil removal required for prospecting activities. May require planting of annual crop to control erosion.	Act (1) specific criteria, e.g.--pH range of 6.0 to 9.0.	Removal and stockpiling to precede each step of mining operation. Topsoil removal required for prospecting activities.	Act (1) grade to $\leq$ 20%, within 90 days after department has determined the operation completed.	Slope of face will be $\leq$ 20%.	Act (1), backfill with 8 ft. of overburden. Soil and overburden analyses required.	Suitable, permanent, diverse and primarily native species.	Effluent standards conform with criteria of State Dept. of Environmental Sciences.
NORTH DAKOTA	$1,500 for each acre affected. (Minimum)	5 years after termination of permit; partial release may be effected for separate tasks.	X	X	Replace all available plant growth material, up to 5 ft. thickness.	Approximate original contour, or serve approved end use.	Slope of face will be $\leq$ 35%.	Requires pH, sodium absorption ratio electrical conductivity texture (by feel).	X	Remedy any impairment to domestic or livestock water supply.
SOUTH DAKOTA	An amount sufficient to cover the costs of reclamation.	Upon approval of Department.	X	X	X	"Achieve contour most beneficial to the proposed land use."	Slope will be $\leq$ 14°.	With 8 ft. of topsoil or suitable overburden.	To create self-regenerative growth without irrigation.	Noxious weeds must be controlled.
WYOMING	Amount equal to estimated cost of reclaiming affected land. In no event will bond be less than $10,000. Issued annually.	75% may be released upon completion. Minimum balance of $10,000 held for an additional 5 years.	Must meet with approval of administrator.	X	Topsoil unless nonexistent; protect from erosion and toxicity; use most suitable plant growth materials.	Approximate original contour; terrace; or serve approved end use.	Stabilize slope; minimize effect on landscape.	X	X	Oelay mining for archeological or paleontological surveys; reclaim according to approved plans.

(Continued)

TABLE 1. ...Continued...

State	RECLAMATION--MAIN ACTIONS REQUIRED AND STANDARDS SET: Reclamation Bonding 1/ Amount	Reclamation Bonding 1/ Release Time	Reclamation of Exploration Disturbance	Control water flow and quality	Conserve and replace topsoil	Backfill and grade	Reduce highwall or pitwall	Bury or neutralize toxic wastes	Revegetate for beneficial use	Other rules or remarks
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	ROCKY MOUNTAIN REGION:									
COLORADO	Depends upon type, costs and extent of reclamation activities, posted before prospecting; Maximum $2,000 per acre, $25,000 for State-wide prospecting.	Upon approval of Board.	Upon approval of Board. Bonding required.	X	X	Final contour appropriate to selected land use.	----------	X	Diverse, permanent vegetative cover capable of revegetation, and at least equal in extent as surrounding area.	Exemptions are obtained for areas unsuitable (infeasible) for corrective actions; each phase must be completed 5 years after initiation.
NEW MEXICO	Required at the discretion of the Commission.	Upon approval of the Commission.	-----------	X	------------	Topography will be "gently undulating" or consistant with proposed end use.	----------	------------	To serve selected end use.	
UTAH	Depends upon type, extent and costs per se not required; No maximum or minimum.	Upon approval of Department.	X	X	------------	X (Where "practical").	----------	X	X (Priority to Non-Noxious, Native species).	Program implementation recognizes site specific (Unique) conditions.
ARIZONA	...No State Law... (Federal regulations apply)									
	PACIFIC REGION:									
WASHINGTON	Required at the discretion of Department; No maximum or minimum.	Upon approval of Department.	-----------	X	------------	Conform to surrounding land area.	Grade of wall <66% (unconsolidated) and <45% (rock).	With 2 feet of clean fill.	X	Other State regulations apply to water rights, flood plains, and fish and wildlife.
ALASKA	...No State Law... (Federal regulations apply)									

(Continued)

of bonds, and information required for licensing. The applicant is normally licensed to mine and to reclaim according to an agreed-upon plan of scheduled, specifically located activities subject to inspection and periodic relicensing. As a safeguard against forfeiture, some state agencies (Montana, Wyoming, South Dakota and Colorado) endeavor to set bonding fees at a level that will cover expected reclamation costs. Typically, these rates are renegotiated annually and the minimum release time is about five years. In the other states (excluding Arizona and Alaska) bonding amounts and release times are not specified by law but are left to the discretion of the enforcement agencies. Montana, Colorado and Wyoming also apply bonding requirements to exploration disturbance.

Most states have rather detailed specifications for handling and conserving topsoil, backfilling and grading spoils, meeting slope requirements, and handling toxic or waste materials [Dames and Moore, 1976]. Exceptions to this are found in the laws of New Mexico and Utah. Differences noted are thought to reflect unique problems or situations in particular states. The abatement of deleterious on-site and off-site effects of mining is fundamental in all state law, and in the early programs such measures were enacted prior to more general state and Federal pollution control legislation. State reclamation acts normally cover most sources of air and water pollution, noise and aesthetic degradation of the landscape.

Considerable flexibility is applied by administrators in interpreting and enforcing the law with respect to revegetation and other reclamation standards. In arid and semi-arid climates little is currently known about the time required to establish a permanent plant cover of suitable species mix. Accordingly, state standards in the West are generally more flexible in this regard than similar standards elsewhere in the nation. Montana's requirement of establishing "primarily native species" is an exception, and serves as a good illustration of why strict standards are controversial: the native species rule does not encourage consideration of alternative land uses.

Requirements for Land Use Planning. The information typically required of the mine operator before operations commence (column 19) have forced mining companies to develop considerable expertise in reclamation practices and planning. However, only three States (Colorado, Utah and North Dakota) currently require the careful consideration of alternative end-uses of the reclaimed land. Procedures for identifying appropriate land use objectives vary from state to state, but the recent trend in western legislation requires the mine operator to consider "alternative" and "multiple" uses. Under Montana law, for example, the operator has essentially no opportunity to suggest an alternative to the specified use. On the other hand, an operator in the state of Colorado is encouraged to make suggestions of his own in cooperation with the land owner.

Special Provisions. Most states have a number of special provisions in the amendments which enhance (or modify) the coverage of the general law. Examples of such provisions may include mineral protection, exclusion of certain areas from mining, provisions for long-term planning, and others. One of the more important provisions is the planning period. Because of the semi-arid conditions in the West, the time frame for reclamation planning is much longer in contrast to the

TABLE 1. ...Continued...

State	REQUIREMENTS FOR LAND-USE PLANNING				SPECIAL PROVISIONS				
	Resources information required	Alternative uses will be considered	End use will be declared	Role of local public planning	Minerals protected from nonmining development	Exclusion of areas from consideration for mining	Long-range or regional mine planning	Substitute lands allowed	Financial or economic analyses required
	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
	NORTHERN GREAT PLAINS REGION:								
MONTANA	Environmental areas, geology, soils, minerals, topography (USGS), vegetation, water resources (use plan & monitoring system), and wildlife.	-----------	X	-----------	-----------	Unreclaimable or where posing hazard to water systems, "unique" lands.	"Intended mining and reclamation plans" are developed to apply to life of operation.	Prohibited.	Reclamation costs requested of applicant.
NORTH DAKOTA	Geology, land-use preference, minerals, soils, topography, vegetation, and water resource.	X	X	-----------	-----------	Act conveys authority to delete certain lands from surface mining.	"Extended Mining Plans" cover 10-yr. period.	-----------	Agency may request estimate of costs of reclamation.
SOUTH DAKOTA	Land use, soil, minerals, topography, wildlife, vegetation, and water resources.	-----------	X	Incompatibility with local land plans can be basis for rejection of mining request by Agency.	-----------	Unreclaimable or where conflicting with local planning, "unique" sites.	-----------	-----------	Applicant provides detailed estimate of reclamation costs.
WYOMING	Geology land use, soils, topography (USGS), vegetation, water resources (use & rights), and wildlife.	-----------	Must be > highest previous use of site (as declared by Agency).	County involvement in administration of act.	-----------	X	-----------	-----------	Socioeconomic analyses may be needed by Agency to set use.

(Continued)

TABLE 1. ...Continued...

	REQUIREMENTS FOR LAND-USE PLANNING				SPECIAL PROVISIONS				
	Resources information required	Alternative uses will be considered	End use will be declared	Role of local public planning	Minerals protected from nonmining development	Exclusion of areas from consideration for mining	Long-range or regional mine planning	Substitute lands allowed	Financial or economic analyses required
	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)
	ROCKY MOUNTAIN REGION:								
COLORADO	Climate, geology, land use, population, minerals, topography, and water resources.	Operator, in consultation with land owner and with approval of board, will select end use.	X	Act on permits and reclamation plans, and establish mining policy in general plans.	State may designate areas reserved for mining.	Permits may be denied for lands within State parks, recreation areas, unreclaimable areas, or federal lands where mining is prohibited by law.	Requirements apply to the life of the operation.	Under certain conditions operator is released from current mining plan if equal acreage of previously mined land [owned by the operator] can be reclaimed.	X
NEW MEXICO	Climate, soils, topograohy, vegetation, land use, water resources, and wildlife.	X	X	Consultation required with soil and water conservation districts.	------------	------------	------------	------------	------------
UTAH	Land use, soils vegetation and water resources.	Explore copability of land to support a variety of end uses.	X	Notified, and comments taken into advisement.	------------	------------	------------	------------	------------
ARIZONA	...No State Law...	(Federal regulations apply)							
	PACIFIC REGION:								
WASHINGTON	Land use, minerals, topography, and water resources.	------------	X	Applicant must show legality of actions with regard to local zoning.	------------	------------	------------	------------	------------
ALASKA	...No State Law...	(Federal regulations apply)							

(Continued)

Midwestern and Eastern States. Time frames have been extended from the customary five years after the initial reclamation effort to ten years for "extended mining plans" (North Dakota) and to the life of the mine (Montana and Colorado).

Substitution of previously mined, but unreclaimed (orphan), lands for lands disturbed in present mining is expressly prohibited in only two states, Montana and South Dakota. In effect, this means that mining will be allowed in these states only where reclamation has a reasonable chance to succeed. The Montana Act leaves no doubt that neither prospecting nor mining permits will be approved on lands that have "special, exceptional, critical or unique characteristics." Broadly interpreted, Wyoming's law appears to say that disturbed lands incapable of sustained grazing by wildlife and livestock at a level at least comparable with its undisturbed condition should not be mined. Other states are expected to adopt similar positions on this issue in the near future [Coal Outlook, 1976].

In general most states require some form of economic feasibility study of mining impact abatement and reclamation costs. Typically, these analyses are submitted annually to the administrative agency for review. These data are used by state agencies as a guide to setting bond limits and as a condition to granting permits for future mining.

State Enforcement Powers. All states require the issuance of permits to surface mining operators. However, the period of validity varies widely: for example, from one year in Montana to five years in Colorado to the life of the operation in Wyoming and New Mexico. Permits can be revoked for non-compliance, but few states carefully

TABLE I. ...Continued...

State	STATE ENFORCEMENT POWERS			CITIZEN PARTICIPATION				OPERATOR'S RELEASE FROM LIABILITY			
	Minimum frequency of inspections (28)	Suspension, revocation (29)	Penalties, civil and criminal (30)	Unsuitable lands review process (31)	Permit review process (32)	Bond release (33)	Enforcement (34)	Completed earthwork (35)	Successful revegetation (36)	Erosion controlled (37)	Extended liability (38)
	NORTHERN GREAT PLAINS REGION:										
MONTANA	No specific provision.	Yes	Yes	No specific provision.	Public hearings.	Public hearings, solicitation of comment.	Citizen law-suits.	Yes	Yes	No specific provision.	Yes
NORTH OAKOTA	No specific provision.	Yes	Yes (imprisonment)	No specific provision.	Public hearings, solicitation of comment.	No specific provision.	No specific provision.	Ooes not restore to A.O.C.	No capability standards.	No provision.	Limited to special cases.
SOUTH OAKOTA	No minimum.	Grounds not specified.	Yes	No specific provision.	No specific provision.	No specific provision.	No specific provision.	No specific provision.	No specific provision.	No specific provision.	No specific provision.
WYOMING	Once a year.	Yes	Yes	No specific provision.	Public hearings, solicitation of comment.	No specific provision.	No specific provision.	Ooes not restore to A.O.C.	No capability standards.	No specific provision.	5-year minimum. (Variance)
	ROCKY MOUNTAIN REGION:										
COLORADO	No minimum.	Yes	Yes	No specified provision.	Public hearings, for "good cause shown."	At L.R.B. public meetings.	No specific provision.	Does not restore to A.O.C.	Variance and substitution allowed.	No specific provision.	No minimum.
NEW MEXICO	No minimum.	Yes	Yes	"Aggrieved persons" may appeal decisions of regulatory authority and request public hearings.				No specific provision.	No specific provision.	No specific provision.	No specific provision.
UTAH	No minimum.	Yes	Yes	No specific provision.	Public hearings, for "written objections of substance."	No specific provision.	Citizen law-suits (limited standing).	No specific provision.	No specific provision.	No specific provision.	No specific provision.
ARIZONA	...No State Law... (Federal regulations apply)										
	PACIFIC REGION:										
WASHINGTON	Annually, or after operator's report.	Yes	No	No specific provision.	No specific provision.	No specific provision.	No specific provision.	Ooes not restore to A.O.C.	No capability standards.	No specific provision.	No specific provision.
ALASKA	...No State Law... (Federal regulations apply)										

specify the conditions and actual circumstances which constitute a revocation of mining privileges. Only one state (Wyoming) has a provision for placing the burden of proof on the operator.

Most states have provisions for inspecting mine sites although very few require inspections on a regularly scheduled basis. Only one state (North Dakota) uses both civil and criminal penalties for infractions of the law. By contrast, stiff fines and imprisonment are common practice in non-western coal states [Doyle, 1977]. This should not, however, be construed as a weakness in Western law as the principal deterrent to violations in the West is the permanent revocation of the "right to continue" mining.

Citizen Participation. In general, no state law offers sufficient opportunity for citizen participation. Public notice is given in the case of permit review processes, but provisions for public nomination of unsuitable lands and participation in bond release and enforcement are almost nonexistent in Western reclamation law.

Only three states (Montana, Wyoming and North Dakota) have nondiscretionary provisions which clearly require public notice and opportunity for a public hearing before permit approval. Montana is the only state in the nation that requires public notice and hearing prior to bond release. No laws examined in this study provide for citizen request of mine-site inspections, and only Montana laws open the possibility for citizen suits.

Operators Release from Liability. Montana apparently has the most stringent requirements for release from liability, although no specific provisions are given for the control of surface erosion. Most states do have (and enforce) requirements for backfilling and recontouring, revegetation, and control of erosion, but these required actions generally take the form of (promulgated) rules and regulations rather than provisions of law. Accordingly, some experts argue that for this reason (i.e., the fact that such rules and regulations are not "legally" enforceable in the courts, Western reclamation standards are actually weaker than they appear on the surface [Doyle, 1977].

One of the more controversial issues in the West stems from a disagreement as to what constitutes "successful" reclamation. In order to insure that reclamation is successful over time, as specified in Montana law (and in the "intent of the law" of other Western states), it is important that the operator be held accountable for a period of time following revegetation. In Montana the waiting period may be indefinite, while in other states the period of liability may extend beyond five years (Wyoming), be limited by special conditions (drought, in in North Dakota), or left up to the discretion of the administrator who can extend the period for as long as seems appropriate (New Mexico, Utah and Colorado).

The Surface Mining Control and Reclamation Act of 1977 (PL 95-87) 1/

Two major objectives to this new Federal legislation are to reclaim abandoned mine lands and to control the environmental impacts of potential or ongoing surface coal mining. These objectives are to be implemented primarily through Titles IV and V of the Act, respectively.

Title IV establishes a trust fund and procedures for the surface reclamation of abandoned mine sites and the abatement of certain adverse offsite effects. Abandoned surface and underground mines are both covered, the latter through provision for abatement of adverse surface effects. Revenues for the fund are to come from a Federal reclamation fee of 35 cents a ton of coal produced by surface mining, and 15 cents a ton by underground mining (or ten percent *ad valorem*, coal at minemouth, whichever is less), although for lignite the amount is the lesser of 10 cents or 2 percent *ad valorem*.

Expenditures from this trust fund are to be divided for special programs in approximately the following shares: 50 percent to States and Indian Reservations; 20 percent to the Secretary of Interior; 20 percent to the Secretary of Agriculture; and 10 percent to operators of small coal mines ($10 million maximum funding) for certain expenses associated with Title V mining permits.

Based on the above distribution of the Fund's revenues, several programs to achieve reclamation of abandoned mine lands are authorized by the Act. Among them are programs to be prepared by the States, Rural Lands Program (cost sharing and technical assistance for private landowners)

1/ Prepared by Joseph R. Barse, Agricultural Economist, Natural Resource Economics Division, ERS, USDA.

to be administered by USDA, the Filling Voids and Sealing Tunnels Program to be administered by Interior, and the Abandoned Mine Land Acquisition and Reclamation Program administered by the States or Interior.

Title V, the heart of the Act, authorizes Federal surface mining controls. A requirement for mining permits for surface coal mine operation is established, along with procedures to apply for, grant, deny, and revise these permits. Bonding, hearings, and appeals are also covered. Any permit issued is to require that the mine operator meet the new statutory reclamation and environmental performance standards and comply with additional regulations to be promulgated. These performance standards cover, among other items, restoration of capability for original land use, restoration of original land contour (with exceptions), stabilization of surface areas, replacement of topsoil, restoration of mined prime farmlands, water impoundments, augering operations, hydrologic balance, mine spoil and waste disposal, blasting, access roads, revegetation, slide or erosion barriers, surface mining on steep slopes, and proximity to underground mines. Inspections, monitoring, enforcement, and penalties are also authorized, as well as procedures for releasing performance bonds.

The designation of certain areas as unsuitable for surface coal mining is authorized, as well as the methods of designation and the criteria. Mining permits are to be denied for the designated unsuitable areas. Permit applications will also be denied if the regulatory authority rules that: (1) There would be "Material damage to hydrologic balance outside (the potential) permit area"; (2) The proposed mining operation, if west of the 100th meridian (slightly east of Bismarck, ND) would interrupt, discontinue or preclude farming on alluvial valley floors that are irrigated or naturally sub-irrigated or would damage the quantity or quality of water in surface or underground systems which supply these floors; (3) Prime farmland which would be included in proposed mining areas could not be restored within a reasonable time "to equivalent or higher levels of yield as non-mined prime farmlands in the surrounding areas under equivalent levels of management" or could not be restored to meet the post-mined soil reconstruction standards specified in the Act.

The Act also requires that permits to conduct surface operations accompanying underground mining be obtained by mine operators. This permit requirement aims to control specific surface effects of underground mining, such as subsidence and acid mine drainage. Sealing of unneeded openings, runoff controls, regrading and revegetation of mine tailings are among the control measures necessary to qualify for surface operations permits. In effect, regulating the surface aspects of underground mining brings all deep mines of significant scale, as well as surface mines, under some degree of control by the Act.

In addition, the Act mandates the Secretary of Interior to implement a program for reclamation of surface mined areas of leased Federal lands. The performance standards of the Act and all subsequent reclamation programs for mining on Federal land will be incorporated into the leases.

The relationship between State laws and regulations on mined land reclamation and the new Federal Law is also addressed by Title V. A State law will prevail over the Federal law only if it "provides for more stringent land use and environmental controls and regulations of surface coal mining and reclamation operation than do the provisions of the Act ...". The Secretary of Interior must specify which State laws and regulations are deemed inconsistent with (less stringent than) the Federal Act and which are therefore to be superseded by the Act and the Federal regulations.

In general, the performance standards of the Federal Act are similar to those of many State reclamation laws. However, the performance standards of Montana, North and South Dakota, Wyoming, and Colorado could well be deemed more stringent than those of the Federal Act, and thus might prevail over the latter. By contrast, reclamation laws and standards of other Western States seem less stringent than the new Federal Law and could well be superseded by it.

Other Regulatory Agencies and Provisions

In addition to those already cited there are numerous federal, state and local laws and ordinances which must be complied with in the surface mining of coal. Four major federal laws--the Clean Air Act Amendments, the 1972 Water Pollution Control Act Amendments, the 1969 Coal Mine Health and Safety Act Amendments, and the Mineral Leasing Act of 1920--all provide for regulatory authority which extend to all parts of the country [Energy and Environmental Analysis, Inc., 1976]. Unlike other federal laws, the reclamation regulations (embodied in the Mineral Leasing Act) do not apply to all mining operations; rather they apply only to the reclamation of lands under federal coal leases, including leased land on Indian reservations.

Numerous local laws and ordinances may also apply to the integrated set of mining activities over time [Bisselle *et al*., 1975, and Leathers and Juers, 1976]. Mining operators are typically asked to comply with a wide array of local regulations and ordinances which can influence reclamation and mining practices as well as other land use activities at the mine site. Examples of local ordinances and regulations that typically apply to strip mining operations are reported in table 2. The nature and extent of such "controls" will vary by locale, but the trend in recent years suggests more rather than less influence on the mining industry in the future.

C. SUMMARY AND IMPLICATIONS

Recent changes in the institutional setting--the social environment within which modern surface mining and reclamation must take place--have created a considerable amount of uncertainty and mistrust among the concerned parties (the mining industry, state and federal agencies, and other interested groups). This Chapter has attempted a brief examination of the operating rules and controls placed on the mining industry in the Western United States, a region that has perhaps experienced more rapid change than any other part of the country. It is hoped that this exercise has helped to explain some of the reasons which underlie these uncertainties and has imparted an appreciation for the difficulties encountered in attempting to legislate common sense.

Several general observations can be made with regard to the nature and effectiveness of Western reclamation laws and institutions. First, the fundamental basis for all state mined-area reclamation programs seems to be the attainment of two interrelated objectives: (1) the successful transformation of surface mined lands to a planned productive (and long-term) use, and (2) the control (and/or avoidance) of deleterious side-effects stemming from mining activity. Although there is some disagreement in how these objectives can best be achieved, the Western states have as a whole adopted a "learn-by-doing" philosophy in

TABLE 2. AN EXAMPLE OF STATE AND LOCAL CONTROLS THAT COULD APPLY TO A TYPICAL SURFACE MINE IN THE WESTERN REGION.

TIME PERIOD AND ACTIVITY	POSSIBLE REQUIRED CONTROLS			
	Local Land Use	State Reclamation Requirements	Water, Air, Noise Pollution	Others
A. PRE-MINING (YEARS 0-4):				
Existing land use	X	--	X	----------
Prospecting the area	--	X	--	----------
Mineral and economic evaluations	--	X	--	----------
Acquisition of rights	--	X	--	State water rights.
Surveying & design of mine	--	X	--	----------
Natural resources studies	--	X	X	----------
Reclamation planning	--	X	--	----------
End land-use planning	X	X	--	----------
Costs analyses	X	X	X	State and local environmental controls.
Obtaining mine permit[2/]	X	X	--	Waste discharge permits.
Constructing roads and buildings[2/]	X	X	X	State location of development.
Obtaining utilities	X	--	--	State utilities regulation.
Drainage and erosion control[2/]	--	X	X	State water board.
Fencing and screening[2/]	X	X	--	State fish and game.
Environmental monitoring[2/]	--	X	X	----------
B. JOINT MINING AND RECLAMATION (YEARS 4-30):[2/]				
Removal and segregation of soils	X	X	--	Local soil & water conservation.
Disposal of debris	X	X	X	Sanitary land fills.
Drilling and blasing	X	X	X	State permit.
Extracting and hauling minerals	X	X	X	State severance taxes.
Filling and grading	X	X	X	----------
Reducing pitwalls or highwalls	X	X	X	----------
Burying toxic materials	X	X	X	----------
Revegetation	--	X	--	----------
C. POST-MINING (YEARS 4-36):				
Vegetation survival studies[2/]	--	X	--	State agriculture.
Pest and weed control[2/]	X	X	--	State agriculture.
Land capability studies	X	X	--	State agriculture.
Divesting ownership or rights	X	--	--	Official acceptance of lakes and roads.
Water quality performance	X	X	X	State agriculture.
Decommissioning mine (dismantling, demolishing, etc.)	X	X	--	State mine abandonment laws
Established end use	X	--	X	----------
Recovery of bonds	X	X	--	----------

SOURCE: Adapted from Imhoff, et al., [1976].

1/ Does not include controls pertaining to mine safety.

2/ A process that tends to be maintained or repeated, as necessary, throughout much of the life of the mine.

writing law and promulgating rules and regulations. Further, program administrators evidently exercise considerable discretion in enforcing particular standards. Often it is the interpretation of the Act rather than the Act itself that becomes the basis for reclamation standards and procedures. However, there is little evidence to suggest that "liberal interpretations" of the law will ever (purposefully) compromise these two important objectives.

Second, some standards common to most state programs appear contradictory in terms of post-mining land use options. For example, "restore to the original contour...replace topsoil...restore to native species..." can place limitations on the consideration of certain alternative uses of the disturbed site, i.e., recreation, residential, wildlife habitat, landfill, badlands, and perhaps others. Only a few states specifically require that alternative end-uses (uses other than the premining use) be considered in the planning phase. This is an especially critical constraint to local land-use planning, in that opportunities for diversified and creative development of the land and related resources are not encouraged within the context of local needs. Until significant public involvement occurs in the planning phase, especially at the local level, this shortcoming will not be resolved easily.

Third, the extent of community involvement in premining planning currently ranges from passive to active participation in the licensing and bonding processes and review of activities once they are underway. However, South Dakota law is perhaps illustrative of the probable trend toward more local input in premining planning:..."No permit shall be issued . . . (where) surface mining would be incompatible with . . . local plans for land development..." [Imhoff et al., 1976].

Fourth, as long as there is sufficient economic incentive to mine coal, rock and other minerals in the arid Western region, mining operators will comply with the state reclamation legislation. To fail to do this would mean forfeiture of all future rights to mine. Inasmuch as renewals of mining permits are 'tied' to successful reclamation efforts, it is incumbent upon mine operators to pursue reclamation planning just as carefully as other mining procedures. Variances which allow a waiver of this liability are very limited at the state level.

Fifth, the influence that the federal reclamation legislation will have on the mining industry will not be known for some time. There is some concern that many state regulations need bolstering (although some state laws are fairly strict in all areas except mine safety provisions and therefore would supersede the federal standards). However, some state regulations might prove to be "too tough", making legally-acceptable reclamation of lands in certain areas (primarily the Rocky Mountain southwest) highly precarious and unlikely. Then, timely development of federally owned coal in a time of critical national need might be judged too slow, leading to a reevaluation of the relationships between State and Federal legislation.

The monetary implications of reclamation law in terms of the additional costs to the mining industry (hence, to the users of electrical power) will be the focus of the chapters to follow.

Chapter III

THE ENGINEERING COMPONENT OF SURFACE MINE RECLAMATION

A. INTRODUCTION

Surface mining, in contrast to underground mining, involves the removal of all earth materials that overlie the mineral or ore body to be mined. Consequently, the potential for massive disturbance of land surfaces is much greater with surface mining than with conventional underground mining methods. Because of the advance made in earth-moving technology in recent years, surface mining in general, and strip mining in particular, account for an increasing proportion of the Nation's mined mineral resources. In a recent report by the U.S. Bureau of Mines, Paone and others [1974] point out that 86 percent of all crude ore (sand and gravel, phosphate, clay, stone, iron, copper, coal, etc.) mined in 1971 was obtained with surface methods.

Earthworks--the stripping, recontouring and hauling operations--are formidable engineering tasks in surface mining and land reclamation. In this chapter the engineering requirements for reclaiming surface mined lands are empirically examined. Present mines, and mines that will be operating in 1980, are identified and described. Earthwork requirements (and costs), consistent with the reclamation laws of each state, are estimated with the use of detailed empirical characterizations of mine sites, operating conditions and methods. On the basis of these estimates, major differences between mines, coal production areas and states are evaluated in a comparative analysis of the Western region.

The analysis is reported in three main sections. In section B, coal recovery methods and alternative technologies are reviewed in order to identify the nature and range of earthwork handling requirements in surface mining. Section C describes actual strip mining operations in the Western region, and compares site-specific cost estimates for the recontouring and topsoiling phases of reclamation. The summary section (part D) reviews the findings and limitations of the analysis.

B. THE SENSITIVITY OF EARTHWORK REQUIREMENTS TO MINING METHOD AND TECHNOLOGY

In the large-scale surface mining of coal the earthwork procedures comprise the overwhelming proportion of operating costs [Katell and Hemingway, 1974]. Similarly, overburden contouring and topsoiling (hauling, grading and leveling) also contribute substantially to the cost of reclaiming surface mined land [Skelly and Loy, 1975 and Watts, 1975]. This is true because, to a large degree, the stripping technology used determines the physical configuration and condition of the spoil piles to be reclaimed. Depending upon the extraction method and the type and size of equipment used to "create" the spoils, overburden handling costs in the reclamation effort can be greatly affected [Engineering Mining Journal, 1973].

Surface mining broadly covers any process of removing earth, rock and other strata in recovering the underlying mineral or fossil fuel deposit. Basic mined-area reclamation techniques, emphasizing earthworks handling requirements and technology, are briefly reviewed in this section. An excellent, detailed discussion of these topics is reported elsewhere [Grim and Hill, 1974 and Skelly and Loy, 1975].

Overview of the Surface Mining Process

In general, the first operational phase in coal mine development is exploration. In surface mining this usually entails drilling core samples to establish the extent of the coal deposit, its quality and accessibility and the mining sequence to be followed at the site. Improperly plugged drill holes may allow water under artesian pressure to escape to the surface, or if unreclaimed, present a moonscape appearance [National Academy of Sciences, 1974]. Although considerable surface disturbance can be caused in the drilling process, the greatest potential that exploration activities hold for impacting the land lies in extensive off-road vehicular travel.

Under present reclamation law, the first major earthmoving activity at a surface mine involves the removal and stockpiling of topsoil. In the Western region this is typically accomplished with the use of heavy-duty tractors, scrapers, or other conventional earthmoving equipment. Where diversion dams and ditches are required to keep surface runoff from reaching the pit area, these structures are built prior to any further earthwork activity.

The next operation is the removal of all overlying soil and rock to expose the coal deposit. If this "overburden" material is indurated (highly consolidated), blasting is normally required to facilitate its removal. The drill hole pattern and blasting charges (ammonium nitrate and fuel oil) are gauged according to the hardness of the material and the degree of fragmentation desired. Highly fragmented material (powder) often can lead to problems with spoil bank subsidence, is sometimes more difficult to revegetate, and can contribute to severe soil erosion [Dalsted and Leistritz, 1973]. Where overburden is relatively soft and does not require blasting, removal can be accomplished with conventional scrapers and dozers. However, at most mines in the West large shovels and draglines are used almost exclusively for overburden stripping.

The removal of coal is typically accomplished with smaller electric shovels. Coal is loaded into large trucks and hauled to a central storage point for preparation (crushing) and/or loading on unit trains for transportation to steam-electric power plants. Front-end loaders are also commonly used to load coal, and are perhaps the best method of handling some soft, Western coals which cannot support the weight of heavy shovels.

The remaining earthwork operations comprise the major engineering phases of strip mine reclamation: backfilling, recontouring and replacement of topsoil. Depending upon the surface mining method used (whether contour or area stripping techniques), the types and sizes of earth-moving equipment, and the physical conditions of the site itself, the earthwork handling requirements will vary widely. (The influence of these factors is discussed in some detail in the following section.)

In the West backfilling also includes the reduction of the highwall which is left by the final mining cut, whereas in some Midwestern states the final cut is allowed to remain as a catchment or water impoundment [Imhoff, et al., 1976]. Seeding is usually done with conventional agricultural equipment, and fencing of revegetated areas is commonly practiced to limit grazing for a period of one or two years.

The above sequence of activities is repeated many times throughout the life of the mine. Typically, reclamation operations are phased with regular mining activities to facilitate reseeding at appropriate times during the year. Careful monitoring of selected environmental factors (eg., air, water, wildlife, vegetation) continues throughout the life of the mine and even for a period after the actual mine closing.

Western Surface Mining Methods

There are several different surface mining methods in use in Western region coal fields. The most common of these are strip and open pit mining. Each method presents a different type of materials handling problem for the mine operator.

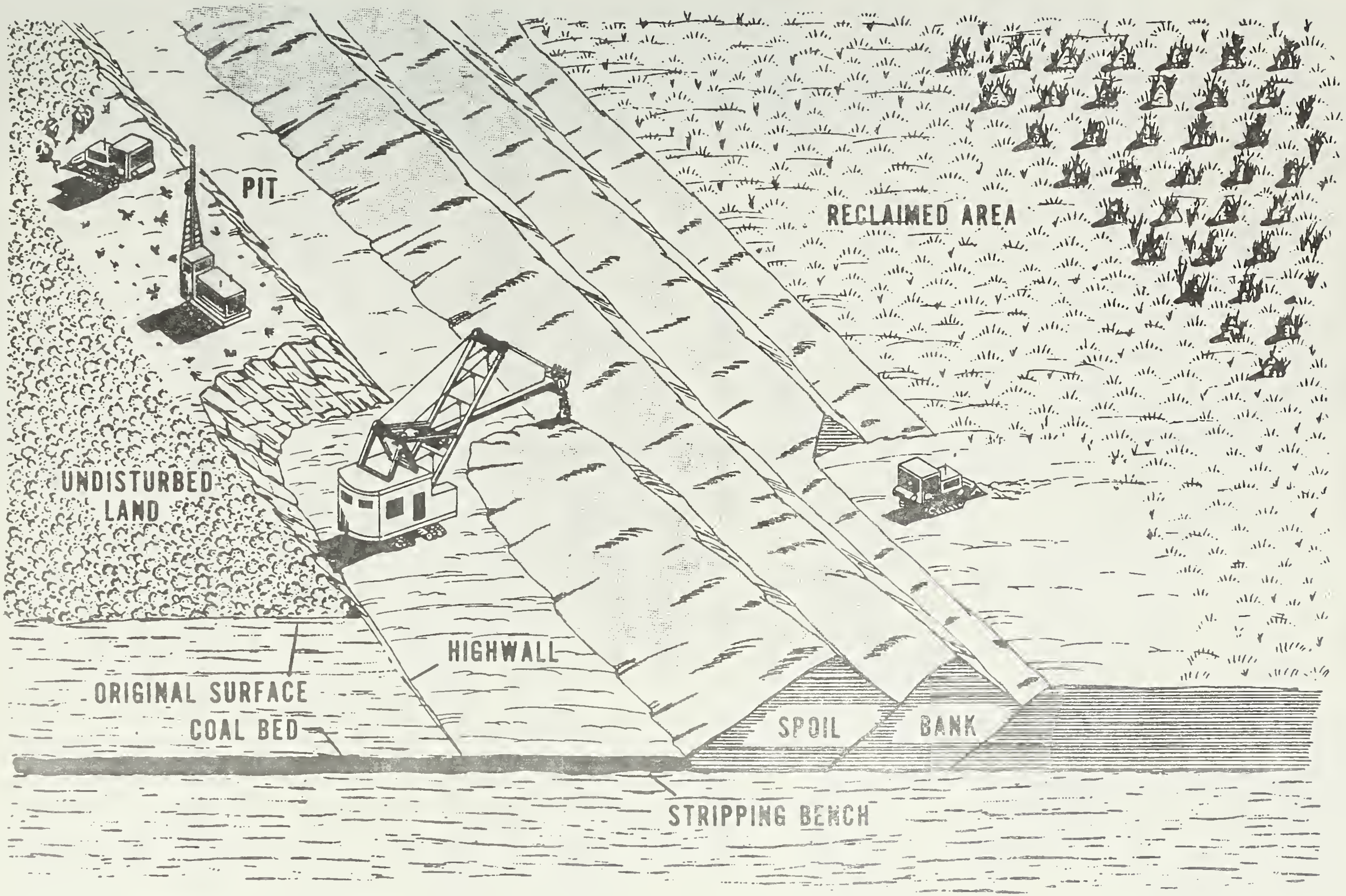
Strip Mining

The methods of strip mining are of two general types: area mining and contour mining. Area mining is practiced in relatively flat terrain (slopes of 14 degrees or less), and it involves making a series of narrow, parallel cuts. Once the operation has begun, overburden from the new cut is placed in an adjacent, previous cut which has already had the coal removed. The series of parallel cuts progresses across the site until the depth of overburden and/or coal quality make mining uneconomic. If left ungraded, the mined area resembles a large plowed field (figure 1).

Leveling of the spoil banks typically proceeds concurrently with coal extraction, and involves the use of heavy earth moving equipment (dozers and blades) to level the banks to grades prescribed by State law (figure 2). In instances where overburden materials are less consolidated (i.e., soft sandstones and shales as opposed to bedrock), blasting is an expensive method of reducing the slope of highwalls. Small draglines (when available) have also been used to level spoilbanks

Source: Grim and Hill (1974).

Figure 1. Aerial view of area mining.



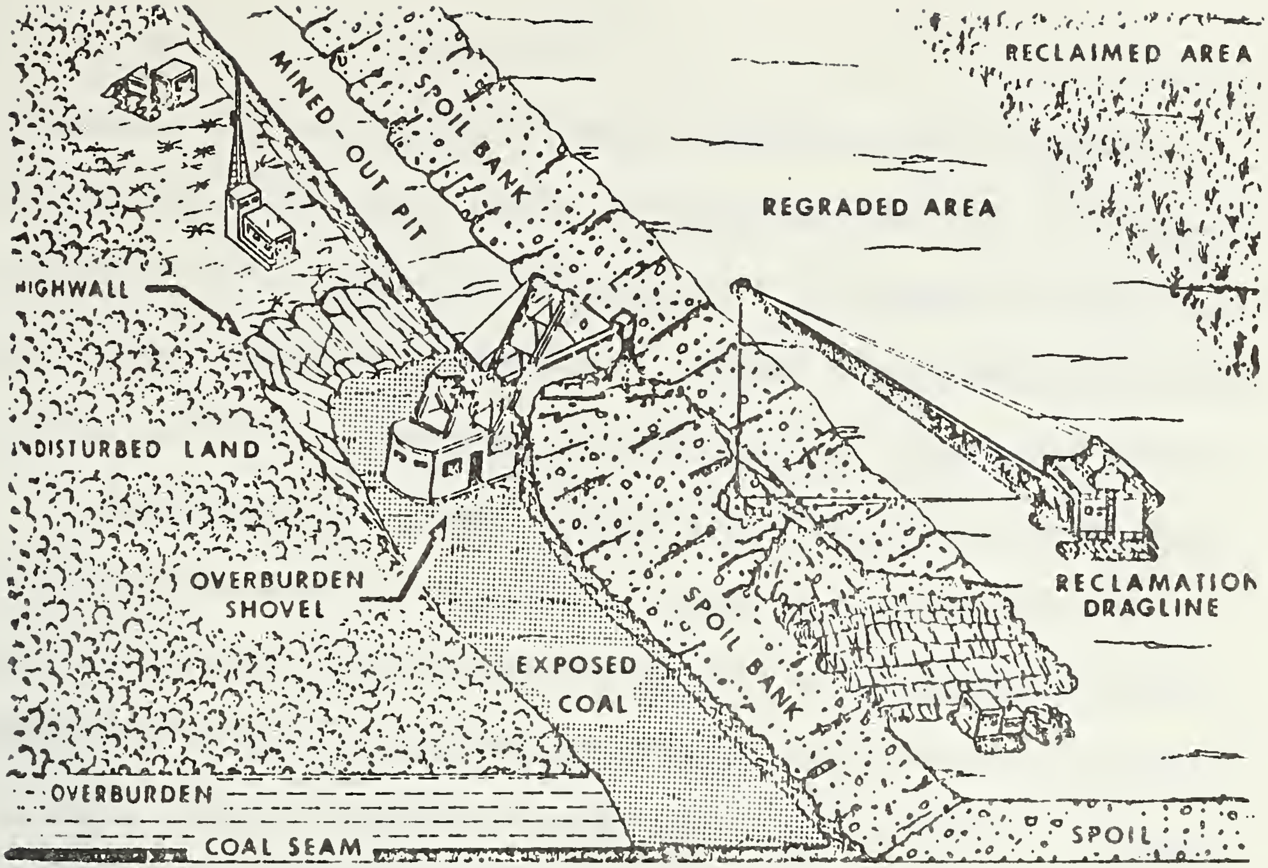
Source: Grim and Hill (1974).

Figure 2. Area stripping with concurrent reclamation.

at considerably lower per unit costs than bulldozers (figure 3). Area stripping is the most widely used recovery method in the Western region.

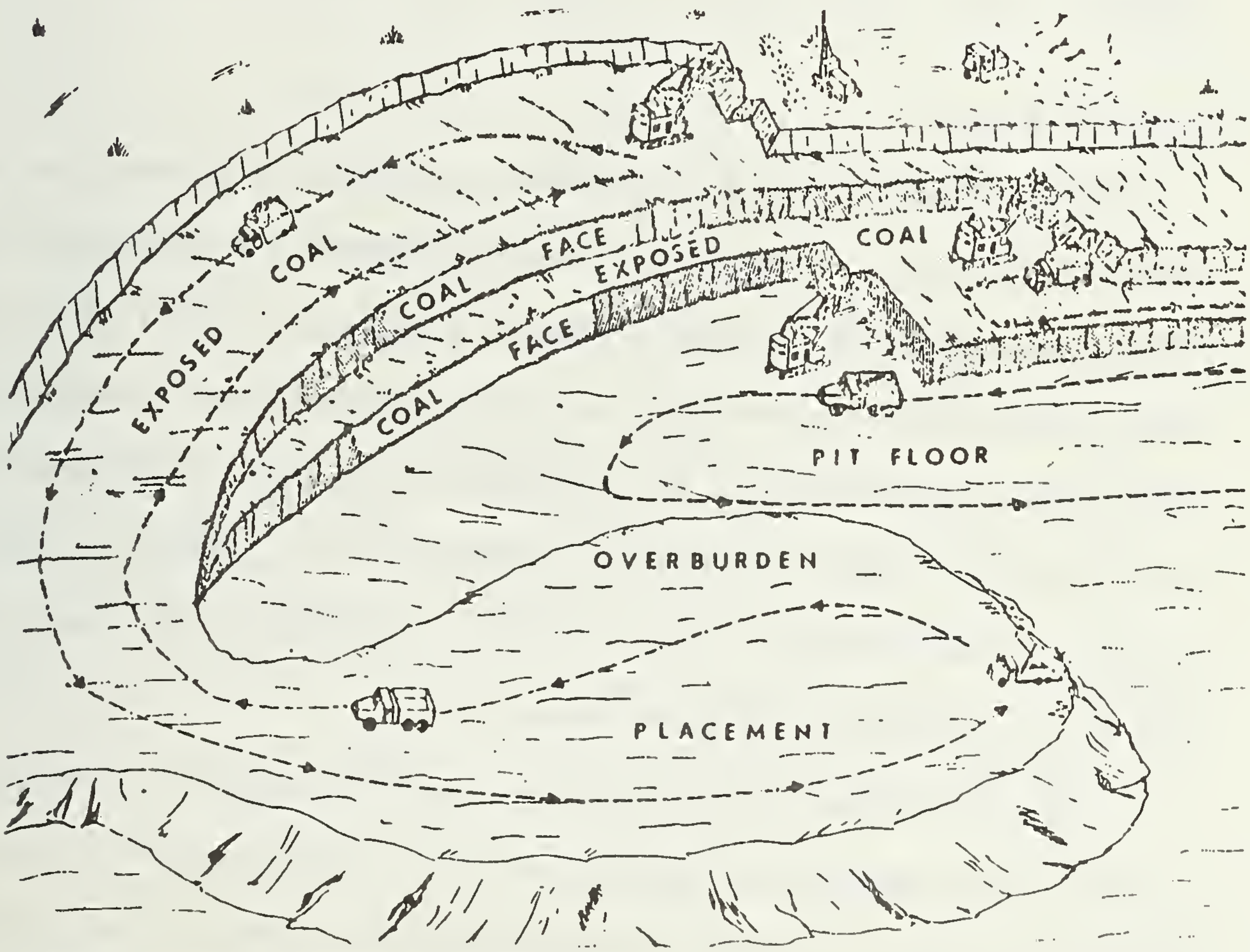
Contour mining is typically required on steeper terrain. Although this technique is more common to such areas as Appalachia, contour methods are currently being employed at several large mines in southwestern Wyoming (Sorenson and Elkol mines) and in northwestern Colorado (Energy, Edna and Williams Fork mines). This method is used to extract coal that crops out along the sides of steep hills, where the operation can follow the coal seam around the hillside. It generally involves cutting a bench into the mountain, often creating a highwall several hundred feet high.

Handling overburden in contour stripping is a more challenging engineering task in comparison to area stripping, primarily because of the limited working space. Historically, contour stripping involved casting the overburden down the hill. Under present reclamation requirements, such practices are prohibited in the Western states. Mining a steep contour in the West usually requires the shovel-and-truck method of overburden removal and backfilling. Depending on the amount of backfilling required, the overburden can be replaced and the spoils regraded to approximately the original contour--"contour backfilling." Alternatively, only the highwall may be covered (at considerably lower cost) leaving a narrow terrace on the mountainside as in "terrace backfilling." Modern practice emphasizes replacing overburden immediately after coal removal. In one such practice, known as "modified box cut," spoils from successive contour cuts are used to fill the previous cuts as in area stripping.



SOURCE: Skelly and Loy [1975].

Figure 3. Spoil Bank Recontouring with a Pull-Back Dragline



SOURCE: Skelly and Loy [1975].

Figure 4. An Illustration of Open Pit Coal Mining Procedures

Area and contour methods, used in conjunction, are sometimes refered to as "mountaintop mining." In this case the entire top (or a portion) of the mountain is removed in sequential cuts and replaced after the coal seam is removed. Grading the spoil typically creates a flatter appearance than the original topography. For this reason, mountaintop mining is discouraged in several eastern states.

The conservation of topsoil in area and contour stripping proceeds in essentially the same sequence of operations. Topsoil (or a particular strata of overburden material deemed most appropriate for plant growth), ranging in depth from several inches to several feet, is stripped off with the use of self powered scrapers and is stockpiled adjacent to the open cut. Recontouring and redistributing topsoil generally occur concurrently in both types of strip mining.

Open Pit Mining

Used primarily in the extraction of metals and mineral ore bodies, open pit mining is economically feasible where the extractable resource is present in huge quantities. Open pit mines of 1,000 feet in depth and a "mile-wide" can be found in several of the Rocky Mountain States. Mining coal by this method is limited to very thick, level seams under fairly shallow overburden materials (figure 4). Examples of such operations can be found in the Gillette area (Wyodak and Amax mines) and north of Sheridan (Big Horn mine).

Open pit mining usually continues uninterrupted for many years and produces large amounts of waste material. Large acreages of land (often hundreds of acres per mine) are required for overburden and topsoil stockpiling. Because of the expense of moving such large quantities of soil and rock, it is unlikely that some of the larger pits will ever be refilled. Accordingly, most operators (including the Big Horn mine) use the overburden to backfill lowlying areas or build terraces adjacent to the mined area. These are graded and revegetated concurrently with mining and, in some cases, in "lieu of" reclaiming the pit itself.

Alternative Technologies

Howland [1976] has shown that the trend in the mining industry to adopt larger earth-moving equipment, specifically draglines, has had a marked effect on spoil leveling requirements. Draglines tend to pile overburden in long, steep banks with ridge lines 200 or more feet apart (figure 2). Leveling such banks with conventional tractor-dozers is very costly, and improved equipment (larger, pull-type blades) will not be readily available to the industry for some time. An alternative procedure, the shovel and truck method, allows removal and replacement of overburden in one operation. Although being a less capital intensive means, truck and shovel operations require additional labor and overhead. Both methods are comparable on a cost-effectiveness basis [Skelly and Loy, 1975 and Stefanko, et al., 1973].

Marcus [1976] suggests that the evolution of technology in the mining industry may turn away from larger machines to more longer-lasting, less expensive and more versatile machinery. Expected are changes to reduce operating costs by decreasing maintenance requirements, down time, and supply bottlenecks. Because the present lead time for delivery of draglines is five years or more, the recent trend to truck and shovel methods can be expected to continue in the Western strip mining industry.

Conceptual Difficulties in Cost Separation

Earthwork procedures, which tend to be mine specific, present a problem in separating reclamation from normal mining practice. Depending on mining method, the types and sizes of stripping equipment used, and the particular engineering requirements of a given site configuration, production and reclamation procedures and costs are often jointly determined and therefore difficult to identify as separate activities.

This is clearly demonstrated in the case of backfilling. For example, when a dragline is used in area stripping the overburden, material is replaced in the mined-out area as mining continues across the site. Thus, with the exception of the first and last mining passes, the backfilling operation occurs simultaneously with stripping, and consequently a large proportion of the backfilling cost is actually "production" rather than reclamation cost. Conversely, with shovel and truck methods the backfilling operation is a genuine reclamation activity, since the overburden material is deliberately returned to the pit area rather than to an adjacent dump site.

Further, with the shovel and truck method overburden is replaced in a leveled configuration and thus recontouring and backfilling are accomplished jointly. In contrast, draglines and large shovels produce steep spoil banks that require extensive leveling and a definite recontour phase in reclaiming lands mined with this technique of surface stripping.

Other examples of this problem include the difficulty of separating premining planning activities into production and reclamation components, reclamation's share of overhead and unallocated costs, etc. These aspects will be taken up in appropriate sections of the balance of this report.

C. ESTIMATING THE COSTS OF MATERIALS HANDLING

A sound, comparative analysis of the 'engineering' requirements and costs of reclamation requires a considerable amount of empirical data. Specific information might include the types and sizes of equipment, operating efficiencies and costs, physical characteristics of the overburden materials and coal seams, beginning and ending slopes, size and configuration of area to be mined, average depth of topsoil, and many other factors.

Watts [1975] has shown, for example, that differences in the depth of overburden and the percent slope of the recontoured spoil banks (and highwall) have marked effects on per acre reclamation costs. Flat slopes (0-5%), having less erosion potential and (therefore) being better prospects for revegetation, can be achieved at relatively nominal incremental increases in per acre costs when overburden is comparatively shallow. As the depth increases beyond about 50 feet, the handling costs increase more than proportionately. And, even for relatively shallow overburdens, the cost of recontouring the spoils can be the most expensive operation in the reclamation process. The most reliable source of such information would be the mining companies themselves, but, due to the competitive nature of the industry, accurate characterizations of overburden depths, coal thickness and mining costs are not routinely disclosed to the public. Often, the only available information comes from "synthetic" budgeting models which simulate "representative" mining practices [Otte and Boehlje, 1975; Bitler and Evans, 1975; and U.S. Bureau of Mines, 1975].

The principal sources of information used in the present study were: (1) annually updated mining plans (submitted by the mining companies in compliance with state law) which are maintained in open files by the various state agencies charged with reclamation enforcement; (2) published and open file reports of other concerned state agencies (Bureau of Mines, Geological Survey, Department of Natural Resources, etc.) involved with coal development planning, enforcement, monitoring, and research; (3) published data by the mining industry; (4) several publicly funded studies and surveys; and (5) consultations with a number of experts in the fields of mining, geology and reclamation. An attempt was also made to secure corroborative evidence through personal interviews with nine mining operators in the study area [Leathers, 1977]. For the most part, the limited data collected from direct sampling was not sufficient to warrant generalizations at the regional level.

Description of Mines

All known stripping operations in the Western Region are described by name, operator, location, coal field and seams mined, and annual output in table 3. In 1976 some 52 individual mines were operated commercially in the region, accounting for an annual output of approximately 104 million tons. Assuming the announced mining plans through 1980 are implemented on schedule, approximately 87 mines will be producing 360 million tons at the end of that time frame. During this period, average annual output per mine will increase from 2 million to over 4 million tons per year.

On a regional basis, the specific coal production areas likely to experience the greatest increase in surface mining activity are found

TABLE 3. IDENTIFICATION AND SELECTED DESCRIPTIVE CHARACTERISTICS OF MAJOR SURFACE COAL MINING OPERATIONS IN THE WESTERN REGION.

State and Coal Production Area[1/]		Mine: Name	Mine: Year Open	Mine: Operator	County	Coal Field	Seam(s) Mined	Annual Production (MTY)[2/] 1976	Annual Production (MTY)[2/] 1980
	NORTHERN GREAT PLAINS REGION:								
Montana,	MT1 ... No strip mine operations scheduled through 1980 ...								
	MT2	Savage		Knife River Coal Co.	Richland	Breezy Flat	Pust	1.2	2.2
	MT3	Circle West	1978	Oryer Bros.	McCone	Weldon-Timber Cr.	"S"		3.0
	MT4	Oecker #1		Oecker Coal Co.[3/]	Bighorn	Oecker	Oietz #1, 2	10.2	7.5
	MT4	Absaloka		Westmoreland & Co.[4/]	Bighorn	Sarpy Cr.	Stray #1, 2	4.0	10.0
	MT4	Big Sky		Peabody Coal Co.	Rosebud	Colstrip	Rosebud; McKay	2.8	5.5
	MT4	Rosebud		Western Energy[5/]	Rosebud	Colstrip	Rosebud	13.1	19.1
	MT4	Oecker N.	1979	Oecker Coal Co.	Bighorn	Oecker	Dietz		2.0
	MT4	Oecker W.	1980	Oecker Coal Co.	Bighorn	Oecker	Oietz		5.0
	MT4	Youngs Cr.	1978	Shell Oil Co.	Bighorn	n.a.	n.a.		4.0
	MT4	Tanner Cr.	1980	Shell Oil Co.	Bighorn	n.a.	n.a.		6.0
	Annual Production, MT4:							30.1	59.1
Total Annual Production, Montana:								31.3	64.3
North Dakota,	ND1	Velva		Consolidated Coal Co.[6/]	Ward-McHenry	Lignite	Coteau	1.1	2.5
	ND1	Noonan		Baukol-Noonan, Inc.	Burke	Lignite	Noonan	1.5	2.0
	Annual Production, ND1:							2.6	4.5
	ND2	Center		Baukol-Noonan, Inc.	Oliver	Lignite	Hagel	3.0	5.0
	ND2	Glenharold		Consolidated Coal Co.	Oliver-Mercer	Lignite	Lignite #2, 3	3.8	3.8
	ND2	Beulah		Knife River Coal Co.	Mercer	Lignite	Beulah-Zap	1.8	3.8
	ND2	Indian Head		North American Coal, Inc.	Mercer	Lignite	Beulah-Zap	1.3	1.5
	ND2	Falkirk (NAC, Inc.)	1978	North American Coal, Inc.	Mercer	Lignite	Beulah-Zap		5.0
	ND2	?	1980	North American Coal, Inc.	Mercer	Lignite	Beulah-Zap		5.0
	ND2	Falkirk	1978	Falkirk Mining Co.	Mercer	Lignite	Beulah-Zap		5.5
	Annual Production, ND2:							9.9	29.6

(Continued)

TABLE 3. ...Continued...

State and Coal Production Area 1/	Mine: Name	Mine: Year Open	Mine: Operator	County	Coal Field	Seam(s) Mined	Annual Production (MTY)2/ 1976	Annual Production (MTY)2/ 1980
North Dakota (continued)								
ND3	Gascoyne		Knife River Coal Co.	Bowman	Lignite	"No. 1"	2.7	6.0
ND3	Lehigh		Husky Industries	Stark	Lignite	Lehigh	.2	.5
ND3	Heart Butte	1980	Peabody Coal Co.	Grant	Lignite	n.a.		2.0
Annual Production, ND3:							2.9	8.5
Total Annual Production, North Dakota:							15.4	42.6
South Dakota, SD1 ... No strip mine operations scheduled through 1980 ...								
Wyoming, WY1	Bighorn		Bighorn Coal Co.7/	Sheridan	Sheridan	Monarch,Dietz#2,3	1.0	1.5
WY1	PSO#1		Public Service of Okla.	Sheridan	Sheridan	Anderson, Dietz	.3	.5
Annual Production, WY1:							1.3	2.0
WY2	Belle Ayr S.		Amax Coal Co.	Campbell	Powder R.	Wyodak-Anderson	5.0	12.5
WY2	Wyodak N.S.		Wyodak Resources Dev., Inc.8/	Campbell	Powder R.	Wyodak-Anderson	.7	5.0
WY2	N. Rawhide	1977	Carter Mining Co.9/	Campbell	Powder R.	Wyodak-Anderson		8.5
WY2	Coballo	1977	Carter Mining Co.	Campbell	Powder R.	Wyodak-Anderson		3.5
WY2	?	1977	Falcon Coal, Inc.	Campbell	Powder R.	Felix		1.0
WY2	Cordero	1977	Sunco Energy Dev. Co.	Campbell	Powder R.	Wyodak-Anderson		12.0
WY2	Eagle Butte	1977	Amax Coal Co.	Campbell	Powder R.	Wyodak-Anderson		12.0
WY2	Black Thunder	1978	Atlantic Richfield	Campbell	Powder R.	Wyodak-Anderson		10.0
WY2	Coal Cr.	1978	Atlantic Richfield	Campbell	Powder R.	Wyodak-Anderson		7.5
WY2	Thunderbird	1978	El Paso Nat. Gas	Campbell-Johnson	Powder R.	Felix, Ulm		4.0
WY2	E. Gillette #16	1978	Kerr-McGee Coal Co.	Campbell	Powder R.	Wyodak-Anderson		4.0
WY2	Jacobs Ranch	1978	Kerr-McGee Coal Co.	Campbell	Powder R.	Wyodak-Anderson		12.5
WY2	?	1978	Texaco, Inc.	Johnson	Buffalo	Healy		8.5
WY2	E. Gillette	1979	Texaco, Inc.	Campbell	Powder R.	Wyodak-Anderson		4.5
WY2	?	1979	Mobile Oil Co.	Campbell	Powder R.	Wyodak-Anderson		5.0

(Continued)

TABLE 3. ...Continued...

State and Coal Production Area 1/	Mine: Name	Year Open	Operator	County	Coal Field	Seam(s) Mined	Annual Production (MTY) 2/ 1976	1980
Wyoming (continued)								
WY2	Rochelle	1978	Rochelle Coal Co. 10/	Campbell	Powder R.	Wyodak-Anderson		8.0
WY2	Buckskin	1979	Shell Oil Co.	Campbell	Powder R.	Wyodak-Anderson		4.0
WY2	Powder River	1980	Pittsburg-Midway	Campbell	Powder R.	Wyodak-Anderson		15.0
Annual Production, WY2:							5.7	138.5
WY3	Seminoe #1		Arch Mineral, Inc.	Carbon	Hanna	Bedo #24, 25	3.0	3.0
WY3	Seminoe #2		Arch Mineral, Inc.	Carbon	Hanna	Hanna #2	2.5	2.2
WY3	Jim Bridger		Bridger Coal Co. 11/	Sweetwater	Rock Springs	Deadman	1.8	7.5
WY3	Rim Rock		Energy Development Co. 12/	Carbon	Hanna	Brooks	.7	1.0
WY3	Medicine Bow		Medicine Bow Coal Co.	Carbon	Hanna	Beds #62-66	3.0	3.3
WY3	Dave Johnson		Pacific Power & Light	Converse	Glenrock	School, Badger	2.8	2.8
WY3	Rosebud Pits 4 & 5		Rosebud Coal Sales 13/	Carbon	Hanna	Beds #80, 82	1.9	1.5
WY3	Black Butte	1978	Black Butte Coal Co. 14/	Sweetwater	Rock Springs	Deadman		4.5
WY3	China Butte	1979	Arch Mineral, Inc. 15/	Carbon	L. Snake R.	Ft. Union A-G		2.5
WY3	Red Rim	1979	Energy Development Co.	Carbon	L. Snake R.	Ft. Union A-G		2.5
WY3	Atlantic Rim	1979	Rocky Mountain Energy Co. 16/	Carbon	L. Snake R.	Mesa Verde A-D		2.0
Annual Production, WY3:							15.7	32.8
WY4	Skull Point		FMC Coal Co. 17/	Lincoln	Kemmerer	Adaville #1	.6	1.5
WY4	Elkol		Kemmerer Coal Co.	Lincoln	Kemmerer	Adaville #1	.9	1.0
WY4	Sorenson		Kemmerer Coal Co.	Lincoln	Kemmerer	Beds #2-11	2.5	4.0
WY4	Twin Cr.	1977	Rocky Mountain Energy Co.	Lincoln	Kemmerer	Adaville		3.0
WY4	North Block	1979	Kemmerer Coal Co.	Lincoln	Kemmerer	Beds #2-11		2.4
Annual Production, WY4:							4.0	11.9
Total Annual Production, Wyoming:							26.7	185.2
Total Annual Production, NGP Region:							73.4	292.1

(Continued)

TABLE 3. ...Continued...

State and Coal Production Area 1/	Mine: Name	Mine: Year Open	Mine: Operator	County	Coal Field	Seam(s) Mined	Annual Production (MTY) 2/: 1976	Annual Production (MTY) 2/: 1980
ROCKY MOUNTAIN REGION:								
Colorado, CO1	Edna		Pittsburg-Midway	Routt	Green R.	Lennox, Wadge	1.2	1.4
CO1	Energy #1		Energy Fuels Corp.	Routt	Green R.	Wadge	.5	.5
CO1	Energy #2		Energy Fuels Corp.	Routt	Green R.	Fish Cr.	1.2	2.0
CO1	Energy #3		Energy Fuels Corp.	Routt	Green R.	Lennox, Wadge	1.5	2.0
CO1	Seneca #2		Seneca Coals, Ltd.	Routt	Green R.	Wolf Cr., Wadge	1.4	1.4
CO1	Williams Fork #1		Empire Energy, Inc.	Moffat	Green R.	n.a.	.2	.7
CO1	Williams Fork	1977	Utah International	Moffat	Green R.	n.a.		2.7
CO1	?	1980	American Electric Power	Routt	Green R.	n.a.		.5
Annual Production, CO1:							6.0	11.2
CO2	Marr #1		Kerr Coal Co.	Jackson	N. Park	n.a.	.2	.4
CO2	Canadian		Sigma Mining Co.	Jackson	N. Park	n.a.	.2	.2
Annual Production, CO2:							.4	.6
CO3	Nucla		Peabody Coal Co.	Montrose	San Juan	Wadge	.1	.1
(Other Mines) 18/							.3	4.9
Total Annual Production, Colorado:							6.8	16.8
New Mexico, NM1	Navajo		Utah International	San Juan	Navajo	Beds #6-8	8.3	9.6
NM1	San Juan		Western Coal Co.	San Juan	Fruitland	(Various)	2.8	4.4
Annual Production, NM1:							11.1	14.0
NM2	McKinley		Pittsburg-Midway	McKinley	Gallup	(Various)	.8	5.0
NM2	Star Lake	1979	Peabody Coal Co.	McKinley	Fruitland	(Various)		3.0
Annual Production, NM2:							.8	8.0

(Continued)

TABLE 3. ...Continued...

State and Coal Production Area[1/]	Mine: Name	Mine: Year Open	Mine: Operator	County	Coal Field	Seam(s) Mined	Annual Production (MTY)[2/] 1976	Annual Production (MTY)[2/] 1980
New Mexico (continued)								
(Other Mines)[19/]							.4	1.5
Total Annual Production, New Mexico:							12.3	23.5
Utah, UT1 ... No strip mine operations scheduled through 1980 ...								
UT2 ... No strip mine operations scheduled through 1980 ...								
UT3	?	1980	Nevada Power Co.	Kane	Alton	n.a.		9.5
UT3	?	1980	Utah International	Kane	Alton	n.a.		2.5
Annual Production, UT3:								12.0
Arizona, AR1	Black Mesa		Peabody Coal Co.	Navajo	Black Mesa	Wepo, Toreva	4.5	5.0
AR1	Kayenta		Peabody Coal Co.	Navajo	Black Mesa	Wepo, Toreva	2.5	4.0
Annual Production, AR1:							7.0	9.0
Total Annual Production, RM Region:							26.1	61.3
PACIFIC REGION:								
Washington	Centralia		Washington Irrig. and Dev. Co.	Lewis	Centralia-Chehalis	Big, Little, Smith	4.0	4.5
Alaska	Usibelli		Usibelli Coal Mine, Inc.	(near Healy)	Nenana	Beds F, 1-3	.7	1.0
Total Annual Production, PAC Region:							4.7	5.5
Total Annual Production, Western Region:							104.2	358.9

TABLE 3. ...Continued, Footnotes

SOURCES: The principal sources of information used to identify, locate and describe present and future strip mining operations included: Glass [1977], Coal Age [1977], Colorado State Bureau of Mines [1977], New Mexico State Bureau of Mines [1977], U.S. Bureau of Mines [1976, '72, '71], Whetzel [1976a, b], Keystone Industry Manual [1976], Averitt [1975], Smith et al. [1972], Peirce and Wilt [1970] and Roberts [1958].

1/ A coal production area is defined as one or more contiguous counties within a state having essentially the same quality of surface mineable coal (BTU's, ash, sulfur and moisture) with a minimum strippable reserve of 10 million tons [Whetzel, 1976].

2/ Annual production levels are measured in millions of short tons (2,000 lbs.) per year (MTY).

Mine owner-operators: 3/--known as Nytana, Inc., a joint venture between Peter Kiewit and Sons and Pacific Power and Light; 4/--in partnership with Morrison-Knudson (Kewanee Oil) and Pennsylvania Virginia, Inc.; 5/--with Montana Power; 6/--joint venture with Mobil Oil Corporation; 7/--subsidiary of Peter Kiewit and Sons; 8/--subsidiary of Black Hills Power; 9/--subsidiary of Exxon Corporation; 10/--joint venture with Powder River Coal Co.; 11/--joint venture of Pacific Power and Light and Idaho Power; 12/--subsidiary of Iowa Public Service; 13/--owned by Peter Kiewit and Sons; 14/--joint venture with Peter Kiewit and Sons and Rocky Mountain Energy; 15/--joint venture of Hunt Enterprises and Ashland Oil Co.; 16/--subsidiary of Union Pacific Corporation; and 17/--subsidiary of Morrison-Knudson (Kewanee Oil).

18/ Black Diamond Mine (GEC Minerals, Inc.), Watkins Mine (Mintech Corp.), Station Creek Mine (Cameron Engineers), Mel Martinez Mine (Milton Fuller, Inc.) and three unnamed mines (Sun Coal Co., Consolidated Coal Co. and Midland Coal Co.).

19/ Gamerco Mine (Carbon Coal Co.) and West York Canyon Mine (Kaiser Steel Corp.).

in Wyoming (WY2, a 24-fold increase), North Dakota (ND2), Montana (MT4), and New Mexico (NM2). However, nearly all coal production areas can expect significant increases in activity (and impacts) as the entire region's output more than triples by 1980.

Mine-site descriptions of coal deposits, overburden characteristics and representative stripping ratios for most operations in the study area were obtained from the information contained in the operator's mining plans. These data are reported in table 4. The values enclosed in parentheses for 'recoverable' seam thickness and overburden depth are assumed representative of "current" operating conditions (conditions that will prevail through 1980), and are not necessarily mean values of those production parameters. This information was derived from stratigraphic maps of the actual mine site (developed by the operator), and where such data were not available, from geologic cross-sectional analyses of the coal field and representative portions of individual seams and overlying soil and rock formations in the vicinity of the mining tract.

The wide variability observed in mineable seams and overburden depths, generally greater among regions than within a given production area or set of areas, would suggest that the regional characterizations are perhaps less subject to the influence of measurement error. Noting two mines in Montana as possible exceptions (Decker #1 and Absaloka), both the individual and aggregated results compare favorably with most recently published estimates reviewed by Whetzel [1976 a, b].

Also summarized in table 4 are the types of equipment typically used at each mine to remove overburden and to accomplish the major earth-moving operations in reclamation. Approximately 70 percent of

TABLE 4. SUMMARY OF PRODUCTION EFFICIENCY PARAMETERS, EARTHMOVING TECHNOLOGIES AND ESTIMATED COSTS OF THE ENGINEERING COMPONENT IN WESTERN SURFACE MINE RECLAMATION.

Coal Production Area	Mine[1/]	Mined Coals		Depth of Overburden (Ave.)[2/]	Average Stripping Ratio[3/]	Earthmoving Technologies			Estimated Costs of Earthworks Handling ($/AC.)[4/]		
		Rank	Seam Thickness (Ave.)[2/]			Overburden Removal	Recontouring	Topsoiling	Recontouring	Topsoiling	Total
	NORTHERN GREAT PLAINS REGION:										
MT2	Savage	Lig.	8-27' (20')	50-85' (70')	3.5	Dragline	Dozer	Scraper	$1,680	$2,460	$4,140
MT4	Decker#1	Sub.	N.A. (67')	<150' (70')	1.0	Dragline	Dozer	Scraper	1,680	2,460	4,140
MT4	Absaloka	Sub.	25-55' (40')	20-200' (80')	2.0	Dragline	Dozer	Scraper	2,200	2,460	4,660
MT4	Big Sky	Sub.	25-36' (26')	50-90' (58')	2.2	Dragline	Dozer	Scraper	1,276	2,460	3,736
MT4	Rosebud	Sub.	23-27' (25')	30-160' (65')	2.6	Dragline	Dozer	Scraper	$1,466	$2,460	3,926
	Weighted Average, MT4[5/]:		41.3'	68.0'	1.6						$4,038
	Weighted Average, Montana:		39.7'	68.7'	1.7						$4,171
ND1	Velva	Lig.	N.A. (12')	60-80' (68')	5.7	Dragline	Dozer	Scraper	$1,625	$2,952	$4,577
ND1	Noonan	Lig.	7-10' (8')	25-60' (40')	5.0	Dragline	Dozer	Scraper	$ 860	$2,952	3,812
	Weighted Average, ND1:		9.7'	51.8'	5.3						$4,040
ND2	Center	Lig.	8-22' (11')	30-75' (45')	4.1	Dragline	Dozer	Scraper	$ 945	$2,952	$3,897
ND2	Glenharold	Lig.	8-14' (11')	<80' (50')	4.6	Dragline	Dozer	Scraper	1,050	2,952	4,002
ND2	Beulah	Lig.	10-22' (16')	10-90' (18')	1.1	Dragline	Dozer	Scraper	497	2,952	3,449
ND2	Indian Head	Lig.	10-14' (12')	20-65' (33')	2.8	Dragline	Dozer	Scraper	$ 742	$2,952	3,694
	Weighted Average, ND2:		12.5'	37.8'	3.0						$3,761
ND3	Gascoyne	Lig.	8-24' (12')	10-30' (20')	1.7	Dragline	Dozer	Scraper	$ 550	$2,952	$3,502
ND3	Lehigh	Lig.	N.A. (10')	50-75' (58')	5.8	Dragline	Dozer	Scraper	$1,276		4,228
	Weighted Average, ND3:		11.8'	23.0'	1.9						$3,538
	Weighted Average, North Dakota:		12.0'	38.2'	3.2						$3,747

(Continued)

TABLE 4. ...Continued...

Coal Production Area	Mine 1/	Mined Coals: Rank	Mined Coals: Seam Thickness (Ave.) 2/	Depth of Overburden (Ave.) 2/	Average Stripping Ratio 3/	Earthmoving Technologies: Overburden Removal	Earthmoving Technologies: Recontouring	Earthmoving Technologies: Topsoiling	Estimated Costs of Earthworks Handling ($/AC.) 4/: Recontouring	Estimated Costs of Earthworks Handling ($/AC.) 4/: Topsoiling	Estimated Costs of Earthworks Handling ($/AC.) 4/: Total
WY1	Bighorn	Sub.	53-62' (57')	15-250' (100')	1.8	Scpr., Shvl.	Scraper	Scraper	$3,800	$ 738	$4,538
WY1	PSO #1	Sub.	N.A. (65')	<140 (95')	1.5	Dgln.-Shovel	Dozer	Scraper	$3,278	$ 738	4,016
	Weighted Average, WY1:		59'	98.7'	1.7						$4,459
WY2	Belle Ayr S.	Sub.	N.A. (70')	15-200' (30')	.4	Shovel-Truck	Dozer	Scraper	$ 705	$ 738	$1,443
WY2	Wyodak N,S.	Sub.	80-110' (80')	20-110' (30')	.4	Scpr., F.E.Ldr.	Scraper	Scraper	705	738	1,443
WY2	N. Rawhide	Sub.	N.A. (107')	20-240' (80')	.8	Shovel-Truck	Dozer	Scraper	2,200	738	2,738
WY2	Coballo	Sub.	N.A. (70')	20-200' (85')	1.2	Shovel-Truck	Dozer	Scraper	2,465	738	3,203
WY2	Cordero	Sub.	N.A. (60')	<200' (85')	1.4	Shovel-Truck	Dozer	Scraper	2,465	738	3,203
WY2	Eagle Butte	Sub.	65-200' (125')	<200' (100')	.8	Shovel-Truck	Dozer	Scraper	3,800	738	4,538
WY2	Black Thunder	Sub.	60-73' (66')	15-240' (70')	1.1	Shovel-Truck	Dozer	Scraper	1,680	738	2,418
WY2	Thunderbird	Sub.	12-15' (13')	<150' (45')	3.5	N.A.	N.A.	N.A.	990	738	1,728
WY2	E. Gillette #16	Sub.	50-75' (68')	<200' (74')	1.1	Shovel-Truck	Dozer	Scraper	1,850	738	2,568
WY2	Jacobs Ranch	Sub.	N.A. (57')	10-150' (47')	.8	Shovel-Truck	Dozer	Scraper	1,034	738	1,772
WY2	E. Gillette	Sub.	50-75' (65')	<200' (78')	1.2	Shovel-Truck	Dozer	Scraper	2,067	738	2,805
WY2	Rochelle	Sub.	N.A. (52')	20-150' (80')	1.5	Dragline	Dozer	Scraper	2,200	738	2,938
WY2	Buckskin	Sub.	N.A. (100')	<100' (90')	.9	Dragline	Dozer	Scraper	2,880	738	3,618
WY2	(Texaco, Inc.)	Sub.	50-220' (125')	<200' (89')	.7	N.A.	N.A.	N.A.	$2,840	$ 738	3,578
	Weighted Average, WY2:		82.5'	77.2'	.9						$2,784
WY3	Seminoe #1	Sub.	23-29' (26')	40-200' (47')	1.8	Dragline	Dozer	Scraper	$1,034	$ 738	$1,772
WY3	Seminoe #2	Sub.	N.A. (35')	40-250' (52')	1.5	Dragline	Dozer	Scraper	1,149	738	1,887
WY3	Jim Bridger	Sub.	15-30' (27')	40-150' (45')	1.7	Dragline	Dozer	Scraper	990	738	1,728
WY3	Rim Rock	Sub.	N.A. (7.5')	40-80' (50')	6.7	Dragline	Dozer	Scraper	1,100	738	1,838
WY3	Medicine Bow	Sub.	3-10' (9')	20-200' (32')	3.6	Dragline	Dozer	Scraper	723	738	1,461
WY3	Dave Johnson	Sub.	N.A. (48')	60-110' (85')	1.8	Dragline	Dozer	Scraper	2,465	738	3,203
WY3	Rosebud Pits 4 & 5	Sub.	N.A. (18')	N.A. (70')	3.9	Dragline	Dozer	Scraper	$1,680	$738	$2,418

(Continued)

TABLE 4. ...Continued...

Coal Production Area	Mine 1/	Mined Coals: Rank	Mined Coals: Seam Thickness (Ave.) 2/	Depth of Overburden (Ave.) 2/	Average Stripping Ratio 3/	Earthmoving Technologies: Overburden Removal	Earthmoving Technologies: Recontouring	Earthmoving Technologies: Topsoiling	Estimated Costs of Earthworks Handling ($/AC.) 4/: Recontouring	Estimated Costs: Topsoiling	Estimated Costs: Total
Wyoming (continued)											
WY3	Black Butte	Sub.	5-26' (24')	40-150' (57')	2.4	Oragline	Oozer	Scraper	$1,274	$738	$2,012
WY3	China Butte	Sub.	4-26' (22')	<150' (60')	2.7	Oragline	Oozer	Scraper	1,344	738	2,082
WY3	Red Rim	Sub.	4-24' (20')	<150' (55')	2.8	N.A.	N.A.	N.A.	1,221	738	1,959
WY3	Atlantic Rim	Sub.	3-9.5' (8.5')	<200' (40')	4.7	Shovel-Truck	Oozer	Scraper	$ 852	$ 738	1,590
	Weighted Average, WY3:		22.3'	53.9'	2.4						$1,891
WY4	Skull Point	Sub.	40-60' (50')	40-120' (55')	1.1	N.A.	N.A.	N.A.	$1,221	$ 738	$1,959
WY4	Elkol	Sub.	50-120' (87')	130-160' (140')	1.6	Scpr., Shvl.	Scraper	Scraper	7,700	738	8,438
WY4	Sorenson	Sub.	4-35' (30')	25-140' (65')	2.2	Scpr., Ogln.	Dozer	Scraper	1,469	738	2,207
WY4	Twin Cr.	Sub.	5-60' (40')	40-710' (65')	1.6	Shovel-Truck	Oozer	Scraper	1,469	738	2,207
WY4	North Block	Sub.	25-38' (29')	40-240' (52')	1.8	Oragline	Oozer	Scraper	$1,149	$ 738	1,887
	Weighted Average, WY4:		39.5'	67.1'	1.7						$2,281
	Weighted Average, Wyoming:		68.8'	72.6'	1.1						$2,610
	Weighted Average, NGP Region:		53'	67.2'	1.3						$3,040
	ROCKY MOUNTAIN REGION:										
CO1	Edna	Bit.	N.A. (6')	5-60' (35')	5.8	Oragline	Oozer	Scraper	$ 748	$1,230	$2,014
CO1	Energy #1	Bit.	N.A. (10')	20-60' (28')	2.8	Oragline	Oozer	Scraper	644	1,230	1,874
CO1	Energy #2	Bit.	N.A. (4.5')	5-80' (15')	3.3	Shovel-Oozer	Oozer	Scraper	450	1,230	1,680
CO1	Energy #3	Bit.	N.A. (7.5')	25-60' (52')	7.0	Oragline	Dozer	Scraper	1,113	1,230	2,343
CO1	Seneca #2	Bit.	9-20' (10')	20-70' (45')	4.5	Oragline	Oozer	Scraper	945	1,230	2,175
CO1	Williams Fork	Bit.	N.A. (25')	N.A. (100')	4.0	Oragline	Dozer	Scraper	$3,750	$1,230	4,980
	Weighted Average, CO1 (Colorado)		8.7'	41.8'	4.8						$2.120

(Continued)

TABLE 4. ...Continued...

Coal Production Area	Mine[1/]	Mined Coals: Rank	Mined Coals: Seam Thickness (Ave.)[2/]	Depth of Overburden (Ave.)[2/]	Average Stripping Ratio[3/]	Earthmoving Technologies: Overburden Removal	Earthmoving Technologies: Recontouring	Earthmoving Technologies: Topsoiling	Estimated Costs of Earthworks Handling ($/AC.)[4/]: Recontouring	Estimated Costs of Earthworks Handling ($/AC.)[4/]: Topsoiling	Estimated Costs of Earthworks Handling ($/AC.)[4/]: Total
NM1	Navajo	Sub.	4-30' (24')	N.A. (55')	2.3	Dragline	Dozer	Scraper	$1,199	$ 738	$1,937
NM1	San Juan	Bit.	N.A. (16')	5-65' (35')	2.2	Dragline	Dozer	Scraper	$ 782	$ 738	1,520
	Weighted Average, NM1:		21.5'	48.8'	2.3						$1,763
NM2	McKinley	Sub.	8-24' (20')	20-70' (45')	2.2	Shovel-Truck	Dozer	Scraper	$ 945	$ 738	$1,683
NM2	Star Lake	Sub.	≤16' (15')	22-80' (50')	3.3	Dgln.-Shovel	Dozer	Scraper	$1,050	$ 738	1,788
	Weighted Average, NM2:		18.2'	46.8'	2.6						$1,721
	Weighted Average, New Mexico:		20.3'	48.0'	2.4						$1,746
UT3	...Insufficient information for computations...										
AR1	Black Mesa	Bit.	5-28' (25')	<130' (45')	1.8	Dragline	Dozer	Scraper	$ 945	$ 738	$1,683
AR1	Kayenta	Bit.	N.A. (25')	<140' (49')	2.0	Dragline	Dozer	Scraper	$1,034	$ 738	$1,772
	Weighted Average, AR1 (Arizona):		25'	46.6'	1.9						$1,717
	Weighted Average, RM Region:		17.2'	45.6'	2.7						$1,869
	PACIFIC REGION:										
Washington	Centralia	Sub.	25-40' (38')	N.A. (65')	1.7	Dragline	Dozer	Scraper	$1,469	$ 738	$2,207
Alaska	Usibelli	Sub.	15-60 (22')	<150' (85')	3.9	Shovel	Dozer	Scraper	$2,465	$ 492	$2,957
	Weighted Average, Pacific Region:		35.6'	68.0'	1.9						$2,320
	Weighted Average, Western Region:		46.5'	63.6'	1.4						$2,826

TABLE 4. ...Continued, Footnotes

1/ Because of insufficient information on some mining operations (i.e., specific data on seam thickness and overburden depth) several mines identified in table 2 were omitted from the present analysis.

2/ Estimates of average seam thickness and overburden depth apply to only current (1976) conditions. In addition to the references cited in "sources" of table 2, supporting references include Jory [1977], Ackerman [1977], Anderson [1977], Kandalin [1977], Ford [1977], Kottlowski [1976], Bettwy [1976], McCall [1976], Melvin [1976], Mooney [1976], Klein [1976] and Daniels [1976].

3/ Defined as feet of overburden per foot of seam thickness (average values used).

4/ Standard engineering cost schedules were applied uniformly to all mines (Caterpillar Performance Handbook [1977], Leathers [1977] and Watts [1975]). The cost estimates for spoil recontouring were determined from an average cost function with a range of $20.80 to $45.00 per vertical foot of overburden depth. Topsoiling costs were estimated from a linear function with an average cost (including stripping, stockpiling and replacement) of $123 per acre inch of final topsoil depth. The following topsoil requirements for the various states were assumed: Montana, 18-24" (averaging 20"); North Dakota, 12-60" (24"); Wyoming, 4-8" (6"); Colorado, 6-12" (10"); Utah, New Mexico, Arizona and Washington, 4-8" (6"); and Alaska, 2-24" (4").

5/ The weighting scheme is based on annual output in 1980.

operators use draglines for overburden stripping, while the most common methods of recontouring and topsoiling envolve tractor-dozers and self powered scrapers, respectively.

Assumptions and Procedure

In most earlier studies rather rigorous budgeting techniques were employed to establish "representative" cost functions by type and size of machine, operation, work load and other factors [Skelly and Loy, 1975, and Stefanko, et al., 1973]. In addition to these, other standard cost schedules for a wide range of equipment options and operating conditions are also available (for example, the Caterpillar Performance Handbook [1977]). Upon review of the various sources, the estimating procedures developed by Watts [1975] were considered to be most appropriate for use in this study. These procedures are limited, however, to a single mining method and stripping technology--area stripping with draglines used for overburden removal. Accordingly, all surface coal mines in the Western region are handled as area strip-dragline type operations for the purpose of cost estimation.

The approach used to generate cost estimates was fairly simple and straightforward. On the basis of a number of assumptions which define the preconditions, two cost functions were synthesized--one each for the recontouring and topsoiling operations. These cost functions, under assumed conditions of applicability summarized in figure 5, were applied uniformly to all mines in the study area.

As a consequence of this approach, several individual mining operations in the study area, namely those operations that employ open pit or contour strip mining methods or operations using shovel and truck methods of overburden removal, are not appropriately specified in the

(a) TOPSOILING

Topsoil thickness = uniform over mined area:

State	Depth in Inches Range	Average
North Dakota	6-60"	24"
Montana	6-24"	20"
Colorado	6-14"	10"
Wyoming	2 - 8"	6"
Utah	2 - 8"	6"
New Mexico	2 - 8"	6"
Arizona	2 - 8"	6"
Washington	6-30"	6"
Alaska	2-24"	4"

Average Handling Cost = $123 per acre inch (including stripping, stockpiling and replacement)

(b) RECONTOURING

Mined Area = 100 acres -- 1,452' x 300'

Length of Highwall = 1,452'

Width of Pit = 120'

Ramp Roads = 4 on site, 30' wide

Overburden = uniform thickness over area -- swell factor 25 percent

Surface Slopes: premining 10 percent (area average), spoil bank .8:1, post mining -- highwall 15 percent, all others 10 percent

Recontouring Equipment: Tractor-dozers

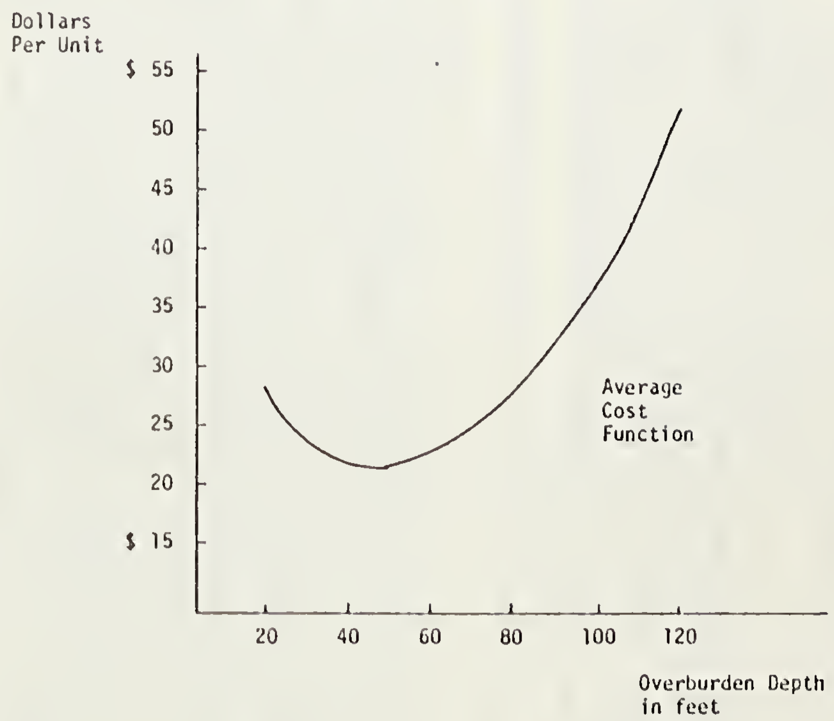


Figure 5. Summary of Assumptions Used to Estimate Topsoiling and Recontouring Costs.

analysis. Thus, for a number of specific mines some estimated costs for earthwork handling will be biased either upward or downward. The individual mines most likely affected are located in the following coal production areas: WY2, WY4, CO1, and possibly NM2 (refer to table 4).

Cost Comparisons

The estimated costs for recontouring and topsoiling operations are summarized in the last portion of table 4. Mines located in Montana, North Dakota and northern Wyoming are shown to have the greatest earth-moving requirements in the Western region. Per acre costs range upward from $3,500. For the majority of these mines, topsoiling (the combined operations of stripping, stockpiling and redistributing) accounts for the largest proportion of total earthwork costs.

In the balance of the region earthwork handling requirements are more variable and generally less costly; average costs range from a low of $1,700 per acre in New Mexico and Arizona to about $2,600 per acre in most areas of Wyoming. The observed variability in cost estimates among mines in the same coal production area is explained by recontouring requirements, since the same topsoil requirement is assumed for an entire state. In terms of broad regional comparisons, the Northern Great Plains has the highest overall average cost, roughly $3,000 per acre, whereas the Rocky Mountain States apparently have the lowest average at less than $1,900 per acre.

D. SUMMARY AND LIMITATIONS

This phase of the study reported an attempt to carefully evaluate the engineering aspects of land reclamation. Based upon fairly detailed descriptions of mine characteristics, mining methods and other factors which influence earthhandling requirements, cost estimates were obtained for each mine and major coal production area in the Western region. On balance the mine characterizations and estimated costs compare favorably with previously published reports. However, the earlier studies do not provide mine-by-mine summaries, and therefore the findings reported here should be regarded as preliminary until such time that further corroborative evidence is available.

Several limitations of the analysis should be considered in using these results. In any empirical analysis in which standard assumptions are uniformly applied, the "uniqueness" of individual cases is sacrificed for consistency and generality. In the present case the uniqueness of each mining situation can involve vast differences in operating conditions at the same site over time as well as between mines operated in the same general area. Accordingly, the insights gained in "generalizing" situations for comparative purposes must be weighed against the "over-generalization" of actual situations.

Other limitations have to do with the simplicity of the approach and method of analysis. The use of more rigorous estimating procedures might generate different results. However, the evidence available to the author supports the contention that the sensitivity of the reported findings to more rigorous engineering analyses would not yield significantly different conclusions.

The reported results are based on the assumption that, in the near term (i.e., through 1980), significant changes will not occur in reclamation law pertaining to topsoiling and recontouring requirements. Such changes would significantly alter the cost estimates. Further, the estimated costs were derived on the assumption that all mines in the study area are area strip-type operations that employ draglines or large shovels for overburden removal (as summarized in figure 5). Accordingly, the procedures followed allow comparisons of mining "conditions" rather than comparisons of mining methods and technological alternatives. Fortunately, the vast majority of Western strip mines currently employ the procedures specifically examined in this study.

Chapter IV

THE REVEGETATION COMPONENT OF SURFACE MINE RECLAMATION

A. INTRODUCTION

The apparent inevitability of extensive strip mining of coal in the Western United States has stimulated much public concern over the potential for these disturbed lands to be reclaimed to a useful long-term postmining condition. A careful review of the research literature on mining reclamation suggests that the majority of work in the past five years has focused explicitly on the problem of revegetation. This is explained in part by the problematic nature of the natural environments where strippable coal resources have been identified. In the semi-arid West an intimate relationship between sparse rainfall, shallow, erodable soils, and a cold-desert biome gives rise to diverse and often fragile ecosystems. If disturbed on a massive scale, it is unlikely that some of these natural systems can ever be "restored" to their present state, and in some cases even to a useful alternative condition, without the careful attention of man. [National Academy of Sciences, 1974].

In this chapter the problem of revegetating surface mined lands in the Western region is examined in some detail. The analysis focuses on the environmental characteristics of present and future sites of coal development in order to facilitate a systematic comparison of site-specific revegetation "potentials." An evaluations methodology, recently developed by the U.S. Forest Service, is used to provide a qualitative ranking of each site on the basis of selected environmental factors thought to be critical to successful revegetation efforts. The descriptive characteristics of each mining operation, presented in Chapter III, are developed further here to assess the magnitude of the problem at present (i.e., the number of acres requiring revegetation in 1976) and in the year 1980. Finally, site-specific revegetation costs are obtained with the use of a weighting scheme, indicating the sensitivity of representative costs to the qualitative site rankings.

The analysis is presented in three parts. In section B, the physical factors used to perform the site evaluations are described, and broad, regional distinctions in environments are briefly reviewed. Results of the analysis, including site-specific estimates of surface disturbance and representative costs of revegetation are reported in part C. A summary section, part D, reviews the findings and implications of the analysis.

B. CHARACTERIZING THE REGIONAL ENVIRONMENTS

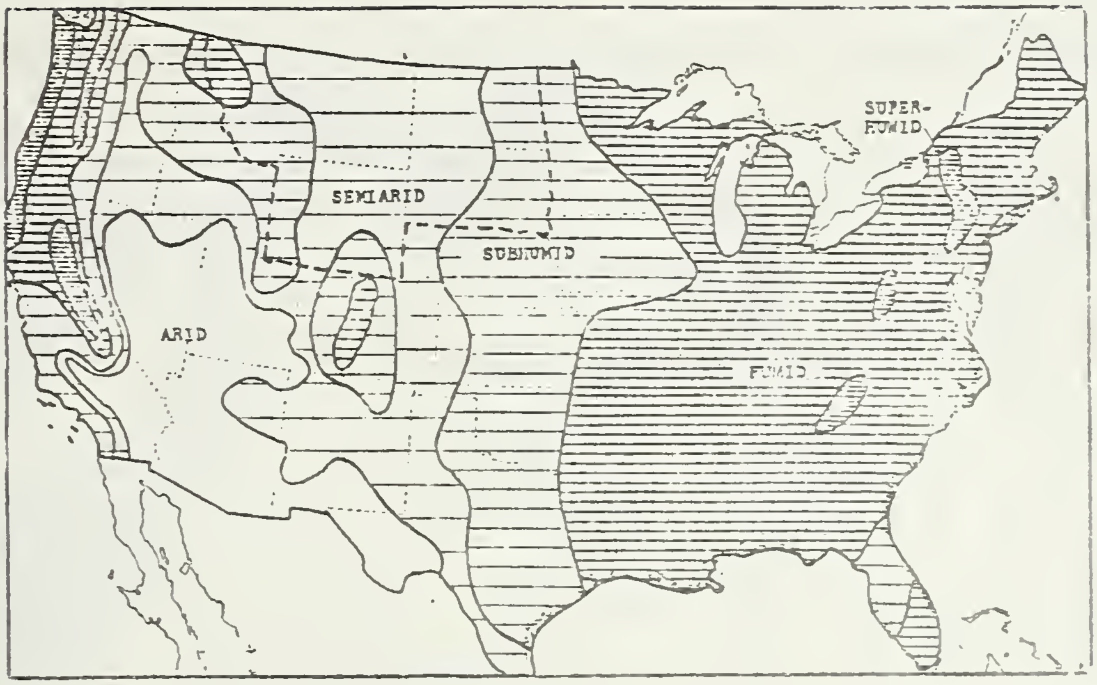
Numerous environmental factors can be identified which determine, to a large degree, the success or failure of reclamation efforts. As pointed out in chapter I, revegetation can be the most critical phase in the sequence of reclamation activities. The natural factors that largely influence the probability for successful revegetation in the Western region are: (1) the amount and distribution of seasonal precipitation; (2) the physiography of the area, especially soil productivity and stability; and (3) the availability of suitable plant species for reestablishment. This section presents a general overview of the influence of these factors in the study area.

Moisture Regimes

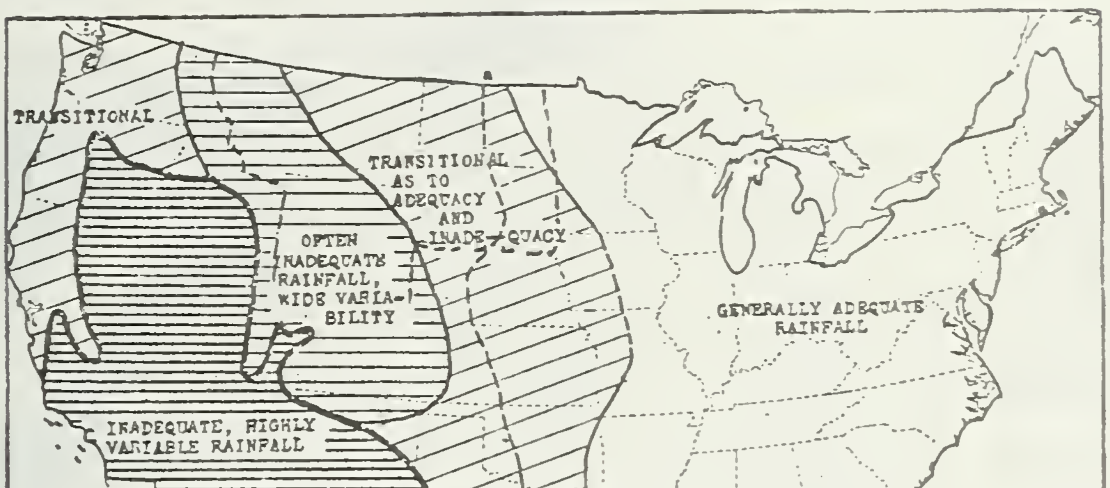
The vast intermountain area between the Great Plains and the Pacific Coast is a region where atmospheric forces interact to produce a multiplicity of climates. Weather patterns in the Western United States are largely influenced by climatic conditions elsewhere: from Canada to the north, and from Mexico and the Gulf Coast to the south and southeast. These forces, in combination with the broad expanse and varied topography of the West, result in extreme variations in climatic conditions.

The climate of a region is not always accurately characterized by a single element such as precipitation; numerous other characteristics may also be important, including air and soil temperature, humidity, wind velocity and duration, atmospheric pressure, solar radiation, and snow cover. Because precipitation and temperature are the principal elements of climate in the semi-arid West, significant differences in the regional distribution of these factors deserve special attention.

Northern Great Plains Region. The climate of the Northern Great Plains varies from "arid" in the southwest portion to "subhumid" in the northeastern extremes (figure 6). The moisture regime is characterized by relatively small mean annual precipitation with often large year-to-year (and seasonal) variability. A moisture deficit condition exists throughout much of the area but the degree of severity varies with location and season. In one study, based upon the precipitation-evaporation index for 37 years of observations, Thornthwaite [1941] classified the area' climate as: arid (5 years), semi-arid (25 years), dry subhumid (5 years), moist sub-humid and humid (1 year each). The



(a) Regions Based on General Climatic Classifications.



(b) Regions Based on General Variability of Rainfall.

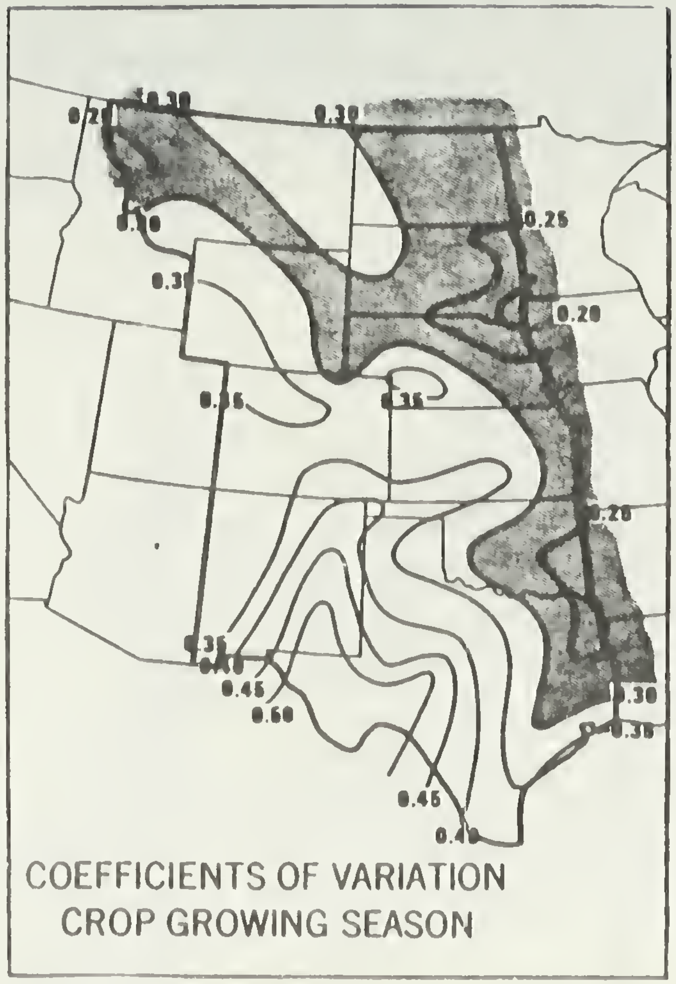
Figure 6. Thornthwaite Classifications of General Climatic Regions of the United States.

incidence of seasonal precipitation has a preponderant influence on climate, and is the most significant physical determinant to the success or failure of the region's agriculture in any given year.

Average annual precipitation ranges upward from 8 inches in the interior and southern parts of Wyoming to over 20 inches in the mountains and eastern parts of North and South Dakota (Table 1-A, Appendix). Based upon the location of known and strippable coal deposits, areas of potential coal production average between 12 to 16 inches of moisture annually. As much as 75 percent of this typically occurs during the growing season--from May to October. However, "normal" precipitation can be a misconception for the Northern Great Plains, since mean rainfall events may only occur once in every 8 or 10 years. The coefficient of variability (defined as the standard deviation divided by the mean), shown in figure 7, is about 30 percent for most of the area.

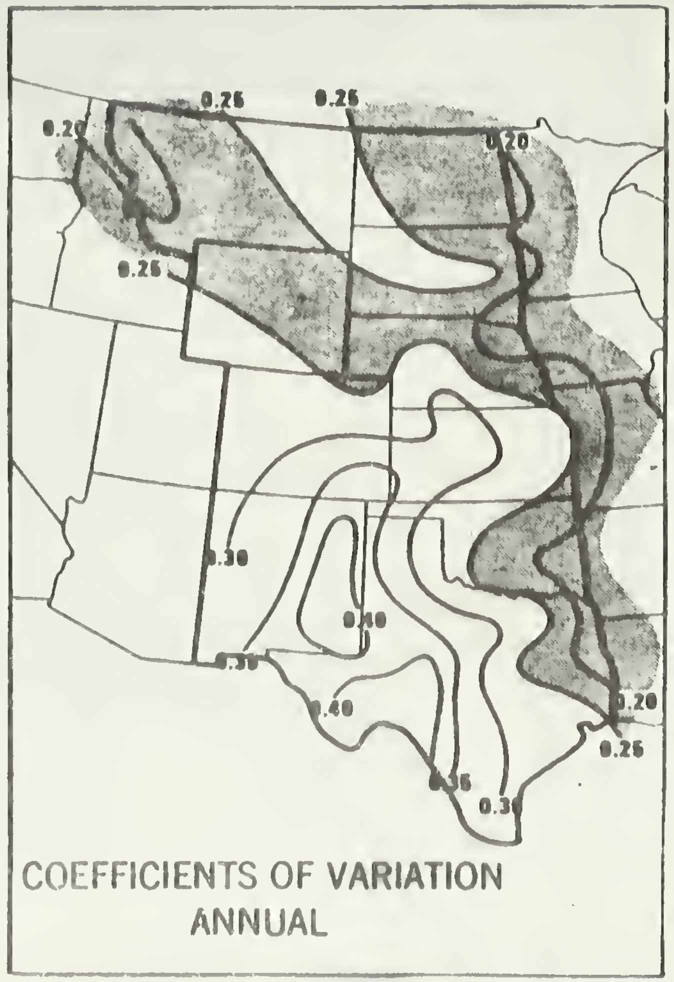
Drought conditions, defined as a "prolonged" period of abnormal moisture deficiency, do not occur frequently in the Northern Great Plains, but when they do they can be very severe. One of the worst droughts of this century took place in the summer of 1936. The Palmer Index, which measures the soil moisture situation during periods of abnormally dry weather, indicated that the most severe conditions during this period occurred in the Northern Great Plains Region (figure 8).

During the growing season the distribution of rainfall is usually favorable for vegetative growth. In the fall months, declining precipitation and abundant sunshine are favorable for maturing native grasses and planted crops. However, a deficiency of only a couple of inches of moisture during the critical stages of growth (usually June and July) can mean the difference between success or failure whether it



SOURCE: Whiteman [1973].

(a) Distribution of Coefficients of Variation for Crop Growing Season (April through September).



SOURCE: Whiteman [1973].

(b) Distribution of Coefficients of Variation for Annual Precipitation Amounts.

Figure 7. Coefficients of Variation for Precipitation in the Rocky Mountain and Great Plains Subregions

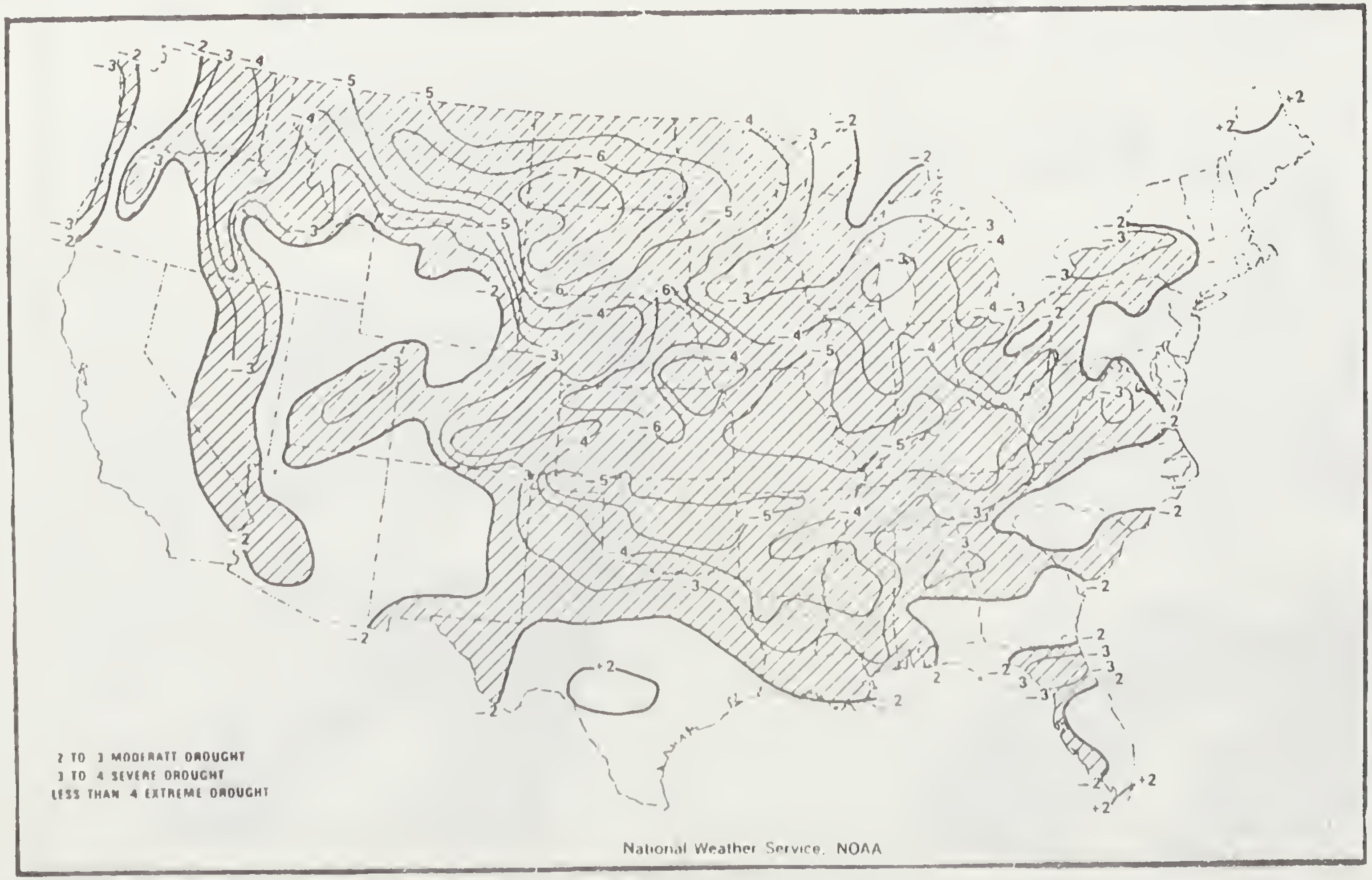


Figure 8. Maximum Drought Severity in the United States, May 1-October 1, 1936: **Palmer Index Values.**

be dryland farming or revegetated surface-mined lands. On the other hand, above normal precipitation can cause severe soil erosion especially in areas of sparsely vegetated surfaces and uneven topography.

Rocky Mountain Region. Variations in temperature and seasonal precipitation in the Central Rockies are even more extreme than that of the Great Plains which lie to the north and east. The northwestern portion of Colorado is characterized as "semi-arid" to "humid" while the southern portions of Utah and Colorado and the northwestern portion of New Mexico are typically "arid" climates [Thornthwaite, 1941]. With the exception of a very few isolated areas in the northern part of the region, successful agriculture is not feasible without irrigation.

As summarized in table A-1, the annual mean precipitation for areas of strippable coal deposits ranges from a low of seven inches in Arizona and New Mexico to 20 inches in Northwestern Colorado. Differences in temperature are less extreme, with a general trend to warmer climates and longer growing seasons in a southerly direction. The seasonal distribution of moisture is similar to that of the Northern Great Plains, although occurring with higher variability (see figure 7). Evidence of soil erosion is common throughout the region due to infrequent but often severe thunder showers over sparsely vegetated, sloping soil surfaces.

Pacific Region. The climate in the Northern Coastal zone stands in marked contrast to the dry, semi-arid regions of the Western interior. The moisture regime of the area encompassing Washington's strippable coal is characterized as "humid"; mean annual precipitation at Centralia is 54 inches, most of which occurs during the winter months (November through February). Although the amount of rainfall and the mild, humid conditions are normally adequate to sustain good plant growth during the summer months, significant soil moisture depletion can occur during this time due to the seasonal pattern of rainfall. The severe drought conditions currently being experienced in the Northwest is a clear demonstration of a case where the seasonal distribution of moisture can be most critical to plant survival, even in a humid environment.

The strippable coal deposits of Alaska cover a broad expanse of differing topography and thus are subject to tremendous climatic extremes. Temperature generally plays a greater role than does precipitation, with the most notable effect being a very short growing season (table A-1). Subfreezing temperatures prevail for approximately six months nearly everywhere from October or November to March or April. January is usually the coldest month, and mean values are generally below zero. At the Usibelli strip mine in the Nenana Coal Field, near Healy, the length of the frost-free growing period averages only 34 days per year.

The southern coastal area near Anchorage is typically humid, averaging 20 inches of precipitation annually. In contrast to the southern and interior regions, the northern coastal zone near Point Barrow, an area of extensive coal reserves as well as oil and gas, receives an annual average of less than four inches--slightly more than Death Valley, California.

Physiography and Soils

The western United States contains many abruptly divergent landforms which constitute different environmental landscapes for the development of soils [U.S. Department of Agriculture, 1964]. This heterogeneity of form is associated with differences in sources of weathered rock from which soils have developed, precipitation, and natural vegetation. Differences in soil erosion and drainage are usually related to variability among these landforms. Owing to the evolutionary origin of many western soils, i.e., the weathering of sedimentary material and minerals deposited in the process of evaporation of ancient inland seas, infertility and the presence of natural salts in subsurface soil horizons can pose serious problems to revegetation once they are disturbed.

Northern Great Plains Region. This region is the northwestern, higher elevation portion of the Great Plains of the United States. It extends eastward from the foothills of the Rocky Mountains for approximately 600 miles and varies in elevation from 9000 to 500 feet above sea level. Much of the region is a rolling, prairie topography, but in the western portions of Montana and Wyoming mountain terrain is common. Natural washes, gullies and small intermittent streams are typical over much of the landscape.

Forty-two major soil associations have been identified within the boundaries of the region [Aandahl, 1972]. Of these only 17 actually occupy surface mineable areas [Packer, 1974]. The majority of these are classified as Borolls and Ustorthents: Borolls are soils with clay horizons and often contain large amounts of sodium; Ustorthents are typically better drained (lighter) soils, but lack sufficient moisture to sustain plant growth during hot, dry periods. These two soils are mainly found in the Dakotas (refer to table A-1). Other main soil groups--the Torriorthents (dry), Natrargids (sodium on clays), Ustics (alternately moist and dry), Aridisols (low in organic matter), and Camborthids-Haplargids (little soluble salts or sodium clays)--are more common to Montana and Wyoming.

The soils are quite heterogenous in terms of texture, productivity, mineral toxicity, stability and distribution. Accordingly, it is difficult to identify different soil conditions (characteristics) with respect to certain locales within the region. In general, the soils of Montana and Wyoming and west of the Missouri River in North Dakota are deficient in soil nutrients, notably phosphorus. Nitrogen is more noticeably deficient in the moister areas of North Dakota. Erosion is a serious problem in some localities where lighter, coarser soils predominate. Sandy soils are highly erodable due to an absence of silt or clay, and the repeated freezing and thawing processes promote wind and water movement of nearly all soil types.

Land subsidence or "piping" is also an important problem with some of the prairie soils, particularily in the sodium areas of western North Dakota and eastern Montana. Piping, or the formation of depressions in reclaimed surfaces, usually does not show up until several years after the overburden materials are replaced and have had time to settle. The action of water percolating through unconsolidated material which contain pockets of highly sodic soils can cause uneven settling as illustrated in figure 9. The problem can be avoided in most cases by properly mixing soil strata in the backfilling phase.

SOURCE: Jacobs [1975].

Figure 9. An Example of "Piping" on a Reclaimed Site Near Noonan, North Dakota

Rocky Mountain Region. Rugged mountains are the dominant feature of this region, but there are some broad valleys and remnants of high plateaus as well. Elevations range from over 14,000 feet in the north-eastern frontrange of Colorado to about 4,500 feet in the four-corners area. Soil classifications vary extensively by location, and in some cases they are not well mapped. Beginning in the Northwestern portion of Colorado, the principal soil groups are of the Borolls and Camborthids types; the principal groups in the coal regions of Utah are

Torriorthents and Argixerolls (subsurface clay horizons); and in Arizona and New Mexico, Natrargids and Torriorthents predominate. In general, few of these soils pose toxicity problems similar to those of eastern Montana and North Dakota, but most are low in organic matter, have poorly developed A and B horizons, and, in the case of the Natrargids, have very poor structure.

Pacific Region. The northwest coastal region is characterized by a contrast of mountains, and narrow to broad, gently sloping valleys and plains. The predominant soil classification of interest in Washington is the Naplohumults, a soil high in organic matter with a very thin subsurface clay horizon. Few problems have been encountered in revegetating soils of this group [McCarthy, 1975]. Alaskan soils are generally classified as cold-zone types, glacial and alluvial in origin (Cryoborolfs). These soils tend to be rich in organic matter but often very shallow, and where developed in place from weathered parent material such as granite, they are prone to rapid water erosion when disturbed. In the northern Tundra regions the soils are classified as bog and may be only a few inches thick above permafrost.

Natural Vegetation

In the eastern and central United States a gradual north-south trend in climate has a conspicuous effect on the pattern of vegetation. In the western region the situation is more complex in that variable oceanic climate and physiography give rise to more diverse ecosystems [Kuchler, 1964].

In the nonforested plains along the east flank of the Rockies the principal native vegetation is steppe. To the north, Western Wheatgrass is the dominant species with Blue Grama grass on overgrazed areas. The lowest belt of woody vegetation is savanna or woodland comprised of Pinyon and/or Juniper. At higher elevations Ponderosa pine forests are common, and above this, Douglas fir. The transition zone between grass prairie and woodland has considerably diverse vegetation with sagebrush being the dominant vegetation in the dryer areas. The incidence of specific species for each coal production area is reported in table A-1.

Northern Great Plains Region. Sixteen broad vegetation types have been delineated in the Northern Great Plains on lands overlying recoverable coal deposits [Packer, 1974]. The more prominent plant species include, in order of relative proportion of the surface area: (1) Mid-Grass Prairie--a type which occupies rolling plains on loam to clay loam soils in eastern Montana and North and South Dakota (needlegrasses, wheatgrasses, and blue stem grasses); (2) Grassland-Sagebrush --occupies open grassland on silty clay loam soils in southeastern Montana and northeastern Wyoming (mid and short grass species with scattered sagebrush); (3) Mid-Short Grass Prairie--occurs on rolling plains on loam to clay soils also in eastern Montana (Western Wheatgrass, Needle-and-Thread grass and Blue Grama grass); (4) Ponderosa Pine forest--occurs mainly in eastern Montana and northeastern Wyoming on uplands, ridges and north slopes having shallow loam soils (Ponderosa pine, Snowberry, Blue grasses, and fescues); and (5) Short-Grass Prairie--occupies dry, shallow soils in southeastern Montana and northeastern Wyoming (Blue Grama grass, Western Wheatgrass, and various needle grasses).

Except for rehabilitating disturbed agricultural lands (largely in North Dakota), most revegetation efforts that focus on native species will involve these five basic vegetation classifications.

Rocky Mountain Region. In addition to these five broad species classifications, which are also common to the Rocky Mountain region, Juniper-pinyon woodland, Grama-galleta steppe, and Saltbrush-greasewood are found in the more arid, southwestern portion of the region (Utah, Arizona and New Mexico). With the exception of several sites in Northwestern Colorado, there are no significant crop lands in the region's strippable coal areas.

Pacific Region. Overlying the strippable coal deposits in Washington and most of Alaska are Cedar-Hemlock-Douglas fir forests. The tundra of the northern and western coastal areas of Alaska are transition zones between the frost-bound, barren polar ice cap and the wooded extensions of the boreal forest to the south. It is a region of subtly varied landscapes, a rolling, nearly level terrain that is almost completely devoid of trees. The treeless nature of the tundra arises in part from the fact that only a very shallow layer of surface soil is released from winter frost during the brief summer growing season. Roots of growing plants cannot penetrate the permafrost, hence tundra foliage is limited to grasses, moss, lichens and small woody shrubs.

C. ESTIMATING REQUIREMENTS AND COSTS

The first comprehensive examination of revegetation requirements in the Western region was undertaken in the early 1970's [National

Academy of Sciences, 1974]. In a follow-up study, the U.S. Forest Service conducted a more intensive investigation of potentials and limitations of current mining sites in the Northern Great Plains [Packer, 1974]. Other detailed analyses have been performed by the U.S. Bureau of Land Management [1975] and other government agencies and Universities, but in most cases the results of this work are area-specific and not easily generalized to the entire region. For the purposes of the present study, the evaluations technique employed by Packer and his colleagues was extended to other important coal development areas in the West.

The Evaluations Methodology

The approach suggested by Packer requires a detailed description of each potential coal development site with respect to: (1) the productivity and stability characteristics of surface soil materials, (2) the suitability of native plant species for plant cover establishment and reproduction, and (3) the distribution and amount of normal precipitation. In the Forest Service study this was accomplished by site visitations and the use of overlay maps including, in addition to the above, present coal operations (as of 1972) and all (known) sites of strippable deposits. In some respects the level of detail in site descriptions attained in the Northern Great Plains region was not possible in the Rocky Mountain and Pacific regions due to less descriptive material available for some areas. Also, careful on-site evaluations of revegetation efforts at the mines was not within the scope or budget of this study.

The surface mineable lands in the Northern Great Plains occur in 17 soil associations, 9 general vegetation types, and 7 annual precipitation zones ranging from less than 12 inches to more than 16 inches by one-inch increments. Subsequently, some 146 individual "revegetation (rehabilitation) response units" were identified in that region. Response units (mine sites) in the other regions having similar soil-vegetation-precipitation characteristics were assumed to exhibit essentially the same response to revegetation efforts. However, new response units had to be constructed for the majority of mines situated outside the Northern Great Plains region.

The evaluation procedure involved ranking mine sites according to a standard set of "qualitative" criteria. A composite ranking number for each response unit was obtained by giving an equal weight to the separate evaluations: (1) soils--productivity, toxicity, stability (texture, slope); (2) vegetation for the declared end use of the reclaimed land--suitability (erosion control and resilience), availability of seed supply; and (3) mean precipitation--its annual amount and seasonal distribution. To be consistent with Packer's procedure a numerical scale of +8 (very good) to -8 (very poor) was used. These numbers indicate... "the relative degree of ease or difficulty [potential] that should be anticipated in attempting to rehabilitate a unit area of surface-mined land of given soil, native vegetation and precipitation characteristics" [Packer, 1974].

In the present analysis emphasis is also placed on the input requirements for successfully establishing a permanent plant cover, consistent with state and/or federal reclamation laws (i.e., introduced and native species), once the overburden has been replaced and graded and an appropriate topsoil redistributed. Since the sensitivity of these results depend upon natural influences, standard cultural practices, soil amendments, seeding rates, range management, etc. are assumed.

Results of the Analysis

The principal questions addressed in this part of the study involved: (1) the capacity of these various, diverse natural environments to foster sustained revegetation under normal conditions and accepted practice; (2) the incidence of mined area disturbance now and in the near future; and (3) the nature and magnitude of revegetation costs. The following is a review of the more important conclusions to be drawn from the analysis with the empirical evidence summarized in table 5.

Revegetation Potentials

Throughout the western region the potential for successfully revegetating surface mined lands in a normal weather year is highly variable (table 5). In the Northern Great Plains, for example, revegetation efforts in Montana and North Dakota are expected to be (on average) "fairly good," while Wyoming is ranked "fairly poor." In the Rocky Mountain Region Colorado receives a "good" rating, but the states of Utah, Arizona and New Mexico are considerably lower with a ranking of "poor" to "very poor." In the Pacific Region Washington is rated "very good" while Alaska, in the absence of better information, must also be regarded having fairly poor revegetation potential. On the whole the entire Western region is given only a "fair" chance for revegetation

TABLE 5. SUMMARY OF REVEGETATION POTENTIALS, ANNUAL MINED ACREAGE AND ESTIMATED COSTS OF THE REVEGETATION COMPONENT IN WESTERN SURFACE MINE RECLAMATION.

Coal Production Area	Mine	Revegetation Potential 1/ On-Site Evaluation		Revegetation Potential 1/ Numerical Ranking	Annual Mined Acreage 2/		Mined Acreage per 10^5 Tons of Coal Mined		Acreage Weighted Numerical Ranking 3/		Estimated Revegetation Cost ($/AC) 4/
		Descriptive	Numerical		1976	1980	1976	1980	1976	1980	
	NORTHERN GREAT PLAINS REGION:										
MT2	Savage	Good	+6	+2	56	103	4.7	4.7	+2	+2	$175
MT3	Circle West			+3		62*		2.1	+3	+3	162
MT4	Decker #1	Fairly Good	+3	+2	130	95					175
MT4	Absaloka	Fairly Poor	-3	-2	85	212					250
MT4	Big Sky	Fairly Good	+3	+2	92	180					175
MT4	Rosebud	Fairly Good	+3	+2	445	633					175
MT4	Decker N.			+2		41*					175
MT4	Decker W.			+2		103*					175
MT4	Younger Cr.			+1		82*					188
MT4	Tanner Cr.			-1		123*					225
	Totals, MT4:				752	1,469	2.5	2.5	+1.5	+1.4	$181
Totals, Montana:					808	1,634	2.6	2.5	+1.6	+1.5	$183
ND1	Velva	Very Good	+9	+8	85	194					$100
ND1	Noonan	Very Good	+9	+7	175	233					112
	Totals, ND1:				260	427	10.0	9.5	+7.3	+7.5	108
ND2	Center	Fairly Good	+3	+1	254	424					188
ND2	Glenharold	Fairly Good	+3	+1	322	322					188
ND2	Beulah	Good	+6	+5	105	221					138
ND2	Indian Head	Fairly Good	+3	+1	101	116					188
ND2	Falkirk (NAC, Inc.)			+3		373*					162
ND2	(North American)			+2		373*					175
ND2	Falkirk			+3		410*					162
	Totals, ND2:				782	2,239	7.9	7.6	+1.5	+2.3	$181

(Continued)

TABLE 5. ...Continued...

Coal Production Area	Mine	Revegetation Potential[1/] On-Site Evaluation Descriptive	Revegetation Potential On-Site Evaluation Numerical	Revegetation Potential Numerical Ranking	Annual Mined Acreage[2/] 1976	Annual Mined Acreage 1980	Mined Acreage per 10^5 Tons of Coal Mined 1976	Mined Acreage per 10^5 Tons of Coal Mined 1980	Acreage Weighted Numerical Ranking[3/] 1976	Acreage Weighted Numerical Ranking 1980	Estimated Revegetation Cost ($/AC)[4/]
North Oakota (continued)											
NO3	Gascoyne	Good	+6	+5	210	466					$138
NO3	Lehigh			+4	19	47					150
NO3	Heart Butte			+3		158*					162
	Totals, NO3:				229	671	7.9	7.9	+4.9	+4.5	$136
Totals, North Oakota:					1,271	3,337	8.3	7.8	+3.3	+3.4	$158
WY1	8ighorn	Good	+6	+5	14	21					$138
WY1	PSO #1			+4	4	7					150
	Totals, WY1:				18	28	1.4	1.4	+4.8	+4.8	$142
WY2	8elle Ayr S.	Fairly Good	+3	0	58	146					$200
WY2	Wyodak N, S.	Good	+6	+1	7	51					188
WY2	N. Rawhide			+1		65					188
WY2	Coballo			+1		41					188
WY2	(Falcon Coal)			+1		10*					188
WY2	Cordero			+1		163					188
WY2	Eagle Butte			0		78					200
WY2	8lack Thunder			-1		124					225
WY2	Coal Cr.			+1		74*					188
WY2	Thunderbird			0		251					200
WY2	E. Gillette #16			+1		48					188
WY2	Jacobs Ranch			+1		179					188
WY2	(Texaco, Inc.)			0		55					200
WY2	E. Gillette			+1		56					188
WY2	(Mobile Oil)			0		49*					200
WY2	Rochelle			-2		126					$250

(Continued)

TABLE 5. ...Continued...

Coal Production Area	Mine	Revegetation Potential[1/] On-Site Evaluation: Descriptive	Numerical	Numerical Ranking	Annual Mined Acreage[2/] 1976	1980	Mined Acreage per 10^5 Tons of Coal Mined 1976	1980	Acreage Weighted Numerical Ranking[3/] 1976	1980	Estimated Revegetation Cost ($/AC)[4/]
Wyoming (continued)											
WY2	Buckskin			+1		33					$188
WY2	Powder River			+1		148*					188
	Totals, WY2:				65	1,697	1.1	1.2	+ .1	+ .4	$198
WY3	Seminoe #1			-2	94	94					$250
WY3	Seminoe #2			-2	58	51					250
WY3	Jim Bridger			-3	54	227					275
WY3	Rim Rock			-2	76	109					250
WY3	Medicine Bow			-2	272	299					250
WY3	Dave Johnson	Fairly Good	+3	-1	48	48					225
WY3	Rosebud Pits 4&5			-2	86	68					250
WY3	Black Butte			-3		153					275
WY3	China Butte			-2		93					250
WY3	Red Rim			-2		102					250
WY3	Atlantic Rim			-2		192					250
	Totals, WY3:				688	1,436	4.4	4.4	-2.0	-2.2	$250
WY4	Skull Point			-2	10	24					$250
WY4	Elkol			-2	8	9					250
WY4	Sorenson			-2	68	109					250
WY4	Twin Cr.			-2		61					250
WY4	North Block			-2		68					250
	Totals, WY4:				86	271	2.2	2.3	-2.0	-2.0	$250
Totals, Wyoming:					857	3,432	3.2	1.9	-1.7	- .8	$243
Totals, NGP Region:					2,936	8,403	4.0	2.9	+1.4	+1.3	$182

(Continued)

TABLE 5. ...Continued)

Coal Production Area	Mine	Revegetation Potential 1/ On-Site Evaluation: Descriptive	Numerical	Numerical Ranking	Annual Mined Acreage 2/ 1976	1980	Mined Acreage per 10^5 Tons of Coal Mined 1976	1980	Acreage Weighted Numerical Ranking 3/ 1976	1980	Estimated Revegetation Cost ($/AC) 4/
	ROCKY MOUNTAIN REGION:										
CO1	Edna			+4	159	185					$150
CO1	Energy #1			+4	40	40					150
CO1	Energy #2			+4	211	352					150
CO1	Energy #3			+4	159	211					150
CO1	Seneca #2			+4	111	111					150
CO1	Williams Fork #1			+3	18*	64*					162
CO1	Williams Fork			+3		86					162
CO1	(American Electric)			+4		46*					150
	Totals, CO1:				698	1,095	11.5	9.8	+4.0	+3.9	$150
CO2	Marr #1			+1	18*	36*					$188
CO2	Canadian			+1	18*	18*					188
	Totals, CO2:				36*	54*	9.0	9.0	+1	+1	$188
CO3	Nucla			+3	9*	9*	9.0	9.0	+3	+3	$162
Totals, Colorado:					743	1,158	10.9	6.9	+3.8	+3.8	$153
NM1	Navajo			-8	282	326					$400
NM1	San Juan			-8	139	218					400
	Totals, NM1:				421	544	3.8	3.9	-8	-8	$400
NM2	McKinley			-4	33	204					$300
NM2	Star Lake			-5		163					325
	Totals, NM2:				33	367	4.1	4.6	-4	-4.5	$300
Totals, New Mexico:					454	911	3.7	3.9	-7.7	-6.6	$391

(Continued)

TABLE 5. ...Continued...

Coal Production Area	Mine	Revegetation Potential[1/] On-Site Evaluation Descriptive	Numerical	Numerical Ranking	Annual Mined Acreage[2/] 1976	1980	Mined Acreage per 10^5 Tons of Coal Mined 1976	1980	Acreage Weighted Numerical Ranking[3/] 1976	1980	Estimated Revegetation Cost ($/AC)[4/]
UT3	(Nevada Power)			-5		502*					$325
UT3	(Utah International)			-5		132*					325
	Totals, UT3 (Utah):					634*		5.3	-5.0	-5.0	$325
ARI	Black Mesa			-8	143	159					$400
ARI	Kayenta			-8	79	127					400
	Totals, ARI (Arizona):				222	286	3.2	3.2	-8.0	-8.0	$400
Totals, RM Region:					1,419	2,989	5.4	4.9	-1.7	-2.4	$243
	PACIFIC REGION:										
Washington	Centralia			+8	86	97			+8	+8	$100
Alaska	Usibelli			-2	27	39			-2	-2	$250
Totals, PAC Region:					113	136	2.4	2.7	+6.5	+6.0	$130
Totals, Western Region:					4,468	11,528	4.5	3.4	-0.4	-0.3	$198

TABLE 5. ...Continued, Footnotes

SOURCES: Consulted reference works included Keefer and Hadley [1976], Ecology Consultants, Inc. [1976], Bisselle et al. [1975], Johnson et al. [1975], Lang et al. [1975], Wali [1975], Packer [1974] and Cook et al. [1974].

1/ Completed rows are data reproduced from an earlier U.S. Forest Service study [Packer, 1974].

2/ Mined acreage (A) was estimated with the following computational formulas and assumptions:

$$y = (\bar{S} \cdot W)R \quad \text{and} \quad A = \left(\frac{Y}{y}\right)K$$

where: y = net coal yield in tons per acre,

$\bar{S}$ = average seam thickness in feet (table 4),

W = specific weight of coal in tons per acre foot,

R = recovery factor (90 percent),

Y = annual production in tons (table 3), and

K = a scaler to allow for an additional 25 percent disturbance to contiguous lands (K = 1.3).

Recovery rates for specific coal qualities (i.e., $W \cdot R$ in tons per acre foot) were: lignite, 1,395 (North Dakota and Montana); subituminous, 1,530 (Montana, Washington and Alaska), and 1,593 (Arizona, Colorado, New Mexico and Wyoming); and bituminous, 1,640 (Arizona, Colorado and New Mexico). The estimates with asterisks (*), indicating mines with insufficient information for computations, are based on coal production area weighted averages.

3/ A composite ranking based on the acreage proportions and relative potentials of individual mine sites in each coal production area.

4/ Values are determined from the scale of revegetation potential rankings, assuming +8 = $100 per acre, and increasing in equal increments through -8 = $400 per acre.

success under given conditions of soil and vegetation, normal patterns of precipitation and the incidence of current mining activity.

The sensitivity of these findings to "non-normal" weather conditions and other factors is also worth noting. Recurring drought conditions (apparently following a cycle of about 20 years in the West) can have a marked effect on revegetation efforts in <u>any</u> region. Since the evaluations procedure uses mean values, year-to-year variations in seasonal precipitation could yield substantially different conclusions. Thus, it is important that the reported findings are understood as "long term" probable consequences that do not necessarily hold for any particular time period.

Inasmuch as these results are also dependent upon the regional distribution of mining activity and levels of output, any major change in either of these variables could also change the present regional assessments. In fact, one of the important questions about revegetation in the diverse Western region is whether the present assessment will improve or worsen with the incidence of future coal development. Using the 1980 forecast of stripping coal output, the analysis indicates that (on average) change at the subregional level is of little consequence (table 5). However, significant impacts at the regional level can occur if mining activity increases relatively more in one area than another over time.

An example of this is demonstrated in the Rocky Mountain region where coal output in New Mexico, Arizona and Utah (states with lower revegetation potentials) increase relative to Colorado (having a better ranking) causing the regional ranking to fall from -1.7 to -2.4. Over a longer time horizon (e.g.,1990 or 2000) such trends could become more meaningful.

Since increases and decreases in the response ranking is indicative of relative use or difficulty in revegetating disturbed lands, sequencing lands of higher potential for poorer ones in the mining schedule is an apparent public policy option. Such comparisons might be used to restructure development forecasts or to select development sites with a more uniform rehabilitation prospect over time.

Revegetation Costs

At present no comprehensive analyses have been performed on the cost of revegetation on an area-by-area basis in the Western United States. In general, the range in costs from secondary sources of information are quite large and are typically not significantly different between regions. For the Midwestern and Eastern regions (where moisture and soils are not so limiting), Grim and Hill [1974] report the costs of numerous earlier studies which range from a low of $50 per acre to more than $200 for native grass establishment. The costs of planting trees and shrubs typically run higher, averaging perhaps $600 to $1,000 per acre. In a number of recent western studies, Hodder [1976], Berg [1977], Wali [1975], Cook [1974] and Watts [1975] report estimates from less than $100 to over $800, depending upon the levels soil amendments and treatments required (or assumed) to meet current state laws and specified end uses of the reclaimed lands. Cost estimates obtained by the author from interviews with nine operators in the study area fall in the range of $85 to $600 per acre for grazing (range) as an end use [Leathers, 1977].

Following the application of topsoil or selected overburden material, revegetation procedures usually include the incorporation of soil amendments (gypsum, sulfur or other trace elements, fertilizer, etc.) seed bed and surface preparation (ridging, gauging, or other methods to improve moisture retention), planting (in the case of broadcast methods this may also include harrowing), and in some cases mulching with straw or other crop residues to inhibit evaporation at the soil surface. In some instances a side dressing of fertilizer may be applied in the spring following the first season of plant growth. Under normal circumstances the expected direct costs of such operations in most areas of the western region should not exceed about $150 per acre (in 1976 dollars) for native grass establishment [Watts, 1975 (Appendix B)]. Reseeding in years of abnormally low rainfall, possibly as often as every third year, could increase this base estimate by one-third or more.

Sprinkler irrigation methods during the first year of revegetation have been advanced as a possible solution to the problem of establishment where ample water supplies are available [National Academy of Sciences, 1974]. Thus far, the cost effectiveness of this technology has not been carefully examined. Only one operation in the study area, Utah International's Navajo mine, routinely uses sprinkler irrigation for first-year establishment.

A careful review of available literature and conversations with specialists in the field of reclamation suggest that direct costs per acre of $100 to $400 would likely bracket 90 percent of all western mines' revegetation costs. Using this range, site-specific costs were derived with an indexing procedure: the revegetation cost of each response unit (mine site) was determined by monotonic transformation of the revegetation potentials, with the rank of +8 = $100 and -8 = $400 per acre as the two end points. Although response potentials are probably not a reliable indicator of actual revegetation expenditures within a given area or subregion, they do provide an opportunity for systematic comparisons on a regional basis which may be more reliable. The results are reported in the last column of table 5. Because of the procedure used, regional variations in cost are precisely the same as for response potentials discussed earlier.

Current and Future Disturbance

Because of substantial differences chiefly in the quality and thickness of the coal seams mined in the various regions, the amount of surface disturbance in a particular region or area is highly related to per acre tonnages rather than total output. The estimated mined acreage for each production site and subregion and each time period are reported in table 5. These estimates vary proportionally with the seam characteristics and annual output reported earlier in tables 3 and 4. It should be noted that the above estimates reflect "mined area" disturbances, and do not include the related surface disruptions caused by such activities as exploration, access roads, equipment storage and repair facilities, rail and pipe lines, and drainage catchment basins and dams. These are important sources in that they can account for as much as two to three times the area actually mined. Accurate estimates of such disturbances would involve a case-by-case study of each mine site on a recurring basis, hence it was infeasible to estimate "total" disturbance under the time and resource constraints of this study.

Based upon current levels of technology (coal recovery) and production, these data indicate that some 4,500 acres were mined in 1976. With the assumption of constant technology and production efficiency over the next four years, one can expect about 11,500 acres to be mined annually by 1980. Annual mining disturbance will increase three-fold in the Northern Great Plains and double in the Rocky Mountain region during this period. Recalling that the anticipated change in total output over the same time period was a more than three-fold increase (table 3), it follows that the improved production efficiencies (thicker coal seams) of new mines coming into production by 1980, especially in the Gillette area of Wyoming, will have a less than proportional effect on mined area disturbance.

A comparison of annual production efficiencies for each subregion, based on mined acreage estimates per 100,000 tons of coal mined during this time frame, is reported in table 5. For the entire Western region, these data suggest a drop in mined area reclamation requirements (per 100,000 tons of coal produced) from about four and one-half to less than three and one-half acres per given unit of coal mined. It is unlikely, however, that such a trend will continue much beyond 1980 as the thinner portions of coal seams become more prominent in the production mix. Rather, it is more likely that the reverse will hold beyond 1980, significantly increasing reclamation requirements both in the absolute number of acres disturbed and per unit of coal recovered.

D. SUMMARY AND LIMITATIONS

The response-unit methodology seems to be an appropriate approach to the systematic description of site-specific revegetation "potentials" in large, diverse regions such as the Western United States. The primary advantage of this technique is that individual sites can be compared qualitatively on the basis of a number of specified regional environmental factors and classification criteria. Thus, with such a method specific problem areas can be identified ex ante, and such information might prove useful to policy makers in the long term planning of coal developments.

Several shortcomings of this approach should be mentioned. The reliability of the environmental ranking scheme can be questioned as well as the method used in estimating mining disturbance. As a test of the appropriateness of the response unit methodology, Packer performed on-site evaluations of the actual reclamation efforts at all surface mines then operating in the Northern Great Plains. In general, the revegetation potentials derived from the response unit classifications appear to be well correlated with actual on-site evaluations, although somewhat more conservative. However, this does not corroborate the validity of the rankings for the Rocky Mountain and Pacific regions.

The procedure used to develop estimates of mining disturbance should yield fairly reliable results, insofar as the technical mining coefficients (chapter III) prove to be representative of current conditions. A major shortcoming of the present analysis is the fact that related disturbances (apart from actual mined acreage) were identified but not estimated. The costs of reclaiming such disturbances may not be as significant as mined land on a comparative per acre basis, but in total these costs are probably greater in absolute terms.

Clearly, a more appropriate method of estimating the costs of revegetation would be to survey representative practices (and costs), to assess revegetation response by careful on-site study, and to relate the two by applying rigorous correlation-regression analyses or similar statistical techniques to establish more reliable associations. If it can be demonstrated that mining sites with lower response potentials require greater expenditures of time and resources to achieve a standard level of revegetative performance, then the response unit methodology would be improved substantially as an analytical tool.

Chapter V

ADDITIONAL COMPONENTS AND ESTIMATES OF THE FULL COSTS OF SURFACE MINE RECLAMATION

A. INTRODUCTION

Apart from the more conventional reclamation procedures discussed in the two previous chapters, there are other aspects of the reclamation activity, less easily measured but nonetheless important, which require careful examination. This chapter brings together all of the separate elements in an attempt to estimate the full costs of mined-area reclamation.

One of the more critical phases in the reclamation of surface mined land has to do with the abatement of side-effects, namely environmental impacts which extend beyond the disturbed site. As reported in chapter II, disruption of wildlife habitat, pollution of surface streams and the dewatering of aquifers are problems which receive specific treatment in Western reclamation law. One such impact of major consequence in the semi-arid Western region is the potential disruption of scarce water supplies. The possible effects of strip mining on surface and ground water resources are discussed in section B.

Other components of reclamation cost--primarily unallocated overhead expenditures--are identified and estimated in section C. The last section of this chapter (section D) reports the estimates of total reclamation cost developed in this study. The estimated costs are summarized for each mine, coal production area and subregion. Area and regional differences are noted as well as the relative significance of the estimates in light of current coal prices.

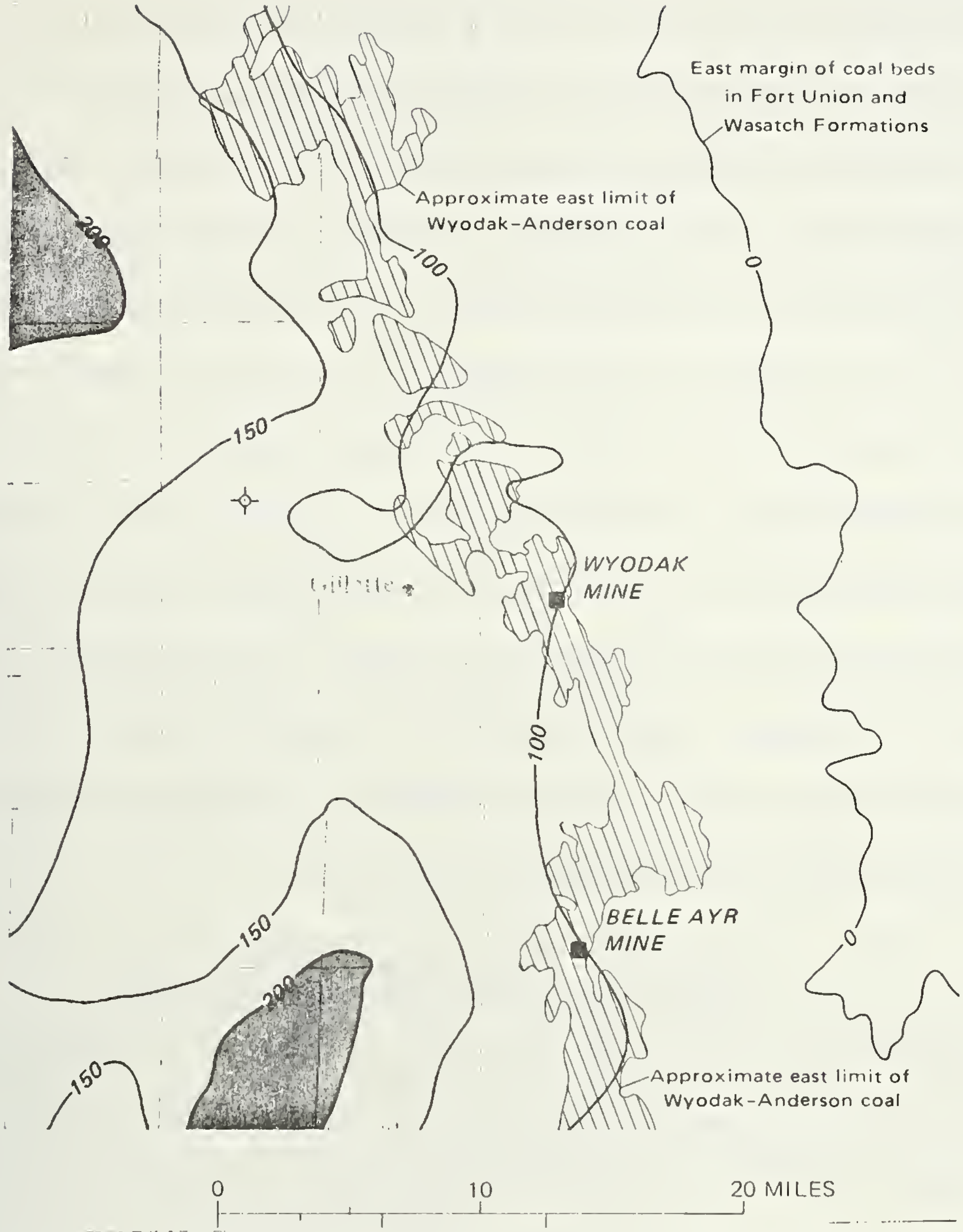
B. MINING IMPACTS ON SURFACE AND GROUNDWATERS

Surface mining of coal cannot be accomplished without some alterations in surface topography and major disruption of subsurface structures. In the semi-arid West surface and groundwaters are typically limited in both quantity and quality, and the impacts that extensive mining activity will have on local supplies is yet unknown and highly controversial.

A Case Study of Gillette Wyoming

This section reviews a case study conducted in the Gillette area of Wyoming (WY2) on the potential surface and groundwater impacts of surface mining [Keefer and Hadley, 1976]. Although development in the area has been minimal to date, current proposals call for the opening of numerous large strip mines in the next few years (Chapter III). Because the anticipated increase in activity has the potential of causing a variety of major environmental impacts, many federal, state and local government agencies as well as private organizations are focusing considerable attention on the Gillette area. As indicated in table 5, the estimated rate of disturbance in Campbell County is about 1,600 acres annually by 1980.

The greatest proportion of the vast coal resources in Campbell County is buried too deeply to be extracted with surface mining methods. However, one bed--the Wyodak-Anderson seam contained in the Fort Union and Wasatch formations--averages 50 to 100 feet thick over large areas close to the surface. The strippable portions of the seam, extending for nearly 100 miles in a north-south direction and averaging 3 miles in width, are depicted in figure 10.



SOURCE: Keefer and Hadley [1976].

Figure 10. Map of Gillette Study Area Showing Combined Thicknesses of All Coal Beds in the Fort Union and Wasatch Formations (Cross-hatched Area Represents Coal Deposits under less than 200 Feet of Overburden)

Land in the Gillette area is used principally for agricultural purposes. Although rangeland predominates, significant other uses include dryland farming and urban and industrial development. For this reason the Gillette area might be considered somewhat atypical of the majority of coal production areas in the Western region.

Most of the surface waters in the area are ephemeral, flowing only during the spring runoff period. The primary use of surface water is for irrigation of hay grown on flood plains and for livestock watering. These supplies are usually kept in small reservoirs in the lower reaches of tributary basins. Surface waters, however, account for only a small part of total available supplies. The balance is derived from groundwater sources. Two aquifer systems are of major importance: one, at a depth of less than 500 feet, is used mainly for domestic and livestock purposes, and the other deeper system supplies municipal and industrial users.

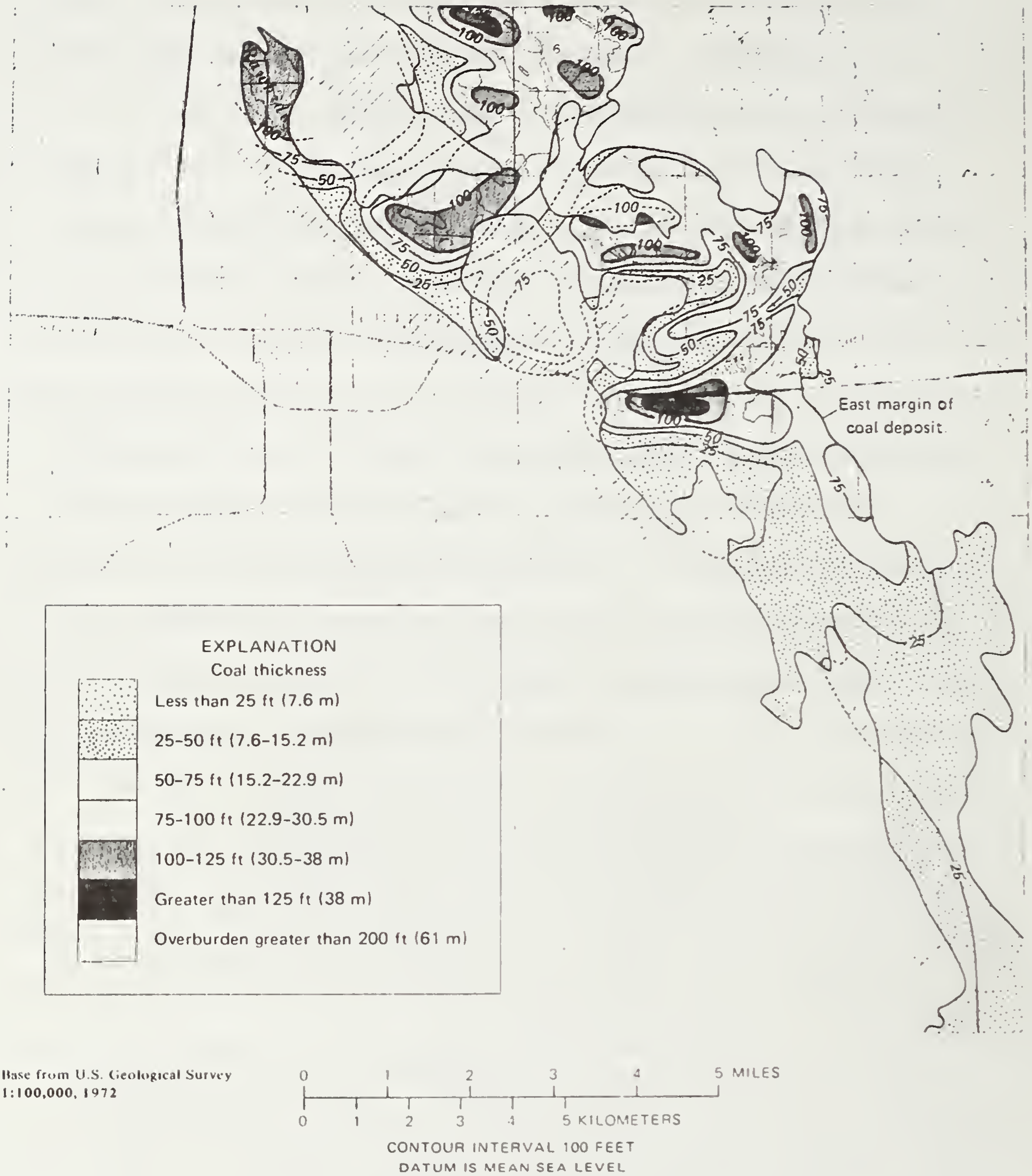
Summary of Findings and Implications

The degree to which the topography is altered by strip mining depends primarily upon the depth and thickness of the coal being mined, the composition of the overburden material before and after blasting, and the replacement of the material in the mined-out pit. The "bulking" or swell factor of the overburden material means more is replaced than removed. In certain instances the bulking factor (normally about 20 to 25 percent) may compensate for the removal of the coal, leaving about the same topographical relief as before mining. Thus, for stripping ratios of 1:4 or 5 surface topographies of relatively flat lands are modified only slightly. As demonstrated in an earlier section of this report, this is not the case for many mining operations in the Western region. This is especially true in the Gillette area, where stripping ratios are currently less than 1:1 (WY2, table 4).

Where coal seams are thick, close to the surface, and underlie large areas of land the potential for intercepting or diverting surface waters becomes a relevant reclamation problem. Figure 11 shows areas where specific thicknesses of Wyodak-Anderson bed lie less than 200 feet below the surface, and in figure 12, a cross-sectional view of changes in topography that could result where the seam exceeds 100 feet in depth over a large area. It should also be noted that subsidence over the years will add further to the depression of the mined area. Unless surface flows are carefully diverted around such extensive closed depressions, or compensated for on the mining site, impoundment of waters will take place with downstream surface supplies possibly lost to deep percolation and evaporation. Other problems may result from "gullying" along stream courses and from increased erosion both inside and outside of the mined area. Accordingly, the potential water course disruptions must be recognized and planned for on a site-specific basis.

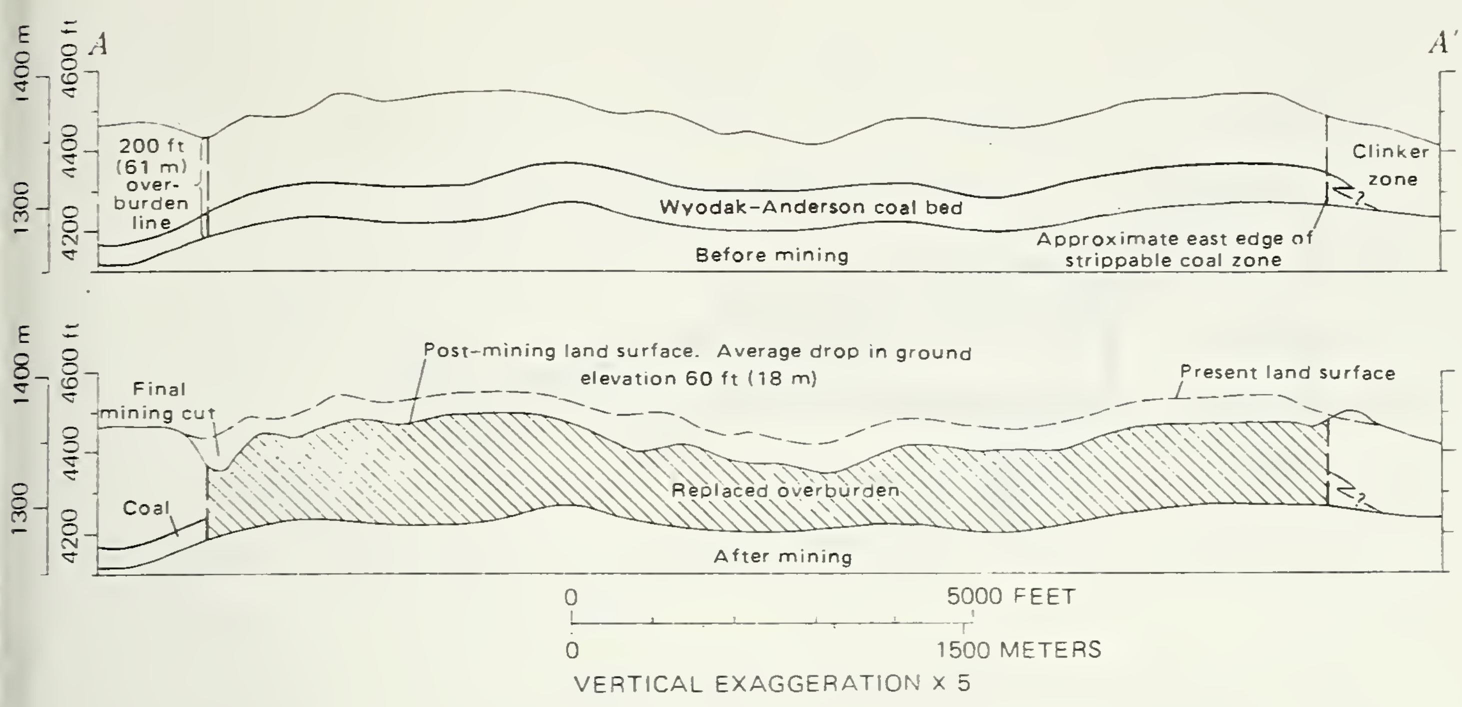
Because of the importance of groundwaters in most dry regions, the implications of mining disturbance on aquifers are potentially greater. Possible effects on groundwater levels that may result from surface mining in the Gillette area are depicted in figure 13.

Nearly everywhere along the strippable zone, highwall depths will intersect the water table (the shallow aquifers). Pre-mining conditions are represented by the cross-section lettered A in figure 13. Water wells numbered 1 through 6 illustrate the range in pumping



SOURCE: Keefer and Hadley [1976].

Figure 11. Outline of the Strippable Zone, Wyodak-Anderson Coal Deposit

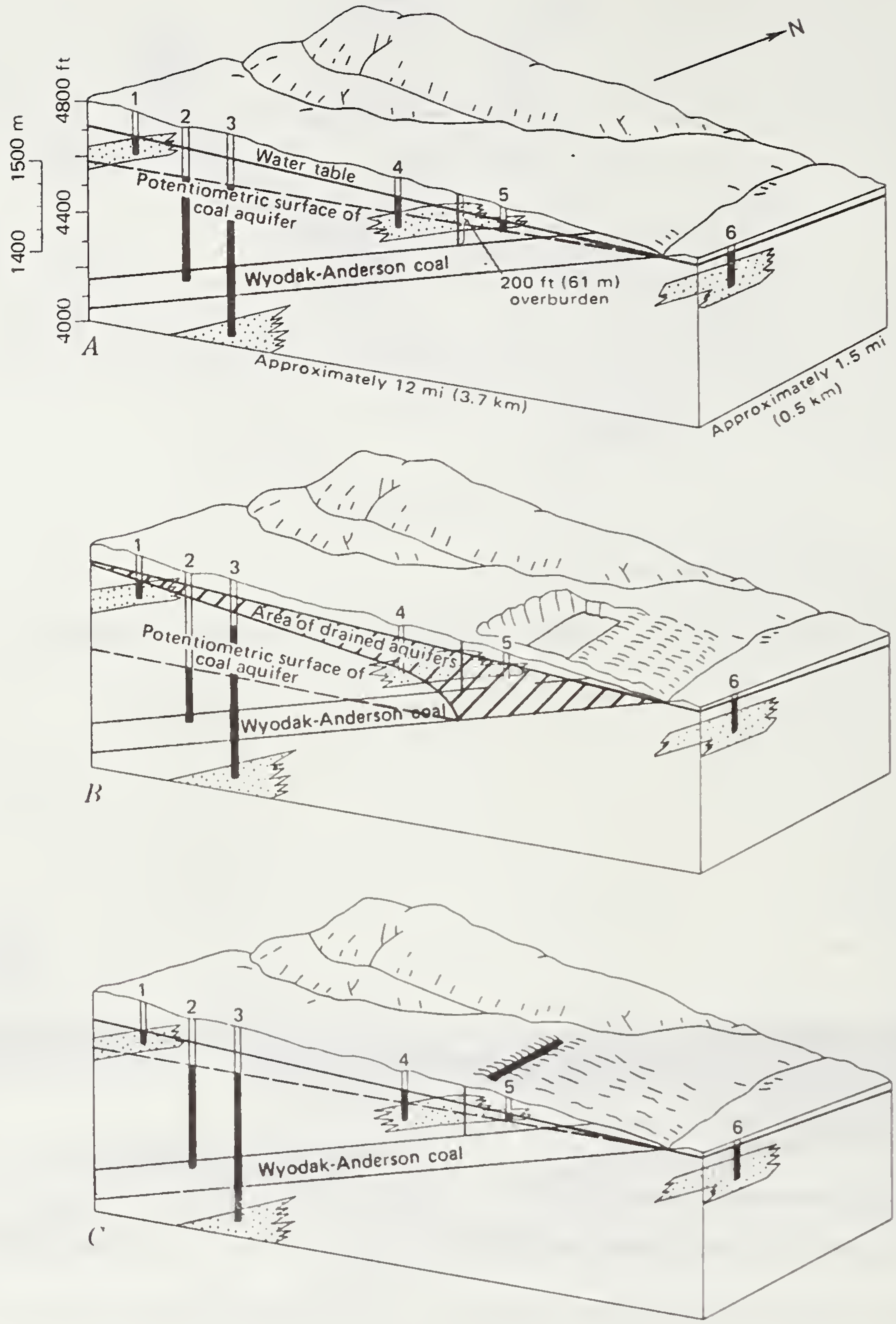


SOURCE: Keefer and Hadley [1976].

(a) Cross-Section Showing Potential Changes in Surface Topography

(b) Photo Showing an Exposed Portion of the Wyodak-Anderson Coal Bed at the Wyodak Mine, East of Gillette

Figure 12. An Example of Possible Changes in Surface Topography in the Gillette Area Due to Surface Mining



SOURCE: Keefer and Hadley [1976].

Figure 13. Cross-Sectional Diagram Showing the Possible Impacts of Surface Mining on Shallow Aquifers

depth found in the Gillette area. In cross-section B a surface mine is superimposed on the groundwater system as an illustration of the probable impact on the water table. As a consequence of mining, the water table drops in the immediate vacinity of the pit area and wells #4 and 5, and a shallow well located above the site (#1), are dewatered. Water levels in wells which bottom in the coal aquifer itself (illustrated by well #2) are affected also, since this aquifer is recharged by the tributary stream which runs below and to the east of the mined area. Well #6, which is east of the outcrop, and #3, a deep well, will probably be unaffected.

The duration of these impacts is not known. Presumably, the dewatering of shallow wells will continue for as long as mining operations are underway. Post-mining conditions, represented by cross-section C, suggest that the overburden will eventually become saturated allowing the water table to return to its previous level. This is, however, only conjecture. The permeability of certain overburden materials (eg., heavy clays with high sodium adsorption ratios) may prohibit the redevelopment subsurface flows. In such cases a suitable surrogate for the original aquifer material (the mined coal) must be replaced as a transfer medium. If appropriate materials (eg., gravel, overburden aggregates, clinker) are not readily available, it may become necessary to leave a portion of the coal seam for this purpose.

It is too early to know what the actual dimensions of the problem are in the Gillette area or what abatement measures will be required and at what costs. Other areas in the Northern Great Plains and Rocky Mountain regions face similar problems, especially where significant surface mining is proposed on alluvial fans or within natural drainage basins. However, under the new Federal law, surface mining on alluvial floors is sharply restricted. (See pages 30-31.)

C. OTHER RECLAMATION COMPONENTS

In addition to the direct expenditures for the engineering and revegetation phases, other costs are typically incurred in support of these activities. Examples of such costs include premining reclamation planning (figure 14); unallocated overhead (including the salaries of legal and reclamation specialists); monitoring, research and consultant fees; and in some cases, mine closure activities involving specific post-mining environmental standards.

Premining Planning

Planning for reclamation prior to the initiation of mining activities is required by law in all states in the Western region. Reclamation activities in the planning phase are: (1) studies of the site's drainage

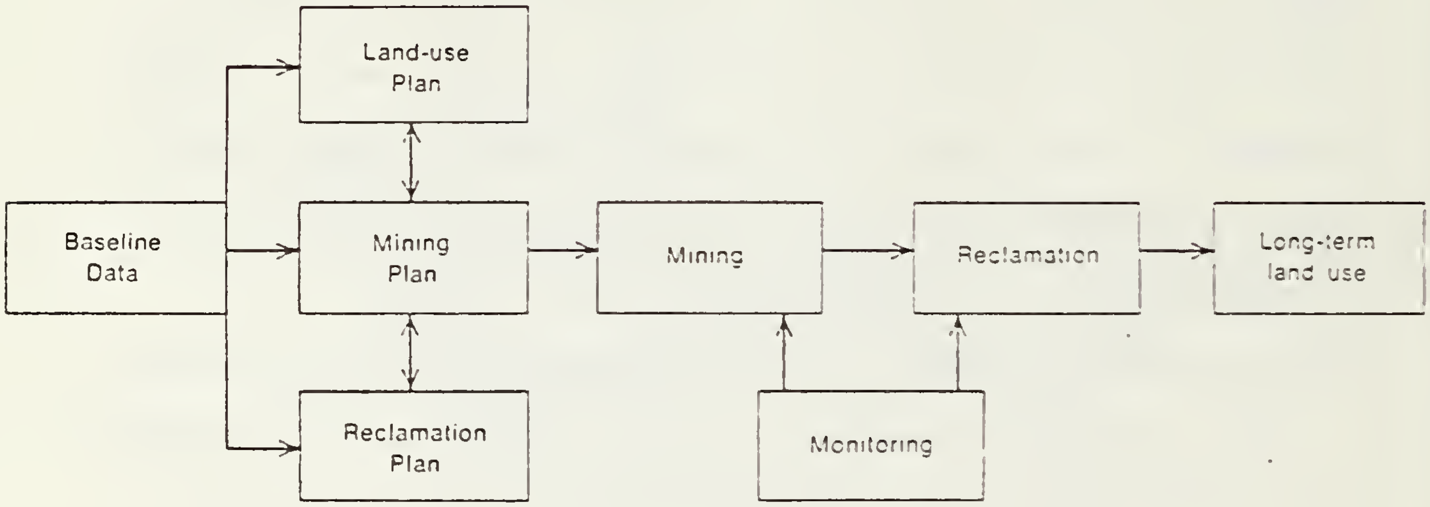


Figure 14. Simplified Schematic of Planning Activities in the Development and Operation of a Surface Coal Mine

pattern and development of appropriate baseline data on all important natural features of the site; (2) actual construction costs of various pollution abatement structures (dams, diversions, channels, sediment impoundments); and (3) the nonrefundable fees for licenses, permits, applications, bonds and fines collected by the state.

The costs of premining planning were found to be very difficult to measure. The mining operations samples in the author's survey reported costs ranging from a few dollars to over $800 per acre, with the higher estimates being reported by the larger, newer operations. In a recent U.S. Bureau of Mines study, Evans and Bitler [1976] report estimates of $190 to $380 per acre as representative of operations in the Midwest and Eastern regions. In the absence of sound information for Western operations, Bureau of Mines data was relied upon in the present study to establish the lower bound on these costs.

Operating Overhead

Most mining operations in the West maintain a staff of reclamation specialists (people with professional training in agronomy, wildlife biology, soil chemistry, range management, etc.) who are responsible for the planning and supervision of reclamation activities. In addition to reclamation specialists, all companies have a legal staff whose time is partly allocated to reviewing reclamation law and enforcement standards and policies that the operator must comply with as a condition of his right to continue mining. On the basis of the author's limited interview data, these support staffs can be of considerable size, accounting for annual expenditures by the operator of as much as $1,000 per acre in one case, and averaging about $400 per acre generally.

Other unallocated (overhead) costs include expenditures for funding research programs, consultant fees for baseline monitoring and advisory assistance, staff training and participation in workshops, and public relations.

Approach and Method of Estimation

The estimated costs of premining planning provided by Evans and Bitler [1976] were used as a lower bound for both the planning phase and unallocated (overhead) costs in this study. On the presumption that overhead costs might be better correlated with the difficulty (or ease) in reestablishing vegetation (i.e., the response potentials) than with the engineering aspects of reclamation, mine-specific overhead expenditures were determined using the indexing procedure discussed in chapter IV. Individual estimates were obtained over the range +8 = $200 and -8 = $800 per acre, with an average of $400 reflecting the results obtained in the author's sample of western operators. These results are summarized in table 6.

D. SUMMARY AND APPRAISAL OF THE ESTIMATES

The total per acre cost reported in table 6 is considerably larger than previously published estimates for the Western region [Goldstein and Smith, 1976]. Average per acre costs in Montana and North Dakota fall within the range of $4,000 to $5,000. In Wyoming per acre costs average $3,300, while estimates for New Mexico, Colorado and Arizona are slightly less than $3,000. The weighted average for the entire Western region is $3,500 per acre.

As pointed out in chapter II, most state enforcement agencies require the mining companies to submit brief reports of annual reclamation

TABLE 6. SUMMARY OF THE ESTIMATED TOTAL COSTS OF MINED AREA RECLAMATION, STATE TAXES ON COAL PRODUCTION, AND F.O.B. STEAM COAL PRICES IN THE WESTERN UNITED STATES.

Coal Production Area	Mine	Estimated Cost of Mined Area Reclamation 1/ ...By operation ($/AC) Earthworks	Revegetation	Overhead 2/	Total	...Per ton Coal Mined ($/T.)	Severance; Other State Taxes ($/T.) 3/	Coal Price f.o.b. Mine ($/T.) 4/
	NORTHERN GREAT PLAINS REGION:							
MT2	Savage	$4,140	$175	$350	$4,700	$.17		$ 5.00
MT4	Oecker #1	4,140	175	350	4,700	.05		
MT4	Absaloka	4,660	250	500	5,400	.09		
MT4	Big Sky	3,736	175	350	4,300	.11		
MT4	Rosebud	3,926	175	350	4,500	.12		
	Weighted Average, MT4:	$4,038	$181	$375	$4,600	$.07		$ 6.00
Weighted Average, Montana:		$4,171	$183	$380	$4,700	$.08	$.90	$ 6.00
N01	Velva	$4,577	$100	$200	$4,900	$.29		
N01	Noonan	3,812	112	225	4,100	.37		
	Weighted Average, N01:	$4,040	$108	$220	$4,400	$.33		$ 5.00
N02	Center	$3,897	$188	$375	$4,500	$.29		
N02	Glenharold	4,002	188	375	4,600	.30		
N02	Beulah	3,449	138	275	3,900	.17		
N02	Indian Head	3,694	188	375	4,300	.26		
	Weighted Average, N02:	$3,761	$181	$363	$4,300	$.25		$ 5.00
N03	Gascoyne	$3,502	$138	$275	$4,000	$.24		
N03	Lehigh	4,228	150	300	4,700	.34		
	Weighted Average, N03:	$3,538	$136	$280	$4,000	$.24		$ 5.00
Weighted Average North Oakota:		$3,747	$158	$318	$4,200	$.25	$.60	$ 5.00

(Continued)

TABLE 6. ...Continued...

Coal Production Area	Mine	Estimated Cost of Mined Area Reclamation[1/] ...By operation ($/AC) Earthworks	Revegetation	Overhead[2/]	Total	...Per ton Coal Mined ($/T.)	Severance; Other State Taxes ($/T.)[3/]	Coal Price f.o.b. Mine ($/T.)[4/]
WY1	Big Horn	$4,538	$138	$275	$5,000	$.06		
WY1	PSO #1	4,016	150	300	4,500	.04		
	Weighted Average, WY1:	$4,459	$142	$280	$4,900	$.05		$ 7.00
WY2	Belle Ayr S.	$1,443	$200	$400	$2,000	$.02		
WY2	Wyodak N,S.	1,443	188	375	2,000	.02		
WY2	N. Rawhide	2,738	188	375	3,300	.02		
WY2	Coballo	3,203	188	375	3,800	.03		
WY2	Cordero	3,203	188	375	3,800	.04		
WY2	Eagle Butte	4,538	200	400	5,100	.03		
WY2	Black Thunder	2,418	225	450	3,100	.03		
WY2	Thunderbird	1,728	200	400	2,300	.11		
WY2	E. Gillette #16	2,588	188	375	3,200	.03		
WY2	Jacobs Ranch	1,772	188	375	2,300	.03		
WY2	E. Gillette	2,805	188	375	3,400	.03		
WY2	Rochelle	2,938	250	500	3,700	.04		
WY2	Buckskin	3,618	188	375	4,200	.03		
WY2	(Texaco, Inc.)	3,578	200	400	4,200	.02		
	Weighted Average, WY2:	$2,784	$198	$393	$3,400	$.03		$ 9.00
WY3	Seminoe #1	$1,772	$250	$500	$2,500	$.06		
WY3	Seminoe #2	1,887	250	500	2,600	.05		
WY3	Jim Bridger	1,728	275	550	2,600	.06		
WY3	Rim Rock	1,838	250	500	2,600	.22		
WY3	Medicine Bow	1,461	250	500	2,200	.15		
WY3	Dave Johnson	3,203	225	450	3,900	.05		
WY3	Rosebud Pits 4 & 5	2,418	250	500	3,200	.11		
WY3	Black Butte	2,012	275	550	2,800	.07		

(Continued)

TABLE 6. ...Continued...

Coal Production Area	Mine	Estimated Cost of Mined Area Reclamation[1/] ...By operation ($/AC) Earthworks	Revegetation	Overhead[2/]	Total	...Per ton Coal Mined ($/T.)	Severance; Other State Taxes ($/T.)[3/]	Coal Price f.o.b. Mine ($/T.)[4/]
Wyoming (continued)								
WY3	China Butte	$2,082	$250	$500	$2,800	$.08		
WY3	Red Rim	1,959	250	500	2,700	.08		
WY3	Atlantic Rim	1,590	250	500	2,300	.17		
	Weighted Average, WY3:	$1,891	$250	$500	$2,600	$.07		$ 9.00
WY4	Skull Point	$1,959	$250	$500	$2,700	$.03		
WY4	Elkol	8,438	250	500	9,200	.07		
WY4	Sorenson	2,207	250	500	3,000	.06		
WY4	Twin Cr.	2,207	250	500	3,000	.05		
WY4	North Block	1,837	250	500	2,600	.06		
	Weighted Average, WY4:	$2,281	$250	$500	$3,000	$.05		$12.00
Weighted Average, Wyoming:		$2,610	$243	$486	$3,300	$.03	$.50	$ 9.00
Weighted Average, NGP Region:		$3,040	$182	$470	$3,700	$.04	$.60	$ 8.00
	ROCKY MOUNTAIN REGION:							
CO1	Edna	$2,014	$150	$300	$2,500	$.25		
CO1	Energy #1	1,874	150	300	2,300	.14		
CO1	Energy #2	1,680	150	300	2,100	.28		
CO1	Energy #3	2,343	150	300	2,800	.23		
CO1	Seneca #2	2,175	150	300	2,600	.16		
CO1	Williams Fork	4,980	162	325	5,500	.13		
Weighted Average, CO1, (Colorado):		$2,120	$153	$305	$2,600	$.18	$.60	$13.00

(Continued)

TABLE 6. ...Continued...

Coal Production Area	Mine	Estimated Cost of Mined Area Reclamation[1/] ...By operation ($/AC) Earthworks	Revegetation	Overhead[2/]	Total	...Per ton Coal Mined ($/T.)	Severance; Other State Taxes ($/T.)[3/]	Coal Price f.o.b. Mine ($/T.)[4/]
NM1	Navajo	$1,937	$400[5/]	$800	$3,100	$.08		
NM1	San Juan	1,520	400	800	2,700	.10		
	Weighted Average, NM1:	$1,763	$400	$800	$3,000	$.09		$13.00
NM2	McKinley	$1,683	$300	$600	$2,600	$.08		
NM2	Star Lake	1,738	325	650	2,800	.12		
	Weighted Average, NM2:	$1,721	$300	$600	$2,600	$.09		$11.00
Weighted Average, New Mexico:		$1,746	$391	$785	$2,900	$.09	$.40	$12.00
AR1	Black Mesa	$1,683	$400	$800	$2,900	$.07		
AR1	Kayenta	1,772	400	800	3,000	.07		
Weighted Average, AR1, (Arizona):		$1,717	$400	$800	$2,900	$.07	$.30	$11.00
Weighted Average, RM Region:		$1,869	$243	$485	$2,600	$.09	$.40	$12.00
	PACIFIC REGION:							
Washington	Centralia	$2,207	$100[5/]	$400	$2,700	$.05	N.A.	$ 7.00
Alaska	Usibelli	$2,957	$250	$500	$3,700	$.11	$.40	$ 9.00
Weighted Average, Pacific Region:		$2,320	$130	$484	$2,900	$.06	N.A.	$ 7.00
Weighted Average, Western Region:					$3,500	$.05	$.60	$ 9.00

TABLE 6. ...Continued, Footnotes

[1]/Costs for earthwork and revegetation are reproduced from tables 4 and 5, respectively.

[2]/Values determined from the scale of revegetation potential rankings (table 4), assuming +8 = $200 per acre, and increasing in equal increments through -8 = $800 per acre.

[3]/Total State taxes, including revenues from property tax, license fees, severance taxes and other charges levied on coal operators, were estimated from a narrative summary of taxing policies [Stinson, 1977]. Values rounded to the nearest ten cents.

[4]/Based on October, 1976 term contract quotations [Coal Week, 1976], [Voelker, 1977] and [Ackerman, 1977]. Values rounded to the nearest dollar.

[5]/Actual costs are probably considerably higher since at the Navajo mine sprinkler irrigation is used for first-year establishment of range grasses, and at the Centralia mine trees are reestablished on most mined lands.

activities and estimated costs. These data are used by the agencies to set the amount of surety bonds, which are supposed to cover the full costs of reclamation in the event that the state should have to reclaim the areas by forfeiture. In general, the cost estimates submitted by the operators during the 1976 production year compare fairly well with those reported above. Differences between the computed and reported estimates were basically random (i.e., there was no discernable trend in the discrepancies), except for the Colorado data [Jory, 1977]. The bonding levels set by the State of Colorado in that year averaged about $1,000 per acre higher than the author's computed estimates for most mines.

In comparing component costs, the data summarized in table 6 clearly indicate the singular importance of the 'engineering' requirements which account for 70 to 90 percent of total costs. The other reclamation components--revegetation, overhead and planning--typically account for only 15 to 20 percent of total costs.

Converting per acre cost to cost per ton of coal recovered is perhaps a more meaningful measure of the magnitude of reclamation costs in the Western region. In the non-western coal producing states, reclamation costs on a per ton basis range upward from about one dollar to several dollars per ton [Evans and Bitler, 1976]. Compared on a similar basis, western reclamation costs are considerably less: Montana, $.07; North Dakota, $.25; Wyoming, $.04; Colorado, $.18; New Mexico, $.09; Arizona, $.07; Washington, $.05; and Alaska, $.11.

The author did not rigorously examine the sensitivity of production costs to alternative reclamation practices. However, several general observations can be made with respect to the relative importance of reclamation in relation to other considerations including mining costs. One such comparison is with the various state taxes levied against the mine operators. Although the author's estimates of state taxes are preliminary, it is apparent from the data in table 6 that severance and other state taxes have a more significant financial impact on the mining industry than the states' reclamation requirements. In most Western states such tax levies exceed the costs of reclamation by as much as 5 to 10 times.

Perhaps of more importance is the relationship between reclamation cost and the market value of coal. Mined area reclamation in most Western states accounts for no more than one percent of mine-mouth coal values (f.o.b. prices at the railhead). The only state with reclamation costs that are a significant part of the production costs of coal is North Dakota (table 7). In that state reclamation requirements and procedures account for about 5 percent of total mining costs. For the Western region as a whole, however, reclamation costs have little practical impact on the market price of coal.

Finally, it is important to point out that the above estimates do not include the abatement costs of various environmental impacts. Depending upon the specific circumstances, such costs could add substantially to the total cost of reclamation. For this reason the estimated "full" costs reported here possibly represent a lower bound on the actual direct cost incurred by the mining companies.

TABLE 7. SUMMARY OF STATE AND SUBREGIONAL ESTIMATES OF MINED AREA DISTURBANCE AND RECLAMATION COSTS

State and Subregion	Annual (Mined) Acreage Disturbed		Mined Acreage per 100,000 Tons of Coal Recovered	Estimated Reclamation Cost		Reclamation Cost at Percent of Coal Price ($/Ton)
	1976	1980		Per Acre	Per Ton	
NORTHERN GREAT PLAINS:						
Montana	808	1,634	2.5	4,700	.08	1.3
North Dakota	1,271	3,337	7.8	4,200	.25	5.0
South Dakota	(No mining through 1980)					
Wyoming	857	3,432	1.9	3,300	.03	.3
Total or Average	2,936	8,403	2.9	3,700	.04	.5
ROCKY MOUNTAIN REGION:						
Colorado	743	1,158	6.9	2,600	.18	1.4
Utah		634	5.3			
New Mexico	454	911	3.9	2,900	.09	.8
Arizona	222	286	3.2	2,900	.07	.6
Total or Average	1,419	2,989	4.9	2,600	.09	.8
PACIFIC REGION:						
Washington	86	97	2.2	2,700	.05	.7
Alaska	27	39	3.9	3,700	.11	1.2
Total or Average	113	136	2.9	2,900	.06	.9
WESTERN REGION	4,468	11,528	3.4	3,500	.05	.6

1/ Summarized from the data reported in Table 6.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The West's vast, undeveloped reserves of strippable coal have become in recent years an important factor in the Nation's long term energy plans. Our increased reliance on coal in the future (as a possible alternative to more expensive fossil fuels) will, however, place greater pressure on the region's land and scarce water resources. The incidence and magnitude of the environmental impacts which will accompany Western surface mining are not yet known, nor are the long term private and social costs associated with the use of Western coals. This study has addressed only one of many uncertainties involved with the West's newest and most rapidly developing industry.

Mined land reclamation is a transitional phase between the pre and post mining uses of the surface land resource. In this context "reclamation" itself should carry no special connotations of goodness or badness with respect to end results, except in the sense that, as an activity, reclamation represents an "opportunity" whereby alternative end uses can be considered and planned for. Bypassing the opportunity can mean the irreversible forfeiture of choice in the reuse of land and related water and other resources in the future. To some, reclamation is necessary at any cost. To others, reclaiming mined land is warranted only if the costs to reclaim in the present are exceeded by the benefits to society in the future. Still others do not consider the future at all. This study concludes with comments addressing these different perspectives.

B. REVIEW OF MAJOR FINDINGS

Reclamation laws in the West were shown to have a number of common attributes. These, the author feels, are more important than their differences. First, the laws are strict in the sense that the mining industry is forced to comply with the "intent" as well as the letter of the law in order to protect the "right" to mine in the future. Second, they are flexible in that the promulgated rules and regulations are open to interpretation by the enforcing agencies, and inasmuch as these state agencies are partly political in nature, the opportunity exists for responding to special interests. And third, the laws are perhaps myopic in the sense that what constitutes approved standards of performance and end uses from the state perspective may not be consistent with the needs and desires of the land owner, the mine operator, the local community or society-at-large.

Most earlier studies examined the problem from a national or state perspective, attempting to identify loop-holes or required actions that would result in failure to adopt the best practicable means of achieving approved standards of performance. The findings of this study suggest that, until such time as the assumed "best practicable means" and "approved standards" are proven workable in practice, actually little can be said about the "appropriateness" of state or federal reclamation laws.

The estimates obtained in the empirical analysis of reclamation costs are the direct financial burden of the mine operators. As such the reported estimates do not reflect the public costs of administration, enforcement, monitoring and abatement of off-site externalities. Further, the cost estimates apply only to mined lands and do not include related surface disturbances. These can represent a considerable additional expense to mine operators. Thus, the reclamation costs developed in this study are only partial estimates of the full costs. Finally, it would not be appropriate to attribute these costs solely to the existence of reclamation laws. What a mine operator would do, how he would change his mining plans and procedures, in the absence of imposed regulations is only conjecture.

The wide variability observed in the mine-specific costs, the fact that large per acre costs can translate into small costs per ton (and vice versa), and the observation that per ton costs are only meaningful when considered in light of coal quality, price and the costs of production, leads to a better understanding of the complexities involved in evaluating the importance of reclamation in the West.

B. IMPLICATIONS FOR PUBLIC POLICY

Reclamation is a fairly expensive proposition in the arid Western United States: direct costs average $3,500 per acre (based on 1976 production data and 1977 dollars). On the basis of current costs, coal mining companies in the region incurred a minimum direct expenditure of $15.6 million in 1976. By 1980, based on announced production schedules and assuming an inflation rate of 8 percent, the Western coal mining industry will spend some $54.9 million annually for surface mined land reclamation.

If one views this level of expenditure from the perspective of national efficiency in resource use, the possibility arises that western reclamation represents a considerable public burden. A rigorous test of this assertion is not possible since the benefits to reclaiming western lands are not well established. Most mined lands in the region are now being reclaimed to their premining use, namely grazing land, and in some isolated instances, to dryland crop production. If one were to place a market value on such lands, for example $300 per acre (which is perhaps high), this yields a benefit-cost ratio of .1:1 at current reclamation costs, a return of ten cents on the dollar. In other words, at present costs (and performance) annual net returns from reclaimed lands would have to average about $250 per acre for reclamation to pay for itself. This rate of return is about twice that of current net returns on Class I irrigated farm land, and it is unlikely that many reclaimed areas in the West could generate this level of earnings. From a national accounting stance, then, western reclamation appears to represent a net social cost.

Of equal importance is the question of who experiences this presumed social burden. Under present contractual arrangements between the coal mining industry and the public power utilities, supply price is renegotiated periodically in response to rising production costs. Accordingly, the cost of reclamation is ultimately "passed on" to the consumers of coal-fired electrical power. Since Western coal (or electricity) is typically transported out of the region, it is more precisely the eastern households and industries who pay for reclaiming western coal lands. As pointed out earlier, however, the impact of reclamation on the price of electricity is presently not of any major consequence to individual users.

The implication to be drawn from national benefit-cost analysis is that western mined land reclamation is a sound idea whose time has not yet come; for the time being, the nation can apparently afford to sacrifice mined lands.

On the other side of the coin are the people and communities who would be asked to make this sacrifice in the interests of national economic efficiency. One of the important findings of this study was that local interests now play a very small role in the determination of reclamation objectives and standards which ultimately affect rural and small town quality of living. State legislatures have passed severance tax laws to protect small communities from the fiscal burdens of "boom town economics," but there is another dimension to the quality of rural life which apparently has not been given much attention in the working out of federal and state reclamation policies: local autonomy.

The fact that most state reclamation laws, in practice, provide for the returning of mined land to its original premining use does not set aside the fact that these laws also disenfranchise communities of self determination. The choices of alternative end uses which mined lands represent are foregone opportunities to most communities under present law, and this becomes especially important when one realizes that the possibilities for modifying regional environments are limited in the absence of coal development. Given the opportunity, local people could negotitate reclaimed land uses that are otherwise beyond their financial resources to provide themselves. Such community "projects" may not necessarily cost more than the rehabilitation of native range lands. On balance it seems a small price to pay in national economic efficiency.

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APPENDIX

APPENDIX A

WESTERN REGION COAL PRODUCTION AREAS: States and Counties[1/]

Northern Great Plains Region:

Montana

MT1 Sheridan

MT2 Dawson
Fallon
Richland
Roosevelt
Wilboux

MT3 McCone
Prairie

MT4 Bighorn
Garfield
Musselshell
Rosebud
Treasure

MT5 Custer
Powder River

South Dakota

SD1 Carson
Dewey
Harding
Perkins

North Dakota

ND1 Burke
Divide
McKenry
McKenzie
McLear
Mountrail
Ward
Williams

ND2 Billings
Burleigh
Dunn
Golden Valley
Mercer
Morton
Oliver

North Dakota (Cont.)

ND3 Adams
Bowman
Grant
Hettinger
Slope
Stark

Wyoming

WY1 Sheridan

WY2 Campbell
Johnson

WY3 Carbon
Converse

WY4 Lincoln
Sweetwater

Rocky Mountain Region:

Colorado

CO1 Moffat
Routt

CO2 Jackson

CO3 Montrose

New Mexico

NM1 San Juan

NM2 McKinley

Arizona

AR1 Apache
Conconino
Navajo

Utah

UT1 Emery
Sevier

UT2 Wayne

UT3 Garfield
Kane

Pacific Region:

Washington

Lewis

Alaska

(near Healy)

1/ Summarized from Whetzel [1976a, b].

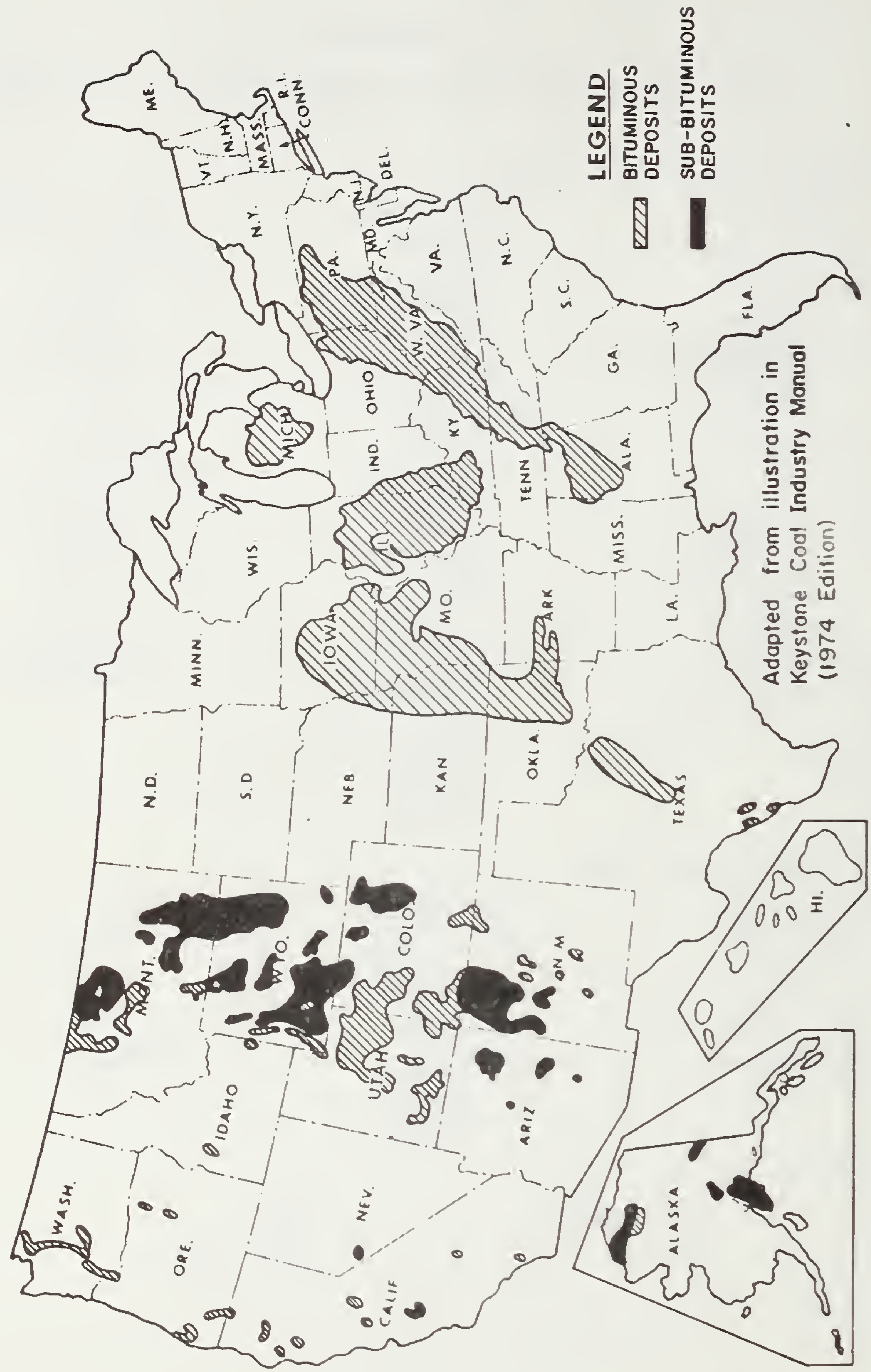
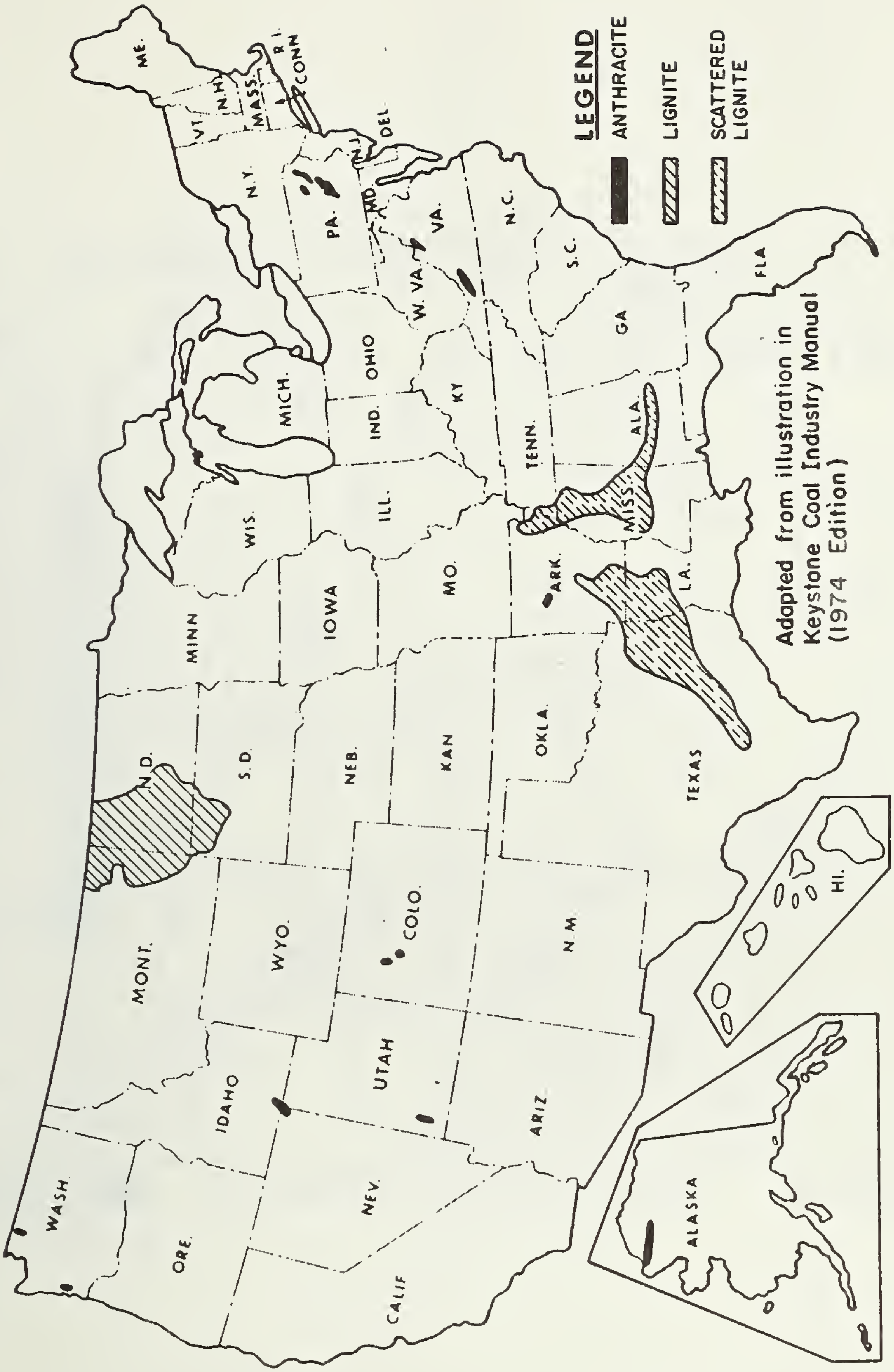


Figure A-1. Location of Major Strippable Coal Deposits in the Western United States



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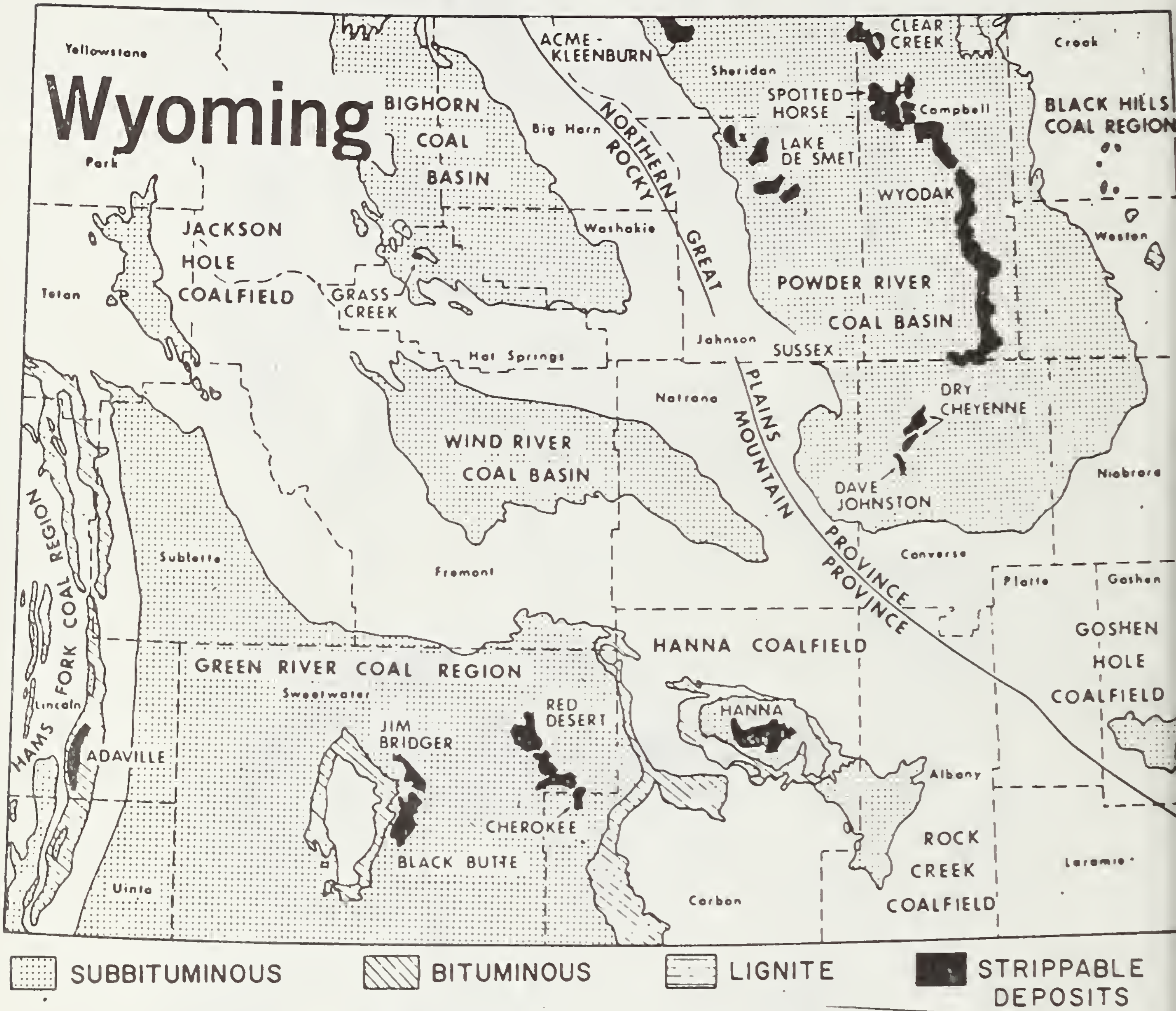
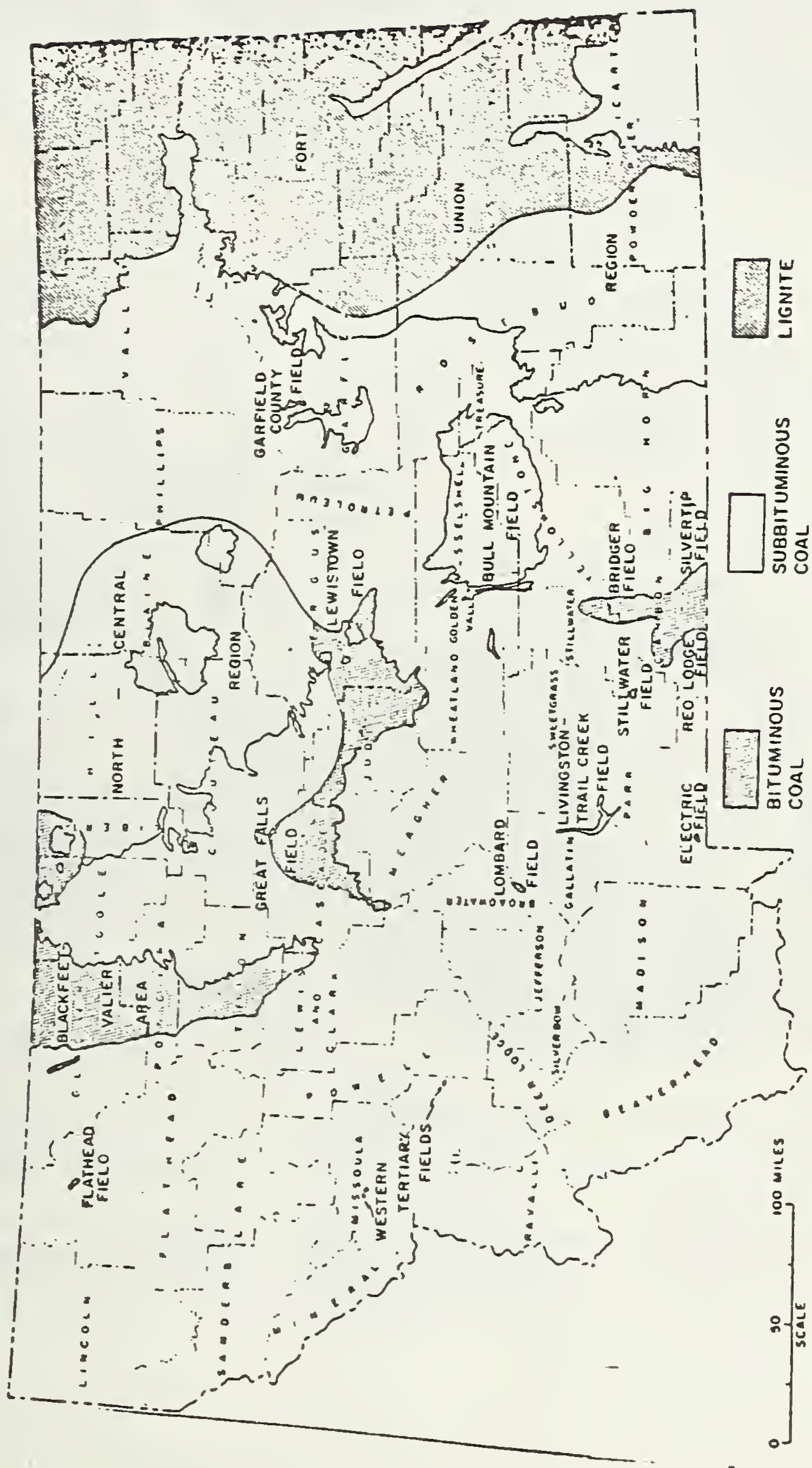


Figure A-1. ...Continued...

Montana


FLATHEAD FIELD
BLACKFEET
VALIER AREA
NORTH CENTRAL REGION
GREAT FALLS FIELD
LEWISTOWN FIELD
GARFIELD COUNTY FIELD
FORT UNION REGION
BULL MOUNTAIN FIELD
LOMBARD FIELD
LIVINGSTON-TRAIL CREEK FIELD
STILLWATER FIELD
BRIDGER FIELD
SILVERTIP FIELD
RED LODGE FIELD
ELECTRIC FIELD
WESTERN TERTIARY FIELDS
POWDER RIVER REGION
BITUMINOUS COAL
SUBBITUMINOUS COAL
LIGNITE
0 50 100 MILES
SCALE

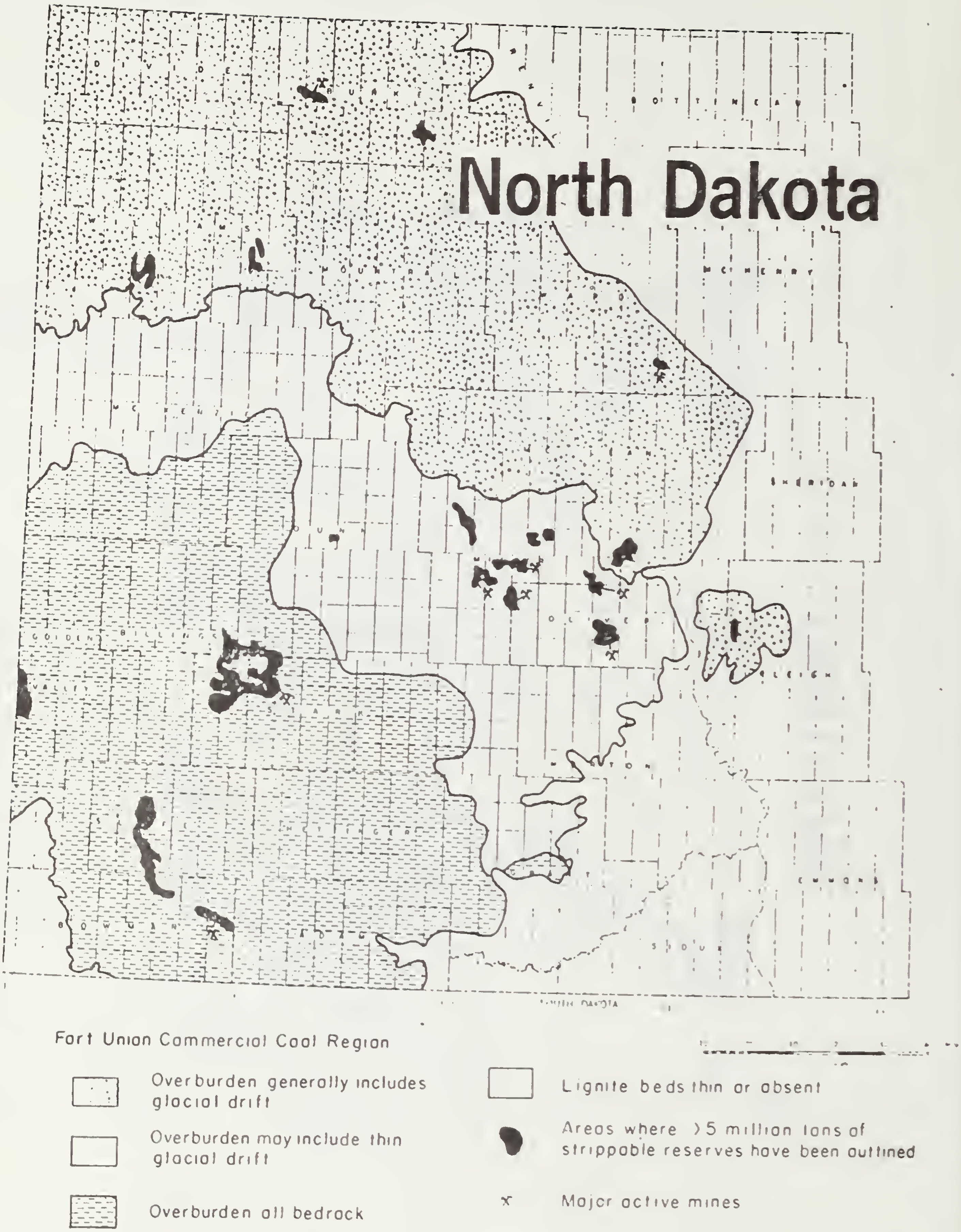
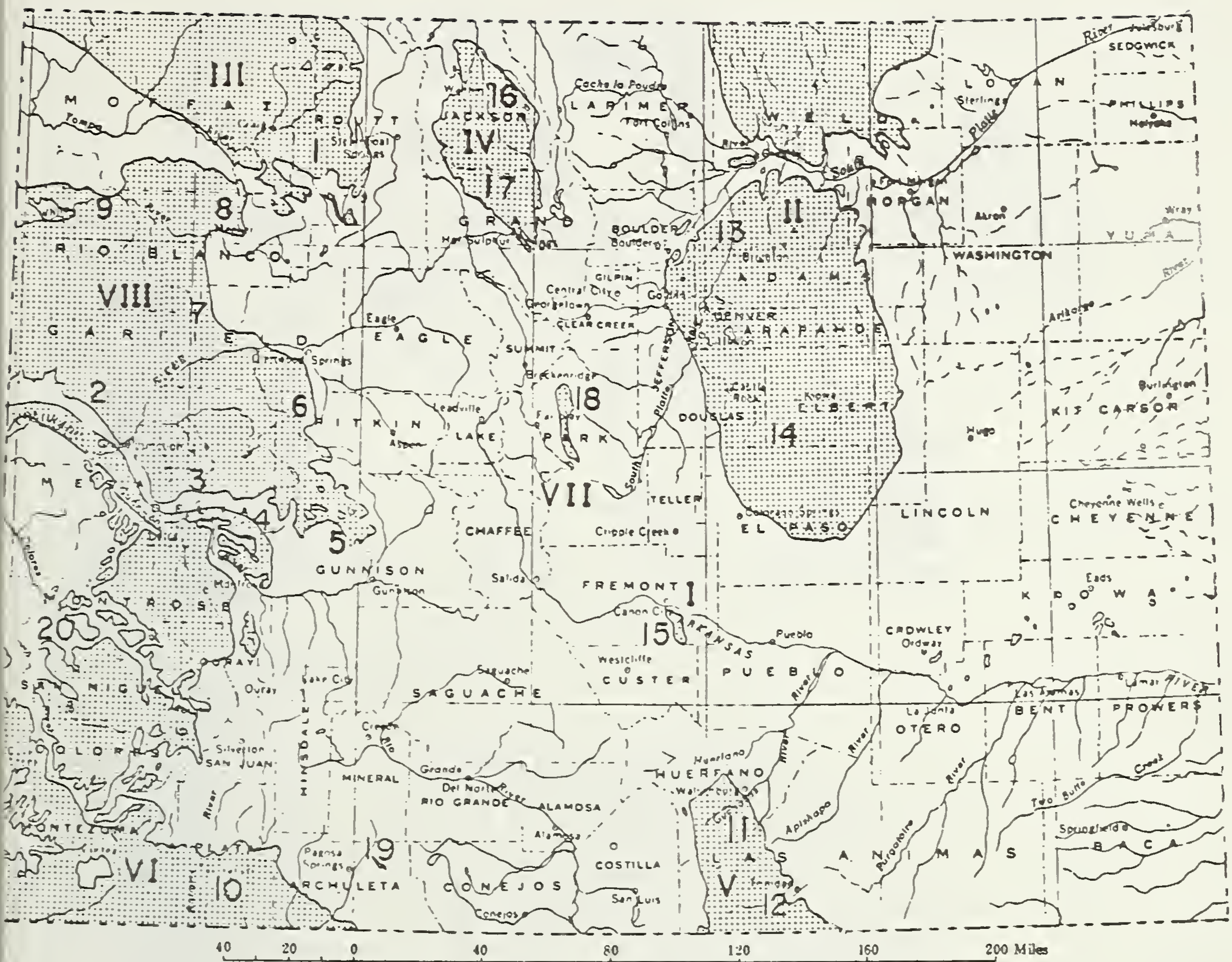


Figure A-1. ...Continued...



Coal regions and fields **Colorado**

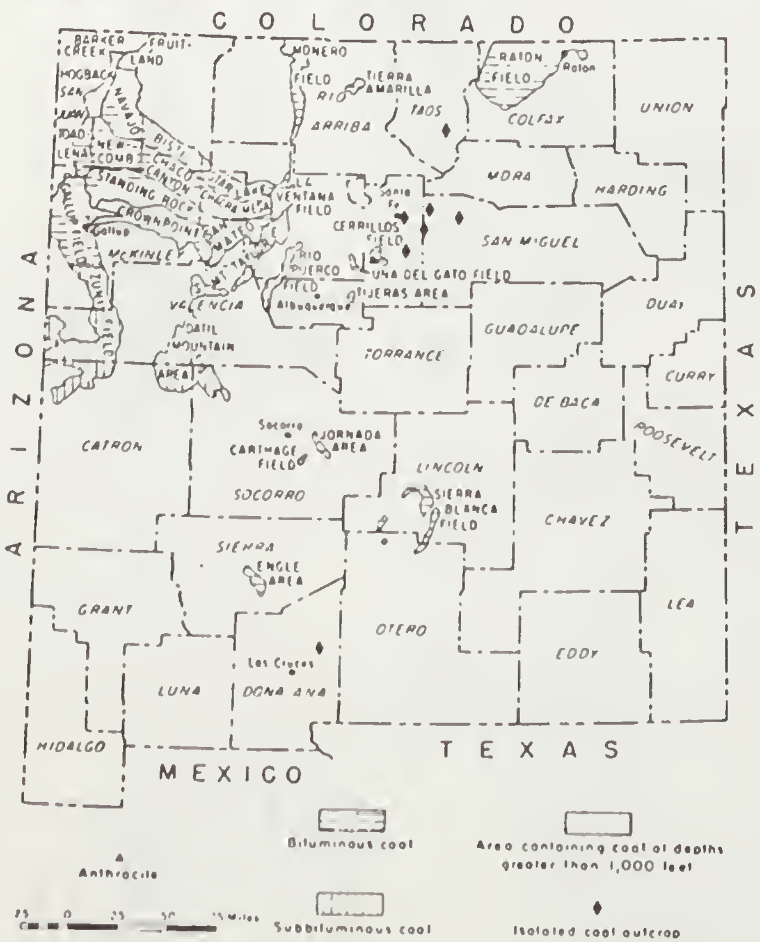
COAL REGIONS	
I	Canon City
II	Denver Basin
III	Green River
IV	North Park
V	Raton Basin
VI	San Juan
VII	South Park
VIII	Uinta

COAL FIELDS

1. Yampa
2. Book Cliffs
3. Grand Mesa
4. Somerset
5. Crested Butte
6. Carbondale
7. Grand Hogback
8. Danforth Hills
9. Lower White River
10. Durango
11. Walsenburg
12. Trinidad
13. Boulder-Weld
14. Colorado Springs
15. Canon City
16. North Park
17. Middle Park
18. South Park
19. Pagosa Springs
20. Nucla-Naturita

Figure A-1. ...Continued...

New Mexico



Utah

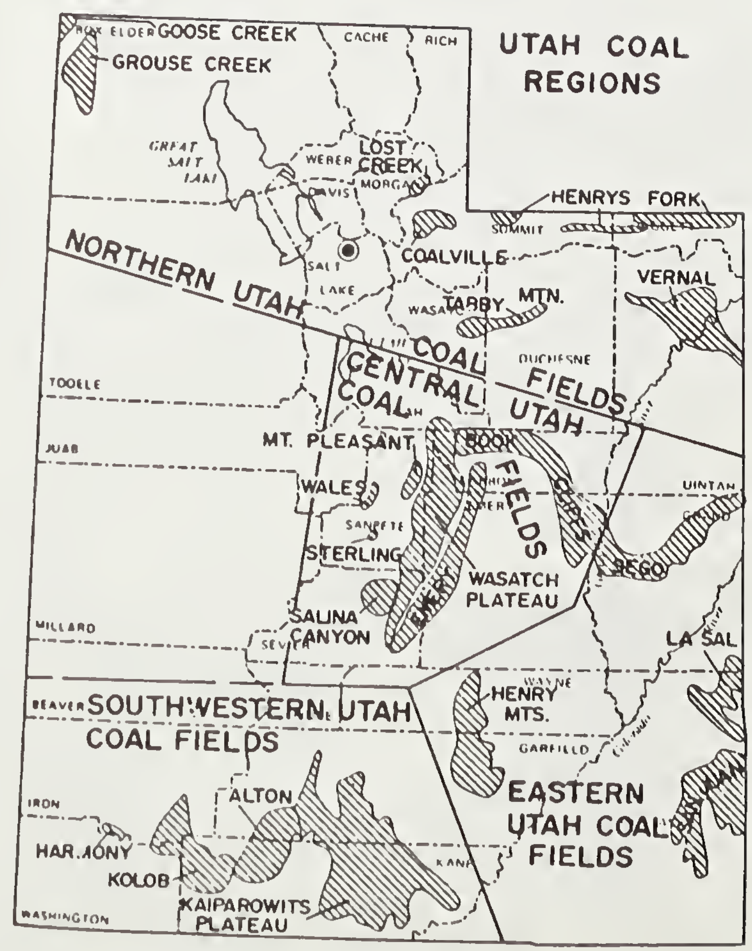
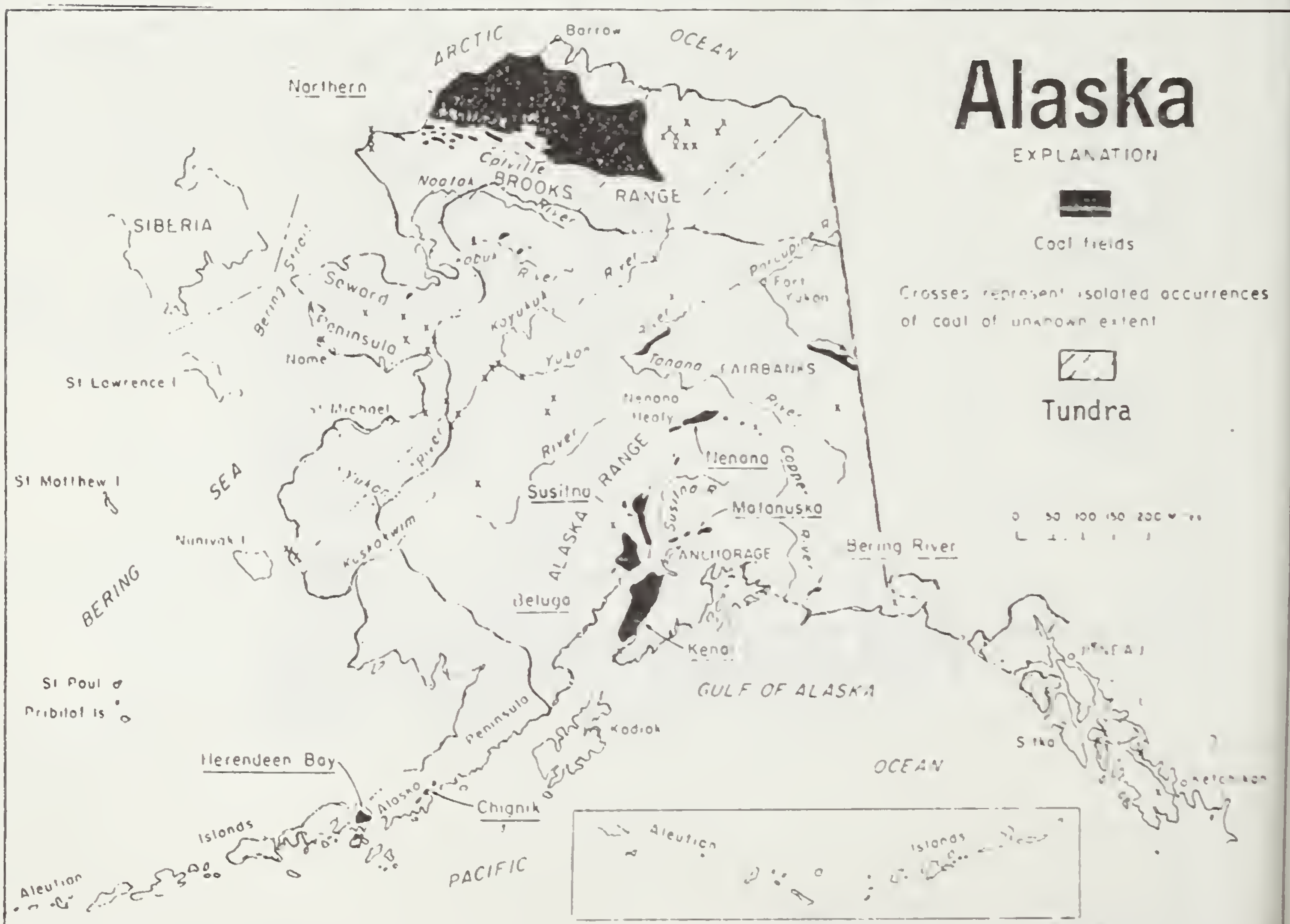


Figure A-1. ...Continued...

Figure A-1. ...Continued...


Washington
Whatcom County
Bellingham
Skagit County
Issaquah - Grand Ridge
Green River
Roslyn
Wilkeson-Carbonado
Toneum-Manastosh
Fairfax-Ashford
Centralia-Chehalis
Eastern Lewis County
Morton
Kelso - Castle Rock
EXPLANATION
Isolated coal occurrence
Anthracite coal
Bituminous coal
Subbituminous coal
Lignite
10 0 10 20 30 40 MILES


Alaska
EXPLANATION
Coal fields
Crosses represent isolated occurrences of coal of unknown extent
Tundra
ARCTIC OCEAN
Barrow
Northern
Colville River
Noatak
BROOKS RANGE
SIBERIA
Seward Peninsula
Nome
St Lawrence I
St Michael
Yukon River
Koyukuk
Tanana
FAIRBANKS
Fort Yukon
Nenana
Healy
Susitna
ALASKA RANGE
Matanuska
ANCHORAGE
Bering River
Beluga
Kenai
GULF OF ALASKA
Kodiak
St Matthew I
BERING SEA
Nunivak I
St Paul
Pribilof Is
Herendeen Bay
Chignik
Alaska Peninsula
Aleutian Islands
PACIFIC
OCEAN
Sitka

APPENDIX B

TABLE A-1. SELECTED ENVIRONMENTAL PARAMETERS FOR THE STRIPPABLE COAL AREAS OF THE WESTERN UNITED STATES

Coal Area	County	Weather Station	Precipitation (inches) Annual Mean	Precipitation (inches) Month of Max./Min.	Temperature (°F) Jan. Mean	Temperature (°F) July Mean	Temperature (°F) Frost-free Days	Soils Major Group	Soils Percent of Area	Vegetation Prominent Species	Vegetation Percent of Area
	NORTHERN GREAT PLAINS REGION:										
MT1	Sheridan	Coal Ridge	13	June/Dec.	8.6	69.8	105	Argiborolls	100	Wheatgrass-Needlegrass	100
MT2	Roosevelt	Culbertson	13	June/Feb.	9.5	70.7	111	Argiborolls	100	N. Floodplain forest Wheatgrass-Needlegrass	50 ± 15 50 ± 15
MT2	Dawson	Savage	12.4	June/Dec.	24.8	69.8	130	Argiborolls Ustorthents	50 ± 10 50 ± 10	Grama-Wheatgrass Needlegrass	 100
MT2	Richland	Crane	13	June/Dec.	10.4	69.8	130	Ustorthents Argiborolls	75 ± 10 25 ± 10	Wheatgrass-Needlegrass	100
MT2	Fallon	Plevna	11.8	June/Dec.	14	71.6	116	Ustorthents Argiborolls	40 ± 10 60 ± 10	Wheatgrass-Needlegrass	100
MT2	Wibaux	Wibaux	11.8	June/Dec.	12.2	68	138	Haploborolls	100	Wheatgrass-Needlegrass	100
MT3	McCone-Prairie	Circle	11.4	June/Feb.	11.2	69.8	110	Argiborolls Ustorthents	80 ± 10 20 ± 10	Grama-Needlegrass Wheatgrass	 100
MT4	Musselshell	Melstone	11.8	June/Feb.	21.2	73.4	130	Ustorthents	100	E. Ponderosa forest Wheatgrass-Needlegrass	60 ± 15 40 ± 15
MT4	Bighorn	Decker	15.7	June/Jan.	21.2	71.6	118	Ustorthents Paleargids	50 ± 10 25 ± 10	Grama-Needlegrass	90 ± 10
MT4	Bighorn	Hardin	12.2	June/Feb.	20.1	71.6	123	Ustorthents	80 ± 10	E. Ponderosa forest Grama-Wheatgrass	50 ± 15 50 ± 15
MT4	Rosebud	Colstrip	15	June/Dec.	21.2	71.6	130	Ustorthents	100	E. Ponderosa forest Grama-Wheatgrass	70 ± 15 30 ± 15
MT5	Custer	Miles City	11.8	June/Dec.	15.9	75.2	149	Ustorthents	100	Wheatgrass-Needlegrass	90 ± 15
MT5	Powder River	Broadus	13.6	June/Jan.	20.1	71.6	125	Arguistolls	90 ± 10	Grama-Needlegrass	90 ± 5
MT5	Powder River	Sonnetta	11.4	June/Dec.	20.1	72	125	Arguistolls Ustorthents	50 ± 10 50 ± 10	E. Ponderosa forest Grama-Wheatgrass	90 ± 10 10 ± 10

(Continued)

SOURCES: General references include U.S. Bureau of Land Management [1975], National Academy of Sciences [1974], Packer [1974], Whiteman [1973], Aandahl [1972], Bassett and Jensen [1971], Gifford [1967], Austin [1965], Kuchler [1964], U.S. Department of Agriculture [1964], and Thornthwaite [1941].

TABLE A-1. ...Continued...

Coal Area	County	Weather Station	Precipitation (inches) Annual Mean	Precipitation (inches) Month of Max./Min.	Temperature (°F) Jan. Mean	Temperature (°F) July Mean	Temperature (°F) Frost-free Days	Soils Major Group	Soils Percent of Area	Vegetation Prominent Species	Vegetation Percent of Area
ND1	Burke	Columbus	14.2	June/Feb.	6.8	71.6	114	Arguistolls Haplustolls	75 25	Wheatgrass-Bluestem	100
ND1	Ward	Kenmore	15.6	June/Jan.	6.8	68	100	Arguistolls Haploborolls	80 20	Wheatgrass-Bluestem	100
ND1	Williams	Williston	14.6	June/Feb.	8.6	72	128	Haplustolls	70 ± 15	Wheatgrass-Needlegrass	100
ND1	Mountrail-McKenzie	Stanley	13.4	June/Dec.	6.8	68	104	Ustorthents Haplustolls	55 45	Wheatgrass-Needlegrass N. Floodplain forest	65 35
ND1	McHenry	Velva	14.5	June/Feb.	8.6	69.8	116	Arguistolls	100	Wheatgrass-Bluestem	100
ND2	Golden Valley	Beach	14.6	June/Dec.	12.2	69.8	116	Haplustolls Arguistolls	35 ± 10 35 ± 10	Wheatgrass-Needlegrass	100
ND2	Billings	Bellfield	16.9	June/Dec.	10.4	70	113	Natrustolls Arguistolls	50 ± 10 40 ± 10	Wheatgrass-Needlegrass	100
ND2	Dunn	Dickenson	17.3	June/Dec.	10.4	70	112	Natrustolls Haplustolls	50 ± 10 30 ± 10	Wheatgrass-Needlegrass	100
ND2	Morton	New Salem	18.1	June/Dec.	8.6	69	122	Arguistolls Ustorthents	70 ± 10 50 ± 10	Wheatgrass-Needlegrass N. Floodplain forest	67 33
ND3	Stark-Mercer	Beulah	15.0	June/Dec.	6.8	69.8	112	Arguistolls Haplustolls	45 ± 15 35 ± 15	Wheatgrass-Needlegrass	100
ND3	Mercer	Washburn	15.0	June/Dec.	10.4	71.6	113	Ustipsamments Arguistolls	60 ± 10 15 ± 10	Wheatgrass-Needlegrass	100
ND3	Oliver	Center	18.1	June/Dec.	8.6	69	113	Arguistolls Ustorthents	70 ± 10 20 ± 10	Wheatgrass-Needlegrass N. Floodplain forest	60 40
ND3	Slope	Bowman	15.0	June/Dec.	15.2	77	127	Arguistolls Ustorthents	60 ± 10 25 ± 10	Wheatgrass-Needlegrass	100
ND3	Bowman-Adams	Reader	13.0	June/Dec.	15.2	71.6	127	Arguistolls Haplustolls	60 40	Wheatgrass-Needlegrass N. Floodplains forest	55 45
SD1	Harding	Ludlow	13.4	June/Dec.	17.6	71.6	116	Ustorthents Natrustolls	65 35	Wheatgrass-Needlegrass	100

(Continued)

TABLE A-1. ...Continued...

Coal Area	County	Weather Station	Precipitation (inches) Annual Mean	Precipitation (inches) Month of Max./Min.	Temperature (°F) Jan. Mean	Temperature (°F) July Mean	Temperature (°F) Frost-free Days	Major Group	Percent of Area	Vegetation Prominent Species	Vegetation Percent of Area
WY1	Sheridan	Sheridan	15.7	June/Jan.	19.4	72	120	Ustorthids Haplargids	70 ± 10 15 ± 10	E. Ponderosa forest Grama-Sagebrush Steppe	80 ± 10 10 ± 10
WY2	Johnson	Buffalo	12.6	May/Jan.	24.8	68	120	Paleargids Haplargids	50 50	Grama-Needlegrass	100
WY2	Campbell	Billette	13.0	May/Feb.	21.2	72	128	Haplargids	100	Wheatgrass-Needlegrass Gramagrass-Sagebrush Steppe	55 ± 10 45 ± 10
WY3	Converse	Glenrock	14.2	May/Feb.	23	71.6	125	Paleargids	100	Grama-Needlegrass	100
WY3	Carbon	Hanna	9.4	May/Feb.	23	64.4	105	Haplargids	100	Sagebrush Steppe Grama-Wheatgrass	50 ± 10 50 ± 10
WY4	Lincoln	Kemmer	9.1	May/Sep.	17.6	62.6	65	Argiborolls	100	Sagebrush Steppe	100
WY4	Sweetwater	Rock Springs	8.3	Apr./Dec.	18.5	68	78	Haplargids	100	Sagebrush Steppe Saltbrush-Greasewood	90 10
	ROCKY MOUNTAIN REGION:										
CO1	Moffat	Craig	15.7	May/Feb.	15.2	66.2	150	Paleborolls Cryoborolls	35 ± 10 25 ± 10	Mountain-Mahogany-Oak Western Spruce-fir forest	85 ± 10 10 ± 10
CO1	Routt	Hayden	20.7	May/Nov.	15.2	62.6	68	Paleborolls Cryoborolls	55 ± 10 30 ± 10	Sagebrush Steppe Mountain-Mahogany-Oak	85 ± 10 10 ± 10
CO2	Jackson	Walden	9.1	Aug./Jan.	15.1	59	61	Haplargids	100	Sagebrush Steppe Western Spruce-fir forest	90 ± 5 10 ± 5
CO3	Montrose	Uravan	15.7	Aug./June	23.2	66.2	112	Torriothents Haplargids	60 ± 10 30 ± 10	Great Basin Sagebrush Juniper-Pinyon woodland Pine-Spruce-fir forest	20 ± 10 40 ± 10 40 ± 10
NM1	San Juan	Fruitland	7.1	Aug./Nov.	27.8	77	161	Torriorthents	100	Grama-Galleta Steppe	100
NM2	McKinley	Gallup	11.4	Aug./June	27.8	69.8	170	Torriorthents Arguistolls	75 ± 10 20 ± 10	Juniper-Pinyon woodland Grama-Galleta Steppe	80 ± 10 10 ± 10
NM2	McKinley	Crown Point	8.7	Aug./Nov.	30	71.6	175	Haplorgids	95 ± 5	Juniper-Pinyon woodland Grama-Galleta Steppe	50 50
NM2	McKinley	Thoreau	9.4	July/Aug.	30	69.8	170	Torriothents	95 ± 5	Juniper-Pinyon woodland Grama-Galleta Steppe	60 40

(Continued)

TABLE A-1. ...Continued...

Coal Area	County	Weather Station	Precipitation (inches) Annual Mean	Precipitation (inches) Month of Max./Min.	Temperature (°F) Jan. Mean	Temperature (°F) July Mean	Temperature (°F) Frost-free Days	Soils Major Group	Soils Percent of Area	Vegetation Prominent Species	Vegetation Percent of Area
UT1	Emery	Emery	7.5	July/Nov.	21.2	68	153	Argixerolls Torrifluvents	60 ± 10 25 ± 10	Juniper-Pinyon- Saltbrush-Greasewood-Sage	35 ± 10 50 ± 10
UT2	Wayne	Hanksville	5.1	Aug./Feb.	24.8	70.8	157	Torriorthents Cryoborolls	45 ± 10 25 ± 10	Juniper-Pinyon Ricegrass, dropseed	40 ± 15 40 ± 15
UT3	Garfield-Kane	Escalante	13.0	Aug./June	22.8	69.8	152	Torriorthents Cryoborolls	50 ± 10 25 ± 10	Juniper-Pinyon-fir Shadscale-Wheatgrass	70 ± 15 20 ± 15
AR1	Navajo	Kayenta	9.8	Aug./May	30	69.8	120	Natrargids	100	Grama-Galleta Steppe Juniper-Pinyon woodland	60 40
	PACIFIC REGION:										
Washington	Lewis	Centralia	59.0	Nov./July	39.2	64.4	210	Haplohumults	100	Cedar-Hemlock-fir Silver Douglas-fir	95 5
Alaska	Matanuska	Anchorage	15.6	Aug./Apr.	-13	55	55	Haplohumults	100	Boreal Forest Biome	100
	Fort Yukon	Fairbanks	7.1	July/Nov.	-22	61	38	Haplohumults	100	Boreal Forest Biome	100
	Point Barrow		4.3	July/Apr.	-16	40	18	Haplohumults	100	Tundra	100

TABLE A-2. EFFECT OF SEAM THICKNESS ON THE AMOUNT OF RECLAMATION REVENUES GENERATED PER SURFACE MINED ACRE1/

Coal Characteristics 2/		Cost in Dollars Per Ton of Coal Mined (Reclamation revenues generated per acre)					
Seam thickness (feet)	Recovery per acre (tons)	$1,000	$2,000	$3,000	$4,000	$5,000	$10,000
		($/ton)					
3	4,590	.218	.436	.654	.871	1.089	2.179
4	6,120	.163	.327	.490	.654	.817	1.634
5	7,650	.131	.261	.392	.523	.654	1.307
10	15,300	.065	.131	.196	.261	.327	.654
15	22,950	.044	.087	.131	.174	.218	.436
20	30,600	.033	.065	.098	.131	.163	.327
25	38,250	.026	.052	.078	.105	.131	.261
30	45,900	.022	.044	.065	.087	.109	.218
40	61,200	.016	.033	.049	.065	.082	.163
50	76,500	.013	.026	.039	.052	.065	.131
75	114,750	.009	.017	.026	.035	.044	.087
100	153,000	.006	.013	.020	.026	.033	.065
150	229,500	.004	.009	.013	.017	.022	.044

1/ Adapted from Walsh, [1974].

2/ Assumptions: Heating value -- 8,000 Btu per pound,
Recovery factor -- 90 percent,
Volumetric weight -- 1,700 tons per acre foot.