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WATER AS A PARAMETER FOR DEVELOPMENT OF ENERGY RESOURCES IN THE UPPER GREAT PLAINS — EFFECTS ON LAND AND WATER RESOURCES OF ALTERNATIVE PATTERNS OF COAL-BASED ENERGY DEVELOPMENT

by
Donald F. Scott
George H. Pfeiffer
Duane E. Gronhovd

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Donald F. Scott
George H. Pfeiffer
Duane E. Gronhovd

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FOREWORD

The growth in energy demands and the demand for clean energy has focused attention on the extensive lignite and subbituminous deposits of the Upper Great Plains. The Fort Union coal beds, which underlie a large area of northeastern Wyoming, southeastern Montana, and western North Dakota offer the greatest potential for development. Massive development of the region's coal reserves would dramatically affect the socioeconomic structure of the region, alter the use of land and water resources, and lead to fiscal impacts that may be positive or negative, depending on the level of government. The purpose of this study was to analyze the impacts associated with alternative levels of coal-based energy development in the Upper Great Plains.

Members of the research team representing the Department of Agricultural Economics at North Dakota State University included:

Donald F. Scott (Co-Principal Investigator)
F. Larry Leistritz (Co-Principal Investigator)
Norman L. Dalsted
Duane E. Gronhovd
George H. Pfeiffer
Norman E. Toman
James S. Wieland

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PREFACE

In an era of dwindling domestic supplies of oil and natural gas and an increasing demand for energy, attention has focused on western coals, particularly the extensive lignite and subbituminous deposits of the Upper Great Plains. The Fort Union coal beds, which underlie a large area of northeastern Wyoming, southeastern Montana, and western North Dakota offer the greatest potential for development.

The Upper Great Plains accounts for almost 61 percent of surface minable coal reserves in the United States and 40 percent of total reserves. The relatively low costs of mining and the low sulfur content of the region's coal are its major advantages over coal mined in other parts of the country and serve to offset its lower heat (Btu) content.

Upper Great Plains coal is expected to play an increasingly important role in meeting national energy needs. By 1990, coal production in the region could be four to nine times the 1974 production level of 41.3 million tons. Extensive environmental and socioeconomic impacts will accompany such development. The coal-related industrial developments will produce a dramatic change in the present social and economic structure of the region. Public decision makers and area residents face a number of issues (and associated environmental impacts) related to coal development. These include: (1) the allocation of limited supplies of land and water; (2) the effect on population, employment, and income in affected areas; (3) the effect on the level of services demanded from state and local governments and the revenues available to these governmental units; and (4) the effect of different types and levels of development on the economic future of the region.

The purpose of this study was to analyze the effects of alternative patterns of coal-based energy development in the Upper Great Plains on resource use, economic activity, and population distribution in the region. The study report is contained in two volumes. Volume I (North Dakota Research Report Number 71), "Water as a Parameter for Development of Energy Resources in the Upper Great Plains — Socioeconomic Effects of Alternative Patterns of Coal-Based Energy Development," addresses the effects on economic activity, population growth and settlement patterns, and the costs and revenues to state and local levels of government of coal development in the region. Volume II (North Dakota Research Report Number 70), ". . . Effects on Land and Water Resources of Alternative Patterns of Coal-Based Energy Development," addresses the effects of coal-based energy development on the region's land and water resources.

In this volume a detailed analysis of mined land reclamation costs in North Dakota is presented in Chapter I along with costs for selected mine sites in Montana and Wyoming. Existing surface water supplies and use in the region are identified in Chapter II and the impacts of alternative levels of coal development on water resources are discussed.

CHAPTER I

RECLAMATION OF STRIP-MINED LAND IN THE UPPER GREAT PLAINS

Coal mining in the Upper Great Plains[1] has increased dramatically in recent years. In 1970, slightly over 16 million tons of coal were produced; while in 1976, 68 million tons were produced. Industry capacity for 1977 was estimated to be 97.8 million tons (Table 1). Virtually all of the coal is from surface mines. The number of acres disturbed is difficult to estimate because of varying geographical and physical characteristics associated with specific mining activities, and the difficulty in estimating land required for support facilities. Approximately 2,241 acres of land would be disturbed in producing 98 million tons of coal (Table I-1) with support facilities (roads, buildings, etc.) requiring some additional land. The approximate number of acres disturbed (associated with production) under each coal development scenario analyzed in this study is presented in Table I-2. The acreage disturbed under each level of development represents a small proportion of the land base in counties where development may occur — ranging from .001 to .25 percent. The total acreage disturbed would be greater than the estimates presented in Table I-2 since support facilities are not accounted for and land disturbed (and not yet reclaimed) by mining activity prior to the baseline estimates has not been accounted for.

Each state in the study area has legislation pertaining to mined land reclamation. In addition, the Federal Surface Mining Control and Reclamation Act which was passed in 1977 takes precedence over state laws pertaining to recla-

TABLE I-1. COAL INDUSTRY CAPACITY AND ACRES DISTURBED IN THE UPPER GREAT PLAINS, 1977

State	Industry Capacity* (million tons/year)	Acres Distrubed[1]
North Dakota	18.8	1,003
Montana	27.6	488
Wyoming	51.4	969
Total	97.8	2,241

* SOURCE: Office of Coal Energy Resource Development, Federal Energy Administration, *Summer Quarter Western Coal Development Monitoring System*, Washington, D.C., August 1, 1977.

[1] Estimated on the basis of average coal seam thickness at each mine site in the region, 1,750 tons per acre-foot, and a coal recovery factor of .9. For a description of mine characteristics see: Leathers, Kenneth L., *The Economics of Land Reclamation in the Surface Mining of Coal: A Case Study of the Western Region of the United States*, Working Paper No. 39, Economic Research Service, U.S. Department of Agriculture, Washington, D.C., October, 1977.

TABLE I-2. COAL PRODUCTION AND ACRES DISTURBED IN THE UPPER GREAT PLAINS UNDER ALTERNATIVE LEVELS OF DEVELOPMENT

	1980			1985		
State	Production (millions of tons)	Acres Disturbed[1]	Range In Acres Disturbed as Percent of County Land Base[2]	Production	Acres Disturbed[1]	Range In Acres Disturbed as Percent of County Land Base[2]
North Dakota						
Baseline (1977)	18.8	1,003	.001-.05	18.8	1,003	.001-.05
Level I	18.8	1,003	.001-.05	49.7	2,603	.001-.20
Level II	18.8	1,003	.001-.05	72.3	3,737	.001-.25
Montana						
Baseline (1977)	20.5	315	.004-.006	20.5	315	.004-.006
Level I	42.5	654	.01	43.1	670	.01
Level II	71.9	1,106	.01-.02	103.1	1,585	.02-.03
Wyoming (Campbell County)[3]						
Baseline (1977)	23.1	178	.01	23.1	178	.01
Level I	90.2	694	.02	174.6	1,344	.04
Level II	109.2	840	.03	174.6	1,344	.04

[1]Estimated on the basis of average coal seam thickness for each county where mining occurs or is proposed to occur.
[2]The acres disturbed in each county varies, depending on production and average coal seam thickness.
[3]Estimated capacity in Campbell County in 1977 is 45 percent of Wyoming capacity and 67 percent in 1985. Capacity estimates taken from: Office of Coal Energy Resource Development, Federal Energy Administration, *Summer Quarter Western Coal Development Monitoring System*, Washington, D.C., August 1, 1977.

[1]Montana, Wyoming, and North Dakota.

mation where state law does not meet federal standards. The state and federal legislation makes reclamation an important and inseparable part of the mining process. It also serves as a basis for defining reclamation. For this study, reclamation is defined as the process whereby affected land is reconstructed in such a manner as to return it to, or near, its original contour, structure, and productivity.

Land Use

Land use in the coal development areas of the Upper Great Plains reflects the dependency on agriculture. Pastureland and rangeland account for about 68 percent (52,994,291 acres) of the total land area in counties where coal development may occur or have an impact. About 28 percent (21,686,433 acres) of the land is cultivated, 5 percent (3,520,390 acres) is in forest and woodland, and .4 percent (1,123,811 acres) is in urban and built-up areas (Table I-3).

North Dakota has the highest intensity of cultivated land while Wyoming has the highest intensity of pasture and rangeland, forest and woodland. The principal crops are wheat, barley, flax, rye, oats, corn, and alfalfa. Cattle, sheep, and hogs comprise most of the livestock population with poultry, eggs, and dairy products being important in some local areas.

less than 100 in the north.

The region encloses a number of basins with the Powder River and Williston basins being the most notable. Persse, Lockard, and Lindquist described the region as follows:

> The southern or Wyoming part of the region (upper Powder River basin) is a major depression, extremely dissected in places, with spurs, buttes, and terraces capped with shale that was baked by intense heat from burning coal beds. In the Montana part of the Powder River basin, the terrain gradually changes to a broad plain characterized by extensive badlands along the larger streams and red hills, benches, ridges, and buttes of shale and sandstone. Here, too, deposits of baked shale are common. North of the Powder River basin in Montana, and to the east into the Dakotas is the Williston basin, which is larger than the Powder River basin. The terrain in the southwestern part of the Williston basin is similar to the northern part of the Powder River basin. However, the northern and eastern part of the Williston basin is a glaciated area of generally flat to rolling topography.

Soil profiles in the region are generally well developed and topsoils are rich in both nutrients and organic matter with high potential for revegetation. The subsoils are deep, often consisting of mixtures of shale or sandstone. In low

TABLE I-3. LAND USE STATISTICS FOR AREAS OF THE UPPER GREAT PLAINS IN WHICH COAL DEVELOPMENT AND RELATED IMPACTS MAY OCCUR

State	Total Land Area	Cropland			Pastureland and Rangeland	Forest and Woodland	Urban and Built-up Areas
		Total	Irrigated	Non-irrigated			
	acres						
North Dakota	25,832,575	14,705,446	55,119	14,650,327	10,434,323	154,400	546,006
Montana	34,100,834	6,284,575	361,435	5,923,140	26,419,864	1,649,238	272,197
Wyoming	18,472,441	696,412	212,446	483,966	16,140,104	1,716,752	305,608
Total	78,405,850	21,686,433	629,000	21,057,433	52,994,291	3,520,390	1,123,811

SOURCE: Northern Great Plains Resources Program, *Effects of Coal Development in the Northern Great Plains: A Review of Major Issues and Consequences at Different Rates of Development*, Denver, Colorado, April, 1975.

Climatic and Physical Characteristics

The potential for reclaiming strip-mined land is influenced by several factors. These include climate (especially the amount and distribution of precipitation), soil productivity and stability, and suitability and availability of plant materials for reclamation purposes.

The climate of the region is semiarid. Weather conditions are affected by altitude which ranges from 5,800 feet in eastern Wyoming to less than 2,000 feet in west-central North Dakota. Mean annual precipitation is between 12 and 16 inches, about 70 percent falling as rain during the growing season from April to October. Temperature varies within the region from subfreezing during winter months to the 70's in July with extremes to over 100° F. Frost-free days range from approximately 130 in the southern area to

drainage areas the shale may be close to the surface which presents problems for supporting plant growth. Segregation of topsoil and subsoil in the mining process is important to achieve revegetation since shale material presents problems as a medium for plant growth (National Academy of Sciences).

Native vegetation is a mixture of midgrasses and short grasses. Trees and shrubs occur only in scattered stands. Rehabilitation of damaged mixed grass sites can be accomplished if proper seeding methods are used (National Academy of Sciences). Packer concluded that virtually all surface-mined lands in the Northern Great Plains can be successfully reclaimed — some more easily than others. Sites having the highest reclamation potential are in west-central North Dakota. Sites having intermediate reclamation potential are in the extreme western portion of North

Dakota and southeastern Montana. Sites that have the poorest reclamation potential are in northeastern Wyoming and northeastern Montana. Those areas in the Northern Great Plains that present the most difficult reclamation problems represent the smallest areas to be disturbed for a given amount of extracted coal, while those areas in which the least difficult reclamation problems arise represent areas where the greatest disturbance per unit of extracted coal takes place.

Reclamation and Associated Costs

In this section reclamation costs are presented for Montana, Wyoming, and North Dakota.

Reclamation is site specific and, therefore, the costs must be viewed as being representative of conditions found in each state, but they may not apply to a given mine site.

The cost of reclaiming strip-mined land depends on a number of factors, most of which vary from area to area and in most cases are site specific. These factors include shaping spoils, soil surfacing, seedbed preparation, seeding, fertilization, soil amendments, drainage control, and mulching. Reclamation costs vary from site to site as a result of the physical and geographical characteristics of the area where mining occurs, equipment use, wage rates, institutional requirements, and reclamation objective.

The physical and geographical characteristics of areas where surface mining is presently taking place vary considerably in the Northern Great Plains. Although the topography may be somewhat similar, there are differences in soils, depth of overburden, and coal seam thickness. Coal seams in Montana and Wyoming are generally thicker than those found in North Dakota and are covered by a relatively thin overburden. Since shaping the land and replacing topsoil may comprise the largest items in the cost of reclamation, depth of overburden and coal seam thickness are important parameters in estimating reclamation costs.

Watts found that overburden depth has a significant effect on the cost of reclamation. He also found that while the reclaimed slope has a relatively small influence on the cost of reclamation if the overburden depth is small, as overburden depth increases, so does the influence of the reclaimed slope on the cost of reclamation.

The cost of replacing topsoil represents a significant portion of reclamation costs and varies directly with the depth of topsoil replaced. As the depth of topsoil increases, the cost of reclamation increases almost proportionally (Watts).

The type of equipment used in reclamation varies as a result of a number of factors. These include: the mining firm; the area to be reclaimed (both geographical area and topography); the stage in the life cycle of the mining activity (i.e., new mine versus existing mine); and the laws governing reclamation. It would be expected that wage rates would be fairly uniform across the Upper Great Plains for the labor required in the reclamation process. However, if there are differences in the type of equipment used, there may be differences in labor costs.

All states in the Upper Great Plains have laws pertaining to reclamation. However, the laws vary with respect to reclamation requirements and are continuously being amended. Although different, the laws of each state contain specifications pertaining to grading and shaping spoils, providing surface drainage, surfacing of spoils with topsoil, and revegetation. Specifications dealing with subsurface reclamation are of significant importance from the standpoint of reclamation costs. That is, specifications dealing with segregation of overburden and reclamation of subsurface aquifers. Although the state laws vary with respect to subsurface reclamation requirements, the costs of such activities may equal the cost of surface reclamation. Other factors that affect the cost of reclamation that vary according to state law are requirements for mining plans and site specific soils surveys.

The reclamation objective varies by law and conditions existing prior to mining. However, the legislation of each state requires revegetation at least comparable in quality to that which existed prior to mining. There are only minor differences in the cost of reclamation between cropland and grassland objectives while a combination of grassland and trees has a more significant effect on reclamation costs (Watts).

The type of mining conducted in the Upper Great Plains is predominately area strip mining. Area strip mining is practiced on relatively large tracts of land where the topography is level to gently rolling. In area mining an initial (box) cut is made through the overlying material (overburden) to the top of the coal seam and extends the length of the coal seam or area being mined. The width of the cut varies, but is usually 100-150 feet wide. The overburden is either placed on adjacent unmined land or on adjacent land to be mined. The latter case requires that all the spoils be rehandled before the second cut can be made, but allows mining closer to the edge of the permit area. The overburden from succeeding cuts is placed on the previous pit. This continues across the width of the permitted area with the final pit forming the final highwall.

The reclamation process can be divided into segments that reflect the stages necessary to complete the process. In this study reclamation costs for representative sites in Montana and Wyoming are those published by Persse, Lockard, and Lindquist and are divided into four categories: design, engineering, and overhead; bond and permit fees; backfilling and grading; and revegetation.

Design, engineering, and overhead includes development of the reclamation plan, environmental reports and monitoring during mining, and supervision of reclamation work. The bond reflects bondable costs and covers the costs that would be encountered to complete the reclamation process if the mining firm did not. The amount of the bond often varies depending on the mine site. Surety bonds are frequently used to satisfy the bonding requirement. The permit (license) provides authorization for mining on a specified parcel of land. A fixed amount plus a per-acre fee is often required.

Backfilling and grading includes the removal of vegetative cover where necessary for topsoil salvage; the removal, stockpiling, and reapplication of topsoil; and recontouring. Bulldozers and scrapers are primary pieces of equipment used to accomplish this part of the reclamation process.

Revegetation includes those procedures required to establish vegetation after topsoil reapplication and grading. It includes soil preparation, seeding, and fertilizing. Also included would be irrigation to establish a vegetative cover; however, irrigation has not been extensively used and experimentation is still being conducted.

For North Dakota, a model mine layout which was assumed to be representative of mining conditions in the state was developed and an engineering approach used to estimate the cost of reclamation. Each segment of the reclamation process was subdivided with costs estimated for each component.

Montana and Wyoming[2]

Costs (estimated in 1976 dollars) for each of the four categories in the reclamation process for specific mine sites in Montana and Wyoming are presented in Table I-4.[3] The average and range of costs per acre, per ton of coal produced, and per million Btu are presented. In general, reclamation costs for the Montana site are double those for the Wyoming site. The difference occurs primarily as a result of differences in backfilling and grading costs. A number of factors help to explain this difference.

At the Montana site, the coal bed averages 25 feet in depth and the topsoil ranges from zero to eight feet. Topsoil must be removed and stockpiled or placed on recontoured spoil. Final highwalls are from 60 to 85 feet high and must be returned to the approximate original contour which averages less than 10 degrees from the horizontal.

The coal bed at the Wyoming site averages 40 feet in depth and the topsoil seldom exceeds eight inches. The topsoil is placed directly on graded spoils if possible or stockpiled otherwise. The coal bed slopes downward about 4 percent and mining continues until a highwall height of 140 feet is reached. At that point, the highwall is reduced to approximate the original terrain.

The difference in topsoil depths between the mine sites in Montana and Wyoming and the opportunity for direct application of topsoil at the Wyoming site help to explain the difference in backfilling and grading costs between the two sites. Also, the greater coal seam thickness at the Wyoming site would result in a lower average cost per ton of coal and per million Btu, other things held constant.

Backfilling and grading accounts for 80 to 90 percent of the total reclamation cost at both sites; design, engineering, and overhead accounts for 8 to 12 percent of the cost.[4] The bond and permit fees and revegetation represent relatively minor aspects of total reclamation costs.

[2]The material presented here on reclamation costs for Montana and Wyoming is taken from: Persse, Franklin H., David W. Lockard, and Alec E. Lindquist, *Coal Surface Mining Reclamation Costs in the Western United States*, Information Circular 8737, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1977.

[3]The location of the mine sites and the states where the sites are located are not identified by Persse, Lockard, and Lindquist. However, sufficient information is given so that knowledgeable readers can determine in which states the sites are located.

[4]Design, engineering, and overhead may account for a larger proportion of reclamation costs in the future since recent legislation requires more detailed reports and monitoring. However, at the sites examined the mines were in operation before the legislation was passed and, therefore, it did not apply to those sites.

North Dakota

The North Dakota strip-mining reclamation law makes reclamation an important and inseparable part of the mining process. Mining cannot be undertaken unless reclamation can be successfully completed. Biennial changes have been made in the state's reclamation legislation since the 1969 legislative session. These changes have dramatically changed the reclamation process. The most important changes occurred as a result of the 1975 law, but the full magnitude and effect of the law is just beginning to be seen and understood because most land mined to date has been reclaimed under previous laws.

The 1975 and 1977 North Dakota reclamation laws will be reviewed because of the importance of both laws to present and future mining operations. The reclamation process and associated costs will then be presented.

1975 Reclamation Law

The provisions of the 1975 law (North Dakota Century Code, 1975; North Dakota Public Service Commission, 1975) applied to all surface mining operations. An operator was required to submit a soil survey of the soil material overlying the coal and a permit application containing both a limited and extended mining plan to the Public Service Commission (PSC).[5]

Both the limited and extended mining plans required a description of the land to be affected by mining that included:

1. a legal description of the land;
2. the identity of the owner of the surface rights and subsurface mineral rights;
3. the source of the operator's legal right to mine the land;
4. hydrologic data and geologic, topographic, and soils maps;
5. a detailed soil survey.

The approximate number of tons of coal to be mined along with the location and composition of the coal was required. The extended mining plan had to be amended yearly to reflect any proposed mining practices that would take place within 10 years.

The PSC was given supervisory, administrative, and enforcement powers over reclamation plus other duties and responsibilities dealing with reclamation. A permit could be amended to cover additional land or to withdraw land by taking appropriate action with the PSC. The permit was deemed automatically approved if not acted on in 60 days. The PSC was required to publish notice of a mining application in the official newspaper of counties where mining would occur, and the affected landowners and mineral owners had to be notified by the PSC.

A nonrefundable fee of $250 plus $10 per acre of land to be affected was required when filing for a permit. A bond of

[5]The limited mining plan is a detailed plan covering land to be mined within three years, while the extended mine plan has less detailed requirements and covers land to be mined within ten years.

TABLE I-4. ESTIMATED AVERAGES AND RANGES OF MINED-LAND RECLAMATION COSTS AT SELECTED SITES IN MONTANA AND WYOMING, 1976

Item	Montana	Wyoming
Design, engineering and overhead:		
Average, per acre	$410	$230
Range, per acre	$350-730	$200-400
Average, per ton	0.01	<0.01
Range, per ton	0.01-0.02	<0.01-0.01
Average, per million Btu	0.0007	0.0004
Range, per million Btu	0.0006-0.0010	0.0003-0.0006
Bond and permit fees:		
Average, per acre	60	70
Range, per acre	50-70	60-100
Average, per ton	<0.01	<0.01
Range, per ton	<0.01-<0.01	<0.01-<0.01
Average, per million Btu	0.0001	0.0001
Range, per million Btu	0.0001-0.0002	0.0001-0.0002
Backfilling and grading:		
Average, per acre	4,410	2,050
Range, per acre	3,700-6,200	1,800-2,900
Average, per ton	0.14	0.06
Range, per ton	0.12-0.20	0.05-0.09
Average, per million Btu	0.0079	0.0038
Range, per million Btu	0.0066-0.0111	0.0034-0.0054
Revegetation:		
Average, per acre	170	150
Range, per acre	100-200	140-200
Average, per ton	<0.01	<0.01
Range, per ton	<0.01-<0.01	<0.01-<0.01
Average, per million Btu	0.0002	0.0002
Range, per million Btu	0.0001-0.0003	0.0002-0.0003
Total reclamation:		
Average, per acre	5,050	2,500
Range, per acre	4,200-7,200	2,200-3,600
Average, per ton	0.15	0.07
Range, per ton	0.13-0.23	0.06-0.10
Average, per million Btu	0.0089	0.0045
Range, per million Btu	0.0074-0.0126	0.0040-0.0065

SOURCE: Persse, Franklin H., David W. Lockard, and Alec E. Lindquist, *Coal Surface Mining Reclamation Costs in the Western United States*, Information Circular 8737, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1977, p. 7.

at least $1,500 was required for each acre affected and the PSC was given authority to require more than $1,500. Release of the bond could be accomplished in the following stages:

1. after backsloping and grading — 40 percent of the bond released;
2. upon completion of spreading suitable plant growth material (SPGM) — an additional 30 percent released;
3. the remainder released upon completion of reclamation.

Duties of a mine operator under the 1975 law were:

1. regrade the area to approximately the original contour or topography;
2. save, segregate, and respread SPGM to a maximum of five feet provided that if five feet was not available the operator would respread all SPGM available;
   a. the removal, segregation, and replacement of SPGM was to be carried out as directed by the PSC based on the results of the soil survey;
   b. the SPGM saved from the property of one owner had to be returned to the same owner's property unless otherwise agreed upon;
3. impound, drain, or treat all runoff water so as to minimize damages;
   a. runoff water and mine seepage had to be treated in accordance with the State Water Quality Standards;
   b. dam construction plans had to meet standards set forth by the North Dakota State Water Commission;
4. obtain the owner's written preference for land use;
5. backslope all final cuts, end walls, and highwalls to an angle not exceeding 35 percent from the horizontal;

6. remove or bury all refuse material;
7. submit to the PSC by October 25 of each year a map showing the specific locations of mining pits;
8. make necessary repairs if the surface owner's domestic or livestock water supply was disrupted;
9. maintain a book containing specific information on the permitted mines.

The PSC was required to reject the mining application for areas which could not be reclaimed. The PSC had the power to reclaim all land on which the bond was forfeited.

Violation of the permit requirement was subject to a class B misdemeanor, which consisted of a $500 fine, six months in jail, or both. A knowing or willful violation was a class A misdemeanor, subject to a $1,000 fine, one year in jail, or both.

1977 Reclamation Law

Under the 1977 law, any operator who wishes to engage in surface mining must obtain a permit from the PSC (North Dakota Century Code, 1977; North Dakota Public Service Commission, 1977b). However, the PSC may delete or modify portions of the requirements for hydrologic data and geologic, topographic, and soils maps for operations which will affect less than two acres per year.

Both the limited and extended mining plans require a description of the land to be affected which includes:

1. the legal description of the land;
2. the identity of the owner of the surface rights and subsurface mineral rights;
3. the source of the operator's legal right to mine or affect the land;
4. hydrologic data and geologic, topographic, and soils maps;
5. a detailed soil survey for the limited plan.

The approximate tonnage of coal to be mined along with the location and composition of the coal is required. The extended mining plan must be amended yearly to reflect any changes in proposed mining practices which will take place within ten years.

The PSC may grant an expedited amendment to an existing permit to cover an additional 15 acres contiguous to the active permit area. In doing so they are empowered to waive data and map requirements of a normal application.

The PSC must publish notice of a mining application in the official newspaper of the county where the mining would occur. The affected landowners and mineral owners must also be notified by the PSC.

The PSC must serve the operator with a notice of noncompliance stating the needed remedial measures if any requirement of the reclamation law is not complied with. An order revoking the mining permit is issued if the operator does not take corrective measures.

The filing fee consists of a nonrefundable fee of $250 plus a refundable fee of $10 per acre. The bond is set at a minimum of $1,500 with the exact amount determined by the Commission. The bond is released in stages in the same way as specified under the 1975 law.

Duties of the operator under the 1977 law include:

1. backfill and regrade the mined area to the gentlest topography consistent with adjacent unmined land;
2. save, segregate, and respread all soil material determined by the PSC to be suitable for plant growth;
3. establish natural drainage compatible with the topography of all unreclaimed land and treat runoff water so as to minimize erosion;
4. obtain the landowner's written preference for land use;
5. backslope all final cuts, end walls, and highwalls to an angle not exceeding 35 percent;
6. remove or bury all refuse material;
7. submit a map showing the specific locations of the mining pits to the PSC by October 25 of each year;
8. make necessary repairs if the surface owner's domestic water supply has been disrupted;
9. maintain records or specific information on the permitted areas;
10. restore all lands outside the permit area affected by road construction and related mining activities.

The operator, under direction of the PSC, may stockpile SPGM outside the permit area. An operator who violates the reclamation law is subject to a civil penalty of $10,000 for each day of the violation, as well as the class A and B misdemeanors specified in the 1975 law.

Major Differences Between the 1975 and 1977 Laws

The 1977 reclamation law is not substantially different than the 1975 legislation. The changes should not be of major economic importance but will improve and facilitate the reclamation process. The differences in the two laws are listed below in their order of importance.

1. The provision allowing suitable plant growth material (SPGM) to be stockpiled outside the permit area facilitates the mining process. The operator does not have to put land under permit that is used to stockpile SPGM. It is also easier for the operator to estimate how many acres should be put under permit for future mining.
2. Deletion of the provision that required five feet of SPGM be returned, and adding language which requires all soil material in the area, if suitable for plant growth be returned, is not as significant as it might seem. The reason for the change was to allow the PSC to require more than five feet of SPGM to be saved where erosion has caused large accumulations of topsoil in gulleys and low spots. The intent is still to return up to five feet, but where SPGM has accumulated in low spots to depths greater than five feet, the material will have to be spread over the entire area.
3. Returning the land to the gentlest topography consistent with the adjacent unmined landscape will result in greater moisture retention and less soil loss from runoff. Consequently, a better job of establishing vegetation on reclaimed land will result.
4. The requirement that the PSC must issue notice of noncompliance, suspension, and revocation of the permit makes the actions that the PSC must take

against violators of the law much more clear. It is not of economic significance and will not affect a mining company complying with the law.

5. The establishment of natural drainage on reclaimed land will prevent potholes and other water from accumulating. The very high sodium soil just below the SPGM makes the soil virtually impenetrable by water. Problems, such as saline seep, can occur in such situations because of standing water.

Federal Reclamation Law

The Federal Surface Mining Control and Reclamation Act (Surface Mining Control and Reclamation Act of 1977) was signed into law on August 3, 1977. It takes precedence over the state law in all areas in which the state law does not meet federal standards. This legislation will affect reclamation practices and, therefore, reclamation costs in North Dakota. The details of these changes are not yet known, but the effect on reclamation practices of some of the major provisions of the law are considered here.

The final highwall must be leveled to the original contour under the federal law. Under North Dakota law, the final highwall must be a minimum of 35 percent from the horizontal. The operator can move spoils from behind the final highwall to level the final highwall to the original contour. A 69-foot highwall would require that spoils be moved 290 feet to get the final highwall to a 5 percent slope. The operator could also move overburden stockpiled after initial passes to fill the final pit or the mining operation could be designed to avoid a final highwall.

The present North Dakota reclamation law allows the stockpiling of SPGM outside the permit area. The federal law requires the SPGM to be stockpiled within the permit area. This provision will increase the number of acres that must be taken under permit.

The federal law will increase the size of the permit application. Mr. Ray Walton, Commerce Council for the North Dakota Public Service Commission, estimates that the increased requirements imposed by the Federal law will double or triple the volume of the permit application (Walton). The federal law also specifies inspection and enforcement requirements over and above those of the North Dakota law.

The federal law requires payment of a reclamation fee of \$.10 per ton, or 2 percent of the value of the coal, whichever is less. If the price of coal were \$3.50 per ton,[6] the reclamation fee would be \$.07 per ton, or \$1,050 per acre at \$15,000 tons of coal mined per acre. Fifty percent of these funds will be returned to the state to reclaim abandoned (orphan) spoils. The remainder of the funds are allocated at the discretion of the Secretary of the Interior.

Reclamation Process

The reclamation process was divided into the following segments: preparation and planning; recontouring; topsoiling; and revegetation. Four areas of primary importance in reclaiming surface mined land are the final highwall area, box cut area, ramp roads, and the remaining spoil banks. The proportion of the total mine area that each of these areas comprises depends on such factors as postmining topography, length and width of mine, and overburden depth.

A model mine layout was developed for the purpose of estimating reclamation costs. This layout is not meant to represent any one mine in North Dakota; rather it is designed to represent typical mine conditions encountered in the state and to serve as a basis for developing the methodology for estimating reclamation costs. Selected characteristics of mines located in North Dakota are presented in Table I-5.

TABLE I-5. CHARACTERISTICS OF SELECTED MINES IN NORTH DAKOTA AND EQUIPMENT USED

Mine	Overburden Depth Average (ft.)	Overburden Depth Range (ft.)	Swell Factor of Spoils (percent)	Tons of Coal Mined in 1974	Pit Width (ft.)	Total Thickness of Coal Seams (ft.)	Equipment Used: Scrapers	Equipment Used: Dozers
Center	45	30-75	25	1,563,446	120	11	Cat. 637	Graders
Glenharold	50	-80	—	1,292,921	120	14	—	1 HD-41 2 Cat. D-9 2 Cat. D-9
Beulah (North and South)	40	10-90	20	1,726,349	—	22	2 Cat. 637 1 M-R-S I-80's	2 Cat. D-9
Velva	68	60-80	20	428,163	100-110	12	—	2 Cat. D-8
Indian Head	45	20-65	20	1,090,144	100-120	10	Cat. 637	1 Cat. 12 Grader 2 Cat 824B 2 Let-West 777 Grader 1 Cat. D-9G
Noonan	40	25-60	—	482,299	—	6	—	Graders

SOURCE: U.S. Environmental Protection Agency, Office of Energy Activities, *Surface Coal Mining in the Northern Great Plains of the Western United States*, Denver, Colorado, June, 1976.

[6]The approximate price of coal in North Dakota at the present time.

The conditions assumed in the model mine are as follows. The area being mined contains 450 acres,[7] 1,760 yards by 1,237.5 yards.[8] The mine pit width is 120 feet. There is a uniform overburden depth of 58 feet, with the overburden swelling 20 percent upon being handled. A uniform coal seam of 12 feet is assumed, with a coal recovery factor of .90. The highwall slope is 71.56 degrees and the spoil bank slope is 38.66 degrees. There is a uniform suitable plant growth material depth of five feet, and all of the material is stockpiled. All initial spoil banks are leveled toward the mine.

Preparation and Planning

Preparation and planning can be defined as those procedures necessary to obtain a mining permit, including those procedures specified in the limited and extended mining plans. It also includes those procedures undertaken prior to mining for the purpose of securing more productive reclaimed land.

Preparation and planning is an important and inseparable part of the reclamation process. Extensive maps, reports, and surveys are required of the mine operator on both a long-range and a short-range basis. The long-range information is contained in the "extended mining plan" which is a detailed written statement setting forth information required by the reclamation law. The extended plan covers not less than ten years immediately succeeding the date of its making or the date of any amendment made thereto. The purpose of this plan is to inform the PSC of conditions existing in an area proposed for mining sufficiently in advance of the commencement of operations to allow the PSC to accurately assess the effects of such proposed operations. The short-range information, or "limited mining plan," is for a period of three years, with extensions granted. It is defined as a detailed statement setting forth certain information required by the reclamation law covering those years of mining included in the permit term.

Preparation and planning can be divided into six components which include the filing fee, bond, extended mining plan, limited mining plan, annual map, and semiannual report. The annual map and semiannual reports provide specific information on the progress of the mining operation.

The present reclamation law requires a minimum bond of $1,500 per acre of land under permit. Two recently approved permits required the minimum $1,500 per acre bond. They were granted to Husky Industries and NL Industries. The largest bond to date was $3,700 and was required of Consolidation Coal Company (North Dakota Public Service Commission, 1977a). It should be noted that the bond reflects bondable costs, and does not reflect the total cost of reclamation. Bondable costs are those costs which the PSC would encounter if it had to complete the reclamation process. Costs associated with preparation and planning are not bondable costs. Also, since the suitable plant growth material (SPGM) must be removed and piled before mining can take place, the removal of SPGM is not a bondable cost. Costs for backfilling and grading, returning of SPGM, and revegetation are bondable costs.

The filing fee consists of a nonrefundable fee of $250 plus a refundable fee of $10 per acre or fraction thereof. The $10 per acre fee is returned to the operator should the application be rejected.

The extended mining plan, which must be updated annually, covers the land to be disturbed in the succeeding 10 years and usually covers about four times as much land as does the limited mining plan. The extended mining plan requires the following types of information:

1. geologic;
2. hydrologic;
3. topographic;
4. soil map;
5. archaeologic and historic survey;
6. legal description of the land.

The geologic information must be obtained from a minimum of one drill hole per section corner. Chemical and physical analysis of overburden for acidity (pH), sodium adsorption ratio (SAR) [which includes sodium (Na), magnesium (Mg), and calcium (Ca) cation concentrations], electrical conductivity (EC), and texture must be conducted for samples taken at five-foot intervals. The depth of the drill holes usually goes about 20 feet below the deepest coal seam mined. The geologic data consist of cross-sections sufficient to depict the major subsurface variations.

The hydrologic information includes a general account of the water resources and use in the area. A minimum of one data point per four square miles must be used to show the water table of each aquifer on a contour map. The data point is a set of drill holes, each one to a different aquifer. Water samples must be collected from the data points with analysis conducted for specific common ions and trace minerals.

The topographic map must be at a scale of one inch to 2,000 feet and show the following:

1. a legend with appropriate information;
2. boundaries on proposed mining sequence of plan area;
3. location of streams, natural drainways, and watersheds;
4. current land use including haul roads and utilities.

The soils map must show both the kind and extent of soils in the extended mine plan area. The land capability classes must be indicated on a separate map. The archaeological and historical survey must be conducted in accordance with the survey requirements of the North Dakota State Historical Society. The legal description of the land must be to the nearest quarter section.

[7]Four of the latest permits granted in North Dakota include one for 1,016 acres at the Falkirk Mine, one each for 261 acres and 640 acres to Consolidation Coal Company, and one for 445 acres to North American Coal Company.

[8]The dimensions of mines in North Dakota vary greatly, ranging in length from slightly over one-half mile to over 1.5 miles. U.S. Environmental Protection Agency, Office of Energy Activities, *Surface Coal Mining in the Northern Great Plains of the Western United States*, Denver, Colorado, June, 1976.

The limited mining plan has much of the same type of information as the extended mining plan but is a much more intensive plan and only covers an initial three-year period, although extensions are granted. The limited plan can be divided into the following areas:

1. geologic;
2. hydrologic;
3. planimetric;
4. soil survey;
5. archaeologic and historic survey;
6. description of lands;
7. coal composition information;
8. certified copies of relevant lease agreements.

The number of drill holes from which information is taken depends on mine size, but usually ranges from six to ten holes per permit. An isopach (soil thickness) map to the top of the deepest seam to be mined is required. With the exception of scale, the rest of the requirements are the same as for the extended mining plan.

The hydrology requirements are the same for both the extended and limited mining plans. There may be special tests performed if circumstances warrant.

The planimetric map and as many additional maps as necessary are used to depict the following information about the proposed permit area:

1. description of the exact area to be mined;
2. location of streams, utilities, roads, etc.;
3. location of drill holes;
4. present and postmining land use;
5. layout, proposed mining sequence, soil placement, final graded spoil line, crop line, and proposed areas for stockpiling SPGM;
6. intended postmining topography and surface drainage;
7. location of proposed sediment dams and water holding impoundments.

The soil survey consists of both a map and report. The map shows the SPGM considered best for top dressing (first lift) and the location and extent of the remaining SPGM (second lift). The report includes the following:

1. the results of chemical and physical analysis of the SPGM along with a textural analysis of second lift material;
2. the volume of first lift material and the volume of second lift material;
3. description and discussion of SPGM properties;
4. capability units of each soil unit mapped and the total acreage and productivity level of each capability unit.

The archaeologic and historical survey are the same as for the extended plan except it must be in accordance with the historical survey requirements for limited areas. The description of lands to be permitted must be to the nearest acre.

Coal composition information is developed for the mining process. The cost of obtaining this information is, therefore, not considered a cost of reclamation.

Certified copies of relevant lease agreements that give the mine operator the right to mine must be presented to the Public Service Commission. The names and addresses of owners of surface rights and subsurface mineral rights must be included. In addition, all utility easements within the permit area must be identified.

The costs associated with preparation and planning are based on the assumption that the permit application is for 475 acres, although the area mined would be 450 acres. The additional 25 acres are used to deposit the overburden from the initial cut. Other assumptions applicable to this phase of reclamation are discussed in the model mine layout. The cost of each component of preparation and planning was estimated separately based on information provided by industry sources and representatives of firms that contract with mining companies for work performed. The total cost of an area under permit of 475 acres is $89,005 (Table I-6).

Recontouring

Recontouring is the process by which the postmining contour is altered to be the same as the gentlest topography of the surrounding landscape or other contour consistent with state and federal law. The major factors affecting the cost of recontouring are the volume of overburden to be moved, distance the overburden is moved (push distance), and the operating cost of machinery.

There are four areas associated with a mine that must be considered in recontouring. These include the initial spoil bank area, the final highwall area, ramp roads, and the remaining spoil banks. The initial spoil bank area is formed when the overburden from the initial cut is piled. The initial spoil bank area extends from the initial spoil bank (ISB) toward the mine side for the entire distance in which the ISB spoils are moved (Figure I-1). Overburden from the first cut can be deposited in three locations. It can be deposited on the side of the cut not to be mined (Figure I-2), it can be deposited on the side of the cut to be mined (Figure I-3), or a combination of the two can be done.

A common procedure is to deposit the overburden from the first cut on the side not to be mined. This method allows mining to be conducted immediately on the second cut upon completion of mining the first cut. Fewer cubic yards of spoils have to be moved to recontour the area by depositing the overburden on the side not to be mined. However, the tonnage of coal that can be extracted may decrease if the coal seam extends to the edge of the surface owner's property.

When overburden is piled on the side of the cut to be mined a complete rehandling of spoils is required and may delay the mining process until the first cut has been filled. This method does, however, allow the mining operation to extend closer to the edge of the property line or roads.

The highwall and initial spoil bank areas are difficult to work with geometrically. A level contour of the area of the initial spoil bank was assumed to facilitate working with these areas. Using the highwall area as an example (the same logic can be used for the initial spoil bank area), a contour represented by the line BCDF (Figure I-4) will be the assumed postmining contour. Since area ABC equals

TABLE I-6. COSTS OF PREPARATION AND PLANNING, 475 ACRES UNDER PERMIT

Activity	Cost Per Item	Total Cost
Reclamation Fee:	$ 5,000	$ 5,000
Bond:[1]		
Stage I	17,812	
Stage II	3,562	
Stage III	14,250	$35,624
Extended Mine Plan:		
Geologic		
Drilling (8 drill holes to depth of 90 feet)[2]	2,160	
Analysis (18 samples each for 8 drill holes)[3]	9,360	
Office Work	960	
Hydrologic		
Drilling (4 aquifers averaging 241.25 feet)[2]	2,895	
Analysis (2 samples per aquifer)[4]	2,880	
Office Work	960	
Topographic		
Office Work	320	
Soil Map		
Office Work	200	
Archaeologic and Historic Survey ($3 per acre for 1,920 acres)	5,760	
Description of Lands		
Office Work	64	$25,559
Limited Mine Plan:		
Geologic		
Drilling (8 drill holes to depth of 90 feet)[2]	2,160	
Analysis (18 samples each of 8 drill holes)[3]	9,360	
Office Work	960	
Hydrologic	—	
Planimetric		
Aerial Maps	500	
Office Work	3,200	
Soil Survey		
Survey Cost ($7.50 per acre)	3,562	
Office Work	64	
Archaeologic and Historic Survey	—	
Legal Description of Land		
Office Work	64	
Coal Composition Information	—	
Certified Copies of Lease Agreements	265	$20,134
Annual Map ($384 per map)[5]	1,152	$ 1,152
Semiannual Report ($512 per year)[6]	1,536	$ 1,536
TOTAL		$89,005
Total Per Acre		$187.38

[1]The bond requirement was assumed to be $2,500 per acre. Surety bonds which cost $10 per year per thousand dollars of bond are used to satisfy the reclamation bond. The bond is reduced in stages over a six-year period as reclamation is completed.
[2]The cost of drilling was estimated to be $3 per foot.
[3]The soil sample is required for every five feet of depth with the analysis estimated to cost $65.
[4]The common ion analysis and trace mineral analysis cost $60 and $300 per sample, respectively.
[5]Three annual maps are required, one each year for the length of the limited mine plan.
[6]Six semiannual reports are required, two each year for the length of the limited mine plan.

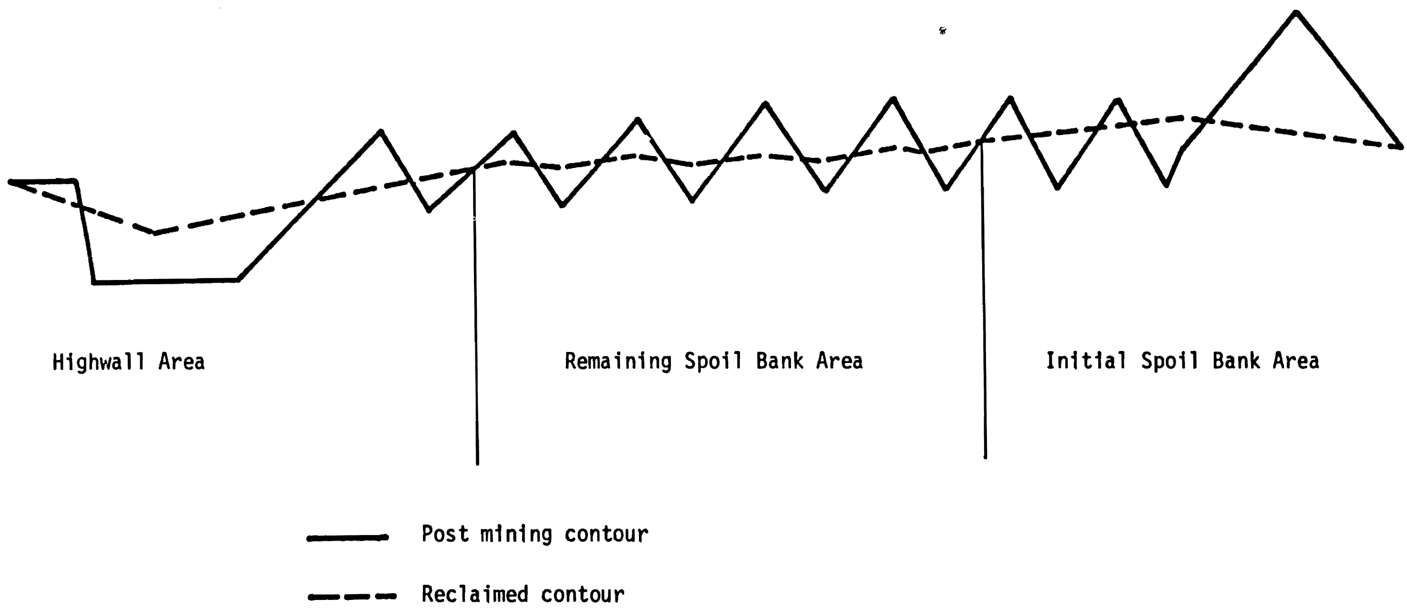

Figure I-1. Cross-Section of mining area.

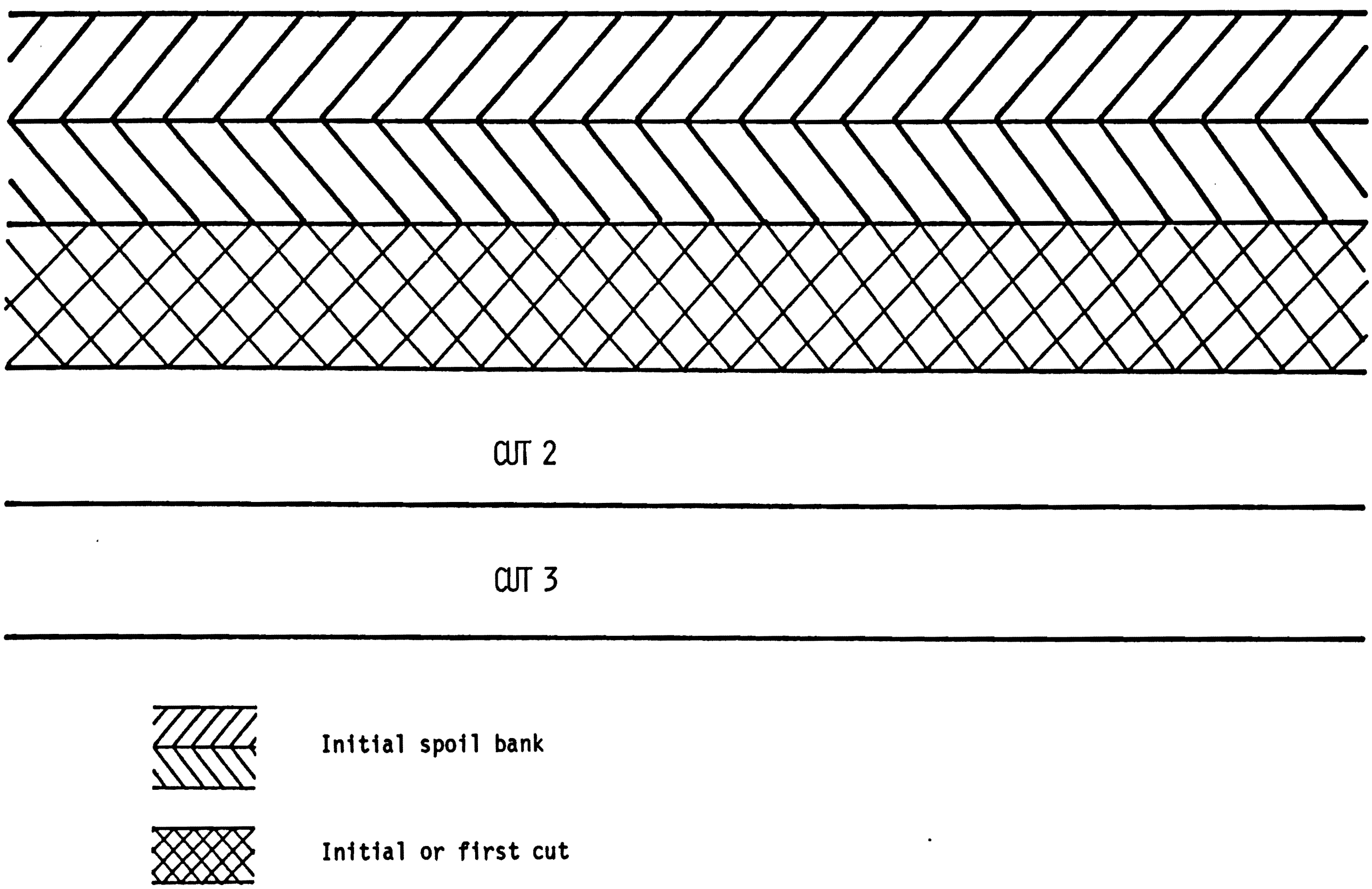

Figure I-2. Depositing spoils on the unmined side of the initial cut.

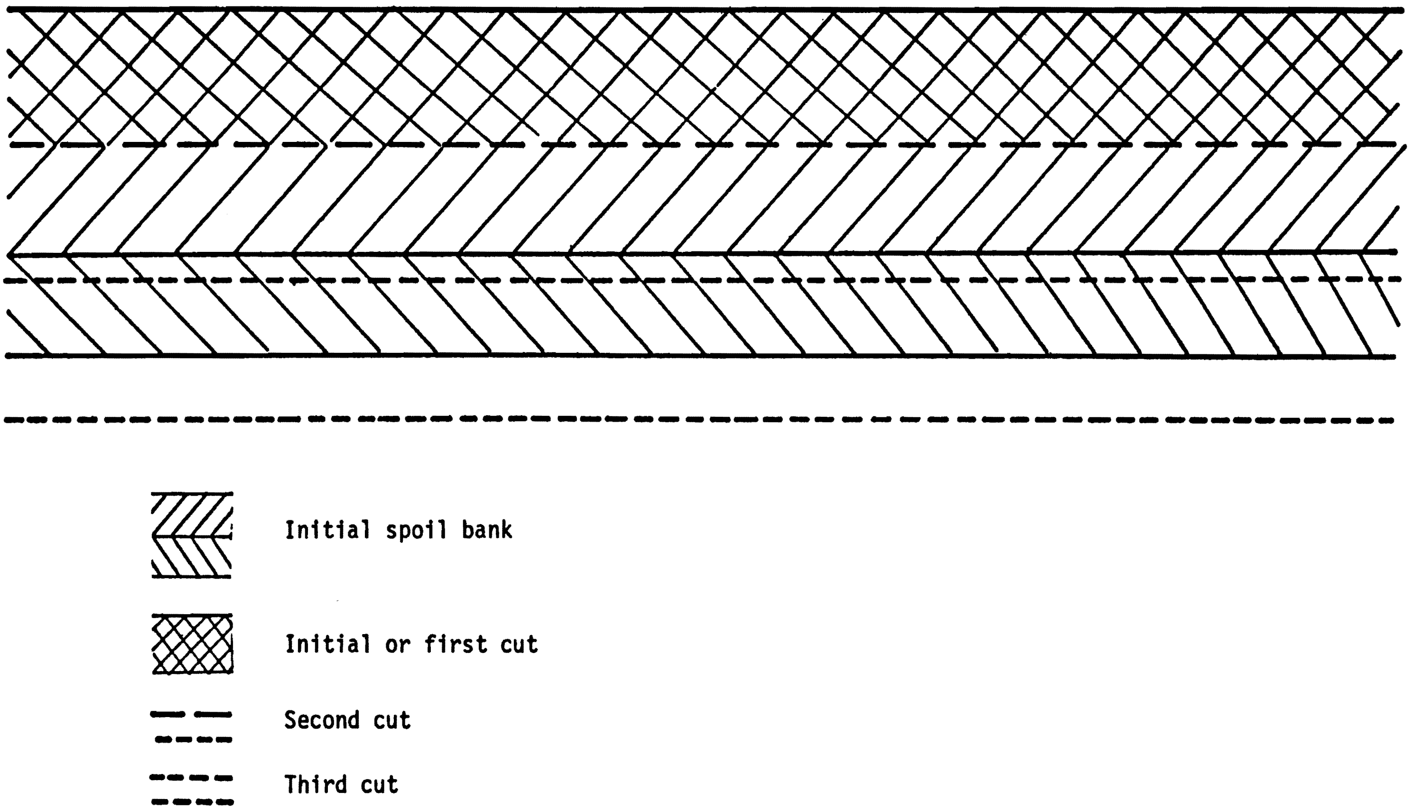

Figure I-3. Depositing spoils on the side of the initial cut to be mined.

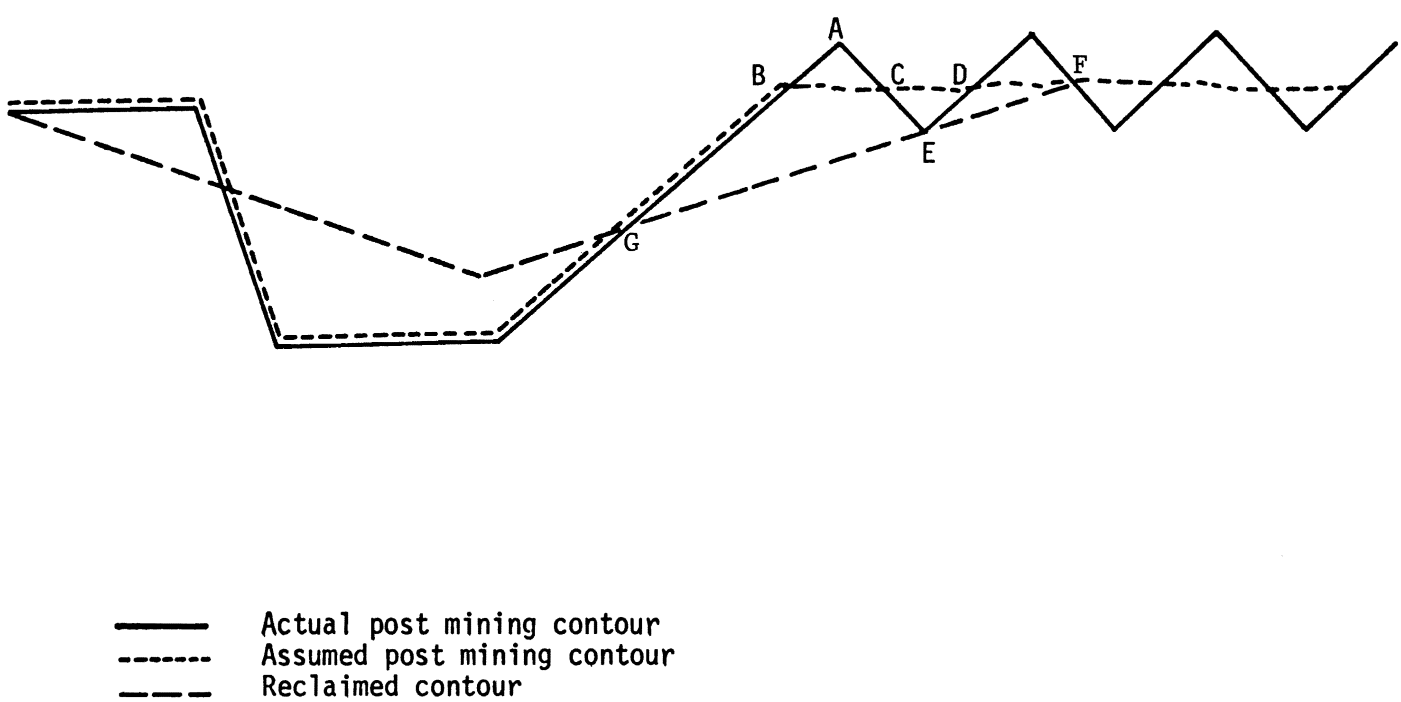

Figure I-4. Cross-Section of Final Highwall Area.

area CDE the yardage of overburden to be moved is the same in both the assumed and actual contour (▲BFG equals ▲GAE + ▲EDF). The push distance, however, is greater with the assumed contour.

Ramp roads are located at periodic intervals. They run from the coal seam through the spoil banks to the leveled spoil area. For the purpose of this study it was assumed that the ramp roads are located at quarter-mile intervals.

The cubic yards of overburden to be moved for the remaining spoil bank area (Figure I-5) are not difficult to estimate, but the distance it must be moved can vary greatly. In other studies of this nature it has been assumed that half of the spoils from the spoil bank are moved to one side and the other half moved to the other side (in Figure I-5, area BEW would be filled by area CHB and area EFJ). In actual practice a mine operator is seldom able to do this. Rather, the spoils from an area such as EFG (Figure I-5) are all moved toward the final highwall side of the spoil bank. It is necessary to do this because of the leveling of the initial spoil bank. Using the assumed contour of LZ (Figure I-6), the slope of the initial spoil bank (PA) can extend to the bottom front corner of the area to be moved (area ABC). In this case all of the spoils in area ABC must be moved to the highwall side (into area CDE). The slope can extend all the way to the far corner (point C of area ABC), in which case all of the spoils in area ABC except ACX are moved to the highwall side. If the slope touches anywhere between points A and C, the push distance is somewhat less than 60 feet, but greater than that when the initial spoil bank slope is PC. For ease of calculation it was assumed the slope touches at point A and, therefore, the average push distance is 60 feet. Under the assumption that half of the spoils can be moved to each side of the spoil pile, the push distance would be only 30 feet.

It was assumed that the primary piece of equipment used in recontouring is a D-9 Caterpillar with a universal blade. Although the D-9 is not used in all reclamation operations, it is a common machine in most reclamation operations. The Caterpillar Performance Handbook (with appropriate performance correction factors) was used to estimate the production of a D-9. The cost estimator from the Caterpillar Performance Handbook was used as the basis for hourly cost estimations with appropriate changes made to adapt the estimator for North Dakota situations.

Multiple coal seams are often encountered in North Dakota. Generally, the first layer of coal is removed and

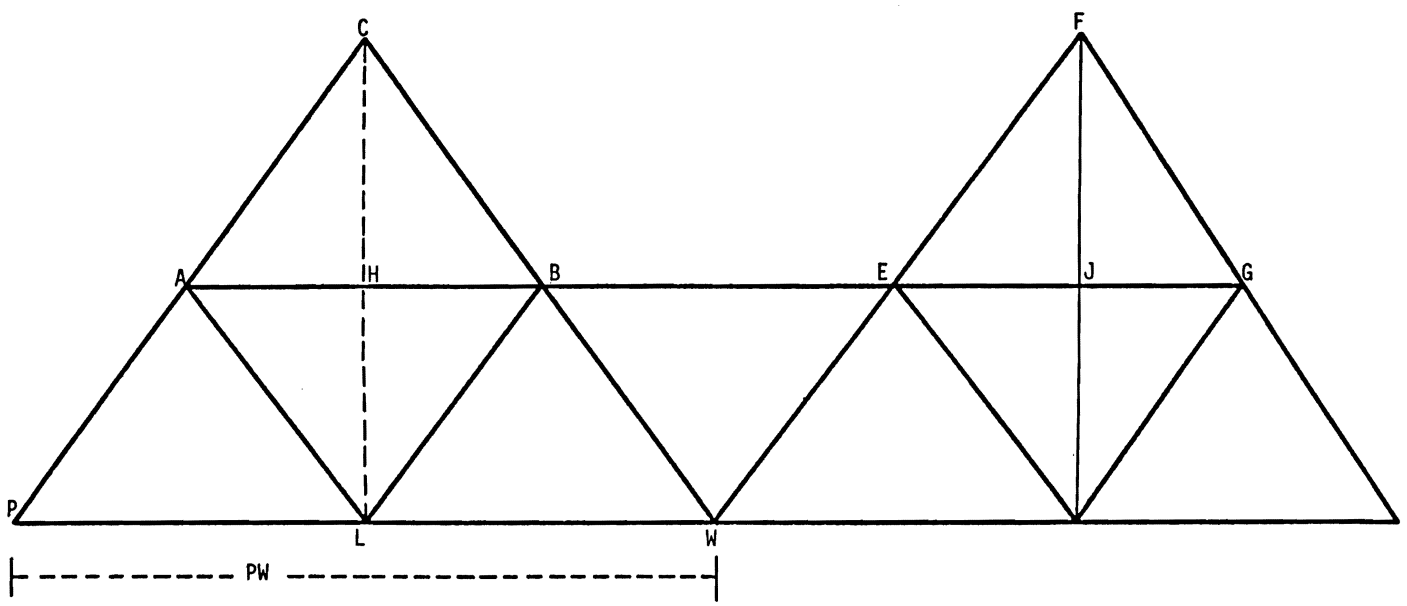

Figure I-5. Cross-Section of the portion of the remaining spoil banks that will be moved.

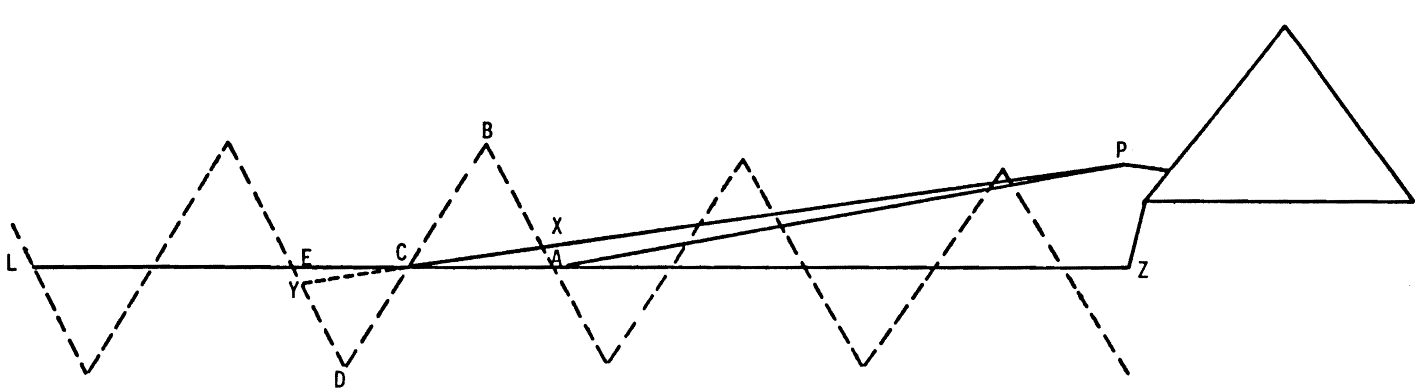

Figure I-6. Movement of initial spoil bank spoils to the mine side.

then the overburden above the second seam is removed and deposited in the same manner as the overburden above the first seam. This has the effect of increasing the depth of the overburden but has no other effect on reclamation. To simplify the analysis, a uniform overburden depth and coal seam thickness were assumed.

The cost to move a cubic yard of overburden and the yardage of overburden to be moved for each of the mine areas was estimated using an engineering approach. The cost was estimated on the basis of equipment costs, equipment performance, labor costs, and average push distances. Overburden moved was estimated on the basis of length of area, yardage of overburden moved per unit of distance, and a reclaimed slope of 5 percent.[9]

The total cost of recontouring can be found by summing the costs for each individual area. These costs are presented in Table I-7.

2. sodium adsorption ratio of less than four;
3. a free lime percentage ($CaCO_3$ equivalent) of less than ten;
4. organic matter percentage of one and one-half or greater.

Second lift material must have an electrical conductivity of less than four millimhos per cm. and a sodium adsorption ratio of less than ten.

The depth of SPGM can vary greatly from area to area and often varies within a particular area. The 1977 law requires all soil material within the permit area determined by the Public Service Commission to be suitable for plant growth to be saved, segregated, and returned. The PSC can require that where SPGM has accumulated to depths greater than five feet, it must be saved and respread over the permit area. A uniform SPGM depth of five feet was assumed since this depth is most often encountered (Scherbinske).

TABLE I-7. COSTS OF RECONTOURING, 450-ACRE MINE

Area	Cubic Yards of Overburden Moved	Cost Per Cubic Yard	Total Cost
Initial Spoil Bank	1,274,224	$.221	$281,603
Remaining Spoil Bank Area	2,238,569	.0464	103,870
Ramp Road Area[1]	3,179,598	.092	292,523
Highwall Area			
Spoil Bank Side	1,359,944	.1856	252,406
Highwall Side	82,016	.0442	3,625
Total			$934,027
Total Per Acre			$ 2,075.62

[1]Three ramp roads are assumed.

Topsoiling

Topsoiling is the process whereby suitable plant growth material (SPGM) is removed, stored, and reapplied or put directly on recontoured spoils. The process involves two lifts that are commonly based on color change of the soil. These two lifts must be kept separate, with the second lift material being returned first and the first lift material being returned last.

SPGM refers to that portion of the soil material (normally the A, and in some cases the upper portion of the B horizon) lying above the coal which, based on a soil survey, is found to be acceptable for respreading on the surface of regraded areas to provide a medium for plant growth. First lift material must meet the following conditions:

1. electrical conductivity of less than two millimhos per cm;

There are two methods of removing and reapplying SPGM. It can be removed, stockpiled, and reapplied on the site from which it is removed, or it can be directly applied to leveled spoils from previous cuts.

Direct application, where possible, is the least cost method of topsoiling since the SPGM is handled only once, eliminating the need for stockpiling except for the first few cuts. It also eliminates the need to remove first lift material from second lift material stockpiles and the need for maintaining stockpiles to insure SPGM quality.

Mine design and land ownership patterns in the mine area make direct application of SPGM very difficult. Many times, certain coal seam properties make irregular mining patterns necessary. Since SPGM from a surface owner's property must be returned to that property, this also becomes a roadblock to direct application of SPGM. For these reasons, stockpiling is the most common method of topsoiling and will remain so in the future.

[9]The procedure used to estimate overburden yardage figures can be found in: Gronhovd, Duane E., *Estimation of Reclamation Costs for Strip-Mined Land in Western North Dakota*, Unpublished M.S. Thesis, Department of Agricultural Economics, North Dakota State University, Fargo, 1978.

In direct application, the SPGM from the ISB and the first few mining passes (normally mining passes one, two, and three) must be stockpiled. The SPGM from cut four is placed on the leveled ISB spoils nearest cut one.[10] Therefore, cut five SPGM is placed on cut one, cut six SPGM on cut two, etc. Upon completion of mining operations, enough SPGM must be removed from behind the final highwall area to allow the leveling of the final highwall. After the final highwall area is leveled to the desired slope, the SPGM from mining passes one, two, and three plus portions from the ISB are transported to and deposited on the leveled final highwall area spoils. The remainder of the material for the ISB is used to topsoil that portion of the ISB spoils not topsoiled with material from mining pass four.

The SPGM is returned to the mining pass from which it was removed after the spoils have been leveled when the stockpiling method is used. Most of the material is stockpiled within approximately one-half mile of the mine (Brown).

The cost of topsoiling depends on the type of machinery used, method of topsoiling, SPGM depth, and the haul distance. The cost of handling the topsoil material was based on the cost to move a cubic yard of SPGM and the cubic yards moved per acre.[11] A 637 Caterpillar push-pull scraper was assumed to be the primary piece of equipment used. The Caterpillar Performance Handbook was used as the source for much of the performance and cost data. This was supplemented by interviews with equipment dealers and representatives of coal companies.

The cost was estimated to be $.265 per cubic yard for both stockpiling and reapplication of SPGM. There are 8,066 cubic yards of SPGM per acre.[12] Multiplying the cost per yard ($.265) times the yardage moved (8,066), the cost to stockpile is $2,137 per acre, and $2,137 per acre to return the SPGM to the leveled spoils. The total cost of topsoiling is therefore $4,274 per acre, or $2,030,150 for the 475 permitted acres.

Revegetation

Four different reclamation goals were considered including cropland, tame pasture, native grass, and wildlife habitat. Cropland and tame pasture occur on land which has a gentle slope. Land which will be returned to native grasses normally has a steeper slope than tame pasture or cropland. In some instances the land is returned to wildlife habitat. Although the reclamation goals require different seed mixtures (which affects cost of revegetation), the management practices are similar.

The normal ground preparation for land to be revegetated is one trip over the land with a chisel, one trip with a disc, and one trip with a harrow. Groundwork, seeding, and fertilizing costs were determined using the custom farm rate schedule for 1977, published by the Cooperative Extension Service at North Dakota State University.

[10]The SPGM from beneath the initial spoil bank has been removed and stockpiled.

[11]See Gronhovd for a discussion of procedures used to estimate topsoiling costs.

[12]There are 4,840 square yards per acre, and with five feet of SPGM, this amounts to 8,066 cubic yards.

Normally, 200 lbs. of 18-46-0 fertilizer per acre is put on land to be revegetated. Mulch is not applied to soils that have less than a 6 percent slope, unless the soil is sandy. One ton of straw is applied per acre to land with a 6 to 10 percent slope and two tons of straw applied where the slope is greater than 10 percent.

Land to be returned to cropland or tame pasture has the same grass mixture applied. This grass mixture varies depending on whether the land has sandy dry soils or heavier moist soils. The grass mixture, rates, and costs are listed in Table I-8.

The total cost for the revegetation of reclaimed land to the different revegetation goals is given in Table I-9. A summary of the costs of reclaiming a 450 acre strip-mined area is presented in Table I-10.

Mine Conditions and Alternative Reclamation Requirements

Physical, geologic, and topographic conditions vary greatly between and even within mine areas so that each mine is unique. Consequently, the cost of reclaiming each mine site is different. Mine conditions, along with reclamation laws, dictate the procedure that must be used in reclamation. The effect on reclamation costs of changing some of the conditions assumed in the model mine layout are considered here.

The mine conditions which vary the most and have the greatest effect on reclamation costs are the slope of the reclaimed land, overburden depth, depth of SPGM, coal seam thickness, and reclamation goal. Direct application of SPGM on leveled spoils, rather than stockpiling, also has a significant effect on reclamation costs.

Slope

The cost of recontouring is affected by varying the grade on reclaimed slopes. The yardage of overburden to be moved is decreased by increasing the degree of slope and the push distance in the ISB area is reduced. These two factors combined, significantly reduce the recontouring cost for the ISB area. Increasing the reclaimed slope also reduces the cost of reclaiming the spoil bank side of the final highwall area because the amount of overburden to be moved and the distance it must be moved decline. Decreasing the amount of overburden moved on the spoil bank side increases the size of the area that must be filled by final highwall spoils. The decrease in push distance for the ISB and spoil bank side of the final highwall area reduces the size of these two areas. This increases the size of the remaining spoil bank area, but the increase in cost due to the larger acreage is partially offset by a decrease in yardage of overburden which has to be moved per acre. Finally, the increase in slope reduces the yardage of overburden moved to recontour the ramp roads. The recontouring costs for a 5 percent, 10 percent, and 15 percent slope are summarized in Table I-11.

Overburden Depth

The depth of overburden has a large effect on recontouring costs and a relatively small effect on preparation and

TABLE I-8. PER ACRE GRASS SEED MIXTURE AND COST

Grass Seed	Seeding Rate[1]	Seed Cost[2]	Total
Cropland and Tame Pasture Mix (dry soils)			
Crested Wheatgrass	7 lbs.	$ .60 per lb.	$ 4.20
Pubescent Wheatgrass	3 lbs.	1.15 per lb.	3.45
Alfalfa	1½ lbs.	1.50 per lb.	2.25
Sweetclover	½ lb.	.32 per lb.	.16
			$10.06
Cropland and Tame Pasture Mix (moist soils)			
Crested Wheatgrass	2 lbs.	.60 per lb.	$ 1.20
Smooth Bromegrass	5 lbs.	.65 per lb.	3.25
Pubescent Wheatgrass	3 lbs.	1.15 per lb.	3.45
Alfalfa	1½ lbs.	1.50 per lb.	2.25
Sweetclover	½ lb.	.32 per lb.	.16
			$10.31
Native Grass Mix			
Western Wheatgrass	6 lbs.	3.00 per lb.	$18.00
Green Needle Grass	4 lbs.	3.50 per lb.	14.00
Pubescent Wheatgrass	1½ lbs.	1.15 per lb.	1.73
Little Blue Stem	2 lbs.	4.50 per lb.	9.00
Side Oats Gramma	3 lbs.	3.00 per lb.	9.00
Alfalfa or	1 lb.	1.50 per lb.	1.50
Sweetclover	½ lb.	.32 per lb.	.16
			$53.23
Wildlife Grass Mix			
Intermediate Wheatgrass	4 lbs.	1.25 per lb.	$ 5.00
Tall Wheatgrass	3 lbs.	.90 per lb.	2.70
Alfalfa	3 lbs.	1.50 per lb.	4.50
Sweetclover	1 lb.	.32 per lb.	.32
			$12.52

[1]Obtained in an interview with Jim Doutch, Reclamation Division, North Dakota Public Service Commission.
[2]Obtained from Interstate Seed and Grain (Fargo, North Dakota).

TABLE I-9. PER ACRE COSTS OF REVEGETATION

Activity	Cropland and Tame Pasture Mix Dry Soil	Cropland and Tame Pasture Mix Moist Soil	Native Mix	Wildlife Mix
Preparation of Land				
Chiseling	$ 3.40	$ 3.40	$ 3.40	$ 3.40
Discing (tandem)	2.59	2.59	2.59	2.59
Harrowing	1.34	1.34	1.34	1.34
Seeding	2.95	2.95	2.95	2.95
Fertilizer Application	1.61	1.61	1.61	1.61
Seed Mixture	10.06	10.31	53.23	12.52
Fertilizer	16.50	16.50	16.50	16.50
Total	$38.45	$38.70	$81.63	$40.91

TABLE I-10. TOTAL RECLAMATION COST OF A 450-ACRE MINE

Activity	Cost
Preparation and Planning	$ 89,005
Recontouring	934,027
Topsoiling	2,030,150
Revegetation[1]	18,264
Total	$3,071,446
Cost per mined acre	$6,825.44
Cost per permitted acre	$6,466.20
Cost per M Btu[2]	$.033
Cost per ton of coal[3]	$.454

[1]Cropland revegetation goal.
[2]Estimated at 7,000 Btu per lb. of coal and 15,000 tons of coal per acre.
[3]Estimated at 15,000 tons of coal per acre.

planning costs. A change in overburden depth affects the size of the base of the ISB and, therefore, the number of acres that must be put under permit. There is a direct relationship between depth of overburden and preparation and planning costs. For each one acre change in permit area (from the 475 acre permit area assumed), preparation and planning costs change by about $100.

A change in the depth of overburden affects the recontouring costs for all areas in the mining process. The effect on cost is small for the remaining spoil bank area, but substantial for the other three areas.

An increase in the depth of overburden increases the yardage that must be used to level the ramp roads. This occurs because the distance to the bottom of the ramp road increases which in turn increases the width of the ramp road area.

The increase in the width of the ramp road area slightly reduces the length of the remaining areas. An increase in overburden depth increases the yardage that must be moved per unit of distance, as well as the average push distance for the ISB area and spoil bank side of the final highwall area. The result of these factors is an increase in recontouring costs that is only slightly offset by a decrease in the length of these areas.

The effect on the final highwall side is the same as described above except there is no decrease in length of the area. The ramp roads do not extend into this area so that the length remains constant. The decrease in length of the remaining spoil bank area, along with a small decrease in width due to an increase in the width of the final highwall and ISB area, causes the cost for recontouring the remaining spoil bank area to decline as the overburden depth is increased. The logic used in the preceding discussion can also be used to determine the effect of a decrease in the overburden depth. The costs of recontouring with 40-foot, 58-foot, and 68-foot overburden depths are presented in Table I-12.

Coal Seam Thickness

Coal seam thickness has a small effect on per acre reclamation costs, but has a substantial effect on reclamation costs per ton of coal. The coal seam depth does not affect the yardage of overburden to be moved for the ISB area, but it does affect the push distance. A thinner coal seam increases the height of the leveled spoil banks and, therefore, requires a longer push distance to level the ISB spoils. This increased push distance increases the cost of recontouring the ISB area.

A change in the coal seam depth has a negligible effect on recontouring cost for the remaining spoil bank area. The

TABLE I-11. RECONTOURING COSTS FOR SLOPES OF 5, 10 AND 15 PERCENT

Area	Cost With Reclaimed Slopes At:		
	5 Percent	10 Percent	15 Percent
ISB	$281,603	$181,030	$130,378
Remaining Spoil Bank	103,870	124,909	117,399
Final Highwall			
Spoil Bank Side	252,406	102,933	61,724
Final Highwall Side	3,625	6,296	8,553
Ramp Roads	292,523	272,351	251,727
Total	$934,027	$689,595	$569,781
Per Acre Under Permit	1,966.37	1,451.78	1,199.54
Per Acre Mined	2,075.62	1,532.43	1,266.18
Per Ton of Coal[1]	.1384	.1022	.0844

[1]Estimated at 15,000 tons of coal per acre.

per acre cost does not change but the size of the area changes slightly due to a change in the width of the ISB area and final highwall side of the final highwall area (these two factors change in opposite directions).

The cost of recontouring the ramp roads is only slightly affected by the coal seam depth since there is a very small change in the length of the ramp roads. The cost of recontouring the spoil bank side of the final highwall area remains unchanged.

A change in the coal seam depth changes the height of the final highwall. This affects both the yardage of overburden to be moved per unit of distance and the distance it must be moved. Table I-13 shows the effect that changing the coal seam depth has on recontouring costs.

Depth of SPGM

The cost of removing, stockpiling, and reapplying a cubic yard of overburden is $.53. The total cost for topsoiling an acre of land, assuming it is all stockpiled, varies directly with the depth of SPGM. Topsoiling costs for various SPGM depths are presented in Table I-14.

Reclamation Goal

Four reclamation goals were considered: cropland, tame pasture, native range, and wildlife habitat. The most productive land, which normally has gentle slopes, is generally returned to cropland. If land will not be good for cropping, but is still quite productive, it may become tame pasture. Native range and wildlife lands are poorer quality land that will not support much vegetation. Most of these lands were range and wildlife land before mining and are not suited for any other use. Reclaimed land is usually re-

TABLE I-12. RECONTOURING COSTS FOR OVERBURDEN DEPTHS OF 40, 58, AND 68 FEET

	Cost With Overburden Depths At:		
Area	40 Feet	58 Feet	68 Feet
ISB	$154,133	$281,603	$ 353,055
Remaining Spoil Bank	123,192	103,870	93,776
Final Highwall			
Spoil Bank Side	105,377	252,406	417,963
Final Highwall Side	2,491	3,625	4,259
Ramp Roads	153,774	292,523	383,595
Total	$538,967	$934,027	$1,257,648
Per Acre Under Permit	1,134.67	1,966.37	2,647.68
Per Acre Mined	1,197.70	2,075.62	2,794.77
Per Ton of Coal[1]	.0798	.1384	.1863

[1]Estimated at 15,000 tons of coal per acre.

TABLE I-13. RECONTOURING COSTS FOR COAL SEAM THICKNESSES OF 6, 12, AND 28 FEET

	Costs With Coal Seam Thicknesses At:		
Area	6 Feet	12 Feet	28 Feet
ISB	$303,010	$281,603	$278,163
Remaining Spoil Bank	105,332	103,870	104,269
Final Highwall			
Spoil Bank Side	252,406	252,406	252,406
Final Highwall Side	2,509	3,625	8,175
Ramp Roads	292,899	292,523	291,206
Total	$956,156	$934,027	$934,219
Per Acre Under Permit	2,012.96	1,966.37	1,966.78
Per Acre Mined	2,124.79	2,075.62	2,076.04
Per Ton of Coal[1]	.2833	.1384	.0593

[1]Estimated at 1,389 tons per acre-foot of coal.

turned to the reclamation goal that conforms to its use before mining. In some instances, however, it may be returned to a more productive use.

The only direct effect of a change in the reclamation goal is a change in the cost of seed mixtures. The cost per acre of the seed mixture for cropland and tame pasture goals is $10.06 for sandy dry soils and $10.31 for heavier soils. The native mix is the most costly, at $53.23, while the wildlife land mix is $12.52.

Direct Application of Topsoil

The most common method of topsoiling is to stockpile all the SPGM before it is returned. The least cost method of topsoiling is direct application of SPGM on previous cuts. This cuts in half the time consuming process of loading and unloading the scraper. The cost of topsoiling using direct application is presented in Table I-15.

TABLE I-14. TOPSOILING COSTS FOR SPGM DEPTHS OF ONE TO FIVE FEET

SPGM Depth	Total Cost Per Acre
1 foot	$ 855
2 feet	1,710
3 feet	2,565
3.5 feet	2,993
4 feet	3,420
4.5 feet	3,848
5 feet	4,275

The cost of removing the overburden from beneath the initial spoil bank and mining passes one, two, and three is the same as for the stockpiling method of topsoiling. All of the stockpiled SPGM is transported to the final highwall region, with the exception of that which will be used to finish topsoiling the leveled ISB. SPGM from mining pass four is deposited on the leveled ISB nearest the initial cut. This leaves a portion of the leveled ISB which must be topsoiled with stockpiled SPGM. The rest of the mine is topsoiled with direct application of SPGM.

Irrigation

Irrigation of revegetated land is not currently being practiced. However, first year irrigation of newly revegetated land is being considered as a way to increase the effectiveness of revegetation. Erosion and lack of moisture are major causes of revegetation problems. Application of the proper amount of moisture improves the stability of the soil and, therefore, reduces erosion losses. Preliminary work being done by the Agricultural Research Service (ARS) indicates that irrigation will increase the number of plants per acre and improve the effectiveness in getting a vegetative cover established.

Whether irrigation becomes an important factor in reclamation depends on its cost effectiveness, federal reclamation requirements, and availability of adequate water. A major obstacle in irrigation of revegetated land will be obtaining water of adequate quality and quantity. Water from the mine pit along with well and river water are possible sources of irrigation water. The use of river water is limited by the distance the mine is from a river. Adequate quantities of underground water tend to be quite limiting in

TABLE I-15. DIRECT APPLICATION TOPSOILING COSTS FOR 5 FEET OF SPGM AND 475 ACRES UNDER PERMIT

Section of Mine	Cost Per Yard	Cubic Yards of SPGM in the Area	Total Cost
SPGM Directly Applied to Leveled Spoils	$.2494	3,278,000	$ 817,533
Stockpiled SPGM From ISB Through Cut 3	$.265	551,819	146,232
SPGM Hauled to Final Highwall Area	$.3645	469,333	171,072
SPGM Returned to ISB area	$.265	82,486	21,859
Total			$1,156,696
Per Acre Under Permit			2,435.15
Per Acre Mined			2,570.44
Per Ton of Coal[1]			.1384

[1]Estimated at 15,000 tons per acre.

most mine areas. Water from the mine pit is available in many areas in North Dakota but it tends to be salty. The effect of a limited, short-term amount of this water on land being reclaimed is not yet known. The cost per acre and per ton of coal mined for the big gun and solid set irrigation systems are presented in Table I-16. Both systems have been mentioned as irrigation systems that may be adaptable to reclamation situations.

The costs of irrigation are based on the assumption that well water is used. If water from the mine pit is found to be acceptable, the total investment cost for either system would be reduced by $253.13, and the other costs related to the total investment cost reduced proportionately. There would be a pumpsite preparation cost of at least $4,000 if river water is used, and a cost for moving the water from the river to the mine site. Underground installed eight-inch polyvinyl chloride (PVC) pipe costs $5 per foot or $26,400 per mile (Agricultural Research Service and North Dakota Agricultural Experiment Station).

Summary

The cost of reclamation under the conditions assumed varies considerably between Montana, Wyoming, and North Dakota. The average cost per acre (estimated in 1976 dollars) in Montana ($5,050) is double the cost in Wyoming ($2,500). The range in per acre costs for both Montana and Wyoming is quite great, reflecting the fact that conditions encountered at a given mine site are subject to considerable variation.

The cost per acre mined in North Dakota was estimated to be $6,825 (in 1977 dollars), with considerable variation found to exist as the assumed conditions are altered. The most important factors affecting reclamation costs in North Dakota are depth of SPGM, depth of overburden, reclaimed slope, and method of applying topsoil.

The total reclamation cost decreases by 40 percent to $3,988 per mined acre if the depth of SPGM is reduced from five to two feet. A change in overburden depth affects recontouring costs. The recontouring cost increases from $2,076 to $2,795 per mined acre when the overburden depth is increased from 58 to 68 feet; and it declines to $1,198 per mined acre when the overburden depth is decreased to 40 feet. Recontouring costs per acre mined are

TABLE I-16. IRRIGATION COSTS FOR THE BIG GUN AND SOLID SET IRRIGATION SYSTEMS USING WELL WATER

Item	Per Acre Costs For: Solid Set	Big Gun
Total Investment[1]	$2,223.75	$518.75
Annual Ownership Costs		
Depreciation on System[2]	19.62	8.35
Depreciation on Well, Pump, Motor, and Pipe[3]	96.48	19.69
Average Interest on Investment[4]	100.07	18.84
Insurance[5]	11.12	2.60
Total Annual Ownership Costs	227.29	49.48
Annual Operation Costs		
Power[6]	16.60	27.70
Labor[7]	6.00	6.00
Repairs and Lubricants[8]	33.36	7.82
Total Annual Operation Costs	55.96	41.52
Total Annual Ownership and Operation Costs Per Acre	$285.35	$91.00
Per Ton of Coal	.0189	.0061

[1]The total investment is estimated for a 160-acre irrigation system. The dimensions for the solid set system are 1 mile by ¼ mile.
[2]15-year straight line depreciation.
[3]20-year straight line depreciation with three wells over the life of the system.
[4]$\frac{\text{(Original Cost)}}{2} \times .09$
[5]Fifty cents per $100 investment.
[6]Based on electrical rate of 2.5¢ per KWH and $12.50 per HP yearly demand and a 14-inch gross water application.
[7]Estimated at $3.00 per hour.
[8]Estimated at 1.5 percent of new cost.

SOURCE: Interview with Darnell R. Lundstrom on January 20, 1978, and Lundstrom, Darnell R., *Selecting a Sprinkler Irrigation System*, Circular AE-91, Cooperative Extension Service, North Dakota State University, Fargo, December, 1977.

also affected when the reclaimed slope is increased. The cost is $1,966 per mined acre with a 5 percent slope and decreases to $1,452 and $1,200, respectively, with a 10 and 15 percent slope. Direct application of SPGM, if possible, reduces topsoiling costs by about one-half in comparison to stockpiling and reapplying SPGM.

The largest portion of reclamation costs is accounted for by handling and reshaping the topsoil and spoil material. On average, these factors account for about 87 percent of the reclamation cost in Montana, 82 percent in Wyoming, and 96 percent in North Dakota. Preparation and planning and revegetation, though important to the reclamation process, have considerably less effect on cost.

CHAPTER II

WATER RESOURCES

Water is critical for life on earth. Its uses include human consumption, animal consumption, irrigation, sanitation, hydroelectric power generation, a multitude of industrial uses, and use as a medium for waste disposal. Inadequate water resources can severely constrain the level and type of activity in a region.

Uses of water may be classed as either consumptive or nonconsumptive. Consumptive use implies that water is used up in the production process, while nonconsumptive use implies that the purpose for which the water is used does not deplete the quantity available. Many production processes have both consumptive and nonconsumptive characteristics. Only a small portion of municipal water is consumptively used — the remaining portion returning to be used again in treated or untreated form. The portion of irrigation water consumptively used by crops depends on a host of agronomic, technological, and management factors. The consumptive use of irrigation water may range from 20 to 95 percent. Industrial uses of water similarly vary widely in consumptive use. Hydroelectric power generation consumes almost no water all, though vast quantities are used in the production process. Thermal power generation, however, requires a smaller quantity of water for production but a much higher consumptive use, as a substantial quantity is lost as steam in the cooling process.

Finally, the use of water may alter the physical characteristics of the portion not consumptively used. Municipal uses may return water high in organic content if untreated before discharge. Irrigation return flows may contain substantially higher concentrations of plant nutrients, dissolved solids, and suspended soil particles than the irrigation water applied. Effluent from thermal power generation typically contains high concentrations of dissolved salts resulting from steam losses in the production process. Thermal power generation return flows may also be substantially warmer than the water originally diverted for use. Even hydroelectric power generation may contain abnormally high levels of dissolved atmospheric nitrogen, resulting in a deleterious impact on fisheries downstream.

Surface Water Resources of the Upper Great Plains

Figure II-1 shows the major rivers and streams in the Upper Great Plains. It is apparent that the Missouri River system dominates the surface water resources of the region, and is the inevitable source of water for most of whatever thermal power generation, coal gasification, and slurry pipeline coal exportation that does (or may) take place. In addition, the Missouri River and its tributaries provide water for many of the cities and towns in the region and is the source of irrigation water for much of existing and potentially irrigated land in the region.

The source of the Missouri River is the mountains of western Montana where snow melt provides a far more uniform flow than that found in prairie rivers. It flows in an easterly direction, augmented by a multitude of mountain streams. The first major impoundment of the Missouri River within the Upper Great Plains is Fort Peck Reservoir, a likely source of water for nearby coal conversion complexes. The Missouri continues its easterly flow through Montana and into North Dakota. Just inside North Dakota, it is joined by a major tributary, the Yellowstone River.

The Yellowstone River system is important to coal development in the region because of its strategic location near rich coal deposits. It flows northeasterly out of Wyoming through Montana. Joining it in succession are the Bighorn River, the Little Bighorn River, the Tongue River, and the Powder River. Within the area bounded on the east and west by the Powder and Bighorn Rivers respectively, and on the north by the Yellowstone, lies the major lignite and subbituminous coal deposits of southeastern Montana and northern Wyoming.

The second major impoundment of the Missouri River in the Upper Great Plains is Lake Sakakawea which stretches for 200 miles from near the Montana-North Dakota border well into central North Dakota. Substantial minable lignite deposits lie both to the north and south of Lake Sakakawea which serves as a source of water for existing and proposed thermal power generating and coal gasification facilities. Also flowing into Lake Sakakawea is the Little Missouri River which flows northerly from northeastern Wyoming through southeastern Montana, then north and east through North Dakota.

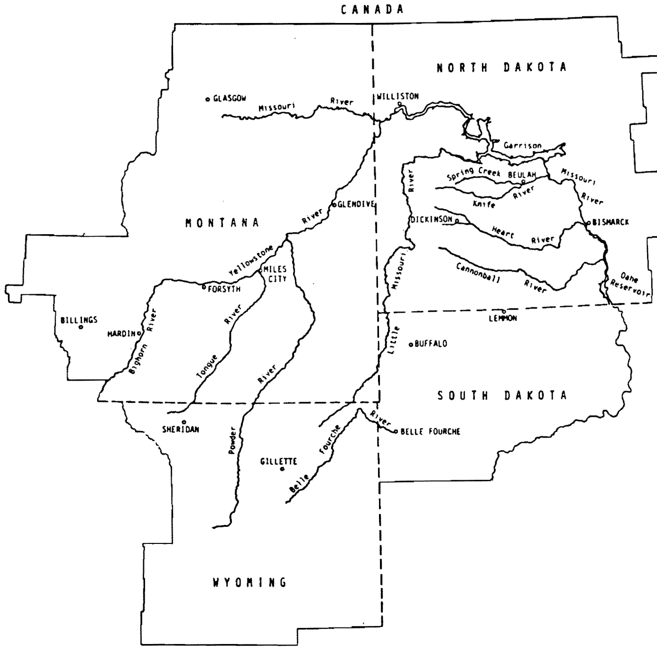

Figure II-1. Major Rivers and Streams in the Upper Great Plains

Below Lake Sakakawea, the Missouri is joined by a number of prairie rivers including the Knife, Heart, and Cannonball Rivers. These rivers exhibit characteristics typical of prairie rivers with high spring runoff volumes and low fall and winter flows. It is unlikely that these rivers will constitute a major source of water for coal conversion complexes because of their seasonal flows, but they may provide supplemental water as needed and serve as return flow channels for effluent discharges.

The last major impoundment on the Missouri River in the region is Lake Oahe which lies within both North and South Dakota. Lake Oahe does not lie immediately adjacent to areas of current mining as do Lake Sakakawea and Fort Peck Reservoir. Use of Lake Oahe water in coal conversion processes, therefore, appears to be unlikely in the immediate future. Discovery of new coal deposits and legal or institutional constraints on the availability of water close to existing or proposed mines and coal conversion complexes may make water from Lake Oahe an economical water source.

Groundwater Resources of the Upper Great Plains

The availability of groundwater sufficient to meet the needs of significant coal conversion development in the Upper Great Plains is uncertain. Shallow groundwater aquifers presently used for domestic and livestock water requirements are not sufficient to meet industrial needs. Deep groundwater aquifers underlie much of the Northern Great Plains. Whether or not the location, quality, and quantity of deep groundwater is sufficient to measurably contribute to surface water used in coal conversion is a matter of considerable conjecture. For the purposes of this study, significant development of groundwater resources for industrial use was not considered.

Surface Water Flow Volumes

A number of factors must be considered in the estimation of water available for use by coal conversion facilities in the Upper Great Plains. Variations in the quantity available occur annually and seasonally. To some degree, water requirements by conversion facilities will vary with peak power load demands, seasonal gas demands, and the degree to which atmospheric conditions affect cooling requirements. Storage reservoirs assist in making water available in adequate quantities throughout the year, but at substantial construction, operation, and environmental costs.

Table II-1 shows annual mean river flows, critical year annual flows, and estimated in-stream requirements for the major rivers in the region. While storage facilities can mollify the impacts of seasonal and, to some extent, annual flow variations, depletion of water resources to the extent that estimated in-stream requirements are not satisfied will result in economic or environmental sacrifices in the region. Additionally, water commitments may exceed water availability during periods of extended drought and concomitant low stream flows. Rationing of water during such periods may tend to favor those with the greatest political power rather than those whose uses for water yield the highest economic return. Complete elimination of such problems can only be avoided if water use is restricted to that available during periods of extreme low flows. Such a policy would result in severe underutilization of water resources during periods of normal or supernormal flows.

TABLE II-1. STREAM FLOWS IN THE UPPER GREAT PLAINS[1]

River and Basin	Average Annual Flow	Critical Year Annual Flow	Estimated In-stream Requirements
		1,000 acre feet	
Yellowstone Basin			
Clarks Fork	767.0	538.0	207.8
Wind and Bighorn	2,550.0	1,429.0	1,527.6
Tongue	304.0	32.0	148.5
Powder	416.0	43.0	162.5
Yellowstone (at Missouri River)	8,800.0	3,720.0	4,083.8
Upper Missouri Basin			
Missouri at N.D. border	7,276.0	NA[2]	NA[2]
Missouri at Lake Sakakawea	16,952.0	NA[2]	NA[2]
Missouri at Oahe Reservoir	18,525.0	NA[2]	NA[2]
Western Dakota Tributaries			
Little Missouri	390.0	35.0	184.8
Knife	118.0	3.0	61.7
Heart	154.0	17.0	70.0
Cannonball	149.0	1.0	68.3
Grand	156.0	9.0	44.8

[1]Averaged as of 1970.

[2]Not estimated.

SOURCE: Northern Great Plains Resources Program, *Water Works Group Report*, Denver, Colorado, 1974.

Water Requirements for Coal Conversion Facilities

Some uncertainty exists regarding the water "requirements" for alternative forms of coal conversion facilities. In some cases, coal gasification for example, the technologies employed are in the experimental stage. In other cases, thermal power generation for example, alternative technologies exist to accomplish the purposes which water serves. Dry cooling requires far less water than does wet cooling, which requires less water than does "once through" cooling. (See Townsend and VanLanen, and May and Kube for a more complete discussion of available technologies.) Alternative technologies also vary widely in construction, operation, and maintenance costs. Thus, the concept of water "requirements" must be tempered by the recognition that the quality of water actually used will be influenced by the quantity available, water costs, and the relative costs of alternative technologies, in addition to the absolute level of coal conversion development.

Despite the uncertainty surrounding water requirements for conversion processes, estimates have been made regarding water usage. Table II-2 shows the estimated annual consumptive water use for alternative processes used in this study. Consumptive use estimates do no reflect the quantity of water actually withdrawn from streams, but rather are the net amounts of water depleted from stream flows. Water used in mining does not include that used for reclamation and revegetation because the degree to which irrigation will be utilized in the reclamation process remains highly uncertain. Harza Engineering estimated annual consumptive use for reclamation at 149 acre-feet per million tons of coal mined in North Dakota, 90 acre-feet per million tons in eastern Montana and north-central Wyoming, 56 acre-feet per million tons in south-central Montana, and 23 acre-feet per million tons in eastern Wyoming.

Other Demands for Water

Irrigated land in the Upper Great Plains makes up only a small part of the total cropland acreage. About 6 percent of the region's harvested cropland is irrigated. Over 75 percent of the irrigated land is used to produce relatively low value hay and forage (U.S. Department of Commerce). However, this irrigated cropland provides a large part of the winter feed base on which the region's extensive livestock industry depends. Without a reliable source of winter feed, cattle raising would become a more risky enterprise, and it is likely that summer ranges would be used less intensively and cattle numbers in the area might decline.

In addition, there is a desire for continuation and expansion of irrigated agriculture in states in the Upper Great Plains. Irrigation is seen as a means of stimulating local economies, halting the out-migration of residents that has occurred in many areas, and supporting a population whose goals, moral standards, and life styles are consistent with the existing population. It is conceivable that in some areas, in Wyoming particularly, large scale use of water for coal conversion would preclude the levels of irrigation development envisioned by state leaders.

The major stimulus for in-migration to the region, with or without additional irrigation, will be the expansion of coal mining and coal energy conversion facilities. Labor requirements during construction will exceed requirements during operation (Toman, *et al.*). However, sufficient water will be required to meet the drinking and sanitation needs of the peak level of population. Stroup and Townsend estimated water demand in municipalities with populations of 2,500 to 10,000 to be from 125 to 150 gallons per capita per day with consumptive use of 25 gallons per capita per day. In municipalities under 2,500 population, demand was estimated to be 80 to 120 gallons per capita per day and consumptive use from 5 to 45 gallons per capita per day. Using the 25 gallon consumptive use estimate, one acre-foot of water would be sufficient to satisfy the consumptive requirements of 13,034 people for one day. Total daily water withdrawal for this population (based on demand of 125 gallons per capita per day) would be 5 acre-feet per day and return flows would be 4 acre-feet per day. It

TABLE II-2. ANNUAL CONSUMPTIVE USE OF WATER IN MINING, RECLAMATION, AND COAL ENERGY CONVERSION FACILITIES

Activity	Unit	Water Consumed
Mining	acre feet/million tons	20
Thermal Electric Power		
Mechanical Draft Wet Tower	acre feet/megawatt capacity	10.6
Mechanical Draft Dry Tower	acre feet/megawatt capacity	2.9
Coal Gasification		
Normal Process	acre feet for 250 MCFD capacity	10,000
Partial Air Cooled Process	acre feet for 250 MCFD capacity	6,000
Coal Slurry Pipeline	acre feet/million tons	600

SOURCE: Harza Engineering Company, *Analysis of Energy Projections and Implications for Resource Requirements,* Report prepared for the Missouri River Basin Commission, Chicago, December, 1976.

would appear that such consumptive use of water would not place a severe burden on the region's total water resources under estimated levels of coal development and population expansion. Population growth will inevitably strain the available water resources and delivery systems in some communities and this may require substantial and costly investments in municipal water supply systems.

Increased population will lead to increased demands for water related recreation activities. These range from such nonconsumptive uses as boating, fishing, and waterfowl hunting to activities which do consume water such as swimming pools and the irrigation of public parks and recreation areas. It is believed that consumptive use for recreation purposes will be negligible in relation to the region's total water requirements. Depletion of stream flows resulting from coal energy development may have serious adverse effects on wildlife related recreational activities during years of low stream flows or if in-stream storage reservoirs are constructed. The states in the Upper Great Plains region have traditionally husbanded a strong awareness of the economic and aesthetic value of wildlife resources and the environment. They view with understandable trepidation the potential debasement of these resources which may result from massive energy development. A detailed analysis of the environmental impacts of coal energy development is beyond the scope of this report, however.

Coal Energy Development — Level I and II

Table II-3 shows existing (1977) and projected levels of coal mining and conversion development in the Upper Great Plains for two levels of development by 1990. These levels are substantially below the development forecast presented by the Harza or the Northern Great Plains Resources Program. However, it was felt that these data accurately reflect likely development prospects in the region, as they reflect existing development, construction begun, and announced plans by companies involved. As can be seen, both Levels I and II represent a rather substantial increase in thermal generating capacity — Wyoming's capacity quadrupling, North Dakota's almost tripling, and Montana's more than doubling. Two coal gasification plants of 250 MMCFD capacity are projected to be constructed in each state by 1990. Coal mining is projected to increase in response to increased demands by energy conversion facilities and increased demands for coal exported from the region.

Water Consumption — Levels I and II

Table II-4 shows estimated consumptive use of water for mining, thermal electric generation, and coal gasification by state. Estimated consumptive use is based on consumptive use by activity in Table II-2 and levels of development shown in Table II-3. Estimates are for the year 1990, so prior years would experience lower levels of consumptive use.

Total annual water consumption in the Upper Great Plains for coal mining and conversion is estimated to be 132,732 acre-feet under Level I and 140,632 under Level II. Explicitly ruled out in these estimates is the exportation of coal by slurry pipeline. Recent congressional action forbidding the use of eminent domain for land acquisition in pipeline routing makes slurry pipeline construction unlikely in the near future. It is also important to note that estimates of consumptive use in thermal generation and coal gasification vary widely. May and Kube, for example, estimated annual consumptive use at 15.2 acre-feet per KW capacity using mechanical draft wet cooling as compared to 10.6 acre-feet used here. Kube estimated annual consumptive use producing synthetic natural gas using the Lurgi process as 43,750 acre-feet compared to 20,000 acre-feet used here.

Wyoming Water Consumption

Based on projected levels of development, total annual

TABLE II-3. CURRENT AND PROJECTED COAL PRODUCTION AND CONVERSION CAPACITY IN THE UPPER GREAT PLAINS BY 1990

Activity and Region	Unit	Industry Capacity (1977)[1]	Level I	Level II
Coal Production				
North Dakota	million tons	18.8	49.7	72.3
Montana	million tons	27.6	43.1	103.1
Wyoming	million tons	51.4	122.5	199.2
Thermal Electricity				
North Dakota	MW	1,220	2,560	3,000
Montana	MW	950	2,350	2,350
Wyoming	MW	390	1,550	1,550
Coal Gasification				
North Dakota	MMCFD	0	500	500
Montana	MMCFD	0	500	500
Wyoming	MMCFD	0	500	500

[1]SOURCE: Office of Coal Energy Resource Development, Federal Energy Administration, *Summer Quarter Western Coal Development Monitoring System*, Washington, D.C., August 1, 1977.

TABLE II-4. ANNUAL WATER CONSUMPTION BY MINING AND CONVERSION ACTIVITIES IN THE UPPER GREAT PLAINS BY 1990

Activity	Region[1]	Level I	Level II
		— acre feet per year —	
Thermal Power			
(wet cooling)	1	27,136	31,800
	2	530	530
	4	24,380	24,380
	5	11,130	11,130
	6	5,300	5,300
		68,476	73,140
Coal Gasification	1	20,000	20,000
	4	20,000	20,000
	5	20,000	20,000
		60,000	60,000
Mining	1	994	1,446
	2,3,4	862	2,062
	5,6	2,450	3,984
		4,306	7,492
North Dakota Total		48,130	53,246
Montana Total		45,772	46,972
Wyoming Total		38,830	40,414

[1]Region designations are as follows:
1 - North Dakota Lignite
2 - Eastern Montana Lignite
3 - Powder River Basin Lignite (Montana)
4 - Powder River Basin Subbituminous (Montana)
5 - Powder River Basin Lignite (Wyoming)
6 - Powder River Basin Subbituminous (Wyoming)

consumptive use of water in Wyoming by 1990 is estimated to be 38,830 acre-feet under Level I development and 40,414 under Level II development. Most of the development in Wyoming will be in the Tongue and Powder River drainages. As seen in Table II-1, the Tongue River has an average annual flow of 304,000 acre-feet with in-stream requirements of 148,500 acre-feet, while the Powder River has an annual average flow of 416,000 acre-feet with in-stream requirements of 162,500 acre-feet. Thus, the flow of these two rivers would be depleted by approximately 5.6 percent by Level II development, a level well within estimated in-stream requirements in an average year. Critical year flow is only 32,000 acre-feet in the Tongue and 43,000 in the Powder River, well below estimated in-stream requirements. Diversion and consumption of Level II water requirements would deplete stream flows by nearly 70 percent without the use of water storage facilities.

It is clear that water is sufficiently available in northeastern Wyoming to meet projected needs in an average year. However, stream flows during critical years are only 24 percent of in-stream requirements *without* additional coal mining and energy conversion development. Additional development can only exacerbate the low flow problems which already exist during drought years. It is likely that substantial development of water storage facilities will be required to capture water during high runoff years for use during drought years.

Montana Water Consumption

Based on projected levels of development, total annual consumption of water in Montana by 1990 is estimated to be 45,772 acre-feet under Level I development and 46,972 under Level II development. Development in Montana will also withdraw water from rivers in the Yellowstone Basin, including the Clarks Fork, Wind, Bighorn, Tongue, Powder, and Yellowstone River itself. These rivers constitute a substantial water resource with an annual average Yellowstone Basin outflow of 8,800,000 acre-feet (8,760,000 acre-feet after subtracting Wyoming's consumptive use of the Tongue and Powder Rivers). Examination of Table II-1 indicates that estimated in-stream requirements are 27, 60, and 46 percent of average annual flows for the Clarks Fork, Wind and Bighorn, and Yellowstone River respectively. Level II development in Wyoming and Montana would deplete the average outflow from the Yellowstone Basin by approximately .7 percent, and deplete the critical year outflow by approximately 1.5 percent. Nonetheless, critical year flows are below estimated in-stream requirements in the basin at the present time. Preventing further depletion would again require the use of water storage facilities or less water intensive energy conversion technologies. Moreover, depending on the pattern of development, one or more of the streams and rivers in the region may be depleted to an undesirable extent. While the total water resources of the basin would appear to be only minimally affected by projected development, individual segments may be greatly affected.

North Dakota Water Consumption

Among the states in the Upper Great Plains region, North Dakota would appear to possess the most favorable combination of abundant water located adjacent to rich coal deposits. The region's largest river, the Missouri, with an average annual flow of almost 17 million acre-feet, borders the state's most important coal deposits in Dunn, Mercer, Oliver, and McLean counties. Lake Sakakawea, formed by the construction of the Garrison Dam, constitutes the part of the river closest to existing and potential mining energy conversion facilities.

Total annual consumptive use of water in North Dakota by 1990 is estimated to be 48,130 acre-feet under Level I and 53,246 acre-feet under Level II. Combined with Level II development in Wyoming and Montana, North Dakota's development would suggest a depletion of the Missouri River at Lake Sakakawea of less than one percent. Actual depletion of Lake Sakakawea may be somewhat greater as return flows may be returned to the Missouri via tributaries below the lake. Nevertheless, the return flows will be available for downstream use.

Summary

It would appear that the water resources of the Upper Great Plains are more than adequate in the aggregate to meet the needs of either Level I or Level II coal development during average stream flow years. The area in which water availability may pose the greatest problem is northeastern Wyoming. Surface water resources, while adequate on average, are highly variable. Critical year flows are not presently sufficient to meet in-stream needs, and projected development would have the capability of nearly using up the meager flows during those years. Orderly development will necessitate careful planning of water storage facilities to minimize the impact of additional depletion during critical years.

Development in Montana and to an even greater extent in North Dakota will have a smaller relative impact on stream flows than in Wyoming. The magnitude of water resources available suggest that the energy needs of the region and the nation can be met with a minimal impact on the region's water resources.

Linear Programming Analysis

A linear programming model developed by Harza Engineering Company was adapted for use in estimating water requirements in the Upper Great Plains. The Harza linear programming model selects the minimum cost size, location, and shipping destinations of energy resources, subject to constraints on energy demand and resource availability. Inasmuch as the development patterns outlined previously as Level I and Level II specify rather than select plant sites and levels of development, these patterns are not directly applicable to linear programming analysis. Instead the assumption regarding energy demand and the minimum cost means of satisfying these demands as presented in the Harza study were adapted for use in analyzing the impact on water resources of the Upper Great Plains region.

Linear Programming

Briefly, linear programming is a normative tool which seeks to optimize an objective function subject to a set of constraints. In the context of the Harza model, the objective function consists of the costs of mining and converting and/or transporting coal energy in the Upper Great Plains with the goal of minimizing the total cost. Obviously, the model assumes that people act in economically rational ways by choosing the lowest cost alternative which meets the stated objectives. The constraints of the linear programming model constitute a mathematical representation of both the stated objectives and the social, physical, and environmental factors which limit or constrain development to maximum or minimum levels. Among the constraints considered are the demands for various coal energy forms in different areas, the availability of coal resources, the capacity of transportation systems, and air quality constraints. A solution to the linear programming model specifies the location, type, and level of development in each area of the region resulting in the minimum total cost while simultaneously satisfying the constraints specified. In that sense, the result is an "optimal" solution.

Levels of Development

Three levels of development were analyzed in the Harza study, designated respectively the high, most probable, and low scenarios. Projections were made for 1985 and 2000.

High Scenario

The high scenario is an estimate of the maximum reasonable contribution the area could make in meeting the nation's energy needs. Total mining activity is limited to 100 million tons in 1985 and 200 million tons in 2000. Extensive upgrading of railroad facilities and electric transmission facilities would be required. Coal slurry pipelines were assumed to be constructed upon saturation of the railroad capacity. Annual rail export capacity was estimated to be 40 million tons in 1985 and 100 million tons in 2000.

Most Probable Scenario

The same basic assumptions contained in the high scenario were adopted for the most probable scenario with one major exception. Slurry pipeline transportation of coal was precluded from consideration. The most probable scenario held rail export capacity to the maximum specified in the high scenario.

Low Scenario

The low scenario limited coal production to that necessary to meet local needs and to cover exports that are already guaranteed or are highly probable. No coal gasification was assumed to occur by 2000. Total mining for energy export was limited to 90 million tons annually and local needs were estimated to be 21 million tons. The total of 111 million tons per year production was assumed to be the same in both 1985 and 2000.

Coal Production and Disposition

Table II-5 shows production and disposition of coal production in the Upper Great Plains for 1985 and 2000 for

TABLE II-5. ANNUAL COAL PRODUCTION AND DISPOSITION IN THE UPPER GREAT PLAINS BY STATE AND DEVELOPMENT SCENARIO[1]

Scenario and Use	Wyoming	Montana	North Dakota	Total
	million tons			
1985 and 2000 Low				
Transport by rail	73.1	21.9	5.9	100.9
Thermal electric generation[2]	1.4	3.1	5.6	10.1
Total	74.5	25.0	11.5	111.0
1985 Most Probable				
Transport by rail	40.0	99.4	0	139.4
Thermal electric generation[2]	1.5	4.7	6.9	13.1
Coal gasification[2]	0	0	10.3	10.3
Total	41.5	104.1	17.2	162.8
2000 Most Probable				
Transport by rail	108.5	226.8	0	330.8
Thermal electric generation[2]	1.5	4.1	29.4	35.0
Coal gasification[2]	26.5	38.0	83.0	147.5
Total	136.5	268.9	112.4	513.3
1985 High				
Transport by rail	63.8	63.3	0	127.1
Transport by slurry pipeline	38.2	69.8	19.2	127.2
Thermal electric generation[2]	1.5	3.2	24.6	29.3
Coal gasification[2]	0	0	10.3	10.3
Total	103.5	136.3	54.1	293.9
2000 High				
Transport by rail	118.7	193.2	0	311.9
Transport by slurry pipeline	38.8	176.7	25.6	241.1
Thermal electric generator[2]	1.5	3.2	28.6	33.3
Coal gasification[2]	44.5	57.0	104.0	205.5
Total	203.5	430.1	158.2	791.8

[1]Adapted from: Harza Engineering Company, *Analysis of Energy Projections and Implications for Resource Requirements*, Report prepared for the Missouri River Basin Commission, Chicago, December, 1976.
[2]Power or gas produced in study area.

the high, most probable, and low scenarios by state. It is clear that these levels of projected development are somewhat different from the projections made earlier denoted in Table II-3 as Levels I and II for 1990. The 1985 and 2000 low scenario is 104.3 million tons below Level I and 263.6 million tons below Level II. The 1985 most probable scenario is 52.5 million tons below Level I and 211.8 million tons below Level II while the 2000 most probable scenario is 298 million tons above Level I and 138.7 million tons above Level II. These values are reasonably consistent in view of the fact that Levels I and II are estimates for 1990 while the most probable scenarios are estimates for 1985 and 2000.

The high scenario for 1985 is 78.6 million tons above Level I and 80.7 million tons below Level II. However, by 2000, the high scenario is 576.5 million tons above Level I and 417.2 million tons above Level II. It is clear that the high scenario for 2000 represents a very intensive level of coal development.

It would appear that the low scenario concentrates the greatest coal tonnage in Wyoming, consistent with Levels I and II development. However, as further expansion takes place, represented by the most probable and high scenarios, the largest producing state in the region becomes Montana. This is in part explained by Montana's favorable location with respect to rail transportation and water for exporting raw coal and coal in slurry pipelines. North Dakota becomes a more important producer of thermal electric power and synthetic coal gas for three reasons. First, there exists an abundant water source in Lake Sakakawea. Second, North Dakota's deposits are largely low Btu lignite coal which is expensive to transport on a Btu-mile basis. Lower costs can be attained by exporting the higher Btu coals of Montana and Wyoming while converting North Dakota's lignite to electricity or gas in mine-mouth plants. Third, North Dakota is more favorably located with respect to power and gas consuming population centers of the midwest than are Montana and Wyoming.

Water Use

The linear programming model also selected the least cost cooling technology in computing the optimal solution. In all cases the mechanical draft wet cooling methods for thermal power generation were selected over mechanical draft dry cooling technologies as long as the cost of water at the consumption point was less than $450 per acre-foot for new base load and $750 per acre-foot for new intermediate load plants. Above these costs for water, new plants adopted dry cooling technologies. Existing plants were not given the option to change cooling technology. Relative technology prices are based on 1975 construction costs.

Consumptive use of water by state and by use is shown in Table II-6, based on the assumption that water can be delivered to point of use for less than $450 per acre-foot. Slurry pipeline export use in the high scenarios is based on water use of 600 acre-feet per million tons of coal. The source of water by use is somewhat conjectural. It is likely that the major uses for cooling, coal gasification, and slurry export will require most water to be drawn from major rivers in the area. Mining uses are largely for dust control and much of this water may be drawn from that which usually collects in the mine pit. Reclamation use entails irrigation of newly established seedbeds and requires high quality water. To the extent that water from the mine pit is suitable, it will probably be used. However, the brackish nature of much of the water collecting in pits may require importation from the area's rivers or the development of irrigation wells.

Wyoming Water Consumption

Low Scenario

Annual water use totalling 9,598 acre-feet is projected for Wyoming in 1985 and 2000 under the low scenario. The

TABLE II-6. ANNUAL CONSUMPTIVE WATER USE IN THE UPPER GREAT PLAINS BY SCENARIO, YEAR, STATE, AND USE[1]

Scenario and Use	Wyoming	Montana	North Dakota	Total
	acre-feet			
Low 1985 and 2000				
Mining	1,490	510	220	2,220
Reclamation	2,117	1,450	1,639	5,206
Thermal electric generation	5,979	14,564	18,733	39,276
Total	9,598	16,524	20,592	46,702
Most Probable 1985				
Mining	828	2,830	345	3,256
Reclamation	1,374	6,505	2,571	10,450
Thermal electric generation	5,982	21,381	22,978	50,341
Coal gasification	0	0	9,986	9,986
Total	8,184	30,716	35,880	74,033
Most Probable 2000				
Mining	2, 638	5,377	2,247	10,262
Reclamation	3,907	16,143	16,742	36,793
Thermal electric generation	5,982	17,897	104,415	128,293
Coal gasification	31,588	40,014	80,469	152,071
Total	44,115	79,431	203,873	327,419
High — 1985				
Mining	2,069	2,726	1,082	5,877
Reclamation	3,111	7,897	8,060	19,068
Thermal electric generation	5,982	14,198	85,494	105,674
Coal gasification	0	0	9,986	9,986
Slurry pipeline	22,982	24,376	11,365	58,724
Total	34,144	49,197	115,987	199,329
High — 2000				
Mining	4,069	8,602	3,165	15,837
Reclamation	5,911	25,180	23,580	54,671
Thermal electric generation	5,982	14,198	102,015	122,194
Coal gasification	53,044	60,021	100,828	213,893
Slurry pipeline	23,314	110,932	11,365	149,437
Total	92,320	218,933	224,779	556,032

[1]Adapted from: Harza Engineering Company, *Analysis of Energy Projections and Implications for Resource Requirements*, Report prepared for the Missouri River Basin Commission, Chicago, December, 1976.

mean annual flows of the Tongue and Powder Rivers would be depleted by only 1.3 percent with this level of development and flows appear to be sufficient even during critical years. As observed earlier, critical year flows are not presently sufficient to meet in-stream requirements, and even the low level of development would intensify this problem.

Most Probable Scenario

The most probable scenario in Wyoming entails the annual consumptive use of 8,184 acre-feet in 1985 and 44,115 acre-feet in 2000. This constitutes a 1.1 percent depletion in 1985 and a 6.1 percent depletion in 2000. Existing average annual flows are sufficient to meet these withdrawals while still satisfying in-stream needs, though shortages may exist during parts of critical years, necessitating the construction of storage facilities or groundwater development.

High Scenario

The estimated annual consumptive use in Wyoming under the high scenario is 34,144 acre-feet in 1985 and 92,320 in 2000. These estimates result in a 4.7 percent depletion in 1985 and a 12.8 percent depletion in 2000, again well within the water in excess of in-stream needs during an average year. These requirements involve a 45 percent depletion of critical year flows in 1985 and a 123 percent depletion of critical year flows in 2000. This suggests that water demand may exceed that physically available during critical years if the high scenario of development takes place. Needless to say, in-stream requirements would not be met during critical years.

Montana Water Consumption

Low Scenario

Montana's annual consumptive use of water under the low scenario is estimated to be 16,524 acre-feet in 1985 and 2000. Development in Wyoming and Montana will withdraw water from the Yellowstone Basin. Mean annual outflow from the Yellowstone River is 8.8 million acre-feet, of which slightly more than 4 million is estimated in-stream requirement. Coupled with Wyoming's low scenario use of 9,598 acre-feet, Montana's use of 16,524 acre-feet would deplete the terminal flow of the Yellowstone River by approximately 0.3 percent. It would appear that any of the major tributaries of the Yellowstone could accommodate the low scenario level of development without noticeable damage during average years. Critical year depletion would constitute a depletion from the Yellowstone River of 0.7 percent, though the critical year flow is presently lower than the estimated in-stream requirements.

Most Probable Scenario

The most probable scenario results in an annual consumptive use of 30,716 acre-feet in 1985 and 79,431 acre-feet in 2000 for the state of Montana. Coupled with annual consumptive use in Wyoming of 8,184 and 44,115 acre-feet in 1985 and 2000 respectively, total withdrawal from the Yellowstone Basin would be 38,900 acre-feet in 1985 and 123,546 acre-feet in 2000. This results in a depletion of the Yellowstone River's terminal annual flow of, respectively, 0.4 percent and 1.4 percent. Depletion of the critical year flow would be 1.0 percent and 3.3 percent, though the river would not be able to satisfy all in-stream requirements.

High Scenario

The high scenario annual consumptive use of water in Montana is 49,197 acre-feet in 1985 and 218,933 acre-feet in 2000. Combined with consumptive use in Wyoming of 34,144 and 92,320 acre-feet respectively, total Yellowstone Basin water consumption for coal uses is estimated to be 83,341 acre-feet annually in 1985 and 311,253 acre-feet annually in 2000. These values represent a depletion of the Yellowstone River of 0.9 percent in 1985 and 3.5 percent in 2000, based on mean river flow. Based on critical year flow, depletion is 2.2 percent and 8.4 percent respectively. It would appear that development under the high scenario can be accommodated with existing water supplies with some qualifications. Intensive development along one or more of the Yellowstone's tributaries may result in depletion of that particular tributary to an unacceptable level. Second, the greater the level of development, the greater the risk of regional hardship during low flow years. The seasonal nature of irrigation may result in a significant hardship to agriculture during critical flow years if water use for energy related purposes is given a priority right. This further underscores the need for sufficient reservoir capacity to meet critical year needs.

North Dakota Water Consumption

Low Scenario

Low scenario consumptive use of water in North Dakota is estimated to be 20,592 acre-feet annually in 1985 and 2000, most of which will be withdrawn from Lake Sakakawea on the Missouri River. Total depletion from the Missouri under the low scenario is 46,702 acre-feet annually or 0.3 percent of the mean outflow from Lake Sakakawea.

Most Probable Scenario

Annual consumptive use in North Dakota for coal energy development is estimated at 35,880 acre-feet in 1985 and 200,873 acre-feet in 2000 under the most probable scenario. When combined with the most probable scenario depletions from Wyoming and Montana, estimated annual depletion of the Missouri River at Lake Sakakawea is 74,033 acre-feet annually in 1985 and 327,419 acre-feet annually in 2000, or 0.4 percent and 1.9 percent respectively of mean annual flow.

High Scenario

Consumptive use of water in North Dakota is estimated to be 115,987 acre-feet annually in 1985 and 224,779 acre-feet annually in 2000 under the high scenario. Use in Wyoming and Montana makes the annual high scenario depletion of the Missouri River 199,329 acre-feet in 1985 and 556,032 in 2000. This is a depletion of the mean annual Missouri River flow at Lake Sakakawea of 1.2 percent and 3.3 percent respectively. This would appear to be a relatively minor level of depletion in view of the extensive (and perhaps excessively optimistic) energy development embodied in the high scenario.

Conclusions

Energy development in the Upper Great Plains will have an impact on the region's water resources. Another oil embargo or Middle-east war may make the development forecasts of the high scenario appear to be conservative. It would appear, however, that the available water resources of the area are sufficient to satisfy the needs of increased reliance on these coal reserves without undue hardship on the sectors of the region's economy. While aggregate average water appears to be available in sufficient quantity, detailed planning will be required to prevent overutilization of specific rivers, to prevent hardships associated with critical flow years, and to prevent the degradation of water and air quality which may occur if development is permitted in an uncontrolled and haphazard fashion.

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