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REGIONAL STUDIES PROGRAM

**Extraction of North Dakota
Lignite: Environmental and
Reclamation Issues**

December 1976

U. S. ENERGY RESEARCH
AND DEVELOPMENT
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ANL/AA-7

REGIONAL STUDIES PROGRAM

**Extraction of North Dakota
Lignite: Environmental and
Reclamation Issues**

December 1976

by

James R. LaFevers,
Donald O. Johnson,
and Anthony J. Dvorak

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PREFACE

This study was performed as part of the Argonne National Laboratory Regional Studies Program, which is sponsored by the Energy Research and Development Administration, Assistant Administrator for Environment and Safety, Division of Technology Overview.

The purpose of the Regional Studies Program is to assess the impacts and consequences associated with alternative energy options on a regional basis, and to identify and analyze alternative mitigation and solution strategies for increasing the acceptability of these options. Program leadership is provided by Argonne's Energy and Environmental Systems (EES) Division. The assessments are conducted primarily by staff from three ANL Divisions: EES, Environmental Impact Studies (EIS), and Biological and Medical Research (BIM). Other research institutions and consultants also contribute.

This study addresses the environmental implications of lignite mining in North Dakota. Efforts were coordinated by James R. LaFevers (EES), with the cooperation of Donald O. Johnson (EES) and Anthony J. Dvorak (EIS). Each assumed responsibility for individual sections of this report, as outlined below:

J. R. LaFevers, economic geographer

Environmental Problems: Land (IV C)*
Reclamation -- the Problems (V)
Reclamation Options: Reclamation Economics,
Factors Affecting Reclamation (VI B,C)

D. O. Johnson, coal geologist

Regional Perspective: Geology, Hydrology (II A,C)
Coal and its Use (III)
Environmental Problems: Air, Water (IV A,B)

A. J. Dvorak, terrestrial ecologist

Regional Perspective: Climatology, Edaphic Factors
Soils of the Four-County Area, Biological Description,
Land Use (II B,D,E,F,G)
Environmental Problems: Ecosystem (IV D)
Reclamation -- the Problems: Reclamation Research (V B)
Reclamation Options: Descriptions (VI A)

L. John Hoover, Director
Regional Studies Program
Energy and Environmental
Systems Division

* Report section numbers are in parentheses.

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EXTRACTION OF NORTH DAKOTA LIGNITE:
ENVIRONMENTAL AND RECLAMATION ISSUES

by

J. R. LaFevers, D. O. Johnson, and A. J. Dvorak

ABSTRACT

This study, a component of the Regional Studies Program sponsored by the U.S. Energy Research and Development Administration, addresses the environmental implications of extraction of coal in North Dakota. These implications are supported by details of the geologic and historical background of the area of focus, the lignite resources in the Fort Union coalfield portion. The particular concentration is on the four-county area of Mercer, Dunn, McLean, and Oliver where substantial coal reserves exist and a potential gasification plant site has been identified.

The purposes of this extensive study are to identify the land use and environmental problems and issues associated with extraction; to provide a base of information for assessing the impacts of various levels of extraction; to examine the economics and feasibility of reclamation; and to identify research that needs to be undertaken to evaluate and to improve reclamation practices.

The study also includes a description of the physical and chemical soil characteristics and hydrological and climatic factors entailed in extraction, revegetation, and reclamation procedures.

I. EXECUTIVE SUMMARY

The U.S. Energy Research and Development Administration (ERDA) has made a substantial commitment to the development of alternative technologies for the direct combustion of coal and conversion to synthetic fuels. Hence the Assistant Administrator for Environment and Safety of ERDA, concerned with ensuring the environmental and social acceptability of coal utilization, is sponsoring the related Regional Studies Program (RSP) whose objective is to assess the impacts and consequences of alternative regional energy supply and demand options. The case study detailed here is in turn one of the building blocks of the RSP.

The report addresses the environmental implications of extraction of coal in North Dakota. The study focus is on the lignite resources in the North Dakota portion of the Fort Union coalfield, and, in particular, concentrates on the four-county area of Mercer, Dunn, McLean, and Oliver where substantial coal reserves exist and a potential gasification plant site has been identified. The purposes of this study are: (1) identify the land use and environmental problems and issues associated with extraction, (2) to provide a base of information for assessing the impacts of various levels of extraction, (3) to examine the economics and feasibility of reclamation, and (4) to identify research that needs to be undertaken to evaluate and improve reclamation practices.

Although the report does provide a regional perspective on the various factors and conditions that are significant in determining impacts and consequences of extraction as well as a description of the environmental problems associated with extraction, it does not intend to provide a regional level analysis at this point.

The land use and environmental issues associated directly and indirectly with extraction are diverse. Among these are the development of a gasification industry, which will require a significant increase in lignite production over the relatively light production experienced in North Dakota in the past. It is possible that a single Lurgi plant would require more lignite per year than the current total annual production for the entire state. A complex of four such plants would have the potential of consuming as much lignite in less than four years as has been produced in total in North Dakota since 1884. The land impacts related to the extraction of the lignite and the siting of gasification facilities would also be markedly greater than the past mining impacts. Estimates of the total area affected by mining of lignite in North Dakota vary from approximately 13,000-27,000 acres over the past 40-50 years. By comparison, a single gasification facility and the mines necessary to supply it with lignite would affect more than 15,000 acres during its 25-30-year lifespan, including an initial 1,400 acres for the plant site and more than 500 acres per year for mining. Of this total affected area, approximately 10,000 acres or two-thirds would be currently cultivated cropland, with an average annual production value of \$69-\$120 per acre in 1973. The value of the lignite that would be produced might average up to \$50,000 per acre or more.

The increased extraction of lignite, along with land use impacts, will be accompanied by water and air quality impacts that may require mitigating measures. Potential atmospheric problems related to lignite extraction can be minimized by selective mining practices. Dust from haul roads and storage piles can be controlled by watering. Proper design and maintenance of lignite storage piles and refuse banks can reduce spontaneous combustion fires. Establishment of a vegetative cover on spoil banks lessens the impact of wind erosion. Similarly, mining practices that divert surface water around an active mining area and control surface and groundwater within the pit area are necessary for an environmentally sound mine. Uncontrolled water has the potential to increase the lignite's moisture content and by introducing silt into an active pit can raise its ash content. This activity may potentially lower the quality and value of the lignite.

Many other water-related environmental issues arise in mining. Mining may expose potentially polluting elements put into solution by rainfall. Leaching of spoil piles, refuse areas, and storage piles is a particularly complex problem, as the dynamics of water movement within the piles are poorly understood. Programs to characterize mine effluents and to investigate spoil pile hydrodynamics are needed; such programs should assess the related impacts on human health and agriculture.

Mining or disrupting a lignite aquifer is a minor local problem as yields from these aquifers average 10 gallons per minute or less. On the other hand, mining which disrupts a glacial aquifer could be a serious problem, especially in McLean County. Many of the glacial aquifers are in hydrostatic continuity with surface waters and mining could change their hydrostatic head relationships. An important hydrologic concern is the possibility of mining in recharge areas. Mining in these areas could be critical; flow could decrease or cease in aquifers and/or surface water, with subsequent effects downstream. Recharge areas must be delineated and possibly excluded from mining.

Revegetation requirements are becoming regular components of reclamation regulations. Methods for reducing the land impacts related to extraction are constantly being researched and improved. A primary goal is to recontour and revegetate mined areas so they can become at least as valuable and productive as they were before mining. In general, two major problems

must be dealt with to achieve successful revegetation in North Dakota; climate and the physical and chemical characteristics of the spoils. Climatic factors cannot be altered sufficiently to eliminate their controlling influence on revegetation. Problems associated with spoils include high clay content ($>40\%$), high concentrations of adsorbed sodium ($SAR \geq 12$), high concentrations of soluble salts resulting in saline conditions ($EC \geq 4$), calcium carbonate (equivalent) or free lime ($>10\%$), low organic matter ($\leq 2\%$), low concentrations of phosphorus, and after a few years, low nitrogen. Problems associated with the physical and chemical characteristics of spoil material are possible to offset but long-term ramifications remain unknown.

Present regulations for reclamation require both topsoil and subsoil segregation, storage and reapplication of that portion of the upper five feet that meet certain chemical and physical criteria. Based on the present criteria for segregation, and on the possibility that at least five feet of suitable plant growth material must be returned to the recontoured spoils, it is possible that some surface minable coal deposits in Dunn, Mercer, and Oliver counties should not be mined. Figure 1.1 delineates those areas that may not have the five feet of suitable plant growth material available and thus mining in these areas may be restricted. Although experiments are under way, research data are not presently available to define the depth to which surface material should be returned. Questions concerning the fate of soil microbiota and microbial transformation during topsoil storage are to date also unanswered.

Research is needed in many areas before some of the significant problems related to the reclamation of mined lands can be successfully solved. The areas suggested for initial and further studies are included in the following recommendations. The long- and short-term effects of utilizing reclaimed lands must be monitored. Such monitoring programs should consider productivity, species composition, plant cover, grazing intensity, physical and chemical characteristics of the plow layer, and soil microbiology and mineralization. The results of this monitoring program should be used to develop management guidelines for post-mining land use. Also because of the value and importance of impoundments in the Northern Great Plains, investigations should be conducted to determine the feasibility of establishing impoundments on mined lands for multiple use by man and wildlife.

Fig. 1.1. Surface Mineable Coal Deposits and Soil Associations with Emphasis on Associations Having Less than Five Feet of Suitable Plant Growth Material

Additional assessments need to be made regarding grassland. A mixed grassland is a diverse community composed of numerous species of grasses and The recommended species to plant (January 1974 *Guidelines for Reclaiming Coal Mine Lands in North Dakota*) in reclaiming land results in a community made up of five grasses and a single legume. The ability of wildlife to recolonize revegetated areas and the influence of plant diversity on faunal recolonization needs to be assessed. The suggested native grass plant seed mix does not include blue grama, *Bouteloua gracilis*, which is a major forage producer and contributor to ground cover in native mixed-grass ecosystems. The assumption that blue grama will invade reestablished grassland over time from adjoining stands should be investigated.

As to reclamation costs, these are calculated and reported with little uniformity in method. Some generalizations can be drawn based on the data obtained from industry in North Dakota. Before topsoiling was required by law, the most significant cost factor in the reclamation program was the grading requirement. Grading typically accounted for 23-55% of the total reclamation cost, which was \$700-\$1800/acre. More stringent reclamation (specifically North Dakota's 1973 law) requiring the replacement of up to five feet of surface material, inflation and increased operating costs, and more complete cost reporting have resulted in much higher estimates of total reclamation costs during the past 3-5 years. With complete topsoiling, reclamation costs are now estimated at \$2400-\$6600/acre or 1.2-3.5 ¢/MBtu. In the latter case, topsoiling accounted for 61% of the total reclamation cost, thus displacing grading as the largest factor. With fuel costs associated with lignite power generation varying from 18-51 ¢/MBtu, reclamation costs represent 2-20% of the fuel costs. More cost-effective reclamation could be a significant factor in keeping down energy costs.

2. REGIONAL PERSPECTIVE

A. Geology

1. Structure

Rocks of every geologic period from the Precambrian through the Quaternary have been found in North Dakota. The bedrock geologic map (Fig. 2.1) shows a basinal structure, the Williston Basin, in the western half of the state; the map of the surficial deposits (Fig. 2.2) shows a Quaternary mantle over the eastern half and northwestern quarter of the state, but the presence of the Williston Basin is still obvious. The Williston Basin is an intracratonic structure whose center is located near the city of Williston in the northwestern quarter of the state. The depth of the basin to the Precambrian rocks is in excess of 15,000 feet below mean sea level at its center. A generalized cross section (Fig. 2.3) shows the distribution of the rocks of various ages and reflects the present subsurface expression of the basin. The full extent of the Williston Basin is shown in Fig. 2.4 as are two major structures: the Nesson and the Cedar Creek Anticlines.

2. Stratigraphy

The following information is mainly from Bluemle (1971), Carlson (1973), and Clayton (1970).

a. Precambrian Rocks

Precambrian igneous and metamorphic rocks underlie all of North Dakota at depths from less than 1500 ft in the east to more than 15,000 ft in the west. Precambrian rocks have been divided into two distinct provinces (Fig. 2.5), the Superior Province to the east with rocks approximately 2.5 billion years old, and the Churchill Province to the west with rocks averaging 1.8 billion years old. Their boundaries are postulated from isotopic age dating of rock samples and from analyses of gravity data. A recent earthquake had its epicenter near the boundary between the two provinces. In the four-county study area, Precambrian rocks range in thickness from 8500 ft (southeast) to 13,000 ft (northwest).

b. Paleozoic Rocks

Sedimentary rocks in North Dakota have been classified according to the sequence concept of Sloss (1963), which separates depositional intervals

TERTIARY SYSTEMS

TW—WHITE RIVER GROUP
 TG—GOLDEN VALLEY GROUP
 TS—SENTINEL BUTTE FORMATION
 TT—TONGUE RIVER FORMATION
 TL—LUDLOW, CANNONBALL, TULLOCK FORMATIONS

CRETACEOUS SYSTEMS

KH—HELL CREEK FORMATIONS
 KF—FOX HILLS FORMATION
 KP—PIERRE FORMATION
 KN—NIOBRARA FORMATION
 KC—CARLISLE, GREENHORN, BELLE FOURCHE, MOWRY,
 NEWCASTLE, & SKULL CREEK FORMATIONS
 KL—FALL RIVER & LAKOTA FORMATIONS

J—JURASSIC ROCKS

O—ORDOVICIAN ROCKS
 PC—PRECAMBRIAN ROCKS

Fig. 2.1. Generalized Bedrock Geologic Map of North Dakota
 (Modified from Carlson, revised November 1973)

Fig. 2.2. Surface Geology of North Dakota
(Source: North Dakota Geological Survey, 1973.)

Fig. 2.3. Generalized North Dakota Stratigraphic Column and Cross Section across the State (Modified from Carlson and Anderson, 1966.)

Fig. 2.4. Full Extent of Williston Basin, Showing Prominent Structures and Location of Cross Section of Fig. 2.3 (Modified from Carlson and Anderson, 1966.)

Fig. 2.5. Precambrian Provinces and Structural Elements of North Dakota
(Source: North Dakota Geological Survey, 1973.)

by major regional unconformities. The seven sequences, in ascending order, are Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, Tejas, and Sakakawea (Fig. 2.6). The first four sequences contain all the Paleozoic Era rocks and the Triassic rocks of the Mesozoic Era.* In the study area, the Paleozoic rocks range in thickness from 4000-8000 ft, dipping to the northwest down the flank of the Williston Basin. The following descriptions represent conditions in the four-county study area. A representative cross section is shown in Fig. 2.7.

(1) Sauk Sequence. The Sauk Sequence represents the basal sedimentary deposits of the Paleozoic Era and ranges in time from the Late Cambrian Period through the Early Ordovician Period. No Early or Middle Cambrian rocks are present. The sedimentary record begins with the Deadwood Formation, a typical onlap depositional sequence of basal sandstone, overlain by shale and limestone, followed by another of sandstone. Thickness of the Deadwood ranges from 200 ft in northeastern McLean County to 700 ft in the northwest part of the county, perhaps reflecting early Paleozoic activity in the Williston Basin.

(2) Tippecanoe Sequence. Following a major interval of non-deposition and/or erosion, the Williston Basin began to develop as a slightly negative area. The Tippecanoe Sequence, containing rocks of Middle Ordovician through Middle Silurian age, ranges in thickness from 1300 ft in eastern McLean County to approximately 2200 ft in the west. The Winnipeg Group clastics, in ascending order, sandstone, shale, and siltstone, are the basal transgressive deposits of the Tippecanoe Sequence. Contacts within the Winnipeg are gradational as is the contact with the overlying series of carbonates and evaporites. Another major erosional or non-depositional interval ensued following carbonate deposition.

(3) Kaskaskia Sequence. The Kaskaskia Sequence consists of rocks deposited during the Devonian and Mississippian Periods. Thickness of this sequence ranges from 2000 ft in the southeast to more than 4000 ft in the northwest indicating more basin development than in the two previous sequences. The Devonian formations are mostly limestones and evaporites with halite (salt)

*The Zuni sequence contains the Jurassic and Cretaceous rocks of the Mesozoic Era and the Paleocene and Eocene rocks of the Cenozoic Era. The Tejas sequence contains rocks from the Oligocene to the beginning of glaciation (Late Pliocene). The Sakakawea sequence contains glacial and post-glacial deposits.

UNITS	SEQUENCE								
GEOLOGIC-TIME:		ERA	PERIOD	EPOCH					
TIME-STRATIGRAPHIC:			SYSTEM	SERIES					
ROCK-STRATIGRAPHIC:									
Fig. 2.6. Stratigraphic Column of North Dakota Heavy Dashed Lines Represent Major Regional Unconformities (Modified from Carlson and Anderson, 1966, p. 1835.)	SAKAKAWEA	CENOZOIC	QUATERNARY	PLEISTOCENE	GROUP OR FORMATION		DOMINANT LITHOLOGY		
	TEJAS		TERTIARY	PLIOCENE	Coleharbor	Glacial Drift			
				MIOCENE	Flaxville?	Silt and Sand			
				OLIGOCENE	Arikaree?	Sandstone and Limestone			
				EOCENE	White River	Clay, Sand, Limestone			
	ZUNI	MESOZOIC	CRETACEOUS	PALEOCENE	Golden Valley	Clay, Sand, Silt			
					Fort Union Group	Sentinel Butte	Sandstone, Shale, Lignite		
					Tongue River	Sandstone, Shale, Lignite			
					Cannonball	Marine Sandstone, Shale			
					Hell Creek	Sandstone, Shale and Lignite			
					Montana Group	Fox Hills	Marine Sandstone		
						Pierre	Shale		
						Niobrara	Shale, calcareous		
						Carlile	Shale		
					Colorado Group	Greenhorn	Shale, calcareous		
						Belle Fourche	Shale		
						Mowry	Shale		
						Newcastle	Sandstone		
					Dakota Group	Skull Creek	Shale		
						Fall River	Sandstone and Shale		
						Lakota	Sandstone and Shale		
						Morrison	Shale and Clay		
					Sundance	Shale, green and brown, Sandstone			
					ABSAROKA	PALEOZOIC	TRIASSIC	Piper	Limestone, Anhydrite, Salt and Red Shale
							PERMIAN	Spearfish	Siltstone, Salt and Sandstone
					KASKASKIA	PALEOZOIC	PENNSYLVANIAN	Minnekahta	Limestone
							MISSISSIPPIAN	Opeche	Shale, Siltstone and Salt
	Minnelusa	Sandstone and Dolomite							
	Amsden	Limestone, dolomitic, Shale and Sandstone							
	DEVONIAN	Big Snowy Group	Heath	Shale					
		Otter	Sandstone						
		Kibbey	Limestone						
		Madison	Limestones and Evaporites						
		Bakken	Siltstone and Shale						
		Three Forks	Shale, Siltstone and Dolomite						
		Birdbear	Limestone						
		Duperow	Dolomite and Limestone						
	Souris River	Dolomite and Limestone							
	Dawson Bay	Dolomite and Limestone							
	Prairie	Halite							
TIPPECANOE	PALEOZOIC	ORDOVICIAN	Winnipegosis	Limestone and Dolomite					
			Interlake	Dolomite					
			Stonewall	Dolomite and Limestone					
SAUK	PALEOZOIC	CAMBRIAN	PRE-CAMBRIAN	Stony Mountain Fm.	Gunton Mbr.	Dolomite and Limestone			
				Stoughton Mbr.	Argillaceous Limestone				
				Red River	Limestone and Dolomite				
				Winnipeg Group	Roughlock	Calcareous Shale and Siltstone			
				Icebox	Shale				
				Black Island	Sandstone				
				Deadwood	Limestone, Shale and Sandstone				

Fig. 2.6. Stratigraphic Column of North Dakota Heavy Dashed Lines Represent Major Regional Unconformities (Modified from Carlson and Anderson, 1966, p. 1835.)

Fig. 2.7. Cross Sections of Sedimentary Rocks of Mercer and Oliver Counties (Source: Carlson, 1973.)

deposits approximately 300 ft thick in the northwest parts of the study area. A few thin argillaceous beds are present. Basin conditions become more restricted in latest Devonian time (the Three Forks Formation) and these continued into the Mississippian with the deposition of the Bakken Formation, a black siltstone/black shale unit. Following deposition of the Bakken, the basin returned to a normal marine environment, and the massive Madison Formation, a series of limestones and dolomites with some evaporites near the top, was deposited. The Madison is the source of much of the groundwater in the Northern Great Plains. The Kaskaskia Sequence ends with the Big Snowy Group, a series of siltstones, shales, carbonates, and sandstones.

(4) Absaroka Sequence. Included in this sequence are rocks deposited during the late Mississippian (?) or Early Pennsylvania Period to the Triassic Period. Thickness of this sequence ranges from 250 ft (southeast) to 1100 ft (northwest) and consists primarily of clastic and evaporitic redbed units.

c. Mesozoic Rocks

(1) Zuni Sequence. Mesozoic rocks of the Zuni Sequence range in thickness from 3300 ft (southeast) to 5000 ft (northwest). The Jurassic deposits consist of evaporites and red shales grading upward through a clastic interval. Cretaceous deposition began with sandstones; but the remainder of the Cretaceous rocks up to the Fox Hills Formation are mostly gray shales deposited in marine environments.

The Fox Hills Formation, a marine sandstone unit, an important aquifer, ranges in thickness from 240 ft in Mercer County to 450 ft in northeastern McLean County, dipping to the northwest at 6-20 ft per mile.

The Hell Creek Formation, another important aquifer, consists primarily of non-marine deposited sandstones, siltstones, mudstones, and a few thin lignite seams. The contact of the Hell Creek Formation, the youngest in the Cretaceous deposit, with the Ludlow Formation, the oldest in the Tertiary deposit, is gradational and usually placed at the base of the first prominent lignite bed. The combined thickness of the Hell Creek and Ludlow Formations ranges from 100 ft in eastern McLean County to 500 ft in western McLean County. The Late Cretaceous Mesozoic deposits and the full range of Cenozoic deposits are shown in Fig. 2.8.

AGE	UNIT NAME			DESCRIPTION	
PLEISTOCENE	SA ANAWA SEQUENCE	COLE HARBOR GROUP	OKHE FM	COARSE SILT, CRAY OVER REDDISH OVER TAN (FOUL)	
			DEWDITCH FM	WELL SORTED MEDIUM SAND (FOUL)	
			COTTEAT FM	ORGANIC POORLY SORTED, CRAYFILT, SANDY, CLAYEY SILT (FLUVIAL, ETC.)	
			FOUR BEARS FM	NONORGANIC SAND AND GRAVEL (FLUVIAL SHORLINE)	
			EMMUN'S FM	AND NONORGANIC SILT AND CLAY (OFFSHORE)	
		BRADDOCK FORMATION	SLIGHTLY CRAYFILT, SANDY, CLAYEY SILT (CLACIAL SEDIMENT) AND GRAVEL (INCLUDING CRANITE LIMESTONE AND BASALT) SAND SILT AND CLAY		
PLEISTOCENE	TEXAS SEQUENCE	FLAXVILLE? FORMATION		CLAYEY SILT WITH LIGNITE FRAGMENTS (FLUVIAL OVERBANK SEDIMENT) AND CROSSBEDDED SAND WITH SOME QUARTZITE ARCHITECTURE AND PORPHYRY PEBBLES (FLUVIAL CHANNEL SEDIMENT)	
MIOCENE		ARIKAREE? FORMATION		TUFFACEOUS LIGHT CRAY, GREENISH OR WHITE CROSSBEDDED COARSE SANDSTONE AND LIMESTONE (LACUSTRINE AND FLUVIAL)	
OLIGOCENE		WHITE RIVER GROUP	BRUTE FORMATION	PINKISH SILTSTONE AND CLAY (LACUSTRINE OFFSHORE) AND SOME SAND (FLUVIAL AND LACUSTRINE SHORLINE) STEEP SLOPES	
			CHADRON FORMATION	DARK CLAY WITH THIN LIMESTONE (LACUSTRINE), FLUFFY, ROUNDED SLOPES	
Eocene	TEXAS SEQUENCE	WHITE RIVER GROUP	UPPER MEMBER	CROSSBEDDED SAND WITH QUARTZITE AND PORPHYRY PEBBLES (FLUVIAL)	
			LOWER MEMBER	YELLOWISH MICACEOUS CROSSBEDDED SANDSTONE, MONTMORILLONITE SHALE, SILTSTONE AND MINOR LIGNITE (FLUVIAL AND LACUSTRINE)	
PALEOCENE	FORT UNION GROUP	SENTINEL BUTTE FORMATION	LIGNITE OR SILTIFIED SILTSTONE	(LACUSTRINE OR FLUVIAL)	
			LAVENDER CLAY		
			WHITE OR ORANGE KAOLINIC CLAY		
			CRAY CLAY		
			CROSSBEDDED AND (PART OF COLDEN VALLEY FM.) (FLUVIAL)		
		TONGUE RIVER FORMATION	UPPER YELLOW BED	SOMBER BROWNISH CRAY, 60% SILT AND CLAY (FLUVIAL OVERBANK, FLOODBASIN AND OFFSHORE LACUSTRINE), 35% SAND (FLUVIAL AND SHORLINE), 5% LIGNITE (SWAMP), SOME SANDSTONE, SCORIA AND LIMESTONE, PETRIFIED STUMP ZONE BELOW, BIG BLUE STEEP RILLED SLOPES	
			LOWER YELLOW BED		
			"BIG BLUE" CLAY BED		
			BASAL SAND BED		
			HT LIGNITE BED		
PIERRE FORMATION	FORT UNION GROUP	BASAL SAND BED	YELLOWISH 75% SILT AND CLAY (FLUVIAL OVERBANK, FLOODBASIN AND OFFSHORE LACUSTRINE), 10% SAND (FLUVIAL AND SHORLINE), 3% LIGNITE (SWAMP), SOME LIMESTONE, SCORIA AND SANDSTONE, CENTRE ROUNDED SLOPES		
		LEBO MEMBER			
		TULLOCK MEMBER			
		LEBO MEMBER			
		TULLOCK MEMBER			
LATE CRETACEOUS	ZUNI SEQUENCE	PIERRE FORMATION	PRETTY BUTTE MBR	DARK CRAY CLAY, FLUFFY, ROUNDED, DARK SLOPES (LACUSTRINE), SOMBER CRAY, LIGNITE SHALE AND DIRTY CROSSBEDDED SAND, DARK PURPLE CONCRETIONS (FLUVIAL, SOME MARINE)	
			COLECAT MBR	WHITE, CROSSBEDDED SAND (FLUVIAL)	
			BULLHEAD MBR	THINLY INTERBEDDED BROWNISH CRAY SILT AND CLAY	
			TIMBERLY MBR	YELLOWISH CLAUCONITIC, DIRTY FINE SAND	
			TRAIL CITY MBR	CRAYISH BROWN SILT AND CLAYEY SAND	
		PIERRE FORMATION	PIERRE FORMATION	VIRGIN CR MBR	SOFT DARK CRAY, FLAKY, NONCALCAREOUS SHALE
				ODONAH MEMBER	HARD SILICEOUS NONCALCAREOUS CRAY SHALE, REDDISH BROWN STAINS ON JOINTS, A FOOT THICK BED OF LIGHT YELLOW WAXY CLAY AT BASE, FORMS STEEP SLOPES
				DE CRAY MBR	SIMILAR TO ODONAH MEMBER
				CRECORY MBR	SOFT SHALE THAT LACKS TREES IN WOODED AREAS
				PEMBINA MEMBER	THINLY BEDDED CALCAREOUS CRAY TO YELLOWISH SHALE WITH FLUFFY SURFACE, COMMONLY SLUMPS
PIERRE FORMATION	PIERRE FORMATION	PEMBINA MEMBER	SLIGHTLY ORGANIC	SOFT NONCALCAREOUS BLACK SHALE WITH YELLOW STAINS, POORLY EXPOSED	
			HIGHLY ORGANIC (FISH SCALES)		
		WITH WHITE WAXY CLAY BEDS			
		NIORARA FORMATION	TAN TO ORANGE CALCAREOUS SHALE, FORMS STEEP SLOPES		
		CARLILE FORMATION	CRAY CALCAREOUS SHALE WITH WHITE SPECKS		
PIERRE FORMATION	PIERRE FORMATION	NIORARA FORMATION	SOFT BLACK NONCALCAREOUS SHALE WITH LARGE ELLIPSOIDAL CONCRETIONS, FINE SAND AT TOP		
		CARLILE FORMATION			

Fig. 2.8. Lithostratigraphic Units Exposed at the Surface in North Dakota (Source: Ting (ed.) 1972.)

d. Cenozoic Rocks

(1) Zuni Sequence. The Cenozoic rocks of the Zuni Sequence include the Fort Union Group of Paleocene Age, which contains most of the state's lignite deposits, plus the Golden Valley Formation of Paleocene-Eocene Age. These rocks are approximately 250 ft thick in southeastern Oliver County and 1350 ft thick in northwestern Mercer County. The Fort Union Group consists of the Ludlow, Cannonball, Tongue River, and Sentinel Butte Formations. Only the Cannonball Formation is a marine deposit; the others are non-marine fluvial, alluvial, and swamp deposits. The Ludlow and Cannonball are continental/marine equivalents.

The Ludlow Formation underlies the Cannonball in western North Dakota; along the Little Missouri River Valley, the Cannonball and Ludlow interfinger. The Ludlow consists of poorly consolidated sandstone, shale, and lignite; the Cannonball, of interbedded sand, silt, and shale, and ranges from 150-360 ft, thickening to the southeast.

The Tongue River Formation consists of interbedded sand, silt, clay, shale, lignite, and limestone. The formation outcrops along the Missouri River and its tributaries in southeastern McLean County and is the surficial deposit of southeastern Oliver County. In the latter area, only the lower 200-300 ft of the formation is exposed; in the subsurface, the thickness ranges from 375-450 ft, thickening to the west and northwest. Lignite beds of commercial thickness have been identified in southeastern McLean County, southeastern Mercer and eastern Oliver Counties, and southwestern Dunn County. Carlson (1973, p. 25), in referring to Mercer and Oliver Counties, noted, "Perhaps the most striking feature ... is the scarcity of thick lignite beds; most exposures of thick lignites are in mines or abandoned mines ... subsurface information tends to verify that thick lignite beds are scarce in the Tongue River in this area. The lignites will be examined in detail under Section III (Coal and Its Use).

Differentiating the Tongue River Formation from the overlying Sentinel Butte Formation is problematical as their lithologies are similar. The contact is usually denoted by a color change, with the Tongue River sediments light yellowish gray to light yellowish brown, and the Sentinel Butte by a darker gray or brown. Royce (1967) defined three criteria to define the contact in western North Dakota: (1) a lignite horizon (HT Butte bed), the uppermost Tongue River lithology; (2) a basal sandy unit, the lowermost Sentinel

Butte lithology; and (3) a color change from buff-yellow (Tongue River) to somber gray (Sentinel Butte). In the study area, the basal sand is most useful in defining the contact between the two formations. The Sentinel Butte is about 350 ft thick in the eastern portion of Mercer County, 500 ft thick in the western, and 650 ft thick in northwestern Dunn County. The formation consists primarily of interbedded silt, clay, and lignite, with sands at the base and top. Lignite of commercial value occurs in most of Mercer County and in central Dunn County. The Golden Valley Formation is present as erosional remnants on some of the drainage divides in Mercer, Oliver, and Dunn Counties, and in the Killdeer Mountain area of western Dunn County. The Golden Valley ranges up to 200 ft thick where preserved and is divided into two members, a lower kaolinitic clay stone member interbedded with sandstone and capped by a thin layer of lignite (except at Alamo Bluff where it reaches a thickness of 6 ft) and an upper micaceous sandstone/siltstone member. The lignite marks the Paleocene-Eocene contact (Hickey, 1966, 1972). Following deposition of the Golden Valley Formation, the Zuni Sequence terminated; an erosional interval separates it from the pre-glacial Tejas Sequence. The Tejas Sequence, with thicknesses up to 400 ft is found only in the Killdeer Mountain area of Dunn County, and consists of the Oligocene White River Group of cross-bedded sandstones and the Miocene Arikaree (?) (Killdeer) Formation of lacustrine limestone, mudstone, sandstone, and volcanic ash.* The Coleharbor Formation (Late Pliocene and Pleistocene) contains all the deposits of glacial origin, including till, outwash gravel, and sand and lacustrine deposits. Pleistocene and recent deposits are the surface materials over much of the study area, except the western third of Dunn County. Extensive sections of Pleistocene and recent deposits are given by the three authors mentioned at the outset of this section.

3. Physiography-Topography

North Dakota is divided into two major physiographic provinces, the Great Plains Province in the southwest and the Central Lowland Province to the northeast (Fig. 2.9). A 30-50-mile wide zone, the Missouri Coteau, separates the two provinces. Elevations range from 750 ft above sea level in the northeastern corner of the state to more than 3500 ft in the southwest.

In the study area, the Central Lowland Province has been identified only in the extreme northeastern corner of McLean County. Streams in this

*The Sakakawea Sequence contains the glacial deposits of the Coleharbor Formation.

area empty into the Sheyenne River and eventually reach Hudson Bay. The remainder of the northeastern quarter and the northeastern portion of the southeastern quarter of McLean County belong to the Missouri Coteau. The Coteau is separated from the Central Lowland Province by the Missouri Escarpment, a slope which rises approximately 400 ft in five miles, to the 2000-ft elevation of the Coteau. The surface, composed of glacial moraines and other glacial-related features, has a local relief of 30-35 ft and marks the continental drainage divide between the Gulf of Mexico and Hudson Bay. The remainder of the four-county area lies in the Glaciated Missouri Plateau Section of the Great Plains Province, with the exception of the eastern third of Dunn County that lies in the Unglaciated Missouri Plateau Section. The Missouri Plateau, except for the lowland area (known as the Missouri River Trench District) that borders the Missouri River, increases in elevation southwestward to a four-county high 3314 ft in the southern end of the Killdeer Mountains. Drainage was drastically changed by glaciation. Previously all streams drained northeastward toward Hudson Bay. Drainage on the Coteau and in the Drift Prairie of the Central Lowlands Province is poorly developed and internal, with many lakes and sloughs intermittently dry and wet. Drainage in the glaciated Missouri Plateau Section of the Great Plains Province, where a thin veneer of glacial drift overlies bedrock, is well developed; in the unglaciated portion of the Missouri Plateau, drainage is also well developed.

B. Climatology

This section describes the climatic factors of the environment of North Dakota with emphasis on the mixed-grass prairie, the predominant ecosystem in the four-county study area. No attempt will be made to cover all the inter-relationships that exist between factors or to arrange the factors according to importance.

Climate will be described by considering microclimate, the area from the soil surface up to and including the layer of air just above the vegetational canopy, separate from macroclimate, the remaining atmosphere. The macroclimate has a controlling influence on the nature of vegetation, while microclimate determines what species will be there (Oosting 1956). Collins (1969) and Whitman (1969) have separated micro- and macro-climate at the five-foot level for the grasslands of the Northern Great Plains based on the seldom exceeded three-foot heights of the flowering stalks of the native mixed-grass prairie.

1. Macroclimate

North Dakota has a typical continental climate, characterized by large annual daily and day-to-day temperature changes, light to moderate precipitation that tends to be irregular in time and coverage, low relative humidity, abundant sunshine, and nearly continuous air movement. Cold dry air masses originating in the polar regions, warm moist air masses from tropical regions, or mild dry air, from the northern Pacific, influence North Dakota's weather every season of the year (Jensen undated).*

a. Temperature

The length of time between the last freeze in the spring and the first freeze in the fall is critical to the vegetation of an area. This period is called the freeze-free period, or, relating this time frame to vegetation, the growing season. A freeze is defined as the occurrence of a temperature of 32°F or lower, recorded five feet above the ground in a standard instrument shelter. Sanderson (1963) has calculated the probability of spring and fall temperatures falling below 32°F in North Dakota. For the normal distribution, the 50% probability level is represented by the average date of the last occurrence in the spring and the first occurrence in the fall. These dates for two cities reporting weather within the four county area are May 25 $\pm$ 10.7 days and September 12 $\pm$ 9.3 days (Center, Oliver County) and May 20 $\pm$ 10.7 days and September 13 $\pm$ 9.3 days (Dunn Center, Dunn County). The freeze-free period or growing season in these two areas is 119 and 125 days $\pm$ 20, respectively.

In the four-county region, March is the transitional month between spring and winter. A rapid warming occurs in April, with temperatures 16° to 19°F., higher than March. The last freezing temperature occurs about mid-May and the first fall frost about mid-September. The extreme recorded temperatures have ranged from a high of 118°F., to a low of -58°F. (Jensen undated). The average of the mean monthly average temperature for the months of April through September is two degrees warmer than the corresponding value for April through July. This late season warmth increases evaporative demand during a time when soil moisture may be lacking. An annual temperature curve for the center of the four-county area, approximately two miles north of Beulah and Zap in Mercer County, is depicted in Figure 2.10.

*Publications cited as references for climatic information have utilized the 30-year period, 1931-60 as the data base, unless stated otherwise.

Fig. 2.10. Mean, Maximum, and Minimum Annual Temperature Curves for an Area 10 Miles North of Beulah and Zap in Mercer County
(Source: Based on Jensen undated.)

b. Precipitation

The annual precipitation pattern for North Dakota is shown in Fig. 2.11. The first substantial spring rains usually occur in early April, with amounts increasing monthly until a peak is reached in June (Fig. 2.12). The mean annual precipitation for the area 10 miles north of Beulah-Zap in Mercer County is 15.8" with 70% falling during the freeze-free period. Precipitation averages 0.6 inches per month for the six winter months of October through March. The generally low winter precipitation is associated with a strong westerly continental airflow between two major storm paths, one originating in the northern polar regions the other the southern tropical regions (Borchert 1950).

The amount of precipitation received during a 24-hour period is usually light, i.e., 0.10 inch or less, 46-62% of the time (Jensen undated). Estimates of extreme precipitation are given in Table 2.1 for Bismarck and Dickinson. At Dickinson, precipitation during a one-hour period may equal or exceed 1.1 inches on the average of once every two years or 1.4 inches on the average of once every five years. During a 10-day period 3.2 inches or more fall on the average of once every two years.

Dry spells or drought are an important aspect of the precipitation patterns of North Dakota. Beginning with 1890, there have been 11 years that could be classified as being major drought years in the Midwest and Great Plains region. These were 1889, 1890, 1894, 1901, 1910, 1917, 1930, 1931, 1933, 1934 and 1936 (Borchert 1950). The extent of the area affected by drought was dependent on the strength of the dry continental westerlies that had replaced the normal summer maritime gulf flow.

Variations (cycles) in solar activity (sunspots) have been observed over time, and it may be that the 22-year sunspot cycle is correlated with climatic cycles. The drought from 1932 to 1936 occurred when sunspots were decreasing and from 1937 through 1939 when sunspots were increasing. A similar pattern may be drawn for the latest completed 22-year cycle in solar activity when dry spells occurred from 1953 through 1959. Based on background information Ramirez (1975) and other colleagues have stated: "If the cyclical patterns of sunspot numbers continue as they have in the past 250 years, and if the correspondence of drought severities to the past cycles of solar activity continues, and noting that the last minor cycle (first 11-year cycle of 22-year

Fig. 2.11. Annual Precipitation in North Dakota
in Inches (Based on National Weather
Service Normal Average - Precipitation
Data for the Years 1931-1960)
(Source: North Dakota Geological
Survey, 1973.)

Fig. 2.12. Mean Annual Precipitation for an Area 10 Miles North of Beulah and Zap in Mercer County
(Source: Based on Jensen, undated.)

Table 2.1. Return Period Values in Inches of Precipitation for Selected Duration at Bismarck and Dickinson, North Dakota (Adapted from Jensen undated.)

	Duration	Return Period in Years					
		2	5	1.0	2.0	5.0	100
Bismarck	1 hour	1.1	1.5	1.8	2.1	2.4	2.7
	1 day	2.0	2.8	3.3	3.8	4.3	4.8
	10 days	3.5	4.6	5.3	6.3	7.3	8.3
Dickinson	1 hour	1.1	1.4	1.7	2.0	2.3	2.7
	1 day	1.8	2.6	3.1	3.5	4.0	4.5
	10 days	3.2	4.2	4.9	5.9	6.8	7.8

cycle) peaked in 1969, then we probably could expect a series of dry spells in the mid-seventies, probably around 1974 through 1977." In support of this theory, 1974 was described as having an unusually dry summer with spotty inadequate rainfall patterns.

c. Sunshine and Solar Radiation

The months of May, June, July, August, and September receive 62, 62, 76, 73, and 65 percent of possible sunshine, respectively. Of the states that border Canada, only eastern Montana equals North Dakota in this respect. The energy flow from the sun (solar radiation) is expressed in langleys, a unit of which is defined as one gram calorie per square centimeter of irradiated surface. North Dakota averages 350 to 370 langleys per day with the highest monthly averages occurring in June and July. No state east of North Dakota receives more solar energy during these two months (Jensen undated). This high energy input can be very beneficial to vegetation in a region having a short growing season if other necessary factors (i.e., water, nutrients etc.) are not limiting.

2. Microclimate

a. Air Temperature

The temperature gradient from the soil surface up to five feet of the atmosphere is affected by many factors, including: solar radiation, wind, vegetation, relative humidity, slope, aspect, soil, and litter. During the day

a temperature gradient normally exists in which the temperature decreases as the distance from the soil surface increases. At night, temperature increases from the soil surface upward. These two phenomena are depicted in Fig. 2.13 as maximum and minimum, respectively. The average daily air temperatures throughout the 5-ft range (Fig. 2.13) are also constant, which is misleading in regard to the temperature extremes to which vegetation at different heights is exposed during a 24-hour period. The greatest fluctuation in temperatures in the mixed-grass prairie of North Dakota is within the soil surface and the adjacent 12 inches (Whitman, 1969). Measurements made August 10, 1963, at the five-foot, one-foot and one-inch level, yielded temperatures of 44°F, 55°F and 70°F, respectively.

b. Soil Temperature

Several properties of the soil affect surface and subsurface temperature. Moist soils will have surface temperatures lower by day and higher by night than when dry. Soils that are light colored have a reduced rate of energy absorption due to reflection, whereas dark soils will absorb more energy resulting in increased temperatures. The variability of soil temperatures decreases as depth increases (Fig. 2.13).

Switzer (1969) recorded surface temperatures on lignite mine spoils in North Dakota from July 19 to August 23, 1968, as part of a revegetation study. The highest temperatures recorded were at the spoil surface, where 137°F was continuous from 2 to 5 p.m. on one day. This temperature was recorded in the bottom of a trough between two spoil piles. Surface temperatures of 120°F for five consecutive hours were recorded on four separate days on a barren lower slope facing southwest. During the 36-day period, the maximum air temperature recorded six inches above the ground was 109°F, the lowest surface temperature recorded was 38°F.

c. Relative Humidity

In the native mixed-grass prairie of western North Dakota, the 6-in. level above the soil surface had higher daily average relative humidities (Fig. 2.14) and a higher daily maximum with less daily variation than the 5-ft level (Whitman, 1969). Figure 2.14 delineates relative humidity at the 6-in. and 5-ft levels recorded at the International Biological Program (IBP) grassland microclimate station near Dickinson, North Dakota. Relative humidity decreases

Fig. 2.13. Average Daily Maximum, Average Daily Minimum, and Daily Average Air and Soil Temperatures for the 1962, 1963, and 1964 Seasons at the Mixed-grass Microclimate Station in Southwestern North Dakota (Source: Whitman, 1969.)

Fig. 2.14. Representative Relative Humidity Values at 6 in. and at 5 ft above Native Grass for Selected Days in the Months of June, July, and August during the Summer of 1963 (Source: Adapted from Whitman, 1969.)

at both levels during the warmer periods of the day and during the drier part of the summer season. A reduction in relative humidity potentially can increase water loss via transpiration from plants.

Relative humidity is indicative of potential evapotranspiration from a given site, but temperature of the air must also be incorporated to determine evaporative potential. Calculations of vapor pressure deficits (mm of Hg at specific relative humidities and air temperatures) of the various data points on Fig. 2.14 show that evaporative potential of the air at 5 ft is usually greater than at 6 inches. This difference is expected since the relative air humidity was normally lower at the 5-ft level. However, at the time of minimum relative humidity (approximately 2-4 pm, Fig. 2.14), the air at the 6-in. level had the greatest evaporative potential, because it had a temperature of approximately 94°F compared to 86°F at the 5-ft level (Fig. 2.14). The capacity to hold water (evaporative potential) will be greater at the higher temperature when the relative humidities are similar (Oosting 1956). Seedlings with aerial parts near the ground surface are thus exposed during the early afternoon to temperature and air moisture regimes that may be injurious or even lethal.

d. Air Movements

Dense vegetation has a moderating effect on air movements beneath the canopy. Measurements at the IBP grassland site in southwestern North Dakota serve to illustrate this point. In July, the average velocity of air movement was 0.43 mph 6 in. above the ground and 4.95 mph 5 ft above the ground (Whitman, 1969). This difference influences both temperature and humidity near the ground surface.

e. Aspect

A south-facing slope in the Northern Hemisphere receives more solar radiation per unit area, and a north-facing one receives less, than a flat surface. These differences affect the temperature and moisture regimes. The South-facing slope will be warmer and drier, with wide extremes, as compared to a cooler, more moist, and less variable microclimate on the north-facing slope (Oosting, 1956). These conditions often give rise to different plant communities on north-facing and south-facing slopes. The revegetation of coal mine spoils graded to a rolling topography will be similarly affected by aspect.

C. Hydrology

1. Surface Water

Most of the water used in the four-county area comes from reservoirs, with Lake Sakakawea and the Missouri River supplying the major portion. Throughout the area, surface waters are connected with aquifers of unconsolidated deposits of sand and gravel found in stream and river valleys. In McLean County, where glacial deposits are most common, the small lakes and potholes of surface water are connected with the aquifers in an integrated subsurface network, reflecting in part preglacial drainage conditions.

The most important source of surface water is Lake Sakakawea, containing an estimated 22.6 million acre-ft of usable storage behind the Garrison Dam. The Missouri River flow is regulated between the Garrison and Oahe Dams, but provides approximately 20,000-cubic-feet-per-second discharge used primarily for power-plant cooling, recreation, and irrigation. Knife River, dammed near Beulah, provides a water supply for that city and is also used for stock watering, irrigation, and recreation. Nelson Dam, on Square Butte Creek, provides water for recreation and power-plant cooling. Average flow on the Little Missouri River in Dunn County has been measured at 585 cubic feet per second. Most North Dakota streams average less than 500 milligrams per liter concentration of dissolved-solids at medium and high flows and are acceptable for most domestic uses, although the waters do become unacceptably saline for particular uses. The Missouri River has a dissolved-solids concentration average of 400 mg/l, ranging from 300-600 mg/l, and a hardness of 200-300 mg/l. The Missouri brings 39 million tons of suspended sediment annually to Lake Sakakawea, but it settles out within the lake; the concentration at Garrison Dam is therefore minor. Downstream, an average of 7 1/2 million tons of suspended sediment enters the Missouri from Garrison Dam to Bismarck.

a. Surface-water Monitoring Station Network

North Dakota has an extensive network of water monitoring stations throughout the state and especially within the study area. This network is maintained through a cooperative effort of state and federal agencies and programs including:

Cooperators

<u>Agency Name</u>	<u>Abbreviations*</u>
North Dakota State Highway Department	SHD
North Dakota State Water Commission	SWC
Oliver County	OC
U.S. Army Corps of Engineers - Omaha District	CE-0
U.S. Army Corps of Engineers - St. Paul District	CE-S
U.S. Army Bureau of Land Management	BLM
U.S. Bureau of Sport Fisheries and Wildlife	FWL
U.S. Dept. of Interior - Missouri River Basin Program	MRB
U.S. Environmental Protection Agency	EPA
U.S. Geological Survey - Federal Program	FED
U.S. Geological Survey - National Water Quality Accounting Network	NASQAN

The network consists of four components:

Surface-Water Stations
Groundwater Stations
Sediment Stations
Water-Quality Stations

The objectives and the location of the sampling stations for each network component are listed for the four-county study area.

(1) Surface-water Stations. The objectives of the surface-water station program are: (1) to collect surface-water data sufficient to satisfy needs for current-purpose uses, such as assessment of water resources, operation of reservoirs or industries, forecasting, disposal of wastes and pollution controls, discharge data to accompany water-quality measurements, compact and legal requirements, and research or analytical studies; and (2) to collect data necessary for analytical studies to define for any location the statistical properties of, and trends in, the occurrence of water in streams, lakes, estuaries, etc., for use in planning and design (U.S.G.S. 1975).

This program consists of four types of stations: streamflow, river stage, reservoir and lake, and crest-stage.

(a) Streamflow Stations. Figure 2.15 shows the location of the streamflow stations. The locations and cooperating agencies for the streamflow stations in the study area are listed below:

*Abbreviations used for cooperators in this report. Most of the above and following water information is adapted from a 1975 USGS open-file report entitled "Water-Resources Investigations in the Fort Union Coal Region North Dakota, 1974-75."

Fig. 2.15. Locations of Streamflow Stations of North Dakota
(Source: USGS, 1975.)

Streamflow Stations

<u>County</u>	<u>Station Number</u>	<u>Station Name</u>	<u>Cooperator</u>
McLean	338490	Missouri R. at Garrison Dam	CE-0
"	341400	Turtle C nr Turtle Lake	MRB
"	341800	Painted Woods C. nr Wilton	MRB
Mercer	339490	Elm C. nr Golden Valley	SWC
"	339500	Knife R. nr Golden Valley	FED
"	339560	Brush C. nr Beulah	BLM
"	340000	Spring C. at Zap	SWC
"	340500	Knife R. at Hazen	SWC, CE-0
Oliver	240200	W. Br. Otter C. nr Beulah	SWC
"	324100	Square Butte C. trib. #2 nr Center	OC
"	342260	Square Butte C. bl. Center	OC
Dunn	339100	Knife R. at Manning	SWC
"	339300	Knife R. Marshall	SWC

(b) River-stage Stations. Figure 2.16 shows the location of the river-stage stations. The locations of the river-stage stations and the frequency of sampling are listed below:

River-stage Stations

<u>County</u>	<u>Station Number</u>	<u>Station Name</u>	<u>Frequency</u>
McLean	339000	Missouri River below Garrison Dam	Continuous
"	341000	Missouri River at Washburn	"
Mercer	340700	Missouri River near Stanton	"
Oliver	340900	Missouri River near Hensler	"
"	342020	Missouri River at Price	"
Dunn	None		

(c) Reservoir and Lake Stations. None in study area.

(d) Crest-stage Stations. Figure 2.17 shows the locations of the crest stage stations, which are listed below. The North Dakota State Highway Department is the cooperating agency.

Crest-stage Stations

<u>County</u>	<u>Station Number</u>	<u>Station Name</u>
McLean	3376	East Branch Douglas Creek Tributary near Garrison
"	3379	Snake Creek Tributary near Garrison
Oliver	3402	West Branch Otter Creek near Beulah
"	3403	Otter Creek near Hannover

Fig. 2.16. Locations of the River-stage Stations of North Dakota
(Source: USGS, 1975.)

Fig. 2.17. Locations of the Crest-stage Stations of North Dakota
(Source: USGS, 1975.)

Crest-stage Stations (Cont'd.)

<u>County</u>	<u>Station Number</u>	<u>Station Name</u>
Oliver	3420.5	Square Butte Creek at Center
"	3421.5	Square Butte Creek tributary near Center
"	3422.5	Square Butte Creek tributary No. 3 near Center
Mercer	None	
Dunn	None	

Surface-water station data are published in the annual series "Water Resources Data for North Dakota, Part I - Surface Water Records," USGS, 1969.

(2) Groundwater Stations. The objectives of the groundwater station program are: (1) to collect water-level data sufficient to provide a minimum long-term data base so that the general response of the hydrologic system to natural climatic variations and induced stresses is known and potential problems can be defined early enough to allow proper planning and management; and (2) to provide a data base against which the short-term records acquired in areal studies can be analyzed. This analysis must (a) provide an assessment of the groundwater resource, (b) allow prediction of future conditions, (c) detect and define pollution and supply problems, and (d) provide the data base necessary for management of the resource (U.S.G.S., 1975).

The cooperating agencies for this program are the North Dakota State Water Commission and the U.S. Army Corps of Engineers, Omaha District. The data are on open-file at the U.S. Geological Survey office in Bismarck, North Dakota; selected data are published at 5-year intervals in the U.S. Geological Survey water-supply papers.

The number and types of groundwater stations in the study are listed below:

<u>Groundwater Stations</u>						
<u>County</u>	<u>Total Recorders</u>	<u>Weekly</u>	<u>Monthly</u>	<u>Quarterly</u>	<u>Annual</u>	<u>Total</u>
McLean	4	-	7	3	22	36
Mercer	-	-	-	9	3	12
Oliver	-	-	-	1	3	4
Dunn	-	-	-	-	-	0

(3) Sediment Stations. The objectives of the sediment station program are to provide a national bank of sediment data for use in broad federal and state planning and action programs and to provide data for federal management of interstate and international waters (U.S.G.S., 1975).

Figure 2.18 shows the locations of the sediment stations. The cooperating agencies are the U.S. Army Corps of Engineers, the U.S. Bureau of Land Management, the U.S. Geological Survey-National Water Quality Accounting Network and the State International Commission of North Dakota.

<u>Sediment Stations</u>			
<u>County</u>	<u>Station Number</u>	<u>Station Home</u>	<u>Cooperator</u>
McLean	338490	Missouri R. at Garrison Dam	NASQAN
Mercer	339560	Brush Creek near Beulah	BLM
Mercer	340500	Knife R. at Hazen	NASQAN

Data from the sediment station program are published in the annual series, "Water Resources Data for North Dakota, Part 2 - Water-Quality Records," U.S.G.S., 1976, and in the Water-Supply Paper series, "Quality of Surface Waters of the United States," U.S.G.S., 1941 to date.

(4) Water Quality Stations. The objectives of the Water Quality Station program are to provide a national bank of water-quality data for broad federal planning and action programs and to provide data for federal management of interstate and international waters (U.S.G.S., 1975). Figure 2.19 shows the location of the water-quality stations. The cooperating agencies are the U.S. Environmental Protection Agency, the U.S. Geological Survey-National Water Quality Accounting Network, the North Dakota State Water Commission, and the U.S. Bureau of Land Management. The station number, name, location, sampling schedule, and parameters measured are listed in Table 2.2 by sampling agency.

Fig. 2.18. Locations of the Sediment Stations of North Dakota
(Source: USGS, 1975.)

Fig. 2.19. Locations of the Water-quality Stations of North Dakota (Source: USGS, 1975.)

Table 2.2. Water-quality Stations

<u>U.S. Environmental Protection Agency</u>	
<u>(Baseline Water-quality Data)</u>	
<u>Station Number</u>	<u>Station Name</u>
06338490	Missouri R. at Garrison Dam, N.D., S 1/2 sec. 31, T. 147 N. R. 84 W., McLean County
06340000	Spring C. at Zap, N.D., SW 1/4 sec. 14, T. 144 N., R. 89 W., Mercer County
06340500	Knife R. at Hazen, N.D., SE 1/4 sec. 18, T. 144 N., R. 86 W., Mercer County

Sampling Schedule and ParametersField Measurements
(Monthly)

Temperature	pH
Specific conductance	Oxygen, dis.

Lab Measurements
(Monthly)

Calcium, dis.	Chloride, dis.
Magnesium, dis.	Silica, dis.
Sodium, dis.	Residue, susp. 110° C
Potassium, dis.	Nitrogen, Tot KJD
Carbonate	Phosphorus, Tot.
Bicarbonate	Nitrogen NH ₄ , Tot
Sulfate, dis.	Nitrate + nitrite, Tot.
	Biochemical Oxygen Demand

(Quarterly)

Dissolved Total

Aluminum	Lead
Boron	Zinc
Copper	Selenium
Fluoride	Mercury

Nelson Lake Study

(Located Upstream from 06342260, Oliver County)

Eight sites--four on the lake, Ash pond, two tributaries, and one downstream--were selected for sampling and analysis for trace-element composition of aqueous effluents from coal-fired powerplants to surface waters. Two suites of samples were collected in 1974, May and September. Analysis consisted of the following:

Table 2.2. Water-quality Stations (Cont'd.)

<u>Parameters</u>	
Dissolved Total	
Aluminum	Molybdenum
Barium	Nickel
Beryllium	Silver
Bismuth	Strontium
Boron	Tin
Cadmium	Titanium
Chromium	Vanadium
Cobalt	Zinc
Copper	Zirconium
Gallium	Radium
Germanium	Uranium
Iron	Arsenic
Lead	Fluoride
Lithium	Mercury
Manganese	Selenium

<u>U.S. Geological Survey</u>	
(Missouri River Basin)	
<u>Station Number</u>	<u>Station Name</u>
06338490 ^a	Missouri R. at Garrison Dam, N.D., S 1/2 sec. 31, T. 147 N., R. 84 W., McLean County
06339010 ^b	Missouri R. above Stanton, N.D., E 1/2 sec. 22, T. 145 N., R. 84 W., McLean County
06340900 ^b	Missouri R. near Hensler, N.D., SW 1/4 sec. 22, T. 144 N., R. 83 W., Oliver County
06341800	Painted Woods C. near Wilton, N.D., McLean County

<u>Sampling Schedule and Parameters</u>	
<u>Field Measurements</u>	
(Monthly)	
pH	Specific conductance
Temperature	

^aDaily temperature and specific conductance.

^bContinuous temperature recorder only.

Table 2.2. Water-quality Stations (Cont'd.)

<u>Lab Measurements</u> (Monthly)	
Bicarbonate	Magnesium, dis.
Boron, dis.	Potassium, dis.
Calcium, dis.	Silica, dis.
Carbonate, dis.	Sodium, dis.
Chloride, dis.	Sulfate, dis.
Color	Turbidity (JTU)
Residue, dis. 180° C	Phosphorus, dis.
Fluoride, dis.	Nitrate + Nitrite, dis.
 (Semiannually)	
Aluminum, dis.	Manganese, dis.
Arsenic, dis.	Mercury, dis.
Barium, dis.	Nickel, dis.
Chromium, dis.	Strontium, dis.
Cobalt, dis.	Zinc, dis.
Copper, dis.	Cadmium, dis.
Cyanide	Selenium, dis.
Iron, dis.	Molybdenum, dis.
Lead, dis.	Vanadium, dis.
Lithium, dis.	
 U.S. Geological Survey (National Water Quality Accounting Network)	
<u>Station Number</u>	<u>Station Name</u>
06338490 ^a	Missouri R. at Garrison Dam, N.D., S 1/2 sec. 31, T. 147 N., R. 84 W., McLean County
06340500 ^a	Knife R. at Hazen, N.D. SE 1/4 sec. 18, T. 144 N., R. 86 W., Mercer County

Sampling Schedule and Parameters

<u>Field Measurements</u> (Monthly)	
Temperature (Daily)	Coliform, fecal
Conductivity (Daily)	Streptococci, fecal
pH	

^aDaily collected sample for temperature and specific conductance.

Table 2.2. Water-quality Stations (Cont'd.)

<u>Lab Measurements</u> (Monthly)	
Silica, dis.	Turbidity, JTU
Calcium, dis.	Fluoride, dis.
Magnesium, dis.	Phosphorus, total
Sodium, dis.	Nitrate + nitrite as N, Tot.
Potassium, dis.	Total Kjeldahl as N
Bicarbonate	Organic carbon, Tot.
Carbonate	Phytoplankton, (3-codominant: genera) (Total count)
Sulfate, dis.	Suspended sediments
Chloride, dis.	Suspended sediments, sieve diameter, % finer than 0.062 mm.
Dissolved solids at 180° C	
Total hardness as CaCO ₃	
Non-carbonate hardness	

<u>Lab Measurements</u> (Quarterly)	
Dissolved Total	
Arsenic	Lead
Cadmium	Manganese
Chromium	Mercury
Cobalt	Selenium
Copper	Zinc
Iron	
Periphyton (3-codominants genera, Biomass-dry and ash weights)	
Chlorophyll a, periphyton	
Chlorophyll b, periphyton	

 North Dakota State Water Commission

<u>Station Number</u>	<u>Station Name</u>
06339300	Knife R. at Marshall, N.D., NW 1/4 sec. 10, T. 142 N., R. 83 W., Dunn County

Sampling Schedule and Parameters

<u>Field Measurements</u> (Monthly)	
pH	Specific conductance
Temperature	

Table 2.2. Water-quality Stations (Cont'd.)

<u>Lab Measurements</u> (Monthly)	
Bicarbonate	Potassium, dis.
Boron, dis.	Silica, dis.
Calcium, dis.	Sodium, dis.
Carbonate	Sulfate, dis.
Chloride, dis.	Phosphate, dis.
Residue, dis. 180° C	Nitrate, dis.
Fluoride, dis.	Iron, dis.
Magnesium, dis.	Manganese, dis.

North Dakota State Water Commission (Specific Conductance Network)	
<u>Station Number</u>	<u>Station Name</u>
06339100	Knife R. at Manning, N.D. SE 1/4 NW 1/4 sec. 6, T. 143 N., R. 95 W., Dunn County
06339490	Elm C. near Golden Valley, N.D., SE 1/4, NW 1/4 sec. 23, T. 142 N., R. 90 W., Mercer County
06339500	Knife R. near Golden Valley, N.D., SE 1/4 sec. 34, T. 143 N., R. 90 W., Mercer County
06340200	W. B. Otter C. near Beulah, N.D., NW 1/4, NW 1/4, SW 1/4, sec. 12, T. 142 N., R. 87 W., Oliver County
06341400	Turtle C. near Turtle Lake, N.D., N. line of sec. 19, T. 146 N., R. 80 W., McLean County
06342100	Square Butte C. Tr. 2 near Center, N.D., NE 1/4, NE 1/4 sec. 24, T. 142 N., R. 84 W., Oliver County
06342260	Square Butte C. below Center, N.D., SW 1/4 sec. 4, T. 141 N., R. 83 W., Oliver County

<u>Sampling Schedule and Parameters</u>	
<u>Field Measurements</u> (Monthly)	
Temperature	Specific conductance
<u>Lab Measurements</u> (Semiannually)	
Bicarbonate	Potassium, dis.
Boron, dis.	Silica, dis.
Calcium, dis.	Sodium, dis.
Chloride, dis.	Sulfate, dis.
Carbonate, dis.	Phosphate, dis.
Residue, dis. 180° C	Nitrate, dis.
Fluoride, dis.	Iron, dis.
Magnesium, dis.	Manganese, dis.

Table 2.2. Water-quality Stations (Cont'd.)

U.S. Bureau of Land Management	
<u>Station Number</u>	<u>Station Name</u>
06339560	Brush C. nr Beulah, N.D., NW 1/4, SW 1/4, NW 1/4 sec. 25, T. 143 N., R. 88 W., Mercer County
<u>Sampling Schedule and Parameters</u>	
<u>Field Measurements</u>	
(Monthly)	
DO	Conductance
pH	Bicarbonate
Temp.	Carbonate
<u>Lab Measurements</u>	
(Monthly)	
Calcium, dis.	Boron, dis.
Magnesium, dis.	Dissolved solids
Sodium, dis.	KGN, total
Potassium, dis.	NH ₄ , total
Silica, dis.	BOD
Chloride, dis.	Turbidity
Sulfate, dis.	Organic Carbon, dis.
Nitrate-nitrite, total	Organic Carbon, susp.
Phosphate, total	
(Quarterly)	
Dissolved Total	
Arsenic	Manganese
Beryllium	Mercury
Cadmium	Molybdenum
Chromium	Nickel
Copper	Selenium
Lead	Vanadium
Iron	Aluminum
Lithium	Zinc
<u>Annual (Low Flow)</u>	
Gross Alpha, dis.	
Gross Beta, dis.	
Gross Alpha, susp.	
Gross Beta, susp.	
Radium	
Uranium, flourmetric	

Water-quality data are published in the annual series, *Water Resources Data for North Dakota, Part 2 - Water-Quality Records*, USGS, 1969, and in the Water-Supply Paper Series *Quality of Surface Waters of the United States*, USGS, 1941 to date.

(a) Water Quality. Groundwater contains dissolved mineral matter in varying quantities. As the mineral matter comes in contact with the land surface and as it infiltrates the soil and bedrock, rainfall begins and continues its dissolution. The dissolved mineral constituents in water are a function of the type(s) of soil and rock encountered, the organic compounds in the soil, the temperature of the water, and the length of contact time between water and soil and/or rock. Water remaining underground over a long period of time tends to be more mineralized than "fresh" water.

Dissolved mineral matter is usually referred to in parts per million (ppm), milligrams (mg), or micrograms (Mg) per liter (l) or grains per U.S. gallon (gr/gal). For water containing less than 7000 ppm, milligrams per liter is approximately equal to parts per million. Equivalents per million (epm), the unit chemical combining weight of a constituent in a million weights of water, is used in calculating percent sodium and the sodium adsorption ratio (SAR).

Chemical parameters and constituents of concern are: (1) dissolved solids and the related specific conductance, (2) sodium-adsorption ratio, (3) hardness, (4) iron, (5) sulfate, (6) nitrate, (7) chloride, and (8) fluoride. Appendix D lists the major chemical constituents, their effects, and recommended limits. The projected end use of the water determines the relative importance of these properties.

The suitability of water is inversely related to the quantity of dissolved solids. Humans have safely consumed water with 2000 ppm dissolved solids; stock has survived on 15,000 ppm water, but their growth and reproduction may be affected when water contains more than 3000 ppm. Specific conductance, related to the ability of water to conduct an electric current, is a function of the amount and kind of dissolved mineral matter. Specific conductance is related to the salinity hazard; the sodium-adsorption ratio is related to the sodium hazard -- both important parameters for qualifying water for irrigation purposes.

Fig. 2.20 shows the standard salinity and sodium hazard classification. Values of 3 or 4 indicate marginal or unsuitable irrigation water. Water with C (salinity) values of 3 -- high salinity -- can be used with coarse textured soils and good drainage. Water with (alkalinity) values of 3 can be selectively used when chemicals are added. Hardness is a measure of the amount of calcium carbonate in the water and is useful in determining the suitability of water for laundry and certain industrial use. Soft water contains 0-60 ppm calcium carbonate, moderately hard water between 61-120 ppm, hard between 121 and 180 ppm, and very hard more than 180 ppm.

2. Groundwater

Groundwater provides most of the state's rural population as well as many municipalities with adequate supplies of water. Within the study area, groundwater is obtained primarily from sandstones and lignites of Late Cretaceous and Tertiary age and from unconsolidated Quaternary age sand and gravel deposits. Locally, surface water sources are in hydraulic connection with groundwater aquifers. Either may be a source of recharge or a discharge receiver, depending on hydrostatic head conditions.

a. Pre-Late Cretaceous Aquifers

Almost all of the Pre-Late Cretaceous rocks contain brackish or saline water. The Dakota Group, an important Cretaceous aquifer in eastern North Dakota, dips to the northwest, down the flank of the Williston Basin and is found at depths of more than 3500 ft in the study area. Tests have shown specific conductivity values of 7000-10,000, indicating very brackish water in the study area. The Dakota group's recharge area is western North Dakota and water taken from this area is relatively fresh. As the water moves down and dips under the influence of gravity, it comes into contact with and dissolves more mineral matter. By the time this water underlies the study area, it has become quite brackish.

b. Late Cretaceous Aquifers

(1) Pierre Formation. The Pierre Formation contains only a few thin sandstone beds, being composed mainly of shale. The formation is about 1000 ft thick but contains no significant aquifers.

(2) Fox Hills Formation. The Fox Hills Formation consisting of interbedded sandstone, siltstone, and shale ranges in thickness from 240 ft in

Fig. 2.20. Salinity and Sodium Hazard Classification
(Source: U.S. Salinity Laboratory Staff, 1954.)

Mercer County to 450 ft in northeastern McLean County. The water is soft and is a sodium bicarbonate type containing from 1200-1600 mg/l total dissolved solids. The salinity and sodium hazard index was very high. Yields of 10 gpm (gallons per minute) are common, with developmental yields of 25-50 gpm probable. The water is suitable for livestock, and some domestic and industrial purposes, but not for irrigation because of very high SARs.

(3) Hell Creek Formation. The Hell Creek Formation consists of fine- to medium-grained sandstone interbedded with silty shale, and ranges in thickness from less than 100 to more than 400 ft. The water is soft, of a sodium bicarbonate type, and contains from 1200-1630 mg/l total dissolved solids. Yields of 10 gpm are common, from 25-50 gpm possible. The very high SAR precludes using this water for irrigation, but it is acceptable for domestic and stock use. Prior to 1970, the city of Turtle Creek, McLean County, obtained its municipal use water from the Hell Creek Formation.

c. Tertiary Aquifers

(1) Cannonball-Ludlow Formation. Except for a few thin beds of sandstone and a thin, locally occurring lignite bed near the base of the formation, most of the remaining lithologies are relatively impermeable and the unit is considered non-water-bearing.

(2) Tongue River Formation. The Tongue River Formation consists of interbedded sandstone, siltstone, clay, shale, lignite, and limestone, with the main aquifer (the sandstones) in the lower part of the formation. The sandstone beds range from a few feet to over 200 ft and are fine-grained in McLean County, becoming fine- to medium-grained to the south in Mercer and Oliver Counties. The water is relatively hard and is a sodium bicarbonate type. Total dissolved solids show an extremely wide variation, ranging in McLean County from 206-3500 mg/l, in Mercer County from 1810-1930 ppm, and in Oliver County from 1400-1700 ppm. Yields range from 5-75 gpm, but wells in the thicker portion of the sandstone in McLean County may yield 200 gpm. In the Beulah (Mercer County) area, the quality of the aquifer is poor and yields are less than 5 gpm. The water is not recommended for irrigation due to its high SAR, but is suitable for livestock and domestic use; the cities of Garrison, Underwood, and Wilton use water from this formation for their municipal supplies.

(3) Sentinel Butte Formation. The Sentinel Butte Formation consists primarily of silt, clay, and lignite with sands at the base and top. No significant aquifers are present in the Sentinel Butte Formation.

(4) Lignite Aquifers in the Fort Union Group. The lignites range in thickness from a few inches to 20 ft and most yield from 1 to 10 gpm of water, having a highly variable chemical quality. Water may be soft or hard and commonly is reddish-brown from organic compounds. This water is used for livestock and domestic purposes.

d. Glacial Drift Aquifers

Glacial drift aquifers are the most important sources of groundwater and have the greatest potential for development. The quantity of yield is dependent upon the amount in storage and the recharge ability; the amount in storage depends on the aquifer geometry and its grain size.

(1) Mercer and Oliver Counties. Most of the glacial aquifers in McLean County are associated with buried valleys and ice-margin channels. These deposits consist mainly of sand and gravel with occasional lenses of till, overlain by alluvium. The alluvium may consist of reworked glacial deposits or eroded silt and clay from Tertiary deposits. The aquifers range from 1-5 miles in width, from 10-250 ft in thickness, and have a storage of approximately 2,640,000 acre-ft of water, half of which is suitable for irrigation. Local yields of 500+ gpm have been measured.

The Missouri River aquifer extends the entire length of the two county's eastern border, reaching a thickness of more than 200 ft in a buried valley from Stanton to Hensler where yields greater than 5000 gpm are possible. The aquifer contains 470,000 acre-feet of reserve, half of which (without recharge) is recoverable through wells. Total dissolved solids ranged from 585 to 1660 ppm. The water is a sodium bicarbonate type with low SAR (6-13).

The Knife River aquifer, underlying the terraces and flood plain of the Knife River, reaches a thickness of 240 ft near Beulah. Yields range from 100-500 gpm, in the thicker parts of the aquifer, and over 500 gpm in the Stanton area. The aquifer contains about 920,000 acre-feet of water, half recoverable through wells (without recharge). Water to the southwest of Beulah has a high dissolved solids content (1130-1980 ppm) and is high in

sulfate. From Beulah to Coal Creek, the aquifer water is a sodium bicarbonate type with 742-1040 ppm dissolved solids in the lower part and 419-535 ppm in the calcium bicarbonate upper part. From Coal Creek to Stanton, the water is a calcium-magnesium bicarbonate type with dissolved solids ranging from 503-1740 ppm. The water southwest of Beulah is not suitable for irrigation. The SAR values range from 2-10, except for wells from the southwest.

The Antelope Creek aquifer in northwestern Mercer County is approximately 1-1 1/2 miles wide and 200-250 ft thick. The aquifer contains 260,000 acre-feet in storage and, without recharge, 130,000 acre-feet should be recoverable through wells. The water is suitable for irrigation with a dissolved solids range from 420-1460 ppm and yields from 100-500 gpm. The water is very hard (264-576 ppm) and usually a sodium bicarbonate type. SAR values range from 1 to 11. The Goodman aquifer in western Mercer County has the same width and thickness dimensions as the Antelope Creek aquifer, but almost twice the length. Storage is 530,000 acre-feet, half recoverable without recharge. The water is usually a sodium bicarbonate type, very hard (275-375 ppm) with a total dissolved solids range of 771-1090 ppm, and SAR values of 5 to 10.

The Square Butte Creek aquifer extending from Hazen to the southeast corner of Oliver County is almost one mile wide and, locally, 130 ft thick but usually between 40-80 ft thick. Yield is usually 10-100 gpm southeast of Center and 100-500 in the thicker parts of the aquifer northwest of Center. The aquifer contains, without recharge, 125,000 recoverable acre-feet of water of the 250,000 in storage. The water is a sodium bicarbonate type with total dissolved solids ranging from 374-863 ppm, and SAR values of 1-11.

Elm Creek aquifer in southwest Mercer County varies from a quarter of a mile to 2 miles in width and from 100-150 ft in thickness (without alluvium). Yields of 10-100 gpm are common, but locally greater yields can be expected. The aquifer contains 210,000 acre-feet of reserves half recoverable (without recharge) by wells. Total dissolved solids range from 2320-4650 ppm. The water is sodium sulfate type with SAR values greater than 20 and should not be used for irrigation unless special procedures are taken.

(2) Dunn County. No chemical analysis data was available for Dunn County, but some generalities may be expressed. The Goodman Creek aquifer extends into Dunn County and should yield 100-500 gpm.

The Spring Creek aquifer extends across central Dunn County and intersects the Goodman Creek aquifer in Mercer County. Yields of 100-500 gpm are expected and, locally, at Dunn Center, greater yields may be possible, especially if Lake Ilo and the aquifer are in hydraulic connection.

The Knife River aquifer system, including the Schaffner Creek, Little Knife River, and Crooked Creek aquifers, will yield from 100-500 gpm in their deeper parts, but their quality is suspect. The Knife River aquifer in Mercer County deteriorated in quality southwest of Beulah, and Elm Creek in southwestern Mercer County is normally unsuitable for irrigation. This trend may continue into Dunn County.

The Killdeer-Glen Ulin Channel extends from Lake Sakakawea to the Dunn-Dickinson county line passing through the middle of the county west of Dunn Center. Estimated yields are 100-500 gpm, possibly greater near Dunn Center and Lake Ilo. No information on quality is available. No information is available on the Green River aquifer in the extreme southwestern part of the county.

(3) McLean County. The Lake Nettie aquifer system, including the Lake Nettie, Strawberry Lake, Turtle Lake, and Horse Show Valley aquifers is a large, interconnected aquifer system with an areal extent of 166 square miles in eastern and northeastern McLean County containing 940,000 acre-feet storage. Yields in the Lake Nettie Aquifer of 1500 gpm are common in the thicker portions of the 2-8 mile-wide aquifer. The waters in the system are generally either a sodium or calcium bicarbonate type and have a wide range of chemical parameters. Most of the water is very hard and, except for an area near Crooked Lake, the water is suitable for irrigation.

The Fort Mandan and Painted Woods Lake aquifers lie adjacent to the Missouri River and development of these aquifers could induce recharge from the river. Yields of 1500 gpm are possible. The water is usually very hard and is a calcium-magnesium bicarbonate in the Fort Mandan aquifer and a sodium bicarbonate in the Painted Woods Lake aquifer. Storage water available is 71,000 acre-feet from the Fort Mandan and 63,000 acre-feet from the Painted Woods Lake aquifers.

The Lost Lake, a buried valley aquifer, in the southeastern part of the county, is probably connected hydrostatically with the Painted Woods Lake aquifer. The average thickness of the aquifer deposits is 71 ft

and it is about a mile wide. Yields of 50-100 gpm are possible depending upon the well's location within the unit. Approximately 170,000 acre-feet are available from storage with a dissolved solids range of 367-1500 mg/l (almost equivalent to ppm). The water is usually sodium bicarbonate type, hard to very hard, and is of little value for irrigation purposes. The SAR values are very high.

The Snake Creek aquifer occupies a buried valley in the north central part of the county between the towns of Max and Benedict. Average unit thickness is 60 ft (aggregate) and approximately 110,000 acre-feet of water are available from storage. The water is hard to very hard, and is composed of 3 types -- calcium-magnesium bicarbonate, sodium calcium sulfate, and sodium bicarbonate. Yields from 50-500 gpm are possible depending upon well location. The bicarbonate water is suitable for irrigation; the sulfate water is questionable.

The White Shield aquifer extends from the northwest corner of the county southeastward to Lake Sakakawea about 11 miles southwest of Garrison. The aquifer is about one mile wide and has an average thickness of 100 ft. Approximately 380,000 acre-feet are available from storage with yields of 1000 gpm possible. The water is very hard and of a sodium bicarbonate or sodium sulfate type. Total dissolved solids ranged from 910-2250 mg/l. SAR values are low to medium.

The Garrison aquifer occupies a narrow bedrock valley underlying part of the city of Garrison and extending northwest from Lake Sakakawea through Garrison. Average unit thickness is 31 ft and approximately 9000 acre-feet of water is available from storage. The water is very hard, sodium bicarbonate type, with a total dissolved solids content ranging from 885-1570 mg/l. The SAR values range from medium to very high. Wells yielding 200 gpm are possible if proper spacing is maintained.

The Weller Slough aquifer occupies a 14-mile long, 1-mile wide buried valley extending from Lake Sakakawea southwestward to an area midway between the towns of Falkirk and Underwood. The unit averages 40 ft in thickness and contains an estimated 54,000 acre-feet of available water. The water is hard to very hard, sodium bicarbonate type with a dissolved solids content of 867-1730 mg/l. The full range of SAR values is encountered. Yields of 1,000 gpm can be expected in the thicker part of the aquifer.

D. Edaphic Factors

Plants depend on soil as a medium to provide anchorage, mineral nutrients, water, and root aeration. This dependence varies among plant species but in a terrestrial ecosystem all are essential for the maintenance or reestablishment of the system. The characteristics of soils that directly or indirectly affect plant establishment, growth, and reproduction are called edaphic factors. The following discussion on edaphic factors will include: (1) physical characteristics, (2) organic matter, (3) water, (4) soil air, (5) soluble salts, (6) exchangeable sodium percentage, and (7) free lime. The amount and proportions of these components will vary from one area to another and this variation will have a significant effect in determining which species are present or can be established on a given soil.

1. Physical Characteristics

The percentages by weight of the various mineral particle sizes (sand, silt, and clay) determine soil texture classes. The particle size limits the mechanical analyses of the three soils, sandy loam, loam, and clay, that are listed in Table 2.3.

Table 2.3. The Classification of Soil Particles and the Mechanical Analyses of Three Soils (Adapted from Lyon, Buckman, and Brady, 1952.)

Separate	Diameter Limits, (mm)	Sandy Loam, (%)	Loam Soil, (%)	Clay Soil, (%)
1. Very coarse sand	2.00-1.00	3.1	4.3	0.2
2. Coarse sand	1.00-0.50	10.5	6.0	0.3
3. Medium sand	0.50-0.25	8.2	4.5	1.4
4. Fine sand	0.25-0.10	25.3	11.7	4.8
5. Very fine sand	0.10-0.05	22.0	13.2	16.8
6. Silt	0.05-0.002	21.1	43.2	28.0
7. Clay	below 0.002	9.8	17.1	48.5

Sandy soils have a low water-holding capacity because of low surface area per unit volume associated with the large particle size. Water percolation is rapid because of the relatively large spaces between particles. Therefore, good drainage and aeration are characteristic of soils dominated by sand or gravel (Lyon, Buckman, and Brady, 1952). Plant nutrients and available water may be limiting. Sandy soils either lack or have weak structure and are highly susceptible to wind erosion.

Clay soils have a high surface area per unit volume resulting in a high absorptive capacity for water, gases, and soluble salts. When wet, clay expands, becomes sticky and is highly plastic; on drying, it shrinks and becomes quite hard. Silt particles possess these same qualities but to a lesser degree. The predominance of clay and silt cause solids to be highly plastic and sticky when wet, and hard and cloddy when dry. Nutrient and water holding capacity are high and soil aeration is low. Soil structure ranges from moderate to strong and is resistant to wind erosion.

The arrangement of the soil particles into aggregates is termed the soil structure. Soil structure affects the movement of air and water into and within the soil, seed germination, seedling development, and the activity of soil microorganisms. When North Dakota clayey soils are lacking in structure or are tilled or trampled by livestock when too wet, they puddle and dry into hard impervious masses with deep fissures. However, the amount of organic matter present will temper these wetting and drying-cycle effects. The presence of excessive sodium and free lime, on the other hand, will reduce the stability of the aggregates, causing an increase in erosion and a reduction in crop yield.

2. Organic Matter

Organic matter accumulation and that found in the surface layer of soil is derived primarily from the remains of plants and animals. The residues of its decomposition have the capacity to attract, absorb, and release ions, thus recycling plant nutrients.

Decomposing organic matter aids in the development and stability of solid aggregates and increases soil water-holding capacity. According to Omodt et al. (1968), 4-5% of the dark surface layer of most soils in North Dakota is organic matter. The amount present in a given soil is contingent upon vegetation, texture, landscape, position, drainage, and climate.

3. Soil Water

The source of soil water is primarily precipitation in the form of rain, hail, or snow, which, either directly or after melting, enters the soil by infiltration. Factors affecting infiltration are the texture of the soil (Table 2.4), its structure, slope, rate of precipitation, and initial soil water. A steep slope results in greater surface runoff than does a more gradual one. Intensive precipitation over a short time period on land relief other than a depression will result in greater runoff than a gentle rain. The rate of infiltration decreases as soil becomes saturated. As indicated in Table 2.4, the finer the texture of the soil, the slower the rate of infiltration. Sodic soils, characteristic of portions of the four-county region under study, also have a very slow infiltration rate.

Gravitational water is that portion of the water contained in a saturated soil that, under the influence of gravity, percolates downward through the soil toward the water table. It occupies the larger pores of the soil after a saturating rain and usually drains out of the upper layers of soil within two days. If this drainage is delayed, the lack of air (oxygen) in the pores may cause serious damage to root systems. Gravitational water is not generally utilized by plants, and may even be detrimental.

Capillary water exists in capillary pores as loosely held films around the mineral particles, and is readily available to plants. The amount of this water present is dependent on the surface area, which varies inversely with particle size. Clay has the greatest surface area per unit volume of the mineral components and would therefore contain the highest amounts of capillary water compared to silt or sandy soil.

Hygroscopic water is the capillary water remaining in an air dried soil. Like capillary water, the amount present is a function of the surface area of the soil particles, but it is tightly bound and unavailable to plants.

As the amount of capillary water in a given soil decreases, a concentration is reached that is available for plant survival, but not for growth. Absorption of water from the soil becomes too slow to replace water lost by transpiration. This level of soil water is called the permanent wilting percentage.

Table 2.4. Minimum Infiltration Rate of Various Groups of Soils
(Adapted from Slatyer, 1967)

Soils	Minimum Infiltration Rate (hr^{-1})
Deep sands, aggregated silts	0.45-0.3
Sandy loams	0.3 -0.15
Many clay loams, shallow sandy loams, soils low in organic matter, soils high clay content	0.15-0.05
Soils of high swelling capacity, sodic soils	<0.05

A clay loam soil compared to a sandy loam soil would have a higher soil moisture content expressed as a percent dry weight in all three soil/water categories. It would have not only the greatest percentage by weight of water available to plants for growth but also a higher percentage of water unavailable at the permanent wilting point.

4. Soil Air

A well aerated soil is defined by Lyon et al. (1952) as: "...one in which gases are available to growing organisms (particularly higher plants) in sufficient quantities and in the proper proportions to encourage optimum rates of the essential metabolic processes of these organisms."

Adequate soil aeration is determined by: (1) sufficient pore space devoid of water, and (2) unimpeded exchange of essential gases, oxygen and carbondioxide (O_2 and CO_2), into and out of these spaces (Lyon et al. 1952).

Aerobic respiration of soil organisms and roots consumes O_2 and releases CO_2 as a by-product. The exchange of these gases with the atmosphere, primarily by diffusion, is essential for the renewal of O_2 consumed by respiration and for the elimination of CO_2 .

Generally speaking, two types of field conditions result in poor soil aeration: soils whose texture and structure impede the exchange of gases and water saturated soils in which the pore spaces are filled with water, leaving no room for gases. At standard temperature and pressure, water will contain only 3% as much oxygen per unit volume as does air and the diffusion coefficient of oxygen is about one ten-thousandth as great in water as it is in air (Black,

1968). Heavy soils (high in clay), which may be susceptible to a loss of structure under mismanagement, could develop a surface layer impermeable to the diffusion of gases.

Lyon et al (1952) state that aeration is often inadequate in fine-textured soils but almost never limiting in sandy soils. However, diffusion is greater in a fine-textured soil than in a coarse-textured soil if the soil is dry, because the total pore space is usually occupied by water (Terwilliger, 1969).

5. Soluble Salts

Soluble salts include sodium, calcium, magnesium, and potassium cations and chloride, sulfate, carbonate, and bicarbonate anions (Lyon et al., 1952). The stress imposed on plants by salts can be subdivided into salt stress and ion stress based on whether or not water uptake is retarded (Levitt, 1972). If the salt concentration is high enough to retard the uptake of water (lowering the water potential 0.5-1.0 bar), the stress will be a salt stress; if not, the stress will be an ion stress.

Soluble salt concentrations that may cause salt stress in vegetation are determined by electrical conductivity (EC) expressed as millimhos per cm at 25°C. An EC less than 2 is considered to have a negligible effect, 2 to 4 is slightly saline, 4 to 8 is moderate, 8 to 16 is severe, and values over 16 indicate severe salinity (U.S. Salinity Laboratory Staff, 1954). The concentration of soluble salts varies inversely with available soil water. During dry periods, available water becomes low, salt concentration in solution increases, and salt stress may result.

6. Exchangeable Sodium Percentage (ESP)

Two terms are used to define the amounts of sodium present in soil, ESP, and Sodium Adsorption Ration (SAR). The former is based on cation exchange capacity and the latter on the saturation extract and the concentrations of calcium and magnesium ions (U.S. Salinity Laboratory Staff, 1954). The resultant values from the two methods are quite similar.

Sodium-affected soils have a dense claypan with excessive amounts of sodium (SAR >12, ESP >15) (Omodt et al. 1975). The claypan may occur near the surface or to depths of 12 inches or more. Three to eight-inch

depths are most often found in North Dakota alkali soils. This claypan restricts root penetration and air and water movements to the layers below. High sodium soils with a pH of 9.5 or greater is toxic to plants.

7. Free Lime

Free lime (expressed as CaCO_3 equivalent) is composed of calcium and magnesium carbonates. When the amount of free lime present is 10% or greater, soil aggregates break down easily by rain. Water infiltration is impeded, runoff increases, and wind and water erosion increases too (Omodt et al., 1975). Also, phosphorus becomes insoluble as calcium phosphates.

E. Soils of the Four-county Area

The soils of North Dakota can be divided into two major categories based on the origin of the parent material. Southwest of the Missouri River the parent materials have weathered in place from sedimentary rock (residuum). The remaining soils of the state have predominantly parent material transported by glacial ice (glacial till) (Omodt et al., 1968). Other origins for parent materials of soils found within the four-county region include glacial outwash, alluvium and loess (Fig. 2.21). Glacial outwash is parent material being carried and ultimately deposited by the water flowing from a melting glacier. Alluvia are sediments from floodwaters on stream bottoms and loess is silt transported and deposited by winds.

McLean County soils have parent materials originating almost entirely from glacial till, whereas Dunn County is predominately residuum. Mercer and Oliver Counties are composites of the types of parent materials mentioned above (Fig. 2.21). The soils that ultimately formed in the four-county region were determined not only by the parent materials present but also by the interrelationships of climate, biota, and relief. The combination of these factors have resulted in the twenty soil associations numbered in Fig. 2.22 and listed in Table 2.5.

Eleven of these soil associations occur over present surface mineable coal deposits of the four counties (Fig. 2.23). These eleven soil associations are numbered 24, 29, 33, 35, 36, 37, 40, 59, 63, 64, and 66. Soil associations 24 through 40 belong to a soil group broadly defined as "chestnuts" (dark brown soils of semiarid grassland). Chestnut soils are well drained, derived from varying parent materials and found in the western portion of the state.

Table 2.5. Soil Associations of Dunn, McLean, Mercer, and Oliver Counties
(from Omodt et. al., 1968)

Black Soils of Subhumid Grasslands (Chernozems)

4. Barnes-Svea^a

Dark Brown Soils of Semiarid Grasslands (Chestnut)

24. Agar-Williams-Zahl	35. Parshall-Lihen
26. Morton	36. Vebar
28. Morton-Rhoades	37. Vebar-Williams
29. Morton-Williams	39. Oahe-Sioux
33. Williams	40. Williams-Zahl

Alkali Soils (Solonetz)

59. Rhoades-Morton

Soils of Stream Valleys (Alluvial)

60. Havre-Banks

Soils on Steep Slopes and Soils of Sand Hills (Regosols)

62. Badlands-Bainville	65. Bainville-Rhoades
63. Bainville-Flasher-Agar	66. Bainville-Zahl
64. Bainville-Morton	72. Zahl-Williams

Soils on Steep Slopes (Lithosols)

69. Flasher-Vebar

^aThese numbers correspond to the numbers found on the four-county soil map, Fig. 2.21.

Note: See Table 2.4 for names of the soil association members.

Fig. 2.21. Soil Associations and Origin of the Parent Materials for Dunn, Mercer, and Oliver Counties (Source: Omodt et al., 1968.)

Fig. 2.22. Soil Associations
(Source: Omodt et al., 1968.)

Fig. 2.23. Surface Mappable Coal Deposits
(Source: Northern Great Plains
Resource Program, 1974.)

The native vegetation supported by these soils consists primarily of grasses that compose the mixed-grass prairie. The chestnut soils are the most important soils for crop production in the western portion of the state (Omodt et al., 1968).

Soil association 59 belongs to the Solonetz soil group or "alkali soils." These soils have developed under the influence of excessive sodium and restricted drainage. Alkali soils are used predominantly for pasture because of the high alkalinity and the limited root penetration and water permeability associated with its physical characteristics (Omodt et al., 1968).

The last three soil association, 63, 64, and 66, are Regosols (soils on steep slopes and soils of sand hills). The slopes in this soil group range from 6-50% with most areas having slopes from 10-30%. Surface water runoff is rapid and water infiltration is limited. Because erosion removes the surface soil as quickly as it is formed, pasture is the predominant use for these associations.

F. Biological Description

1. Ecosystems in the Four-county Area

Three major natural ecosystems or vegetation types, badlands, floodplain and mid-grass prairie,* occur on the land areas of Dunn, McLean, Mercer and Oliver counties (Northern Great Plains Resource Program 1974). The floodplain and mid-grass prairie are the two natural ecosystems that occur on surface minable land in the four counties (Table 2.6).

Table 2.6. Areas of Different Vegetation Types Occupying Surface Minable Lands in the Four-county Area of North Dakota^a

Counties	Vegetation Type	Acres
Mercer-Oliver	Floodplain	12,416
Mercer-Oliver	Mid-grass prairie	126,643
McLean	Mid-grass prairie	19,866
Dunn	Mid-grass prairie	22,349

^a Adapted from NGPRP-Surface Resources Work Group-Regional Profile, 1974.

*The term mid-grass prairie comes from the citation, NGPRP 1974. This ecosystem is normally referred to as a mixed-grass prairie.

a. Floodplain

The floodplain ecosystem occurs on alluvial soils along perennial and some intermittent streams and rivers. Alluvial soils are characteristic of lowlands that formed as deltas in or at the mouths of streams or as floodplains along streams that periodically overflow their banks (Oosting, 1956). Because of the favorable moisture conditions, alluvial deposits usually support the richest natural flora of a region.

The floodplain ecosystem in North Dakota has three strata of vegetation. The upper or canopy strata is dominated by the plains cottonwood, which in favorable sites may grow to heights of 75 to 100 or more feet. This forest type covers 41,700 acres or 10% of the acreage of forested lands in North Dakota.* Other trees that may occur with the plains cottonwood are green ash, juniper, willow, and box elder (Table 2.7). The shrub understory vegetation beneath the canopy contains chokecherry, red-osier dogwood, western wild rose, and Virginia creeper. The third strata, or grass and forb understory, characteristically contains slender wheatgrass, marsh muhly, prairie sandreed, poison ivy, and sweetclover.

The shrub stratum dominant, wolfberry, one of two snowberries occurring in North Dakota, is an important wildlife food in the western states. The fruits ripen in the fall and often remain on the bush for half a year or more, serving as food for sharp-tailed grouse, pheasant, other birds, and small mammals. The leaves and twigs are eaten by deer and antelope. The shrub also provides nesting cover and protective shelter for gamebirds, rabbits and other animals (Martin, Zim, and Nelson, 1961).

Poison ivy (a shrub but because of a greatly variable habit of growth is listed as a forb in the herb stratum) bears fruits eaten by many kinds of upland game birds and songbirds primarily in the winter when other foods are scarce. Mule deer and some small mammals will consume the leaves and twigs.

The floodplain ecosystem provides some or all of the following to the fauna that inhabit it: vegetative food in the form of fruits, leaves, twigs, bark, buds, or catkins; prey such as small mammals, amphibians and birds; nesting cover; protective shelter from weather or predators, and water. Characteristic fauna that inhabit this system are listed in Table 2.8.

*North Dakota Forest Service, Long Range Planning 1966-1975.

Table 2.7. Major Species of a Typical Cottonwood Vegetation Type as Found on some Stream Valley Bottomland Sites in Dunn County^a

Plant Type	Scientific Name	Common Name	Percent Composition
Tree Stratum	<i>Populus deltoides</i>	Plains cottonwood	60
	<i>Juniperus scopulorum</i>	Rocky Mtn. Juniper	26
	<i>Fraxinus pennsylvanica</i>	Green ash	10
	<i>Ulmus americana</i>	American elm	4
Shrub Stratum			
Shrubs	<i>Symphoricarpos occidentalis</i>	Wolfberry	35
	<i>Rosa woodsii</i>	Western wild rose	29
	<i>Cornus stolonifera</i>	Red-osier dogwood	10
	<i>Shepherdia argentea</i>	Buffaloberry	4
Saplings	<i>Fraxinus pennsylvanica</i>	Green ash	8
	<i>Acer negundo</i>	Box-elder	2
	<i>Ulmus americana</i>	American elm	1
Herb Stratum			
Grasses	<i>Agropyron trachycaulum</i>	Slender wheatgrass	7
	<i>Muhlenbergia racemosa</i>	Marsh muhly	5
	<i>Calamovilfa longifolia</i>	Prairie sandreed	5
	<i>Elymus canadensis</i>	Canada wildrye	5
	<i>Poa pratensis</i>	Kentucky bluegrass	4
Forbs	<i>Rhus radicans</i>	Poison ivy	23
	<i>Melilotus</i> spp.	Sweetclover	18
	<i>Smilacina stellata</i>	False Solomon's seal	3
	<i>Apocynum sibiricum</i>	Dogbane	2

^aAdapted from Whitman, W. C., et al. 1974.

Table 2.8. Some Characteristic Faunal Inhabitants of the
Floodplain Ecosystem^a

Scientific Name	Common Name
<i>Odocoileus virginianus</i>	White-tailed deer
<i>Odocoileus hemionus</i>	Mule deer
<i>Castor canadensis</i>	Beaver
<i>Procyon lotor hirtus</i>	Raccoon
<i>Mustela vison letifera</i>	Mink
<i>Mustela longicauda</i>	Long-tailed weasel
<i>Silogale putorius interrupta</i>	Spotted skunk
<i>Mephitis hudsonica</i>	Striped skunk
<i>Vulpes regalis</i>	Red fox
<i>Canis latrans</i>	Coyote
<i>Buteo jamaicensis</i>	Red-tailed hawk
<i>Pica pica</i>	Magpie
<i>Thannophis radix</i>	Garter snake

^a Adapted from NGPRP-Surface Resources Work Group-Regional
Profile, 1974.

b. Mid-Grass Prairie

The mid-grass prairie is the predominant ecosystem to be affected by strip mining, since it overlies 168,858 acres of surface minable coal in the four-county area (Table 2.6). It occurs on gently rolling topography with slopes ranging from 0-15%. It is dominated by grasses of medium height such as western wheatgrass (Agropyron smithii), needle-and-thread (Stipa comata), prairie junegrass (Koeleria cristata), and green needlegrass (Stipa viridula) in association with a number of shorter grasses and sedges, blue grama (Bouteloua gracilis), Sandberg bluegrass (Poa secunda), threadleaf sedge (Carex filifolia), and needleleaf sedge (Carex eleocharis). The existing uncultivated mid-grass prairie is utilized primarily as rangeland, producing forage for animal consumption.

The species that make up this grassland association are quite variable, site specific, and are listed for individual range sites. A range site is an area with similar soil and environmental conditions capable of producing certain kinds and amounts of native forage. The major site factors that influence species distribution include topsoil depth, soil texture, available soil moisture, land slope and exposure, soil salinity and native soil fertility (Dodd and Galt, 1973). Specific range-site descriptions, including the major forage grasses and production, are given in Table 2.9.

The first three range sites (wetlands, wet meadow and subirrigated) occur predominately in the eastern portion of North Dakota. The remainder of the sites can be found throughout the state with the exception of shallow, which is located in west-central and western North Dakota.

The three major forage grasses occurring most often in the western range sites are western wheatgrass, needle-and-thread and blue grama. Whitman (1954) found that western wheatgrass and needle-and-thread (mid-grasses) accounted for 60% of the total production and less than 16% of the ground cover in a clipping study on a number of grazed upland native grass areas. Blue grama (shortgrass) and upland sedges provided 23%, other grasses accounted for 11% with the remaining 7% of the yield coming from forbs. The blue grama-sedge combination accounted for 68% of the ground cover. In this study, total yield averaged 1350 kg/ha/yr.

Grama grass, wheatgrass and needle grass seeds are an important food for songbirds and rodents, and the vegetative portions are consumed by

Table 2.9. Descriptions of Range Sites Recognized in North Dakota^a

Range Site	Site Description	Major Forage Grasses	Production lb/acre
Wetlands	Soil saturated or water stands over the surface for most of the growing season	Slough sedge, rivergrass, reed-canary grass, prairie cordgrass, northern reedgrass	5200 to 6600
Wet meadow	Poorly drained shallow depressions, flooded in spring, surface dry by mid-summer but free water still present in the root zone	Prairie cordgrass, northern reedgrass, wooly sedge, slim sedge	4000 to 5200
Subirrigated	Low-lying lands, rooting zone moist for most of the growing season	Switchgrass, prairie cordgrass, big bluestem, little bluestem, and indian grass	3600 to 4400
Overflow	High soil moisture, bottomlands, lower ends of long slopes	Big bluestem, slender wheatgrass, green needlegrass, needle-and-thread, western wheatgrass	West-2300 East-3600
Saline lowland	Saline soils, poor drainage, water seepage	Nuttall alkali-grass, western wheatgrass, slender wheatgrass, inland saltgrass	West-2200 East-2850
Closed depression	Basins with small runoff area as support, water availability	Western wheatgrass, slender wheatgrass, prairie cordgrass	West-2000 East-2700
Sands	Deep, loose, coarse, textured soils, level to rolling uplands and stream terraces, susceptible to wind erosion	Prairie sand-reed, needle-and-thread, sand bluestem, western wheatgrass, sand dropseed	West-1750 East-2600
Sandy	Deep coarse textured soil level to hilly topography	Prairie sand-reed, needle-and-thread, prairie junegrass, western wheatgrass, blue grama	West-1600 East-2400
Silty	Deep to moderately deep, well drained, medium to fine texture, glaciated and residual plains	Western wheatgrass, needle-and-thread, green needlegrass, prairie junegrass, blue grama	West-1550 East-2750

Table 2.9. (Cont'd)

Range Site	Site Description	Major Forage Grasses	Production lb/acre
Clayey	Deep, well drained, fine textured soils, lake plains and high stream terraces	Western wheatgrass, green needlegrass, prairie junegrass, blue grama	West-1450 East-2550
Shallow	Fine to coarse textured soils, excessive runoff, beds of sandstone, siltstone and shales at depths of 10 to 22 inches	Little bluestem, plains muhly needle-and-thread, western wheatgrass, prairie sand-reed side-oats grama, blue grama	West-1250 West-Central 1700
Thin upland	Deep to fine to coarse texture soils, excessive runoff, thin topsoil, hilly topography	Little bluestem, plains muhly needle-and-thread, western wheatgrass, side-oats and blue grama, porcupine grass	West-1700 East-2450
Thin sand	Deep, well drained and coarse texture thin topsoil, natural fertility and organic matter content are low	Sand bluestem, sand dropseed, prairie sand-reed, needle-and-thread, blue grama	West-1750 East-2100
Shallow to gravel	Fine to coarse texture soils underlined with coarse sand or gravel at depths of 10 to 20 inches	Needle-and thread, plains muhly, green needlegrass, western wheatgrass, prairie junegrass, blue grama	West-1300 East-1850
Shallow clay	Fine texture, nonsodic, slowly permeable, runoff medium to rapid, occurs on undulating to steep uplands	Western wheatgrass, thickspike wheatgrass, green needlegrass	West-1000
Claypan	Fine soils underlain by a dense slowly permeable subsoil due to high sodium content at depths of 4 to 8 inches	Western wheatgrass, needle-and-thread, prairie junegrass, blue grama, occasionally in land saltgrass	West-1400 East-1950

Table 2.9. (Cont'd)

Range Site	Site Description	Major Forage Grasses	Production lb/acre
Thin claypan	Fine soils, hard impervious sub-soil due to high sodium, topsoil depths of 1 to 4 inches, areas may be devoid of vegetation	Blue grama, western wheatgrass, needle-and-thread, buffalo grass, sandberg bluegrass, inland saltgrass	West-550 East-1100
Very shallow	Rock strata 10 inches or less below surface, restricted rooting depth	Needle-and-thread, blue grama, western wheatgrass, little bluestem, plains muhly	West-600 East-1000

^aRange site descriptions from D. L. Dodds and D. Galt, Range Site Identification, Cooperative Extension Service, Circular R-580, NDSM, Fargo, November, 1973.

hoofed browsers (Martin, Zim, and Nelson, 1961). Common fauna characteristically inhabiting the mid-grass prairie ecosystem are listed in Table 2.10

Table 2.10. Some Characteristic Faunal Inhabitants of the Mid-grass Prairie Ecosystem^a

Scientific Name	Common Name
<i>Antilocarpa americana</i>	Antelope
<i>Lepus townsendii</i>	White-tailed jack-rabbit
<i>Odocoileus hemionus</i>	Mule deer
<i>Canis latrans</i>	Coyote
<i>Cynomys ludovicianus</i>	Prairie dog
<i>Taxidea taxus</i>	Badger
<i>Vulpes regalis</i>	Red fox
<i>Thomomys talpoides</i>	Pocket gopher
<i>Speotyto cunicularia</i>	Burrowing owl
<i>Circus hudsonius</i>	Marsh hawk
<i>Sturnella neglecta</i>	Western meadowlark

^aAdapted from NGPRP-Surface Resources Work Group-Regional Profile, 1974.

c. Other Ecosystems

Several types of vegetation and associated wildlife have been described as ecosystems for southwestern North Dakota by Stewart and Stewart (1974) based on earlier U.S.D.A., Forest Service, scheme. Included here are: Bottomland Terraces, Toe Slope, Scoria, Badland, Upland Grassland, Rolling Grassland, Hardwood Draw, and Freshwater Marsh.

The Toe Slope, Upland Grassland and Rolling Grassland ecosystems are all part of the mid-grass prairie ecosystem. The Bottomland ecosystem was discussed earlier as the Floodplain ecosystem.

The Terrace ecosystem is composed of former floodplains of streams and rivers now located adjacent to but as higher elevation than present floodplains of streams in the Floodplain ecosystem (Stewart and Stewart, 1974). Floodplain species that survived the river channel changes often occur in this ecosystem. A shrubby vegetation (sagebrush-grass) commonly develops on low terraces. In Dunn County, dwarf sagebrush, Artemisia cana is the dominant

shrub with a grass understory accounting for 50-60% of the total cover (Whitman et al., 1974). This ecosystem potentially can provide the habitat requirements of the pheasant, red fox, prairie dog and coyote and, to some degree, the white-tailed deer, mule deer, burrowing owl, black-footed ferret, swift fox, bobcat and pronghorn (Stewart and Stewart, 1974).

Scoria is composed of shale, sandstone, and limestone and was produced by the baking and fusing of material overlying burning lignite beds (Whitman and Hanson 1939). The scoria ecosystem is made up of buttes and rounded, moderately steep hills with drainageways and numerous low knobs of scoria outcrop (Stewart and Stewart, 1974). Buttes vegetation might be characterized as the Mentzelia decapetala (scoria lily)-Juniperus horizontalis (creeping cedar) type. As the butte weathers away and the slopes of the sides becomes more gradual, cover and grasses such as blue grama increase and the shrubby species tend to decrease (Whitman and Hanson, 1939).

The habitat requirements for the red fox and coyote can be provided for by the scoria ecosystem. Partial requirements can be met for the mule deer (Stewart and Stewart, 1974).

The Badland ecosystem is composed of very steep, broken lands adjacent to major rivers and streams (Stewart and Stewart, 1974). Badlands form a belt 5-25 miles wide and more than 200 miles long bordering the Little Missouri River (NGPRP, 1974). Slopes range from 20 to over 100% and display multicolored bands of exposed sandstone, siltstone, scoria, lignite and clays.

A Rocky Mountain Juniper (Juniperus scopulorum) vegetation type is developed on steep easterly and northerly slopes in the badlands area of Dunn County, as well as in other parts of the North Dakota Badlands (Whitman et al., 1974). Green ash and American elm may also occur as young trees. Chokecherry, Prunus virginiana, and dwarf juniper, Juniperus communis are dominant shrubs and little ricegrass, Oryzopsis micrantha is abundant under fairly dense stands of J. scopulorum. The badland ecosystem exhibits severe microclimatic conditions especially on south facing slopes, because of the steep slopes and lack of soil due to erosion. Regardless, the system supports a highly complex vegetation, due mainly to topography. Common fauna characteristically inhabiting the badlands ecosystem are listed in Table 2.11.

Table 2.11. Some Characteristic Faunal Inhabitants
of the Badlands Ecosystem^a

Scientific Name	Common Name
<i>Odocoileus hemionus</i>	Mule deer
<i>Lepus townsendii</i>	Jack rabbit
<i>Vulpes regalis</i>	Red fox
<i>Canis latrans</i>	Northern coyote
<i>Taxidea taxus</i>	Badger
<i>Mephitis mephitis</i>	Skunk
<i>Citellus tridecemlineatus</i>	Ground squirrel
<i>Cynomys ludovicianus</i>	Prairie dog
<i>Mustela longicauda</i>	Weasel
<i>Peromyscus maniculatus</i>	White-footed mouse
<i>Aquila chrysaetos</i>	Golden eagle
<i>Buteo jamaicensis</i>	Red-tailed hawk
<i>Falco mexicanus</i>	Prairie falcon
<i>Crotalis viridis</i>	Prairie rattlesnake
<i>Phrynosoma douglassi</i>	Short-horned lizard

^aAdapted from NGPRP 1974.

The hardwood draw ecosystem is a complex of trees and shrubs associated with, and common to, upland narrow drainageways and minor draws that often contain intermittent and ephemeral streams in swales, and other moisture collecting areas (Stewart and Stewart 1974). The vegetation is predominately a complex of shrubs and trees with the most common community dominated by green ash associated with American elm, chokecherry, western wild rose, wolfberry and Juneberry, Amelacnhier alnifolia (Whitman et al., 1974). Together with the bottomland and terrace ecosystems, the hardwood draws are important in providing travel routes, cover and winter food for much of the big game population of the prairie region (Whitman and Wali, 1975). It is doubtful that the prairie region could support any sizable big game population without this woody vegetation.

The freshwater marsh ecosystem is composed of large depressions or basins that are frequently ponded. These ponds are slightly brackish, and often a mixture of open water and marsh and poorly drained soils vegetated by rushes, sedges and marsh grasses (Stewart and Stewart, 1974). Broadleaf cattail (Typha latifolia) and hardstem bulrush (Scirpus acutus) are two emergent species dominating in the marsh areas.

G. Land Use

As in other resource areas, lignite mining was first initiated in North Dakota when the early settlers began excavating locally exposed deposits for their personal needs. Since stripping equipment was limited primarily to hand implements and horse-drawn scrapers, surface excavation could be dispatched to a depth of only a few feet. Therefore, most of the early lignite mining was conducted by underground methods. In general, exposed seams were initially surface mined and then the seam was followed in drift or slope fashion until it was either uneconomical or unsafe to continue. With the advent of steam and electric-powered shovels and draglines, surface mining became a much more efficient operation than underground mining wherever geologic conditions were favorable, and stripping eventually became the dominant method of lignite production in North Dakota. The trend toward surface mining is illustrated by the fact that in 1923, only 24% of North Dakota's 1.4 million-ton production was by surface methods, but by 1933, when production had risen to 1.8 million tons, 61% was produced by surface methods (Carlson et al., 1964). If coal gasification becomes a reality, a very rapid increase in the growth of lignite development will occur. A single Lurgi plant like that proposed by American Natural Gas could consume more lignite each year than is currently being produced in the entire state. A complex of four such plants would have the potential of consuming more lignite in four years than the total recorded production of North Dakota since 1884.

In terms of acreage disturbed for the production of lignite in North Dakota, estimates vary considerably because accurate records were not kept until the reclamation law became effective in 1970. A study conducted in 1974, in which aerial photographs were used to measure areas affected prior to 1970, estimates the total area disturbed by surface mining prior to 1970 to be 12,378 acres. An additional 2024 acres were said to be affected by subsidence of underground mines (Thompson, 1974). Since 1969, the North Dakota Public Service Commission has kept records of all active mine operations, and data from their files bring the total area disturbed by surface methods to 13,312 acres through September, 1974. Figure 2.24 shows the distribution by county of the surface mined area and the distribution of land currently under permit to be mined, based on a combination of data from both of these sources. It should be recognized that other estimates of disturbed area are

4804 = AREA UNDER ACTIVE PERMIT

13,312 = TOTAL AREA DISTURBED TO SEPTEMBER, 1974

Fig. 2.24 Areas Disturbed by Strip Mining Operations
in North Dakota, by County

as much as twice as high as these figures. One Bureau of Mines report, for example, shows 27,200 acres disturbed for coal in North Dakota (Paone, 1974), and although this figure includes surface features of underground operations, it is still higher than the total reported by Thompson.

With 69.3 thousand square miles of territory, North Dakota ranks 17th in size among the 50 states. In terms of population, however, the state ranks 45th, with only 640 thousand people. It is also primarily a rural state with only 44.3% of the population living in urban areas, thus ranking 47th in percent urban population. About 98% of the total land area is in farms. Wheat is the major crop, being produced on nearly half of the 19 million acres of farm land harvested each year. Livestock farms account for another 25% of the total of 41,000 farms in the state, and provide a significant portion of the total farm product value of approximately \$958 million in 1973. By comparison, total lignite sales in 1974 were less than \$15 million, and the total area disturbed for this product has been only 200-300 acres per year. Anticipation of extreme increases in the production, and gasification of lignite, however, has prompted considerable speculation concerning the impacts this would have on the region. Section 4 addresses the land use impacts that would result directly from the operation of one gasification plant and its supportive mines in Mercer County, which is the leading lignite producing county in the state. See Section 4 for a more detailed analysis of the land use implications of lignite development in Mercer County.

1. Agricultural Land Use in the Four-county Area.

The climate of North Dakota is characterized as having long, cold winters and a warm, short growing season (Sec. 3). Precipitation is normally heaviest during the early and middle parts of the growing season and often limiting in late summer to the point of causing dry spells. Precipitation during and between seasons is quite variable with the possibility of drought occurring during any season. This climate has resulted in a native vegetation dominated by grasses and, therefore, the crops that are best adapted for growth and success are the small grains such as wheat, barley, and oats. On a national comparison, North Dakota in 1974 ranked* number one in the production of Durum wheat (accounting for 87% of the total U.S. production), other spring wheat,

*State ranking is from the 1975 North Dakota crop and livestock statistics.

barley and flaxseed. Other crop rankings include second in all wheat and rye production, fifth in oats, and tenth for all hay.

Land use in the four-county region is listed in Table 2.12. Over 95% of the land area within each county is utilized for either crop production or grazing. McLean County has the greatest proportion (73%) of land in crop production. Dunn County, the most western of the four counties, has the greatest acreages in two categories, pasture/rangeland and forest/woodland. Mercer and Oliver Counties, the two smaller counties, have almost equal proportions of cropland and pasture/rangeland.

A summary of the main 1973 crops produced, acres planted, and yields is given in Table 2.13. Only two categories, all wheat and summer fallow, separately exceed 20% of the total acreage in each of the four counties. Summer fallow is a farming practice during which no crop is grown and plant growth is controlled by cultivation or chemicals as a means to increase the water available for succeeding crop growth (USDA Agricultural Research Service 1974).

The 1973 season average price received by North Dakota farmers for all wheat was \$4.82 per bushel. The average dollar value per acre of all wheat produced in the four-county area was \$119.66. Another cereal grain, barley, primarily produced in McLean County, had a season average price of \$2.09 per bushel and an average dollar value per acre of \$69.08.

Table 2.12. Agricultural Land Use in the Four-county Region^a

Land Use	County							
	Dunn		McLean		Mercer		Oliver	
	Acres	%	Acres	%	Acres	%	Acres	%
Cropland	487,887	38	966,678	73	343,052	52	208,922	45
Pastureland and range- land	741,085	58	309,778	24	299,322	45	239,697	52
Forest and woodland	34,500	3	7,000	1	1,900	<1	2,900	1
Urban and built-up areas	12,536	1	32,249	2	21,430	3	9,400	2
TOTAL	1,276,008	100	1,315,705	100	665,704	100	460,919	100

^aAdapted from NGPRP-Surface Resources Work Group-Regional Profile, 1974.

Table 2.13. 1973 Crop Data Summary for the Four-County Region^a

	Dunn			McLean			Mercer			Oliver		
	Planted acres,	%	Yield, Bu/acre	Planted acres,	%	Yield, Bu/acre	Planted acres,	%	Yield, Bu/acre	Planted acres,	%	Yield, Bu/acre
All Wheat	101,000	23	25.5	348,000	29	26.3	87,000	29	24.0	43,000	23	23.5
Corn	18,200	4	-	5,700	<1	-	15,500	5	-	13,200	7	-
Barley	24,500	6	35.5	310,000	26	35.8	11,500	4	29.6	9,500	5	31.3
Oats	46,000	11	45.0	62,000	5	38.0	36,000	12	42.0	22,000	12	34.0
Rye	300	<1	27.0	2,100	<1	33.0	200	<1	32.0	100	<1	30.0
Flaxseed	1,000	<1	9.0	35,000	3	9.0	3,000	1	7.0	5,000	3	8.0
All Hay	126,000	29	1.13 (tons)	105,000	9	0.89 (tons)	64,000	21	1.61 (tons)	54,000	29	1.17 (tons)
Summer Fallow	119,000	27	-	330,000	23	-	87,000	29	-	42,000	22	-
TOTAL	436,000	101		1,197,000	101		304,200	101		188,800	101	

^aUSDA Statistical Reporting Service, North Dakota Crop and Livestock Statistics, North Dakota State University Agr. Exp. Sta., Dept. of Agr. Econ., Ag. Statistics No. 35, May 1975

Livestock in the four counties consisted of 292,000 cattle and 11,000 sheep as of January 1, 1975. Calculations based on the assumption that each head of cattle and every 5 sheep constitute one animal unit (au) yield a total grazing load of 294,000 amu (Whitman and Wali, 1975). The 1,589,000 acres of pasture and rangeland in the four-county area divided by the total au results in 5.4 acres/au, compared to an average of 5.2 acres/au given by Whitman et al. (1975) for all of North Dakota. Whitman et al. indicated that the value represented a fairly heavy grazing pressure on the grassland ecosystem.

The estimated dollar value of agricultural production (wheat, corn silage, barley, oats, hay flaxseed, and pasture) according to 1973 crop prices of a 40-square-mile area north of Buelah-Zap in Mercer County, was \$22,000/sq. mi or \$34.37/acre.* This value can vary between the four counties depending on the proportions of the different land uses.

*Environmental Impact Report 1975. North Dakota Gasification Project for ANG Coal Gasification Company. Woodward-Envicon, Inc., Clifton, N.J.

3. COAL AND ITS USE

A. History of Mining

Although the earliest record of commercial production in North Dakota dates from 1884, lignite had been mined for domestic use many years prior to that date. The early settlers found lignite a convenient and readily available source of domestic fuel, though not as good a fuel as the coals of the Midwest and east. Lignite coal, or lignite, is higher in moisture and volatile matter and lower in fixed carbon and heating value than bituminous coal. The Indians may have introduced the settlers to the locations and use of lignite, for, in all probability, they had been using lignite as fuel for a few hundred years. Investigations in Arizona (Brew and Hack, 1939) have shown coal use by Indians in the 14th Century; such use may have started as early as 900 A.D. Hack believes that over 100,000 tons of coal was mined in Arizona from 1300-1600, based on a daily output of 450 pounds.

The settlers began mining the lignite where it was exposed, along steep-sided coulee (stream) banks. Drifts were driven into the exposed lignite seam and mining proceeded underground away from the stream. The size of these mines was limited by the availability of wood for constructing the supporting structure and by the strength of materials composing the mine roof. As most of the rocks above and below the lignite bed are soft and unconsolidated, the underground miners were forced to leave two feet or more of lignite in the mine to act as a roof and often a comparable amount in the floor to give a stable surface to hold the timber support structure. Large pillars had to be left and recovery was severely reduced. This common mining practice produced a series of relatively shallow, small, underground mines along the length of the lignite outcrop on both slopes of the streambed.

Strip mining occurred where the lignite was at or near the land surface and was easily loaded where the overburden was thin or missing. As the overburden increased in thickness, it was stripped off by scrapers or other devices pulled by horses. These primitive stripping methods were very inefficient and, as a result, most of the lignite was mined by underground methods.

As surface mining technology advanced with the development of drag-lines, shovels, bulldozers, and tractors, so that overburden could be more efficiently and economically removed, surface mining has increased in importance. North Dakota was one of the early states practicing large-scale surface mining; in 1927 40% of the lignite was strip mined compared with 2% of the national coal production, and by 1950, the figures had reached 87% compared to the U.S. total of 22% (Table 3.1).

Commercial mining began in the 1870s and reached a total of 35,000 tons in 1884, the first year of recorded production. Considerable mining for domestic use was still occurring at this time; most of the mining was never reported. The total number of mines reached 357 in 1935; two years earlier 301 mines had been producing lignite and two years later the number had decreased to 307 mines (Table 3.1). During this time the number of surface mines increased dramatically from 103 (34% of the total number of mines) in 1933, to 185 (52%) in 1936, reaching an all-time high of 192 in 1939. During this time underground mining was decreasing from 210 mines (62%), the all-time high in 1934, to 148 mines (48%) in 1937. The war years took their toll in reducing the total number of mines from 309 in 1940 to 138 mines by 1945. Since the war, the number of mines has gradually decreased (except for a sharp drop-off between 1963-1964), while the percentage of surface mines has steadily increased from 60% in 1946, 70% in 1948, 80% in 1952, 90% in 1959, to 100% since 1966. (The average production per surface mine has also shown dramatic increases in 1965-1966 and 1970-71, Table 3.2.)

Lignite production has steadily increased from 35,000 tons in 1884, to 1 million tons in 1922, 2 million in 1937, and reached 3.26 million in 1950 (Table 3.3). Initial lignite production was for domestic use, but the increase in production roughly parallels the development of the railroads. Much of the coal land was, and still is, owned or leased by the railroads. Later, as towns developed along the railroads, lignite was used in the production of electricity.

A 15-year stagnation set in, until in 1966 production began a dramatic increase which is still continuing. The stagnation was due, in large part, to the development of natural gas as an economic fuel, to the switch by the railroads from coal to diesel power, and to the development of hydroelectric power from the Missouri River. The North Dakota trend paralleled the national

Table 3.1. Number of Licenses and Lignite Production
by Type of Mine, 1927-Present

Year	Licenses	Strip Mines		Underground Mines		Production (10 ³)				
	No.	No.	%	No.	%	Strip	% Total	Underground	% Total	Total ^a
1927	227	81	36	146	64	612	40	917	60	1529
1928	227	71	31	156	69		40			1784
1929	213	68	32	145	68					1903
1930	259	75	29	184	71					1849
1931	290	100	34	190	66					1552
1932	283	100	35	183	65					1743
1933	301	103	34	198	66	1140	61	730	39	1872
1934	340	130	38	210	62					1746
1935	357	158	44	199	56					1828
1936	355	185	52	170	48					1704
1937	307	159	52	148	48					2184
1938	312	169	54	143	46					2142
1939	326	192	59	134	41					2177
1940	309	174	56	135	44	1406	63	812	37	2218
1941	248	136	55	112	45	1527	66	782	34	2309
1942	204	114	56	90	44	1715	68	822	32	2537
1943	184	109	57	73	43	1750	70	750	30	2500
1944	184	106	58	78	42	1656	70	710	30	2366
1945	138	80	58	58	42	1860	74	662	26	2522
1946	118	71	60	47	40	2128	83	427	17	2555
1947	119	80	67	39	33	2288	83	472	17	2760
1948	107	75	70	32	30	2476	84	485	16	2961
1949	93	67	72	26	28	2497	84	470	16	2967
1950	104	80	77	24	23	2828	87	432	13	3260
1951	99	75	76	24	24	2973	92	251	8	3224
1952	90	72	80	18	20	2800	94	184	6	2984
1953	83	69	83	14	17	2641	94	162	6	2803
1954	75	65	87	10	13	N/A	N/A	N/A	N/A	N/A
1955	75	66	88	9	12	3081	99	21	1	3102
1956	70	61	87	9	13	2806	99	9	1	2815

Table 3.1 (Cont'd)

Year	Licenses	Strip Mines		Underground Mines		Production (10 ³)				
	No.	No.	%	No.	%	Strip	% Total	Underground	% Total	Total ^a
1957	61	54	89	7	11	2557	99	4	1	2561
1958	58	51	88	7	12	2311	99	3	1	2314
1959	52	48	92	4	8	2409	99	4	1	2413
1960	49	46	94	3	6	2523	99	2	1	2525
1961	48	45	94	3	6	2724	99	2	1	2726
1962	50	47	94	3	6	2731	99	2	1	2733
1963	46	45	98	1		2397	99	2	1	2399
1964	29	28	97	1	3	2635	99	2	1	2637
1965	29	28	97	1	3	2731	99	2	1	2732
1966	25	25	100			3543	100			3543
1967	24	24				4156	100			4156
1968	22	22				4487	100			4487
1969	20	20				4704	100			4704
1970	20	20				5639	100			5639
1971	15	15				6075	100			6075
1972	14	14				6632	100			6632
1973	13	13				7400	100			7400
1974	13	13				7463	100			7463
1975						8183	100			8183

^a Production totals for years 1927 through 1939 are for fiscal years ending June 30 for each year
Production totals for years 1940 to present are for calendar years

Production Data Sources: Annual Reports of State Coal Mine Inspector and Bureau of Mines IC 8537, 1972.

Table 3.2. Average Mine Production, Surface and Underground Tonnage 1940-1974

Year	Average Production per Surface Mine (ton)	Average Production per Underground (ton)	Average Production per Mine (all) (ton)
1940	8080	6015	7178
1941	11228	6982	9310
1942	15044	9133	12436
1943	16055	10274	13587
1944	15623	9103	12859
1945	23250	11414	18275
1946	29972	9085	21653
1947	28600	12103	23193
1948	33013	15156	27673
1949	37269	18077	31903
1950	35350	18000	31346
1951	39640	10458	32566
1952	38889	10222	33156
1953	38275	11571	33771
1954	N/A	N/A	N/A
1955	46682	2333	41360
1956	46000	1000	40214
1957	47352	571	41984
1958	45314	429	39897
1959	50188	1000	46404
1960	54848	667	51531
1961	60533	667	56792
1962	58106	667	54660
1963	53207	2000	52152
1964	94107	2000	90931
1965	97536	2000	94207
1966	141720		141720
1967	173167		173167
1968	203955		203955
1969	235200		235200
1970	281950		281950
1971	405000		405000
1972	473714		473714
1973	569231		569231
1974	574077		574077

Source: Bureau of Mines, 1972.

Table 3.3. Growth in Lignite Production,^a
1884-1975^b

Year	Prod.	Year	Prod.	Year	Prod.	Year	Prod.	Year	Prod.
1884	35	1902	227	1920	879	1938	2142	1956	2815
1885	25	1903	279	1921	896	1939	2177	1957	2561
1886	26	1904	272	1922	1058	1940	2218	1958	2314
1887	21	1905	318	1923	1436	1941	2309	1959	2413
1888	34	1906	306	1924	1029	1942	2537	1960	2524
1889	29	1907	348	1925	1357	1943	2500	1961	2726
1890	30	1908	321	1926	1385	1944	2366	1962	2733
1891	30	1909	373	1927	1529	1945	2522	1963	2399
1892	41	1910	417	1928	1784	1946	2555	1964	2637
1893	50	1911	503	1929	1903	1947	2760	1965	2732
1894	42	1912	499	1930	1849	1948	2961	1966	3543
1895	39	1913	495	1931	1552	1949	2967	1967	4156
1896	78	1914	507	1932	1743	1950	3260	1968	4487
1897	77	1915	528	1933	1872	1951	3224	1969	4704
1898	84	1916	635	1934	1746	1952	2984	1970	5639
1899	99	1917	791	1935	1828	1953	2803	1971	6075
1900	130	1918	813	1936	1704	1954	N/A	1972	6632
1901	167	1919	784	1937	2184	1955	3102	1973	7400
								1974	7463
								1975	8183

^aProduction figures are rounded to the nearest thousand ton

^bProduction for years 1884-1939 are based on fiscal years ending June 30

trend of reduced cost production. From a high of 533.7 million tons of bituminous coal in 1951, U.S. production dropped to a low of 391.7 million tons by 1954, and only once (1956) reached the 500 million ton level (500.9), until 1965 (Fig. 3.1). Since that time, coal production has increased to the present national level of 640 million tons. The lignite industry in North Dakota is now dominated by companies producing lignite for electrical generation by large-scale combustion power plants. Some lignite is mined for use by sugar refineries for evaporation purposes, while other uses are for the manufacture of cooking briquets and for recovery of uranium minerals from ash. Mining for domestic heating purposes continues on a small scale. Production passed the 4-million-ton level in 1967, and the 5-, 6-, and 7-million-ton levels in 1970, 1971, and 1973, respectively. Estimates of future production based on current production trends, range in millions of tons from 16-20 by 1980, 26-30 by 1985, more than 40 by 1990, and over 100 by 2000.

Leistritz, Dalstead, and Hertsgaard (1974) have outlined three development alternative levels for lignite production in southwestern North Dakota for the years 1985 and 2000. Alternative one limits lignite development to the level necessary for meeting regional energy demand. Coal production would reach 19.3 million tons by 1985 and 28.6 by 2000. Alternative two involves development of lignite resources to meet both national and regional demands, but without a goal of energy self-sufficiency. Major dependence on imported oil and gas is assumed, although two coal gasification plants are planned before 1985 and seven more gasification plants between 1985 and 2000. As each of these units require approximately 11.5 million tons of lignite annually, lignite production is expected to rise under alternative two to 42.5 million tons by 1985 and 135.7 by 2000. Alternative three seeks national energy self-sufficiency; oil and gas imports are severely limited and nuclear generating capacity is not meeting expected output. As a result, energy production is mainly from lignite and coal. In southwestern North Dakota six new gasification plants are assumed to be on-line before 1985, and seventeen between 1985 and 2000. Lignite production under this scenario is expected to reach 83.2 million tons by 1985 and the incredible figure of 249.7 by 2000.

The Northern Great Plains Resources Program has similarly defined three production scenarios. Other estimates for North Dakota lignite production were 11.7 million tons by 1975, 35.2 by 1980, 58.4 (2 gasification units) by 1985, and 97.6 (with 6 gasification units) by 1990 (Groenewold,

Fig. 3.1. Lignite Production in North Dakota and Bituminous Coal and Lignite Production in the U.S., 1940-1974 (Source: Pollard, Smith, and Knox, 1972; and National Coal Association, 1975.)

personal communication, 10/24/74). The current study shows 8 million tons in 1975 (actual), and estimates 17.5 by 1980, 27 by 1985, and 87 (with gasification units) by 2000. Future production levels for various scenarios are given in Table 3.4.

The future production levels of North Dakota's lignite are directly linked to the emerging technologies of gasification and liquefaction. Other markets for lignite will continue to be the expanding electric power generation industry and the chemical industry. Leonardite (weathered lignite), a humic acid compound, has been used as a stabilizer in oil- and gas-well drilling mud, as a wood stain, and as a soil conditioner and fertilizer.

B. Resources and Reserves

The lignite field of western North Dakota, containing over 70% of the U.S. lignite resources, covers an area of 32,000 sq mi of which approximately 28,000 sq mi (18 million acres) are underlain by beds of lignite over 4-1/2 ft thick but only 700,000 acres are underlain by surface minable coal. All the lignite beds are in the Fort Union Group of Paleocene age, but attempts to correlate beds from area to area have proved difficult due to a lack of drill-hole data. Attempts to place the beds in a correct stratigraphic relationship have led to the identification of over 100 beds more than 4 ft thick; as information becomes available and correlations are discovered, that number is expected to decrease. Relatively thick lignite beds are scattered throughout the area. Glaciation has divided the lignite field into three overburden provinces; north of the Missouri River the overburden is composed of glacial drift, an aid in reclamation; the area between the Missouri River and the glacial limit has scattered areas of drift, but contains mostly fine-grained clastic rocks of the Fort Union group; and the overburden in the unglaciated area in the southwestern part of the state consists of Fort Union clastic rocks.

The definitive study of the lignite resources of North Dakota was made by Brant (1953), although coal exploration drilling since that time has revised some of Brant's estimates. The original lignite resource was estimated at 350.91 billion tons (Table 3.5 from Brant 1953) and was based on the standard U.S. Geological Survey criteria for measured, indicated, and inferred resource categories, all of which include tonnage of coal in the ground, Averitt (1975).

Table 3.4. Estimated Future Production of North Dakota Lignite

Year	NGPRP ^a			Leistritz et al ^b (1974)			Production Trend ^c	Groenewold et al ^d	ANL
	I	II	III	I	II	III			
1975	9	9	9					11.7(E) ^e	8.2(Actual)
1980	19	19	42				16-20	35.2 (1G.P.) ^f	17.5
1985	26	44	76	19.3	42.5 (2G.P.)	83.2 (6G.P.)	26-30	58.4 (2G.P.)	27
1990							40+	97.6 (6G.P.)	43 (1G.P.)
1995									67 (2G.P.)
2000	33	119	198	28.6	135.7 (9G.P.)	249.7 (23G.P.)	100+(E)		87 (3G.P.)

^aNGPRP I, II, III = The 3 coal development profiles of the Northern Great Plains Resource Program, 1974.

^bLeistritz, Dalsted, and Hertsgaard in North Dakota Farm Research, Vol. 31, No. 6, 1974, p.12-16

^cProduction trend based on announced new mine openings and planned expansions

^dGroenewold, personal communication, 10/27/74

^eE = Estimated

^fG.P. = Gasification Plants

TABLE 3.5. Estimated Original Resources of Lignite in North Dakota
(million short tons)

County	Measured Reserves	Indicated Reserves	Inferred Reserves	Total
Adams	103.16	367.49	1,386.11	1,856.76
Billings	527.62	3,129.80	14,060.61	17,718.03
Bowman	266.67	1,227.56	5,526.75	7,020.98
Burke	143.40	648.33	5,818.39	6,610.12
Burleigh	41.86	165.93	949.56	1,157.35
Divide	138.50	1,038.32	7,087.31	8,264.13
Dunn	1,270.98	5,747.91	64,023.36	71,042.25
Golden Valley	360.59	2,563.36	5,394.95	8,318.90
Grant	296.10	1,157.46	3,204.17	4,657.73
Hettinger	132.61	1,148.21	11,371.93	12,652.75
McHenry	21.46	32.36	64.08	117.90
McKenzie	1,170.87	4,526.94	26,485.31	32,183.12
McLean	599.75	2,664.42	13,214.24	16,478.41
Mercer	1,323.56	5,419.37	23,169.30	29,912.23
Morton	597.50	3,023.37	11,629.90	15,250.77
Mountrail	295.61	957.65	14,124.52	15,377.78
Oliver	397.55	3,011.91	14,429.34	17,838.80
Renville	27.62	152.05	603.11	782.78
Sheridan	-	-	660.06	660.06
Slope	638.31	5,604.37	13,847.92	20,090.60
Stark	392.08	3,007.42	22,298.20	25,697.70
Ward	259.52	1,260.79	8,765.74	10,286.05
Williams	<u>516.08</u>	<u>3,265.37</u>	<u>23,153.17</u>	<u>26,934.62</u>
Total	9,521.40	50,120.39	291,268.03	350,909.82

Source: Brant, Russell A., 1953, Lignite Resources of North Dakota,
U.S. Geological Survey, Circ. 226

Measured resources are based on assured coal bed correlations and on closely spaced observations about one-half mile apart. Computed tonnage is judged to be accurate to within 20% of the true tonnage. Indicated resources are based partly on specific observations and partly on reasonable geologic projection. The points of observation and measurement are about one mile apart but may be 1-1/2 miles apart for beds of known continuity. And, inferred resources are based on an assumed continuity of coal beds downdip from and adjoining areas containing measured and indicated resources. In general, inferred coal lies two miles or more from outcrops or from points of precise information.

Brant has also estimated 180 billion tons of lignite in the "hypothetical" resource category (resources in unmapped and unexplored areas), resulting in a total original resource estimate of 539.91 billion tons. Resources depleted to January 1, 1976, are 169.6 million tons produced and an assumed equal amount lost in mining for a total of 339 million tons. The remaining resource is thus 530.57 billion tons (Table 3.6).

Table 3.7 divides the identified resource into two categories: (1) subeconomic (89.3%) inferred resources and seams less than 5 ft thick in the measured and indicated categories (Column 2); and (2) demonstrated (10.7%) measured and indicated resources 5 ft thick and greater (Column 3). Column 4, the surface mining reserve base, lists slightly over 16 billion tons within 100 ft of the land surface and at a 90% recoverability rate gives a recoverable reserve of 14.4 billion tons (Column 5). As the size and capacity of surface mining equipment continues to increase, the depth of overburden that can be removed will also increase, thus raising the reserve base total. Likewise, as more efficient equipment comes on-line and improved mining methodology is realized, the recoverability rate will also rise.

The 14.4 billion tons represents 4.1% of the states identified resources and 38.5% of the demonstrated resource. The underground mining reserve base, 21.45 billion tons (Column 6) is 57.3% of the total demonstrated reserve and 6.1% of the identified resource. The recoverability factor for underground mining was assumed to be 50% (Column 7).

Table 3.6. Estimated Original Resources and Remaining Resources of Lignite in North Dakota
(in millions of short tons)

County	Measured Resources				Indicated Resources				Inferred Resources				Total in all categories			Identified Resources
	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	County totals
Adams	36.40	28.56	38.20	103.16	168.72	115.64	83.13	367.49	485.01	452.97	448.13	1,386.11	690.13	597.17	569.45	1,856.75
Billings	62.63	251.54	213.45	527.62	759.14	1,066.26	1,304.40	3,129.80	9,197.73	2,441.88	2,421.00	14,060.61	10,019.50	3,759.68	3,938.85	17,718.03
Bowman	47.34	52.94	166.39	266.67	310.74	472.52	444.30	1,227.56	1,055.93	1,296.92	3,173.90	5,526.75	1,414.01	1,822.38	3,784.59	7,020.98
Burke	23.57	108.78	11.05	143.40	238.07	329.70	90.56	648.33	5,513.55	275.67	29.17	5,818.39	5,775.19	714.15	120.78	6,610.12
Burleigh	....	5.66	36.20	41.86	....	89.86	76.07	165.93	44.35	865.97	39.24	949.56	44.35	961.49	151.51	1,157.35
Divide	21.24	63.41	53.85	138.50	363.76	374.48	300.08	1,038.32	6,899.39	136.56	51.36	7,087.31	7,284.39	574.45	405.29	8,264.13
Dunn	772.27	303.78	194.93	1,270.98	3,254.43	1,574.52	918.96	5,747.91	60,000.32	3,377.68	645.36	64,023.36	64,027.02	5,255.98	1,759.25	71,042.25
Golden Valley	127.20	205.77	27.62	360.59	1,507.17	979.46	76.73	2,563.36	4,695.81	690.96	8.18	5,394.95	6,330.18	1,876.19	112.53	8,318.90
Grant	94.15	180.45	21.50	296.10	689.44	457.43	10.59	1,157.46	3,054.78	149.39	....	3,204.17	3,838.37	757.27	32.09	4,557.73
Hettinger	35.63	47.96	49.02	132.61	397.91	508.56	241.74	1,148.21	8,723.38	931.74	1,716.81	11,371.93	9,156.92	1,488.26	2,007.57	12,652.75
McHenry	7.62	3.91	9.93	21.46	6.68	21.44	4.24	32.36	0.12	63.96	....	64.08	14.42	89.31	14.17	117.40
McKenzie	384.27	761.04	25.56	1,170.87	2,102.23	2,116.00	308.71	4,526.94	3,803.51	2,665.46	16.34	26,485.31	20,292.01	5,542.50	350.01	32,184.12
McLean	262.13	305.87	31.75	599.75	1,079.73	1,200.48	379.21	2,660.42	7,927.40	4,433.35	853.49	13,214.24	9,268.26	5,945.70	1,264.45	16,478.41
Mercer	243.01	425.94	649.61	1,323.56	1,741.31	2,050.17	1,621.89	5,413.37	13,738.60	5,653.27	3,747.43	23,139.30	15,727.92	8,165.38	6,018.93	29,712.23
Morton	217.04	338.04	41.92	597.50	1,435.41	1,301.75	276.21	3,013.37	11,156.01	469.35	5.54	11,629.90	12,808.46	2,108.74	333.57	14,250.77
Mountrail	143.12	67.97	79.52	290.61	356.03	368.05	233.57	957.65	13,813.38	310.64	....	14,124.52	14,313.03	746.66	313.09	15,172.78
Oliver	149.09	206.25	52.21	397.55	1,347.43	1,257.16	407.32	3,011.91	11,857.34	2,121.35	450.65	14,429.34	13,343.86	3,584.76	910.18	17,938.80
Renville	3.76	5.29	19.57	27.62	117.04	35.01	....	152.05	603.11	....	....	603.11	723.91	40.30	12.57	782.78
Sheridan	....	....	....	....	....	....	....	....	660.06	....	....	660.06	660.06	....	....	660.06
Slope	72.55	169.68	396.08	638.31	1,176.62	1,827.30	2,600.45	5,604.37	2,223.60	716.96	10,902.36	13,847.92	3,477.77	2,713.94	13,848.89	20,090.60
Stark	104.70	150.94	136.44	392.08	1,078.31	836.39	1,092.72	3,007.42	15,406.49	3,076.94	3,814.77	22,298.20	16,589.50	4,064.27	5,343.93	25,937.70
Ward	76.54	37.43	145.55	259.52	538.50	381.36	340.93	1,260.79	6,091.92	2,305.86	367.96	8,765.74	6,706.96	2,724.65	854.44	10,286.05
Williams	210.30	241.91	63.87	516.08	1,427.31	1,251.64	586.42	3,265.37	17,223.07	4,471.92	1,458.28	23,153.17	18,860.65	5,905.37	2,103.57	26,934.52
State total	3,094.56	3,963.72	2,463.12	9,521.40	20,094.98	18,627.18	11,398.23	50,120.39	224,180.36	36,937.70	30,149.97	291,268.03	247,369.90	59,528.60	44,011.22	350,909.82
hypothetical resources in Unmapped and Unexplored Areas																180,000.00
Total Estimated Resources																530,909.82
Cumulative Production and Losses in Mining to Jan. 1, 1976																339.00
Remaining Resources, Jan. 1, 1976																530,570.82

Source: Brant, 1953

Table 3.7. Method of Recovery of Lignite Reserves of North Dakota, Jan. 1, 1972
(in millions of short tons)

County	Identified Resources (Brant 1953)	Surface Mining			Underground Mining		
		Inferred Resources Plus Measured and Indicated Resources Less than 5' Thick (Subeconomic Resource)	Measured and Indicated Resources 5' Thick and Greater (Demonstrated Resource)	Reserve Base Coal 5' or Thicker Overburden 100' or Less	Recoverable Reserve 90.0% Recov- erability Factor	Reserve Base	Recoverable Reserve 50% Recoverability Factor
Adams	1,857	1,591	266	163	146.7	103	51
Billings	17,718	14,882	2,836 ✓	1,078	970.2	1,758	879
Bowman	7,021	5,885	1,136	785	706.5	351	175
Burke	6,610	6,080	530	117	105.3	413	207
Burleigh	1,157	949	208	156	140.4	52	26
Divide	8,264	7,472	792	137	123.3	655	328
Dunn	71,042	68,050	2,992	2,000	1,800.0	922	496
Golden Valley	8,319	7,029	1,290	278	250.2	1,012	506
Grant	4,658	3,988	670	115	103.5	555	278
Hettinger	12,653	10,806	1,847	980	882.0	867	434
McIntosh	118	78	40	15	13.5	25	13
McKenzie	32,183	28,972	3,211	825	742.5	2,386	1,193
McLean	16,478	14,555	1,923	1,009	908.1	914	457
Mercer	29,913	25,159	4,754	1,986	1,787.4	2,768	1,384
Morton	15,250	13,282	1,968	342	307.8	1,626	813
Montrail	15,378	14,629	749	148	133.2	601	300
Oliver	17,839	15,916	1,923	629	566.1	1,294	647
Renville	783	724	59	8	7.2	51	25
Sheridan	660	660	0	0	0	0	0
Slope	20,091	15,097	4,994	2,236	2,012.4	2,668	1,334
Stark	25,697	23,481	2,216	1,275	1,147.5	941	470
Ward	10,256	9,381	905	501	450.9	404	202
Williams	26,935	24,791	2,144	1,130	1,017.0	1,014	507
Total	350,910	313,457	37,453	16,003	14,402.7	21,450	10,725

Sources: Brant, 1953; and certain data modified from Northern Great Plains Resources Program - Mineral Resources Work Group

The (estimated) surface minable recoverable reserve of 14.4 billion tons approximates the 15 billion of Averitt (1970) and exceeds the 7-10 billion estimate of Ball (1966). Two Bureau of Mines studies (IC 8531, Staff, 1971 and IC 8537, Pollard, Smith, and Knox, 1972) examined selected well-defined, large deposits for their calculation of strippable reserves and, as a result, their reported 2- and 4-billion-ton (respectively) estimates do not reflect a statewide total.

Figure 3.2 shows the location of 28 well-defined coal deposits, each containing a minimum of 5 million tons of strippable reserves, the amount of reserves, and the maximum overburden thickness for each deposit. The largest reserve deposit in the study area, in McLean County, contains an estimated 5 billion tons of reserves. The Center-Stanton deposit in Oliver and Mercer Counties contains an estimated 1.8 billion tons of reserves. A small portion of the Dickinson deposit, the state's largest reserve, is in the southwestern corner of Dunn County, but the largest reserve deposit within Dunn County is the 1.7-billion-ton reserve in the Dunn Center area. Other areas with substantial reserves are Renners Cove and West Renners Cove deposits with a combined total of 935 million tons, and the Beulah (north and south) and Zap area with an aggregate 631-million-ton total.

Table 3.8 from Brant (1953) lists the original lignite reserves by township and range for the four counties of the study area.

C. Present Mining

Over 99% of North Dakota's 1974 production of 7.463 million tons of coal came from eight mines, according to the 1975 Keystone Coal Industry Manual. Three of the mines produced over a million and a half tons, the largest being the Beulah Mine of the Knife River Coal Mining Company with a 1974 tonnage of 1.722 million tons. The mines, their locations and 1974 production are listed in Table 3.9. Figure 3.3 shows the location of the mines and is coded in Table 3.9. Appendix A lists major coal and leonardite mine operations in North Dakota.

The four largest mines are operating within the four-county study area and in 1974 mined almost 83% of the states total coal production. A brief profile of each mine follows.

MAJOR STRIPPABLE DEPOSIT

	Strippable Reserves (million tons)	Maximum Over- burden Thickness (feet)
1-Dickinson	6,000	100
2-McLean	5,000	50E
3-Center-Stanton	1,800	50
4-Bowman-Gascoyne	1,700	120
5-Dunn Center	1,700	50
6-Williston-Avoca	1,500	100
7-Slope	850	100E
8-Morton	800	50E
9-Renners Cove	548	50
10-Hazen	530	50
11-Square Butte	500	100E
12-Beach-Little Beaver	450	120
13-Havelock	400	100E
14-Manning	400	75E
15-West Renners Cove	387	50
16-South Beulah	373	120
17-Washburn	371	50
18-Underwood	314	50E
19-New England- Scheffield	280	100E
20-Bullion Butte	250	120E
21-Slope-Bowman	150	120E
22-Niobe	146	100
23-Zap	140	120
24-North Beulah	118	120
25-New Leipzig	106	100E
26-Wilton	15	50E
27-Noonan-Kincaid	15	50
28-Velva	5	50

E = Estimated

Fig. 3.2. Major Strippable Lignite Deposits in North Dakota

Table 3.8. Original Lignite Reserves by Township and Range - Four-County Study Area

Township	Measured reserves				Indicated reserves				Inferred reserves				Total in all categories			Township Total
	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	
Dunn County																
T.150N., R. 91W.	1.16	....	....	1.16	....	....	....	....	18.11	....	....	18.11	17.86	....	....	17.86
T.150N., R. 92W.	0.82	....	....	0.82	0.06	....	....	0.06	7.57	....	....	7.57	8.45	....	....	8.45
T.150N., R. 93W.	36.18	5.12	....	36.30	28.12	16.93	....	44.06	76.66	0.90	....	77.56	139.96	19.96	....	159.91
T.149N., R. 91W.	44.19	....	....	44.19	184.86	....	....	184.86	413.76	....	....	413.76	642.61	....	....	642.61
T.149N., R. 92W.	104.32	....	....	104.32	162.99	....	....	162.99	450.32	....	....	450.32	717.63	....	....	717.63
T.149N., R. 93W.	28.45	....	....	28.45	171.59	9.54	....	181.13	702.87	115.85	....	818.72	902.61	125.39	....	1,028.00
T.148N., R. 91W.	13.60	....	....	13.60	36.05	....	....	36.05	209.24	....	....	209.24	260.89	....	....	260.89
T.148N., R. 92W.	40.00	5.74	....	45.74	94.07	1.53	....	97.60	730.49	....	....	730.49	846.56	7.27	....	873.83
T.148N., R. 93W.	48.66	0.66	....	49.58	93.19	....	....	93.19	959.93	....	....	959.93	1,101.78	0.66	....	1,102.44
T.148N., R. 94W.	5.82	0.31	....	6.13	110.34	20.65	....	130.99	1,296.81	28.74	....	1,325.55	1,412.67	49.70	....	1,462.37
T.148N., R. 95W.	6.27	7.58	....	13.85	37.09	27.40	....	64.49	1,064.55	0.29	....	1,064.84	1,107.69	35.27	....	1,143.16
T.148N., R. 96W.	0.22	....	....	0.22	7.10	....	....	7.10	989.47	....	....	989.47	996.79	....	....	996.79
T.148N., R. 97W.	....	....	....	....	....	....	....	....	1,058.30	....	....	1,058.30	1,068.30	....	....	1,052.30
T.147N., R. 91W.	25.51	....	....	25.51	209.69	....	....	209.69	790.30	....	....	790.30	1,023.60	....	....	1,023.60
T.147N., R. 92W.	107.93	5.80	....	113.73	192.76	21.72	....	214.48	494.44	6.40	....	500.84	795.13	33.92	....	829.05
T.147N., R. 93W.	103.06	15.95	....	119.01	266.86	13.18	....	280.04	589.87	11.98	....	601.85	961.19	41.11	....	1,002.30
T.147N., R. 94W.	29.39	23.66	35.81	88.66	92.74	146.48	30.62	269.84	656.65	80.34	....	736.99	778.78	250.47	66.43	1,006.65
T.147N., R. 95W.	2.61	3.93	46.62	53.16	....	58.60	99.77	158.27	1,067.75	150.89	4.66	1,223.33	1,070.39	213.92	151.06	1,434.76
T.147N., R. 96W.	1.78	4.42	....	6.20	22.56	21.80	....	43.56	1,508.34	16.66	....	1,525.00	1,532.68	42.48	....	1,578.16
T.147N., R. 97W.	10.89	47.53	....	58.42	77.26	68.79	....	146.06	1,244.85	....	....	1,244.86	1,538.00	116.32	....	1,449.38
T.146N., R. 91W.	1.96	0.42	....	2.38	37.69	18.40	....	56.09	1,153.48	....	....	1,153.48	1,193.15	18.82	....	1,211.96
T.146N., R. 92W.	54.43	34.86	....	89.31	112.50	135.12	....	247.62	1,017.56	94.40	....	1,111.96	1,184.49	264.40	....	1,446.89
T.146N., R. 93W.	2.08	....	....	2.08	48.48	32.08	....	81.16	1,221.71	241.27	47.40	1,510.36	1,272.27	273.96	47.40	1,593.82
T.146N., R. 94W.	3.09	5.21	1.32	10.02	40.32	73.42	29.30	143.04	1,165.87	66.36	5.25	1,235.40	1,208.68	165.41	35.87	1,407.96
T.146N., R. 95W.	....	....	....	....	....	5.41	....	5.41	1,591.50	173.38	....	1,764.88	1,591.50	176.79	....	1,770.29
T.146N., R. 96W.	....	....	....	....	....	....	....	....	1,745.84	....	....	1,745.84	1,745.84	....	....	1,745.84
T.146N., R. 97W.	0.62	....	....	0.62	14.35	....	....	14.35	1,329.06	....	....	1,329.06	1,344.03	....	....	1,344.03
T.145N., R. 91W.	0.82	1.88	....	2.68	2.89	40.35	0.77	44.01	945.36	81.56	....	1,026.92	948.87	123.77	0.77	1,075.41
T.145N., R. 92W.	....	3.56	....	3.56	10.07	48.99	3.04	62.10	1,002.24	138.47	51.49	1,192.20	1,012.31	191.02	54.55	1,257.86
T.145N., R. 93W.	....	....	33.13	33.13	0.27	....	293.50	293.77	1,044.55	0.80	225.09	1,270.44	1,044.88	0.80	551.72	1,897.34
T.145N., R. 94W.	....	....	1.45	1.45	6.86	....	39.21	46.07	1,122.07	197.88	190.32	1,510.27	1,128.93	197.88	230.96	1,587.79
T.145N., R. 95W.	....	....	....	....	....	....	....	....	1,599.96	92.01	1.43	1,693.40	1,599.96	92.01	1.43	1,693.40
T.145N., R. 96W.	....	....	....	....	....	....	....	....	1,736.71	....	....	1,736.71	1,736.71	....	....	1,736.71
T.145N., R. 97W.	....	....	....	....	....	....	....	....	1,311.26	....	....	1,311.26	1,311.26	....	....	1,311.26
T.144N., R. 91W.	....	7.56	....	7.56	36.17	66.06	....	102.23	954.96	25.55	....	980.51	991.13	99.17	....	1,090.30
T.144N., R. 92W.	1.61	3.64	....	5.25	20.46	49.19	....	69.65	1,081.18	109.09	....	1,190.27	1,103.25	161.92	....	1,265.17
T.144N., R. 93W.	3.10	3.97	....	7.07	39.45	27.86	114.74	181.45	1,135.93	132.94	16.98	1,285.85	1,178.48	164.17	131.72	1,474.57
T.144N., R. 94W.	....	....	....	....	....	....	14.23	14.23	1,261.66	191.48	31.92	1,415.06	1,261.66	121.48	46.15	1,429.29
T.144N., R. 95W.	1.44	....	4.15	5.59	8.45	30.65	48.69	87.79	1,265.70	193.25	28.98	1,487.93	1,275.59	223.90	81.82	1,581.31
T.144N., R. 96W.	0.24	....	....	0.24	34.22	0.15	....	34.37	1,562.16	65.38	....	1,627.54	1,562.16	65.38	....	1,627.54
T.144N., R. 97W.	....	....	....	....	6.57	....	....	6.57	1,380.55	....	....	1,380.56	1,387.12	....	....	1,387.12
T.143N., R. 91W.	....	....	1.71	1.71	6.09	9.07	1.35	16.51	1,075.64	45.18	....	1,120.79	1,061.73	54.22	3.06	1,139.01
T.143N., R. 92W.	....	7.56	1.58	9.14	21.83	82.86	8.49	113.17	1,041.99	61.07	1.75	1,104.81	1,063.82	151.48	11.82	1,227.12
T.143N., R. 93W.	2.12	0.44	4.02	6.58	47.43	79.07	49.22	175.72	997.20	71.45	6.10	1,074.73	1,046.75	150.96	59.34	1,257.05
T.143N., R. 94W.	9.53	....	....	9.53	58.99	0.13	....	59.12	1,113.58	....	....	1,113.58	1,128.10	0.13	....	1,128.23
T.143N., R. 95W.	2.79	....	....	2.79	9.46	....	....	9.98	1,180.88	....	....	1,180.88	1,193.65	....	....	1,193.65
T.143N., R. 96W.	5.10	2.07	6.08	13.25	57.90	19.87	36.69	114.46	1,283.13	28.15	4.25	1,315.53	1,346.13	50.09	47.02	1,432.24
T.143N., R. 97W.	22.42	1.64	4.19	28.25	192.27	20.74	22.18	235.19	1,519.85	37.91	1.29	1,559.05	1,534.54	60.29	27.66	1,622.49

Table 3.8 (Cont'd)

Township	Measured reserves				Indicated reserves				Inferred reserves				Total in all categories			Township Total
	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	
Dunn County (Cont'd)																
T.142N., R. 91W.	8.43	....	0.59	9.02	31.43	22.58	1.05	55.06	523.43	14.07	....	537.50	523.29	36.65	1.64	601.58
T.142N., R. 92W.	11.83	5.58	5.12	20.53	84.82	17.11	4.30	106.23	618.81	113.84	....	732.65	715.46	134.53	9.42	859.41
T.142N., R. 93W.	4.29	5.96	....	10.25	86.37	54.43	1.24	142.04	721.61	19.79	....	741.40	812.27	80.18	1.24	893.69
T.142N., R. 94W.	7.42	3.96	....	11.38	77.06	13.41	....	90.47	1,063.11	....	....	1,063.11	1,147.59	17.37	....	1,164.96
T.142N., R. 95W.	....	....	....	....	20.59	....	....	20.59	1,416.22	....	....	1,416.22	1,436.81	....	....	1,436.81
T.142N., R. 96W.	3.18	10.93	....	14.11	31.74	17.90	....	49.64	1,245.99	0.65	....	1,246.64	1,280.91	29.48	....	1,310.39
T.142N., R. 97W.	2.92	10.03	....	12.95	53.49	11.97	....	65.46	971.48	....	....	971.48	1,027.89	22.00	....	1,049.89
T.141N., R. 91W.	0.76	4.53	....	5.28	24.93	5.90	....	30.83	382.25	....	....	382.25	407.93	10.43	....	418.36
T.141N., R. 92W.	1.32	0.50	....	1.82	22.11	23.25	....	45.36	680.44	43.91	....	724.35	703.87	67.66	....	771.55
T.141N., R. 93W.	1.54	11.34	....	12.88	36.06	100.31	....	136.37	623.46	43.58	....	667.03	681.05	155.23	....	816.28
T.141N., R. 94W.	3.33	14.85	....	18.18	68.46	29.47	....	97.93	1,083.65	18.18	....	1,101.83	1,156.44	62.50	....	1,217.94
T.141N., R. 95W.	8.26	1.31	....	9.57	92.72	25.43	....	118.15	872.59	167.27	....	1,039.86	973.57	194.01	....	1,267.58
T.141N., R. 96W.	....	....	17.64	17.54	13.94	10.49	62.60	87.03	473.29	402.60	30.45	906.34	487.23	413.09	110.59	1,010.91
T.141N., R. 97W.	....	44.69	31.62	76.31	4.34	97.94	57.97	180.25	361.43	143.97	....	505.40	365.77	286.80	89.59	741.96
County total	772.27	303.78	194.93	1,270.98	3,264.43	1,574.62	918.96	5,747.91	60,000.32	3,377.68	645.36	64,083.36	64,087.02	5,255.98	1,759.25	71,042.25

McLean County

T.150N., R. 78W.	1.19	....	....	1.19	6.02	....	....	6.02	7.15	....	....	7.15	14.36	....	....	14.36	
T.150N., R. 79W.	10.77	....	....	10.77	40.68	....	....	40.58	79.47	....	....	79.47	150.88	....	....	150.88	
T.150N., R. 80W.	....	....	....	....	3.64	....	....	3.64	163.56	23.51	....	187.07	167.20	23.51	....	190.71	
T.150N., R. 81W.	....	....	....	....	....	....	....	....	148.44	54.77	....	203.21	148.44	54.77	....	203.21	
T.150N., R. 82W.	....	....	....	....	....	1.26	....	1.26	160.08	18.76	....	178.84	160.08	20.02	....	180.10	
T.150N., R. 83W.	....	6.67	....	6.67	....	96.78	....	96.76	129.72	197.71	....	327.43	129.72	301.14	....	430.84	
T.150N., R. 84W.	....	....	....	....	....	....	....	....	129.99	200.36	124.93	450.28	124.99	200.36	124.93	450.28	
T.150N., R. 85W.	....	....	....	....	....	....	....	....	116.93	59.16	180.47	356.56	116.93	123.64	265.38	506.95	
T.150N., R. 86W.	....	6.16	....	6.16	....	58.32	....	58.32	143.23	96.31	109.37	398.27	112.90	109.37	281.94	504.11	
T.150N., R. 87W.	....	....	9.53	9.53	....	....	....	....	53.21	276.65	....	329.86	53.21	286.78	....	339.99	
T.150N., R. 88W.	....	....	....	....	....	10.13	....	....	283.00	13.83	....	296.83	283.00	13.83	....	296.83	
T.150N., R. 89W.	....	....	....	....	....	....	....	....	145.72	....	....	145.72	145.72	....	....	145.72	
T.150N., R. 90W.	2.42	....	....	2.42	21.85	....	....	21.85	76.71	....	....	76.71	100.96	....	....	100.96	
T.150N., R. 91W.	5.68	....	....	5.68	0.63	....	....	0.63	....	....	....	....	6.21	....	....	6.21	
T.149N., R. 79W.	....	....	....	....	....	....	....	....	112.90	....	....	112.90	112.90	....	....	112.90	
T.149N., R. 80W.	....	....	....	....	....	....	....	....	120.96	....	....	120.96	120.96	....	....	120.96	
T.149N., R. 81W.	....	....	....	....	....	....	....	....	141.12	....	....	141.12	141.12	....	....	141.12	
T.149N., R. 82W.	....	....	....	....	....	....	....	....	167.21	....	....	167.21	167.21	....	....	167.21	
T.149N., R. 83W.	....	....	....	....	....	....	....	....	407.57	....	....	407.57	407.57	....	....	407.57	
T.149N., R. 84W.	....	....	....	....	4.36	....	....	4.36	135.47	213.36	128.72	477.65	139.83	213.36	128.72	481.91	
T.149N., R. 85W.	5.23	....	19.80	25.03	33.46	....	173.54	207.00	103.30	64.48	137.89	306.87	141.99	64.48	331.25	537.70	
T.149N., R. 86W.	....	....	....	....	....	....	2.23	2.23	120.96	223.05	104.84	448.85	120.96	223.05	107.07	481.06	
T.149N., R. 87W.	....	19.24	....	19.24	....	153.43	....	153.43	120.96	130.38	....	251.34	120.96	303.08	....	484.01	
T.149N., R. 88W.	....	....	....	....	....	6.92	....	6.92	253.38	56.98	....	310.34	253.38	56.98	....	317.85	
T.149N., R. 89W.	....	....	....	....	....	....	....	....	176.74	....	....	176.74	176.74	....	....	176.74	
T.149N., R. 90W.	4.50	2.13	....	6.63	9.64	....	....	9.64	38.60	....	....	38.60	52.74	9.13	....	54.87	
T.148N., R. 79W.	....	....	....	....	....	....	....	....	132.20	....	....	132.20	132.20	....	....	132.20	
T.148N., R. 80W.	....	....	....	....	....	....	....	....	206.55	....	....	206.55	206.55	....	....	206.55	
T.148N., R. 81W.	....	....	....	....	....	....	....	....	185.33	....	....	185.33	185.33	....	....	185.33	
T.148N., R. 82W.	....	....	....	....	....	....	....	....	138.01	....	....	138.01	138.01	....	....	138.01	
T.148N., R. 83W.	12.11	13.45	....	25.56	50.26	2.05	....	52.31	55.81	1.75	....	57.56	118.34	17.25	....	135.59	
T.148N., R. 84W.	18.91	29.41	....	48.32	16.95	5.45	....	22.40	78.54	....	....	78.54	114.40	34.86	....	149.26	
T.148N., R. 85W.	24.32	18.31	....	42.63	73.57	5.80	....	79.37	80.53	64.79	....	85.22	119.42	88.90	....	207.32	
T.148N., R. 86W.	29.69	3.87	....	33.56	49.78	0.83	....	50.61	37.63	94.06	....	131.69	117.10	96.76	....	215.86	
T.148N., R. 87W.	23.51	1.09	....	24.60	107.73	....	....	107.73	47.93	70.02	....	117.95	179.17	71.11	....	250.28	
T.148N., R. 88W.	....	....	....	....	30.83	....	....	30.83	246.93	14.92	....	281.85	277.78	14.92	....	292.68	
T.148N., R. 89W.	2.24	16.29	....	19.13	40.15	26.33	....	66.48	197.32	....	....	197.32	239.71	43.22	....	282.93	
T.148N., R. 90W.	1.09	....	....	1.09	8.66	....	....	8.66	32.99	....	....	32.99	42.74	....	....	42.74	
T.148N., R. 91W.	0.94	....	....	0.94	....	....	....	....	....	....	....	....	0.94	....	....	0.94	

Table 3.8 (Cont'd)

Township	Measured reserves				Indicated reserves				Inferred reserves				Total in all categories				Township Total
	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick		
McLean County (Cont'd)																	
T.147N., R. 79W.	....	....	....	....	....	....	....	....	142.52	....	....	142.52	142.52	....	....	142.52	
T.147N., R. 80W.	....	....	....	....	....	....	....	....	210.16	....	....	210.16	210.16	....	....	210.16	
T.147N., R. 81W.	....	....	....	....	0.82	....	....	0.82	253.19	....	....	253.19	254.01	....	....	254.01	
T.147N., R. 82W.	....	....	....	....	2.36	....	....	2.36	302.74	....	....	302.74	305.10	....	....	305.10	
T.147N., R. 83W.	19.30	5.18	....	24.48	53.71	6.90	....	60.61	233.00	7.53	....	240.53	306.01	19.61	....	325.62	
T.147N., R. 84W.	11.49	20.80	....	32.29	39.25	25.17	....	64.42	36.38	4.96	....	41.36	97.12	50.95	....	138.07	
T.147N., R. 85W.	2.83	....	....	2.83	....	....	....	....	....	....	....	....	2.83	....	....	2.83	
T.147N., R. 86W.	17.66	11.18	....	28.84	38.28	56.40	....	94.68	....	....	....	....	55.94	67.58	....	123.52	
T.147N., R. 87W.	20.32	3.57	....	23.89	58.31	28.88	....	87.19	9.66	....	....	9.66	88.29	32.45	....	120.74	
T.147N., R. 88W.	15.30	2.56	....	18.16	43.74	5.06	....	48.80	76.67	....	....	76.67	136.01	7.62	....	143.63	
T.147N., R. 89W.	7.22	19.90	....	27.12	26.39	4.95	....	31.37	7.55	....	....	7.55	41.16	24.88	....	66.04	
T.147N., R. 90W.	0.54	....	....	0.54	....	....	....	....	....	....	....	....	0.54	....	....	0.54	
T.148N., R. 79W.	....	....	....	....	....	....	....	....	140.14	1.52	....	141.66	140.14	1.52	....	141.66	
T.148N., R. 80W.	....	....	....	....	26.77	....	....	26.77	83.14	113.89	....	197.03	83.14	140.66	....	223.80	
T.148N., R. 81W.	0.97	13.91	....	14.88	23.58	72.54	....	96.12	108.72	35.19	....	143.91	133.27	121.64	....	254.91	
T.148N., R. 82W.	3.98	3.71	....	7.60	50.40	37.23	....	87.63	263.10	14.35	....	277.43	317.48	55.27	....	372.75	
T.148N., R. 83W.	....	....	....	....	0.90	....	....	0.90	308.42	102.42	....	410.84	309.32	102.42	....	411.74	
T.148N., R. 84W.	5.15	11.29	....	16.44	126.30	47.38	....	173.68	21.07	120.42	....	141.49	152.52	179.09	....	331.61	
T.148N., R. 79W.	....	....	....	....	....	....	....	....	86.30	93.82	....	180.12	86.30	93.82	....	180.12	
T.148N., R. 80W.	....	....	....	....	....	....	....	....	....	96.60	....	96.60	....	96.60	....	96.60	
T.148N., R. 81W.	....	2.85	....	2.85	....	44.19	....	44.19	36.45	357.96	....	394.41	36.45	425.00	....	441.42	
T.148N., R. 82W.	....	2.45	....	2.45	7.33	59.43	....	66.76	125.91	244.76	....	370.67	133.24	306.64	....	439.36	
T.148N., R. 83W.	4.21	10.73	....	14.94	45.80	106.59	....	154.39	220.02	121.12	....	341.14	270.03	240.44	....	520.47	
T.148N., R. 84W.	0.12	8.02	....	8.14	19.98	67.59	....	87.57	244.52	118.99	....	363.51	264.62	194.85	....	459.22	
T.148N., R. 85W.	3.33	6.61	....	9.94	12.66	31.50	....	44.06	5.45	48.47	....	53.92	21.34	55.58	....	106.92	
T.148N., R. 80W.	....	....	....	....	....	....	....	....	....	465.47	....	465.47	....	465.47	....	465.47	
T.148N., R. 81W.	....	3.50	....	3.50	....	23.58	....	23.58	....	115.38	....	115.38	....	142.46	....	142.46	
T.148N., R. 82W.	3.87	20.34	....	24.21	20.51	26.24	....	46.75	4.79	51.97	....	56.76	29.17	98.55	....	127.72	
T.148N., R. 83W.	2.80	....	....	2.80	19.28	10.40	....	45.65	89.52	....	....	89.52	102.60	54.53	....	157.33	
T.148N., R. 84W.	....	8.58	....	8.58	....	31.21	....	31.21	37.16	2.81	....	39.97	37.16	42.70	....	79.86	
T.148N., R. 80W.	....	6.07	2.42	8.49	....	48.29	22.32	70.61	....	368.31	0.64	368.96	....	422.57	26.28	447.95	
T.148N., R. 81W.	....	9.02	....	9.02	....	52.02	....	52.02	....	59.42	....	59.42	....	120.46	....	120.46	
County total	262.13	305.87	31.75	599.75	1,078.73	1,205.49	379.21	2,664.42	7,927.40	4,433.36	833.49	13,214.24	9,288.26	5,943.70	1,264.45	16,478.41	

Mercer County

T.147E., R. 84W.	....	3.90	....	3.90	2.49	61.58	....	64.27	2.39	15.29	....	17.48	4.88	90.77	....	....	85.55
T.147E., R. 85W.	28.99	3.76	....	30.55	23.23	48.37	1.04	69.94	24.06	17.03	185.41	236.50	76.18	63.36	186.43	326.94	
T.147E., R. 86W.	4.14	26.48	....	30.62	0.87	13.77	....	14.54	4.23	....	140.30	144.53	9.94	40.85	140.30	139.79	
T.147E., R. 87W.	....	10.55	....	10.55	....	5.48	....	5.48	....	....	74.51	74.51	....	17.13	74.51	91.64	
T.147E., R. 88W.	0.04	3.11	....	3.15	0.59	....	....	0.59	2.76	12.38	50.54	65.58	3.38	15.49	50.54	59.41	
T.147E., R. 89W.	5.27	50.77	....	56.04	48.90	46.61	....	95.51	44.54	155.94	....	200.38	98.71	233.92	....	331.93	
T.147E., R. 90W.	10.21	....	....	14.61	97.25	4.00	....	101.23	411.98	48.21	....	460.13	526.78	52.21	....	577.99	
T.148E., R. 84W.	3.28	2.07	....	5.35	2.35	4.34	....	6.69	....	....	....	....	5.63	6.41	....	12.04	
T.148E., R. 85W.	10.48	10.15	....	20.63	68.94	198.60	....	261.44	100.31	434.75	232.60	787.66	179.65	657.80	232.60	1,049.73	
T.148E., R. 86W.	....	5.46	6.05	10.51	07.40	54.78	....	122.18	393.80	184.24	524.16	1,108.20	461.20	244.48	529.21	1,234.89	
T.148E., R. 87W.	2.28	25.01	12.87	39.96	10.74	92.97	341.22	458.83	193.32	943.92	457.57	804.81	214.34	361.80	811.48	1,387.60	
T.148E., R. 88W.	7.74	16.98	33.58	57.60	54.60	35.14	137.81	297.55	289.29	114.60	485.19	888.98	321.63	185.82	656.68	1,144.13	
T.148E., R. 89W.	4.82	7.72	....	12.54	43.37	86.45	....	129.88	559.73	383.55	....	942.28	607.92	476.78	....	1,084.64	
T.148E., R. 90W.	....	....	....	....	7.17	....	....	7.17	1,000.55	63.68	....	1,154.23	1,097.72	63.68	....	1,161.40	
T.148E., R. 84W.	0.32	0.56	....	0.87	32.01	2.94	....	34.95	3.52	5.98	....	9.60	35.95	9.47	....	48.42	
T.148E., R. 85W.	16.34	8.94	....	25.18	88.22	104.09	....	192.31	68.84	243.01	9.45	321.30	173.40	355.94	9.45	638.79	
T.148E., R. 86W.	6.24	13.25	3.56	23.05	65.43	141.86	....	247.98	149.93	435.77	326.60	918.30	221.60	590.28	371.35	1,183.23	
T.148E., R. 87W.	....	....	111.72	111.72	....	....	269.82	269.82	257.47	256.82	503.46	1,017.75	257.47	256.82	884.80	1,399.09	
T.148E., R. 88W.	....	5.32	23.27	28.59	....	71.06	142.12	213.16	376.06	326.85	356.29	1,095.23	376.06	439.23	521.68	1,337.00	
T.148E., R. 89W.	....	1.71	....	1.71	8.43	54.42	....	62.85	758.12	486.06	....	1,244.18	766.55	542.19	....	1,308.74	
T.148E., R. 90W.	4.48	2.98	....	7.46	21.10	26.96	....	48.06	860.71	99.26	....	959.97	886.29	129.20	....	1,015.49	

Table 3.8 (Cont'd)

Township	Measured reserves				Indicated reserves				Inferred reserves				Total in all categories			Township Total
	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2 1/2 to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	
Mercer County (Cont'd)																
T.144N., R. 84W.	....	3.53	3.31	6.84	0.50	17.10	20.14	37.84	139.20	....	....	139.20	139.20	20.63	23.45	183.86
T.144N., R. 85W.	....	10.36	14.65	25.01	1.51	134.59	36.63	172.73	269.89	99.80	....	369.69	271.40	244.75	51.28	567.43
T.144N., R. 86W.	0.51	25.22	....	25.73	0.68	126.16	....	126.84	67.61	258.11	....	325.72	66.80	409.49	....	478.29
T.144N., R. 87W.	....	24.85	53.01	77.86	4.56	112.43	10.71	127.70	100.46	364.20	....	464.66	105.08	501.58	53.72	670.32
T.144N., R. 88W.	3.48	4.06	222.83	300.37	25.70	48.24	31.48	105.42	176.75	584.07	....	710.82	205.93	596.37	284.31	1,116.61
T.144N., R. 89W.	1.16	44.36	7.96	53.47	45.96	60.56	7.07	113.59	349.18	381.89	....	671.07	396.30	426.81	15.08	866.13
T.144N., R. 90W.	....	38.81	1.17	39.98	5.72	228.55	2.44	236.71	611.65	81.35	....	693.00	617.37	348.71	3.61	966.69
T.143N., R. 88W.	8.93	1.72	51.55	62.20	62.77	16.43	243.18	322.38	362.43	296.96	101.96	761.37	434.13	315.11	396.71	1,145.96
T.143N., R. 89W.	3.42	35.34	0.92	39.68	32.49	45.64	72.65	150.78	612.32	1.60	....	614.42	648.73	82.58	73.57	804.88
T.143N., R. 90W.	19.15	0.25	4.90	24.20	130.90	30.62	15.92	177.44	792.01	31.03	....	823.04	942.06	61.90	20.72	1,024.68
T.142N., R. 88W.	14.20	3.87	19.25	37.32	124.68	10.66	130.74	266.08	760.33	64.90	228.19	1,053.42	699.21	79.43	378.18	1,356.82
T.142N., R. 89W.	11.96	18.65	....	30.51	160.11	85.84	90.94	336.89	712.48	11.33	71.18	794.99	884.45	115.82	162.12	1,162.39
T.142N., R. 90W.	34.17	....	....	34.17	102.80	....	....	102.80	624.52	....	....	624.52	761.49	....	....	761.49
T.141N., R. 88W.	10.79	30.38	10.32	51.49	134.10	67.60	26.99	228.69	1,117.80	55.80	....	1,173.60	1,262.69	153.78	37.31	1,453.78
T.141N., R. 89W.	16.05	6.43	....	22.48	174.14	29.83	....	203.97	711.02	0.09	....	711.11	901.21	36.35	....	937.56
T.141N., R. 90W.	15.36	....	....	15.36	81.61	....	....	81.61	768.77	....	....	768.77	865.74	....	....	865.74
County total	248.01	425.94	649.61	1,323.56	1,741.31	2,056.17	1,821.89	5,419.37	13,738.60	5,683.27	3,747.43	23,169.30	15,727.92	8,165.38	6,018.93	29,912.23
Oliver County																
T.144N., R. 81W.	....	....	....	....	....	....	....	....	0.06	....	....	0.06	0.06	....	....	0.06
T.144N., R. 82W.	....	....	....	....	1.83	....	....	1.83	56.10	23.90	0.25	60.25	57.93	23.90	0.25	82.08
T.144N., R. 83W.	....	....	....	....	5.22	....	....	5.22	16.10	....	4.39	20.49	21.32	....	4.39	25.71
T.143N., R. 81W.	....	....	....	....	2.28	....	....	2.28	8.44	....	....	8.44	10.72	....	....	10.72
T.143N., R. 82W.	0.09	5.79	....	5.88	29.53	8.10	49.07	84.80	222.89	122.63	121.68	467.14	252.61	134.52	170.69	567.82
T.143N., R. 83W.	2.75	6.44	19.57	28.76	34.99	60.83	139.25	235.07	222.00	94.72	110.50	487.82	259.74	161.99	269.32	691.06
T.143N., R. 84W.	10.29	36.04	....	46.33	73.81	149.73	....	223.54	501.63	18.24	....	519.77	585.63	904.01	....	789.64
T.143N., R. 85W.	4.41	6.26	....	10.67	26.93	52.49	....	79.42	1,101.46	115.63	....	1,216.99	1,132.80	174.28	....	1,307.08
T.143N., R. 86W.	14.04	17.52	....	31.66	106.54	105.98	....	214.49	470.21	456.75	....	926.96	592.79	580.32	....	1,173.11
T.143N., R. 87W.	15.78	6.91	....	20.69	81.43	140.96	11.97	234.36	241.35	361.20	30.35	632.90	336.56	609.07	42.32	887.95
T.142N., R. 81W.	1.70	0.82	....	2.52	13.56	12.66	....	26.22	35.75	....	....	35.75	51.61	13.48	....	64.49
T.142N., R. 82W.	2.03	6.33	....	8.36	48.01	63.16	....	111.17	356.89	230.88	....	587.47	406.65	300.37	....	707.00
T.142N., R. 83W.	7.35	14.87	6.41	28.63	63.06	55.66	55.09	173.81	456.51	253.90	54.96	765.39	525.92	324.43	118.49	967.83
T.142N., R. 84W.	2.07	24.81	....	26.88	15.37	265.31	15.14	295.82	566.76	148.55	19.50	734.81	584.20	436.67	34.64	1,067.51
T.142N., R. 85W.	7.79	7.22	2.43	17.44	93.36	62.58	27.80	183.76	1,132.96	119.58	29.86	1,282.40	1,234.13	189.36	60.09	1,483.60
T.142N., R. 86W.	21.73	10.45	....	32.18	213.21	26.37	....	239.58	774.73	58.30	....	827.03	1,009.67	89.12	....	1,098.79
T.142N., R. 87W.	22.72	....	....	22.72	206.42	....	....	206.42	972.30	41.74	....	1,014.04	1,201.44	41.74	....	1,243.18
T.141N., R. 81W.	....	....	....	....	....	....	....	....	199.73	....	....	199.73	199.73	....	....	199.73
T.141N., R. 82W.	....	....	....	....	0.28	....	....	0.28	223.96	14.24	....	238.20	224.24	14.24	....	238.48
T.141N., R. 83W.	9.62	2.99	....	12.61	40.97	27.98	....	68.95	401.56	....	....	401.56	458.15	30.97	....	483.12
T.141N., R. 84W.	3.08	21.81	9.52	34.41	45.60	76.95	18.92	141.47	652.43	....	....	652.43	701.11	96.76	28.44	888.31
T.141N., R. 85W.	3.70	....	7.26	10.96	42.14	34.98	37.79	134.91	997.80	65.98	79.20	1,142.38	1,043.04	100.96	144.25	1,288.25
T.141N., R. 86W.	5.85	30.54	7.02	43.41	92.54	101.30	32.29	226.13	1,013.33	1.21	....	1,014.54	1,111.72	133.05	39.31	1,284.08
T.141N., R. 87W.	6.09	7.35	....	13.44	108.23	14.15	....	122.38	1,253.39	....	....	1,253.39	1,867.71	21.60	....	1,399.21
County total	139.09	206.26	52.21	397.55	1,347.43	1,287.16	407.32	3,011.91	11,867.34	2,121.35	450.65	14,429.34	13,843.86	3,584.76	910.18	17,838.80

Source: Brant 1953

Fig. 3.3. Location of North Dakota's Eight Largest Mines

Table 3.9. 1974 Coal Production: North Dakota's
Eight Largest Surface Mines

Mine Name	Company Name	County	1974 Production	Code
Beulah	Knife River Coal Mining Co.	Mercer	1,722,079	A
Center	Baukol Noonan Inc.	Oliver	1,595,378	B
Glenharold	Consolidation Coal Co.	Mercer	1,548,462	C
Indian Head	North American Coal Corp.	Mercer	1,270,254	D
Velva	Consolidation Coal Co.	Ward	548,012	E
Noonan	Baukol Noonan Inc.	Burke	345,708	F
Gascoyne	Knife River Coal Mining Co.	Bowman	223,039	G
Mine No. 2	Husky Industries	Stark	159,733	H
Total			7,412,665	

1. Beulah Mine, Mercer County

The Beulah Mine is owned and operated by the Knife River Coal Mining Company, a wholly-owned subsidiary of the Montana-Dakota Utilities Company; Knife River also operates the Gascoyne Mine in Bowman County, North Dakota, and the Savage Mine in Montana under a similar subsidiary arrangement. The 1974 tonnage was slightly lower than the 1,726,000 tons produced the previous year. All the lignite is used to generate electric power. Part of the production goes to Montana-Dakota Utilities "Old Beulah" plant; the remainder (and larger portion) goes to Mandan, North Dakota, for the MDU Heskett plant and to Crookston and Fergus Falls, Minnesota, for the Crookston and Hoot Lake plants (respectively) of the Ottertail Power Company. The lignite is shipped daily by 55-car unit trains on the Burlington Northern Railroad. Lignite averaging 27' in total thickness is mined from three seams of the Schoolhouse bed of the Sentinel Butte Formation.

The life expectancy of the mine is 50 years, with a 1974 daily capacity of 10,000 tons from two shifts. Equipment as of 1974 includes two Bucyrus-Erie draglines (Models 500W and 480W), 4 loading shovels, 4 bulldozers, 4 front end loaders, and 9 haulage trucks, including three 20-35-ton and six 75-ton trucks. The lignite is crushed and screened at an onsite tippie. Employment includes 60 at the mine, and 9 at the tippie. (Under permit are 838 acres; all active.)

2. Center Mine, Oliver County

The Center Mine is owned and operated by Baukol Noonan Incorporated of Minot, North Dakota, which also owns and operates the Noonan Mine in Burke County, North Dakota. The 1974 production is a slight increase over the 1,563,446 tons produced in 1973. The lignite is shipped by truck to the mine-mouth Milton Young plant of Minnkota Power Cooperative, Incorporated, at Center. Lignite averaging 11' in thickness is mined from the Hagel bed of the Tongue River Formation. The life expectancy of the mine is 50 years, with a 1974 daily capacity of 3,200 tons from three shifts. Equipment in use (1974) includes a 21-yd Page dragline, a 10-yd loading shovel, 3 bulldozers, a 14-yd front end loader, and four 120-yd haulage trucks. Thirty-seven people are employed at the mine. (Under permit are 882 acres; 375 are active, 507 inactive.)

3. Glenharold Mine, Mercer County

The Glenharold Mine is owned and operated by the Consolidation Coal Company, Western Division, which also operates the Velva Mine in Ward County, North Dakota. The 1974 production increased almost 20% over the 1973 total of 1,292,921 tons. The mined lignite is shipped to the Leland Olds power plant of the Basin Electric Power Cooperative, 3 miles from the mine. Eight feet of lignite is mined from the Stanton bed of the Tongue River Formation.

The life expectancy of the mine is 35 years, with a 1974 daily capacity of 12,000 tons from two shifts. Equipment in 1974 consisted of 2 draglines (32-yd, 120 B Bucyrus-Erie and 76,260-cu-yd Page), 2 loading shovels (190 B Bucyrus-Erie and 181 M Marion), 6 bulldozers, 3 front end loaders, and 5 each of 40- and 80-ton haulage trucks. The lignite is crushed and screened at a mechanical cleaning plant. Eighty-eight people are employed at the mine, and three at the cleaning plant. (Under permit are 1318 acres; all active.)

4. Indian Head Mine, Mercer County

The Indian Head Mine is owned and operated by the North American Coal Corporation. The 1974 production increased 16-1/2% over the 1974 production of 1,090,144 tons. Most of the lignite is shipped to the Stanton plant of the United Power Association via unit trains on the Burlington Northern Railroad. The mine also supplies some state institutions and industries with lignite. The lignite averages from 10-12 ft thick and is mined from the Zap bed of the Sentinel Butte Formation. The life expectancy of the mine is 100 years, with

a 1974 daily capacity of 8,000 tons from two shifts. Equipment includes 2 draglines (28- and 100-yard), 2 loading shovels, 3 bulldozers and 6 tractor trailers (four 60-ton and two 120-ton). Forty-three people are employed at the mine. The lignite is crushed and screened at an onsite tipple. (Under permit are 1065 acres; all active.)

D. Future Mining Plans

Future mining plans for the four counties are outlined below.

1. Dunn County

The Natural Gas Pipeline Company of America, a subsidiary of Peoples Gas Company, Chicago, Illinois, has proposed the construction and operation of four mine-mouth coal gasification plants near Dunn Center. In 1973 approximately 110,250 acres were leased for lignite development rights from the Nakota Company of Bismarck. Interspersed among the leases mentioned above are federal coal reserve areas for which the company in 1974 applied for competitive bid leasing. Estimated reserves on the leased acreage amount to 2.1 billion tons at depths from 30 to 200 feet. The first plant is optimistically scheduled for the early to mid-1980s and will require 10.5 million tons of coal annually. The remaining plants are scheduled to come on-line at three to five year intervals, with all four completed by the year 2000. The lignite has a thickness ranging from 11-24 ft with a stripping ratio average of 6 to 1. The average annual mine production will be 12.9 million tons for the first plant and will increase as necessary as the remaining plants are completed.

El Paso Natural Gas Company has tentative plans for four gasification plants in North Dakota, and, as El Paso has extensive coal rights in Dunn County, one or more of the plants could be located there. Production would probably exceed 12 million tons annually per plant. The first plant is expected to go on-line in the mid to late 1980s.

Others with interests in Dunn County for either coal production, leasing, or land speculation include: the American Natural Gas Company and its subsidiary, the Michigan Wisconsin Pipeline Company of Detroit, Michigan; APCO, a subsidiary of the Atlantic Richfield Oil Company; W. H. Hunt Trustees (Hunt is the brother of the late H. L. Hunt of Hunt Oil Company, Dallas, Texas); and Charles Donlin of Bismarck, North Dakota. Star Drilling Company and Plainsmen Petroleum Company, both of Bismarck are thought to have transferred their lease holdings to the Nokota Company of Bismarck which, in turn, leased the lignite to the Natural Gas Pipeline Company of America.

2. McLean County

The United Power Association Cooperative of Elk River, Minnesota and the Cooperative Power Association of Minneapolis are building a two-unit mine-mouth electric generating plant on Coal Creek, near Underwood, North Dakota. The Coal Creek Station will have a capacity of 1 million kilowatts and be fueled by 5.5 million tons of lignite per year. The North American Coal Corporation through its subsidiary, the Falkirk Mining Company, will supply the lignite from a new surface mine scheduled to be operational in 1978. Mine life expectancy is 35 years with an annual production of 7-8 million tons.

Also having interests in McLean County are the American Natural Gas Company and its subsidiary, the Michigan Wisconsin Pipeline Company; the Consolidation Coal Company; and W. H. Hunt Trustees, agents for Hunt Oil Company of Dallas. Some or all of the leases once held by Charles Donlin of Bismarck, A.G. Goldon (Cherokee Land Company) of Bismarck, and The Star Drilling Company are thought to have been transferred to Coteau Properties, the Land Division of North American Coal Corporation, to be reserved for the coal gasification project of the Michigan Wisconsin Pipeline Company.

3. Oliver County

Minnkota Power Cooperative is expanding the capacity of its mine-mouth Milton R. Young plant through the addition of the Square Butte 400-MW plant. The new plant will be built as a separate addition by the Square Butte Electric Cooperative but will be operated by Minnkota. Baukol Noonan is increasing the production of its Center Mine from the current 1.56-4.36 million tons annually by 1977. The contract to supply lignite for the Square Butte plant extends for 50 years. Further development of the Young plant is also expected.

Consolidation Coal Company and the Michigan Wisconsin Pipeline Company also have leases or interests in Oliver County.

4. Mercer County

The Michigan Wisconsin Pipeline Company, a subsidiary of the American Natural Gas Company, has announced plans to build a gasification plant north of Beulah, with an additional unit planned for the late 1980s. Each plant will produce 250 million cu ft of high-Btu gas. The first unit was scheduled to go

on-line in 1980, but delays have been encountered. Lignite for the gasification plants will come from new mines developed by the North American Coal Corporation on leases from their Coteau Properties Land Division. Estimates of the total reserves range from 2.7-4 billion tons, and are concentrated in Mercer County, although holdings in Dunn, McLean, and Oliver Counties are known. Yearly production for each gasification unit will be 12.2 million tons beginning in 1981 or 1982.

Basin Electric Cooperative is currently expanding the capacity of its Leland Olds plant near Stanton by building a second unit. The added capacity, 438 MW, more than doubles the present 216-MW capacity. The lignite will come from expansion of Consolidation Coal Company's Glenharold Mine from its present 1-5 million tons/yr to 4-4.5 million tons per year by 1978; an initial increase to 3.5 million tons per year should occur in 1976.

Montana-Dakota Utilities Company has announced plans to add 880 MW (2 plants) to its capacity at Beulah. (Prospects for a third planned unit are dependent upon delays in construction of the first two.) The first is scheduled to be operative in 1981. Lignite will come from the Beulah Mine or its subsidiary, the Knife River Coal Mining Company. Each plant will require 2½-3 million tons annually. The Ottertail Power Company has also announced plans for a 440-MW unit expansion in Minnesota. Since the Beulah Mine currently supplies Ottertail, one assumes it will also supply the new unit thus adding another 2½-3 million tons per year demand on the Beulah Mine.

The United Power Association has announced plans for additions of 500 MW both in 1978 and 1979 to its Stanton plant. The lignite currently supplied to the existing plant by the Indian Head Mine of the North American Coal Corporation amounts to 900,000 tons annually. Increases of 1.2 million tons in 1978 and a similar amount in 1979 are projected, giving a total production of almost 4 million tons per year by 1980.

The Bechtel, Westinghouse, and Union Carbide Corporations have announced tentative plans for a uranium enrichment plant. Mercer County, North Dakota, is being considered as the plant site. The plant would require 2500 MW of electric generating capacity. Lignite needs for such a plant are estimated at 6 million tons annually.

Other areas within the state where planned production increases have been announced or are expected are in Bowman and Grant Counties. The Knife River Coal Mining Company is expanding its Bowman County Gascoyne Mine to meet the demands of the new Big Stone Power plant. Current production of a quarter-of-a-million tons will increase to 1.8 million by 1976 and 2.7 million by 1977. In Grant County, Peabody Coal Company will produce lignite for the mine-mouth plant at Heart Butte. Other companies believed to have large coal reserve holdings include Tenneco Oil Company, Lone Star Producing Company, ARCO, Kerr-McGee Oil Corporation, and Hunt Coal Company. Mobil Oil reportedly holds reserves of uraniferous lignite in the southwestern part of the state.

E. Seam Characterization

1. Coal Classification

Coal is defined as "a readily combustible rock containing more than 50% by weight and more than 70% by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains, similar to those of peaty deposits. Differences in the kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade) are characteristics of the varieties of coal." (Schopf, 1956.) Thus, coal originated as organic plant remains and inorganic mineral matter under conditions similar to present-day peat swamps.

Coal is classified primarily on the basis of its rank or degree of metamorphism. Other classification schemes exist for the type(s) of plant material that can be identified in the coal and for the grade of coal -- the amount and type of impurities present. The latter classification is common to certain industrial users of coal.

Coal rank is, in general, a function of the deformational or metamorphic pressure and temperature, and on the length of time the metamorphism takes place. As the organic plant constituents -- carbon, hydrogen, oxygen, and nitrogen -- plus the inorganic mineral matter undergo increasing pressure and elevated temperatures, physical and chemical changes take place, and the proportions of the various constituents change. The moisture from the depositional swamp, so critical at the time of formation to prevent oxidation of the organic matter, gradually is squeezed out. From an original mixture of about 90% water in the peat-muck, water is gradually reduced to the 40-45% level and some reordering may take place in the woody plant material, resulting

in a deposit known as lignite. Further increases in temperature and pressure remove more water while proportionately increasing the amount of carbon (and hence the heat value of the coal) and the volatile matter, until the subbituminous-bituminous point is reached. Further heat and pressure begin to squeeze out most of the remaining water and, more important, reduce the amount of volatile matter while increasing the proportion of carbon, giving a progressively higher heat value (Btu) until the anthracite stage is reached. Extreme cases of metamorphism result in a restructuring of the carbon atom and the production of graphite -- almost 100% carbon.

Coals are usually analyzed according to standard procedures for physical properties, the proximate analysis, and for elemental properties, the ultimate analysis. The proximate analysis reports on the coal's moisture, volatile matter, fixed carbon and ash. The ultimate analysis measures the coal's hydrogen, oxygen, carbon, nitrogen, and sulfur content. The heating value or Btu is also determined, as are utilization properties -- caking and coking properties, ash softening and fusion temperatures, etc.

Figure 3.4 shows the most widely used classification system, the "Standard Specifications for Classification of Coals by Rank," adopted by the American Society for Testing and Materials (1971). The ASTM classification categorized by calorific value (Btu) or fixed carbon and volatile matter content plus the caking characteristics.

Figure 3.5 compares the heat value of different ranks of coal to their proximate analysis.

2. Lignite - Characteristics and Analyses

North Dakota's coal is classified as lignite on the basis of its high moisture and volatile matter and relatively low fixed carbon and heat value. The lignite is dense, irregularly banded, medium to very dark brown, and feels moist when freshly mined. Rarely does the lignite cleave vertically; it usually cleaves parallel to the bedding and, as a result, commonly can be mined in slabs a yard or more wide. Fusain - soft fibrous charcoal-like material - occasionally found in lenses, as is a soft earthy lignite. All lignite degrades rapidly in size when exposed to the atmosphere, a process known as slacking. Spontaneous combustion is possible when lignite is stored; wetting and compacting the storage piles usually avoids ignition. Clinker beds or "red-dog"

Legend F C = Fixed Carbon

V M = Volatile Matter.

Btu. = British thermal units

Class	Group	Limits of Fixed Carbon or Btu Mineral-Matter-Free Basis	Requisite Physical Properties
I Anthracitic	1 Meta-anthracite	Dry F C , 98 per cent or more (Dry V M , 2 per cent or less)	Nonagglomerating ^b
	2 Anthracite	Dry F C , 92 per cent or more and less than 98 per cent (Dry V M , 8 per cent or less and more than 2 per cent)	
	3 Semianthracite	Dry F C , 86 per cent or more and less than 92 per cent (Dry V M , 14 per cent or less and more than 8 per cent)	
II Bituminous ^d	1 Low volatile bituminous coal	Dry F C , 78 per cent or more and less than 86 per cent (Dry V M , 22 per cent or less and more than 14 per cent)	Either agglomerating or nonweathering ^f
	2 Medium volatile bituminous coal	Dry F C , 69 per cent or more and less than 78 per cent (Dry V M , 31 per cent or less and more than 22 per cent)	
	3 High volatile A bituminous coal	Dry F C , less than 69 per cent (Dry V M , more than 31 per cent) and moist ^e Btu , 14 000 ^e or more	
	4 High volatile B bituminous coal	Moist ^e Btu , 13,000 or more and less than 14,000 ^e	
	5 High volatile C bituminous coal	Moist Btu , 11,000 or more and less than 13,000 ^e	
III Subbituminous	1 Subbituminous A coal	Moist Btu , 11,000 or more and less than 13,000 ^e	Both weathering and nonagglomerating
	2 Subbituminous B coal	Moist Btu , 9500 or more and less than 11,000 ^e	
	3 Subbituminous C coal	Moist Btu , 8300 or more and less than 9500 ^e	
IV. Lignitic	1 Lignite	Moist Btu , less than 8300	Consolidated Unconsolidated
	2 Brown coal	Moist Btu , less than 8300	

^a This classification does not include a few coals which have unusual physical and chemical properties and which come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 18 per cent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu.

^b If agglomerating, classify in low-volatile group of the bituminous class.

^c Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

^d It is recognized that there may be noncaking varieties in each group of the bituminous class.

^e Coals having 69 per cent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

^f There are three varieties of coal in the high-volatile C bituminous coal group, namely, Variety 1, agglomerating and nonweathering, Variety 2, agglomerating and weathering, Variety 3, nonagglomerating and nonweathering.

Fig. 3.4. Classification of Coals by Rank
(Source: American Society for Testing and Materials, 1971.)

Fig. 3.5. Heat Value of Coal of Different Ranks Compared to Proximate Analyses
(Source: American Society for Testing and Materials, 1971.)

areas where the lignite has burned or is burning are common. Weathered outcrops of lignite can yield humic acid compounds known as leonardite. Leonardite is a soft, earthy, medium-brown coaly material.

Lignite analyses by seam and deposit for the four-county area, taken from Pollard, Smith, and Knox (1972) follow:

a. McLean County: Washburn Deposit

The Washburn deposit is in the Stanton bed of the Tongue River Formation. These reserves will be mined by the Falkirk Mining Company at its new mine near Underwood. Bed thickness averages 8'; overburden averages 50' and consists of clays, sands, and sandy clays overlain by a veneer of glacial drift.

Analysis Percent (as-received)

<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb</u>
38.1	26.1	31.4	4.4	0.5	7100

b. Dunn County: Dunn Center Deposit

The Dunn Center lignite field is in the Sentinel Butte Formation. The seam ranges in thickness from 11-24 ft and is usually covered by less than 50 ft of overburden, mainly shale. These reserves may be mined by either El Paso Natural Gas Co. or by Peoples Gas Co. for their announced gasification plants. A typical analysis of the coal is:

Moisture	-	38.56%
Ash	-	6.84%
Sulfur	-	.8 %
Btu	-	6280

An analysis from the northern part of Dunn County follows:

Analysis Percent (as-received)

<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb</u>
38.9	26.8	26.6	7.7	1.0	6280

c. Oliver County: Center Deposit

Lignite in the Center deposit is found in the Hagel and Keuther beds of the Tongue River Formation. Forty-five to sixty-five feet separate the Hagel bed from the stratigraphically higher Keuther bed. Overburden consists of a thin veneer of glacial till and loosely consolidated sandstone and shale. Eleven feet of the Hagel bed are being mined at the Center Mine of Baukol Noonan Inc. An analysis of the Hagel bed follows:

Analysis Percent (as-received)

<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb</u>
35.0	29.0	29.0	7.0	0.9	7066

d. Mercer and Oliver Counties: Stanton Deposit

Lignite in the Stanton deposit is found in the Stanton bed of the Tongue River Formation. The Stanton bed ranges in thickness from 8 to 11 feet. Currently 8 ft of lignite is being mined at the Glenharold Mine of the Consolidation Coal Company. Overburden consists of soft sandstone, shale, and clay, capped by a thin glacial veneer, but a hard well-cemented sandstone is normally found immediately over the Stanton bed.

A second lignite bed, unnamed, 4-6 ft thick is locally 50 ft above the Stanton bed. An analysis of the Stanton bed from the Glenharold Mine shows:

Analysis Percent (as-received)

<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb</u>
38.3	26.8	30.0	4.8	0.4	6870

e. Mercer and Oliver Counties: Beulah-Zap Deposit

Three separate coal fields -- North Beulah, South Beulah, and Zap -- make up this deposit. Lignite is found in the Zap bed in the North Beulah and Zap coalfields and in the Schoolhouse bed in the South Beulah coalfield. Both the Zap and Schoolhouse beds are part of the Sentinel Butte Formation. The Zap bed averages 10-12 ft in thickness where mined at the Indian Head Mine of the North American Coal Corporation, but a thickness of 17 ft for

the Zap bed has been reported (Pollard, Smith, and Knox, 1972). Average overburden thickness for the Zap bed is 76 ft and consists mainly of clay with minor amounts of sandstone, covered locally by a thin residual till veneer.

The Schoolhouse bed of the South Beulah coalfield consists of 27 ft of lignite in three beds averaging 12, 11, and 4½ ft in thickness. Overburden averages 62 ft; maximum overburden in the South Beulah field is similar to that above -- predominately clay with minor sandstone. The Knife River Coal Company is currently mining the Schoolhouse bed at its Beulah Mine. Analyses of the lignite from each of the three coalfields are as follows:

Analysis Percent (as-received)

<u>Deposit</u>	<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb.</u>
No. Beulah	37.1	26.1	31.0	5.7	0.5	6790
S. Beulah	35.8	26.9	31.7	6.6	1.0	6910
Zap	35.3	26.6	31.3	6.7	.8	7070

f. Mercer County: Renner's Cove Deposit

The Zap bed extends northward from the Zap coalfield and lies at shallow depths south of Lake Sakakawea. Average thickness of the Zap bed is 18 feet. Overburden ranges to 100 ft, with lesser amounts in the northern part of the deposit. Most of this deposit is currently under lease to the Michigan Wisconsin Pipeline Company for development in the near future to provide the lignite for their proposed gasification plant. North American Coal Corporation will operate the mine. An analysis of a northern Mercer County lignite is given below.

Analysis Percent (as-received)

<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb</u>
34.0	30.0	30.0	6.0	0.5	7050

g. Mercer County: Hazen Deposit

Lignite in the Hazen deposit is found in the Zap bed of the Sentinel Butte Formation. This bed averages 11-12 ft thick, but thins eastward and is usually split by a shale parting. Overburden consists of sandstone

and clay capped by a layer of glacial till of varying thickness. A strip mine, the Dakota Star, was operated on the southern margin of the deposit by Consolidation Coal Company until 1966. An analysis of the lignite from this deposit is as follows:

<u>Analysis Percent (as-received)</u>					
<u>Moisture</u>	<u>Volatile</u>	<u>Fixed C</u>	<u>Ash</u>	<u>Sulfur</u>	<u>Btu/lb.</u>
37.3	26.4	30.7	5.8	0.7	6870

Table B-1 in Appendix B lists proximate, ultimate, Btu, and sulfur analyses for lignite samples from the four largest mines in North Dakota.

3. Trace Elements

Table B-2 in Appendix B gives quantitative determinations for twelve trace elements for lignite samples from the four largest mines in North Dakota. Zubovic (1973) discusses the minor element content of North Dakota's lignites and shows that of the 15 elements that can be compared between the lignites and coals of the Eastern Interior region, lignites show higher levels of boron, cobalt, lanthanum, yttrium, and zinc. The potentially environmentally hazardous elements -- beryllium, copper, chromium, nickel and vanadium -- have rather low levels in the lignites. No data was given for selenium, cadmium, or mercury.

None of the metals appear to be concentrated (in the lignites or their ash) at a level at which they could be considered a potential minable resource.

Table B-3 (Appendix B). Gives the major oxide composition of lignite ash for samples taken from the four largest mines in North Dakota.

Table B-4 (Appendix B). Compares chemical analyses of all ranks of coal.

Table B-5 (Appendix B). Compares chemical analyses of various types of U.S. lignites.

F. Uranium in North Dakota Lignite

(From Noble p. 82-85 in Mineral and Water Resources of North Dakota; North Dakota Geological Survey, Bulletin 63)

Although uranium in lignite and related carbonaceous or organic material is fairly common, the only commercial American production from this source has come from the southwestern North Dakota-northwestern South Dakota area. Uranium and other metals in groundwater are readily removed from solution by sorption or by formation of metallo-organic complexes when the groundwater passes through sedimentary rocks containing coal, lignite, or other organic debris. The major North Dakota uranium occurrences are found in thin lignite or carbonaceous beds immediately overlying or underlying a sandstone that apparently functioned as an aquifer. The uranium content of the groundwater in these aquifers is generally attributed (that is, Denson and Gill, 1956 and 1965; Haines, 1958) to groundwater leaching of overlying sediments containing uranium-bearing volcanic ash. The origin of the uranium in the North Dakota lignite is thus pictured as having been extracted by organic material from groundwater of meteoric origin that had taken the metal into solution as it passed downward and laterally. This process of ore formation is relatively simple and took place recently, geologically speaking; both the rocks in which the ore occurs and the rocks from which the uranium presumably was leached are of Tertiary age (not more than 70 million years old).

Uranium in the form of weakly radioactive lignite was first reported from North Dakota in 1948 by (Wyant and Beroni, 1959) geologists of the U.S. Geological Survey. Ore-grade uraniferous lignite was found in 1955 in T. 157 N., R. 100 W., between Belfield and Amidon in southeastern Billings County (Fig. 3.6). The first shipment of North Dakota ore was made from this area in 1956, but only a few hundred tons were shipped from both North and South Dakota in the 1950s because the lignitic material was not amenable to milling by the methods applied to the common sandstone ores of the Colorado Plateau. From 1962 to 1967, uraniferous lignite of the Dakotas was burned in kilns or pits; the ash was then shipped to mills in South Dakota, Colorado, and New Mexico where it was blended and treated along with sandstone ores. Both the burning and mining had been discontinued by the end of 1967, apparently because market demand could be more profitably satisfied elsewhere.

Fig. 3.6. Known and Potential Uranium Areas in North Dakota
(Source: North Dakota Geological Survey, 1973.)

Significant North Dakota production was limited to the so-called North and South Belfield areas, where the deposits are clustered (Fig. 3.6). The total production from North Dakota is listed by pounds of "yellow cake" (U_3O_8). Reserves considered minable at an \$8/lb- U_3O_8 price are carried at 71,000 tons containing 480,000 lb of U_3O_8 . Both production and reserve figures for North Dakota are far less than 1% of the total U.S. production and reserves.

Although North Dakota's present reserves of uraniferous lignite are listed as minable at a U_3O_8 price of \$8/lb, the mining of this "ore" appears less feasible now than it did when mining ceased in 1966 or 1967. The uranium in its thin, impure lignite host can apparently be mined economically only by strip methods, followed by burning, to make it economical to ship and amenable to mill. Both stripping and burning would now be affected by recently enacted laws and regulations pertaining to reclamation and air pollution. Molybdenum and arsenic both occur in appreciable amounts in uraniferous lignite; in fact, molybdenum recovery reportedly made possible the economical mining of some of the uranium deposits. All three metallic elements -- uranium, molybdenum, and arsenic -- can be health hazards when airborne in smoke or dust. Perhaps all could be recovered as by-products during combustion of uraniferous lignite for electric power generation, where demand and technology exist.

Undiscovered deposits of uraniferous lignite are probably present in environments analogous to those of the known deposits. Search should first be made where sandstones of the upper part of the Sentinel Butte Formation are in contact with lignite. Stream-divide areas, where deposits are now known, may be especially favorable because they may represent areas of groundwater infiltration (recharge) at the time of effective leaching of the volcanic-ash-bearing sediments that formerly were widespread in the area.

G. Overburden Chemistry

The thickness and types of overburden were reviewed in earlier sections. This section will present data on chemical analyses of the overburden.

Very little has been published on overburden chemistry. The Mineral Resources Work Group Report of the Northern Great Plains Resource Program devotes one sentence (p. 146) for overburden chemistry. It bears repeating:

"If the mineral content of the overburden material will not allow successful reclamation, the area should not be mined by surface methods."

Sandoval et al. (1973) published analyses of spoil pile and topsoil and also published pre-mining physical and chemical characteristics of overburden. Table 3.10 (same source) shows a moderately alkaline character ($\text{pH} > 7$) in the spoil material compared to the topsoil (sampled before mining). Most of the spoils were moderately calcareous, a contrast to the topsoil. When one examines the particle size another contrast is noted: spoil materials are finer-textured than topsoil and thus have higher saturation percentages. Highly saline spoils were not encountered, but enough soluble salts were present to classify the spoils as slightly to moderately saline. In all North Dakota examples, except the sample from Center, sodium was the dominant cation. The "anomalous" example from Center may represent a "relatively young" spoil as its pH is lower and its texture is coarser than other sampled North Dakota materials.

Table 3.11 (also from Sandoval, etc) relates overburden physical and chemical characteristics to depth before mining takes place. Depending upon the mining method employed and the depth to which coal can be economically removed, various materials would become the surface spoil material. Most of these materials are highly sodic (SARs of 25-35), slightly saline, and have a range of 95-180 in saturation percentages, indicating a fine-textured clay material. Organic matter content of these materials is low, amplifying the sodic hazard and increasing the likelihood of revegetation problems should they become spoil-pile surface deposits. The potential for a suitable revegetation medium at depth appears remote, in contrast to the situation in parts of the glaciated areas in Midwestern and Eastern coalfields. The passage of regulations requiring topsoil storage makes some of the worries listed above moot; however, the knowledge that conditions for revegetation are better near the surface and not at depth should weigh heavily in the pre-mining planning stage of mine development. Mining methodology and equipment should be chosen to utilize such information to mitigate environmental problems.

Argonne National Laboratory under its Land Reclamation Program is investigating candidate reclamation species and assessing topsoil storage and replacement effects on soil microbiota at the Mercer County Indian Head Mine of the North American Coal Corporation. Table 3.12 lists the analyses for

Table 3.10. Physical and Chemical Characteristics of Normal Topsoil and of Surface Spoil Pile Materials from Strip Mined Areas in Western North Dakota, Northeastern Wyoming, and Eastern Montana
(Source: Sandoval et al., 1973.)

Number	Location	pH	CaCO ₃ (equiv)	Particle size ^a			Saturation extract							CO ₃ + HCO ₃	SO ₄
				Sand	Silt	Clay	Sat'n	EC	Ca	Mg	Na	SAR			
													%		
TOPSOIL MATERIALS															
1	Stanton, N.D.	6.8	< 1	40	45	25	43	< 1	3	2	1	< 1	1	4	
2	Zap, N.D.	7.3	1	41	39	20	26	< 1	5	3	1	< 1	4	3	
SPOIL BANK MATERIALS ^b															
3	Beulah, N.D.	8.4	12	14	49	37	141	3	< 1	< 1	34	41	5	30	
4	Beulah, N.D.	8.1	13	8	51	41	115	6	4	5	52	24	3	55	
5	Beulah, N.D.	8.3	8	27	21	52	178	3	1	1	34	34	6	28	
6	Center, N.D.	7.6	10	24	50	26	57	4	14	29	7	2	2	48	
7	Stanton, N.D.	8.3	nd ^c	nd	nd	nd	156	2	< 1	< 1	22	27	3	21	
8	Stanton, N.D.	8.3	nd	12	36	52	144	2	1	1	20	19	6	16	
9	Zap, N.D.	8.9	nd	nd	nd	nd	78	2	< 1	< 1	16	37	7	10	
10	Zap, N.D.	8.8	10	3	43	54	160	2	< 1	< 1	19	48	10	7	
11	Gascoyne, N.D.	8.1	nd	nd	nd	nd	41	8	6	15	74	23	nd	nd	
12	Gillette	7.4	nd	nd	nd	nd	33	8	25	73	31	5	nd	nd	
13	Sheridan, Wyo.	6.1	nd	nd	nd	nd	50	7	29	28	45	8	nd	nd	
14	Colstrip, Mont.	7.2	nd	nd	nd	nd	48	3	15	19	3	< 1	nd	nd	

^aParticle size: Sand = > 0.05 mm; silt = 0.05 - 0.002 mm; clay = < 0.002 mm.

^bSample No. 3 through 10 originated from depths greater than 50 feet; original depth of No. 11 through 14 unknown

^cnd = Analysis not determined

Table 3.11. Physical and Chemical Characteristics with Depth by Overburden at Three Sites in Western North Dakota before Disturbance by Mining

Depth ft	pH	CaCO ₃ equiv. %	Sat'n %	E. Cond. microhm	SAR	Nitrogen	
						NH ₄ -N ppm	NO ₃ -N ppm
<u>Stanton No. 1, Level Site</u>							
0-2	7.6	2	70	1	1	nd	nd
2-11	7.6	13	46	2	1	1	2
11-20	7.4	8	86	5	7	2	11
20-30	8.2	13	122	2	15	2	2
30-57	8.5	10	150	2	39	12	2
57-70 a	7.1	14	-	3	52	13	2
70-90	8.2	13	180	1	34	14	1
90-98 a	6.8	10	-	3	25	16	2
98-105	7.6	11	161	1	25	14	2
<u>Stanton No. 2, Hilly Site</u>							
0-3	7.0	2	50	2	2	1	1
3-10	8.2	15	128	8	13	3	6
10-18	8.0	7	181	5	15	2	34
18-23 a	4.5	3	-	9	15	5	37
23-50	7.7	11	142	3	31	10	2
50-60 a	6.9	8	-	5	30	16	3
60-96	8.1	13	164	2	30	15	2
96-104 a	7.0	11	-	2	22	16	2
104-109	7.5	5	158	2	25	17	2
<u>Golva Site b</u>							
0-20	7.7	3	87	3	2	5	1
20-40	7.9	10	95	1	9	18	1
40-80	7.6	10	95	3	25	17	1
80-120 a	7.9	5	174	2	50	15	1
120-160	8.5	13	133	2	54	24	1
160-200	8.4	7	133	2	53	25	1
200-300 a	8.2	10	142	2	62	28	1
300-400 a	8.3	7	119	2	53	15	1
400-500	8.6	9	128	2	50	14	1

^a Layers with lignite

^b Sampling by courtesy of U.S. Forest Service, Dickinson, N. Dak. The lithologic log shows major lignite layers at 114-120, 280-300, and 340-400 feet

Source: Sandoval et al., 1973

Table 3.12. North Dakota Topsoil and Spoil Analyses: Indian Head Mine

Sample ID	Type	Sand %	Silt %	Clay %
NDTA1	Stored Topsoil (2 years)	68	22	10
NDTA2	Stored Topsoil (2 years)	70	19	11
NDTB1	Fresh Topsoil	20	50	30
NDTB2	Fresh Topsoil	29	43	28
NDSA1	Low Clay Spoils	18	47	35
NDSA2	Low Clay Spoils	18	46	36
NDSB1	High Clay Spoils	8	50	42
NDSB2	High Clay Spoils	8	51	41

ION CONCENTRATIONS FROM ANALYZED MINE SPOILS

Sample ID	pH	P MEQ	K MEQ	CA MEQ	Mg MEQ	MN MEQ	ZN MEQ	NA MEQ	Salt MEQ E-5	SAR
NDTA2	7.400	0.291	4.476	37.425	19.335	0.373	0.034	6.090	28.000	1.145
NDTA1	7.400	0.291	4.476	37.425	18.511	0.346	0.031	6.307	28.000	1.193
NDTB2	7.900	0.048	4.476	54.890	51.419	0.073	0.023	80.470	230.000	11.037
NDTB1	8.000	0.065	4.476	58.633	53.476	0.046	0.019	86.994	270.000	11.619
NLSA1	7.700	0.097	6.714	49.900	45.249	0.218	0.168	82.645	180.000	11.982
NDSB1	7.900	0.065	6.394	37.425	39.852	0.328	0.237	88.734	150.000	15.187
NDSB2	7.700	0.097	6.394	38.049	31.880	0.328	0.229	90.474	185.000	15.301
NDSA2	7.700	0.081	6.074	47.900	32.908	0.246	0.164	80.470	200.000	12.506

Sample ID	pH	SMP	OM T/A	P	K	Ca	Mg lbs/A	Mn	Zn	Na	Salts ^a lbs x 10 ⁵ /cm
NDTA2	7.4	---	30	18	350	3000	940	41	4.5	280	28
NDTA1	7.4	---	30	18	350	3000	900	38	4.0	290	28
NDTB2	7.9	---	21	3	350	4400	2500	8	3.0	3700	230
NDTB1	8.0	---	20	4	350	4700	2600	5	2.5	4000	270
NLSA1	7.7	---	40	6	525	4000	2200	24	22.0	3900	180
NDSB1	7.9	---	40	4	500	3000	1500	36	31.0	4080	150
NDSB2	7.7	---	50	6	500	3050	1550	36	30.0	4160	185
NDSA2	7.7	---	55	5	475	4000	1600	27	21.5	3700	200

four spoil samples and four topsoil samples. Two of the spoil samples are "low-clay" (SA-1 and SA-2) and two are "high clay" (SB-1 and SB-2); two of the topsoil samples were from "stored" topsoil (TA-1 and TA-2) and two are from "fresh" topsoil (TB-1 and TB-2). The analyses indicate the highest phosphorous levels in the stored topsoil, higher overall zinc and potassium levels in the spoils, and the highest calcium and magnesium levels in the fresh topsoil. The lowest sodium levels and soluble salt levels were found in stored topsoil. SARs in the stored topsoil were extremely low. Interpretative Tables for Analyzed Data from Table 3.12 are given in Table 3.13.

U.S. Geological Survey Open-file Report 75-436, "Geochemical Survey of the Western Coal Regions," 1975, lists miscellaneous geochemical data on rocks that compose the overburden in a large part of North Dakota.

TABLE 3.13. Interpretative Tables for Analyzed Data from Table 3.12

Interpretation of Soluble Salts Levels

Soluble Salts in mhos $\times 10^{-5}$ /cm.

<u>Soil Texture</u>	<u>Interpretation</u>		
	Low	Medium	Excessive
Sandy	0-25	26-75	>75
Silty	0-40	41-105	>105
Organic	0-60	61-170	>170

Interpretation of Soil Test Results for All Crop Codes

<u>Soil Test</u>	<u>Nutrient Concentration in the Soil</u>				
	<u>Very Low</u>	<u>Low</u>	<u>Medium</u>	<u>High</u>	<u>Excessive</u>
pH	<5.5	5.5-6.4	6.5-7.2	7.3-7.8	>7.8
P	<15	15-30	31-75	76-200	>200
K	<120	120-200	201-350	351-450	>450
Ca	<500	500-1000	1000-10,000	>10,000	
Mg	<300	300-600	601-2000	>2,000	
SO ₄ -S		0-14	15-20	>20	
Zn		<5.0	5.1-10.0	>10	
B	<1.0	1.0-2.0	2.1-3.0	3.1-10.0	
Mn, OM $\leq$ 60 T/A		<20	21-40	>40	
Mn, OM $\geq$ 61 T/A ^a		pH $\geq$ 7.0	6.0-6.9	>6.0	

^aWhen the OM content is greater than 60 T/A, the interpretation is based upon soil pH.

4. ENVIRONMENTAL PROBLEMS

A. Air

Coal extraction normally releases dust into the atmosphere, but the high moisture content of lignite results in (relatively) less dust being emitted than from coals of higher rank in a comparable mine. Conversely, the semiarid climate and high winds in the lignite area contrasted to the higher rainfall of the Midwestern and eastern coal fields tends to dry the mined coal at a faster rate, and dust from lignite storage piles can become a problem unless proper measures are taken. Dust from haul roads, unless they are kept damp, asphalted, or oiled, can be a significant problem.

Wind erosion of spoil areas before vegetation is reestablished may produce the highest levels of dust pollution. High winds, storms, and aridity are all factors to be considered in the premining plan of reclamation. Identification and monitoring of potential pollution areas should be an integral part of that plan.

Spontaneous combustion upon exposure to the atmosphere is an inherent problem of lignite. Fires in stored lignite piles or in lignite spoil banks are common. Proper design and maintenance of storage piles and refuse banks are necessary. Burial or covering of exposed lignite beds following mining prevents spontaneous combustion.

B. Water

1. Water Quality Problems

The chemical quality of the surface and groundwater for the four-county area was described in previous sections. Water can accumulate in the pit from groundwater or surface water runoff. Water quality in the mine pit area can best be maintained by diverting or channeling all surface water around an active pit. Brief intensive storms can lead to large amounts of runoff that, unless channeled away, can introduce large amounts of water into the pit, the lowest point in the mine area. Groundwater must be controlled within the pit, usually by channeling it to a central area where it can be pumped out. Proper water handling techniques are critical -- not only from an environmental point of view but also from an economical point of view. Uncontrolled runoff brings large amounts of silt into a mine and unless the

silt is removed (an added mine expense), the lignite will have a higher ash content, thus reducing its economic value. Uncontrolled runoff water coming into contact with the lignite seams has the potential to raise the lignite's moisture content, lowering its quality, and reducing its value. Similarly, groundwater must be controlled because water collecting near the active mine face or forming pools on exposed lignite seams will infiltrate the lignite and raise its moisture content, leading to lower quality and a reduction in its value. Obviously, water handling in and around a mine is an integral part of the plans of financially successful mining companies.

The water quality may change due to the mixing of overburden materials and introduction of potentially soluble constituents and organic matter. Organic nitrogen has been reported (Feder, 1975) in abnormal amounts in the Fort Union coal region. Background investigations of this type are critical; baseline characterization is an essential component of any study to measure the impacts associated with mining. Feder (1975) has proposed a sampling schedule for groundwater and surface water to determine the effects of various constituents on human health and agriculture. His work, included in Appendix D, defines recommended detection limits and lists the possible effects on humans and agriculture.

Siltation via runoff is dependent upon the rainfall pattern and its intensity, amount and type of vegetative cover (if present), and soil characteristics. Pollution problems arise when potentially polluting soluble elements are present and when the velocity of the moving water is sufficient to initiate erosion and transportation of particles. The cohesive forces in clay-sized particles require high velocities to initiate movement; however, once these are suspended they tend to remain in suspension because of their exceedingly low settling velocities. Thus, intense storms may initiate erosion and gullyng, and lead to relatively high concentrations of suspended sediments in surface waters.

Leaching is another problem associated with mining. Leaching of coal storage piles, coal refuse areas, and overburden spoil piles may concentrate strongly mineralized waters. Discharge rates will vary according to the characteristics of the pile and are normally unpredictable. Surface leaching by runoff may be partially controlled by diversion, but groundwater leaching is much more difficult to control as the dynamics of water movement are not in general fully understood, and vary from site to site. Most spoil piles have a greater volume than the material in place before mining. Data on the increase

of soil spoil permeability from Colstrip, Montana, indicates that while vertical permeability is increased horizontal permeability appears to decrease.

2. Water Quantity Problems

Most of the lignites of North Dakota are or have the potential to be aquifers. (One might argue that any rock containing 35% moisture is an aquifer.) However, as discussed in the section on groundwater, lignite aquifers normally yield less than 10 gal/min of water that varies considerably in chemical quality. Its color is commonly reddish-brown due to organic compounds, and it may be very hard. Mining or disrupting these aquifers is in general a minor, local problem. Disruption of a glacial aquifer system -- especially in McLean County -- could be a potentially serious problem. Should a town be obtaining its water from an aquifer that is disrupted up-dip, the cessation of flow down-dip to the drawn-down area of the town creates a problem, its dimensions depending upon the magnitude of the disruption, the user-needs, the size and storage capacity of the aquifer, and the potential for recharge from other sources should the hydrostatic head change.

Several towns in the four-county area are located along surface water routes and obviously will not be affected, unless these streams or rivers are recharged by groundwater or alluvial valley flow. Mining these recharge areas could have an effect on stream/river flow volumes and concomitant effects for towns downstream.

C. Land

1. Assessment of Land Impacts

With 2619 acres disturbed through September, 1974, Mercer County is the county with the greatest area affected by the strip mining of lignite. And, as can be seen Fig. 2.24 more than half the area under active strip mining permits is located in this county. At this time, the necessary water use permits have been issued for only one gasification plant. This is the American Natural Gas-Michigan-Wisconsin Pipeline Company coal gasification project to be located in Sections 13, 24, and 25 of Township 145 North, Range 88 West in Mercer County. In addition, four, and possibly five, mines will be needed over a 25-year period to supply the lignite for the plant. These will be located in close proximity to the plant. The entire area for which land use data were compiled is comprised of 228 sq mi (184,320 acres) in the central part of the county. This area includes the southern one mile tier of T147N, R88W and T147N, R87W. The entirety

of T146N, R87 and 88W; T145N, R87 and 88W; and T144N R88W were included as were the E 1/2 of T144N, R89W and the W 1/2 of T144N, R87W.

2. Methodology

The method selected for acquiring land use information on the study area was the interpretation of aerial photographs. The study area was flown in two separate missions, a month apart, on May 12 and July 12, 1975. On the first date, the western one-half of the study area was photographed in black and white, and the entire area was photographed in color infrared. Technical problems were encountered by the contractor, which resulted in the color infrared being of unacceptable quality. On June 12 the eastern one-half of the study area was flown for black and white imagery, and the entire area was again flown in color infrared, this time successfully.

The primary imagery form utilized for the interpretation of land use in the study area was the black and white panchromatic photography taken on May 12 and June 12, 1975. Color infrared transparencies were also obtained on the June 12 mission and were utilized when the classification of land use in a given 40-acre parcel was in doubt.

For comparative purposes, photographs 057 dated May 12 (Fig. 4.1) and 142 dated June 12 (Fig. 4.2) are reproductions of black and white representations of approximately the same scene. Color infrared photographs of the scene were also produced simultaneously and used in the interpretation.

a. Photo 057

Figure 4.1 represents a panchromatic black and white photograph taken on May 12, 1975. This photograph was the last photo exposed on the May 12 date. Clouds began to form over the study area and some clouds are shown as numerous cloud shadows that appear as darkened spots on the surface. These spots could be interpreted as wet areas if the presence of clouds was not known.

The photo lacks contrast and, therefore, field boundaries are in some cases difficult to recognize. Sharp definition between objects is lacking. The lack of photo contrast was attributed to a lack of ground contrast due to the early date.

b. Photo 142

Figure 4.2 represents a panchromatic black and white photograph taken on June 12, 1975. This photograph, exposed one month after photo 057,

Fig. 4.1. Panchromatic Black and White Photograph Taken May 12, 1975

Fig. 4.2. Panchromatic Black and White Photograph Taken June 12, 1975

is of the same geographical area. Contrast is still poor although the season has advanced by one month. This leads one to believe that the problem of photo quality is related not only to the seasonal differences noted but also to the ability to produce quality panchromatic imagery.

The problem of poor contrast in the black and white imagery was partially overcome by the 1:24,000 scale of the imagery. At a scale of one inch equal to 2,000 feet, 40-acre parcels were readily interpreted utilizing a 40-acre grid overlay.

c. Color Infrared Photographs

Color infrared transparencies were taken on June 12, 1975. The "false color" imagery produced was of value in interpreting land use when interpretation from black and white panchromatic imagery proved difficult. Contrast is greatly improved in the color infrared transparency. As a result, field boundaries are readily distinguishable. Because healthy green foliage appears red on such a photograph, growing crops and trees exhibit the darkest red color. Native grasses and pastures appear pink. Emerging crops exhibit a pink tone on a gray background. Fallow ground appears gray. Water appears black and is readily distinguishable from other land use classes.

A transparent grid overlay on a 40-acre scale was prepared for use with the photography. While one trained photo interpreter examined the photography and determined the dominant land use in a 40-acre parcel, an assistant recorded the observed land use on a township coding sheet of the same scale as the base map. If the photo interpreter had difficulty in resolving the land use of a parcel, two other interpreters were asked to classify the parcel, the majority opinion prevailing. When on occasion, a decision still could not be reached, the project manager made a final classification decision. The next step in a map preparation was the land use coding of the base map from the coding sheets. A trained cartographer utilized "stick up" symbols and prepared the map for final printing.

The final step in the preparation of the land use map was a quantitative evaluation of land use in the study area. This required the enumeration of the 40-acre parcels (fortys) in each land use classification from the township coding sheets. The criteria used for the classification of land use in the study area were adapted from the Minnesota Land Management Information System Study. That study recognized nine categories of land use. The criterion for assigning land use classification was the dominant use made of the land in

a given 40-acre parcel in the study area. The classification system and criteria for classification are as follows:

FORESTED--A forty in which the dominant land use consists of trees. To be considered forested, a forty must contain a scattering of trees whose crowns cover at least 10% of the land area.

CULTIVATED--A forty in which the dominant use consists of land which has been recently tilled or harvested mechanically.

PASTURE AND OPEN--A forty of non-forested land not used for any identifiable purpose. Examples are grazing land or abandoned farm land.

WATER--A forty in which the dominant land use is open and permanent water.

MARSH--A forty in which the dominant land use consists of non-forested, shallow permanently wet, vegetated areas.

URBAN RESIDENTIAL--A forty containing five or more residential dwellings, and no commercial buildings.

URBAN NON-RESIDENTIAL OR MIXED RESIDENTIAL DEVELOPMENT--A forty containing at least one commercial, industrial, or institutional development and that may or may not contain residential development.

EXTRACTIVE--A forty in which the dominant land use consists of the extraction of minerals, including ancillary facilities. Examples are mines, tailing piles, gravel pits.

TRANSPORTATION--A forty in which the dominant land use consists of facilities for the conveyance of people or materials.

The existing land use in the study, summarized in Table 4.1, exhibits the following pattern:

3. Land Use: Mercer County, May, 1975

a. Pasture and Open

The category of pasture and open land accounted for 35% of the study area or 51,360 acres. Such land is used predominantly for cattle grazing in Mercer County.

b. Transportation

While Mercer County has a developed rail and highway transportation system, no 40-acre parcel was dominated by a category of land use termed transportation. This is a normal situation in such a mapping project, as only

Table 4.1. Mercer County Study Area, North Dakota
Land Use: May 1973

Land Use Classification	Acres	Percent
Forested	280	00.19
Cultivated	74,200	50.85
Pasture and Open	51,360	35.20
Water	16,440	11.27
Marsh	-	00.00
Urban Residential	560	00.38
Urban Non-residential or Mixed Residential Development	160	00.11
Extractive	2,920	02.00
Transportation	-	00.00
Total	145,920	100.00

airfields or railyards are generally of sufficient size to dominate a 40-acre parcel of land.

c. Urban Residential

Less than 1% of the study area, or 560 acres, was classified as urban residential. This classification includes the towns of Beulah and Zap with 1970 populations of 1,344 and 271, respectively.

d. Urban Non-Residential and Mixed Residential

Four parcels in the study area accounting for 160 acres were classified as urban non-residential. Three of these were located on the outskirts of Beulah while a fourth was located in the center of the study area. This latter parcel was classified as an institutionally related development in the form of a dump.

e. Forested

Forested land occupied 280 acres in the study area and was primarily located along the course of the Knife River.

f. Water

Water occupied 11% of the study area and amounted to 16,440 acres. The dominant water area was the portion of Lake Sakakawea that borders northern Mercer County. Several other 40-acre parcels were dominated by water in the form of small lakes.

g. Marsh

No 40-acre parcel was found to be dominated by marshland. While one might normally expect a marsh transition zone at the land-water interface, such is not the case along the steep banks of Lake Sakakawea.

h. Extractive

The extractive use of land is accounted for by strip mining operations for the recovery of lignite coal. Two percent of the study area, or 2920 acres, was classified as extractive land use. This classification includes land that is currently being mined as well as land that has been formerly mined but is no longer classed as an active mining area.

i. Cultivated

Land classified as cultivated accounted for 74,200 acres or slightly over 50% of the study area. Since western North Dakota is classified as a dry farming area, one may expect that approximately one-half of the cultivated land lies fallow each year as a moisture conserving practice. The exact amount of land lying fallow may be less than one-half of the cultivated area if farmers are anticipating high grain prices. The important fact to remember is that not all the land classified as cultivated is utilized for the production of crops every year.

4. Determination of Future Land Use Changes

After the map of current land use was completed, an overlay of the location of the projected mine areas and gasification plant was made from data provided in Environmental Impact Report (E.I.R.) for the plant (ANGCGC, 1975). These data were transposed onto the original map and measurements were made of the amount of land in each land use category that would be affected by the 25- or 26-year operation of the plant. Figure 4.3 is a composite map showing current land use and the projected mine areas as they will appear after 25 years.

According to Environmental Impact Report (E.I.R.), the gasification plant will consume approximately 12.22 million tons of lignite per year. If the average seam thickness in the study area is 14.5 ft and there are 1750 tons of lignite per acre-foot, then such a seam would yield approximately 25,375 tons per acre or 100% recovery. Even with surface methods, however, there is some waste and some recovery will be approximately 92.5%, or 23,472 tons per acre. Since the total coal requirement for the plant over the 25-year period of peak production, plus the year or two required for scaleup, will be 315.34 million tons, about 340.907 million tons will have to be exposed. This means that during peak operation, about 537 acres will be mined per year. At this rate, a total of 13,435 acres would be mined.

Fig. 4.3. Mercer County Study Area, North Dakota
Land Use: May 1975

Mine site #1 will require the disturbance of 2800 acres (see Table 4.2). Of this, 1200 is currently classified as pasture and open, and 1600 is cultivated. Mine #2 will occupy a total area of 6880 acres. Cultivated land now occupies 5360 acres of this and the other 1520 is pasture and open. Mine #3 will total 1600 acres, of which 1160 is pasture and open, and the other 440 is cultivated. Mine #4 will be the smallest, occupying 1440 acres. Cultivated land comprises 1120 of this, with pasture and open accounting for 280, and 40 acres in water. The total area disturbed by these four mines, excluding off site disturbance, will be 12,720 acres. Since this is not quite enough to satisfy the demand of the plant, a fifth mine has been planned. However, if the lignite seams are thicker and yield more than the expected tonnage, this area may not have to be mined. If it is mined, it will occupy up to 1840 acres. Of this, 960 is currently pasture and open, and 880 is cultivated. In addition to the mines, the plant itself will occupy approximately 1080 acres. Although 1440 has been acquired for the plant, 360 of it will eventually be mined as mine #1 expands. This plant will occupy 760 acres that is now classified as cultivated land, 120 acres of pasture and open land, 160 acres of water, and 40 acres of urban nonresidential land that is being used as a dump or junk yard. In total, 15,640 acres will be directly affected.

D. Ecosystem

1. Rare and Endangered Species

a. Definitions*

Endangered: An endangered species or subspecies is one whose prospects of survival and reproduction are in immediate jeopardy nationwide. Its peril may result from one or many causes -- loss of habitat, or change in habitat, over exploitation, predation, competition, or disease. An endangered species must have help or extinction will probably follow.

Rare: A rare species or subspecies is one that, although not presently threatened with extinction, is in such small numbers throughout its range nationwide that it may be endangered if its environment worsens. Close watch of its status is necessary.

* USDA, 1972, *Rare and Endangered Plant and Animal Species*, Environmentalion Memorandum ND-3, SCS, Bismarck, N.D.

Table 4.2. Land Use Areas to be Affected by
A.N.G. Coal Gasification Plant

Current Land Use	Mine #1	Mine #2	Mine #3	Mine #4	Mine #5	Plant	Total
Pasture and Open	1200	1520	1160	280	960	120	5240
Cultivated	1600	5360	440	1120	880	760	10160
Water				40		160	200
Urban Non-residential						40	40
Total	2800	6880	1600	1440	1840	1080	15640

Peripheral: A peripheral species or subspecies is one whose occurrence in North Dakota is at the edge of its natural range and/or which is rare (R) or endangered (E) within the state, although not in this range as a whole. Special attention is necessary to assure retention in the state's flora or fauna.

Status Undetermined: A status undetermined species or subspecies is one that has been suggested as possibly rare or endangered, but about which there is not enough information to determine its status. More information is needed.

The rare and endangered species of southwest North Dakota listed in Table 4.3 were selected from a longer list of such species for all of North Dakota. Only three animal species, the peregrine falcon, black-footed ferret, and the pigeon hawk, are listed as endangered. Two species are listed as rare: one plant, *Primula incana* and the prairie falcon. The remaining species are rare or endangered only within the confines of North Dakota.

Based on the above definitions, Whitman et al. (1974) have considered several other plant species found in Dunn County to be peripheral. Paper birch (*Betula papyrifera*) is common in parts of eastern and northern North Dakota, but its presence in Dunn County represents a unique occurrence. River birch (*Betula fontinalis*), found on steep north-facing slopes in the Killdeer Mountains as well as the upper slopes of the Little Missouri drainage, is at the southwestern limits of its range in North Dakota. Bur oak (*Quercus macrocarpa*) is a common species in the eastern part of the state but in western North Dakota occurs only on, and to the north of, the Killdeer Mountains. Bearberry (*Arctostaphylos uva-ursi*) occurs in the northern portion of the state,

Table 4.3. Rare and Endangered Plant and Animal Species of Southwestern North Dakota^a

Status	Scientific Name	Common Name	Comments
Peripheral (R)	<i>Sorex merriami</i>	Merriam's shrew	Western sagebrush area; badlands only
Peripheral (R)	<i>Lasiurus cinereus</i>	Hoary bat	Statewide; woodlands needed
Peripheral (R)	<i>Myotis evotis</i>	Long-eared bat	From Billings and Williams Counties, Badlands
Peripheral (R)	<i>Myotis leibei</i>	Masked bat	From Slope and Billings Counties, Badlands
Peripheral (R)	<i>Myotis volans</i>	Long-legged bat	From Ward, McHenry and Billings Counties; Badlands
Peripheral (E)	<i>Sylvilagus auduboni</i>	Desert cottontail	Hillsides in Badlands
Peripheral (E)	<i>Cynomys ludovicianus</i>	Black-tailed prairie dog	Southwestern North Dakota to the Missouri River, River Terraces
Peripheral (E)	<i>Neotoma cinerea</i>	Bushy-tailed wood rat	Badlands
Peripheral (R)	<i>Dipodomys ordii</i>	Ords kangaroo rat	Badlands, needs sagebrush
Peripheral (R)	<i>Lagurus curtatus</i>	Sagebrush vole	Very old record from Fort Buford
Endangered	<i>Mustela nigripes</i>	Black-footed ferret	Feeds on prairie rodents, mainly prairie dogs
Endangered ^b	<i>Vulpes velox</i>	Swift fox	Needs extensive prairies
Peripheral (R)	<i>Cathartes aura</i>	Turkey vulture	Decimated by Wolf and possibly coyote poisoning
Peripheral (R)	<i>Buteo regalis</i>	Ferruginous hawk	Needs extensive native prairie
Peripheral (R)	<i>Aquila chrysaetos</i>	Golden eagle	Badlands

Table 4.3 (Cont'd)

Status	Scientific Name	Common Name	Comments
Rare ^c	<i>Falco mexicanus</i>	Prairie falcon	Western North Dakota
Endangered	<i>Falco peregrinus</i>	Peregrine falcon	Western North Dakota
Endangered ^d	<i>Falco columbarius</i>	Pigeon hawk	Western one-fourth of North Dakota
Peripheral (E)	<i>Numenius americanus</i>	Long-billed curlew	Sagebrush prairie
Peripheral (R)	<i>Speotyto cunicularia</i>	Burrowing owl	Needs pastures and prairies
Peripheral (E)	<i>Tachycineta thalassina</i>	Violet green swallow	Badlands of McKenzie County
Peripheral (R)	<i>Dendroica auduboni</i>	Audubon's warbler	Yellow pine by burning coal vein in Slope County
Peripheral (R)	<i>Spizella breweri</i>	Brewer's sparrow	Sagebrush areas
Peripheral (E)	<i>Rhynchophanes mccownii</i>	McCown's longspur	Isolated grasslands and open areas at higher elevations
<u>Plants</u>			
Peripheral (E)	<i>Clematis pseudoalpina</i>	Rocky Mt. clematis	Known only from Dunn County, Killdeer Mt.
Rare	<i>Primula incana</i>	- - -	Known from two stations in Burke and Mountrail Counties
Peripheral (E)	<i>Chaenactis douglasii</i> (Hook) H. & A.	False yarrow	Known from only one station in Billings County

Table 4.3 (Cont'd)

Status	Scientific Name	Common Name	Comments
Peripheral (E)	<i>Stephanomeria tenuifolia</i> (Torr.) Hall	Wirelettuce	Known only from Little Badlands of Stark County
Peripheral (R)	<i>Astragalus vexilli-flexus</i> Sheld.	Milkvetch	Known from the Little Badlands of Stark County and Killdeer Mts., Dunn County

^aExtracted from U. S. D. A. 1972.

^b*Vulpes velox hebes*, Northern Swift Fox, is listed as Endangered by U. S. Department of Interior (1975).

^cListed as threatened by U. S. Department of Interior (1973), not listed by U. S. D. O. I. (1975).

^d*Falco columbarius richardsonii*, Prairie Pigeon Hawk, is listed as Status-undetermined by U.S. D.O.I. (1973).

in the southwest on the Killdeer Mountains, and to a minor extent in some of the badlands area. The last species, big sagebursh (*Artemisia tridentata*) Nutt. is common throughout western United States but reaches peripheral status in Dunn County in the badlands area.

V. RECLAMATION - THE PROBLEMS

A. Reclamation Regulations1. Reclamation Laws

North Dakota's first reclamation law was enacted in 1969 by the Legislative Assembly, and became effective January 1, 1970. This law, Chapter 38-14 of the North Dakota Century Code, was amended in 1971, 1973, and 1975, and controls both mining and reclamation to a certain extent. As with most state reclamation laws now in effect, the North Dakota law requires a mining permit, reclamation plan, reclamation fee, and performance bond, and specifies certain reclamation procedures as minimum requirements. In general, the amendments that have been added to the law over the years tend to make the requirements more strict and the fees and bonds higher in order to assure complete reclamation. This is typical of most states and will probably continue in similar fashion (LaFevers, 1975B). When the law was first enacted, for example, there was a complicated method of assessing a permit fee. The latest amendments changed that schedule to a uniform \$50 plus \$10 per acre. In addition, the bonding requirement was changed from \$500 per acre to \$1,500 per acre, and provision was made to require a larger bond if the State Public Service Commission determines that the actual cost of reclamation may exceed the \$1,500. The law was also extended to cover all coal surface mines, whereas it had previously applied only to those mines with ten feet or more of overburden, which was recognized as a weakness in the law (Beck, 1973).

The operator of a coal mine is required by this law to regrade the affected area to approximately the original contour or rolling topography unless a different topography is necessary for an intended higher use. According to this law, "rolling topography" means a grade not exceeding that of the approximate original contour, whereas "original contour" means similar to that existing prior to mining. As Beck and Johnson state, "it is not clear that there is any important difference between the two terms" (Beck and Johnson, 1974). They also point out that the law does not specify what lower and higher land uses are.

In addition to grading, the operator was initially required to spread topsoil or approved surface material over the regraded spoils to a depth of two feet. The requirement has now been changed to read "save, segregate, and

respread surface soil or spread approved surface material ... to a depth of five feet." The definition of surface soil differs from topsoil in that the phrase "normally the A and, in some cases, the upper portion of the B horizon" has been deleted, so that it now reads "that material which, based upon an official national cooperative soils survey, is acceptable for resspreading on the surface of regraded areas to provide a medium for plant growth." Presumably, this was changed to allow for some flexibility in utilizing underlying strata that might prove more beneficial than the surface material.

Other articles in the law provide for the impoundment, drainage, and treatment of runoff water, the backsloping of final cuts, the removal or burial (in the pit) of refuse and debris, the input to the reclamation plan of opinions from the landowner and persons experienced in reclamation, and for sowing or planting approved vegetative species. There are also provisions for assuring the timely completion of all reclamation work, and for prohibiting mining in areas that the Commission determines cannot be properly reclaimed. Such areas as parks and historical or archaeological sites can thus be exempted from surface mining.

2. Disturbance Description

Most surface mining operations in North Dakota utilize draglines for overburden removal and power shovels to load the lignite. Prior to 1970, when the overburden was removed in this way, and deposited in spoil ridges and piles, the top layers, including topsoil, were placed in the bottom of a previously excavated pit and covered with the subsequently removed deeper material. The resulting landscape was one of alternating parallel ridges and valleys, with most of the topsoil and organic matter buried beneath the ridges (see Fig. 5.1). In some instances, the mining proceeded in such a manner that nearly concentric ridges were formed, with a box-cut pit in the center eventually forming a pond or lake. Such features are easily distinguishable on the North Dakota landscape, as can be seen in Fig. 5.2.

3. Effect of Legislation

Since the first reclamation law was enacted in North Dakota in 1970, the mining operation has been modified in order to facilitate reclamation. The dragline and power shovel are still used in a manner similar to the pre-Law mining operations and, consequently, the prereclamation landscape is still

Fig. 5.1. Ridge and Valley Topography Created by Surface Mining Operations

Fig. 5.2. Surface Mine Topography with Box Cut Lake in the Center of Concentric Ridges and Valleys

typically ridge and valley, or washboard topography. A modification in this landscape has been caused, however, by the requirement to "save, segregate, and respread surfacessoil" material. This requirement makes necessary the removal and stockpiling of material for spreading on top of the spoils after they have been regraded, and results in the construction of large temporary mounds. This work is usually accomplished by the use of pan scrapers and the effectiveness of stockpiling, (LaFevers, 1975A), the practice may be modified in the future by new mining plans, reclamation plans, and equipment design.

Before the stockpiled material (called "topsoil" in the original version of the reclamation law and changed to "surfacessoil" in 1975) is respread, the mined area must usually be graded to approximate the original contour. The grading is generally accomplished, as in most mine areas, with crawler dozers because of their versatility and because they, like pan scrapers, are more readily available for purchase than some of the other earthmoving equipment used in mining operations.

After grading and surfacessoil replacement are completed, the mined areas usually exhibit approximately the same general relief as the surrounding area. Because of the swelling factor (approximately 25%) associated with such excavations, however, the overall elevation of the reclaimed area is slightly higher in some cases than the surrounding area. Where the stripping ratio is around four to one or less, this swelling is compensated for by the amount of coal removed, and the reclaimed area will be level or depressed in relation to the adjacent unmined land. Both such cases exist in North Dakota, although in most instances the stripping ratio will probably be greater than four to one.

Revegetation of the regraded and topsoiled spoil areas is also required by the reclamation law (S. 45 of 1969). Numerous options are open to the mine operator, who, in planning the revegetation, must consider the advice of various state agencies and state officials, among them the game and fish department, the soil conservation committee, the forester, the geologist, the engineer, and others with experience in reclamation, and must incorporate the landowner's preferences for land use. In essence, the operator may reclaim the land for almost any purpose except forestry, which was eliminated by the 1975 amendment. The revegetation is supposed to be completed within three years of the expiration of the mining permit. If it is not completed within this time frame, however, the period may be extended. It is fortunate that the extension is allowed

since no one has yet been able to complete the reclamation process to the satisfaction of the commission within the three-year time limit. In fact, a total of only four acres has been released from the performance bond since the law became effective (see Table 5.1). Reclamation of the type required by law is relatively new in North Dakota, hence it is somewhat experimental in nature and some time is required to monitor the effects of reclamation practices. The low precipitation in the region, compared with the Midwestern or eastern states, is also a factor in the slow rate of establishment of acceptable vegetative cover. Tables 5.2 and 5.3 show the amount of land mined and under permit to be mined since the law became effective.

Prior to the enactment of S. 45, some mine operators engaged in reclamation activities on a voluntary basis. The total extent of this type of reclamation is not known, but it started out very slowly and gained intensity as the time drew nearer for action on a mandatory reclamation bill. It often consisted of grading the spoil ridges to a width of 10-20 ft, thus eliminating the saw-tooth appearance of the landscape, and planting trees or pasture crops on the low-fertility spoils. Ponds were also created in these areas for watering stock. The State Game and Fish Department has also practiced reclamation on abandoned mine areas. Their work also included tree planting and seeding and included areas now used as recreation sites. Some topsoil replacement and grading to a rolling topography were also conducted prior to the reclamation law. The Knife River Coal Company used a dragline to place topsoil on the previously mined spoils during the early 1960s, and Truax-Traer Coal Company attempted to use a bucket wheel excavator both to uncover the lignite and to spread the overburden smoothly (Carlson et al, 1960). This program was eventually changed, however, when problems developed in trying to operate the excavator in overburden that was too tightly consolidated.

4. Topsoil Segregation and Storage

The present rules and regulations for reclamation of surface mined lands in North Dakota require that the upper 5 ft of overburden (topsoil and subsoils) of the area proposed for mining be described by a soil classifier in regard to the following categories: electrical conductivity (EC), Sodium adsorption ratios (SAR), free-lime percentage and organic matter content. The portion of the soil material that has an electrical conductivity of less than 2 m-mho/cm, a sodium adsorption ratio of less than 4 (exchangeable sodium percentage (ESP) of less than 5), a free-lime percentage (CaCO_3 equivalent of less

Table 5.1. Strip Mining and Reclamation Work in Progress

Mining Completed, Reclamation Work in Progress				
<u>Name of Operator</u>	<u>Permit No.</u>	<u>Location</u>	<u>Acres</u>	<u>Remarks</u>
Baukol Noonan Inc.	4	Noonan Center	368 507	
Husky Industires	14	Dickinson	35	
Underwood Coal Company	1	Underwood	4	
Bonsness Coal Mine	8	Columbus	1	
Davenport Coal Co.	9	New Leipzig	1	
Dickinson Coal Mining Company	7	Dickinson	2	
Arrowhead Mine	13	Haynes	<u>1</u>	
		Total	919	
Reclamation Completed, Performance Bond Released or Used for Reclamation				
Kaelberer Coal Company	6	New Salem	1	
Walters Coal Mine	11	Dickinson	1	
Olin Coal Mine	16	Center	1	bond forfeited, reclamation carried out by contract
Valley Coal Company	7	Sawyer	<u>1</u>	
		Total	4	

Table 5.1 (Cont'd)

Mining and Reclamation in Progress ("Active" Permits)					
<u>Name of Operator</u>	<u>Permit No.</u>	<u>Permit Expires</u>	<u>Location</u>	<u>Acres Under Permit</u>	<u>Bond</u>
Knife River	22	1/1/77	Gascoyne	704	\$ 352,000
Coal Company	23	1/1/77	Beulah	486	243,000
	2(E) ^a	1/1/75	Beulah	352	70,400
			Gascoyne	39	7,800
Baukol Noonan Inc.	24	1/1/77	Larson	210	105,000
			Center	375	187,500
North American Coal Corp.	10(E)	1/1/75	Zap	351	70,200
	18	11/1/75	Zap	223	44,600
	21	9/1/76	Zap	133	66,500
	25	6/1/77	Zap	358	179,000
Consolidation Coal Co.	3	1/1/75	Stanton	450	90,000
	19	1/1/76	Stanton	655	131,000
			Velva	80	16,000
	26	10/1/77	Stanton	328	164,000
Husky Industries	20	1/1/76	Dickinson	40	8,000
NL Industries, Inc.	15(E)	7/1/75	Haynes	14	5,500
Geo-Resources, Inc.	17(E)	1/1/75	Williston	4	800
Sprecher Coal Co.	<u>12(E)</u>	1/1/75	New Leipzig	<u>2</u>	<u>400</u>
Totals	13			4804	\$1,741,700

^a(E) denotes extension to original permit term

Source: Reclamation Division, Public Service Commission, State of North Dakota.

Table 5.2. Total Acreage Permitted
(Active + Inactive, 1/1/70-9/30/74)

County	Acres	% of Total
Mercer	2675	46.7
Oliver	1428	25.0
Bowman	743	13.0
Burke	529	9.2
Ward	246	4.3
Stark	77	
Adams	14	
Williams	4	1.8
Grant	3	
McLean	4	
Total	5723	

Table 5.3. Coal and Leonardite
Acreage by County
(Active Permits, 9/30/74)

County	Acres	% of Total
Mercer	2660	55.4
Bowman	936	19.5
Oliver	671	14.0
Burke	210	4.4
Ward	195	4.0
Stark	40	0.8
Adams ^a	14	0.3
Williams ^a	4	-
Grant	2	-
Total	4804	

^aLeonardite acreage

than 10 on medium- to fine-textured soils, and organic matter percentage of 1.5 or more, will be considered suitable for segregation as top-dressing. The material remaining from the 5-ft depth (if any), that has an EC of less than 4 m-mho/cm and an SAR less than 10 (ESP <12), will also be segregated and applied over the graded spoils prior to applying the top-dressing (Anon. 1975). If only one of the above categories exists in the 5-ft layer, a double segregation is not employed and only that portion of the 5-ft depth which meets the above standards is saved.

Table 5.4 presents chemical and physical data averaged for the upper 5 ft of the major soil associations overlying surface minable coal deposits in the four-county region. Of the soils in the Chestnut group (see Soils of the four-county region, Fig. 2.22), soil associations 35, 36, and 37 exhibit no foreseeable topsoil segregation limitations. Associations 24, 33, and 40 do not have excessive amounts of soluble salts or sodium within the upper 60 in., but contain free lime concentrations that will limit top-dressing to an average depth of 2 ft or less. The remaining 3 ft will be segregated as a subsoil for reapplication. Soil association 29 will limit top-dressing material to a depth less than a foot based on sodium and only one additional foot for a second segregation. This soil association is limited to south-central Oliver County.

The Alkali Soil group is represented by soil association 59. Suitable plant growth substrate is restricted to the upper 10 in. for top-dressing (based on free lime) with a second foot for subsoil (based on EC).

The Regosol Soils (nos. 63,64 and 66) are nonsaline but will provide only 10 in. for top-dressing and an additional 2 ft for subsoil material.

The average depth of suitable plant growth substrate (as defined above) that will be segregated, stored and reapplied, will range from a minimum of less than 2 ft up to 5 ft with the latter condition predominating the four-county area. The data presented in Table 5.4 are average characteristics of major soil associations; the latter do not exhibit uniform physical and chemical characteristics throughout their distribution. Moreover, the actual figures at specific sites can be highly variable (note the average depth to electrical conductivity <4 of soil association 59). The regulations governing reclamation allow for a uniform resspreading of suitable plant growth material if the property (permit area) has only one owner. Should the ownership of the permit area be split between two or more parties, the suitable

Table 5.4. Textural and General Chemical Characteristics of the Soil Associations Overlying Surface Movable Coal Deposits in the Four-county Region^a

Soil Association #	Corresponding Sample # from Omodt et al., 1975	Dominant Texture	Average Depths to organic matter content $\geq 2\%$ (in.)	Average Depth to Electrical Conductivity (soluble salts) (in.)		Depth to Exchange-able Sodium Percentage $\geq 12\%$ (in.)	Depth to Free Lime $\geq 10\%$ (in.)
				≤ 2	≤ 4		
24	49,50	fine (silt)	7-12	>60	>60	>60	24
29	11-20	fine	6-10	35	40	25	24
33,40	39-48	medium	6-14	>60	>60	>60	6-30
35,36,37	26,27	coarse	6-10	>60	>60	>60	>60
59	33-38,51	Claypan from 4-10" deep	9-14	22	28 ^b	48	10
63,64,66	1-3	fine (silt)	6-10	>60	>60	34	10

^aThe data presented was interpreted from analyses on the upper 60 inches of soil core samples performed by the Soil Conservation Service and the Soils Department at North Dakota State University and presented by Omodt et al., 1975

^bIn three soil samples EC ≥ 4 occurred at depths of 5, 8 and 15 inches

plant growth material saved from each property must be respread within the boundaries of that property, unless the property owners agree otherwise. The uniform redistribution of topsoil can potentially improve the chances of successful reclamation by providing additional topsoil to locations within the permit area that originally had a lesser amount of topsoil available for segregation.

Power et al (1974) suggest that highly sodic spoils should be buried to the rooting depths of crops to be grown, e.g., 4 ft for small grains, 5-6 ft for grasses and up to 8 ft for alfalfa. If highly sodic spoils are defined as possessing an ESP >12%, McLean is the only one of the four counties that is free of this problem in the upper 5 ft of overburden (Fig. 2.22). Based on the present criteria for segregation, and on the possibility that at least 5 ft of suitable plant growth material must be returned to the recontoured spoils to insure sufficient rooting depth and successful reclamation, some surface minable coal deposits within the four-county area should not be mined. These deposits are depicted in Fig. 2.23. Power et al. (1974) points out that research data are not presently available to define the depth of surface material that must be returned, but experiments to obtain such data are under way (Table 5.5).

The soils that are segregated may be stockpiled for several years before being reapplied over graded spoils. Questions concerning the fate of soil microbiota and microbial transformation during topsoil storage remain unanswered. The soil microbiota present in undisturbed topsoil are in an aerobic environment, which is drastically altered during storage, becoming essentially anaerobic. The effects on soil microbiota of the depth of the pile and length of time stored are currently being assessed by personnel in the Land Reclamation Program at Argonne National Laboratory.

Table 5.5. Current Reclamation (Revegetation) Research - North Dakota

Study	Location ^a	Investigator
Revegetation of Mine Spoils	Glen Harold	Northern Great Plains Research Center, Mandan
The Effects of Various Depths of Topsoil added to Sodic Coal Mine spoils on Grass Establishment and Growth	The Four major Mines in Mercer and Oliver Counties	Northern Great Plains Research Center
Utilization of Amendments, Topsoil and Mulches to Improve Sodic Spoil Materials	"	"
Effect of Nitrogen, Phosphorus and Vegetative Mulch on Grass Establishment	"	"
Spoil Materials in Relation to their Original Depth as a Medium for Grass Growth	"	"
Reclamation of Strip-Mine Spoils Related to Gypsum and Topsoil Additions at Major Mining Sites in Western North Dakota	"	"
Standardization of Methods of Sampling and Analyzing Overburden and Spoil Material	"	"
Development of Perennial Grass Species Adapted for use in Strip Mine Reclamation	"	R. E. Barker, Northern Great Plains Research Center
Coal Overburden Characterization and Revegetation Studies	Primarily Mercer & Oliver Counties	Fred W. Schroer, Dept. Soils, NDSU
Coal Overburden Characterization and Revegetation Studies	Baukol Noonan & Glen Harold Mine	Warren Whitman, Botany Dept. NDSU
Selection and Increase of Woody Plants for Mine Spoils in the Northern Great Plains	Baukol Noonan-Indian Head	Warren Whitman, Botany Dept. NDSU

Table 5.5 (Cont'd)

Study	Location ^a	Investigator
Firshed Characterization and Predictions of the Dispersion of Air Pollutants	West-Central North Dakota	Juanito Ramirez, NDSU
Pollutant Effects on Plants	West-Central North Dakota	Bill Barker, Don Gallets, NDSU
Plant Establishment and Culture on Surface-Mined Lands	Knife River and Indian Mine	Armand Bauer, Glendon W. Gee, John Gilley, Soils Dept. NDSU
Chemical and Physical Characteristics of Shaped Mined Lands	Baukol Noonan & Glen Harold Mine	Armand Bauer, Glendon W. Gee, John Gilley, Soils Dept. NDSU
Surface and Root Zone Hydrology of Shaped Surface Mined Spoil Banks and Rehabilitated Lands	Indian Head Mine	Armand Bauer, Glendon W. Gee, John Gilley, Soils Dept. NDSU
Species Response to Salt Levels and Soil Texture	Mandan	"
Effect of Electrolyte Concentration and Chemical Composition of Leaching Water on the Hydraulic Conductivity of Sodic Spoil Materials and on the Calcium-exchange Efficiency of Chemical Reclamation Processes	Mandan	"
Clay Mineralogy of Samples from Recently Exposed High Walls	Four Major Mines in Mercer & Oliver Counties	"
Fertility Requirements for Sustained Grass Production on Reclaimed Spoilbanks	Baukol Noonan	"
Effect of Nitrogen Fertilizer Rate and the Effect of Fertilizer Rate and Placement on Corn and Wheat	Glen Harold	"

Table 5.5 (Cont'd)

Study	Location ^a	Investigator
Runoff and Erosion Characteristics of Shaped Spoil Materials	Indian Head Mine	Armand Bauer, Glendon W. Gee, John Gilley, Soils Dept. NDSU
Investigation of Evaporation from Strip Mine Sites by Lysimetry	Indian Head Mine	"
Reclamation of Strip-Mined Land as Affected by Depth of Surface and Subsoil Returned	Glen Harold Mine-Indian Head Mine	NDSU and Northern Great Plains Research Center
Establishment of Range Grasses on Disturbed Land Using Irrigation	West-Central N. D.	NDSU and Northern Great Plains Research Center
Effect of Phosphorus (P) Fertilizer Placement and Topsoil Depth on Growth, Rooting and Availability on Coal Mine Spoils	Knife River Mine	NDSU and Northern Great Plains Research Center, Mandan
Species Evaluation for Revegetation of Coal Mine Spoils	Glen Harold Mine-Oliver County and Mandan	NDSU and Northern Great Plains Research Center, Mandan
Increasing Soil Moisture by Surface Manipulation	Indian Head Mine	Richard Hodder, Montana State Bozeman, Armand Bauer, NDSU
Project Reclamation: A Systems Approach to Mined Land Reclamation	"	Alden Kollman, Project Reclamation U. of North Dakota
Reclamation of Spoil Banks from Strip Mining of Lignite and Western Coal-Managing Coal Wastes and Pollutants	"	W. G. Fowkes, P. G. Freeman, Grand Forks Energy Research Center
Reclamation of Western Mined-Land and Spoil Banks	"	W. W. Fowkes, M. K. Wali, Grand Forks Energy Research Center
Analysis of Overburden of BLM Land	BLM Lands in N. D.	Ernie Rivers Bureau of Reclamation Bismarck, N. D.

Table 5.5 (Cont'd)

Study	Location ^a	Investigator
Microbiology of Surface Mine Spoils	Knife River & Indian Head Mines-Mercer County	ANL-Land Reclamation Program ERDA
Microbiology of Topsoil Storage Piles	Indian Head Mine Mercer County	ANL-Land Reclamation Program ERDA
Evaluation of root response of Range Species to a layered growth medium, topsoil over spoils	ANL	ANL-Land Reclamation Program ERDA
Evaluation of the effects of water stress on the survival of seedlings established on topsoil over spoils	ANL	ANL-Land Reclamation Program ERDA

^aThe four major mines are Baukol Noonan and Glen Harold in Oliver County and Knife River and Indian Head in Mercer County.

B. Reclamation Research

1. Historical Overview

Reclamation of North Dakota coal mine spoils prior to 1963 was limited to revegetation attempts by the Boy Scouts and Wildlife Conservation groups under the supervision of the Soil Conservation Service with assistance from the State Game and Fish Department. Trees, shrubs, vines, grasses and legumes furnished by the Soil Conservation Districts and/or the State Forest Tree Nursery were planted. These early planting trails did not include any quantitative methods for evaluating species success or spoil characteristics. The data gathered on woody species was expressed as either good or poor survival. Observations of grass and legume (clover) were reported as, "legumes doing excellent and grasses, poorly."

Gwynn (1965) reported the first organized study in 1963 on revegetating strip mined lands. This study included some physical and chemical analyses of spoil material, maintenance of planting records and evaluation of species success in following years. Trees were the predominate vegetation type planted because the conclusion drawn at the time was that no amount of leveling and cultivating of spoils could restore these lands to their original agricultural potential. The trees would serve as shelter belts and be harvested for timber products, a commodity in short supply. The areas disturbed by mining would therefore be developed as recreational or wildlife management areas. During the years 1963 through 1966 over 200,000 trees were planted by Knife River Coal Mining Company on its mined lands (Gwynn, 1966).

Switzer (1969), in cooperation with the Knife River Coal Mining Company, was the first to quantitatively investigate the establishment of selected grasses, legumes, shrubs, and trees on slightly alkaline strip-mine spoils in the North and South Beulah strip mines. Trees planted in porous sandy loam and high moisture areas (troughs) had higher survival and growth rates than those planted in heavy clay, slopes, or spoil piles graded flat on top. The grass and legume seedings were unsuccessful. Switzer concluded that the failure was attributable jointly to limited rainfall and extreme soil surface temperatures (See Sec II. B).

2. Ongoing and Past Reclamation Research

The Agricultural Research Service (ARS), USDA Northern Great Plains Research Center at Mandan, North Dakota, became involved in spoil bank

reclamation in 1970. The studies initiated included; physio-chemical properties of spoils and overburden, growth chamber experiments to explore possible plant nutritional problems associated with spoils, infiltration-leaching experiments on spoils with and without amendments, and field studies aimed at the establishment of perennial grasses (Sandoval et al., 1973).

The physio-chemical properties were determined on spoils collected near Beulah, Center, Stanton, Zap, and Gascoyne, North Dakota (Table 3.10). With the exception of Gascoyne, all the sites are within the four-county study area. The spoils were generally described as moderately alkaline ($\text{pH} > 7$), fine textured with clay content often higher than 40%, saturation percentages greater than 75, CaCO_3 equivalent (free lime) ranging between 5-12%, slightly to moderately saline and frequently highly sodic (high SARs).

The analyses of overburden materials near the coal seam, which will be the surface materials after mining, exhibit the same physiochemical characteristics as the spoils sampled (Table 5.6). Using the amount of sodium present (SAR) as an indicator of potential revegetation capability, most of the overburden (except that near the premined surface) will present problems in vegetation reestablishment (Sandoval et al., 1973).

Plants in growth chamber studies exhibited restricted growth on unamended overburden, but growth was normal when both phosphorus (P) and nitrogen (N) were added. Separately, neither P nor N appreciably increased growth (Sandoval et al., 1973). The growth response with the addition of minor elements indicated neither deficient nor toxic levels of the minor elements in the overburden.

The ARS field studies were initiated with plots on recently graded spoils at sites near Stanton, in Mercer County (Consolidation Coal Co.). The treatments were designed to alleviate the fertility, permeability, and structural limitations of the spoil substrate (Sandoval et al., 1973). The amendments applied included straw, gypsum, topsoil (2 in.), topsoil plus straw, and topsoil plus gypsum. Untreated plots served as controls. Different fertilizer concentrations were incorporated into the treatments and the plots were seeded with a native grass mixture. The plots with 2 in. of topsoil showed, by far, the best grass growth. After one year, the plots containing gypsum had an SAR of 13 in the 0-6-in. layer compared to 23 for the control plot. Sandoval et al. (1973) suggest that effects of adsorbed sodium can be reduced with a chemical amendment (gypsum) or by applying a thin surface layer of topsoil.

Table 5.6. Physical and Chemical Characteristics with Depth of Overburden at Three Sites in Western North Dakota before Disturbance by Mining
(Adapted from Sandoval et al., 1973)

Depth (ft)	pH	CaCo3 equiv. (%)	Sat'n. (%)	E. Cond. (mmhos)	SAR	Nitrogen	
						NH ₄ -N (ppm)	NO ₃ -N (ppm)
<u>Stanton No. 1, Level Site</u>							
0-2	7.6	2	70	1	1	nd	nd
2-11	7.6	13	46	2	1	1	2
11-20	7.4	8	86	5	7	2	11
20-30	8.2	13	122	2	15	2	2
30-57	8.5	10	150	2	39	12	2
57-70 ^a	7.1	14	-	3	52	13	2
70-90	8.2	13	180	1	34	14	1
90-98 ^a	6.8	10	-	3	25	14	2
<u>Stanton No. 2, Hilly Site</u>							
0-3	7.0	2	50	2	2	1	1
3-10	8.2	15	128	8	13	3	6
10-18	8.0	7	181	5	15	2	34
18-23 ^a	4.5	3	-	9	15	5	37
23-50	7.7	11	142	3	31	10	2
50-60 ^a	6.9	8	-	5	30	16	3
60-96	8.1	13	164	2	30	15	2
96-104 ^a	7.0	11	-	2	22	16	2
104-109	7.5	5	158	2	25	17	2

^aLayers with lignite.

The continued study of these field plots has shown that three years later, the only remaining native grass planted on the 1970 plots was slender wheatgrass, a relatively unpalatable species adapted to saline areas. Forage production was low on these plots, suggesting that the area had been revegetated but productivity had not been restored (Power et al., 1974).

Current research into methods for revegetating highly sodic spoils includes: (1) covering the sodic spoils with surface soil or other material suitable for plant growth; or (2) altering the physical and chemical properties of the spoils through the use of amendments, mulches, tillage, or other management practices (Power et al., 1974).

The 1970 ARS plots discussed above had the best grass growth with a 2-in. covering of topsoil, the only thickness tried in these experiments. Research is under way to assess the effects of covering spoils with as much as 9 ft of soil material. In addition, experimentation by the ARS includes the effects of segregating surface soil and subsoil; the effects of soil thickness and depth on different cropping systems and plant species; and the effects of using soil material differing in physical and chemical properties (USDA, 1975).

The amelioration of spoils includes reducing adsorbed sodium, thus improving the physical state of the spoils or enhancing water infiltration and root development by the addition of mulches to prevent the spoil surface from sealing (Power et al., 1974). The successful reduction of adsorbed sodium includes dispelling sodium from the clay micelles via an exchange reaction with a cation such as calcium, and leaching the displaced sodium down through the spoil material to a level beyond the rooting depths of the plant species used in revegetation. Gypsum and sulfur have been used with some success for reducing the amount of adsorbed sodium in moderately sodic spoils but are not as effective in highly sodic spoils (Power et al., 1974). Calcium chloride is perhaps the most effective if leaching water is available, however, its use on a large scale is not economical.

Research into the problems such as water infiltration, tight (clay) spoils, amendments and amounts to be added, depth of topsoil to be reapplied, adapted species and the effects of time are continuing with results still forthcoming. Table 5.5 lists the revegetation research projects, ongoing in North Dakota, that have been uncovered to date.

3. Future Research

Numerous investigations are currently under way on the problems associated with achieving successful reclamation of drastically disturbed lands. The problems discussed in this section will specifically relate to surface coal mining activities not presently under investigation in North Dakota. It's quite probable that some of these problems are being or have been studied in other regions of the country, but this does not exclude them from further study in North Dakota. Each mining activity and each geographical region of the country has reclamation problems that may or may not be applicable to other types of mining or other regions. Similarly, the solution of a given problem in a given region may not be applicable to other geographical regions. Finally, the future research suggested in this section should not be interpreted as a complete list, or as original ideas conceived totally by the author. The suggestions are somewhat general, and originate directly and indirectly from individuals involved in some aspect of reclamation.

The native grass-planting seed mix suggested in the January 1974 Guidelines for Reclaiming Coal Mine Lands in North Dakota does not include blue grama, Bouteloua gracilis. Blue grama is a warm-season grass, and either because of the difficulty in establishing warm-season species and/or because of limited seed source availability, it has been omitted as a revegetation species. It is assumed that blue grama will invade over time the reestablished grassland from adjoining stands or from dormant seeds in the replaced surface soil material (Dodds et al., 1974).

Whitman and Wali (1975) refer to several studies that have shown blue grama to be important as a major forage producer and a major contributor to ground cover. Blue grama is also a highly drought resistant species. After the "Great Drought" of 1934, blue grama was found in areas within the central plains previously occupied by more mesic grass species (Weaver et al., 1936). Work done by Mueller and Weaver (1942) on soil and atmospheric drought resistance of prairie grass seedlings substantiated field observations made during the drought. Among the fifteen species included in the study, blue grama was ranked first, followed by buffalo grass. These characteristics of blue grama make it a valuable species of the mixed-grass ecosystem in North Dakota. Future investigations concerning blue grama should include the development of methods for overcoming the difficulties in establishment and for increasing seed availability. The species and quantities of viable seeds within the topsoil after

storage should be determined as a means of assessing the contribution and importance of these soils in revegetation. Is blue grama from adjoining areas invading plant communities that have been reestablished on lands surface mined for coal in North Dakota? The above investigations will provide important contributions towards successful reestablishment of productivity.

The short- and long-term effects of utilization of lands reclaimed for pasture or crop production need to be studied. If lands affected by surface mining for coal have been accepted as being restored to appropriate reuse and the operator is released by the North Dakota Public Service Commission from further obligations pertaining thereto, they are considered to be reclaimed. However, based on that premise, those areas disturbed since 1970 have not been as yet reclaimed. At present, land being reclaimed is idle for a period of approximately six years following seeding. Some lands soon will be so classified and grazing or cropping will commence. It is critical that these lands have certain parameters monitored such as productivity, species composition, plant cover, grazing intensity, physical and chemical characteristics of the plow layer, soil microbiology and soil mineralization. The results of this monitoring program should be used to develop management guidelines for postmining land use and to assess the state of the art of reclamation.

The use of impoundments as settling basins during mining to reduce the suspended solids concentration of effluents has proven valuable in minimizing sedimentation in receiving streams. The settling basins and impoundments formed adjacent to the highwall after the final cut were often not backfilled following cessation of mining activities, and consequently many such impoundments now exist in the western coal regions exhibiting an array of water quality and biotic characteristics. Impoundment characteristics range from alkaline or saline types with little or no development of aquatic biota, to those with good water quality and substantial use by wildlife, as well as for recreation, irrigation, and livestock watering. The principal factor determining use of the impoundment is its water quality, which is generally a result of the physical and/or chemical composition of the mine spoils, these are dependent in turn on the characteristics of the original overburden and also on the mining and reclamation technologies employed.

In consideration of the value and important uses of impoundments, research should be conducted to determine the feasibility of establishing impoundments on mined lands for multiple use by man and wildlife. The development

of techniques or recommendations for the reclamation of existing impoundments should be included in these investigations.

The future research discussed in this section involves revegetation, agricultural utilization, and viable impoundments, topics that are directed primarily towards the economic benefit of man. From an ecological point of view, the subsequent ability of wildlife to recolonize revegetated areas needs to be assessed. A native grassland is a diverse community composed of many grasses, forbs and shrubs, but typical reclaimed pastureland, if planted with only five grass species and one legume, lacks the original diversity. The lack of diversity on reclaimed land should limit the reestablishment of many faunal communities. Studies should be conducted comparing faunal recolonization on lands seeded according to the Reclamation Guidelines (native grassland plantings) and on lands that have been revegetated by acceleration of the process of natural succession. The latter revegetation technique is being researched by Dr. Warren Whitman, Botany Department, NDSU, Fargo. First, a mixture of common weed seeds are broadcast seeded. The following year, a mixture of native grass bulk material (stems and mature flower heads) is harvested from undisturbed grass stands, as a seed source, and spread on the weed stand. This method has the potential of reestablishing plant diversity that may be important for faunal recolonization.

All of these studies help to illustrate that with proper care and amendments, productivity can be returned to mined lands. Much more research is needed, however, to develop methods to make reclamation faster, more predictable, and especially more cost-effective. In the past, reclamation in North Dakota has been retarded primarily by the same factor that has dominated reclamation in all other states. Extensive reclamation work is expensive. If it could have been done inexpensively or free, all the spoils in North Dakota would have been made productive before the mine closed. The area of reclamation economics is one which is in need of development, and research is needed to reduce costs and enhance benefits.

VI. RECLAMATION OPTIONS

A. Descriptions

The possible reclamation options to be considered include; (1) amendments added to the upper layers of the spoil to alter its physical or chemical properties, (2) no topsoil segregation, (3) single or double segregation of "topsoil," (4) application of fertilizers, (5) seeding mixtures, (6) irrigation, (7) postmining land use and (8) no reclamation. The latter category is not a true option in view of Chapter 38-14, Reclamation of Strip-Mine Lands of the North Dakota Century Code. Each of the other options will be discussed in the following paragraphs.

The North Dakota reclamation law requires segregation and reapplication of a suitable plant growth material if the following criteria are met: top-dressing must have an EC less than 2 mmho/cm, and SAR <4 (ESP<5), a free lime percentage <10 and an organic matter percentage of 1.5 or more; subsoil must have an EC <4 and SAR <10 (ESP <12). If these values are exceeded in the soils of the area proposed for mining, it is doubtful that a permit to mine would be granted, due to the questionable success of restoring productivity. The option of no topsoil segregation is thus unlikely.

Research has demonstrated that the sodium problem associated with spoils can be partially alleviated with gypsum or sulfur. In one continuing study, the SAR in the surface six inches of spoil was reduced about 35% four years after gypsum was added at a rate of 10 tons per acre (USDA, 1975). Sulfur appeared to cause a similar reduction in SAR. The addition of gypsum or sulfur was beneficial if the initial SAR of the spoil did not exceed 11. According to the authors, these are tentative findings, however, and are the results of research in progress. They should not necessarily be considered conclusive evidence of predictive results.

Laboratory and field experiments are being conducted by Agricultural Research Service (ARS) at Mandan to evaluate calcium chloride as a chemical amendment to alter the adsorbed sodium concentrations. A range of 15-30 tons/a, combined with 2.5-5.0 acre-inches of water for leaching, may chemically reclaim the upper 12 in. of spoil. Research results indicate that only days are necessary

to achieve reclamation, compared to years with gypsum or sulfur. Unfortunately, the calcium chloride method is not economically feasible for large areas at present.

A double segregation into top-dressing and subsoil (based on the definition of suitable plant growth material above) of the upper 5 ft of cultural soils if the top-dressing layer is >8 inches (Omodt et al., 1975). A soil overlying a surface minable coal deposit may have a surface layer that qualifies as subsoil instead of top-dressing. After segregation of this subsoil and reapplication over the contoured spoils, it may be necessary to add gypsum if high SARs exist.

Phosphorus (P) and Nitrogen (N) fertilizers could be added to the re-spread topsoil prior to planting. The availability of N and P in topsoil stored for some period of time has yet to be determined. It is known that plant-available N is found in relatively high levels in fresh spoils but not in old ones (Power et al., 1974). The addition of 21 lb/a P in a 1971 study changed the dry matter yield of barley from 200 lb/a without P, to over 1500 lb/a with added P (Sandoval et al., 1973). Increasing the P rate from 20 to 200 lb/a resulted in an additional gain of 500 lb/acre. Nitrogen plus P on fresh spoil gave a response similar to that for P alone, indicating N application was not necessary. The recommended fertilizer quantities for vegetation establishment are 10-20 lb/a of N and 50 lb/a of P.

The seeding mix and ultimate postmining land use are almost inseparable options and are covered jointly. Land returned to cropland potential should be seeded to tame grasses and legumes (Table 6.1). The resulting precropland community should be maintained for 3-5 yr before cropping. Land with lower capability classes should be returned to grassland by planting native grass seed mixtures (Table 6.2).

Wildlife habitats can be established by planting adapted trees and shrubs in high moisture areas such as natural drainage channels or drainageways developed during spoil bank contouring.

Impoundments that served as sediment ponds during mining can remain as watering areas for livestock and as habitat for wildlife, providing the resulting water quality is suitable.

Table 6.1. Precropland Planting Mix^a

Species	lb seed/acre	
	Mix 1	Mix 2
Crested wheatgrass	7	4
Smooth brome grass	-	3
Slender wheatgrass	3	3
Alfalfa	1.5	1.5
Sweet clover	<u>0.5</u>	<u>0.5</u>
TOTAL	12.0	12.0

^aFrom *Guidelines for Reclaiming Coal Mine Lands*, Jan. 1974. Prepared jointly by D. L. Dodds and W. C. Whitman, NDSU, Fargo; Research Staff, ARS, Mandan; Technical Staff, SCS, Bismarck

Table 6.2. Native Grassland Planting Mix^a

Species	Nos. seed/acre
Western wheatgrass	5
Green needlegrass	3
Slender wheatgrass	2
Little bluestem	2
Side-oats grama	1
Sweet clover	<u>1</u>
TOTAL	15

^aSource: same as Table 6.1

The reclamation law requires that the land designated for agricultural purposes be restored to the level of inherent productivity equal to or greater than that which existed in the permit area prior to mining. The reclamation plan (Appendix E) submitted by the mining company as part of the application to obtain a permit to mine, includes sections on land use prior to surface mining and intended postmining land use. The latter acreage is usually very similar to the former. In addition, the surface owner has an input as to his post-mining land use preference. The postmining land use options that exist, therefore, are limited to three major categories; (1) cropland, (2) pasture, and (3) stock-watering ponds.

Irrigation is an option that has not been incorporated into reclamation regulations in North Dakota. Before irrigation can be considered as a feasible element of reclamation, the quantity and quality of the water supply must be determined. If water is available it could positively influence the successful establishment of seedlings during dry years and also aid in the leaching of sodium from the root zone following applications of gypsum, sulfur, or calcium chloride. One drawback of irrigation is the cost involved. A 1971 study on the costs and returns of sprinkler irrigation systems in North Dakota yielded an average purchase price of over \$28,000; associated annual fixed and variable costs averaged over \$21 per acre (Taylor et al., 1972). Each system included in this study irrigated on average of 190 acres with 7.9 inches of water.

B. Reclamation Economics

1. Introduction

The purpose of this section is to identify some of the major factors responsible for variations in the cost of reclamation in North Dakota, and to give some indication of the relative costs attributable to these factors, as well as estimating the overall costs and benefits directly related to reclaiming the mined areas. Regardless of the technological advances made in recent years in the art, reclamation is still in the experimental stages. This is true not only of reclamation in North Dakota but of reclamation in general. The processes of topsoil removal and replacement, overburden recontouring, and revegetation, when coupled with other procedures, do not reproduce previously existing physical conditions. Hydrologic conditions, overburden compaction and composition, the availability of nutrients and toxic elements, and numerous other factors are not restored to their premining situation. At the surface, it is technologically possible to create from a mined area a site that potentially is at least as productive and valuable as it was before mining. Even this operation should be considered experimental, however, because it has not generally been demonstrated that reclamation can be economically profitable to the operator. A primary goal of reclamation research, therefore, should be to develop technology that will improve the cost-effectiveness of reclamation programs. When this is done, reclamation laws to ensure the value and reuse of the land will no longer be needed, and the funds that currently must be spent to administer them can be used in the reclamation process, or to reduce the price of the coal. This principle has

already been proven in Hawaii, where demand for land is so great that mined areas are reclaimed as soon as possible because of the profit that can be made on the reclaimed land. According to Christopher Cobb, Chairman of the Board of Land and Natural Resources of the State of Hawaii, there is no longer a necessity for state control of land reclamation there because industry takes the initiative to return the land to productive use.

In the State of North Dakota, as in at least 36 other states, minimum reclamation standards are dictated by law. These laws indicate that the citizens of the state want to have a role in the reclamation of their land and that they are either willing to pay the price for that reclamation or they think they will have to pay a higher price (social costs) for not reclaiming. Some citizens may not of course realize that it is the consumer who has to pay for the reclamation. However, even though there may be short-term situations in which the operator must absorb some of the costs, in the long term these costs will be reflected in other contracts so that profit levels are maintained no matter how expensive reclamation becomes. The alternatives are to stop production or provide financial support for reclamation.

The cost of reclamation that must be paid by the energy consumer is the cost that is not recovered by the operator from the increased value of the land, sale of products resulting from the reclamation, or other related sources. However, on the basis that some costs may be recovered, there are at least two philosophies concerning the theoretical maximum that should be spent on reclamation. One of these philosophies, once considered industry's viewpoint, is that the reclamation costs should not exceed the value of the land after reclamation. The premise is that it is not advisable to spend several thousand dollars per acre to create land worth perhaps only a hundred dollars per acre. Since the public would have to pay the rest in higher energy prices, the philosophy is that the excess could be more profitably spent on other things (social programs, schools, etc.). Also, if reclamation costs have to be added to the price of the coal, the competitive position of the industry in the energy market is worsened. Mining companies should, therefore, be against unrecoverable reclamation costs even if they can pass these costs on to the consumers. The other philosophy, which might be considered the environmentalist philosophy, is that if the coal is to be mined, the land must be returned to premining conditions regardless of the cost. The premise here

is that the value of the coal that can be recovered must be sufficient to pay the reclamation costs. In other words, if reclamation of the land cannot be economically justified, then the coal cannot be mined.

A compromise philosophy has been adopted as the basis for reclamation laws. In this thesis, an acceptable minimum level of reclamation is established by rather arbitrary criteria, and the operators are required to meet or exceed these criteria regardless of the cost. However, if a criterion can be shown to cause an unreasonable hardship in a particular case, provisions are made for the granting of a variance.

2. Reclamation costs

The estimation or prediction of reclamation costs is a very imprecise process. Even for a given site, it is an unmanageable task to list all the variables and their relative effects on the cost of an overall reclamation program. Some of the factors through which reclamation costs are channelled are shown in Fig. 6.1. It should be noted that several options are usually available throughout the reclamation process, and as these options are exercised, costs will vary accordingly. They will also vary in relation to physical and economic conditions that may not be reflected in Fig. 6.1. Further complicating the process of estimating costs is the fact that often operators do not separate reclamation costs from extraction costs in the detail necessary for accurate predictions, and many of the costs are not easily quantifiable. Certain costs should be partially apportioned to the reclamation program and partially to the extraction process. An example of this is that portion of the operating cost of the dragline that results because selectively placing overburden reduces total operating costs by making contouring less expensive. The costs that are not usually quantified are the opportunity costs, such as the loss of income or social benefit from a given land use that results because the land is reclaimed for another use. The loss of a forest or game preserve that is mined and reclaimed as a residential development is a cost that must also be accounted for.

In the case of North Dakota, each operator has a different method of reporting reclamation costs and includes a slightly different set of parameters in figuring his totals. None of the operators contacted could isolate all the factors for a given mine precisely enough to arrive at exact figures for reclamation separately from other processes. An examination of the data provided by

Fig. 6.1. Reclamation Cost Factors

the operators of the state's four largest mines does, however, provide considerable insight into the approximate range of costs of ongoing reclamation.

In each case data compiled were for 1973, 1974, or 1975, and these data have been combined for analysis to ensure confidentiality. Generally, costs for each operation were similar, although exact differences could not be figured because of differences in the ways in which data were compiled. In most cases, however, grading was the single most important cost factor through 1975. The minimum reported for grading was 23% of the total reclamation cost. Backfilling accounted for an additional 15% in this operation, and ranged to as high as 32% in other cases. The maximum percentage cost assigned to grading was 55% of the total, but this includes a part of the cost of backfilling. The total cost of reclamation at these sites varies from a minimum average of \$2400/a under the 1973 law requirements (2 ft of topsoil) to approximately \$6613/a under the requirements of the 1975 law (up to 5 ft of topsoil). At \$2400/a, total costs were broken down as follows:

	<u>\$/Acre</u>	<u>% of Total</u>
Grading	1320	55
Topsoil removal	480	20
Topsoil replacement	192	8
Engineering and administration	336	14
Seeding and fertilizing	72	3

These costs include a maximum of 2 ft of topsoil removal and replacement and do not reflect a separate cost for backfilling. The topsoiling costs in this average 21¢/cu yd. At \$6613/a, topsoiling costs averaged 50¢/cu yd, and 5 ft of topsoil were removed and replaced. At this rate, total costs break down as follows:

	<u>\$/Acre</u>	<u>% of Total</u>
Grading	1500	23
Topsoiling	4033	61
Backfilling	1000	15
Seeding and fertilizing	80	1

In this case, topsoiling is the most expensive part of the operation, and it should be noted that if in the previous case topsoiling costs were projected for 5 ft of material (8067 cu yd/a), these costs would be \$1699/acre. It can, therefore, be stated that the topsoiling requirements of the 1975 law

will make topsoiling the most expensive factor in the reclamation program. This is further substantiated by data from another site in which it was stated that topsoiling costs would go from a maximum of \$800/a to \$3000/a or equivalently \$600/acre-foot.

Another set of figures, using 1973 requirements, indicates that reclamation could be achieved at one site for \$3165/acre. Forty-one percent of this cost is for topsoiling, 25% for grading, 32% for backfilling, and 2% for seeding and fertilizing.

Using published production and Btu data, it is possible to estimate the cost of reclamation per ton of coal and per million Btu. Reclamation costs per ton of coal averaged 47.2¢ (1975 law), 35.7, 22.6, and 17.0¢ (1973 law) for the four sites mentioned. Another mine reported only that reclamation costs were \$1200-\$1500/a in 1974, and that they would be \$2025/a under the new law. This would be 10.5¢/ton at this site. Using the average Btu ratings for each mine (6500-7100 Btu/lb), reclamation costs are calculated at 3.5, 2.6, 1.7, 1.2, and 0.8¢/MBtu, respectively for these sites (see Table 6.3). At a fifth site, an estimate of \$5000/a was given for total reclamation costs, and the ¢/MBtu costs at that rate are given in Table 6.3 for comparative purposes only, since no attempt was made to break costs down by factors as was done for the other four data sets. Some of the discrepancies in these figures are accounted for by the differences in the physical conditions under which mining takes place.

Some of the other relevant factors include differences in equipment use at the various sites, operator efficiency, wages, overhead, and many others. As an example, the speed at which equipment is operated can affect not only overall costs, but also the reclamation plan itself. Watts (1975) explains that since loading, unloading, and haul distance are major expense factors in moving topsoil, the speed at which an operator can complete a cycle can determine whether topsoil should be stockpiled or hauled a greater distance to be spread immediately. He states that since stockpiling requires the topsoil to be loaded and unloaded twice, the time spent in this extra effort could be used to transport the material a greater distance. "If loading and unloading takes 1.2 min and hauling is done at 25 mi/h, then the time spent loading and unloading to stockpile is equal to the time taken to haul the topsoil an extra 2640 ft or 1/2 mile. If stockpiling can be avoided by an extra haul distance (up to 1/2 mi), then stockpiling of topsoil should be avoided," according to Watts. If an operator can drive faster than 25 mi/h

Table 6.3. Representative Estimated Reclamation Costs for Selected Sites

\$/acre	¢/ton	¢/MBtu
6615	47.2	3.47
5000	35.7	2.60
3165	22.6	1.66
2400	17.0	1.23
2025	10.5	.75

then the haul distance can be lengthened, whereas a slower drive might require stockpiling in lieu of a shorter haul. All such factors can affect reclamation costs.

Reclamation practices are approximately the same for each of the sites previously mentioned, since the land currently being mined is primarily used for grazing or hay production prior to mining, and is being reclaimed for a similar land use. Differences in reclamation procedures occur, however, and result in higher or lower reclamation costs. For example, in some cases less than 2 ft of suitable plant growth material is available, whereas the reclamation law requires the segregation and replacement of up to 5 feet. The N.G.P.R.P. reports estimate reclamation costs at \$700-\$1800/a for most of the Northern Great Plains area. These costs, however, are based on a maximum of 18 in. of topsoil replacement, and do not include water costs for irrigation.* Water costs are reported to add as much as \$325/a to the total costs, bringing the maximum to \$2125/acre. Although this is still considerably lower than the figures for the North Dakota mines examined in this study, most of the difference is probably accounted for by the fact that the N.G.P.R.P. figures are based on data from the early 1970s, and that a maximum of 18 in. of topsoil was being salvaged. Table 6.4 shows the relationship between cost per ton, cost per acre, and seam thickness as determined by the N.G.P.R.P.

Some costs related to land reclamation are not included in these quantifications. These include whatever environmental degradation or social costs that might result from treatment of the spoils. Spoil compaction may cause a higher rate of erosion, which will result in increased stream sedimentation, loss of agricultural productivity, etc. Also, fertilization or other amendments may, over a number of years, have a cumulative effect that may not even

* Personal communication with Paul Packer (N.G.P.R.P. report author), 2-2-76.

Table 6.4. Onsite Rehabilitation Costs^a
(Costs per ton based on the N.G.P.R.P. Report)

Coal seam thickness, (ft)	At a minimum cost of \$700/a (¢/ton)	At a maximum cost of \$1800/a (¢/ton)
10	4.94	12.71
30	1.65	4.24
150	0.30	0.77

^aAssumes 1417 tons of coal per acre-foot and a minimal 80% recovery of coal

*Source: *Effects of Coal Development in the Northern Great Plains*, N.G.P.R.P., p. 54 (April 1975)

be known at this time. As explained in N.G.P.R.P., Surface Resources Work Group Report, however, environmental impacts from rehabilitation treatments are generally short-term tradeoffs that are necessary to reestablish vegetation and return sites to their former or higher productive capacities, to their original or improved vegetative covers, and to their former or more suitable land uses.

3. Effectiveness of Reclamation

The benefits directly related to a reclamation program are probably even more difficult to assess and quantify than are the costs. One method of measuring program effectiveness is to compare the determined productivity and value of the land prior to mining with those of the reclaimed site. This is a most popular method, and one that is sometimes espoused by environmental advocacy groups and used as a guideline in preparing state and federal reclamation bills and laws. At least eleven states currently have "original contour" clauses in their reclamation laws, and seven require original, self-regenerative, or natural vegetation. Although this concept allows for a standard against which to measure productivity of the reclaimed land, it almost completely precludes the benefits that can be derived from reclamation planning and from reclamation designed to create a landscape that will fulfill a specific land use need of the local community or state. It has been demonstrated elsewhere that land reclaimed for exotic uses (i.e., recreational housing sites in a forested area, or farm community) can be many times more valuable than unmined land in the same locale (LaFevers, 1974B). It has not been demonstrated, on

the other hand, that the condition in which unmined land currently exists is the best of all possible conditions, and that it should, therefore, be returned to that state. In many cases the original (premining) land use will be the most productive and the most feasible choice in a reclamation plan. However, the opportunity to make that decision, after consideration of alternatives, should not be denied.

As an alternative to these "original conditions" concepts, one must consider the reclaimed area relative to the conditions prevalent after mining but before reclamation, rather than prior to mining. After mining, the land might actually have a negative value, since a debt is owed on it that must be paid before a profit can be realized. The site occupies space, but in most cases the owner would be better off if he did not own it since the law will require him to expend capital in excess of the amount for which he could purchase adjacent similar land, or sell the property. An advantage exists, however, in that the owner (or operator) now has the opportunity and mandate to create an entirely new landscape designed specifically to suit the needs of a projected use.

Many of the benefits that would accrue as a result of this reclamation are almost intangible, and although it is sometimes possible to quantify many of them, to do so is beyond the scope of this report. These "social benefits," as they may be called, include beautification of the landscape, or aesthetic value, provision of noncommercial recreation areas, both public and private, pollution abatement, erosion prevention, preservation of wildlife resources, and maintenance of an acceptable self-image by the residents of the mined areas.

Many of the benefits attributable to reclamation can be quantified, as previously stated. In North Dakota, however, it is difficult to measure these benefits because until recent years, very little mining, and consequently reclamation, was conducted in the state. In fact, through 1975, a total of only four acres had been satisfactorily reclaimed under the reclamation law for a long enough time to have had the bond on them released. In addition, the North Dakota Century Code prohibits mining companies from operating farms for profit. Therefore, there is a very limited amount of data available concerning production from reclaimed lands. Nor are data available from which to compute the value of reclaimed land, since none has yet been sold. Some research has been conducted, however, to determine what productivity levels might be expected of these lands when reclamation is completed. In general, it has been stated

that in comparison with most other mining areas of the Northern Great Plains, the west-central North Dakota sites have a medium to high rehabilitation potential. Table 6.5 shows the relative rehabilitation potentials for several mine sites as determined by the N.G.P.R.P. (For a complete explanation of the technique, see N.G.P.R.P. Surface Resources Work Group report, which explains that the rehabilitation-response units are based on soil productivity and stability, vegetation suitability and availability, and the amount and distribution of precipitation.)

The N.G.P.R.P. also describes the reclamation work that has been done at each of several sites in North Dakota. The following descriptions are from that report:

Baukol Noonan (Center). This mine is a few miles southwest of Center, North Dakota, on rehabilitation response unit 35-5-16. Terrain is rolling and the soil is loamy. The overburden is sandy and shaley. Spoils on this mine have been unusually well shaped and blended into the natural landscape.

Research has shown that the overburden on lignite coal deposits that characterize most of North Dakota contains substantially higher quantities of sodium than does overburden on subbituminous coal deposits farther west in eastern Montana and northeastern Wyoming. This difference has given rise to more serious sodium toxicity problems in connection with rehabilitation efforts on surface mines in North Dakota than has been experienced on most surface mines in Montana or Wyoming. Sodium content of overburden from Baukol-Noonan's (Center) North Dakota mine, while somewhat higher than that encountered on the Montana and Wyoming mines, is still substantially less than that on any of the other major North Dakota mines. Accordingly, overburden on this mine forms a relatively favorable planting medium, limited only by the rather mediocre inherent productivity of soil association 35.

A variety of cool-season grasses and legumes have been planted on this mine, including western wheatgrass, big and little blue stem, sweet clover, and crown vetch. Success of the various plantings is generally good, including those areas drilled in the fall of 1972. This soil association has very poor stability characteristics, and deep drilling has occurred where spoil slopes were left too steep for cross-slope finish work. Where spoils have been drilled up and downslope, a high erosion hazard exists. Level or gentle slopes and cross-slope cultivation appear to be essential for permanently stable reclamation of this rehabilitation response unit.

Table 6.5. Comparison of Rehabilitation Potential Rankings
from Actual Rehabilitation Efforts and from
Classification of Rehabilitation Response Units

Mine No.	Mining Company and Mine	Rehabilitation Response Unit	Rehabilitation potentials		
			From actual rehabilitation		From classifi- cation rankings
			Descriptive	Numerical	Numerical
COAL OPERATIONS					
1	Wyodak Resources Development Co. (Wyodak)	117-6-14	Good	+6	+1
2	AMAX Coal Co. (Belle Ayr)	117-6-13	Fairly good	+3	0
4	Pacific P&L Co. (Glenrock)	126-6-14	Fairly good	+3	-1
5	Bighorn Coal Co. (Bighorn)	25-6-15	Good	+6	+5
11	Decker Coal Co. (Decker)	117-6-15	Fairly good	+3	+2
12	Westmoreland Coal Co. (Sarpy Creek)	31-4-14	Fairly poor	-3	-2
13	Peabody Coal Co.	31-12-16	Fairly good	+3	+2
14	Western Energy Co. (Colstrip)	31-12-16	Fairly good	+3	+2
15 ^a	Knife River Coal Co. (Savage)	26-5-13	Good	+6	+2
20 ^a	Baukol-Noonan Inc. (Center)	35-5-16	Fairly good	+3	+1
21 ^a	North Amer. Coal Co. (Zap)	35-5-16	Fairly good	+3	+1
22 ^a	Knife River Coal Co. (Beulah)	23-5-16	Good	+6	+5
23 ^a	Consol. Coal Co. (Stanton)	35-5-16	Fairly good	+3	+1
24 ^a	Baukol Noonan Inc. (Noonan Strip)	19-9-15	Very good	+9	+7
25 ^a	Consol. Coal Co. (Velva)	19-9-16	Very good	+9	+8
26 ^a	Knife River Coal Co. (Glascoyne)	25-5-15	Good	+6	+5

^aNorth Dakota mines

North American Coal Company (Zap, North Dakota). This mine, located near Zap, North Dakota, is situated on rehabilitation response unit 35-5-16. Overburden resulting from mining here has been shown to have the second highest average sodium content of eight major mine samples in North Dakota. Spoils from this mine have the highest sodium adsorption ratio and pH of any mine for which records are available in the Northern Great Plains. The fine-textured spoil materials consist largely of montmorillonitic clay, are very low in natural organic matter, and are highly toxic to vegetation.

Overburden from this mine -- except that within approximately 10 ft of the original surface -- presents a tremendous rehabilitation problem if placed on the surface of graded spoils. Analyses of North Dakota overburden by depth increments indicate that the sodic nature of the spoils increases with depth within the feasible depth range for surface mining. Experience on this mine indicates that, over a period of several years, adsorbed sodium in the mine spoils can be reduced somewhat with a chemical amendment (gypsum), or it can be circumvented by applying a surface layer of soil. Little success has been achieved in rehabilitating raw spoils originating from deep sodic layers. The dispersing effect of sodium renders the spoil material extremely unstable, highly impermeable, and erodible.

Where graded spoils have been finished off with overburden from shallow depths, immediate fertilizing with phosphorus, followed within 2 years with nitrogen together with vegetative mulch disked into the spoil surface, resulted in grass production increases of as much as 1000% compared to the production on raw spoils.

It seems fair to conclude that, on this mine and others having similar adverse spoil characteristics, further research is needed to overcome the toxicity problems before successful and lasting direct rehabilitation of these spoils can be achieved. Where shallow nontoxic overburden or surface soil can be used to finish spoil surfaces, successful rehabilitation to mid-grass prairie, or, in some cases, to cultivated grain crops, can be achieved.

Knife River Coal Company (Beulah, North Dakota). This mine is located on rehabilitation response unit 23-5-16. Overburden materials on this mine have essentially the same sodium and pH characteristics as those found in overburden on the North American mine at Zap. Little real success has been experienced

in attempts to rehabilitate raw surface spoils originating from deep levels in this mine. On the other hand, attempts to rehabilitate spoils originating within approximately 10 feet of the ground surface or to rehabilitate spoils dressed with surface soil, utilizing both introduced and native grasses and legumes, have been very successful. One of the reasons for this success is due to the inherent good stability and productivity characteristics of soil association 23.

Consolidation Coal Company (Glenharold, North Dakota). This mine -- near Stanton, North Dakota -- is in rehabilitation response unit 35-5-16. The soil, native vegetation, and precipitation characteristics of this mine are similar to the North American mine at Zap. However, the terrain is considerably steeper and more hilly. The soils are loamy but shallower because of the steeper topography. Overburden is dominantly grayish-white, and the surface dries hard after being wet. This indicates a high sodium content, and tests of overburden confirm that the sodium content at this mine -- while not as high as in the Knife River mine at Beulah or in the North American mine at Zap -- is still toxically high. Soil association 35 has very poor stability characteristics, and these are reflected on the steeper spoil slopes where rilling and gullyng have occurred.

Where overburden from shallow depths or topsoil has been used to finish the surface of graded spoils, good rehabilitation results have been achieved. Starting recently, mined areas are being graded to gentle slopes, disked, and seeded to cool-season grasses. The Consolidated Coal Company has treated a substantial acreage in this manner. The Company and the Soil Conservation Service planted a variety of shrubs and trees, including green ash, American plum, buffalo-berry, Russian olive, Siberian pea, ponderosa pine, and Rocky Mountain juniper. After several years, a good percentage of these plantings have survived and are vigorous. Where problems associated with high sodium spoils have been circumvented, vegetation has become so well established that many areas look virtually undisturbed.

In general, it can probably be stated that the benefits from reclamation can be approximately whatever the consumer is willing to pay for in increased energy costs. The reclamation that is actually conducted on any site is generally a response to economic conditions and legal requirements. Although some technological restrictions exist, most sites can be made productive if enough resources are expanded to achieve that goal.

C. Factors Affecting Reclamation (A Summary)

According to the N.G.P.R.P., "the most important factors that determine the probabilities for successfully rehabilitating surface mined land in the Northern Great Plains are the amount and distribution of precipitation, the productivity and stability of soils, and the suitability and availability of different plant species having desirable characteristics." In addition, local geologic factors can have an important impact on the ease with which vegetation can be established. In North Dakota, for example, Power states that "Spoils originally from shallow depths (generally less than 30-50 ft) usually present few major problems in reclamation," primarily because these spoils are usually less sodic than deeper spoils.

The single most important parameter in assessing potential rehabilitation success is local climate, and the amount and distribution of precipitation is the most significant factor, according to the N.G.P.R.P. report. In areas where precipitation is sparse (less than about 10 in./yr), it is also usually quite variable seasonally and annually. In such cases, it is difficult to choose optimum seeding times, and without irrigation, vegetation establishment may fail. In areas with more ample and dependable precipitation, as in most of North Dakota, the problem is somewhat lessened. Irrigation may still be necessary from time to time, however, for some land use plans. The microclimate of the site also has an effect on revegetation, although little research has been concluded to quantify its impact. Wali (1975) says that the major limiting factor is water availability, which depends not only on precipitation but also on temperature, wind, and other climatic elements.

In North Dakota, the problem of availability of suitable plant materials is less than in the drier portions of the N.G.P. This is because the native plants of the mining areas of North Dakota are generally more readily available commercially than are the dryland species of parts of Montana and Wyoming. There is still a need, however, to continue research to develop plants that are more adaptable to reclamation projects.

Packer (1974) concludes that "virtually all surface-mined lands in the Northern Great Plains can be successfully rehabilitated." Power et al. (1974) also concede that the answer to the question of whether productivity can be restored is a "qualified yes," depending on how well the reclamation is planned and the care with which the plans are executed. Power also states that under existing technology, "moderately low sodic spoils with proper treatment and

good management might be made as productive as Class VI soils, at least 50% as productive as Class IV soils, but only about 25% as productive as Class II soils." These estimates do not include topsoiling, and Power goes on to state that with topsoiling, some areas may be made more productive than they were before mining.

Even though subsurface conditions may not be completely reconstructed, it is possible under existing technology to recreate a landscape that will produce vegetation in quantities similar to that produced prior to mining. Whether this constitutes reclamation is a matter that will be determined by the people of the state. Creation of wildlife habitats and other land uses are also technologically feasible on mine sites. On the benefit side of the reclamation economics story, therefore, it can be said that the surface value of the land can, in most cases, be restored to premining levels or higher. Exceptions will occur in the case of special historic, archeologic, or other sites that have an indeterminate value (and which will probably be designated "no mine" areas). In some cases an aquifer may be disrupted, thus reducing the value not only of the reclaimed area, but of surrounding land as well. Much more research is needed to test the feasibility of restoring subsurface conditions as part of a reclamation project.

The soils of the North Dakota mining area are described in another section, but it is important to note that their stability and productivity potential are considered to be among the most important factors affecting rehabilitation potential. Some of the other factors mentioned by the N.G.P.R.P. as affecting the actual success of a reclamation project are site and seedbed preparation, planting procedures, fertilizers and soil amendment, irrigation, spoil surface stabilization, postrehabilitation care, and rehabilitation time frames. In reference to time frames, that report states that the higher rehabilitation response sites, occurring predominantly in North Dakota, can be reclaimed in 1-5 yr, depending on the land use (mixed-grass range to cropland). Medium potential lands would require 5-10 yr and lower rated rehabilitation response units would require 10-15 yr (for establishment of shortgrass and/or shrub steppe range in the drier portions of Wyoming and Montana).

The problems to overcome to achieve reclamation in North Dakota can be divided into two general categories, problems that exist independent of surface mining (climate) and those directly associated with surface mining

(spoil material). As discussed in Section II, North Dakota climate is characterized by annual, daily, and day-to-day temperature variations, light to moderate precipitation that tends to be irregular in time and coverage, low relative humidity, high summer evapotranspiration, and a short growing season. The severity of these climatic conditions is often accentuated on spoil materials, leading to a microclimate surrounding newly established vegetation communities that is often lethal.

The problems associated with the spoils generated from surface mining activities include high clay content ($\geq 40\%$), high concentration of adsorbed sodium ($\text{SAR} \geq 12$), high concentrations of soluble salts resulting in saline conditions ($\text{ER} \geq 4$), calcium carbonate equivalent or free lime ($\geq 10\%$), low organic matter content ($< 2\%$), low concentrations of phosphorus, and, after a few years, low nitrogen. These factors contribute to a poor physical environment for germination and early seedling establishment and root development and/or a plant growth material that is either lacking in essential elements or contains concentrations that are toxic to growth and survival.

APPENDIX A

MAJOR COAL AND LEONARDITE MINE OPERATORS IN NORTH DAKOTA*

A. COALKNIFE RIVER COAL MINING COMPANY

Gascoyne Mine 743 acres under permit (all acres active)

Location: Sec. 33, 34, 35, 27, 28, 29 T131N, R99W, Bowman County

At present, the coal is shipped by rail to Ortonville, Minnesota, for power generation.

North and South Beulah Mines 838 acres under permit (all acres active)

Location: Sec. 6, 7, 8, 18 T143N, R87W, Oliver County
 Sec. 1, 2, 11, 12, 13, 14 T143N, R88W, Mercer County
 Sec. 8, 9, 16, 17 T144N, R87W, Mercer County

The coal is shipped by rail to the MDU power plants at Beulah and Mandan, North Dakota.

BAUKOL NOONAN, INC.

Noonan Mine 578 acres under permit (210 active; 368 inactive)

Location: Sec. 3, 4, 5, 8, 9, 10, 11, 14, 15, 16 T162N, R94W, Burke County

The coal is shipped by rail to a sugar beet processing plant at Drayton, North Dakota, for steam generation.

Center Mine 882 acres under permit (375 active; 507 inactive)

Location: Sec. 23, 24, 25, 35, 36 T142N, R84W, Oliver County
 Sec. 30, 31 T142N, R83W, Oliver County
 Sec. 1 T141N, R84W, Oliver County

The coal is carried by hauler to the mine-mouth Milton R. Young power plant operated by Minnkota Electric at Center, North Dakota.

*Source: North Dakota Public Service Commission

NORTH AMERICAN COAL CORPORATION

Indian Head Mine 1,065 acres under permit (all acres active)

Location: Sec. 19, 28, 30, 31, 32, 33 T144N, R88W, Mercer County
 Sec. 6, T143N, R88W, Mercer County
 Sec. 25, 36 T144N, R89W, Mercer County
 Sec. 1 T143N, R89W, Mercer County

The coal is shipped by rail to the UPA power plant near Stanton, North Dakota.

CONSOLIDATION COAL COMPANY

Glenharold Mine 1,318 acres under permit (all acres active)

Location: Sec. 19, 20, 28, 29, 30, 31, 32 T144N, R84W, Mercer County
 Sec. 5, 6 T143N, R84W, Oliver County

The coal supplies the mine-mouth Basin Electric power plant near Stanton, North Dakota.

Velva Mine 195 acres under permit (all acres active)

Location: Sec. 28, 35 T152N, R81W, Ward County
 Sec. 1, 2 T151N, R81W, Ward County

The coal is shipped to Verendrye, North Dakota, for power generation.

HUSKY INDUSTRIES/DICKINSON COAL MINING COMPANY

Husky Mine 77 acres under permit (40 active; 37 inactive)

Location: Sec. 7, 8, 17 T139N, R95W, Stark County

The coal is processed for briquettes and chemical by-products.

TOTAL FOR COAL MINES: 5696 ACRES (4784 ACTIVE: 912 INACTIVE)

B. LEONARDITEBAROID DIVISION, NL INDUSTRIES, INC.Smith-Ullman/Olson Mines 14 acres under permit (all acres active)Location: Sec. 5, 8 T129N, R94W, Adams County
Sec. 1 T129N, R95W, Adams CountyGEO-RESOURCES, INC.Nelson Pit 4 acres under permit (all acres active)

Location: Sec. 17 T154N, R100W, Williams County

TOTAL FOR LEONARDITE MINES: 18 ACRES

SUBTOTAL FOR COAL AND LEONARDITE MINES: 5714 ACRES

ADD: ACTIVE AND INACTIVE PERMITS HELD
BY SMALL OPERATORS 9 ACRES

TOTAL FOR ALL MINES IN THE STATE: 5723 ACRES

Notes:

- 1) active acres: both mining and reclamation in progress
- 2) inactive acres: Mining completed; reclamation in progress

September 30, 1974

APPENDIX B

CHEMICAL ANALYSES

The first three tables are modified from the Mineral Resources Work Group Report for the Northern Great Plains Resource Program, 1974.

Table B.1 lists proximate, ultimate, Btu, and sulfur analyses of lignites from the four largest mines in North Dakota.

Table B.2 lists quantitative determinations for 12 trace elements in lignites from the four largest mines in North Dakota.

Table B.3 lists major oxide composition, in percent, of the laboratory ash of lignites from the four largest mines in North Dakota.

Table B.4 compares proximate and ultimate analyses for North Dakota lignite with all other ranks of coal from various parts of the U.S. (from U.S. Bureau of Mines I.C. 7691, P. 45, 1954).

Table B.5 compares analyses of North Dakota lignites with those of lignites from other parts of the U.S. (Modified from U.S. Bureau of Mines I.C. 7691, P. 49, 1954, Modifications from data supplies in the Mineral Resources Work Group Report for the Northern Great Plains Resource Program, 1974).

Table B.1. Proximate, Ultimate, Btu, and Sulfur Analyses of Samples
of Lignite from the Four Largest Mines in North Dakota^a

Sample No.	USM Lab. No.	Sample interval (ft)	Moisture		Vol. matter		Fixed C		Ash		Btu		Hydrogen		Carbon		Nitrogen		Oxygen		Sulfur		Sulfate S		Pyritic S		Organic S	
			AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF	AR	MAF
KUETHER (K) and HAGEL (H), GLEN HAROLD MINE, MERCER COUNTY, NORTH DAKOTA																												
D165564	K-31589	4.0(K)	34.6	29.2	47.8	31.9	52.2	4.3	7160	11720	6.8	4.8	42.8	70.0	0.7	1.2	44.9	23.3	0.5	0.7	0.0	0.0	0.02	0.04	0.43	0.70		
D165565	K-31590	7.0(H)	28.6	32.7	49.0	34.0	51.0	4.7	7820	11710	6.4	4.8	46.5	69.6	.8	1.2	41.1	23.6	.5	.8	.02	.03	.03	.05	.46	.69		
D165566	K-31591	4.0(K)	26.6	32.5	47.4	36.0	52.6	4.9	7980	11640	6.3	4.8	47.7	69.6	.9	1.4	39.6	23.4	.6	.8	.0	.0	.03	.04	.54	.79		
D165567	K-31592	7.0(H)	31.4	30.6	47.7	33.6	52.3	4.4	7530	11720	6.7	5.0	44.9	69.9	.8	1.2	42.7	23.2	.5	.7	.0	.0	.03	.05	.42	.65		
ZAP BED, INDIAN HEAD MINE, MERCER COUNTY, NORTH DAKOTA																												
D165576	K-31601	11.0	31.1	26.7	45.4	32.1	54.6	10.1	7010	11900	6.0	4.4	42.6	72.4	0.7	1.2	39.9	20.8	0.7	1.2	0.0	0.0	0.43	0.74	0.26	0.45		
D165577	K-31602	11.0	30.1	27.1	47.1	33.5	52.9	12.3	6870	11930	5.9	4.5	40.9	71.1	.7	1.2	37.4	18.4	2.8	4.8	.03	.05	2.39	4.15	.33	.53		
D165578	K-31603	11.0	30.7	29.3	46.5	33.8	53.5	6.2	7360	11660	6.2	4.5	44.3	70.2	.7	1.1	42.1	23.4	.5	.8	.01	.01	.14	.22	.34	.53		
D165579	K-31604	11.0	31.0	28.3	45.6	33.9	54.4	6.8	7110	11460	6.3	4.5	43.6	70.2	.7	1.2	42.2	23.5	.4	.6	.02	.12	.08	.14	.28	.45		
SCHOOLHOUSE BED, SOUTH BEULAH MINE, MERCER COUNTY, NORTH DAKOTA																												
D165572	K-31597	8.0	29.8	29.1	47.3	32.4	52.7	8.7	7250	11800	6.3	4.8	42.4	69.0	0.5	0.8	39.9	21.8	2.2	3.6	0.05	0.08	1.84	3.00	0.33	0.54		
D165573	K-31598	3.0	32.9	28.9	46.6	33.2	53.4	5.0	7430	11960	6.8	5.0	43.9	70.7	.5	.8	43.1	22.4	.7	1.1	.01	.01	.13	.22	.52	.84		
D165574	K-31599	8.0	29.4	26.5	47.5	29.2	52.5	15.9	6420	11530	5.6	4.4	40.2	72.2	.7	1.3	36.5	20.1	1.1	2.0	.0	.0	.88	1.59	.22	.39		
D165575	K-31600	3.0	30.1	25.1	47.2	28.0	52.8	16.8	6140	11550	5.6	4.3	38.0	71.5	.7	1.3	38.0	21.1	.9	1.8	.01	.01	.74	1.37	.21	.39		
HAGEL BED, CENTER (BAUKOL-NOONAN) MINE, OLIVER COUNTY, NORTH DAKOTA																												
D165563	K-31593	10.0	34.2	27.3	45.2	33.2	54.8	5.3	7090	11720	6.6	4.6	43.1	71.2	0.7	1.2	43.8	22.2	0.5	0.8	.01	0.01	0.14	0.23	0.31	0.51		
D165569	K-31574	10.0	33.8	29.2	50.4	28.7	49.6	8.3	6860	11850	6.7	5.0	40.4	69.7	.7	1.1	42.2	21.2	1.7	3.0	.03	.05	1.26	2.18	.44	.77		
D165570	K-31575	10.0	33.2	29.5	47.3	32.9	52.7	4.4	7260	11650	6.6	4.6	43.5	69.8	.7	1.2	44.5	23.8	.3	.6	.02	.03	.04	.07	.29	.46		
D165571	K-31596	10.0	34.7	28.9	47.4	32.0	52.6	4.4	7100	11660	6.9	4.9	42.5	69.7	.7	1.2	45.2	23.6	.3	.6	.02	.03	.04	.06	.28	.46		

^a All analyses, except Btu in percent; original moisture content may be slightly more than shown because samples were collected and transported in plastic bags to avoid metal contamination; AR, as received, and MAF, moisture and ash free; (T) and (B) indicate top and bottom of bed, respectively. All analyses of mine samples by Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pennsylvania.

Table B.2. Quantitative Determinations (in ppm) for 12 Trace Elements in Samples of Lignite from the Four Largest Mines in North Dakota^a

Sample No.	Thickness of sample interval (ft)	As	Cd	Cu	F	Hg	Li	Pb	Sb	Se	Th	U	Zn	Ash (percent)
KUEHER (K) and HAGEL (H), GLEN HAROLD MINE, MERCER COUNTY, NORTH DAKOTA														
D165564	4.0 (K)	10	<0.1	3.4	<20	0.10	1.	<1.5	0.2	0.7	9.4	2.1	1.4	7.02
D165565	7.0 (H)	5	<.1	6.4	<20	.09	1.2	<1.5	.7	.8	<2.0	1.1	2.2	7.16
D165566	4.0 (K)	15	<.1	3.6	<20	.08	.6	2.0	.4	.8	<2.0	.6	1.3	6.52
D165567	7.0 (H)	5	<.1	2.4	<20	.05	.5	<1.5	3.0	.5	<2.0	.6	2.3	5.78
ZAP BED, INDIAN HEAD MINE, MERCER COUNTY, NORTH DAKOTA														
D165576	11.0	4	<0.1	7.5	<20	0.05	3.4	4.8	0.3	0.5	3.4	0.9	1.5	9.58
D165577	11.0	10	<.1	10.6	<20	.07	3.8	5.3	1.4	.8	4.0	1.9	9.1	10.6
D165578	11.0	10	<.1	5.6	<20	.34	2.1	3.1	.4	.9	5.2	.7	2.1	10.4
D165579	11.0	15	<.1	5.8	<20	.11	3.3	5.2	.3	1.0	5.0	.9	4.7	10.3
SCHOOLHOUSE BED, SOUTH BEULAH MINE, MERCER COUNTY, NORTH DAKOTA														
D165572	8.0	30	<0.1	4.7	<20	0.21	1.8	3.1	0.5	0.6	<2.0	0.7	27.7	10.2
D165573	3.0	10	<.1	3.2	<20	.19	.7	<1.5	.2	.6	2.5	.4	3.5	6.58
D165574	8.0	5	<.1	7.3	20	.10	7.6	7.6	1.1	1.2	5.5	1.6	5.4	19.1
D165575	3.0	8	<.1	11.3	50	.10	9.9	7.0	1.0	1.5	5.6	2.2	15.0	23.5
HAGEL BED, CENTER (BAUKOL-NOONAN) MINE, OLIVER COUNTY, NORTH DAKOTA														
D165568	10.0	10	<0.1	3.2	20	0.22	0.9	<1.5	0.1	1.0	<2.0	0.5	2.2	10.8
D165569	10.0	8	<.1	6.8	30	.11	1.5	4.7	.5	1.3	3.7	1.5	1.7	9.94
D165570	10.0	5	<.1	2.8	<20	.05	.9	1.6	.3	1.6	<2.0	.8	1.6	6.48
D165571	10.0	5	<.1	4.3	<20	.05	.9	2.5	.3	.7	<2.0	.7	1.5	6.28

^aIn thickness column (T), (B), and (M) indicate top, bottom, and middle of bed, respectively. Values for Cd, Cu, Li, Pb, and Zn are calculated from analyses on ash of coal.

Table B.3. Major Oxide Composition, in Percent, of the Laboratory Ash of Samples of Lignite from the Four Largest Mines in North Dakota

Sample No.	Sample Interval (ft)	Ash	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	CaO	MgO	P ₂ O ₅	Fe ₂ O ₃	SO ₃
KUE'THER (K) and HAGEL (H), GLEN HAROLD MINE, MERCER COUNTY, NORTH DAKOTA											
D165564	4.0 (K)	7.02	13.	2.9	8.30	<0.10	26.	5.60	<0.05	4.3	20.
D165565	7.0 (H)	7.16	19.	6.8	9.95	< .10	23.	4.90	.05	5.0	19.
D165566	4.0 (K)	6.52	6.8	4.9	10.4	.20	27.	5.40	< .05	4.4	24.
D165567	10.0 (H)	5.78	12.	4.7	9.20	< .10	28.	4.90	< .05	5.4	23.
ZAP BED, INDIAN HEAD MINE, MERCER COUNTY, NORTH DAKOTA											
D165576	11.0	9.58	34.	11.	3.50	<0.10	22.	6.00	.97	3.0	12.
D165577	11.0	10.6	26.	11.	3.80	.15	19.	5.25	.26	7.9	22.
D165578	11.0	10.4	16.	8.	3.25	< .10	17.	4.70	.71	15.	30.
D165579	11.0	10.3	27.	11.	3.55	< .10	19.	5.25	.58	7.4	20.
SCHOOLHOUSE BED, SOUTH BEULAH MINE, MERCER COUNTY, NORTH DAKOTA											
D165572	8.0	10.2	20.	9.5	3.95	0.71	12.	4.00	0.06	19.	27.
D165573	3.0	6.58	12.	10.	5.85	.55	21.	6.50	.13	7.7	27.
D165574	8.0	19.1	30.	11.	3.55	.18	21.	3.45	.00	6.5	16.
D165575	3.0	23.5	45.	13.	2.70	.76	9.9	3.05	.07	7.0	14.
HAGEL BED, CENTER (BAUKOL-NOONAN) MINE, OLIVER COUNTY, NORTH DAKOTA											
D165568	10.0	10.8	12.	3.4	1.15	<0.10	20.	6.00	<0.05	20.	35.
D165569	10.0	9.94	30.	11.	.70	1.2	18.	5.55	< .05	8.6	20.
D165570	10.0	6.48	14.	7.7	1.45	< .10	31.	8.80	< .05	4.0	17.
D165571	10.0	6.28	14.	9.0	1.40	.29	31.	8.65	.06	4.4	17.

^aIn sample interval column (T), (B), and (M) indicate top, bottom, and middle, respectively.

Table B.4. Proximate and Ultimate Analyses of Samples of Each Rank of Common Bonded Coal of the United States, As-Received Basis

Rank or Type	State	County	Proximate Analysis			Ultimate Analysis						Heating Value	Source
			Moisture %	Volatile matter %	Fixed C %	Ash %	S %	H %	C %	N %	O %	Btu/lb	
Anthracite	Penn.	Lackawanna	4.4	4.8	81.8	9.0	0.6	3.4	79.8	1.0	6.2	13,130	11:64
Semianthracite	Ark.	Pope	2.8	11.9	75.2	10.1	2.2	3.7	78.3	1.7	4.0	13,360	18:11
Low-volatile bituminous	Md.	Garrett	2.3	19.6	65.8	12.3	3.1	4.5	74.5	1.4	4.2	13,220	38:41
Medium-Volatile Bituminous	Ala.	Jefferson	3.1	23.4	63.6	9.9	0.8	4.9	76.7	1.5	6.2	13,530	17:24
High-Volatile A bituminous	Ky.	Letcher	3.2	36.8	56.4	3.6	0.6	5.6	79.4	1.6	9.2	14,090	10:114
High-Volatile B bituminous	Ohio	Muskingum	5.9	43.8	46.5	3.8	3.0	5.7	72.2	1.3	14.0	13,150	19:27
High-Volatile C bituminous	Ill.	Peoria	14.8	33.3	39.9	12.0	2.5	5.8	58.8	1.0	19.9	10,550	9:115
Subbituminous A	Wash.	King	13.9	34.2	41.0	10.9	0.6	6.2	57.5	1.4	23.4	10,330	20:64
Subbituminous B	Wyo.	Sheridan	22.2	32.2	40.3	4.3	0.5	6.9	53.9	1.0	33.4	9,610	21:68
Subbituminous C	Colo.	El Paso	25.8	31.1	38.4	4.7	0.3	6.3	50.0	0.6	38.1	8,580	16:64
Lignite	N.D.	Ward	36.8	27.8	30.2	5.2	0.4	6.9	41.2	0.7	45.6	6,960	8:52

Table B.5. Comparison of Analyses of U.S. Lignites As-Received Basis

State	County	Mine	Type of sample	Proximate analysis (%)				Ultimate analysis (%)					
				Moisture	Volatile matter	Fixed C	Ash	S	H	C	N	O	Btu/lb
Mont.	Sheridan	Acme	1-1/2" lump	39.0	25.1	30.2	5.7	0.5	7.0	40.2	0.7	45.9	6,810
S.D.	Harding			41.0	23.2	28.4	7.4	2.2	7.0	37.8	.5	45.1	6,380
Ark.	Dallas	American Dyewood Co.	Face	34.5	31.8	23.5	10.2	.4	7.1	39.7	.7	41.9	6,950
	Hot Springs	Outcrop	Face	38.9	29.1	19.7	12.3	.8	7.5	34.6	.4	44.4	6,260
	Ouachita	Dunn	Face	37.5	32.4	21.6	8.5	.4	7.5	39.9	.6	43.1	7,080
Texas	Milan	Sandow	Face	31.9	29.3	27.9	10.9	1.7	6.5	41.5	.8	38.6	7,150
	Milan	Sandow	Face	33.2	29.3	29.8	7.7	1.3	6.8	43.4	.8	40.0	7,510
Calif.	Amador	American Lignite Prod. Co.	Column	36.8	36.8	16.2	10.2	1.0	8.0	38.2	.4	42.2	7,060
	Amador	Edwin No. 2 Clay	Face	37.3	32.9	21.4	8.4	1.0	7.2	36.0	.4	47.0	6,280
N.D.	Oliver	Center		34.0	28.8	31.4	5.6	.7	6.7	42.4	.7	43.9	7,080
	Mercer	Indianhead		30.7	27.8	32.6	8.8	1.1	6.1	42.8	.7	40.4	7,080
	Mercer	Beulah		30.3	27.4	30.7	11.6	1.2	6.1	41.1	.6	39.4	6,810
	Mercer	Glenharold (Kuether bed)		30.6	30.9	34.0	4.6	.6	6.6	45.3	.8	42.2	7,570
	Mercer	Glenharold (Hagel bed)		30.0	31.7	33.8	4.6	.5	6.6	45.7	.8	41.9	7,675

APPENDIX C

Table C.1. Required Detection Limits for Constituents, Recommended Frequency of Sampling, and Possible Effects of Constituents on Human Health and Agriculture for Groundwater and Surface Water in the Western United States Energy Regions.*

[Semi-annual sampling should be done shortly after spring snowmelt and during late winter low-flow stage; quarterly sampling should be done each season.
ND, not determined. (---), no data available.]

Constituent	Recommended Detection Limit		Sampling Frequency			Possible Effects	
	Groundwater and surface water dissolved (0.45 µm filter)	Bed material total recoverable	Ground-water	Surface water		Human health	Agriculture
				Dissolved	Bed material		
Ag	10 µg/l	1 ppm	ND	ND	ND	High levels may cause permanent blue-gray discoloration of skin and mucous membranes (argyria) (U.S. Public Health Service, 1962).	
Al	10 µg/l	10,000 ppm	Annual	Semi-annual	ND		High levels may affect plant growth; toxic to plants on coal spoil piles (Sauchelli, 1969; Berg and Vogel, 1973).
As	10 µg/l	0.2 ppm	Annual	Semi-annual	Semi-annual	Poisonous at high levels; skin ulcers at intermediate levels; possibly carcinogenic (U.S. Public Health Service, 1962, Underwood, 1973).	High concentrations may poison livestock; in Asdeficient areas, swine and poultry rations may be supplemented with As; high concentrations toxic to plants (Sauchelli, 1969).
B	50 µg/l	10 ppm	Annual	Semi-annual	ND		Toxic to plants at high levels (sensitivity varies with species; low level needed; B-rich irrigation water in western coal regions may be toxic to certain plants (Sauchelli, 1969; U.S. Environmental Protection Agency, 1973).
Ba	50 µg/l	1 ppm	Annual	Semi-annual	Semi-annual	High levels may increase blood pressure, affects heart, blood vessels, and nerves (U S Public Health Service, 1962, U.S. Environmental Protection Agency, 1973)	
Be	1 µg/l	1 ppm	ND	ND	ND	Dust highly toxic, no known effects from presence in water, normally insoluble (U.S. Environmental Protection Agency, 1973)	
Bi	---	---	ND	ND	ND		
Br	10 µg/l	---	Annual	ND	ND		

Table C.1 (Cont'd)

Constituent	Recommended Detection Limit		Sampling Frequency			Possible Effects	
	Groundwater and surface water dissolved (0.45 µm filter)	Bed material total recoverable	Ground-water	Surface water		Human health	Agriculture
				Dissolved	Bed material		
Ca	1 mg/l	1,000 ppm	Annual	Quarterly	Semi-annual	High levels may reduce residence of heart disease and kidney stones (National Academy of Sciences, 1972)	Deficiency symptoms known (Sauchelli, 1969)
Cd	1 µg/l	1 ppm	Annual	Semi-annual	Semi-annual	High levels may cause hypertension, kidney damage (U S Environmental Protection Agency, 1973, National Academy of Sciences, 1972, Underwood, 1973, U S. Public Health Service, 1962)	High levels are toxic to plants (Sauchelli, 1969)
Ci	1 mg/l	---	Annual	Quarterly	ND	Deficiency symptoms known (U.S. Environmental Protection Agency, 1973, U S Public Health Service 1962)	Deficiency symptoms known (Sauchelli, 1969)
Co	5 µg/l	3 ppm	ND	ND	ND	Deficiency symptoms known (U S Environmental Protection Agency, 1973, National Academy of Sciences, 1972, Underwood, 1973)	Deficiency symptoms known (Sauchelli, 1969)
Cr, total (if >10 µg/l, do Cr ⁺⁶)	5 µg/l	1 ppm	Annual	Semi-annual	Semi-annual	Deficiency results in impaired glucose tolerance (National Academy of Sciences, 1972, Underwood, 1973)	Deficiency reduces crop yields (Sauchelli, 1969)
Cr ⁺⁶	5 µg/l	1 ppm	ND	ND	ND	High levels may cause gastrointestinal hemorrhage and ulceration on dermal exposure (rarely occurs naturally, generally indicates man-made pollution), (U S Environmental Protection Agency, 1973, National Academy of Science, 1972, U S Public Health Service, 1962)	
Cu	2 µg/l	1 ppm	Annual	Semi-annual	Semi-annual	Gives water a foul taste	Deficiency symptoms known, Cu/Mo ratio significant in animal diet (Sauchelli, 1969 Agarwal, 1975).
F	100 µg/l	500 ppm	Annual	Quarterly	ND	Reduces dental caries, excess may mottle teeth or calcify bones and joints (National Academy of Science, 1972, Agarwal, 1975, U S Public Health Service, 1962)	Harmful to cattle at high levels (fluorosis), (Sauchelli, 1969)

Table C.1 (Cont'd)

Constituent	Recommended Detection Limit		Sampling Frequency			Possible Effects	
	Groundwater and surface water dissolved (0.45 µm filter)	Bed material total recoverable	Ground-water	Surface water		Human health	Agriculture
				Dissolved	Bed material		
Fe	20 µg/l	500 ppm	Annual	Quarterly	Semi-annual	High levels cause laundry stains and foul taste; may aid in Fe-deficiency anemia; may stimulate pathogenic bacterial growth (U.S. Public Health Service, 1962, Hopps and Cannon, 1972.)	Deficiency diseases common; overdose can cause rickets (Sauchelli, 1969).
Ga	---	---	ND	ND	ND		
Ge	---	---	ND	ND	ND		
Hg	0.2 µg/l	0.01 ppm	Annual	Semi-annual	Semi-annual	No known need, high levels toxic especially in organic forms (U.S. Environmental Protection Agency, 1973)	No known need, high levels toxic to all animals (Sauchelli, 1969. Underwood, 1973).
I	10 µg/l	---	Annual	ND	ND	Needed for synthesis of thyroid hormones; not known to be toxic in concentrations occurring in water supplies (National Academy of Sciences, 1972).	Some plants interfere with I utilization by animals (Sauchelli, 1969).
K	1 mg/l	100 ppm	Annual	Quarterly	ND	No reported toxic or deficiency effects due to water supply (U.S. Environmental Protection Agency, 1973).	Deficiency symptoms known (Sauchelli, 1969).
Li	10 µg/l	5 ppm	Annual	Semi-annual	ND	Large doses may reduce aggressive tendencies, may be significant in prevention of cardiovascular disease (National Academy of Science, 1972).	Plant tolerance variable among species; citrus plants especially sensitive (Sauchelli, 1969).
Mg	1 mg/l	300 ppm	Annual	Quarterly	Semi-annual	May be significant in prevention of cardiovascular disease and kidney stones (National Academy of Sciences, 1972).	Deficiency symptoms known (Sauchelli, 1969).
Na	50 µg/l	1 ppm	Annual	Quarterly	Semi-annual	Deficiency symptoms known; causes stains and foul taste (U.S. Public Health Service, 1962).	Required; may allow significant toxic and deficiency symptoms in plants and animals; important in poultry production (Sauchelli, 1969, Berg and Vogel, 1973).

Table C.1 (Cont'd)

Constituent	Recommended Detection Limit		Sampling Frequency			Possible Effects	
	Groundwater and surface water dissolved (0.45 µm filter)	Bed material total recoverable	Ground-water	Surface water		Human health	Agriculture
				Dissolved	Bed material		
Mo	1 µg/l	100 ppm	Annual	Semi-annual	Semi-annual	Deficiency symptoms known, may reduce dental caries, may increase kidney stones, causes "ginu valgum" (a crippling bone disease) (National Academy of Sciences, 1972, Agarwal, 1975)	Deficiency symptoms known; high bovine levels can cause molybdenosis, Cu/Mo ratio significant; clovers concentrate Mo (U.S. Environmental Protection Agency, 1973; National Academy of Sciences, 1972)
Ni	1 µg/l	5 ppm	ND	ND	ND	Dust may be carcinogenic, no known toxicity from water source (U.S. Environmental Protection Agency, 1973).	Not required; may be toxic to some plants at low levels (Sauchelli, 1969).
N, total (if >5 mg/l, do NO ₃ , NO ₂ , NH ₃ , and organic N)	0.1 mg/l	100 ppm	Annual	Quarterly	ND	Some forms cause methemoglobinemia in infants, may form carcinogenic nitrosamines (U.S. Environmental Protection Agency, 1973).	Deficiency symptom known; high levels may be toxic to both plants and animals (Sauchelli, 1969).
O ₂	1 mg/l	ND	ND	Quarterly	ND		
P	0.1 mg/l	100 ppm	Annual	Quarterly	Semi-annual	Deficiency symptoms known, organophosphates toxic in water (U.S. Environmental Protection Agency, 1973).	Deficiency symptoms known, some P compounds toxic in water, important in algal growth (Sauchelli, 1969).
Pb	1 µg/l	1 ppm	Annual	Semi-annual	Semi-annual	No known requirement, toxic--damages neural and renal systems (U.S. Environmental Protection Agency, 1973, National Academy of Sciences, 1972, Bowen, 1966, Underwood, 1973, Shakman, 1974, U.S. Public Health Service, 1962)	Not required; horses especially sensitive; may poison livestock (Sauchelli, 1969).
Rb	10 µg/l	---	ND	ND	ND		
SO ₄	1 mg/l	100 ppm	Annual	Quarterly	ND	No known toxicity (U.S. Environmental Protection Agency, 1973 Shakman, 1974).	Deficiency symptoms known, no known toxicity (Sauchelli, 1969).
Sb	1 µg/l	1 ppm	ND	ND	ND	No known effect from water, (U.S. Environmental Protection Agency, 1973)	

Table C.1 (Cont'd)

Constituent	Recommended Detection Limit		Ground- water	Surface water		Possible Effects	
	Groundwater and surface water dissolved (0.45 µm filter)	Bed material total recoverable		Dissolved	Bed material	Human health	Agriculture
Se	1 µg/l	0.1 ppm	Annual	Semi-annual	Semi-annual	Low level required, may inhibit cancer, high level toxic, may cause dental caries (U S. Environmental Protection Agency, 1973, National Academy of Sciences, 1972, Bowen, 1966, Underwood, 1973, Shakman, 1974, U S Public Health Service, 1962)	Low level required, high level toxic to animals, inhibits leukemia in poultry (Sauchelli, 1969).
SiO ₂	1 mg/l	10,000 ppm	Annual	Quarterly	ND		Essential for poultry, may be essential for plants and animals (Sauchelli, 1969).
Sn	1 µg/l	1 ppm	ND	ND	ND		
Sr	50 µg/l	5 ppm	Annual	ND	ND		
Ti	5 µg/l	10 ppm	Annual	Semi-annual	ND		
Tl	1 µg/l	---	ND	ND	ND		
V	5 µg/l	5 ppm	Annual	Semi-annual	Semi-annual	No known need, may cause methemoglobinemia (Shakman, 1974)	
Y	---	---	ND	ND	ND		
Zn	10 µg/l	10 ppm	Annual	Semi-annual	Semi-annual	Essential nutrient, high aqueous levels may be toxic, deficiency results in growth failure, impaired wound healing, delayed sexual maturity (U S Environmental Protection Agency, 1973, National Academy of Sciences, 1972, Bowen, 1966, Shakman, 1974, U S Public Health Service, 1962)	Essential, high levels may be toxic to plants and animals deficiency symptoms known (Sauchelli, 1969).
Zr	5 µg/l	10 ppm	ND	ND	ND		
Specific conductance	---	---	Annual	Quarterly	ND		
Temperature	---	---	Annual	Quarterly	Semi-annual		
Total dissolved solids	---	---	Annual	Quarterly	ND		

Table C.1 (Cont'd)

	Recommended Detection Limit		Sampling Frequency			Possible Effects
	Groundwater and surface water dissolved (0.45 μm filter)	Bed material total recoverable	Ground-water	Surface water		
				Dissolved	Bed material	
Gross α	10 pc/l	---	Annual	Semi-annual	ND	May be carcinogenic (U.S. Environmental Protection Agency, 1973, U S Public Health Service, 1962)
Gross β (if >100 pc/l, do U, Th, ²¹⁰ Pb, and ²²⁶ Ra)	10 pc/l	---	Annual	Semi-annual	ND	May be carcinogenic (U S Environmental Protection Agency, 1973, U S Public Health Service, 1962)
²²⁶ Ra (if ²²⁶ Ra and gross α >5 pc/l do U and Th)	1 pc/l	---	Annual	Semi-annual	ND	Carcinogenic (U S Environmental Protection Agency, 1973).
Dissolved organic carbon (if >5 mg/l, do trace organics)	1 mg/l	---	Annual	ND	ND	

Note. For aquatic organisms see U.S. Environmental Protection Agency (1973). Tolerances vary widely among aquatic organisms, and groups of constituents may show synergistic effects (i.e., a single constituent may be below the toxic level but if certain other constituents are present, also below toxic levels, the result may be toxic).

*Source: From Ground Waters of the Fort Union Coal Region in U.S. Geological Survey Open File Report-75-436, "Geochemical Survey of the Western Coal Regions, 1975

APPENDIX D

PUBLIC SERVICE COMMISSION
STATE OF NORTH DAKOTA

RECLAMATION PLAN FOR STRIP-MINED LANDS

I. THIS SECTION FOR PSC USE ONLY

Date plan received _____

Plan accepted by: _____ Date _____

Title: _____

Permit No. _____

Permit issue date _____

Permit expiration date _____

Plan not accepted because:

Requirements for plan acceptance:

II. Name and Address of Operator		Mine Name	
III. Signature	Title	Address	Date

- IV. Location of permit lands, number of acres to be affected by surface mining during permit term, and surface owner's post-mining land use preference:

Total No. of Acres _____

<u>Location</u>	<u>No. of Acres Affected</u>	<u>Surface Ownership</u>	<u>Post-Mining Land Use Preference</u>
-----------------	----------------------------------	------------------------------	--

- V. Land use prior to surface mining:

<u>Category</u>	<u>Acres</u>	<u>Category</u>	<u>Acres</u>
Commercial/Industrial	_____	Tame Pastureland	_____
Community Services	_____	Recreation	_____
Cropland	_____	Residential	_____
Farmstead/HQ	_____	Transportation Services	_____
Native Hayland	_____	Wildlife	_____
Tame Hayland	_____	Woodland	_____
Native Pasture or Rangeland	_____	Other	_____

VI. Intended post-mining land use:

<u>Category</u>	<u>Acres</u>	<u>Category</u>	<u>Acres</u>
Cropland	_____	Tame Pasture Land	_____
Native Hayland	_____	Recreation	_____
Tame Hayland	_____	Wildlife	_____
Native Pasture or Rangeland	_____	Woodland	_____
Other	_____		

VII. Reclamation Procedures:

A. Alternate Plans for any highwall or endwall areas, if other than backsloping:

B. Size and purpose of any planned dams or impoundments:

C. Soil amendments to be used:

D. Details of soil manipulation prior to planting:

E. Fertilizer usage:

- 1) Solid _____ Liquid _____ (check one)
- 2) NPK rating _____
- 3) Rate of application _____
- 4) Supplemental applications, if planned:

F. Approved seeding mixtures and rates to be used:

G. Details of any woodland or wildlife plantings:

H. Post-planting management plans:

1) cropland:

2) rangeland and pastureland:

3) woodland and wildlife plantings:

VIII. Names, titles and affiliations of individuals or agencies assisting in the development of this reclamation plan, and the specific contribution of each:

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