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An Analysis Of Extreme Danger Problems Associated With Abandoned Coal Mine Lands In Southwestern Indiana

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AN ANALYSIS OF EXTREME DANGER PROBLEMS ASSOCIATED WITH ABANDONED COAL MINE LANDS IN SOUTHWESTERN INDIANA

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J. A. Elbert

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ABSTRACT

The Surface Mining Control and Reclamation Act of 1977 created revenues for the reclamation of Abandoned Mine Land (AML) problems. The data in this study were obtained from the National Inventory Update of Abandoned Mine Lands for the State of Indiana, completed in July 1986. The study area included the coal producing region of Indiana, approximately 6,500 square miles. Specifically those fifteen counties in Southwestern Indiana where there were Extreme Danger Problems resulting from past coal mining.

This study analyzed the Extreme Danger Problems associated with Abandoned Coal Mine Lands in Southwestern Indiana. Identifying the statistical relationships between the total occurrences of Extreme Danger Problems in Indiana and selected coal mine related variables was the first step. Multiple Regression Analysis was the statistical technique employed in this research. The total number of occurrences of Extreme Danger Problems, TOTAL, was the dependent variable. The selected coal mine related variables are: the year coal production began, BEGIN; the year the mine was abandoned, END; the location with respect to glacial boundaries, GLACIATION; the total coal production of each mine, PRODUCTION; the specific coal seam, SEAM; the depth to the coal seam, DEPTH; the thickness of the coal seam, THICKNESS; the local topographic group, TOPOGRAPHY; and a measure of the economics of each mine, the economic ratio, ER, were the independent variables.

Thirty-seven statistically significant relationships for various subgroups resulted. Seven of these subgroups had explained variances of greater than 80%. Overall there is a strong positive relationship between the dependent variable, TOTAL, and the independent variable, GLACIATION. There is also a very strong negative relationship between the dependent variable, TOTAL, and the independent variable, BEGIN.

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CHAPTER I

INTRODUCTION

"Coal is our universal companion" (Caudill, 1971). It is used to produce electricity, and its by-products find their way into paints, tires, plastics, and medicines, even aspirin.

Coal has been an important economic resource in Indiana since 1915. In Indiana thirty-two seams have been observed, commercial operations have mined nine of these and sixteen seams have been locally mined (Karpiniski, 1938). To 1983 Indiana has produced more than 1.5 billion tons of coal (Environmental Systems, 1983). The extraction of coal has not been without its effects on the environment and the creation of safety hazards to people. Vast areas have been subjected to surface and underground mining for the extraction of coal. These disturbances often present dangers to the general public, as well as degrade the environment. Subsidence alone has affected two million acres in thirty states (Carey, 1984). This figure represents about 25% of the total acreage undermined for coal. Subsidence may also pose more serious threats than to property; it also endangers lives. In May of 1984, the Peters Township District in McMurray, Pennsylvania quickly dismissed school for its 930 students as the cafeteria began to sink and the walls and ceilings of eight classrooms above started cracking (Carey, 1984).

Prior to the Surface Mining Control and Reclamation Act of 1978, there were insufficient laws to resolve the hazards to the public and the degradation to the environment. In the United States there are approximately 100,000 underground mines in existence; currently 90,000 of these are identified as quiescent or abandoned (Yarbrough, 1983). All areas of the United States that were mined after 1977 were subject to the provisions of the law for reclamation by the individual mine. Those lands mined prior to 1977 were deemed Abandoned Coal Mine Lands (AML): "any land, including associated buildings, equipment, and affected areas, that was no longer being used for coal mining by August 1977" (Honea and Baxter, 1983). The Act of 1977 provided for their reclamation; the funding for their reclamation is obtained from a tax on coal recovered from current mining.

The National Law also called for an accurate inventory to facilitate the reclamation of these AML problems. The original National Inventory of Abandoned Mine Land Problems of 1982 and the current Update are the informational sources for this study. The "dynamic nature and extent of AML problems will result in additional problems being identified in the future" (Honea and Baxter, 1983), thus the reason for current updates. This Inventory includes an emphasis on health, safety and general welfare impacts, as well as environmental impacts. In the National Inventory, there were three priority levels. Priority 1 problems include "protection of public health, safety, and general welfare and property from extreme danger and adverse effects of coal-mining practices" (Honea and Baxter, 1983). Priority 2 includes the protection from safety problems that are not extreme danger situations. Priority 3 problems deal with the degradation of land and water resources and the environment.

Purpose

This study investigated and analyzed the occurrences of "Extreme Danger Problems" in Indiana. Extreme Danger Problems are defined as: "a condition that could reasonably be expected to cause substantial harm to persons, property, or the environment and to which persons or improvements on real property are currently exposed" or an "AML situation that presents a constant or frequent threat to Health, Safety and General Welfare" (Honea and Baxter, 1983). Previous studies of AML's have concentrated on case studies. However, this study focused on a selected group of problems for the State of Indiana; the distributions and patterns of the occurrences of Extreme Danger Problems and their relationships to specific coal-mine-related variables were examined.

Coal was first discovered in America by Joliet and Marquette near present day Utica, Illinois (Indiana Coal Producers Association, 1940). It was first discovered in Indiana in 1763 along the Wabash River (Karpiniski, 1938).

The first commercial extraction of coal was in Perry County in 1812. In 1840, the coal production for Indiana totalled 9,682 tons, valued at $5,000. In the 1800's mining was done with a pick and shovel or a horse-drawn scraper (Powell, 1972), as the first type of mining in Indiana was surface mining. By 1880 coal production in Clay County was exceeded only by nine other counties in the United States, six of which were in Pennsylvania. The 165-year interval from 1812 to 1977 produced extensive areas of AML's in Indiana. Indiana ranks among the top eight states in acreages of three AML measures (Table 1). Indiana ranks sixth in the category of abandoned acres, eighth in the subsidence category, and fifth in the Waste Banks category. The total projected cost of reclamation for Indiana would be 706.1 million dollars; an overall ranking of sixth.

Table 1

Abandoned Mine Land Measures

	Abandoned (acres)	Subsidence (acres)	Waste Banks (acres)	TOTAL COST (millions)
Alabama	6800	11700	9100	526.1
Illinois	60500	41800	16000	1903.6
Indiana	32700	10900	11900	706.1
Kentucky	51500	37200	22900	1795.1
Ohio	55800	21800	7300	1165.9
Pennsylvania	87600	151400	33500	5834.0
Virginia	7200	13400	8600	555.7
West Virginia	37500	89100	52900	3681.9

(Johnson and Miller, 1979)

The Extreme Danger Problems that will be analyzed in this study are grouped into three categories. The first group is those resulting from surface mining. These problems are dangerous highwalls and hazardous recreational water bodies (See Appendix B). The second group is associated with underground mining and includes hazardous or explosive gases, portals, subsidence areas, surface burning and vertical openings. The third category is problems common to both surface and underground mining: clogged streams, dangerous pile or embankments, dangerous impoundments, hazardous equipment or facilities, industrial or residential waste, and polluted water for human consumption.

In the number of Health, Safety and General Welfare Problem areas, Indiana ranks eleventh of the thirty-five states where coal has been mined (Honea and Baxter, 1983). A working definition of a Problem Area is an area that contains one or more AML problems along with the AML impacted areas (Office of Surface Mining, 1984). Indiana also ranks high in the number of vertical openings (VO's) and dangerous highwalls (DH's), two of the most common safety problems (Table 2). Indiana ranks fourth in the VO (vertical opening) problem category, and seventh in the DH (dangerous highwall) problem category. In view of these statistics, Indiana can be viewed as a state with a relatively large number of diverse problems yet, the numbers are of a manageable size.

The topic of safety hazards associated with AML's has not been sufficiently addressed. While in active coal mining

Table 2

Number of Vertical Openings and Dangerous Highwalls for the Highest Ranked States

VO		DH	
Pennsylvania	- 131	Pennsylvania	- 84
Alabama	- 31	Oklahoma	- 52
Ohio	- 28	Missouri	- 31
Indiana	- 26	Alabama	- 23
		Iowa	- 21
		Virginia	- 13
		Indiana/N. Tenn.	- 10

(Honea and Baxter, 1983)

operations safety has been and continues to be a high priority, the safety problems that were created prior to 1977 have been largely overlooked. The attention that has been given AML safety hazards has been limited to select personal tragedy or citizen concern (Tribune Star, 1978). Much literature has been devoted to reclaiming AML; however, most of the discussion has dealt with reclamation of the environmental problems. An example is the Chauncey Project in Ohio (Harrington, 1982) where eliminating safety problems warranted little discussion. Building removal, filling one slope shaft and fencing around one vertical shaft cost $3,938 to reclaim, a mere 1% of the total cost of the project. The remaining 99% was devoted to reclaiming gob which presented sedimentation and acid water problems.

These safety problems neither disappear or get reclaimed instantly. In the previous 1982 inventory there were 105 Problem Areas, in the present Inventory Update 45 of these Problem Areas still possessed at least one Extreme Danger Problem.

Hypothesis

The general hypothesis is that there are significant statistical relationships between Extreme Danger Problems in Indiana's Abandoned Coal Mine Land problem areas and selected coal mine related variables. More specifically the independent variables are related to the dependent variable; the total occurrences of Extreme Danger Problems (TOTAL). The variables for each problem area that are related to the total occurrences of Extreme Danger Problems in each problem area are: depth to coal (DEPTH), thickness of coal (THICKNESS), the year coal production began (BEGIN), the year the mine was abandoned (END), the total production of the mine (PRODUCTION), glacial history (GLACIATION), specific coal seam (SEAM), topographic position (TOPOGRAPHY) and the economic ratio (ER).

CHAPTER II

NATURE OF THE STUDY AREA

The Eastern Interior Coal Province is located in parts of three states: Illinois, Indiana and Kentucky. The specific coal deposits lie in a structural basin, the Illinois basin. This area has consistently produced one fifth of the nation's bituminous coal (Honea and Baxter, 1983); with Indiana contributing twenty percent of this figure. The Indiana coal field lies on the eastern edge of this basin. In Indiana the sediments dip approximately 30 feet per mile (Environmental Systems, 1983) to the west toward the center of the Illinois basin. Erosion of this structure results in younger coals being found farther to the west (Karpiniski, 1938).

The Indiana coal field covers approximately 6,500 square miles or one sixth of the state (Environmental Systems, 1983). This region is referred to as Southwestern Indiana and nearly all coal mining is confined to this area. Prior to 1978, approximately 150,000 acres in this area were affected by coal mining with at least 13,600 acres being eligible for AML reclamation (Allen, Thomas, and Kelley, 1978). A more recent figure could be estimated by considering the ratio of disturbed acreage to production (LaFevers, 1974) and then looking at the latest production figures

(Indiana Coal Association, 1986). The resulting figure for acreages disturbed by mining of coal in Indiana to 1986 would be 188,000 acres. The scope of the problem is not limited to acreages of disturbed lands. Also included are the safety problems associated with these vast acreages.

The National Inventory Update contained three priority rankings. This study focused on the Extreme Danger or Priority 1 problems. This group of problems was chosen for four reasons. First, their wide geographic distribution which includes fifteen counties in Southwestern Indiana. Second, the number of problems is sufficient to warrant the drawing of conclusions based on statistical significance. Third, the nature of the problems is diverse and nearly every type of problem is represented in the Extreme Danger category. Last, these problems represent a typical cross section of the characteristics of coal-mined areas in the Indiana coal field.

The specific sites of the study area will be confined to those counties which have at least one Problem Area with an Extreme Danger Problem (Table 3) (Figure 1). The counties

Table 3

Counties Included in the Study

Clay-1	Knox-6	Spencer-11
Daviess-2	Martin-7	Sullivan-12
Dubois-3	Parke-8	Vermillion-13
Gibson-4	Perry-9	Vigo-14
Greene-5	Pike-10	Warrick-15

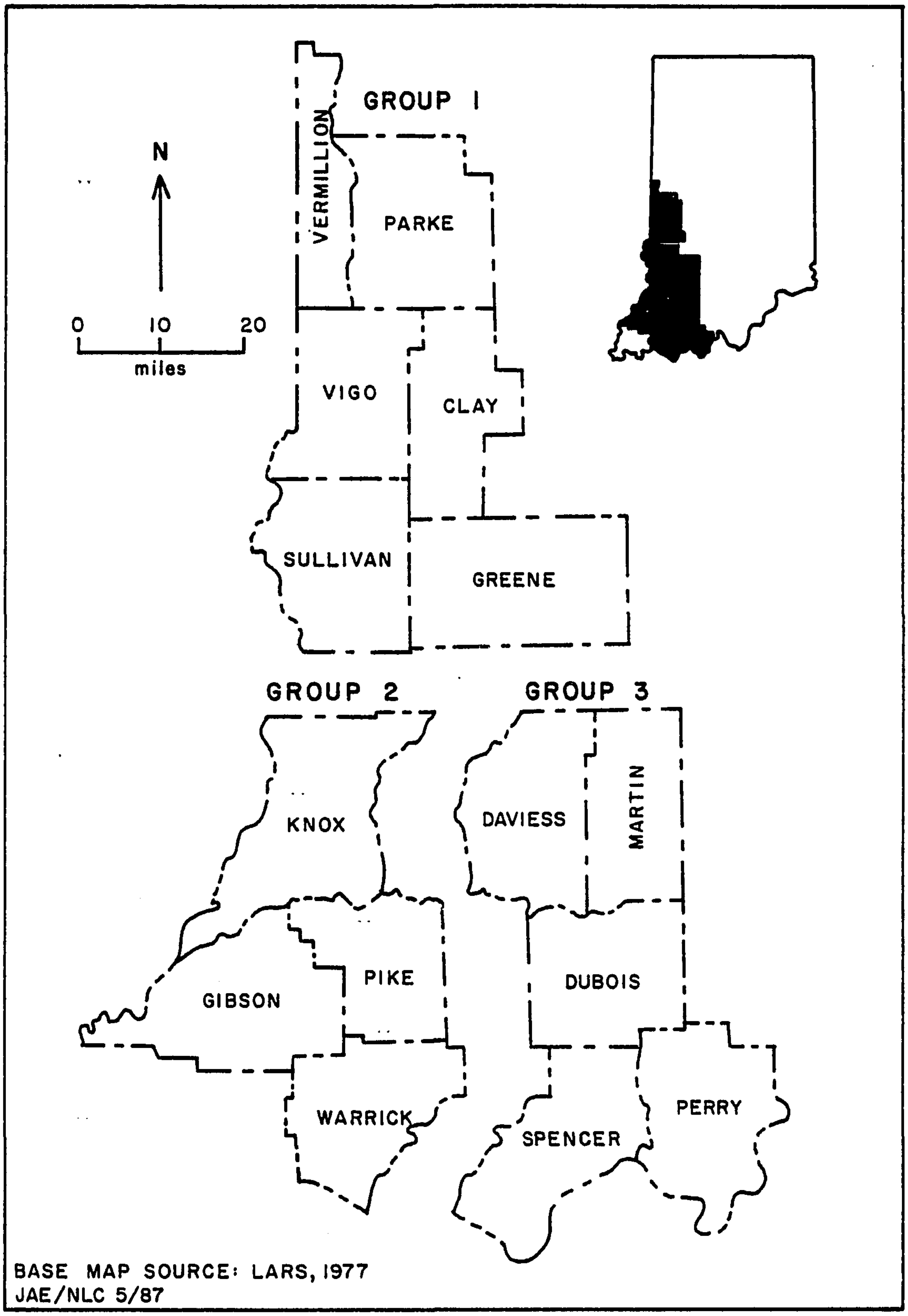

Figure 1. Counties in the Study Area in County Groups.

are divided into three groups. They are based on major and minor groups of coal producing counties. The problem areas are located on 47 U.S.G.S. 7.5' Topographic quadrangles in the aforementioned counties.

In this study, Extreme Danger Problems are referenced in two ways. The first method is by the number of problem areas. A problem area is comprised of the Extreme Danger Problems and their area of impact. There are one hundred forty-eight problem areas in the fifteen counties (Figure 2).

The second method is by the number of occurrences of Extreme Danger Problems. Occurrences refer to the total number of individual Extreme Danger Problems. For example, a problem area with 3 occurrences of HEF and 2 occurrences of VO, would have a total of 5 Extreme Danger Problems.
Table 4 shows the number of problem areas and the occurrences of Extreme Danger Problems. There are three hundred seventy-eight occurrences of Extreme Danger Problems in the study area. Counties like Clay and Vigo have three times the occurrences of Extreme Danger Problems per problem area as a county such as Warrick.

Table 5 shows the type of keywords present per county and their number of occurrences. A keyword references the individual type of Extreme Danger Problem that exists at a given problem area; see Appendix B for definitions. These occurrences are represented cartographically to highlight the counties with the largest number of problems and their distribution (Figure 3).

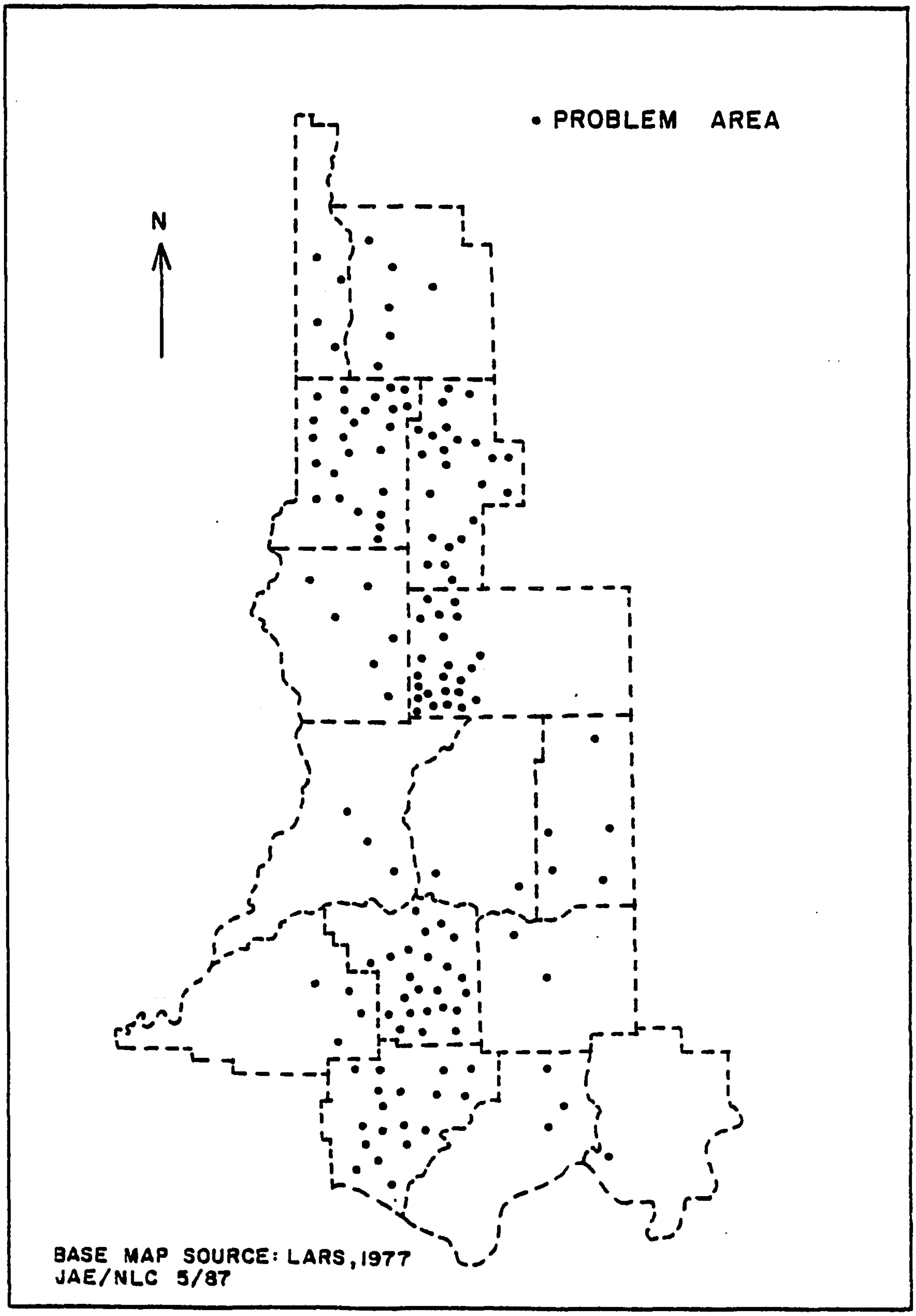

Figure 2. Problem Areas in the Study.

Table 4

Problem Areas and Occurrences per County

County	Problem Areas	Occurrences
Clay	23	63
Daviess	2	4
Dubois	2	4
Gibson	4	7
Greene	23	46
Knox	3	6
Martin	5	21
Parke	6	10
Perry	1	2
Pike	23	48
Spencer	3	14
Sullivan	6	19
Vermillion	4	18
Vigo	25	72
Warrick	18	44

Table 5

Number of Occurrences of Keywords per County

	VO	P	SB	GHE	DPE	DI	PWHC	S	HEF	IRW	HWB	DH	CS
CLAY	25	10			1			5		1	4	17	
DAVIESS	1								1		1	1	
DUBOIS	3								1				
GIBSON	4								2		1		
GREENE	28	1	1					1			1	14	
KNOX	1			2			3						
MARTIN	14	2						2			1	2	
PARKE	7										1	1	1
PERRY	1	1											
PIKE	8	6			4		1				1	27	1
SPENCER	1	1			3						2	5	
SULLIVAN	13	1		2	1				1	1			
VERMILLION	7	1								1		1	
VIGO	39	1	1	2	2	2	2	3	2	1	1	1	
WARRICK	37	1			6			2	15			8	

VO: Vertical Opening
P: Portal
SB: Surface Burning
GHE: hazardous gases
DPE: pile or embankment
DI: dangerous impoundment
PWHC: Polluted Water-Human Consumption
* For Definitions See Appendix B

S: Subsidence
HEF: Equipment & Facilities
IRW: Indust/Res. Waste
HWB: Recreational waterbody
DH: Dangerous Highwall
CS: Clogged Stream

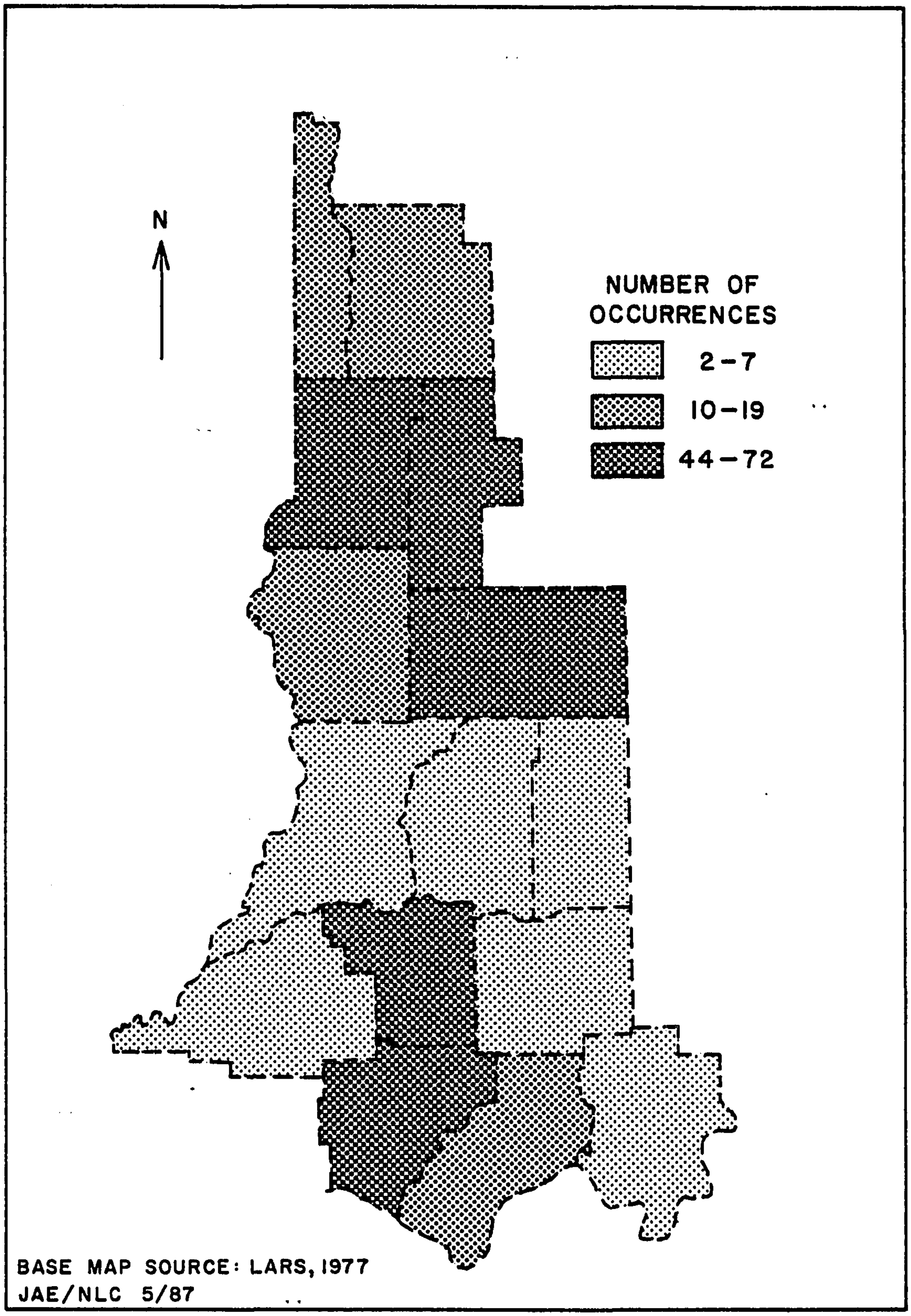

Figure 3. Total Number of Occurrences of Extreme Danger Problems by County.

Physiography

This fifteen county area of Southwestern Indiana extends from approximately 86° 45' to 87° 30' West Longitude. The Latitude ranges from 38° 00' to 39° 45' north. Within this area, there are three physiographic provinces and three areas of diverse glacial history. The terrain varies from flat to hilly. The deposits that overlie the coal seams vary greatly in thickness and composition. Coal mining and its resulting problems are closely related to these variations in topography and therefore, consideration of these variations is essential to the analysis of Extreme Danger Problems.

The three physiographic regions are the Tipton till plain, the Crawford upland and the Wabash Lowland (Figure 4). The Tipton till plain covers Vermillion county, most of Parke county and the northwest corner of Vigo county. The southern boundary of this province is the Shelbyville moraine, which marks the southward extent of Wisconsinan glaciation. This area is a nearly flat to gently rolling glacial plain (Schneider, 1966), a direct result of the leveling power of continental glaciation. The Tipton till plain is not entirely featureless; there are scattered end moraines, eskers, and meltwater drainageways. Postglacial streams have cut through the glacial drift as much as 150 feet (Schneider, 1966). The coal deposits in this region are smaller in comparison to those of the Wabash Lowland

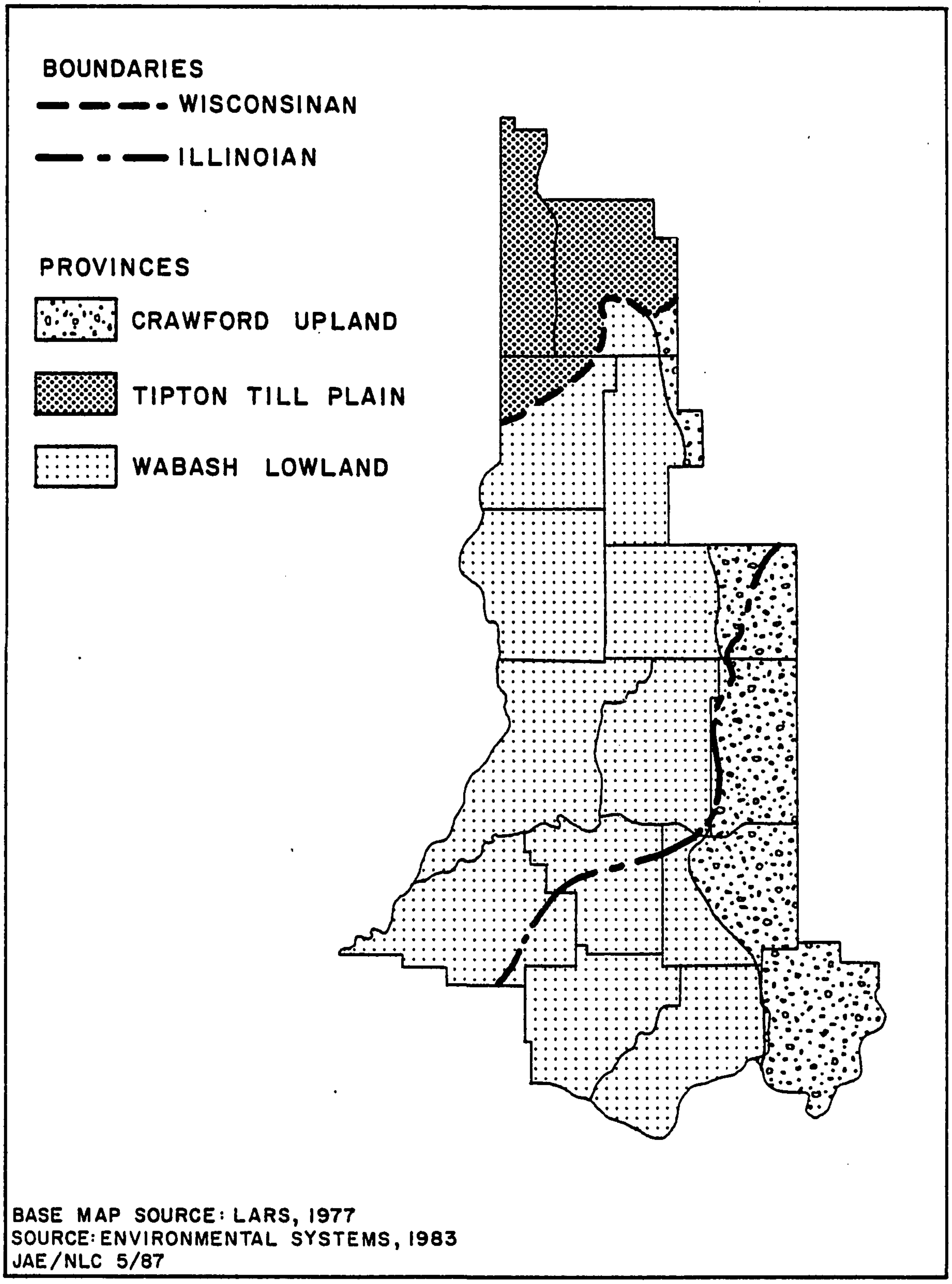

Figure 4. Physiographic Provinces and Glacial Boundaries.

(Environmental Systems, 1983); however, deposits in limited areas are of major importance.

Mississippian age sedimentary rocks lie beneath the Crawford Upland. It covers small parts of Parke and Clay counties, the eastern halves of Greene and Gibson counties, and the counties of Martin and Perry. The extent of this province is nearly coincident with the outcrops of the Indiana coal seams and the extent of mining. The coal deposits in this area are small and scattered. Most are limited to local importance. The differential erosion of sandstones, shales and limestones has created a diversity (Schneider, 1966) of topographic features. This province has not experienced glaciation and is therefore rugged and highly dissected by stream valleys that have formed a mature drainage system. The local relief of 300 to 350 feet is common (Schneider, 1966). Nearly all the area is in slope with only a few level areas which are on the floodplain.

The Wabash Lowland covers the remainder of the study area. Nearly all of the coal deposits of economic importance lie within this province. The elevations average some 300 to 400 feet (Schneider, 1966) below the Crawford Upland. It is underlain by Pennsylvanian age sedimentary rocks. The topography is rather subdued, consisting of rolling hills with flat river valleys and bottomlands. The northern two-thirds of the province have Illinoian glacial deposits. The relief in this area is generally less than the unglaciated one-third of the area. Loess deposits, a result of Wisconsinan glaciation, are particularly in evidence along the Wabash River and its tributaries.

Coal Geology of Indiana

Coal is a combustible carbonaceous rock that was formed from decomposed vegetation. This plant material originated in swamps formed during the Pennsylvanian Period, approximately 280 to 320 million years ago. The climate of the Pennsylvanian Period was very conducive to luxuriate plant growth as evidenced by the thick accumulations of plant material. These plants grew, then fell into the swamp where they were only partially decayed because the high water table slowed bacterial growth. The plant material accumulated and as it did the weight of the overlying material compressed it, slowly squeezing out most of the water and volatile matter. A complex and lengthy process of physical and chemical changes then ensued and transformed these altered plant remains into the bituminous coals of Indiana.

There are two major types of coal that can be differentiated by their origin. They are the bright-banded and the dull-banded coals. Although most of the coal in Indiana is of the bright-banded variety, the dull-banded coals are also important in this study. The bright-banded coals have three alternating bands. The first are the bright bands of vitrain, the second are duller bands of clarain and bright attritus and the third is a charcoal like layer of fusain (Wier, 1973). The dull-banded coals have few bright bands and have a tendency to break into large blocks. In these coals, the vitrain and fusain were the bark and woody parts of the plants, while attritus are the smaller parts of the plants such as the seeds, cuticles of leaves, and waxes. If the decay of the material was more complete, as in the case of dull attritus (Weir, 1973), there are no bright bands.

In this study area fourteen different coal seams (Figure 5) have been mined in the one hundred forty-eight problem areas. The characteristics of these coal seams have influenced the mining and, therefore, the resulting problems. For example, a bad roof may present problems during current mining and create a tendency for subsidence problems after abandonment. Another example is the influence of the dip of the coal beds. For a given coal seam, the outcrop occurs east of the more deeply buried part of the seam. This influences the type of mining. Generally speaking, surface mining of this seam will then occur to the east of an underground mine extracting coal from the same seam.

The following generalized description of each seam includes pertinent information and specific examples where possible. This description will proceed from the youngest coal seam to the oldest. The correlations of the following beds are somewhat uncertain; therefore, for the purposes of this study, the Danville VII and the Millersburg coal seams, as well as the Minshall and Buffaloville coal seams, will occupy the same relative geologic position.

GROUP	FORMATION	STUDY NUMBER	COAL MEMBER OR BED
Carbondale 300'	Dugger	1	Danville (VII) - Millersburg
		2	Hymera (VI)
		3	Springfield (V)
	Petersburg		
		4	Survant (IV)
	Linton		
Raccoon Creek 550'	Staunton	5	Seelyville (III)
		6	Unnamed Staunton
		7	Minshall - Buffaloville
	Brazil	8	Upper Block
		9	Lower Block
	Mansfield	10	Mariah Hill
		11	Blue Creek
		12	Pinnick
		13	St. Meinrad
		14	Unnamed Mansfield

SOURCE: ENVIRONMENTAL SYSTEMS, 1983
WEIR, 1973

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Figure 5. Geologic Column for Study Area.

The Carbondale Group consists of three Formations which contain the first four coal seams.

Dugger Formation:

Danville VII - Millersburg: This member is a bright-banded coal that crops out from the Ohio River at Newburgh northward to Vermillion county. It ranges in thickness from 0.2 to 6.5 feet and thins from north to south (Shaver et al., 1970). The coal contains clay and shale partings and local concentrations of pyrite and marcasite. The roof is usually shale but may be sandstone. Sandstone lenses are found in some mines (Karpiniski, 1938) and may cause instability. It has a low sulfur and ash content (Wier, 1973). The coal at Ditney Hill (0429) is identified as the Millersburg (Spencer, 1953), where it averages 7 feet in thickness.

Hymera VI: This member is a bright-banded coal that can be found in Sullivan, Knox, Daviess, and Gibson counties and is named for its exposures at Hymera in Sullivan county. It ranges in thickness from 0.5 to 11.0 feet (Shaver et al., 1970). There are numerous shale and pyrite partings; however, two outstanding partings can be traced over a large geographic area. They are located in the center of the seam and are about 1" thick and are separated by 5" of coal (Karpiniski, 1938). The roof and floor are usually shale. The coal has moderate ash (Wier, 1973) and low sulfur content.

Petersburg Formation:

Springfield V: This is a bright-banded coal that extends from Warrick to Vermillion county. It is the most widespread and mineable coal in the Eastern Interior Basin (Spencer, 1953). This constant thickness over large areas is one of the most important factors (Karpiniski, 1938) leading to its huge production. Its thickness ranges from 5 feet to as much as 13 feet (Shaver et al., 1970) in east-central Sullivan county. In a few areas, Pennsylvanian age sandstone channels have replaced the coal. There are only a few scattered shale partings that may be of local significance. The roof is usually a gray shale but it may also be sandstone or clay. Where the roof is marine shale, the sulfur content is relatively high (Gray, 1979), in contrast to the nonmarine shale. In some areas, large concretions of pyrite are in the black shale roof. The coal is underlain by silty clay, shale or sandstone. It is overlain by a black fissile shale with iron-rich concretions (Shaver et al., 1970) which ranges from 1 to 6 feet in thickness. The coal may also be overlain by gray shale and shaley sandstone or a combination of these. It has a moderate ash and a high sulfur content (Wier, 1973).

Linton Formation:

Survant IV: Named for the exposures in Pike county, this bright-banded coal ranges in thickness from 0.2 to 8 feet (Shaver et al., 1970). There are workable thicknesses in nearly all the fifteen counties in the study area. Most mining takes place in western Greene county (Karpiniski, 1938). Shale partings range from a few feet to as many as 20 to 30 feet in Greene, Clay and Vigo counties. Where partings are thin the coal is low in ash and sulfur (Wier, 1973). The upper part of the coal may grade into a canneloid coal (Shaver et al., 1970) or a black bituminous shale near Linton. The overlying strata are commonly sandstone or gray shale.

The Raccoon Creek Group consists of three Formations that contain ten coal beds.

Staunton Formation:

Seelyville III: Named after the thick deposits near Seelyville, Indiana. It averages 6 feet in thickness (Shaver et al., 1970) and may vary from 1.5 to as much as 11 feet. There are extensive areas in Vermillion, Vigo and Sullivan counties with smaller deposits in Clay, Greene, Daviess, Dubois, and Spencer counties. It is a bright-banded coal that commonly has two pyrite shale partings. The roof is either a gray, silty, carbonaceous, shale or a brown to gray massive, friable carbonaceous sandstone. Sandstone rolls with pyrite (Spencer, 1953) occur frequently in this bed. The floor is usually a gray underclay that may be plastic and shaley in places. This fireclay floor is a "very mobile layer" (Karpiniski, 1938) that may cause mining difficulties. The seam is high in sulfur and variable in ash content (Wier, 1973).

Unnamed Staunton: These coals are quite variable in quality, thickness and area. The roof strata may be black fissile shale and limestone (Shaver et al., 1970), gray soft shale and interbedded fossiliferous shale or limestone, or massive hard to friable sandstone. The floor is underclay or shale.

Brazil Formation:

Minshall-Buffaloville: The Minshall coal is a moderately bright to very dull (Shaver et al., 1970), semiblocky to blocky coal named after a mining town in Parke county. Its extent is irregular in Vermillion, Parke, Clay, Greene, and Daviess counties. It ranges in thickness from 1 to 6 feet. The roof is clayey to silty shale. The floor is a gray plastic underclay. The Buffaloville coal, named after a town in Spencer county, is blocky. It has a floor of underclay nearly 3 feet thick (Shaver et al., 1970) and a roof of black sheety shale. It is overlain by a soft calcareous shale and above this a 2 foot layer of limestone, which in some places may lie directly above the coal.

Upper Block: The block coals is a trade name first given to the coals mined near Brazil since 1850. This coal is a moderately dull-banded, hard, semisplint coal. It is most abundant in Clay, Greene and Daviess counties. When mined the blocks measure 0.5 to 3.0 feet on a side (Shaver et al., 1970). This is a result of well-developed vertical joints in the coal seam. The coal ranges in thickness from 1.5 to 5 feet. A thin zone of soft flaky coal (Shaver et al., 1970) separates the coal bed into two benches of unequal thicknesses; the top breaks into larger blocks, while the lower breaks into smaller cubes. The roof is usually a hard thick-bedded shale; however, in some areas it is a soft shale overlain by a massive sandstone. Occasionally the upper few inches of the coal seam is bone coal. The floor is a hard carbonaceous underclay that becomes plastic when moist. The coal is low in ash and sulfur (Wier, 1973).

Lower Block: This coal is a dull-banded slabby coal. It has two parallel joints which are about 0.3 to 2.0 feet apart (Shaver et al., 1970). The thickness ranges from 0.7 to 5.8 feet. These coals crop out from Parke to Greene counties. These Lower Block coals have a tendency to occur in narrow depressions (Spencer, 1953) making correlations difficult in many areas. The depressions range in size from several acres to one hundred acres (Karpiniski, 1938). Between depressions the coal thins to a few inches. The lower block coal may have a layer of bone coal either above or below it. The roof is usually a hard shale interbedded with sandstone. The floor is usually a sandy underclay or shale, which may be inferior in places. This coal is low in sulfur (Wier, 1973).

Mansfield Formation:

Coals in this Formation are present in Martin, Dubois, Perry, and Spencer counties, but their distributions are quite erratic. These coals range from a few inches to 4 feet over a small area and mining is usually only in restricted areas. Small operators in these areas were "exempt from filing a work-out-area coal mining maps" (Spencer, 1953). Therefore, this and other information is sketchy.

Mariah Hill: The name of this coal originated from the first company to mine the coal seam in Spencer county. This coal is a moderately bright semi-blocky coal that ranges in thickness from 2.0 to 4.4 feet (Shaver et al., 1970). The roof is commonly a silty carbonaceous shale with local areas of cherty limestone. The floor is a carbonaceous underclay or clay shale. This coal is high in moisture and ash content (Wier, 1973), but low in sulfur.

Blue Creek: This coal member is divided into two branches and named for its mining near Blue Creek. The upper is 2 feet thick, dull-banded (Shaver et al., 1970) while the lower is 2.8 feet thick and is bright-banded with a blocky fracture. This member is extremely variable in thickness and quality. It ranges from an economic seam to a coaly shale. The roof os a carbonaceous ferruginous shale overlain by a thick carbonaceous ferruginous sandstone. The floor is white fire clay.

Pinnick: Generally, this bed is thin and hard to trace. The coal is shiny, blocky and about 2.1 feet thick (Shaver et al., 1970). The roof is carbonaceous shale or massive ferruginous sandstone. The floor is underclay.

St. Meinrad: This coal is a moderately bright, very clean semiblocky (Shaver et al., 1970) coal mined near a town in Spencer county. It ranges in thickness from 0.1 to 5 feet and has numerous thin partings. The roof is a fissile carbonaceous shale or a massive sandstone. The floor is sandy carbonaceous underclay or shale. In places, the upper few inches is bone coal (Shaver et al., 1970).

Unnamed Mansfield: The identity of this coal bed is sketchy; it may be the French Lick coal member (Coal I). It has an estimated thickness of about 2 feet.

CHAPTER III

SURVEY OF LITERATURE

Those articles which are pertinent to this study can be grouped into four main areas: specialized studies, general large area studies, coal mining methods, and studies specifically related to the hazards of abandoned coal mine lands.

The specialized studies may be confined to only one mine or to a localized area. Reports such as those for the Green Valley mine (GEOSCIENCES, 1985) or the Blackfoot mine (TENECH, 1985) deal with possible reclamation techniques. The authors spend considerable time in characterizing the problems on the site. The environmental problems cover large areas and much literature is devoted to their reclamation. Many times the reclamation of safety hazards is overlooked or only of secondary concern. The Blackfoot mine area has highwall problems that are mentioned only briefly with respect to an intensive discussion of the reclamation of the environmental problems. However, the safety problems need to be identified prior to assessing the proper reclamation techniques when environmental and safety problems are combined. One report describes the water chemistry of coal wastes at the Green Valley mine (Eggert, Hailer, Irwin, and Miller, 1981). Several watersheds in Indiana have been adversely affected by acid mine drainage. Two studies have noted the effects on the Patoka River watershed (Corbett, 1969) and the Busseron Creek watershed (Corbett and Agnew, 1968).

Two studies have focused on the abandoned coal mine land problems of Eastern Tennessee. One is a general look at the problems (TVA, 1975) and considers methods to deal with surface flow, minimize erosion and prevent acid mine drainage so that the land may be used for forest or wildlife use. Another study presents a collection of case studies (Nesbitt, Lee, and McGraner, 1981) of AML projects by Nesbitt Engineering. Both studies included sedimentation, dam emergencies, and refuse fire emergencies.

Included in the specialized studies are newspaper articles and interviews. Some articles call attention to the dangers of specific abandoned mines (Ludwick, 1985; Tribune Star, 1978). Others note that problems such as subsidence present a continuing danger to the public over vast areas (Carey, 1984).

Several general studies of the abandoned coal mine land problems of southwestern Indiana have been conducted: Allan (1978), Allan, Thomas and Kelley (1978), Thomas (1978, 1981). One study used aerial photographs to identify and locate abandoned mine land acreages in southwestern Indiana (Weismiller and Mroczynski, 1978). Another study noted the extent of abandoned coal mine lands in the United States (Johnson and Miller, 1979). Several other studies focused on topics dealing with large areas or considerable expanses of time. One addressed the coal strip-mined land in Indiana (Powell, 1972), another the trends in underground mining in Indiana (Harper, 1981), and a third, the development of surface coal mining in Indiana (Harper, 1985).

Inventories are included in these general studies. One report discusses the techniques for inventorying the AML problems using two counties in West Virginia (Mentz, Gorton, Yuill and Abnell, 1978). A study in the State of Washington (LaSalata, Menad, Walsh, and Schlasse, 1985) provided an overview of abandoned coal mine problems that were a part of the inventory of the Office of Surface Mining. Another publication includes an inventory of the AML sites in Illinois (Klimstra, 1974; Massie, 1981). Some of these inventories include possible or recommended reclamation techniques (Illinois AML Reclamation Council, 1982; Nawrot and D'Antuono, 1979; Roberts, 1979). Much of the information on reclamation deals with environmental problems, but the Illinois AML Reclamation Council in 1982 also addressed such safety problems as open shafts, equipment, structures, and highwalls.

Prior to 1977, coal mining methods are an important part of analysis of the abandoned coal mine land problems. One study deals with the coal mining in Vigo county (Harper, 1985). The history of early coal mining methods is discussed in several articles: Andros (1914, 1915), Holmes (1924), Moore (1940), Cassidy (1973). Another study specifically notes how to locate shafts and the types of shaft linings (Ove Arop, 1976).

Numerous other articles deal with surface and underground coal mining in great detail (Cassidy, 1973; Coal Research Section, 1973; Fung, 1981; Moore, 1940 and Pfleider, 1968). This information on mining and the types of mining provide a rather complete picture of the evolution of each mining type and the factors that accounted for these developments.

Written transcripts of interviews (Pickett, 1981a, 1981b) with retired coal miners were available at the Vigo County Public Library. Each of these miners had worked for a time in at least one of the mines in this study and was able to give information on mining methods and other variables of interest.

Trade publications also provide information on previous mining methods (Coal Age, 1938). Some specific examples, with accompanying photographs (Karpiniski, 1938) of mines with extreme danger problems such as the Friar Tuck mine are also found in Coal Age. Many mines within this study were used as examples in the study of mines in Indiana (Karpiniski, 1938). There was information on the pattern of underground mining at the Wick mine, details on how two seams of coal were mined at the Friar Tuck and New Hope mines and various other facts pertinent to this study.

Those studies relating specifically to the hazards of abandoned coal mine lands are sparse. One article briefly mentions the safety hazards (Plass, 1971); but the main concern here was for aesthetics. Another article, in dealing with the problems of open shafts in Scotland (Dean, 1967), briefly describes a few cases of collapse in a study site locality. Another report (Dewey, Robbins, Oehler, Reed, and Bilzi, 1980) focuses on the hazardous mine openings associated with underground mining in Western Colorado. The report also describes an educational safety campaign to reduce the possible injuries to people in the area. Another study describes the hazards related to abandoned mines in southern Quebec (Bolvin, 1982) and explains the most essential steps of reclamation for rendering the openings safe for people in the area.

CHAPTER IV

THE DEVELOPMENT OF COAL MINING IN INDIANA

Coal has been mined in Indiana since 1812. The earliest type of mining was surface mining with horse-drawn scrapers. This was limited to areas with very shallow overburden. Then in the early 1850's shaft mining overcame the overburden limits and became the dominant form of mining.

Underground mine production rose steadily and first peaked in 1910 (Figure 6). Production fell, then rose as "World War I temporarily doubled Indiana's production" (Harper, 1981). The depression years were a time of decreased production; however, Indiana accounted for 4% of the total production in the United States (Karpiniski, 1938). During the depression surface mining for coal was still a profitable venture (Corbett and Agnew, 1968). Following another temporary increase during World War II, the production decreased steadily, so that by 1977 production had fallen below the underground production of 1880. During the post War era there was a shift away from coal mined by underground methods in Indiana.

Significant production by surface mining began about 1915. A steady increase in production occurred until World War II, when production leveled off and only moderately fluctuated during the next twenty years. In 1926 and 1927

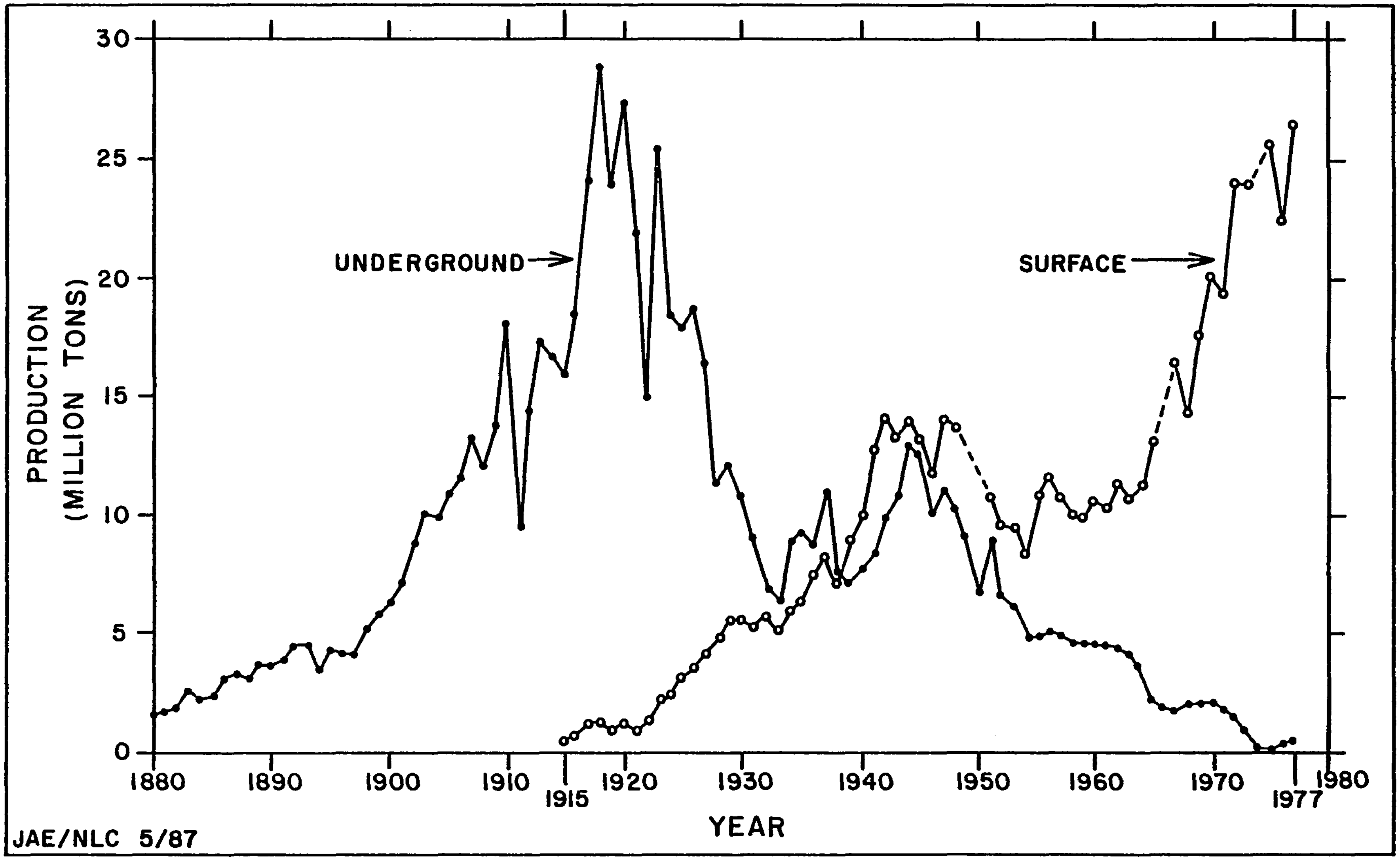

Figure 6. Production of Coal from Surface and Underground Mines in Indiana 1880-1977.

Indiana was the leading producer of surface mined coal in the United States (Harper, 1985b). Shortly after 1960 production grew at an increasing rate, peaked around 1972, and then leveled off to 1977.

It appears that "surface mining did not simply displace underground mining" (Harper, 1981). Underground production experienced two major declines before surface mining became the major producer of coal. While many factors are responsible for the production shifts, this study is concerned with how the fluctuations in production may have contributed to AML Extreme Danger Problems. Suffice it to say that significant coal production from both methods has contributed to the variety and complexity of AML problems in Indiana.

The techniques used in coal mining are of major concern to this study. One example is the difference in mining techniques; they "are major contributing factors to the surface pattern of subsidence and the timing of failure" (DuMontelle and Bauer, 1983). The following discussion of mining methods in the study area and their development through time is not meant to be all inclusive, but rather focuses on the mining techniques which have influenced or contributed to the Extreme Danger Problems.

The ultimate goal of both underground and surface mining is the removal of coal as efficiently as possible. The major distinction is in how the coal is removed. Generally, underground mining involves going underground to bring the coal to the surface, while surface mining involves removing the overlying materials to expose the coal.

The Underground Mining Process

Underground mining techniques discussed will be those used from 1850 to 1977, the time limits of the underground mining in this study. In underground mining of coal a horizontal, inclined or vertical opening is excavated to the coal seam. The horizontal opening is called a drift. This opening enters the seam at its outcrop on a hillside or at a former highwall. Slope mines enter the seam on an incline; shaft mines enter the coal seam vertically. In the latter two types of openings, to gain access to the seam the overlying materials are drilled and blasted, then removed to form a "tunnel" to the seam. A mine may have more than one of these types of access. In addition to these major openings, there may be other openings for ventilation and emergency access.

Drift mines are usually present along hillsides in more rugged topography. These began as small "wheelbarrow" or "dogholes" mining an acre or less and were privately owned (Nawrot and D'Antuono, 1979) but did reach commercial proportions. Slope mines occur where the overlying materials are quite thick and the most efficient access to the seam is by an inclined opening. Shafts are found where the seam is nearly horizontal and overlying materials may be many feet thick. In Vigo county the thick sequences of unconsolidated deposits contributed to the dominance of underground mining (Harper, 1985a).

Room and Pillar Mining

Once access to the coal seam is gained coal removal may proceed in several ways. The most common procedure is the room and pillar first used in the post-Medieval period (Ove Arup and Partners, 1976). It is essentially the only method used in the problem areas in this study. The specifics of this method vary with the characteristics of the coal seam, as well as the time period of mining.

Early room and pillar mining was rather irregular, before it developed into a rather systematic removal of coal. It is difficult to discuss a mine typical of those in this study because of the changes in techniques over a one hundred year span. Since most of the mines were operating in the late 1920's a typical mine for that time will be discussed in detail (Figure 7).

First, a main shaft and an accompanying air shaft were sunk to the coal mine. At a mine near Staunton (Coal Age, 1920) the shaft had two compartments; both were 19 feet 6 inches by 12 feet. As a general rule in sinking a shaft it was necessary to have at least 30 feet of solid material above the coal seam (Karpiniski, 1938); however, this was not a rule always adhered to.

The shafts were lined with various types of material including wood, metal, or concrete. If little water was incurred while sinking the shaft, then the shaft was not totally lined with concrete but received only a concrete curbing (Coal Age, 1920). At the Saxton mine where the

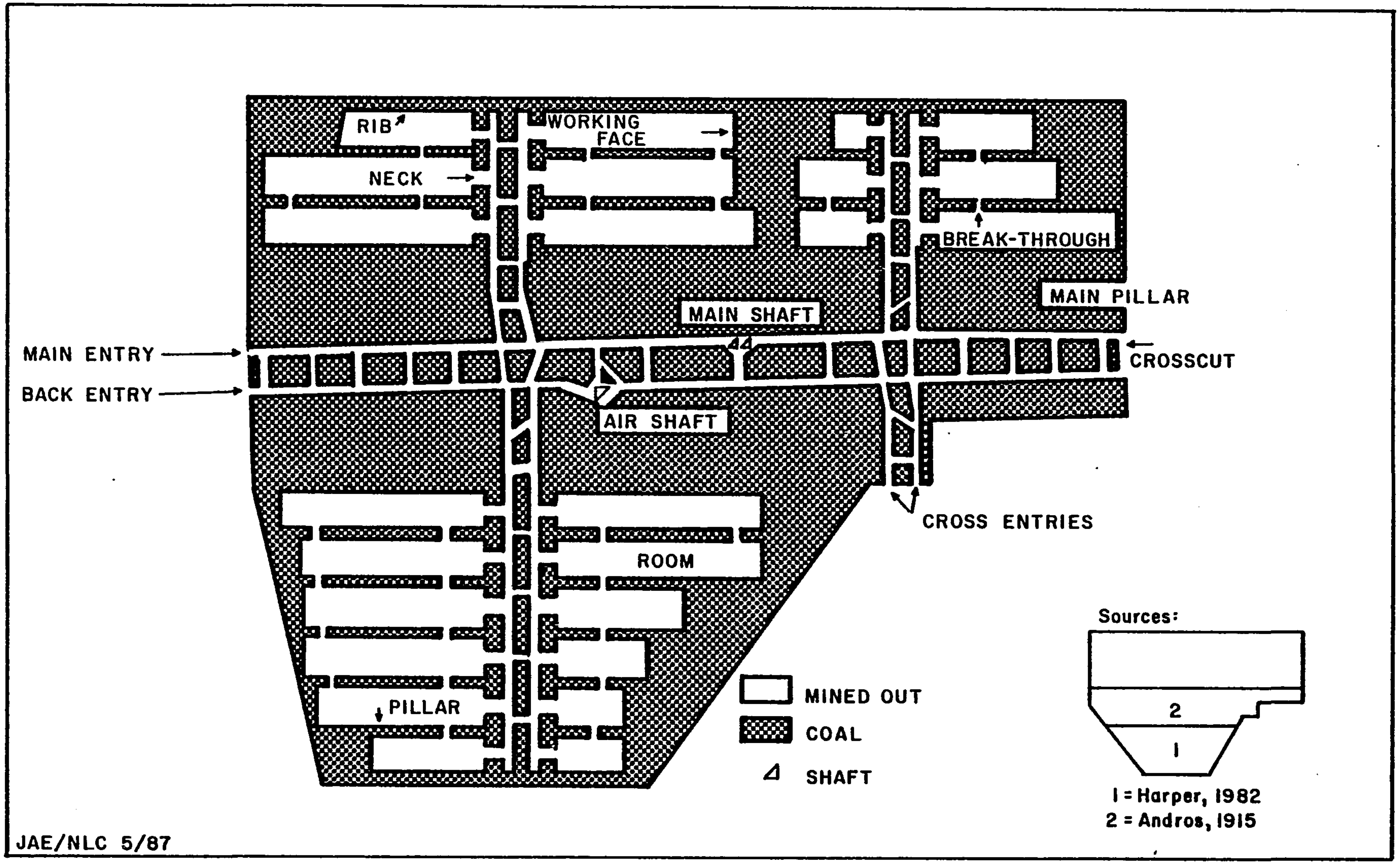

Figure 7. Plan View of an Underground Mine Typical for the Study Area.

overlying material was partially a gravel bed filled with water (Richart, 1944), a concrete shaft was used. These concrete shafts were larger than wooden shafts and were rectangular in shape. A few shafts, especially air shafts, were brick lined and circular in shape. Older shafts often had wood linings and were nearly square in shape. Sometimes they were timber and lined the entire length, and other times the 6 by 8 foot timbers extended down for 22 feet (Coal Age, 1920), then the lining changed to 4 by 12 inch planking. Wooden linings of oak were expected to last for fifteen years (Ove Arup and Partners, 1976). While the wooden shafts were less expensive than concrete, they presented a greater fire hazard and slowed down air currents necessary for ventilation. By 1938 most shafts in Indiana were a combination of timber and concrete (Karpiniski, 1938).

In the seam two wide passageways--the main entry and the back entry--were excavated. The main entry was the primary haulage route and contained track. The back entry was the main intake route for the ventilating air currents (Andros, 1915). Both of these entries were usually driven straight to facilitate the haulage process and increase the flow of air within the mine. In a few of the earlier mines the single entry presented a dangerous situation as an accident could cut off air, haulage, and escape (Moore, 1940).

In Indiana (Harper, 1982) the main and back entries were twelve to eighteen feet wide. Smaller passageways, crosscuts, connected the main entries. These crosscuts aided in ventilation and were short cuts for men and materials. Turned off the main entries at a 90° angle were narrower cross entries. The height of these entries is largely a function of the thickness of the coal seam. The rooms are driven at a 90° angle to these cross entries. The rooms are the areas of coal that have been removed.

A narrower neck, about six feet wide, leads into the room to ensure the stability of the cross entries. These went back nine to fifteen feet, then the rooms widened to their usual width. In Indiana the optimum room width was 20 to 30 feet and the length was 175 to 400 feet (Harper, 1982 and Coal Age, 1920). Wider and longer rooms were possible in areas with excellent roof characteristics. The end of the room where the coal is being removed is called the working face and the sides of the rooms are the ribs.

In Indiana, a panel of rooms is worked. There are between 10 and 48 rooms in a panel (Karpiniski, 1938). Each panel is protected by solid pillars on all sides. This permits a whole panel to be closed off at the completion of mining. When the panel is sealed off, it has the advantage of protection against flooding and escaping gas and also reduces the area of ventilation (Karpiniski, 1938).

The pillars are the areas of coal that remain in place for support. The pillars were usually narrow, 6 to 23 feet wide (Harper, 1982), if the rooms were expected to subside. In these pillars between rooms are break-throughs, which aid in air circulation and movement of workers (Moore, 1940).

The number of rooms that were usually turned off a cross entry was 10 to 32 (Harper, 1982) in Indiana. Room and pillar mining commonly leaves twenty to fifty percent of the coal in the ground as pillars (Harper, 1982). Earlier room and pillar methods left as much as eighty percent in pillars (Nawrot and D'Antuono, 1979). Usually, around the shaft the main pillars were quite large, greater than eighteen feet wide (Harper, 1982), to provide for the continued support of the shaft and the support facilities at the surface.

To remove the coal, a groove is cut at the bottom of the face. This is usually done with a mining machine. This resembles the blade of a gigantic chainsaw. Earlier grooving was done by the miner with a pick, lying on his side. Then the drillers and blasters place charges of explosives in strategic places, which when accompanied by this grooving, bring down the face of the coal. A fall such as this may produce several tons of coal at once. The coal is mechanically loaded into shuttle cars, which are electrically propelled to the main haulage track. Since 1947, continuous mining machines have been available. These machines tear the coal loose from the face continuously.

Early Mines

In the earlier mines, practically all the labor was done manually. Miners used hand tools to break out the coal and to drill holes for explosives. In the Survant coals the room was about 30 inches high; the result was only enough room for the miner (Pickett, 1981b). After the coal was removed a car and mule "took out the bottom" (Pickett, 1981b) to promote more efficient operation. After the coal was loaded by hand into the coal cars, the miners pushed the cars to the main entries where manpower was replaced by horse or mule power. The miner was responsible for all duties associated with his assigned room.

Earlier room and pillar mining was irregular, and the rooms were typically much wider and the entries were much narrower than later mining. Little or no surveying resulted in many pillars that were too narrow to support the roof adequately. The entries tended to wander and changed course at the smallest seam irregularity (Harper, 1982). This also resulted in small, haphazardly placed pillars of odd sizes and shapes (Harper, 1982). The entries may have been 6 to 8 feet wide and the rooms 12 to 30 feet wide. Room depth varied with the type of haulage used. If car changing was done by mules then the rooms would be between 350 and 600 feet deep (Karpiniski, 1938). However, if men were pushing the cars then the length was less, about 165 feet.

Roof and Floor Stability

Roof support is a necessary part of underground mining. The three types of roof support are to leave pillars, timbering and roof bolting. Pillars and timbering are the oldest. Timbering is an attempt to support the mine roof with wood, metal or concrete materials. Proper timbering is based on the nature and thickness of the overburden, the nature and thickness of the coal, the quality of the roof and floor, and the size of the rooms and pillars (Sherman and MacMurphy, n.d.). The timbers are spaced quite closely near the shaft to support the roof. At the Crown Hill #4 mine 5 or 6 timbers were grouped together (Pickett, 1981a). Most systems include vertical posts and horizontal beams. These were first made of wood; oak, elm, hickory, and sassafras were common (Andros, 1915). Later concrete, steel or other types of metal were used. In active mines, high relative humidity and a constant air temperature of 65 degrees was very favorable to timber decay. They decayed rapidly, with an average life of eighteen months (Andros, 1914). The Saxton mine supplied air conditioning to cool the air intake in summer to eliminate the deteriorating effect of the air. Before this method was used, there were "rock rains" (Karpiniski, 1938). Water that stands in the workings and is exposed to oxygen may become quite corrosive. At the Buckskin mine acid conditions were so troublesome that steel lines from gathering pumps were "eaten out" in a year (Karpiniski, 1938).

The second type of support, roof bolting, was used in combination with pillars. Since 1947, the mine roof has been successfully supported with roof bolts (Sherman and MacMurphy, n.d.). This method allows the roof to hold itself in place. The overlying strata, which may be somewhat loosely cemented, are found firmly together by expansion bolts. These are placed in holes drilled deep enough to reach through the loose material into the more solid materials. This artificially forms a strong beam of overlying material (Sherman and MacMurphy, n.d.).

The stability of the coal mine depends on the type of roof and the type of flood. This not only affects the safety of active mining but also the probability of subsidence in the future. The rock types can result in excellent, good or bad roof and floor conditions (Table 6). Any type of discontinuity such as a fault, joint, or horsebacks will degrade the quality.

Poor roof conditions, such as falling slate, are a hazard to miners. The rooms and entries may need to be narrower, resulting in less efficient coal removal. Bad floor conditions are high percentage extraction rates result in pillars that are too narrow. High extraction leaves large areas of the roof area unsupported and this contributes

Table 6

Quality of Rock for Roof and Floor Stability

Quality	Rock Type
Excellent:	Limestone, well-cemented massive siltstone or sandstone
Good:	Medium-bedded sandstone, most siltstone, some silty shales
Bad:	Clay, gray or mottled shale, thinly laminated sandstones

to the development of "squeezes." Squeezes occur where the soft materials ooze from beneath the supporting pillars, block entries and weaken the roof support. Continued weight from the overlying sediments may simply crush the pillars into the floor. Once started, a squeeze is nearly impossible to stop.

The stability of the roof was also affected by the common practice of "robbing" pillars. This involves gouging the most coal possible from the pillars, a practice which can be quite unsafe, especially in cases as the one noted in 1881 (Harper, 1982) where this was occurring around the bottom of the shaft.

Transportation, Ventilation, and Facilities

In slope mines a conveyor belt usually transports the coal to the surface, while cars carrying miners and supplies are drawn along by cables which are wound around a drum at the surface. In shaft mines, miners and materials are transported to the surface in cages. The usual method of coal transport to the surface is by skips, gigantic buckets that contain the coal until it is dumped at the surface. However, in some mines the cages transported loaded coal cars to the surface.

A number of air shafts may be sunk to improve ventilation. Some of these air shafts may double as the emergency escape routes or manways (Coal Age, 1920). By 1940, the law (Moore, 1940) required two separate openings to every mine.

Various gases may be present in active mining operations. These are a result of the alteration of the vegetal materials during the formation of coal. The three gases formed in this manner are methane, carbon dioxide, and hydrogen sulfide. The first is explosive and supports combustion, but not breathing. The second overcomes miners by excluding oxygen from the lungs. The last is a foul smelling poisonous gas. These gases are present in various quantities in different mines, and even within the same mine. Methane was reported to be present in the Saxton and Buckskin mines during active mining (Karpiniski, 1938). The levels in the main return were 0.5% and 0.3%, respectively.

The support facilities and their by products make the first superficial effects. It is here that the coal is first cleaned and sized. This may range from a simple to a complex process. The first steps in the cleaning process are removal of impurities. Then the coal is sized to meet particular specifications. The result of sizing and cleaning is a coarse refuse called gob. It is composed of smaller pieces of coal, inferior grade coal, and waste rock associated with the roof or floor of the coal seam. A more complete cleaning of coal is accomplished by wet washing. The coal is floated in water, ideally washing away some of the impurities. The results of this process are large settling ponds of fine coal particles and impurities, which are called slurry ponds.

Methods at Select Mines

The New Hope mine (0104, 0401) is a slope mine with a 35° inclination and is 107 feet deep (Karpiniski, 1938). The rooms turned at a 45° angle, which resulted in a triangle shaped pillar. This angle was more suited to the track mounted loading machine used there and to haulage (Karpiniski, 1938). The coal was extremely undulating, with grades as high as 25% (Karpiniski, 1938), so the direction of the rooms changed often. Rooms can be driven in any direction, but the resulting pattern of pillars may affect roof stability. The rooms at this mine were 32 feet in width and 30 feet in length (Karpiniski, 1938). Two locomotives, hauling four and one-half ton cars, were the main haulage units. Robbing pillars was also practiced at New Hope (Karpiniski, 1938).

This was also a mine within a mine (Karpiniski, 1938). The Springfield V coal was being worked, but the Hymera VI coal was just 50 feet about the V, and here the VI was six feet thick. To tap the VI seam, an inclined rock tunnel was driven into the VI. Then, the night shift mined the VI and the V was mined during the other shifts. At this mine the total overburden for the V coal was 75 to 100 feet; in other mines, it is usually over 200 feet (Karpiniski, 1938).

At the Saxton mine (0047), the shaft is concrete and circular. The hoisting and the man and materials shafts are about 1,700 feet apart, and the hoisting shaft had a compartment on one end for an escapeway (Richart, 1944). The circular design provided greater resistance to the hydrostatic pressure encountered when this shaft was sunk through the water-filled Wabash Valley gravel (Karpiniski, 1938). The rooms turn off at a 45° angle. The width of the rooms averages 21 to 30 feet (Karpiniski, 1938), and the length averages 30 to 60 feet. This size best suits the track mounted loader and cutting machine to provide maximum extraction for the given roof conditions. A steam hoist was used at this mine to raise the six ton counterweighted skip.

There were two-inch partings, and on the mine map there was a notation, "bad top" (Harper, 1985a). There are extensively connected clay veins, slips, and roof rolls. To obtain acceptable gradients for the haulage ways, nine feet of the roof rock and six feet of the bottom rock were removed. The gradient was as much as 1.4%. In the areas mined beneath the Wabash River, roof falls allowed water to enter the mine and threaten the operation (Harper, 1985a).

At the Green Valley mine there was a notation on the mine map of "bad top" and water problems. At the northeast margin and in the southern half of the mine squeezes were common (Harper, 1985a). At the Victory mine, attempts were made to recover part or all of the supporting pillars (Harper, 1985a). There were also thick rock partings. The coal was seven feet thick in places but thinned to the south. The cropline prevented further mining to the east, and the older mines had worked out the seam to the north, ultimately causing the closing of this mine (Harper, 1985a).

In the Wick mine (0499) the slope entrance was 6.5 by 16 feet and extended 261 feet in depth at a 18° inclination (Karpiniski, 1938). A variation on the room and pillar method called the modified checkerboard (Karpiniski, 1938) was used at this mine. As the name implies, the pillars were almost square, with equal areas mined out around them. The rooms in this 6 foot coal seam were 30 feet wide and 50 feet long; this left 20 by 30 foot pillars that were staggered such that a solid pillar was opposite a crosscut (Karpiniski, 1938). To bring the coal to the surface a belt conveyor with a 100 horsepower motor was most efficient (Karpiniski, 1938), while a hoist moved men and materials.

At the Buckskin mine (0480) the coal was quite rolling with short grades as high as 25% (Karpiniski, 1938). With this grade the direction of the rooms had a tendency to change, rather frequently. Coal was brought to the surface by a steam hoisting the cage. The cage was later replaced with a skip which was balanced by the original cage (Karpiniski, 1938), plus a counterweight in the opposite shaft compartment.

The Surface Mining Process

The discussion of surface mining techniques will be those used from 1880 to 1977, the time span of surface mining techniques in the study. Most of the mines in this study were operating in the 1940's and 1950's. Basically, this involves removing all the overlying materials to gain access to the coal seam. Although this sounds rather simple, it becomes very complex. There seem to be no problems like those in underground mining, but "delusive simplicity has wreaked more than one venture" (Coal Age, 1928).

In the Midwest, the terrain is relatively flat and surface mines extend over large areas. This type of mining can be compared to a farmer plowing a field (Pfleider, 1968). The miner excavates a furrow and casts the overburden over a ridge parallel to the cut; the scale of operation separates the two. Surface mining is facilitated by thin and soft overburden. "About one third of the surface-mining coal-fields in Indiana lie in nonglaciated country where the original overburden has only a thin layer of permeable topsoil" (Honea and Baxter, 1983). The soft clays, lime-stone and shales in unglaciated areas and the unconsolidated materials in the glaciated areas are well suited to surface mining. However, these areas of glacial drift may cause problems. The glacial drift does not make very stable highwalls and there is a tendency for the highwall materials to slump into the pits (Honea and Baxter, 1983).

The first step is to ready the area for mining. This involves the removal of materials on the surface; these may range from trees and vegetation to buildings. Mining usually proceeds according to property lines and begins where the overburden is thinnest. Mining trends along the strike of the seam and continues down dip (Environmental Systems, 1983). Before materials are removed, the strata are fractured by drilling and blasting.

The first excavation is called a box cut. As the name implies, it is simply the removal of material down to the coal seam that resembles a rectangle or box. This cut may be a mile in length and 100 feet wide (Environmental Systems, 1983). The width of the cut allows small loading shovels and large trucks to move in and remove the coal. After the initial box cut has been excavated, then similar ridges parallel to it are excavated. The previous cut is filled with the spoil being presently dug out to form the new pit. This continues until the mining ends and results in a ridge and valley pattern that resembles "wind rows" from the air. The last cut is similar to the initial box cut, except there is no material to fill it as there was with the box cut.

This mining creates a variety of features (Figure 8) that are necessary to understanding the changes in surface mining in Indiana from 1880 to 1977. The material overlying the coal seam is termed overburden. After this material is removed from the cut or pit, it becomes spoil. The spoil is piled on the side of the pit away from the direction of mining. As a result of this excavation, a steep precipice is created on the unmined side; this is the highwall. The excavating machine, usually a dragline, moves from the face which is the most recent point of mining. After the overburden is removed, the coal is loaded for transport.

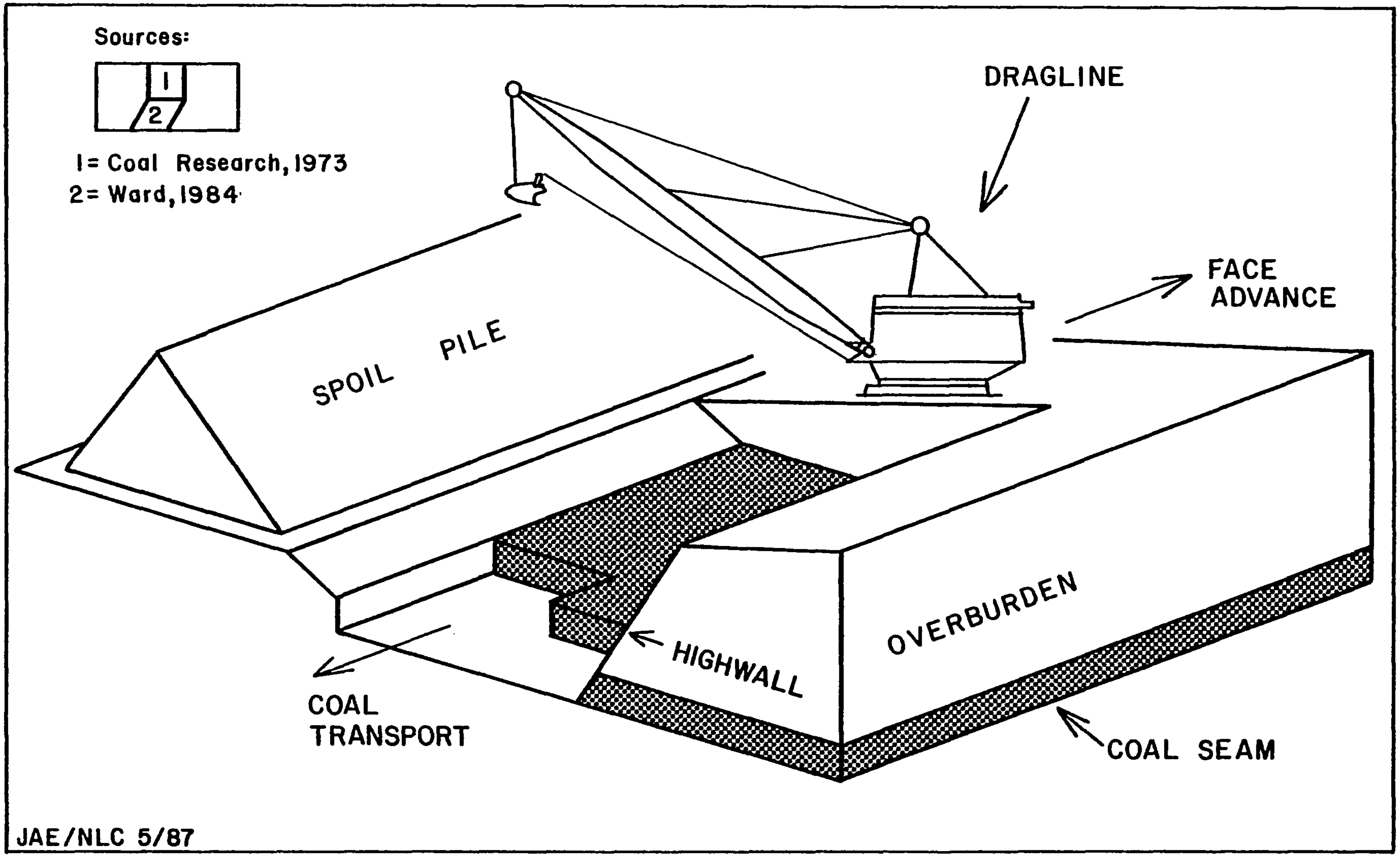

Figure 8. Idealized Surface Mining Techniques for the Study Area.

Draglines and Stripping Shovels

The machines that remove the overburden can be divided into two principal types, draglines and stripping shovels. The first removes the overburden by lowering a cable-hung bucket, located at the end of the boom into the pit; as the bucket swings down it "bites" into the overburden. Then cables drag the bucket back toward the machine; this fills the bucket with material. A second cable elevates the bucket, as the dragline pivots on its base to dump the spoil into a pile. The efficiency of dragline operation is based on having a full bucket, despite the tendency for spillage, on each swing and making each swing as efficient as possible. To load the bucket efficiently requires a high degree of skill (Coal Research Section, 1973). The dip of the coal seam can also affect efficiency; instead of getting a full bucket of overburden, part of it may be coal. The bucket is level with the ground but not with the dipping coal seam. This results in part of the coal being lost in the spoil material because the bucket digs into the coal seam and not just the overburden.

Draglines are best suited for level terrain because they advance on caterpillar treads or by wrenching themselves along; "walking" on large flat structures (Environmental Systems, 1983). Draglines operate above the pit and thus are not as affected by complications in the pit, such as water problems or unstable spoil.

Draglines are more versatile and can rehandle material more efficiently (Cassidy, 1973). They can dig deeper pits than other excavators or equal size, so are more frequently used in mines with thicker overburden. The limit of the depth of overburden removed is usually limited by the height to which the spoil can be piled rather than the depth of the pit.

Stripping shovels consist of a dipper at the end of an arm suspended from a boom. When digging the movement of the dipper is in the opposite motion to that of the dragline. The shovel's dipper moves away and upward to fill itself. This results in a higher loading factor and less operator fatigue (Coal Research Section, 1973).

The depth of material excavated is limited by the level to which the shovel can pile spoil. The shovel rests in the pit and moves on treads. The stripping shovels can work faster than draglines in more resistant or thinner overburden. It also has lower power costs per cubic yard and can move larger pieces of material (Cassidy, 1973). Shovels work much better than draglines in hilly terrain, as they are located on the rather level floor of the pit. However, stripping shovels cannot work as efficiently in thick overburden as can a dragline.

Development of Mining Equipment

Details about surface mining before 1911 are not fully known. They would have been small operations using crude and cheap horsedrawn scrapers that could only remove shallow overgurden. In 1911 the largest stripping shovel had a dipper capacity of 3.5-cubic-yards (Coal Age, 1924). After 1915 steam-powered stripping shovels with 7-cubic-yard capacities were being used in Indiana (Harper, 1985b). These shovels could remove as much as 25 feet of overburden economically. However, these shovels were not inexpensive. In 1929 a 6 to 8 yard stripping shovel cost between $90,000 and $150,000 (Harper, 1985b), and by the mid 1930's the cost was $250,000.

In 1915 the limit of the depth of overburden was 25 feet, and since then the maximum overburden thickness and the bucket and shovel capacities have increased (Table 7) (Coal Age, 1920; Moore, 1940; Tuttle, 1975; Andros, 1915; Harper, 1985b). This increase was at a rather slow rate, until 1960 (Cassidy, 1973), when the capacities increased dramatically.

These gigantic machines reached some very large proportions. The world's largest stripping shovel, at Captain's mine in Illinois, has a 180 cubic yard dipper capacity (Coal Age, 1980).

Indiana had the world's largest dragline before the construction of Big Muskie. Indiana's dragline, the Dugger Digger, was at the Dugger mine; it had a 145-cubic-yard capacity and could excavate 3 1/2 million cubic yards per month (Coal Age, 1968). Big Muskie surpassed this with a 220-cubic-yard capacity bucket. The cost of the machine was

Table 7

Change in Bucket and Shovel Capacities

Year	Maximum Overburden Thickness	Bucket Capacity cu. yd.	Dipper Capacity cu. yd.
1915	25 feet		7
1920	45 feet		
1923	50 feet		8
1927	60 feet		12
1935	70 feet		35
1937	80 feet	12	
1959	125 feet		70
1963	150 feet	85	
1964			140
1965	190 feet		180
1967		130	
1968	185 feet	220	

$24 million dollars, it weighs 26.3 million tons, and can dig deep enough to excavate a pit the depth of Lake Erie, 210 feet at its deepest (Coal Age, 1980). On the swing, the end of the 310 foot boom is travelling at 40 miles per hour. It can move four million cubic yards of overburden per month (Coal Age, 1980). To put this size into perspective, it can dip eight stories below ground level and dump 325 tons of spoil on top of a nine-story building, one tenth of a mile away (Coal Age, 1980). This is in contrast to a dragline in operation in the late 1930's, that had a bucket capacity of three yards and could only uncover three acres a month if the overburden was less than 20 feet (Karpiniski, 1938).

Major increases in the size and capacity of these excavating machines stopped in 1968; a limit to efficiency associated with size had been reached. When the machine reached a certain size the routine maintenance could no longer be done manually (Cassidy, 1973). This cut down on operating time. In some mines, it became more efficient to have tandem operations instead of a single gigantic machine. This also allows one machine used to be a stripping shovel and the other to be a dragline, thereby making the most efficient use of both machines in a single operation. Not all operations in Indiana make use of the massive machines such as draglines and stripping shovels. Some smaller surface mines use bulldozers and earth movers to remove as much as 55 feet of overburden (Harper, 1985b).

Stripping Ratio and Spoil

The stripping ratio is a general measure used to determine the economic feasibility of mining a particular coal seam. This ratio of overburden thickness to coal seam thickness varied with the development of surface mining techniques. The earlier surface mines were able to operate with ratios of ten to one (Powell, 1972). By 1953 the maximum practicable ratio was twenty to one (Spencer, 1953) and in the early 1970's most Indiana mines operate with ratios of fifteen to one (Powell, 1972).

In more recent times, the soil is scraped off and piled for use in later reclamation. This was not the common practice at the mines in this study. These older operations transformed the original sequence of strata and soil into a confused jumble; often leaving the toxic materials on top, and the most productive topsoil on the bottom. These toxic materials hampered or prevented invasion species from naturally helping to "reclaim" the area. Prior to reclamation laws, the spoil piles were left in a series of parallel ridges and valleys. Later laws required the spoil ridges to be graded.

In surface mining, the disturbed area usually exceeds the area where coal was removed. In Indiana the average amount of this excess area is 22% (Powell, 1972). In general, the smaller the mined area the greater the area of additional disturbance. Many small operators have dumped spoil over more acres than the area from which coal was removed (Powell, 1972).

The difference in elevation between ridges and valleys is affected by the depth of overburden. As the depth of overburden increases the difference between the ridges and valleys decreases (LaFevers, 1974).

Mine Specifics

At the Chinook (0533 and 0573) mine the overburden is irregular and includes sandstones topped by 15 feet of surface material (Harper, 1985a). In 1967 a 75-yard dragline was replaced by a 36-yard shovel (Harper, 1985a). A machine of this size is large enough to house a basketball court; it uses as much electricity as 3,500 average homes (Sutliff, 1967).

At the Blackfoot #5 mine, a dragline removed 120 feet of overburden using a 60-cubic-yard bucket; at the time this was the second largest in the world (Coal Age, 1964). At the Ayrshire pit (0400), a fifteen and one-half cubic yard electric shovel was used in mining (Karpiniski, 1938).

At Polk Patch (0494), a 350 Marian electric shovel with an 8-yard dipper operated twenty-four hours a day and moved 7,000 cubic yards of material per day (Coal Age, 1928). Detailed records were kept at this mine; for example, one swing was completed every 57.38 seconds. This led to greater efficiency as "a minute lost is the loss of a ton of coal" (Coal Age, 1928); at the current market price this was $2.50.

At the Friar Tuck (0104, 0401) mine the coal is overlain by 2-8 feet of shale and 0-20 feet of soft yellow sandstone (Karpiniski, 1938). To mine the coal at Friar Tuck, a stripping shovel was used. However, when the overburden exceeded fifty feet, a diesel dragline assisted in the operation.

CHAPTER V

AML PROBLEMS

The coal mining process by its nature greatly modifies the landscape. Underground mining may appear to leave the surface relatively undisturbed. This may be true to some degree initially, but its influence on the surface does not end when coal production ceases. The resulting problems left from surface mining appear to end with the mining process. In both cases the mining process and its subsequent effects may result in many types of Extreme Danger Problems.

Reclamation Laws

Indiana was a pioneer in surface mined land reclamation. In 1918 the Indiana Coal Producers Association was formed by the surface mine operators (Honea and Baxter, 1983). They were the first coal industry group to address the reclamation problem. The revegetation of spoil banks, the initial reclamation technique, met with limited success, as knowledge of spoil characteristics adverse effects on the seedlings was relatively unknown.

In 1941 Indiana's first reclamation law was enacted (Powell, 1972). This law required all companies to grade spoil and make reforestation efforts (Honea and Baxter, 1983). It also required operators to secure bonds and permits to help with compliance. Later amendments were more stringent. Then in 1967, the second reclamation law was enacted. This was stricter and required more extensive grading of spoil to facilitate the return of the area to a near, pre-mining state.

Early, noncompulsory laws met with limited success. The Friar Tuck mine (0104, 0401), which produced surface mined coal from the late 1930's to the 1960's, is one example. The mining practice was described as follows: "They just piled her up and planted trees on it" (Jones, 1984). More specifically the topsoil was scraped off (Jones, 1984), and subsequently subsoil covered it, and on top of that was piled the sub-surface materials which contained pyrite. The previous laws governing reclamation which required tree plantings met with limited success, as there are at least 385 acres of semi-barren spoil at this mine.

The success rate improved in Indiana with subsequent amendments which were stricter. The forty-year reclamation history of Indiana has mitigated or eliminated many of the environmental problems associated with surface mining. However, there were "no requirements for elimination of highwalls" (Honea and Baxter, 1983), nor were there any reclamation requirements imposed on underground mines.

In 1977, Congress passed the Surface Mining Control and Reclamation Act (Public Law 95-87), which mandated reclamation of all abandoned coal mined lands in the United States. Funding for this reclamation was obtained from a tax on current coal mining of thirty-five cents per ton of surface-mined coal and fifteen cents per ton for underground mined coal. To facilitate the reclamation of these areas, the National Law required an Inventory of all AML problems. The first Indiana Inventory was completed in 1982, and the source of data for this study was the Update completed July 31, 1986.

Hazardous Effects of Coal Mining

The Extreme Danger Problems can be divided into three categories. Category one are those associated with surface mining; Category two with underground mining; and Category three with both types of mining. The following is an explanation of the formation and the characteristics that make these danger problems, Extreme Danger Problems. For specific definitions of these Extreme Danger Problems see Appendix B.

It should be noted that some of the Extreme Danger Problems may not have been purposely left. In many instances the operators attempted to eliminate some of the safety problems. However, in a few cases mines were temporarily abandoned until it became economically feasible to mine again, but it never did. Therefore some of these problems could be attributed to economic setbacks rather than negligence or permanent bankruptcy.

Category One

Category one problems include dangerous highwalls (DH) and hazardous waterbodies (HWB). The highwall is the nearly vertical wall left at the edge of a surface mine. Highwalls present "a hazard to unwary people and animals in the vicinity" (Illinois AML Reclamation Council, 1982). When highwalls run along roads they present a potentially hazardous situation. Even when they are located in more remote areas they still present danger to foot traffic. Some highwalls are over 100 feet high and usually have water-filled pits at their bases. Therefore a vehicle that might run over the highwall, subjects its occupants to the impact of a fall and possible drowning in the water at the base of the pit.

A hazardous waterbody is any waterbody associated with past mining, be it a slurry pond or a strip pit. They may be popular party attractions where swimming is a common activity. A highwall along a strip pit is dangerous because of its height, relative to a fall or a dive. Other hazards are shallow water that does not permit diving, submerged rocks and various types of abandoned mining equipment such as steel beams, cables, and old stripping shovels.

Category Two

The second category consists of vertical openings (VO), portals (P), hazardous or explosive gases (GHE), surface burning (SB), and subsidence areas (S).

Vertical openings may be open shafts, improperly filled shafts, depressions that result from subsidence that may endanger life, or deep openings in mine buildings. As long as a VO is large enough for a child to fall into and be injured, it is considered a safety hazard (Honea and Baxter, 1983). This includes mine buildings with deep basements or trap doors. Areas have actively subsided while people were in the vicinity, burying the victim (Dean, 1967). If subsidence areas meet the safety requirements then they are considered VO's rather than economic impacts.

By far the most common vertical opening hazards in Indiana are open shafts, followed by improperly filled shafts. Improperly filled shafts are a deceptively dangerous feature. If shafts appear filled, they should be regarded as suspect (Dean, 1967). Mine operators had a tendency to use this as a refuse dump after abandonment. Gob, subsurface materials, coal cars, and various junk from the tipple were all possible components of the fill in abandoned shafts. Materials dumped down the shaft may become lodged part way to the bottom, creating a false and unstable bottom. At the Green Valley mine (0039), it is "likely cages were pulled to near the top, tied-off and other mine debris dumped in on it" (GEOSCIENCES, 1985). The filling of shafts does not end with mine abandonment; people often continue to fill them with a variety of materials.

There may also be subsidence around a shaft. In Indiana there will be new subsidence sites "that will pose continuous problems because they are a result of collapsing shafts and tunnels" (Honea and Baxter, 1983). Subsidence is commonly associated with shafts, particularly those of older mines like those in the Clay county area (Harper, 1982).

Open shafts present a constant danger, regardless of their location. There is always the danger that people or animals may fall into these shafts. In winter the vegetation may be absent rendering open shafts more visible, in contrast to the extensive summer vegetation which conceals the open shafts. VO's located in wooded areas are dangerous because they are "quite invisible and unexpected" (Boivin, 1982), even if they are in remote areas.

Operators were not required to fill in these shafts and the result is many shafts that are open to great depths. The degree of danger is not proportional to the depth of the shaft (Boivin, 1982). Most shafts have at least some water. The danger increases when the depth to water is greater than the ability of a child to climb out, making drowning a probability. The danger of water-filled shafts varies with the seasonal watertable.

Portals are entries to mines that a person can walk or crawl into. There are many unseen dangers associated with this problem. The most common are the mine gases which have accumulated in the old drift entrances and can overcome an explorer. Once inside there are dangers of a collapsing roof or tunnel due to decaying timbers. These are attractive nuisances and sometimes are mistaken for caves.

Hazardous or explosive gases are often found in conjunction with shafts and portals. The hazardous and explosive gases are the same as those associated with active mining; however, in an abandoned mine, the gases will have had more time to accumulate given the decrease in ventilation. The explosive gases take on another dimension of danger when they are present in a shaft that is used as a place for trash burning. Shafts have even been known to explode spontaneously. One explosion had enough force to blow a 24-foot-square, 16-inch thick concrete cap off a shaft (Dean, 1967).

Surface burning results from spontaneous combustion or careless burning of trash. Spontaneous combustion requires a special set of conditions that are often found in coal refuse areas. First there must be combustible material present in oxidizing conditions. It must also be in a permeable zone where heat is trapped, and enough oxygen available to support combustion (GEOSCIENCES, 1985). Coarse coal refuse frequently provides the ideal set of these conditions.

Snow-free areas are a clue that the area is burning. The heat generated is enough to melt the snow and frozen gob. The result is an area of warm, moist, soggy gob, that may have gone unnoticed during snow-free times. The Green Valley (0039) mine is one example. Although this area was discovered January 20, 1987, after the Update Inventory, it was probably burning during the Update time period. Cases of burning like these are typical of other problem areas. It was an area eight feet in diameter on the side of a gob pile. The area was soggy and warm to the touch.

Surface burning is dangerous because it generates gases like nitrous oxides, CO, CO_2, H_2S, and SO_2; smoke; and voids where the temperatures of the materials burning reach hazardous levels. Temperatures can range from 600 to 2000° Fahrenheit (Nesbitt, Richie, and McGraner, 1981). As the refuse material burns, it weakens and voids develop. Someone walking over the area could fall into the voids, plunging them into these extreme temperatures.

Subsidence occurrence is unpredictable. However, subsidence increases occur during and after heavy rainfall (DuMontelle et al., 1980; Carey, 1984). It can occur 10 to 100 years after mining; "no matter what you do the mine is going to come down eventually and everything is going to have to adjust" (Carey, 1984). Factors affecting the occurrence of subsidence are: time since mining, depth of mine, presence of water in the mine, characteristics of the coal seam and the overyling sediments, and the method of mining (Harper, 1982). Wherever coal has been extracted by the room and pillar method of mining there is always the possibility that subsidence can occur (Guither, 1986; Yarbrough, 1983; Roberts, 1979).

In the entire United States only 25 to 50% of all undermined areas have subsided (Harper, 1982). Subsidence is a serious National problem that will continue well into the next century (Guither, 1979; Carey, 1984). In Indiana underground mining peaked in 1918; therefore, 50% of the undermined areas were worked out 60 years ago and an additional 40% were worked out 30 years ago (Harper, 1982).

Subsidence results when the pillars or the floor under the pillars fail to support the overlying strata. The overlying materials fall into the mined-out rooms and entries (Figure 9) often resulting in surface depressions. The greater the percentage of coal extraction the greater the instability in the overlying strata. A high extraction rate, greater than 60%, and an irregular pattern of mining with wide rooms facilitates subsidence. However, subsidence has even occurred where the extraction rate has been as low as 40% (DuMontelle and Bauer, 1983). A thin layer of solid overlying materials also increases the chance for subsidence. At the Wick mine (0499), the thickness of solid material thinned to less than ten feet (Harper, 1982), as it continued under the Patoka river.

Subsidence can harm buildings, roads, bridges, or pipelines. The surface depressions that present a continued safety problem to people are classified as VO's. There are two main types of subsidence, pit and sag or trough. The first develops suddenly; has steep sides, may be 6 to 8 feet deep and 2 to 40 feet in diameter (Environmental Systems, 1983). In one sudden subsidence case ducks were swimming on a lake then the lake and the ducks suddenly disappeared (Dean, 1967). Pit subsidence occurs above mines that are usually less than 165 feet deep (Environmental Systems, 1983). This type of subsidence is usually the result of failed pillars which come crashing down from the continued

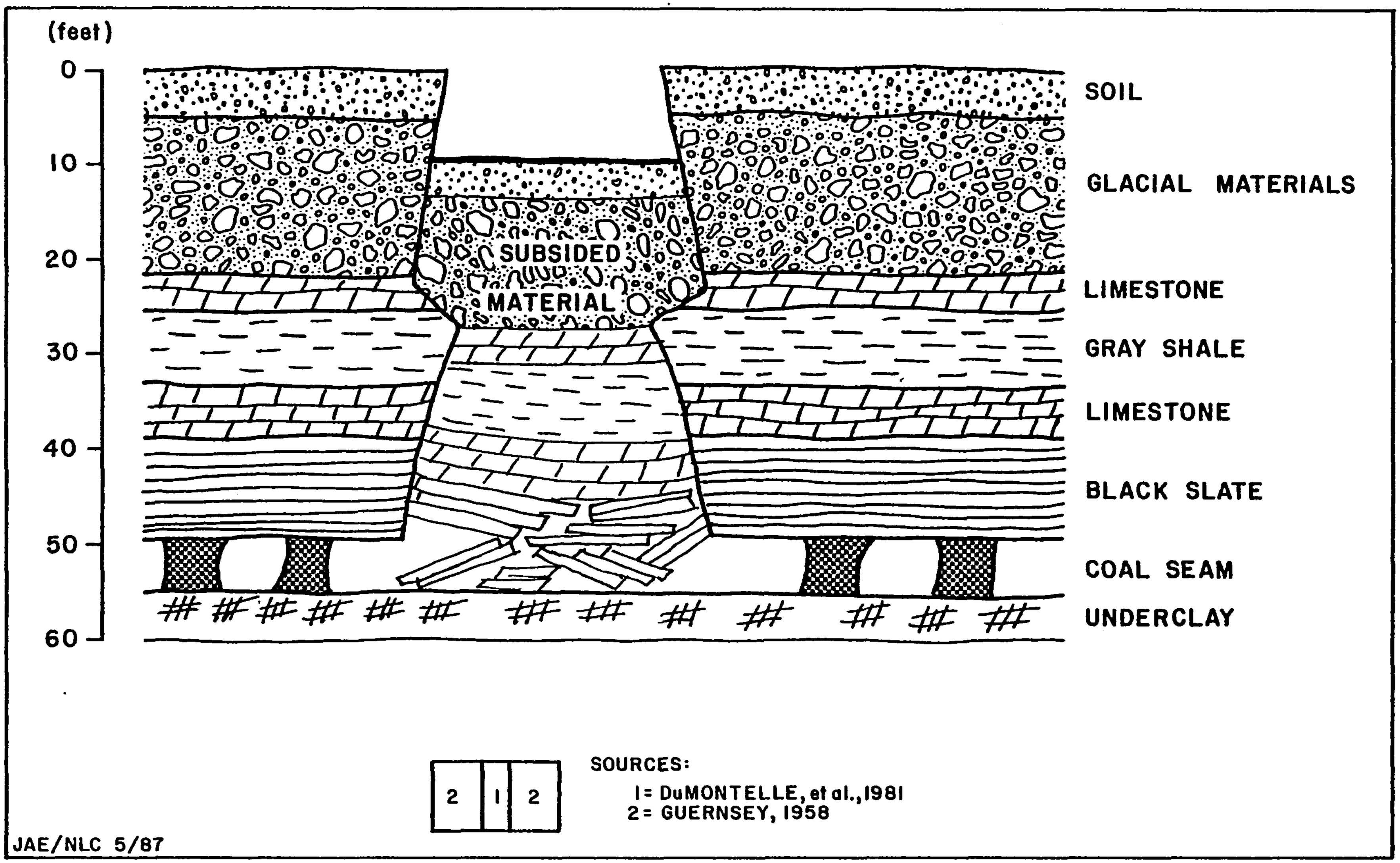

Figure 9. Cross-sectional View of Idealized Pit Subsidence.

weight of the overlying materials. The subsided material may then wash into adjacent mine voids, producing larger holes (DuMontelle and Bauer, 1983).

Sag subsidence usually results from a "squeeze." Here the underclay moves out from under the pillars, allowing the pillars to slowly sink into the floor. In some shallow mines, the subsidence plainly outlines the rooms in the old mine works (Andros, 1915). Sag or trough subsidence occurs over large areas, usually several acres, has a depth of 1 to 4 feet and works its way to the surfaces over a time of a few hours to years (Environmental Systems, 1983) over a mine of any depth. Circulating groundwater can deteriorate the pillars (Harper, 1982) as well as weaken the roof and cause instability in the overlying materials. Lower ranked coals will gradually weather and yield to the pressure of the overlying materials (Moore, 1940).

Category Three

The final category contains the following problems: recurrent flooding or ground saturation (CS), dangerous piles or embankments (DPE), dangerous impoundments (DI), hazardous equipment or facilities (HEF), industrial or residential waste (IRW), and polluted water for human consumption (PWHC).

Recurrent flooding or ground saturation cause severe problems for agricultural land and affects the general welfare of the area. Sedimentation is included within this classification. When streams in close proximity to people have filled with sediment and continually flood, they are detrimental to property and improved land as well as to people. In a special instance water created a 4 foot deep "swampy" area, in a well-traversed wooded area (0011).

Dangerous piles or embankments associated with surface mines are the disturbed materials or refuse that have been piled up in such a fashion as to be a safety hazard. When along a roadway the danger is the same as that for a high-wall. These may also be associated with refuse piles. Gob piles may be as high as 80 feet with unstable slopes. Erosion often increases the slope of the embankments in the gob or spoil. The gob piles are basically unstable because of the nature of material. So when the element of height is added to the slope instability, the danger of falling and suffering injury is increased.

Dangerous impoundments are often associated with clogged streams. Their danger lies in the instability of the dam for a water catchment. When the dam is breached, people and property may be in danger from flooding.

Hazardous equipment or facilities cover a wide variety of problems. When mines are abandoned an assortment of things is often left. Equipment may range from old mine cars and excavation equipment to parts like steel beams and cables. This equipment is usually scattered throughout the mine area and may even be partially buried or hidden. Areas such as this create an attractive nuisance by serving as a play-ground for children or a recreation area for motorbike and three-wheeler riders.

The facilities include the tipple areas and associated mine buildings. These areas are often used as play areas. The buildings are in various states of disrepair and are subject to collapse without warning. These unstable structures may often have trap doors, deep basements, and ladders leading to substantial heights, all of which make them very dangerous to people in the area.

Industrial and Residential waste can be hazardous because of the materials dumped at a problem area or because there is danger from the act of dumping. If materials are dumped over a highwall there is a danger of falling or accidentally backing off the highwall. A wide variety of materials are deposited in mine areas.

These materials may be scattered over acres. Often abandoned shafts become popular neighborhood dumps for old machinery and vehicles, residential garbage, hazardous wastes, raw sewage, and dead animals. Refuse areas are popular areas for residential garbage that ranges from refrigerators, appliances, and abandoned cars to mattresses, furniture, and household garbage. The industrial wastes may not be as unsightly but certainly present a danger. Examples of these wastes are agricultural chemical cans, chemical drums, and PCB's.

Polluted water is usually thought of as an environmental problem. However, when this water is consumed by people it becomes a Health, Safety, and General Welfare problem. Coal mining produces large amounts of waste that have the potential to produce acid mine drainage. The waste from both surface and underground mines may contain shale, sandstone, refuse coal, and other rock materials. The acidity of the spoil varies with the characteristics of the overlying materials. There is a strong positive relationship between pH and the percentage of glacial till in the overlying materials. Areas of glacial till generally have higher pH values of 5.6 (Guernsey, 1967) compared to non-glaciated areas of 4.7 pH values.

The component most responsible for acid production is iron sulfide, which usually occurs as pyrite or marcasite in the rock materials. The chemical reactions that produce the acid conditions are quite complex, but the following is a generalized explanation of the reactions. First the sulfide in the waste reacts with atmospheric oxygen dissolved in rain (Hartke, Hailer, and Fraser, 1983) as follows:

$$2FeS_{2(s)} + 7O_{2(aq)} + 2H_2O = 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

Sulfate (SO_4^{2-}) and the iron Fe^{2+} are two products that are harmful. High levels of sulfate in drinking water can cause digestive upset in people not accustomed to drinking it (Hartke, Hailer, and Fraser, 1983). Other soluble materials, such as chlorides, carbonates, and bicarbonates (Environmental Systems, 1983), may also be leached from these waste materials.

In the second step the Fe^{2+} continues to be oxidized by oxygen in the atmosphere and in the presence of water reacts as follows:

$$4Fe^{2+} + O_{2(aq)} + 10H_2O = 4Fe(OH)_{3(s)} + 8H^+$$

The result is additional acid production and the generation of a yellow-brown sediment, "yellow boy" (Hartke, Hailer, and Fraser, 1983). Fe^{2+} is very soluble and can be carried long distances downstream from the original source of acid production. Acid production can continue for years. Areas may remain vegetation free for more than twenty years (Doerr and Guernsey, 1956) due to the acid conditions. Erosion continually exposes new materials to the atmosphere, which in turn generates more acid production.

A further complication from this high acidity is the mobilization of certain toxic trace elements in coal which subsequently may be released into surface and sub-surface waters. Some of the toxic elements that may be found associated with acid mine drainage in Indiana are arsenic, selenium, cadmium, lead, chromium, copper, nickel, and zinc (Hartke, Hailer, and Fraser, 1983). Even if these waters with toxic metals are not consumed by people directly they may eventually be transmitted to humans who eat fish, meat, eggs, and milk contaminated by toxic metals (Environmental Systems, 1983).

Honey Creek is affected by acid mine drainage. It receives large amounts of pollutants from the Victory Mine

(0029). The stream bed is filled with sediment and coal fines and the water is orange. The iron content exceeds 6 mg/l and the pH is 3.4. This creek feeds a major underground aquifer that supplies part of the water for Terre Haute. The State Board of Health has labeled this stream contaminated.

Associated with this pollution are soluble materials, which may enter streams. Without treatment these waters are not suitable for drinking or recreation. The maximum allowable turbidity for drinking water is one turbidity unit (Environmental Systems, 1983).

Characteristics of Extreme Danger Problems

Each site has a particular set of circumstances that cause some or all of its problems to be classified as Extreme Danger Problems. There are, however, certain generalities that characterize each particular type of problem in Southwestern Indiana.

The following is a summary of the characteristics of the fourteen types of Extreme Danger Problems in Indiana:

There are 377 occurrences of Extreme Danger Problems in Indiana (Table 8) by keyword and the number of problem areas with each type of Extreme Danger Problems.

To understand relationships between Extreme Danger Problems and coal mining variables, it is requisite to be familiar with the overall characteristics of the Extreme Danger Problems in the study area.

Table 8

Problem Areas with Keywords and Number of Keywords

Keyword	Occurrences	Problem Areas
VO	189	90
P	25	15
SB	2	2
GHE	6	6
DPE	17	7
DI	2	2
PWHC	6	4
S	13	12
HEF	22	10
IRW	4	4
HWB	12	9
DH	77	42
CS	2	2
TOTAL	377	

VO: The vast majority of the VO's were shafts. However, some VO's were rusted escape hatches, collapsed manways, or tunnels to shafts. One fifth of the VO's were caused by subsidence either over the rooms or around the shaft entry. About one fifth of the shafts were air shafts. The overall size ranged from 2 by 6 feet to 70 by 70 feet; the most common size was 20 by 25 feet. The estimated depth ranged from 6 to 150 feet, with the most common being 15 to 25 feet. Several of the shafts were collapsing, and a few had crumbled caps. Approximately one-fourth of the shafts were debris filled. The overwhelming majority were water-filled and nearly half of these were filled only to within 4 feet of the surface. The most common shaft lining was concrete; wood ranked second; and rather distantly brick ranked third, as it was a common air shaft lining.

<u>P</u>: The portals range in size from 1 1/2 by 2 1/2 feet to 30 feet in diameter. Two of these were eroding and one is caving in. Three of these are slope entries, one bricked and two concrete; the rest are drift entries. Two are inadequately sealed and the others are open.

<u>SB</u>: One area has experienced recent burning. The other area was burning and smoke and fumes were being emitted. Several houses were nearby.

<u>GHE</u>: One area had gas escaping from an inadequately sealed slope mine; another had explosive gas escaping from an inadequately sealed shaft. A third area is the Green Valley (0039) mine. Here the mine gases in the old mine works contributed to the collapse of the shaft fill.

<u>DPE</u>: Half of these problems are associated with gob piles. They range in height from 25 to 80 feet and are severely eroded with unstable slopes. The other half are associated with spoil. Most of these border water-filled pits and are 40 to 60 feet high.

<u>DI</u>: This is an eroding gob dam that is upstream from a residential area.

<u>PWHC</u>: One of the areas was the previously mentioned drainage from Victory mine (0029). The other is a situation where mine gases have entered a well and rendered it unusable. The latter is mine gases that have entered a well and contaminated it.

<u>S</u>: All of these are actively subsiding areas. These subsidence areas range from 15 to 100 feet in diameter and

are as deep as 30 feet. One area is quite extensive and covers 20 acres, while another is affecting a house and driveway.

HEF: There is one dangerous site with a metal tipple and another has conveyor belts and turbines. The remainder of these problems are buildings made of wood, brick and concrete, in various states of disrepair.

IRW: There are four areas of dangerous waste disposal. The first involves dumping raw waste into a VO. Another area has garbage piled so deep that it must be plowed off the adjacent road. The last two involve the improper disposal of agricultural chemical cans and industrial chemical drums.

HWB: One pit has a quicksand like consistency where a boy fell in, got trapped, and drowned. Most of the problems are attributed to steep sides and rocks under the water surface.

DH: The highwalls range in height from 10 to 80 feet, with the most common being 20 to 30 feet. The length ranges from 65 to 3500 feet, with 200 to 300 feet being the most common. Most have water at the base of the highwall, and several are eroding back toward the road severely. To complicate the situation, at least five of these run parallel to curving roads and many are hidden with roadside vegetation.

CS: One of these problems is a 100 acre "swamp" near a residential area. The other problem area is an old drift entry that drains into an area which contains the flow and creates a four-foot-deep "swampy" area. Several local children have narrowly escaped from this problem area.

All of the aforementioned Extreme Danger Problems present continuing dangers. Some of these problems have already caused injury or death and many presented "close calls." The "close calls" are those situations where injury or death was narrowly avoided. The most serious of the Extreme Danger Problems are listed in Table 9.

Table 9

Most Serious Extreme Danger Problems

Injury	HWB	VO/CS	DH/HWB	DPE	DH	VO/S
Broken Back	1					
Broken Arm					1	
Motorbike accident			1			
Drowning--toddler				1		
Drowning			2		1	
"Close Calls"		1		1		1

These are only the most serious cases that were specifically noted. Many cases of minor injuries were reported throughout the study area.

CHAPTER VI

METHODOLOGY

The purpose of this study is to find significant statistical relationships between Extreme Danger Problems and coal mine related variables. To accomplish this, the data will be analyzed using multiple regression analysis. Regression was chosen bécause it is versatile and can be used to summarize data and to quantify relationships (Norusis, 1982).

Selection of Pertinent Variables

The principal source of data for the Extreme Danger Problems will be the recent Update of Abandoned Mine Lands for the State of Indiana. This Update is not meant to be all inclusive, as the "dynamic nature and extent of AML problems will result in additional problems being identified in the future" (Honea and Baxter, 1983). The previous Inventory included 105 Problem Areas (45 had Extreme Danger Problems), while the present Inventory added 310 more Problem Areas (103 of these had at least one Extreme Danger Problem). The vehicle for obtaining information is the Update Form (Appendix A), which includes locational information, the types and number of problems, a narrative about the attendant problems, and reclamation cost estimates. Attached as part of the form is a graphic representation of the problem area and the locations of the problems on each U.S.G.S. topographic quadrangle. The Friar Tuck - New Hope mine (Figure 10) is an example of the cartographic detail overlaid on the U.S.G.S. topographic quadrangle for each AML area.

Field work and interviews were a necessity in the compilation of information required on the update forms. Additional forms of information supplemented the original data gathered from field work. They included, but were not limited to, the following: U.S.G.S. topographic quadrangles, coal mined area maps[1], Preliminary Coal maps, Coal Investigation maps, consulting reports, and various other Geological Survey reports.

To attest to the accuracy of the data collected in the update study are those Update Forms that have presently been approved. The National Inventory Update Committee has accepted all the Extreme Danger Problems presented in the first two update submissions.

The sources of data for the coal mine related variables are Preliminary Coal maps for each county, Coal Investigation Maps for selected quadrangles, Mined area maps for each topographic quadrangle, Indiana Geological Survey, Coal Section files, Indiana Department of Natural Resources, Division of Reclamation files, and the AML Update information.

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[1]The mined areas were delineated on U.S.G.S. 7.5' quadrangles. The mine information was plotted before 1985; however, the actual date is not known. The estimated year, [1984], is the year of map publication or photo revision.

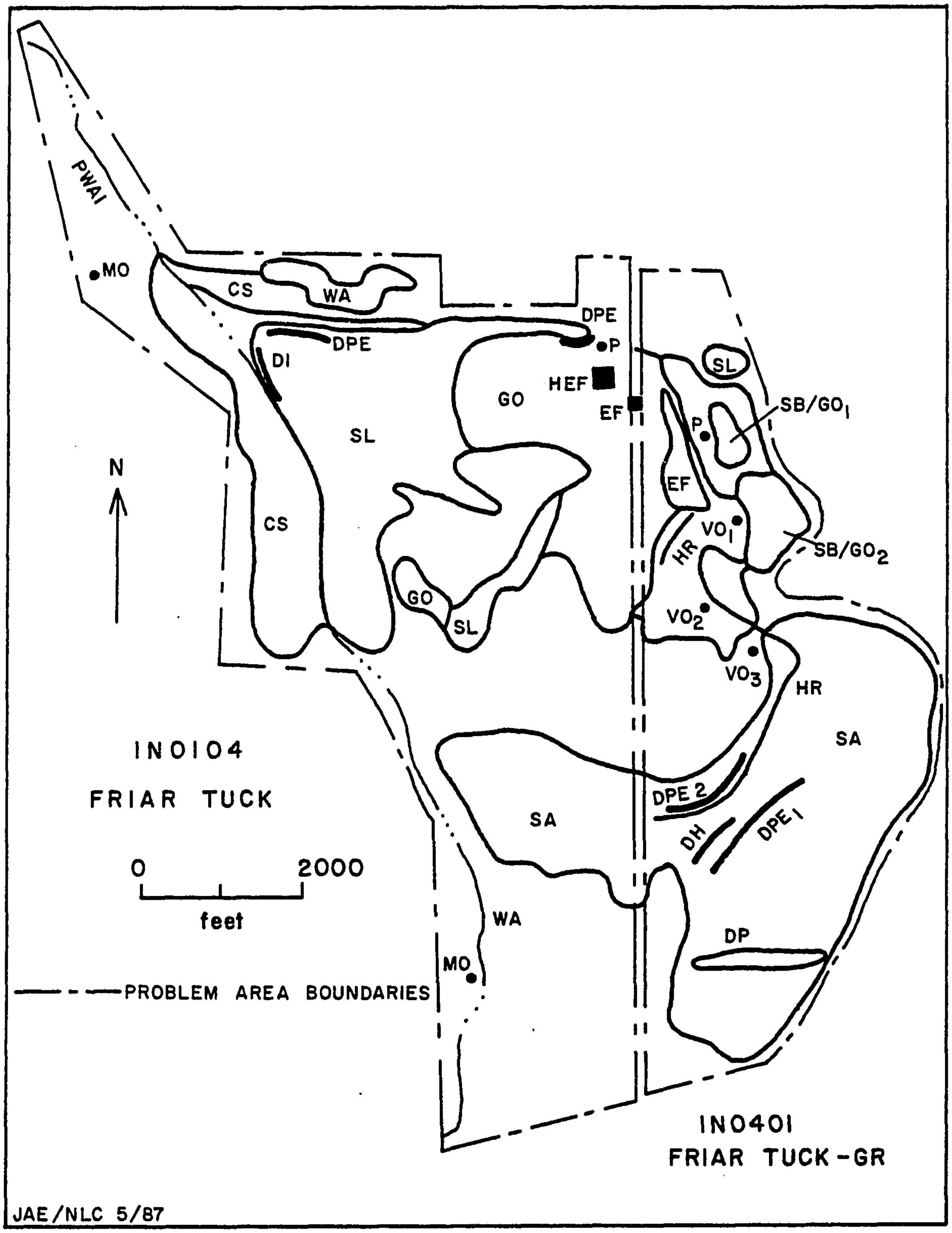

Figure 10. AML Inventory Overlay of Friar Tuck - New Hope Mine.

Information on the coal-mine-related variables was collected and coded for later inclusion in the regression model. The following information was recorded: the county, county group, type of mining, type and total number of Extreme Danger Problems, depth to the coal seam, thickness of the coal seam, year production began, year mine was abandoned, total production, glacial history, coal seam, topography and an "economic ratio." This information for each mine is listed in Appendixes C and D. The mines are identified by the numeric part of their National Inventory number and mine name. Selected pieces of information on a few mines were not readily obtainable. Data for the older and smaller mines were sketchy at best. No estimates or averages were used to the missing data spots except for the production data estimated for eleven mines. The remainder of the missing data was deleted pairwise. Pairwise deletion of data means that where the data were missing it was not assumed to be zero but rather that particular piece of information was deleted from that particular part of the analysis.

Coding of the data was necessary for statistical analysis. The counties were numbered one through fifteen (Table 3) alphabetically. The counties were then divided into three groups. The first two of these three groups are the two major coal mining areas in Indiana, while the third is a minor producing area (Table 10) (Figure 1). Group one is composed of twenty-two quadrangles in a major area of coal

Table 10

Three Groups of Counties

Groups		
ONE	TWO	THREE
Clay	Gibson	Daviess
Greene	Knox	Dubois
Parke	Pike	Martin
Sullivan	Warrick	Perry
Vermillion		Spencer
Vigo		

production centered near Vigo County. Group two is separated from the first by at least the length of two quadrangles and these fifteen quadrangles compose another major production area. Group three is ten quadrangles that are on the eastern edge of the Illinois Basin and represent an area of local production.

The type of mining was given three differentiations. Problem areas with only underground mining were coded as 1, only surface mining as 2, and if there were both types of mining in the problem area it was coded as 3. For the remainder of this study, the 3's will be counted into each type; that is, underground mines will be 1's and 3's and surface mines will be 2's and 3's. This continued procedure will cause the totals of the latter figures to be higher because of this double count. The type and number of Extreme Danger Problems and the total number of Extreme Danger Problems were entered exactly.

The specific coal mine variables are the depth to the coal seem in feet. Those mines with entrances at outcrops, drift entrances, were entered as zero and were not considered missing data. The average thickness of the coal seam at the specific mine was recorded to nearest tenths of inches. All four digits of the specific year for the beginning year of production and the year the mine was abandoned were recorded. The production of the mine was recorded as the total number of tons of coal produced during the run of the mine. There were eleven mines for which production figures were not available, yet the information on seam thickness and the mined out areas were delineated on the mined area maps. For these, a production total was estimated by multiplying 1600 tons per acre foot of coal by the acreage and then the thickness.

For glacial history, each of the mines was within one of three categories. Those mine regions that had Wisconsinan age glaciation were coded as 1, those with Illinoian age glaciation as 2, and those areas that have not been glaciated as 3. The coal seams themselves were simply numbered from youngest to the oldest (Figure 5). This will be referred to as the study number, not to be confused with the coal seam number.

The designation of the topographic code was a two step process. First, the local topography was generally characterized as floodplain, lowland, or upland. Second, the roughness index (Hook, 1958) of the area was derived by counting the number of intersections of the contours on a topographic map with the horizontal and vertical lines of a prescribed grid cell size. These index numbers were used to designate the problem areas into flat, moderate, and steep groups. Combining these two topographic parameters resulted in seven topographic groups (Table 11). They were coded to maximize roughness differentiation and minimize the general topographic situation.

Table 11

Topographic Designations

Topographic Designation	Numeric Code
Floodplain	100
Flat Lowland	230
Flat Upland	260
Moderate Lowland	340
Moderate Upland	370
Steep Lowland	470
Steep Upland	490

A variable, the "economic ratio," was selected to provide an economic measure of the mining operation at a particular mine. It was based on the thickness of the seam, the depth to the seam, and the BTU value of the coal. The BTU was selected because it is the most important characteristic of coal that is burned (Wier, 1973). Most of the coal in Indiana has been and is presently used for home heating or generation of electricity. The "economic ratio" was determined by using the following formula: the first three digits of the BTU value multiplied by the thickness of the coal seam, divided by the depth. The BTU was selected as a measure of coal quality; the thickness of the coal was an advantage and the depth or amount of material to be moved or sunk through would be a disadvantage. The BTU figures (Wier, 1973) are averages for Indiana coals (Table 12).

Table 12

BTU Values for Coal Seams[2]

Coal Seam	BTU
Danville	12,300
Hymera	12,700
Springfield	12,900
Survant	12,400
Seelyville	12,600
Unnamed Staunton coal	12,500
Minshall-Buffaloville	12,000
Upper Block	12,300
Lower Block	12,100
Mansfield coals	11,500

Due to the variability of the quality of coal within a seam, and even within a mine, the average BTU value of a seam was selected instead of ash or sulphur content.

Statistical Analysis

The statistical procedure applied to the data was stepwise multiple regression analysis with the associated descriptive statistics. These statistics were computed with the Statistical Package for the Social Sciences (SPSS). The

[2]British thermal unit -- the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

dependent variable will be the occurrences of Extreme Danger Problems (TOTAL) with many independent variables related to each coal mine.

Regression analysis implies a causal or functional relationship (Schroeder, Sjoquist, and Stephan, 1986). This relationship explains if and to what degree one or more independent variables affect the dependent variable.

In this study, the dependent variable was the number of occurrences of Extreme Danger Problems for each mine. The following coal mine related measures will be the independent variables" depth to coal (DEPTH), thickness of coal (THICKNESS), the year production began (BEGIN), the year the mine was abandoned (END), the total production (PRODUCTION), glacial history (GLACIATION), the specific seam (SEAM), topographic position (TOPOGRAPHY), and an economic ratio (ER).

The specific type of regression used is linear least squares multiple regression. Linear means that only linear relationships will be evaluated; the data will not be analyzed for any significant statistical relationships that are not linear. The least squares method of regression seeks to fit a linear regression line to the data to minimize the sum of the squared errors. These errors are the vertical differences between the observed values and the values predicted by the regression model.

The measure chosen to evaluate the goodness of fit of the regression line is the coefficient of determination. For multiple regression, it is the coefficient of multiple determination, R^2. This is the square of the correlation coefficient between the dependent and the independent variables. It is also the square of the correlation between the observed value of the dependent and the predicted value of the dependent variable. This coefficient measures the percentage of the variation in the dependent variable that is explained by the variations in the independent variables. The addition of more variables to the coefficient will not reduce the explanatory power; it can only remain the same or increase.

Another reported value is the adjusted R^2. This term is adjusted for the number of independent variables in the regression equation (Schroeder, Sjoquist, and Stephan, 1986) and will determine whether another independent variable actually does increase the explanatory power of the regression model. The subgroup of mines in the Seelyville III coal seam with Illinoian glaciation are used as an example of the results of the regression analysis. For step 1, the R^2 is .36818 and the adjusted R^2 is .31958. In the latter case, this means that 31.958% of the variance is explained by the independent variable of year production began. On step 2, the independent variable year production ended is added and the R^2 is .9791 and the adjusted R^2 is .9756. The addition of the second and final variable means that 97.56% of the total variance is explained by the variations in these two variables. The addition of the second variable increased the explanatory power of R^2; however, incremental changes if R^2

values should be interpreted in terms of the combination of the two variables, not separately.

The overall value of F is a ratio of the explained to the unexplained variance of independent variables. Each independent variable is divided by the proper degrees of freedom. This is illustrated by using the overall F values from our previous example. With only the variable Begin, the F=7.58 but with both variables F=280.52. The larger number means that the two variables account for more variation than is left unexplained.

In the Stepwise procedure, the inclusion of variables into the equation is regulated by specific default inclusion values. First, the best predictor is selected on the basis of explained variance. Subsequent predictors are added and if their contribution is judged significant, it is included. The significance of each variable is based on the individual F ratio. The F value for a variable to enter an equation is 0.05 and to remove a variable is 0.1 (Hull and Nie, 1981). In the process some variables may not be judged significant in the presence of other variables and will be deleted. These steps continue until all variables are chosen or the explained variance reaches a point of diminishing returns. Each new examination of the variables is termed a step. The regression analysis seeks to maximize the variance within the dependent variable that can be explained by an optimal combination of independent variables. When the best combination is obtained computation ceases. However, if none of the variables is significant enough to meet the inclusion values, computation also ceases.

Given the diversity and large areal extent of the data, it was necessary to divide the 148 problem areas into smaller subgroups that seek to minimize overall diversity. The first of these subgroups is a geographic sectioning of the fifteen counties into three groups (Table 6). Each of these three groups will be further subdivided into surface and underground coal mines. After these two divisions, there will be six minor groups; surface and underground mining are differentiated within each of the three county groups. These six groups were the initial subgroups; however, as analysis proceeded, further subgroups developed.

Similarities within groups may not be limited to artificial boundaries like counties or need not be different because of the type of mining. The following subgroups are some examples of subgroups contained in the study: all mines located on a floodplain, surface mines with lowland topography, surface mines in the Springfield V coal seam, surface mines with Illinoian glaciation, all mines in the Seelyville III coal seam, underground mines which began production in various time periods, and underground mines which were abandoned in various time periods.

CHAPTER VII

RESULTS

To better understand the results of this study, the distributions of the dependent variable and the independent variables have been analyzed. These distributions are also necessary to understand the methods behind the subgrouping procedure discussed later. The dependent variable was the total number of occurrences of Extreme Danger Problems. The mode of occurrences for TOTAL was 2 (Table 13), with a range of 1 to 19 occurrence of Extreme Danger Problems. The mean of the dependent variable TOTAL was 2.595.

Table 13

Frequency of Occurrences by Mining Type

TOTAL NUMBER OF OCCURRENCES	UNDERGROUND	SURFACE	BOTH
19	1	1	2
13	3	1	4
10	0	1	1
9	2	1	3
7	1	2	3
5	3	0	3
4	7	4	11
3	11	7	18
2	37	18	55
1	36	17	53

The distributions of the independent variables, DEPTH, THICKNESS, BEGIN, END, PRODUCTION, GLACIATION, SEAM, TOPOGRAPHY, and ECONOMIC RATIO are as follows: The mean depth of the mines in the study was 93.2 feet and the mode was 35 feet (Table 14). For more efficient data display, the depth figures were grouped into classes that followed the natural breaks in the data.

The next variable, THICKNESS, has a mode of 5.5 feet and a mean of 4.88 feet. The groups are based on an equal interval of one foot, except for the 1.5 foot thickness, which is a class by itself (Table 15).

Table 14

DEPTH Frequencies

DEPTH	UNDERGROUND	SURFACE	ALL
0	7	0	7
10-30	11	13	24
32-50	12	20	31
55-80	13	6	19
82-90	8	2	8
92-109	13	1	14
120-134	5	0	5
136-185	11	1	11
192-220	6	0	6
225-282	8	0	8
375-580	4	0	4

Table 15

THICKNESS Frequencies

THICKNESS	UNDERGROUND	SURFACE	ALL
1.5	0	2	2
2.0-2.8	1	6	7
3.0-3.8	12	7	18
4.0-4.8	31	12	37
5.0-5.5	23	9	31
6.0-6.8	24	2	26
7.0-7.5	6	5	11

The two variables, year mining began and year mine was abandoned, will be discussed together. The variable BEGIN had a mode of 1911 and a mean of 1926. The variable END had a mode of 1952 and a mean of 1938 (Table 16).

Table 16

Frequencies for BEGIN and END

YEAR	UNDERGROUND BEG	UNDERGROUND END	SURFACE BEG	SURFACE END	TOTAL BEG	TOTAL END
1850-1900	17	4	1	0	18	4
1901-1923	44	35	4	3	45	34
1924-1950	22	33	19	8	39	42
1951-1977	2	21	15	31	17	51

The variable PRODUCTION of the individual mines was different for every mine, with only eight pairs of mines having the same figure. The range of production was 3,000 tons to 23 million tons, with a mean of 2,037,578 tons.

The variable GLACIATION is analyzed along with the county groups for comparison purposes and will be discussed later in this chapter. The most common glacial group was Illinoian glaciation (Table 17).

The variable SEAM has a mode of 3, which is the Springfield V coal seam. Nearly half of the problem areas mined the Springfield V coal seam, followed closely by the Seelyville III (#5) and the Survant IV (#4) (Table 18).

The mode of the TOPOGRAPHY variable was 230, flat lowland. In the flat, moderate, and steep part of the topographic variable, the following number of problem areas

Table 17

Frequencies in County and Glacial Groups

	UNDERGROUND	SURFACE	ALL
COUNTY GROUP:			
1	67	23	88
2	26	24	47
3	8	5	13
GLACIATION:			
1	10	2	12
2	64	27	89
3	27	23	47

Table 18

SEAM Frequencies

SEAM	UNDERGROUND	SURFACE	ALL
1	1	3	3
2	9	3	12
3	40	26	63
4	15	4	18
5	16	6	22
6	0	1	1
7	5	0	5
8	5	2	7
9	1	1	2
10	0	4	4
11	1	2	3
12	2	0	2
13	2	0	2
14	2	0	2

in each division were 53 flat, 45 moderate, and 30 steep. In the type of topography division there were 20 floodplain, 73 lowland, and 55 upland problem areas (Table 19).

The mean of the ECONOMIC RATIO was 32.2 and the mode was 7. The very high ratios are associated with the drift mines, as the depth to coal was 0 feet and therefore tended to greatly inflate the values for those mines (Table 20).

Table 19

TOPOGRAPHY Frequencies

TOPOGRAPHY	UNDERGROUND	SURFACE	ALL
100	9	11	20
230	31	11	40
260	7	6	13
340	17	9	25
370	15	5	20
460	7	3	8
490	15	7	22

Table 20

ECONOMIC RATIO Frequencies

ENERGY RATIO	UNDERGROUND	SURFACE	ALL
1-5	38	3	39
6-10	23	10	32
11-15	12	11	22
16-20	5	8	13
22-30	9	5	13
38-43	1	5	6
79-82	2	0	2
345-606	6	0	6

Statistics and Subgroups

Before presenting the results of this study, it is necessary to demonstrate that these problem areas are representative of coal mines in Indiana, thus reinforcing the statistical analysis. The two measures selected were production by county and production by coal seam for the time span of the study, 1859-1977. Generally speaking, counties with large production had a larger number of mines. In comparing the percentage of production per county and the percentage of problem areas per county (Table 21) the figures are similar. However, a few counties such as Clay, Greene, and Sullivan are under-represented while some low production counties are over-represented. It should be noted that counties not in this study accounted for about 4% of the coal production during this period.

Table 21

Production and Problem Area Percentages by County

COUNTY	PRODUCTION (%)	PROBLEM AREA (%)
CLAY	15.5	7.5
DAVIESS	1.4	1.0
DUBOIS	1.4	0.07
GIBSON	2.7	3.3
GREENE	15.5	10.1
KNOX	2.0	8.8
MARTIN	3.4	0.01
PARKE	4.0	1.5
PERRY	0.67	0.12
PIKE	15.5	11.3
SPENCER	2.0	0.28
SULLIVAN	4.0	14.4
VERMILLION	2.7	6.2
VIGO	16.9	18.4
WARRICK	12.2	13.9

The second measure is included to determine whether the production by seam and the number of problem areas per seam have similar percentages. The production per seam is an average of production from 1917 to 1971 (Wier, 1973). The relative percentages are similar (Table 22), but once again

Table 22

Production and Problem Areas by Seam

SEAM #	PRODUCTION (%)	PROBLEM AREA (%)
1	4.0	2.1
2	15.0	8.2
3	57.0	43.2
4	11.0	12.3
5	9.0	15.1
6-10	4.0	19.2

the low production seams are over-represented.

In the statistical analysis the Multiple R is a measure of the relationship between the dependent and the independent variables. R^2 is the percentage of the variance that can be explained by the independent variables in the equation. The smaller the sample size and the larger the number of independent variables the greater the inflation of R^2 (Cohen and Cohen, 1983). While R^2 tends to be an optimistic estimate of the relationship, it can be modified to present a more realistic estimate. This "Adjusted R^2" attempts to correct this inflation (Norusis, 1982) by taking into account the number of cases and the total number of variables, dependent and independent.

Two other problems that may arise in multiple regression that should be noted are multicollinearity and the independent variable to case number ratio. Multicollinearity occurs when most of the independent variables are highly correlated with each other. The Stepwise method corrects for this because it evaluates all variables at each step for inclusion or removal. This would then lead to the removal of superfluous effects (Shaw and Wheeler, 1985) caused from correlations between the independent variables. The SPSS program also prints a warning if the tolerance levels for these intercorrelations are near the limits (Norusis, 1982). In the results, nearly all of the correlations between independent variables were less than 0.2, with only four exceeding the 0.8 limit (Norusis, 1982).

The ratio of cases to the independent variables has been suggested to be 1 to 40 (Cohen and Cohen, 1983). The results in this study were tested for modifications caused by a smaller ratio in this study. First, a Force Entry method of multiple regression was used on all of the initial subgroups, all mines, each of the three county groups and the divisions of each by mining type, 12 groups in all. This forced all the variables into the regression equation initially. In contrast to Stepwise which evaluates all variables in each step for inclusion or deletion. From this the top four independent variables were chosen. The basis for these top four were the Beta weights. They tend to reflect the importance of the various independent variables to the equation (Norusis, 1982). These four were substituted into the Stepwise regression equation instead of the original nine independent variables. The results of the two sets were compared and found to be identical. Therefore, for this study, all nine of the original independent variables will be used in further analyses because they have not been shown to affect the previous results and may yield some valuable information in further analyses. The following subgrouping of variables will also decrease the ratio of the case numbers to the independent variables.

The initial groups submitted for analysis were all problem areas, underground mining problem areas, surface mining problem areas, the three county groups and then the six groups created from the three county groups divided into surface and underground mining methods. These initial groups were reorganized in an attempt to locate groups that were similar. The problem of scale had entered into the analysis. There were no significant results at the scale of the original groups. The large groups of data had hidden patterns that were evident in smaller groups (Larson, 1986). When the sizes of areal units are modified, different regression coefficients can be obtained (King, 1969). Thus these relationships can only be measured with certainty for a specified scale.

The three county groups provided a convenient way to subdivide the data into smaller groups; however, these political boundaries may not group areas of similar characteristics. It is necessary to construct meaningful areal units (Larson, 1986) which delineate units of interest for a particular phenomenon. The mining of coal need not necessarily follow or be limited by political boundaries such as counties, or states.

The continuing analysis led to the formation of smaller, but more meaningful units. The first subgroup included the areas of glaciation, a physical boundary with an effect on mining, as opposed to the political boundaries of the county groups. Another physical boundary is the divisions of topography from floodplain to steep upland. Depth, be it shallow, moderate or deep is also a major grouping variable for mining. In addition, each of these was separated as surface or underground mines.

The two coal seams with the most production may also be used in grouping. BEGIN and END were variables that lent themselves to many subdivisions. Among them were groupings by surface mining laws, the previously classed year groups, and groupings that reflected overall production trends for Indiana. When each of these subdivisions was grouped in pairs, it resulted in over eighty combinations that had a reasonable number of cases and also that described a meaningful unit. For example, the year divisions for the surface mining laws were not applied to underground mines.

Results of the Study

The following are the results of all of the multiple regressions of all the aforementioned subgroups. They are organized from the strongest relationship based on the multiple R (Table 23 to 26). The independent variables that entered the equation are in the order of importance based on their beta weights or standardized regression coefficients which assess the relative contribution of each variable (Shaw and Wheeler, 1985). The positive or negative designation that follows each variable notes the relationship between the dependent variable, TOTAL, and that particular independent variable.

In many of the results only one independent variable was entered. This does not mean that the other independent variables are totally without merit. Several of the independent variables were strongly correlated with the dependent variable, TOTAL. However, they were not included because they could not meet the tolerance limits. Even if the correlations with the dependent variable are weak, this only demonstrates that for this particular subgroup those particular parameters were not as significant as others were.

The results were divided into four divisions based on their percentages of explained variance, or the adjusted R^2 value. The four divisions are: greater than 80%, 40-80%, 20-40%, and less than 20%.

The test of significance for the values of R^2 was the overall F. This test takes into account the ratio of explained to unexplained variance, the number of cases and the number of independent variables. The two most common significance levels are used in statistical analysis are .05 and .01. This means that these relationships would occur, by chance, with either a 5% or 1% probability.

Of the more than eighty subgroups analyzed, thirty-seven

(Tables 23 to 26) were within the tolerance levels set by the SPSS program.

The variable most frequently entered was BEGIN, which entered into thirteen cases. The other entered variables in order of decreasing number are: GLACIATION, 10; END, 8; DEPTH, 6; THICKNESS and TOPOGRAPHY, 4; and ECONOMIC RATIO, 3.

Each of the thirty-seven subgroups contained either underground, surface, or both types of mining. Also, in each of the subgroups either one, two or four variables were entered. The relative frequencies of each of these within each of the four variance groups are shown in Table 27. The three mining divisions were rather evenly distributed, between variance groups and the mining groups. Eleven of the subgroups contained underground mines; there were thirteen in each of the subgroups surface and both. For the number of variables entered, the most frequent was one as twenty-eight of the subgroups only had one independent variable entered. Two variables were entered in eight subgroups and four in one subgroup. There were fewer numbers in the largest two variance groups; this may be partially attributed to the fact that there were also fewer subgroups originally.

There were thirty positive relationships and eighteen negative relationships between the dependent and each of the independent variables. In all cases there was a positive relationship between four variables: GLACIATION, DEPTH, TOPOGRAPHY and ECONOMIC RATIO. With the variable THICKNESS

TABLE 23

Results with Explained Variance Greater than 80%

SUBGROUPS	INDEPENDENT VARIABLES ENTERED	MULT.R	R^2	ADJ R^2	CASES
SURFACE/ GROUP 3	END (+)	.9986	.9973	.9959*	5
SURFACE/ END 1891-1941	GLA (+) & THICK (+)	.9938	.9877	.9795*	9
SEAM 5/ GLA 2	BEGIN (+) & END (+)	.9895	.9791	.9756*	20
SURFACE/ DEPTH 0-30	BEGIN (-) & END (-)	.9884	.9770	.9712*	13
UNDERGROUND/ TOPO 100	DEPTH (+)	.9296	.8642	.8416*	9
END 1850-1933/ GLA 1	BEGIN (-)	.9286	.8623	.8393*	8
TOPO 100/ BEGIN 1850-1933	DEPTH (+)	.9231	.8521	.8225*	7

(* = .01 significance)

TABLE 24

Results with Explained Variance 40-80%

SUBGROUPS	INDEPENDENT VARIABLES ENTERED	MULT.R	R^2	ADJ R^2	CASES
SEAM 3/ END 1933-1950	THICK (-) & BEGIN (-)	.9210	.8482	.7875#	10
TOPO 100	DEPTH (+)	.8884	.7892	.7682*	20
SURFACE/ DEPTH 32-80	END (-) & BEGIN (-) TOPO (+) & GLA (+)	.8616	.7423	.6779*	28
SURFACE/ TOPO 230 OR 260	BEGIN (-) & GLA (+)	.8065	.6504	.5630#	17
SURFACE/ GLA 3	BEGIN (-)	.7164	.5132	.4757*	23
END 1934-1948	BEGIN (-)	.7099	.5039	.4212#	14

(* = .01 and # = .05 significance)

TABLE 25

Results with Explained Variance 20-40%

SUBGROUPS	INDEPENDENT VARIABLES ENTERED	MULT.R	R^2	ADJ R^2	CASES
UNDERGROUND/ GLA 1	BEGIN (-)	.6809	.4636	.3870#	10
GLA 1	BEGIN (-)	.6381	.4072	.3331#	12
UNDERGROUND/ BEGIN 1850-1900	DEPTH (+)	.6356	.4040	.3614*	17
SEAM 5/ END 1850-1933	THICKNESS (-)	.6331	.4008	.3259#	12
SEAM 5	BEGIN (+)	.5957	.3548	.3118#	22
SURFACE/ GROUP 2	END (-)	.5801	.3365	.2922#	24
UNDERGROUND/ END 1891-1920	DEPTH (+)	.5334	.2846	.2535*	30
DEPTH 32-80	GLA (+) & TOPO (+)	.5283	.2791	.2401*	50
UNDERGROUND/ TOPO 230 OR 260	ER (+)	.5203	.2707	.2437*	38
SURFACE/ SEAM 3	BEGIN (-)	.5051	.2551	.2086#	26
SURFACE/ GLA 2	THICKNESS (+)	.5025	.2525	.2027#	27
UNDERGROUND/ BEGIN 1901-1923	GLA (+) & ER (+)	.5011	.2511	.2137*	44

(* = .01 and # = .05 significance)

TABLE 26

Results with Explained Variance Less than 20%

SUBGROUPS	INDEPENDENT VARIABLES ENTERED	MULT.R	R^2	ADJ R^2	CASES
UNDERGROUND/ END 1921-1945	END (-) & GLA (+)	.4985	.2485	.1984#	36
SURFACE/ TOPO 340 OR 460	END (-)	.4913	.2414	.1908#	23
UNDERGROUND/ END 1920-1930	GLA (+)	.4754	.2260	.1853#	24
UNDERGROUND/ DEPTH 32-80	GLA (+)	.4642	.2155	.1742#	25
SURFACE/ BEGIN 1942-1967	TOPO (+)	.4454	.1984	.1602#	26
UNDERGROUND/ TOPO 340 OR 370	DEPTH (+)	.4218	.1779	.1463#	32
TOPO 230 OR 260	ER (+)	.3927	.1542	.1319#	53
SURFACE/ END 1941-1977	TOPO (+)	.3852	.1483	.1143#	33
SURFACE	END (-)	.3671	.1347	.1068#	52
END 1850-1933/ GLA 2	BEGIN (+)	.3278	.1074	.0839#	47
UNDERGROUND/ END 1850-1933	GLA (+)	.2860	.0818	.0634#	58
END 1850-1933	GLA (+)	.2800	.0784	.0610#	62

(# = .05 significance)

Table 27

Frequency of Independent Variables Entered in Each Variance Class

	Greater than 80%	60-80%	20-40%	Less than 20%
Underground	1	0	5	5
Surface	3	3	3	4
Both	3	3	4	3
Numbers of Variables Entered:				
1	4	3	10	11
2	3	2	2	1
4	0	1	0	0

there were negative relationships two times and positive relationships two times. For the variable END the majority of the relationships, six were negative but there were also two positive relationships. The most commonly entered variable BEGIN, had ten negative relationships and three positive relationships.

CHAPTER VIII

CONCLUSIONS

The regression results had thirty-seven subgroups that were statistically significant. Two variance groups, greater than 80% and 40-80% contained the thirteen most significant relationships. The individual subgroups in these two groups will be discussed in detail along with two noteworthy subgroups from the 20-40% variance group. This does not mean that the remainder of the results were not significant to the study. The direction of the relationships, positive or negative, make a contribution to the overall conclusions drawn in this study.

Some group delimiters produced more homogeneous subgroups than others. For the greater than 80% and the 40-80% variance groups, only one delimiter was underground mines, with the remaining twelve equally divided between surface and both types of mining methods. Three independent variables that became delimiters of meaningful subgroups were END, TOPOGRAPHY, and GLACIATION. Each of these were part of four, four and three subgroups, respectively.

The Multiple R measures the strength of the relationship between the dependent and independent variables. However, it does not distinguish between positive and negative relationships between each individual independent variable and the dependent variable. The correlation coefficient shows whether there is a positive or negative relationship. In this study a positive relationship means that the value of the dependent variable, TOTAL, increases as the independent variable increases. In contrast is the negative relationship where the value of one variable decreases as the other increases. The direction of these relationships must be known in order to explain the possible reasons behind the R^2 values.

Overall Statements

To draw overall conclusions about the relationships of the dependent variable, TOTAL, to all the independent coal mine variables, all thirty-seven of the significant relationships contain meaningful information. Individual conclusions for each of the subgroups are necessary, but conclusions that hold for more than one subgroup can be used to draw other conclusions for the entire study area. The more frequently a specific relationship appears, the more validity can be placed in the conclusions drawn about that relationship (Cohen and Cohen, 1983).

The four strongest relationships are for the independent variables BEGIN, GLACIATION, END and DEPTH. BEGIN and GLACIATION have ten relationships each; END and DEPTH had six relationships each. In all cases when the variable DEPTH was entered there was a positive relationship; deeper mines had more total occurrences of Extreme Danger Problems.

Deeper surface mining results in higher highwalls which are more dangerous. During the time period of the study deeper underground mines usually mined the Springfield V coal seam. It had poor roof and floor conditions which contributed to the increased number of Extreme Danger Problems. Another factor with deeper mines, is the ventilation problems. In older mines many air shafts were sunk and the result is a larger number of vertical openings.

With the variable END there was a negative relationship; older mines had more Extreme Danger Problems. Prior to 1941 usually no attempt was made to reclaim surface mines and this included dangerous highwalls. Mines abandoned after the enactment of the 1941 law or the 1967 law had fewer problems than preceding years, because some grading was required, and this helped to eliminate a few of the potential dangerous highwall problems and dangerous pile or embankment problems.

GLACIATION had a positive relationship with TOTAL; the number of Extreme Danger Problems increased as the GLACIATION variable moved from Wisconsinan to Illinoian to areas of no glaciation. For BEGIN there was a negative relationship; older mines had more Extreme Danger Problems.

The two strongest relationships for GLACIATION and BEGIN will be analyzed further to determine which factors might have produced these relationships over the entire study area.

The positive relationship of GLACIATION with total occurrences of Extreme Danger Problems is an indirect effect of several factors. Glaciation seems to have had the major indirect effect. In Indiana most of the large-scale surface mining has occurred mainly where the overburden was less then fifty feet thick (Harper, 1985b). For the three glacial groups, 17% of the depths were less than sixty feet for Group 1. For glacial Group 2, 37% of the depths were less than fifty feet and for Group 3, 66% of the depths were less than fifty feet. The average depths the three groups were 215.4, 96.27 and 54.34 feet, respectively.

In 1959, 60% of Indiana's idle spoil banks were in Pike and Warrick counties (Guernsey, 1959). The spoil banks in this area were mined before the 1941 reclamation law associated with these would-be dangerous highwalls. Therefore for surface mining, the lack of glaciation made it an efficient area to extract coal because of the decreased thickness of overburden. However, since this was the case, old surface mines tend to be predominant, resulting in large numbers of dangerous highwalls.

The underground mines in the study area are also located in areas of relatively thin overburden. This factor combined with the age resulted in a large number of Extreme Danger Problems. Glacial group 3 has a combination of problems from both mining types. Glacial history has influenced the mining methods so that Group 3 has about the same number of occurrences of Extreme Danger Problems as Group 2, with only half the number of problem areas.

The duration of coal production and the time the mine was in operation were important factors for the variable BEGIN. These factors influence the occurrences of Extreme Danger Problems. The mines in this study had rather short durations (Table 28).

Table 28

Frequencies of Mine Production Duration

DURATION IN YEARS	TOTAL NUMBER OF PROBLEM AREAS
1 - 5	32
6 - 10	27
11 - 15	30
16 - 20	13
21 - 28	9
36 - 106	6

Over half of the mines remained in operation for only ten years. Those mines of less than five year duration were about evenly split between surface and underground mines, 14 and 16, with only one mine with both types of mining. Most underground mines in this duration were in operation in the late 1800's and the early 1900's. The surface mines were in operation in the 1950's.

Of the mines in the six- to ten-year duration, seventeen were underground mines and ten were surface mines. The underground mines in this category were in operation mostly during the 1920's or the 1940's, while the surface mines were mostly in operation in the 1950's and the 1960's.

Mines that were planned to have short durations tended to construct temporary facilities, such as wooden buildings. However, many operations planned to operate for many years and constructed buildings of more durable materials like concrete, steel, and brick. The wooden buildings are not as much of a problem as those of more substantial materials that have since fallen into disrepair and present potential hazards.

Mines of short duration also tended to have more problems because they were usually abandoned rather quickly with no plans for filling the shafts or razing buildings. Several mines in Indiana were "temporarily" abandoned until it was again economic to mine coal; sometimes, however, it just never became economically feasible. Therefore no plans were made to return the area to any semblance of its former self.

The year in which mine production began had an effect on the number of Extreme Danger Problems. This was partially a result of the mining methods employed at the time. Older mining methods were not only more dangerous at the time of mining but also caused subsequent Extreme Danger Problems. Early underground mining methods many times dealt with the present not the future. Coal extraction rates that provided adequate roof support during mining, were too high to support the roof for the next century. Shallow depths were mined leaving an inadequate amount of overlying strata for continued roof support. Shaft linings or roof supports that were made out of wood deteriorated. These early methods frequently resulted in the collapse causing subsidence.

The laws and the mining methods that were in effect at the beginning of the mining operations were usually continuous throughout the life of the mine. Mining methods proceeded differently if reclamation was a part of the mining plan required by law. The mining machinery demanded such a large capital outlay that the machine that the mining began with most likely is the one that will operate for the duration of mining. This is especially true when half of the mines in the study operated only ten years or less.

More specifically the beginning and ending years of the mines in the study area seemed to mirror the trends in coal production for the entire state. Figure 6 showed Indiana's coal production for surface and underground mines. The peaks and troughs in production are related to the beginnings and endings of the mines in the study area. For underground mines the production peaks were at 1910, 1918, 1923, 1937 and 1944. If the year production began (BEGIN) is plotted for each of the problem areas with underground mining against the peak years (Figure 11), in most cases are at or just precede the peak production years. Notice the peak of problem areas at 1909, 1918, 1922, 1943 and 1947. There are also similar trends for the end years (Figure 12) for the problem areas. There were troughs in production for the years 1911, 1922, 1933, 1939, and 1950. The problem area troughs are similar. They proceed the years, 1910, 1913-1916, 1929-1940, and 1950.

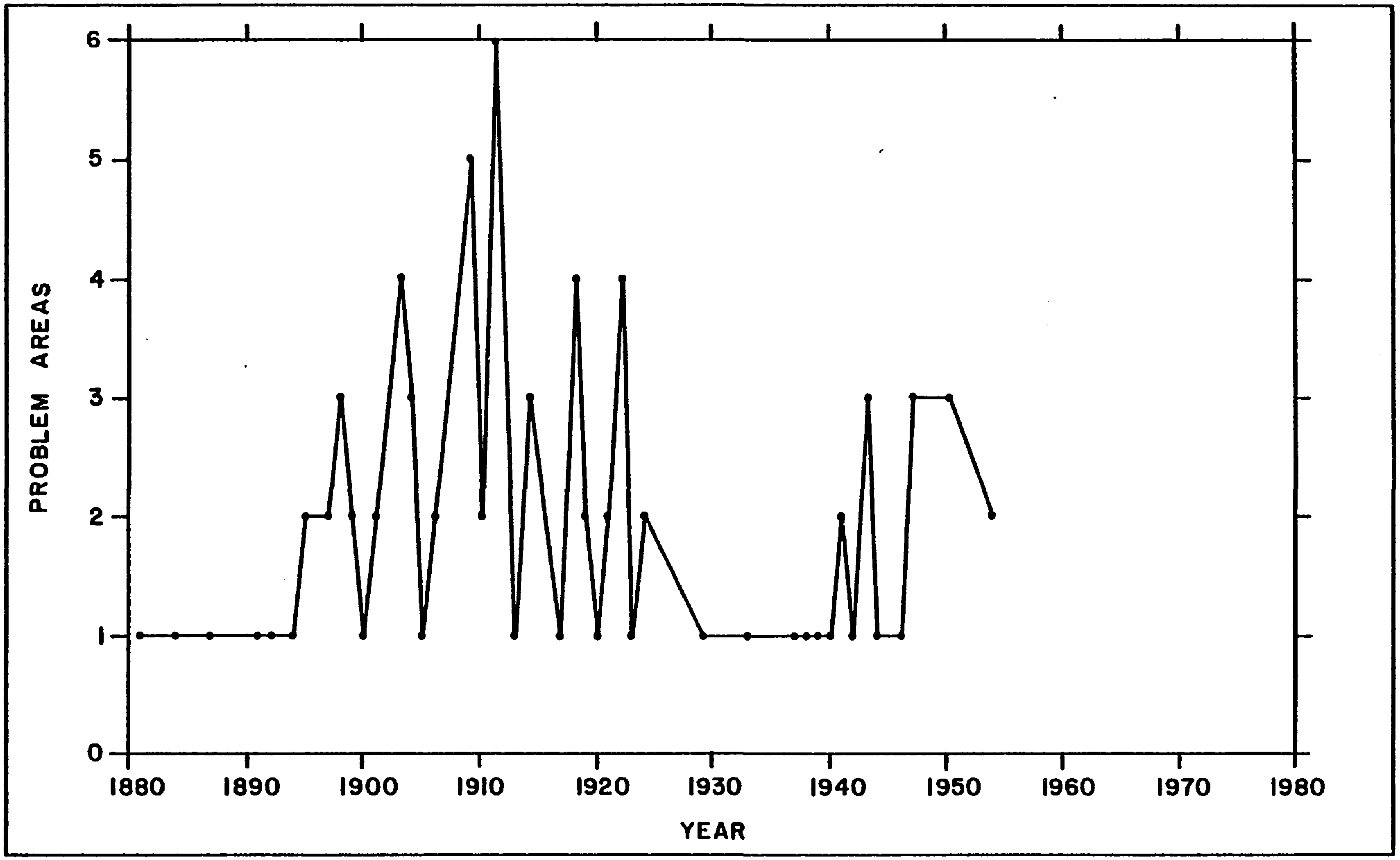

Figure 11. Frequency of Problem Areas by Beginning Year of Production for Underground Mines.

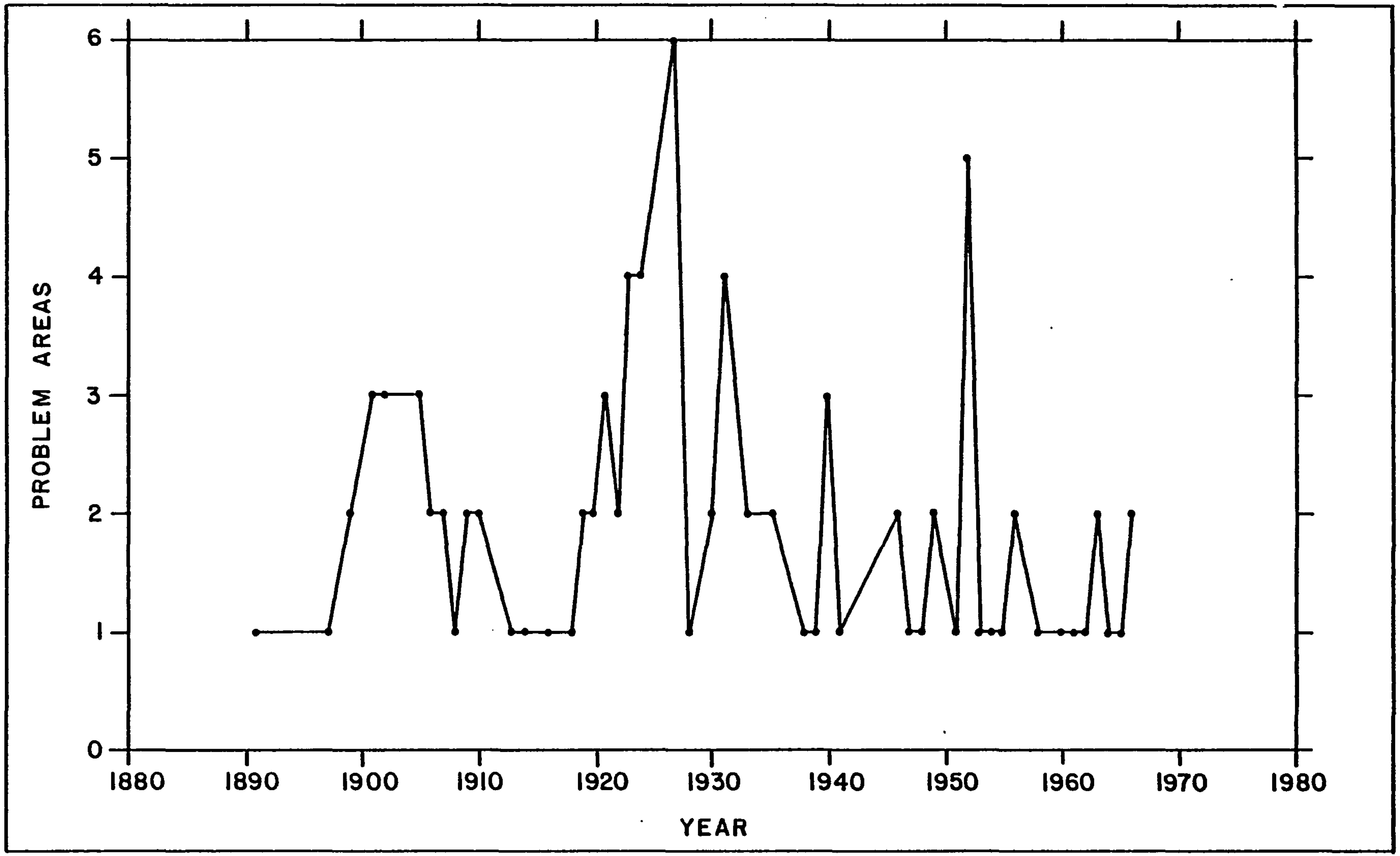

Figure 12. Frequency of Problem Areas by Ending Year of Production for Underground Mines.

These trends relating to production are also present with surface mines. There are peaks in production in 1942 and 1975. The problem area beginning years (Figure 13) are 1939, 1950 and 1960. The surface mine production shows a trough in 1954 and the problem area's end year trough is also 1954 (Figure 14).

From these comparisons of production to mine beginnings and endings and the duration of mine run, some generalizations can be proposed about the mines in the study area and the reasons for the strong negative relationship between the total number of occurrences of Extreme Danger Problems and the independent variable BEGIN.

Specific Statements

Fifteen specific relationships were analyzed. This discussion is intended to focus on the individual reasons for the relationships. The four major overall relationships previously discussed will not be reiterated each time unless there is specific information that concerns that subgroup. The fifteen subgroups will be discussed according to the decreasing value of Multiple R. All are statistically significant. The adjusted R^2 values can be compared because the values have been adjusted for the wide range of case numbers. Therefore, none of the individual relationships is more important than another. However, relationships with larger numbers tend to validate a relationship, moreover, when a subgroup represents a large number of cases other conclusions can be drawn.

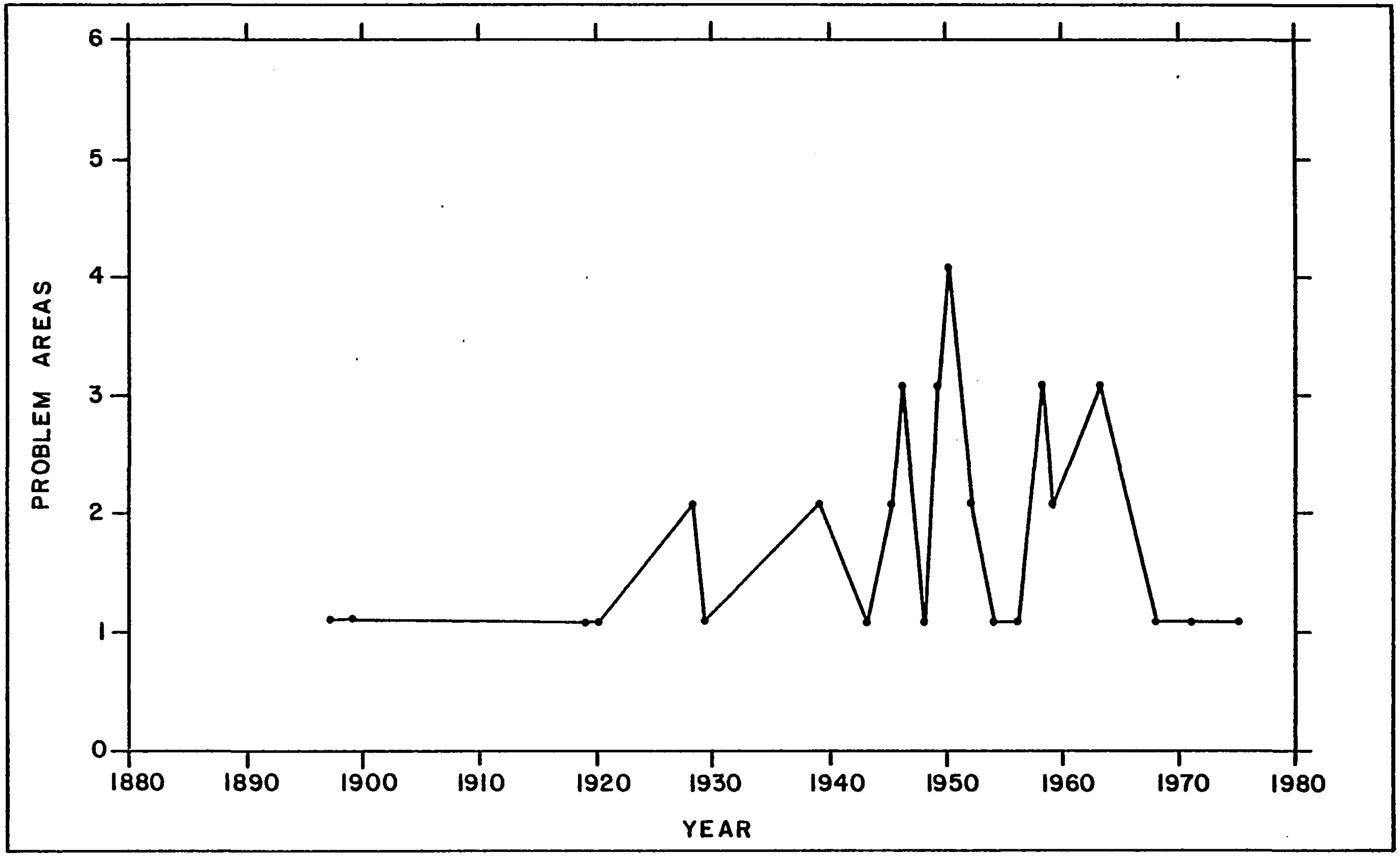

Figure 13. Frequency of Problem Areas by Beginning Year of Production for Surface Mines.

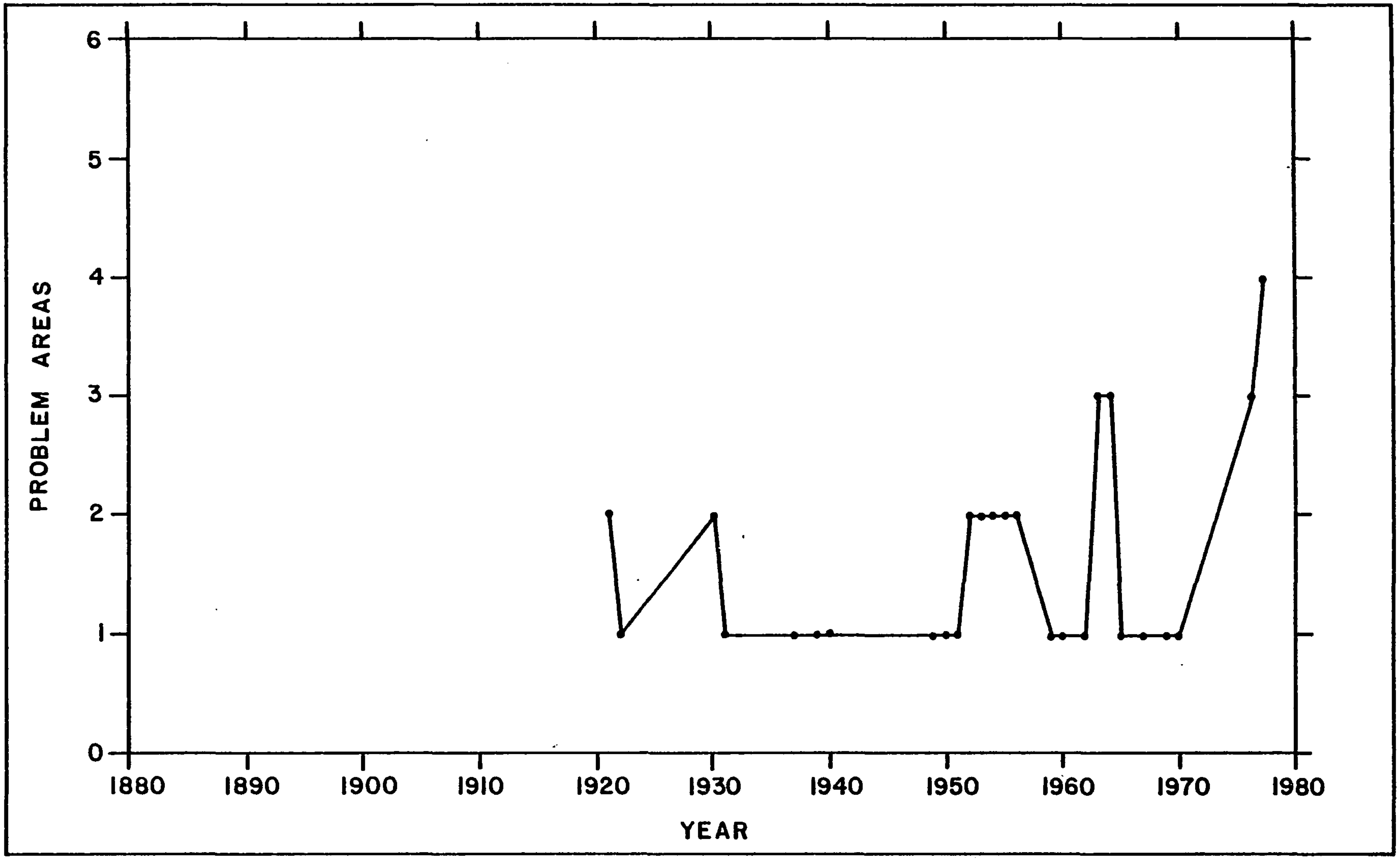

Figure 14. Frequency of Problem Areas by Ending Year of Production for Surface Mines.

Greater than 80% Variance Group

The subgroups in the greater than 80% variance group have explained variances of 80% or more. This means that at least 80% of the variance in the dependent variable can be attributed to the independent variable. The first subgroup is a positive relationship with END, this variable explains 99.59% of the variance. These were surface mines in group 3. There were more problems associated with more recent mines. These mines began production in the 1950's and ceased in the 1960's. The short lived duration and the increase in the number of mines beginning later explains this relationship.

The second subgroup explains 97.95% of the variance with the two variables GLACIATION and THICKNESS entering into the equation. For surface mines that ended production between 1891 and 1941 there was a positive relationship for GLACIATION and THICKNESS. The most common surface mined seam was the Springfield V, the thicker seams were mined in Warrick county at a much earlier time than the thinner seams.

The third subgroup has 97.56% of the variance explained. In the subgroup with Illinoian glaciation and the Seelyville III (#5) coal seam there are positive relationships with BEGIN and END. The distribution of these problem areas is clustered in Vigo and Clay counties (Figure 15). This distribution is also significant because there are only 22 problem areas in this seam and 20 of them are in this subgroup. The types of problems in this distribution are large numbers of dangerous highwalls created in

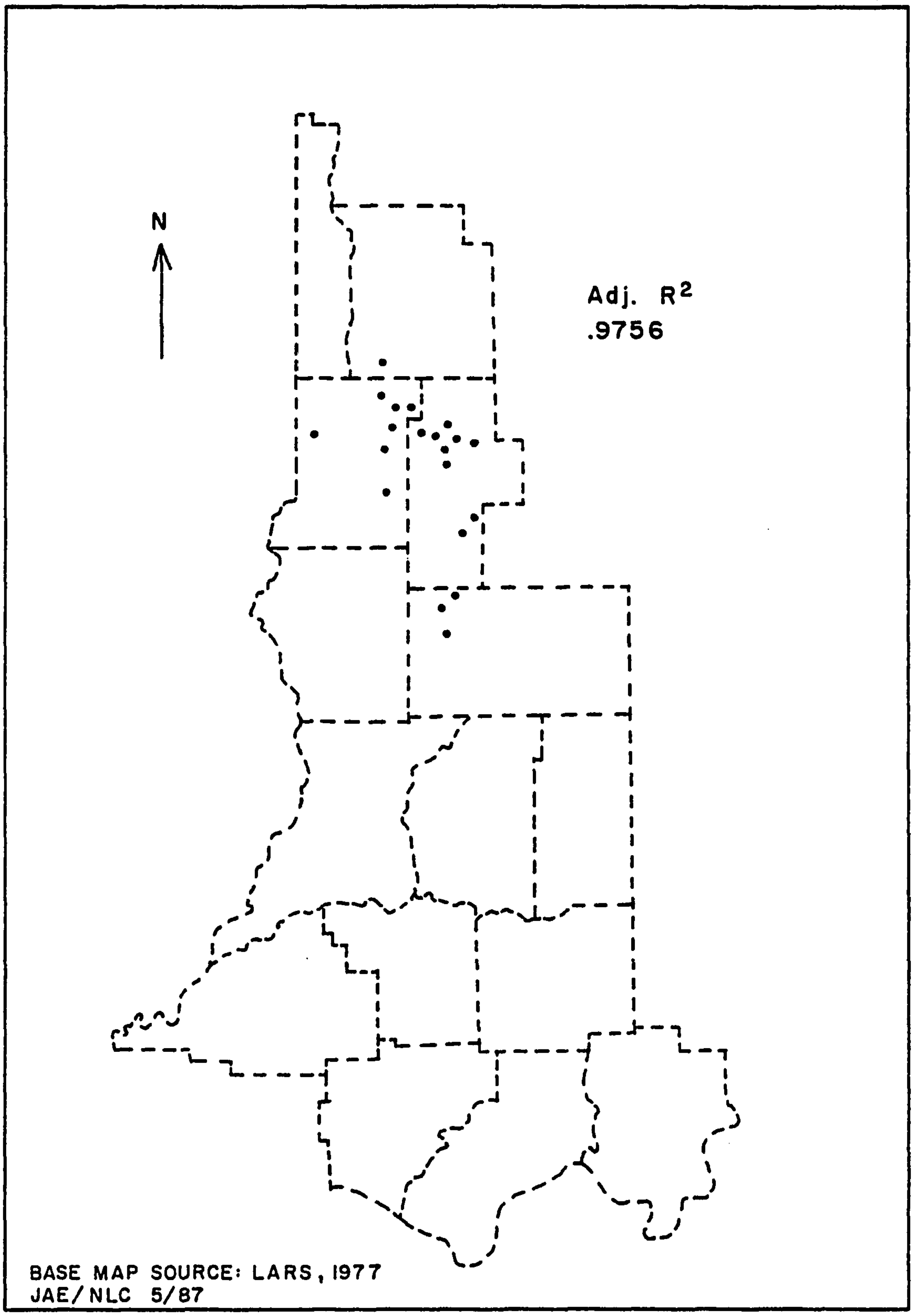

Figure 15. Mines in Seelyville III Coal Seam with Illinoian Glaciation.

the 1950's and single occurrences of vertical openings associated with older mines. The combination of these two factors causes the relationships to be positive for BEGIN and END rather than negative.

The fourth subgroup explains 97.12% of the variance. This is the subgroup surface mines with depths of 0-30 feet (Figure 16). These areas are distributed in Clay county and in along the glacial border in four southern counties. There is a negative relationship with the variables BEGIN and END. This particularly highlights the effect of the mining laws. Those areas with the most problems ended production before the 1967 law, and the later mines with fewer problems were subject to the law.

The fifth subgroup is the underground mines located on a floodplain. The explained variance was 84.16%, and the relationship was positive for DEPTH. This is one-half of the mines that are located on a floodplain. In underground mines associated with floodplains, the positive relationship between total and DEPTH is even more of a factor than in other areas. The unconsolidated materials are rather unstable both during current mining and after the mine is abandoned.

The sixth subgroup is the mines in the Wisconsinan glacial region that were abandoned between 1850 and 1933. The year portion of the subgroup represents a time when the total coal production for Indiana was increasing and was at the highest point for underground mine production. The

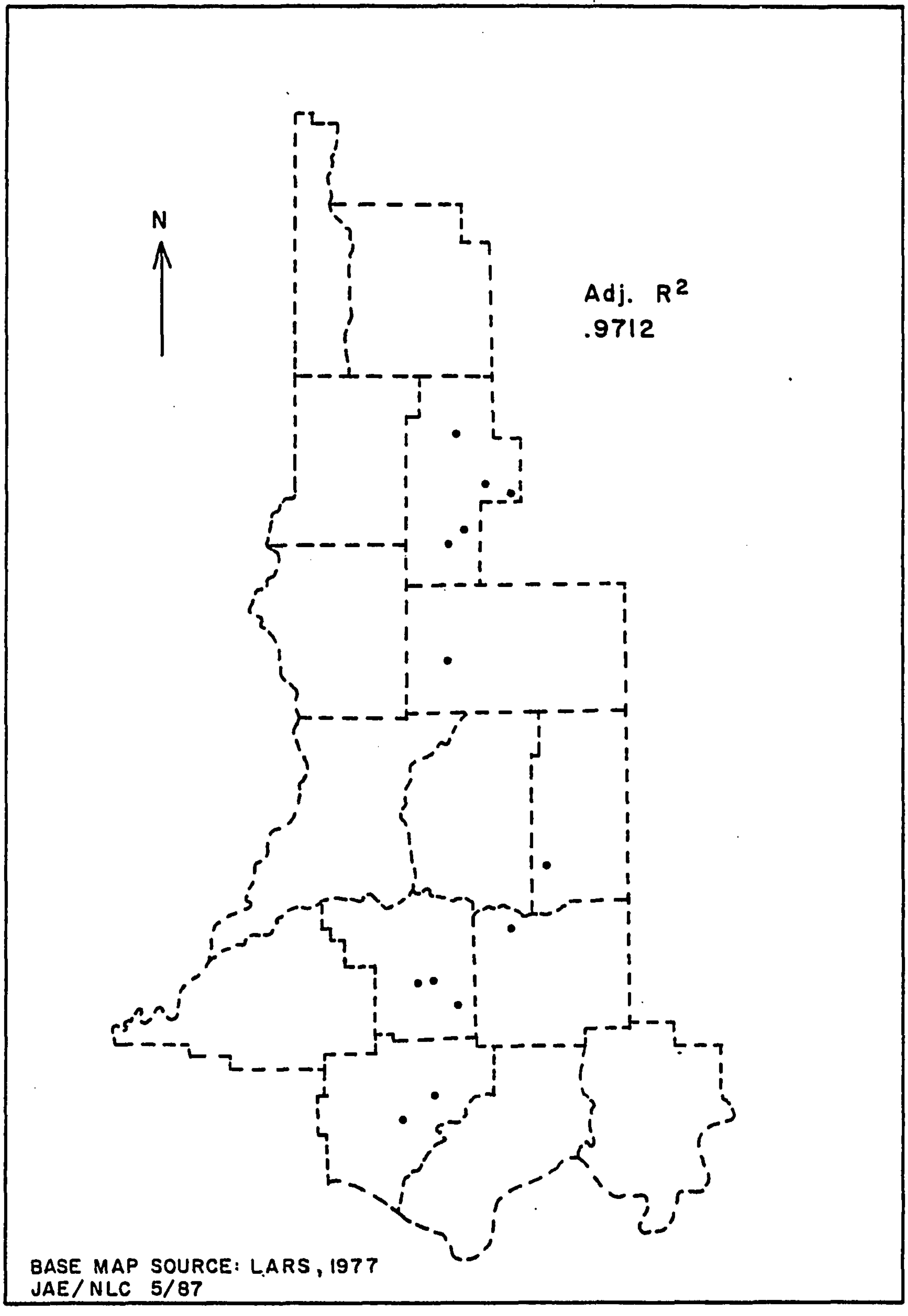

Figure 16. Surface Mines with Depths 0-30 Feet.

relationship was a negative one with the variable BEGIN and 83.93% of the variance was explained.

The seventh subgroup in the first variance group is the mines which began production between 1850 and 1933 and were located on a floodplain. The relationship was a positive one between TOTAL and DEPTH. The reasons for this relationship are the same as the previous discussion for the year period and floodplain topography.

40-80% Variance Group

In the second variance group, the first relationship was for the subgroup of mines that ended production between 1933 and 1950 and were in the Springfield V coal seam (Figure 17). The relationships were negative for THICKNESS and BEGIN for previously discussed reasons. This time period represents the major trough in coal production in Indiana. Underground mining production had already peaked, and surface mining had not yet reached its peak.

The second subgroup is all of the mines in the floodplain areas (Figure 18). These are the floodplains of the Wabash and Patoka rivers. The explained variance is 76.82% and the relationship is a positive one for DEPTH. This is more pronounced in the floodplain areas, as there are special problems associated with mining in these areas. Half of the areas are associated with surface mining and the other with underground mining. Almost all of the surface mines are in Pike county.

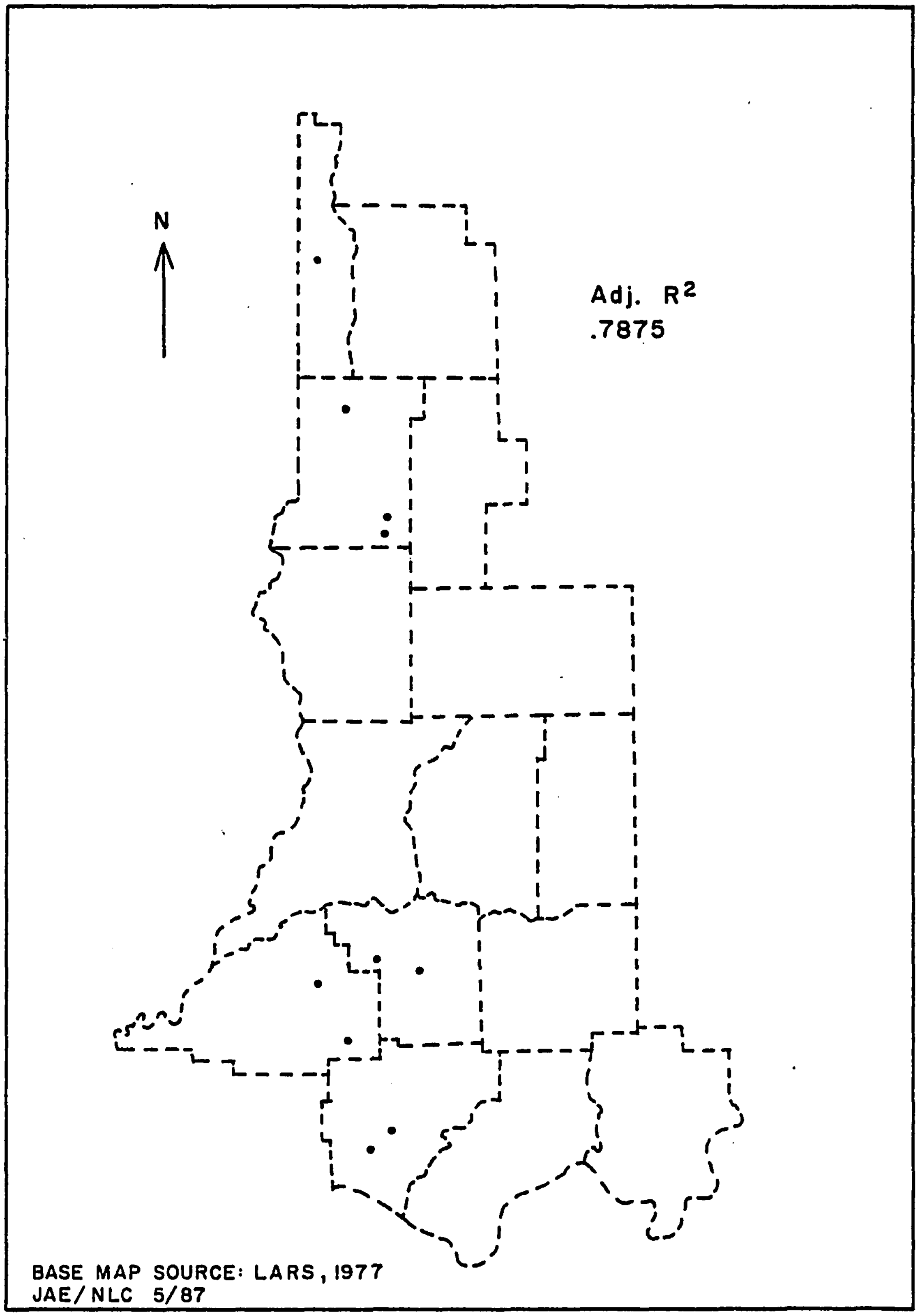

Figure 17. Mines in the Springfield V Coal Seam Ending Production Between 1933 and 1950.

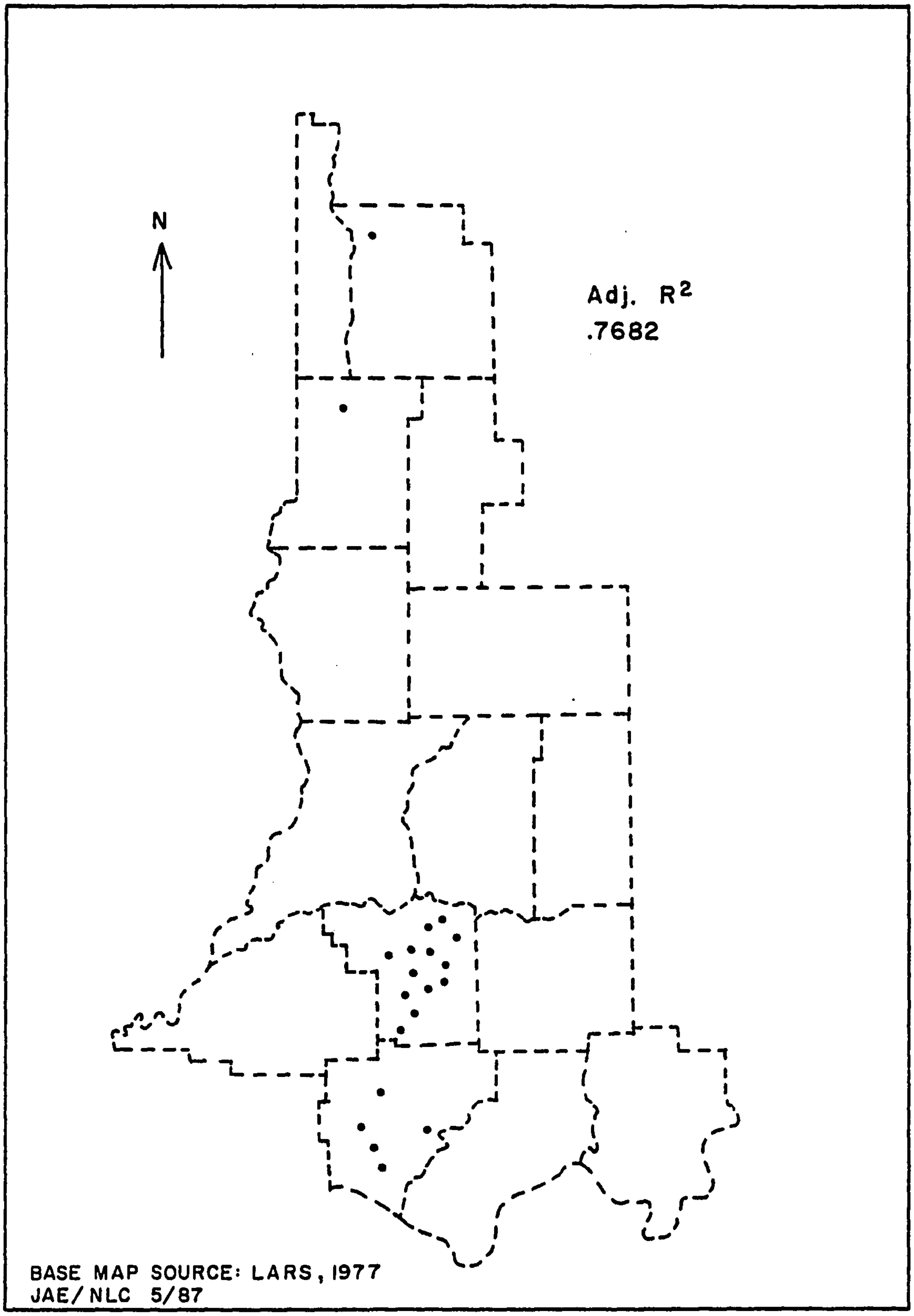

Figure 18. Mines on Floodplain Topography.

The third subgroup includes all surface mines with depths of 32 to 80 feet (Figure 19). This subgroup had the largest number of independent variables entered in the entire study. The four variables entered were END, BEGIN, TOPOGRAPHY and GLACIATION; the four most important for the whole study area. The combination of these four variables accounts for 67.79% of the variance. This subgroup contains one-half of the total number of problem areas with that depth. The distribution is concentrated in the areas of most intensive surface mining in Pike and Warrick counties. For the time period of the study this depth was most conducive to surface mining.

The fourth group includes the surface mines in areas of flat topography (Figure 20). This group represents one third of all the problem areas in the regions of flat topography. There is a negative relationship with BEGIN and a positive one with GLACIATION. The majority of the problem areas are in the counties of Greene and Clay, but more problems are in the southern counties. The surface mines on these flat areas are much older in the southern counties and the coal seams mined were of a greater depth. Both of these factors contributed to a greater number of dangerous highwalls in the earlier years in the nonglaciated area.

The fifth subgroup are surface mines in the unglaciated areas. There is a negative relationship with BEGIN and 47.57% of the variance is explained.

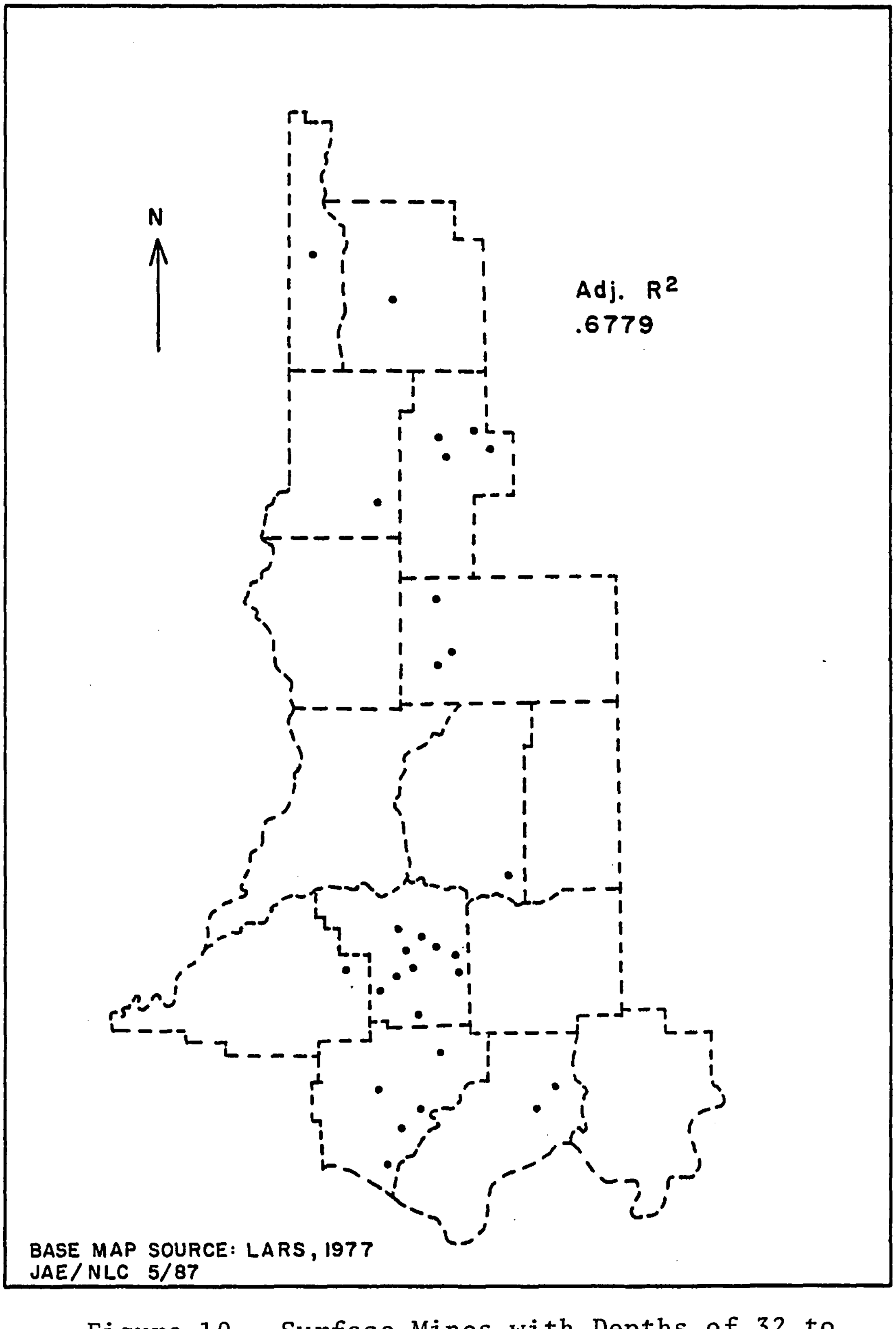

Figure 19. Surface Mines with Depths of 32 to 80 Feet.

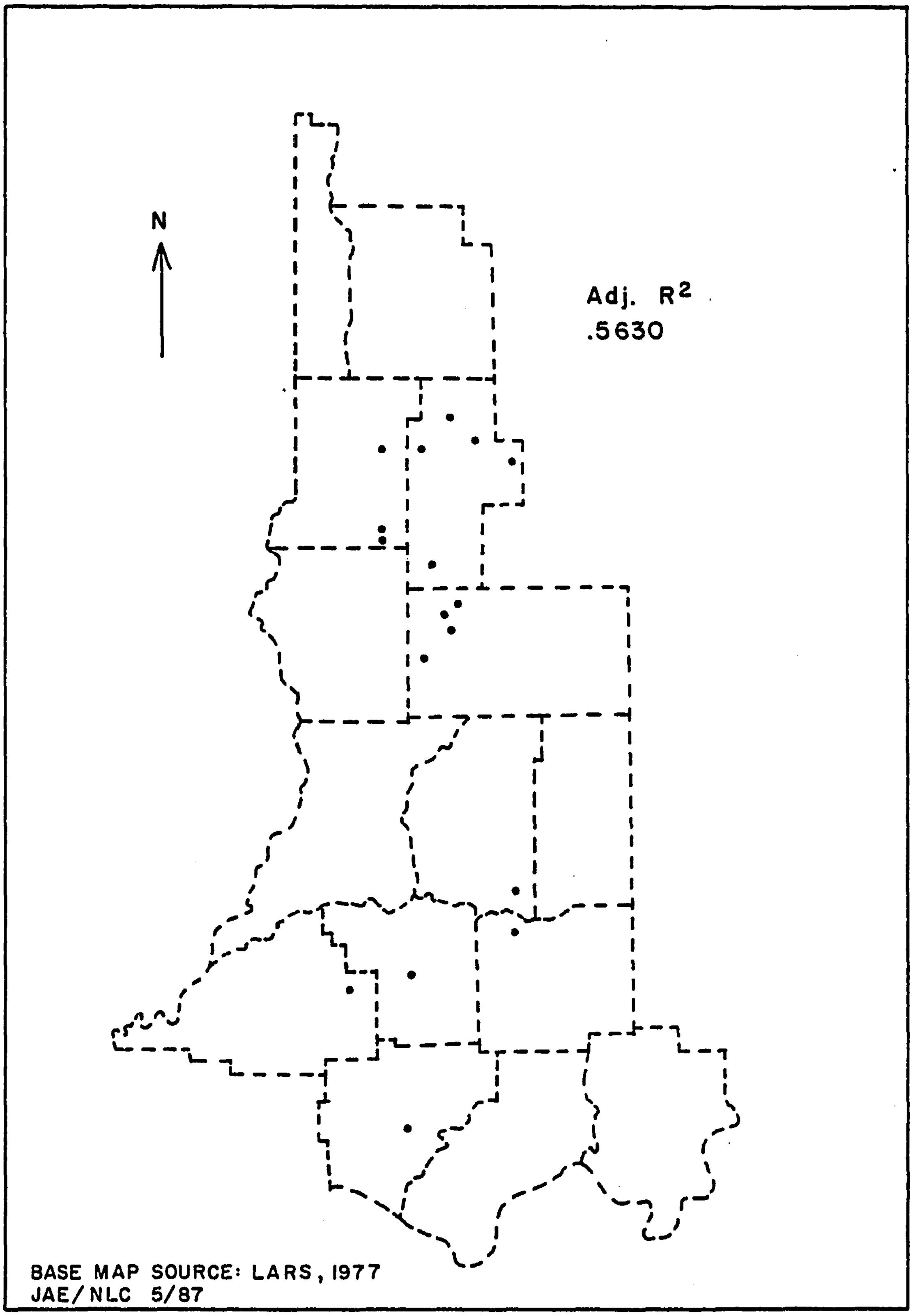

Figure 20. Surface Mines with Flat Topography.

The sixth subgroup in this group is those mines which ended production between 1934 and 1948 (Figure 21). There was a negative relationship with the beginning year. The older mines had twice as many vertical openings as did the more recent mines, the air shafts were associated with the main shaft and the shafts were wood lined. This period of time represents an overall trough in total coal production in Indiana. The distribution is dispersed and twelve of the mines are underground. Underground mine production at this time was on a downward trend, during the Depression years. Most of the mines had operated over ten years, with half of these operating over twenty years.

20-40% Variance Group

Two other relationships are of particular interest because of the large number of cases in each subgroup. The first subgroup includes surface mines in Group 2 (Figure 22). There is a negative relationship with END, and 29.22% of the variance is explained. This subgroup is the largest county group of surface mines. Three-fourths of the problem areas are in Pike county. In looking at the specific years the largest number of occurrences of Extreme Danger Problems are before the 1941 law, another group with two occurrences is before the 1967 law and the single occurrences are after the law.

The second subgroup is mines with depths of 32 to 80 feet (Figure 23). Of the thirty-seven subgroups this subgroup has the fourth largest number of problem areas and

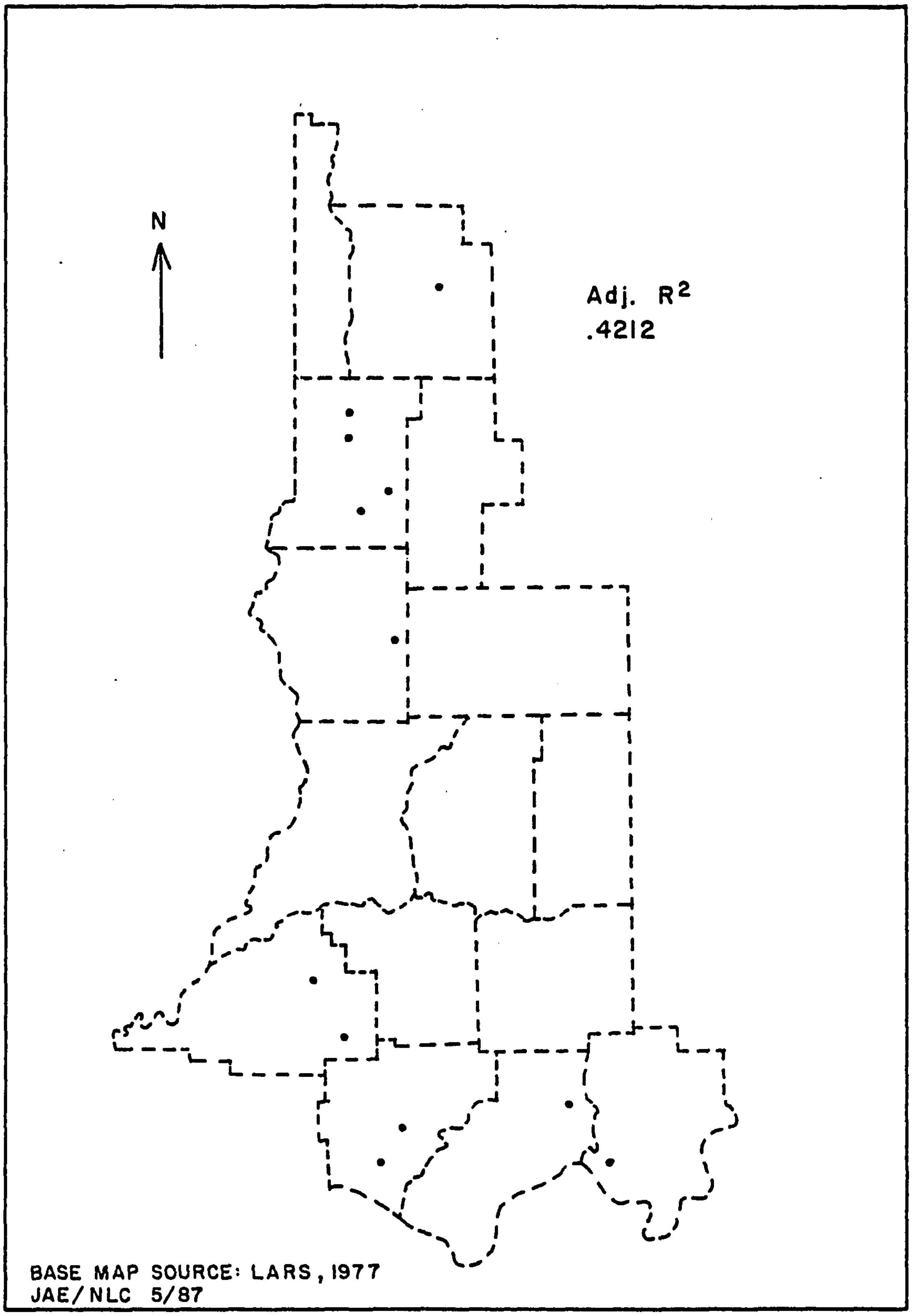

Figure 21. Mines That Ended Production Between 1934 and 1948.

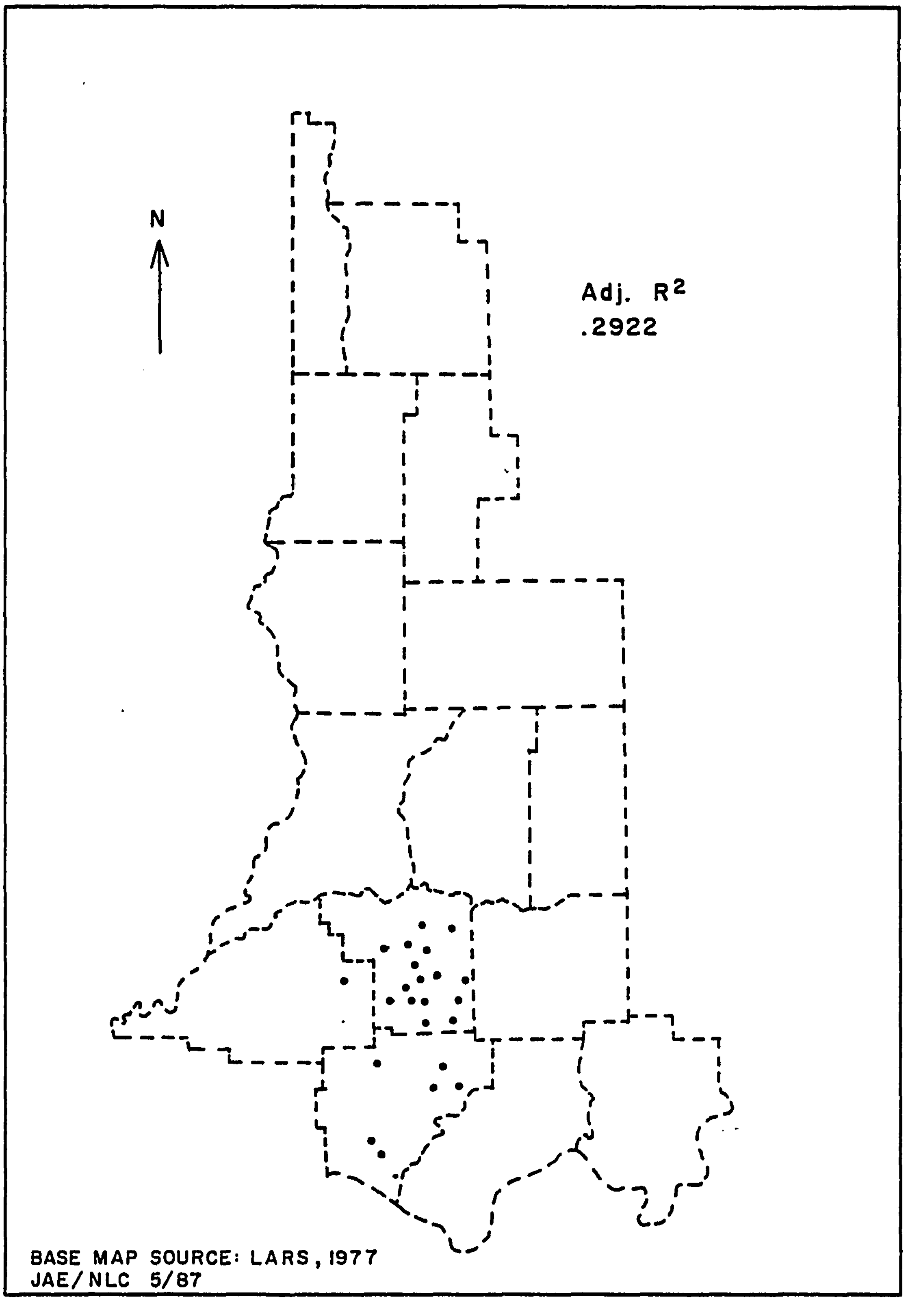

Figure 22. Surface Mines in Group 2.

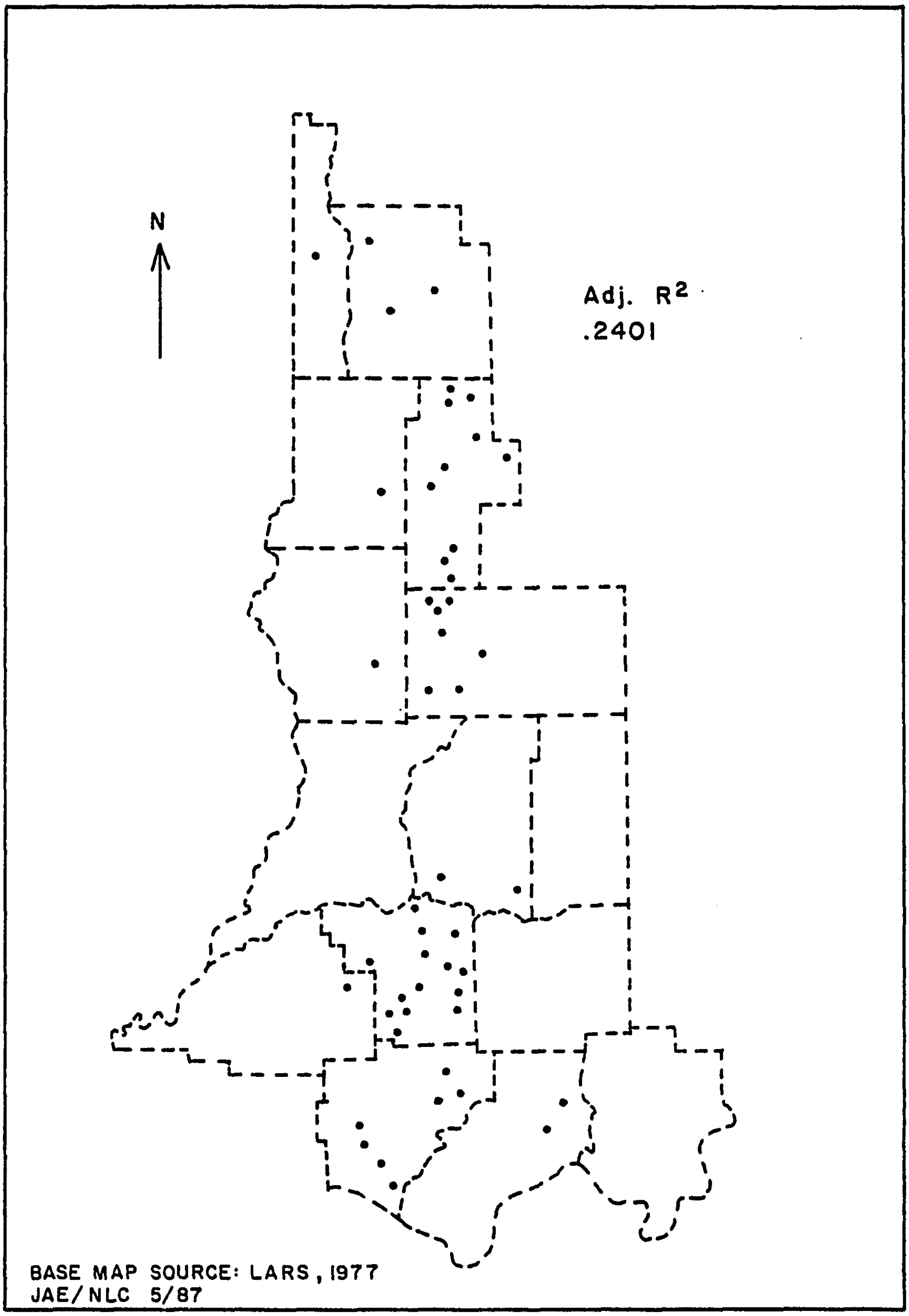

Figure 23. Mines with Depths of 32 to 80 Feet.

still has an explained variance of 24%. This distribution should be compared to the distribution of the same depth with only surface mines (Figure 19). The underground mines were located in Clay and northern Pike counties. The addition of the underground mines reduced the explained variance from 67.79% to 24%. Therefore, the surface mines of this depth were more homogeneous in their characteristics, particularly with reference to the variables BEGIN and END.

Conclusions of the Study

This study is unique in that it addressed the safety problems associated with abandoned coal mine lands. The focus was on Extreme Danger Problems, for an entire state, not one specific area or one safety problem. The hypothesis of this study was that there were significant relationships between the occurrences of Extreme Danger Problems and several coal mining variables.

The data and the analysis support the following conclusions:

Conclusion 1: For specific subgroups of Extreme Danger Problems in Indiana, there are significant relationships between the dependent variable TOTAL and the independent coal mine variables. There were thirty-seven statistically significant relationships for various subgroups between TOTAL and independent variables. Seven of these subgroups have explained variances of greater than 80%.

Conclusion 2: Overall there is a significant positive relationship between the dependent variable, TOTAL, and the independent variable, GLACIATION. There is also a significant negative relationship between the dependent variable, TOTAL, and the independent variable, BEGIN.

Recommendations for Further Study

Extreme Danger Problems have a significant impact on the safety of the people in Southwestern Indiana and warrant further study. The Mid-Course Review of the National Reclamation Program for Coal (Committee on Abandoned Mine Lands, 1986) made several recommendations which concerned danger problems. The Review called for a "concentration on correcting all significant health and safety problems by 1992" and a certification for all states that all safety problems would be corrected by 1992 or no monies would be allotted for environmental reclamation (Committee on Abandoned Mine Lands, 1986). Danger problems are a current research topic concern as it will be necessary to gather information on all problems to "enable Congress to make a reasoned decision on whether to extend the AML program beyond 1992" (Committee on Abandoned Mine Lands, 1986).

The recommendations for further investigation are first, using the same methodology, analyze the priority 2 or danger problems in Indiana and then the priority 3 or environmental problems. Second, the methodology used for the analysis of Indiana's Extreme Danger Problems should be applied to the other thirty-four states with abandoned coal mine lands.

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APPENDIXES

DEPARTMENT OF THE INTERIOR
Office of Surface Mining
ABANDONED MINE LANDS INVENTORY UPDATE FORM

A. GENERAL AND LOCATIONAL DATA

1. Date Prepared: ____/____/____ 2. Prepared by: ____________
3. State/Tribe Name: ____________ 4. Telephone Number: ____________
5. Problem Area (PA) No. ____________ 6. PA Name: ____________
7. ________ (Y/N) This PA has been previously submitted and is included in the National AML Inventory (If YES, skip to Part B).
8. Planning Unit (PU) No. ____________ 9. PU Name: ____________
10. County ____________ 11. FIPS CODE (five digit) ________
12. ____________ Congressional District Number
13. ____________ 8-Digit Water Cataloging Unit (WCU) No. in which PA is located.
14. USGS Quadrangle(s) ____________ ____________
    Principal Quad Secondary Quad
    ____
    Other Quad(s)
15. ____________ Map Series (Enter 7.5', 15', or other basis)
16. ____________ Map Sector (Enter NW, NC, NE, WC, CS, EC, SW, SC, or SE)
17. Principal Quadrangle Coordinates (found on SE map corner)
    N ____________ W ____________
18. This PA is located ____________ Miles ____________
    Distance Direction
    ____
    From (City, Town, Village, Highway, or other prominent feature on map)
19. ______ (S/U/B/P) Type of last coal mining?
    (S)Surface (U)Underground (B)Surf/Undgrd (P)Coal Processing

B. REASONS FOR UPDATE

20. ____________ Enter a letter and an applicable number.
    A. Annual Submission of Projects. New Problem Area.
    B. Construction Grant Application.
        1. New Problem Area
        2. New cost estimates
        3. Existing Problem Area - new or more serious problems
    C. Completion Report.
        ____ 1. State Reclamation ____ 2. Emergency
        ____ 3. Federal Reclamation ____ 4. RAMP
    D. New Problem Area
    E. New or more serious problem(s) at existing Problem Area.
    F. Site visit indicates no problem changes.

AML INVENTORY UPDATE FORM

C. DESCRIPTION OF HEALTH, SAFETY, AND GENERAL WELFARE PROBLEMS (HS&GW)
Priority 1 and 2 Problems (Check the space if the keyword is present)

21.	Extreme Danger Problems	Other HS&GW Problems		Extreme Danger Problems	Other HS&GW Problems
	Priority 1	Priority 2		Priority 1	Priority 2
VO	____	____	PWAI	____	____
P	____	____	PWHC	____	____
SB	____	____	S	____	____
GUB	____	____	HEF	____	____
GHE	____	____	IRW	____	____
DPE	____	____	HWB	____	____
DI	____	____	DH	____	____
DS	____	____	CS	____	____
			N (None)	____	____

D. PRIORITY 1 AND 2 CRITERIA

22. ______ (Y/N) Has there been any occurrences of injury or death to a person, or accident or damage to property due to HS&GW problems?
23. ______ (Y/N) Have local residents/officials been interviewed regarding HS&GW problems in this PA?
24. ______ (Y/N) Is there corroborative evidence concerning the HS&GW problems?
25. ______ (Y/N) Is there evidence of site visitation?
26. ______ (Y/N) Are the HS&GW problems in this PA easily accessible?
27. ______ (Mi.) Distance to nearest population from this PA?
28. ______ (Y/N) Is this PA visible from public use areas?
29. ______ (0-3) How many people are directly impacted by the HS&GW problems?
(0) None (1) 1-10 (2) 11-100 (3) More than 100
30. ______ (S,M,O,U) Is there local support for reclamation of the HS&GW problems?
(S) Support (M) Mixed (O) Opposition (U) Unknown

E. EVIDENCE OF HEALTH, SAFETY, AND GENERAL WELFARE PROBLEMS

31. Narrative evidence of Priority 1 problems: ______________________
____
____
____
____
____
____
____
____
____

AML INVENTORY UPDATE FORM

32. Narrative evidence of Priority 2 problems: ____________________

F. ENVIRONMENTAL RESTORATION PROBLEMS (Land and Water)

	Problem Keyword		Priority 3 Problems		Problem Keyword		Priority 3 Problems	
33.	Spoil Area	(SA)	______	acres	Mine Openings	(MO)	______	number
	Bench	(BE)	______	acres	Slump	(SP)	______	acres
	Pits	(PI)	______	acres	Highwall	(H)	______	Len. in ft.
	Gob	(GO)	______	acres	Equip/Facil	(EF)	______	number
	Slurry	(SL)	______	acres	Ind/Res Waste	(WA)	______	acres
	Haul Road	(HR)	______	acres	Water Problems	(WA)	______	Gal/min.
					Other	(O)	______	
					NONE	(N)	______	
	Total		______	acres				

G. EVIDENCE OF ENVIRONMENTAL RESTORATION PROBLEMS

34. Narrative evidence of Priority 3 problems: ____________________

AML INVENTORY UPDATE FORM

H. RECLAMATION COST

35. $ _______ Priority 1 (Extreme Danger Problems) estimated reclamation cost.

36. Priority 1 Cost Estimate Justification: ____________________

37. $ _______ Priority 2 (Other HS&GW Problems) estimated reclamation cost.

38. Priority 2 Cost Estimate Justification: ____________________

39. $_______ Priority 3 (Environ. Restor.) estimated reclamation cost.

40. Priority 3 Cost Estimate Justification: ____________________

APPENDIX B

AML DEFINITIONS

(Office of Surface Mining, 1984)

CS -- Recurrent Flooding or Ground Saturation: Flooding caused by AML-related sedimentation or degraded water retention characteristics which affects populated areas, property, or improved lands.

DPE -- Dangerous Pile or Embankment: Any AML-related refuse pile or embankment that is considered a health or safety problem because of unstable slopes or windblown particulate matter, and is located within close proximity to a populated area, public road or other public use area.

DH -- Dangerous Highwall: Any AML-related, unprotected, and dangerous highwall located in close proximity to a populated area, public road, or other public use area.

DI -- Dangerous Impoundment: Any AML-related water catchment basin, naturally formed or artificially built, which is dammed or excavated for the retention of water, sediment, or waste, and poses a threat to the safety of life or property. Such an impoundment must be currently leaking and/or structurally unsound or subject to dangerous transient waterflow conditions and be located upstream of manmade structures or populated areas.

DS -- Dangerous Slide: Any AML-related slide area endangering populated or improved areas or one that could cause the impoundment of water or the breach of an existing impoundment.*

GHE -- Hazardous or Explosive Gases: AML-related venting of hazardous gases not related to combustion or venting of explosive gases.

GUB -- Gases from Underground Burning: Any AML-related continuing smoke, haze, heat, or venting of hazardous gases from underground coal combustion.*

HEF -- Hazardous Equipment or Facilities: AML-related hazardous equipment or facilities located within close proximity to populated areas, along public roads or other public use areas.

HWB -- Hazardous Recreational Water Body: Any non-polluted, impounded water, regardless of depth or surface area, that is considered an attractive nuisance and is located within close proximity to a populated area, public road, or other public use area.

IRW -- Industrial or Residential Waste: Unauthorized and dangerous use of AML-impacted areas for residential or industrial waste disposal.

P -- Portal: Any AML-related surface entrance to a drift, tunnel, adit, or entry which is nearly level; not sealed; and is located within close proximity to a populated area, public road, or other public use area.

PWAI -- Polluted Water Agricultural/Industrial: Any surface or subsurface water used for agricultural or industrial purpose which does not meet standards because of AML-related impact.*

PWHC - Polluted Water Human Consumption: Any surface or subsurface water used for human consumption or recreational waters used for swimming whose quality does not meet standards (especially those for suspended solids, acid or alkaline conditions, heavy metals concentrations, or radioactivity) because of AML-related impact.**

S - Subsidence-Prone Area: Any surface expression of AML-related subsidence such as tension cracks, potholes, troughs, or caving whose impact affects populated areas or affects the utilization of improvements.

SB -- Surface Burning: Any AML-related continuing incidence of surface burning resulting in smoke, haze, heat, or venting of hazardous gases.

VO -- Vertical Opening: Any AML-related vertical or steeply inclined excavation or surface opening, regardless of proximity to populated areas, that is large enough for a small child to fall through and be injured, and is not adequately sealed or barricaded.

* In Indiana there are no Extreme Danger Problems (priority 1) in these categories.

** Water is considered polluted if it meets one or more of the three following parameters: pH of less than 5 or greater than 9, suspended solids greater than 70.0 mg/l, or iron content of greater than 7.0 mg/l.

APPENDIX C

MINE NAMES AND DATA

ID	MINE NAME / TYPE	CO	DEPTH	THICK	BEGAN	ENDED	SEAM
0005	Saxton #1 / S	4	40	3.3	1950	1970	1
0006	Somerville #1 / U	4	220	7.0	1922	1963	3
0009	Dering #1 / U	13	201	6.5	1911	1923	5
0011	Coxville #2 / U	8	10	6.5	1887	1891	5
0014	Hickory Grove / S	14	---	---	1939	1940	3
0017	Thrifty #2 / U	2	75	4.0	1919	1930	3
0018	Sand Hill / U	10	42	6.0	1938	1966	3
0020	Donahue / U	7	0	3.3	1850	1956	12
0021	Scales / S	15	20	6.0	1954	1965	3
0022	Clay City / S	1	27	5.5	1952	1956	5
0024	Blackfoot #1 / U	10	42	4.6	1939	1956	3
0027	Blackie Paulin / U	9	0	2.8	----	1946	13
0028	St. Anthony / U	3	0	3.8	----	1955	14
0029	Victory / U	14	80	6.0	1943	1954	5
0031	Honey Creek / S	14	40	6.0	1928	1931	3
0034	Sugar Creek / U	14	105	6.0	1903	1906	3
0035	National / U	14	183	4.2	1911	1927	3
0036	Sugar Valley #1 / B	14	185	4.6	1919	1939	1
0039	Green Valley / U	14	580	6.0	1947	1963	5
0040	Pittsburg #2 / U	14	375	4.7	1913	1927	3
0046	Eagle / U	14	192	4.7	1922	1933	3
0047	Saxton / U	14	240	5.0	1924	1960	4
0057	Speckner / U	11	0	4.3	1897	1948	13
0058	Scott City / U	12	193	3.5	----	1919	2
0060	Jonay / U	12	230	6.6	1947	1953	2
0061	Julian #5 / U	6	218	5.5	1941	1952	2
0065	Burnett #2 / U	14	180	6.0	1921	1931	5
0067	Purity / U	15	101	5.5	1954	1958	3
0068	Decker / U	15	136	6.5	1947	1961	3
0070	Edwards, George / B	15	60	4.0	1950	1964	3
0071	Augusta / S	10	35	4.0	1928	1952	3
0072	Primrose #3 / U	1	35	4.2	----	1920	4
0073	Calora #2 / U	5	151	6.5	1911	1924	5
0075	Williams #1 / U	1	25	5.5	----	----	5
0076	Meakin / U	1	25	5.5	----	1951	5
0077	Brazil Colliers #2 / U	1	100	4.2	1918	1924	7
0078	Plymouth #1 / U	14	215	3.8	1906	1916	8
0081	Diamond #3 / U	1	72	4.3	1895	1902	8
0085	Crossroads #2 / U	7	0	3.0	----	1952	14
0090	Arvin / S	2	45	2.5	1958	1963	10
0097	Midland / U	5	245	7.0	1901	1907	5
0098	Le Noire / U	5	120	3.8	----	1907	5

ID	MINE NAME / TYPE	CO	DEPTH	THICK	BEGAN	ENDED	SEAM
0101	Hunt & Squire #1 / U	5	30	7.0	1917	1923	3
0103	Smith / S	5	---	4.0	1880	1930	2
0104	Friar Tuck / U	12	85	6.6	1943	1952	3
0301	Comet Stock / U	15	87	4.8	1924	1946	3
0303	Riso / U	8	35	3.5	1940	1941	7
0306	LeMasters, Mary / S	10	80	7.0	----	----	3
0321	Love Brothers / S	8	60	1.5	----	1963	6
0322	Bon Ayr #1 / U	5	127	5.0	1918	1930	4
0324	Crawford #1 / U	14	109	4.5	1921	1933	7
0325	Jackson Hill #5 / U	14	180	5.0	1910	1927	4
0334	White Elephant / U	1	90	4.2	----	1920	4
0337	Vivian #5 / U	1	38	5.0	1904	1914	4
0341	Cummins / S	7	10	3.3	----	1976	11
0349	Victoria / S	15	45	4.0	1956	1964	3
0361	Enoco / U	6	413	6.5	1942	1962	3
0376	West End / U	12	160	5.5	1944	1952	2
0379	Squaw Creek / S	15	50	---	----	----	1
0381	Whitmer / B	15	25	5.0	1909	1921	3
0388	Purity / U	15	101	5.5	1954	1966	3
0390	Riddell / S	1	20	3.0	1963	1969	8
0396	Oakleaf #2 / S	1	25	5.3	1952	1954	5
0400	Ayrshire Pit #1 / S	10	45	2.5	1949	1952	4
0401	Friar Tuck / U	12	85	6.6	1943	1952	3
0403	Latta / B	5	80	3.4	----	----	4
0405	Harris / S	5	35	5.5	1963	1967	3
0411	Goins / U	1	35	4.2	----	1947	4
0419	Turner #1 / S	1	32	7.3	1971	1976	5
0420	Hicks / S	1	---	---	1946	----	8
0428	-------- / S	10	16	5.0	1963	1964	3
0429	Ditney Hill / U	15	97	7.5	1941	1965	2
0431	Continential #1 / U	1	65	4.5	1903	1908	8
0432	National / U	14	183	4.2	1911	1927	3
0433	Crown Hill #4 / U	13	249	4.0	1909	1924	4
0436	Dyer, Issac / S	10	---	---	----	----	3
0437	Harmon, Logan / S	10	---	---	----	----	3
0438	Quinn / S	10	40	5.5	1949	1950	3
0439	Saxton #1 / S	10	30	4.3	1950	1959	3
0440	Selby, Oliber / S	10	---	---	1968	1977	3
0442	Mason / S	10	50	4.5	1959	1962	3
0443	Keller / U	12	90	4.5	1946	1949	2
0444	Miami #6 / U	14	156	5.0	1910	1928	3
0445	-------- / U	15	---	---	----	----	--
0446	Templeton #1 / U	5	120	4.5	1914	1919	4
0447	Black Creek / U	5	150	5.5	1898	1913	4
0448	Hi Grade #1 / U	5	27	6.0	1922	1931	3
0452	Island City / S	5	---	---	----	1937	4
0455	Ficker / S	11	50	2.3	----	1977	10
0456	Hidden Lake / S	1	60	2.7	1975	1977	11

ID	MINE NAME / TYPE	CO	DEPTH	THICK	BEGAN	ENDED	SEAM
0459	Worthington / U	7	0	4.0	----	----	11
0460	Ayrshire / U	10	28	5.0	1881	1901	3
0461	Grays / S	5	14	4.5	1929	1930	2
0463	Victoria #1 / U	5	100	3.8	1905	1918	4
0464	Johnson, Davis / S	10	43	4.0	1907	1921	3
0469	Rupprecht / S	11	35	2.0	----	----	10
0471	Cochron Brothers / U	7	85	2.7	----	----	12
0472	Tecumseh #2 / S	15	40	4.0	1949	1955	3
0474	-------- / U	8	---	---	----	----	--
0475	Ayrshire #4 / U	10	0	4.7	1900	1921	3
0476	Stearley / S	1	18	1.5	1948	1953	9
0479	Hasenour/Sternberg / S	3	28	2.8	1959	1963	10
0480	Buckskin #1 & #2 / U	4	225	6.8	1918	1940	3
0481	Sycamore / S	5	---	---	1958	1977	3
0486	Trupin, John / U	10	30	5.3	1937	1949	3
0494	Polk Patch / S	15	60	7.0	1946	1955	3
0496	Rose Hill / U	5	25	5.0	1914	1924	2
0498	Sponsler #1 / U	5	50	5.2	1906	1910	4
0499	Wick / U	10	60	6.6	1929	1940	3
0500	Patoka / S	10	42	4.6	1939	1956	3
0503	Coxville #3 / U	8	94	6.0	1891	1905	5
0505	Beech #3 / B	10	35	4.0	1920	1922	3
0506	Miami #2/ U	14	55	6.0	1903	1910	5
0507	Mary #3 / U	14	240	3.0	1918	1931	7
0508	Norh Creek #1 & #2 / U	13	550	4.4	1884	1897	3
0509	Standard #1 / S	13	35	5.3	1943	1949	3
0510	Chandler / U	15	120	4.4	1904	1940	3
0511	Wizard #2 / U	14	160	4.3	1911	1922	3
0512	Linton #28 / S	5	55	3.5	1945	1960	4
0514	Victoria #2 / S	5	---	---	----	----	2
0516	Harrison #3 / U	1	82	3.5	1898	1901	8
0520	Brazil Block #1 / U	1	74	4.0	1897	1902	8
0521	Hein #1 / U	14	105	---	1950	----	3
0522	Caledonia / U	15	85	7.5	1894	1905	3
0524	Sugar Creek / U	14	105	6.0	1903	1906	3
0526	Fyring #1 / S	10	61	3.6	----	----	3
0528	Harmon, Logan / S	10	100	3.1	----	----	3
0529	Summit / U	5	95	5.5	1892	1901	4
0532	Rose Hill / U	12	25	5.0	1914	1923	2
0533	Chinook / S	1	46	7.2	1958	1976	5
0536	Turner / S	1	25	5.5	1946	1954	5
0538	Patberg / S	10	15	5.0	1950	1951	3
0542	Black Creek #2 / U	5	65	4.2	1911	1927	4
0547	Davin / U	14	10	6.3	----	1899	5
0548	-------- / U	14	---	---	1933	1935	3
0558	Dewey / U	1	64	3.5	1898	1902	9
0560	Miami #1 / U	14	55	6.0	1901	1909	5
0572	Dugger #1 / U	12	41	5.5	1923	1938	2

ID	MINE NAME / TYPE	CO	DEPTH	THICK	BEGAN	ENDED	SEAM
0573	Chinook #2 / S	1	46	7.2	1945	1953	5
0578	Gough / U	15	42	6.4	1895	1899	3
0579	Big Four #3 / U	15	42	5.0	1909	1921	3
0583	Miami #3 / U	14	92	6.0	1904	1909	5
0587	Francisco #2 / U	4	282	6.5	1922	1935	3
0593	Pearl / U	1	78	7.0	1899	1923	5
0598	Wheatland / U	6	238	5.5	1909	1927	3
0601	Sargeant #1 / U	15	96	4.0	1909	1931	3
0602	Lucia / U	8	134	4.0	1899	1905	7
0604	Hurley / U	10	40	5.0	1950	----	3

APPENDIX D

MINE PROBLEMS AND DATA

ID	PRODUCTION	GLACIAL	TOPO.	ER	AML PROBLEMS
0005	987955	2	230	10	HWB-1
0006	1639932	3	230	4	VO-2, HEF-2
0009	286450	1	490	41	VO-1
0011	24000	2	490	82	VO-1, CS-1
0014	-------	2	260	---	SB-1
0017	637584	2	320	7	VO-1, HEF-1
0018	268844	2	340	18	P-1
0020	-------	3	490	380	P-1
0021	950400*	3	100	39	DH-2
0022	316800*	2	490	26	HWB-2, DH-1
0024	7000000	3	490	14	VO-1, P-1
0027	-------	3	490	---	VO-1, P-1
0028	-------	3	460	437	VO-3
0029	6704745	2	230	9	P-1, PWHC-1
0031	27000	2	230	19	DPE-1, HWB-1, DI-5
0034	1246000	1	230	7	VO-1, DPE-1
0035	1169000	2	340	3	VO-2
0036	1023730	2	460	3	VO-1, DH-1
0039	14236652	1	370	1	VO-1, GHE-1
0040	562525	1	260	2	VO-2
0046	742000	2	490	3	VO-3
0047	10959000	2	100	3	VO-4,S-1,HEF-1,IRW-1
0057	9180*	3	460	495	VO-1, P-1
0058	280000*	2	230	2	VO-1, GHE-1, IRW-1
0060	1141796	2	230	4	VO-1, P-1, GHE-1
0061	4913558	2	230	3	GHE-1
0065	55670	2	490	4	VO-2
0067	16178	3	230	7	VO-2, HEF-3
0068	87012	3	340	6	VO-1, HEF-1
0070	800000*	3	340	8	VO-2, DH-2
0071	1728000*	3	340	15	DH-3
0072	201600*	2	230	14	VO-1
0073	53416	2	340	5	VO-1, P-1
0075	-------	2	260	27	VO-6, P-6, S-1
0076	-------	2	260	28	VO-5, P-3, S-1
0077	397192	2	370	5	VO-1
0078	374000	2	370	2	VO-3
0081	343588	2	370	7	VO-1
0085	-------	3	490	345	P-1, S-1
0090	288000*	2	260	6	DH-1
0097	255225	2	260	4	VO-1
0098	167200*	2	370	4	VO-2, SB-1
0101	448000*	2	230	30	VO-2

ID	PRODUCTION	GLACIAL	TOPO.	ER	AML PROBLEMS
0103	-------	2	490	---	DH-1
0104	15000000	2	340	10	HEF-3
0301	564490	3	340	7	VO-2
0303	-------	1	370	12	VO-1
0306	302400*	3	100	11	DH-2
0321	-------	1	490	11	HWB-1, DH-1
0322	-------	2	340	5	VO-2
0324	107000	2	490	5	VO-1
0325	3560000	2	370	3	VO-1
0334	201600*	2	230	6	VO-2
0337	719829	2	340	16	VO-1
0341	451440*	3	490	38	HWB-1, DH-2
0349	6702101	3	490	11	DPE-6, DH-3
0361	11879478	2	230	2	GHE-1, PWHC-3
0376	178000	2	260	4	DPE-1
0379	-------	3	100	---	DH-2
0381	520000*	3	230	25	VO-18, DH-1
0388	16718	3	230	7	VO-1
0390	3228	2	370	18	DH-1
0396	-------	2	230	26	IRW-1, DH-1
0400	468000	3	340	7	HWB-1, DH-2
0401	15000000	2	340	10	VO-1
0403	23000000	2	230	4	VO-1, DH-1
0405	30000	2	340	20	HWB-1, DH-2
0411	268800*	2	230	15	P-1, S-1
0419	116823	2	370	29	DH-4
0420	-------	2	260	---	DH-1
0428	2880000*	3	340	40	DH-1
0429	9567641	3	340	10	VO-1, P-1
0431	53434	2	370	9	VO-2
0433	1363884	1	490	2	VO-2
0436	-------	2	100	---	DH-2
0437	-------	3	100	---	DH-2
0438	3000	3	100	18	DH-1
0439	1593684	2	100	18	DH-1
0440	-------	3	100	---	DH-2
0442	4502968	3	100	12	DH-1
0443	5000	2	340	6	VO-1
0444	2943000	1	370	4	VO-1, GHE-1
0445	-------	3	340	---	VO-1
0446	187519	2	460	5	VO-2
0447	1919492	2	230	5	VO-2
0448	132730	2	230	29	VO-2
0452	-------	2	230	---	DH-2
0455	99360*	3	460	6	DH-3
0456	38880*	2	370	6	DH-2
0459	-------	3	490	370	VO-13
0460	478643	2	100	23	VO-1

ID	PRODUCTION	GLACIAL	TOPO.	ER	AML PROBLEMS
0461	216000*	2	230	41	DH-2
0463	2188811*	2	230	5	VO-1
0464	507300	2	230	12	PWHC-1, CS-1
0469	115200*	3	490	7	DPE-3, HWB-2, DH-2
0471	-------	3	460	6	VO-1, S-1
0472	4115957	3	340	13	HEF-10
0474	-------	2	490	---	VO-1
0475	1742748	3	100	600	VO-1
0476	194400*	2	260	10	DH-2
0479	32256*	3	230	12	HEF-1
0480	2486000	3	340	4	VO-1
0481	-------	2	340	---	DH-4
0486	212000*	3	100	22	VO-1
0494	43217	3	340	15	DH-1
0496	341504	2	230	25	VO-5
0498	355993	2	230	13	VO-1
0499	1807710	2	100	14	VO-1
0500	7000000	3	370	14	DH-2
0503	888673	2	370	8	VO-1
0505	150000*	3	460	15	VO-2, P-3,DPE-3,DH-5
0506	633000	2	490	13	VO-1, S-1
0507	295000	2	370	2	VO-2
0508	72000	1	370	1	VO-4, P-1
0509	727070	1	490	20	IRW-1, DH-1
0510	457523	3	100	5	VO-2, HEF-1
0511	974000	2	230	3	VO-1, HEF-1
0512	5702118	2	230	8	DH-1
0514	-------	2	230	---	DH-1
0516	34116	2	260	5	VO-4
0520	95442	2	370	7	VO-1, S-1
0521	0	2	230	---	VO-4
0522	140738	3	230	11	VO-2
0524	1246000	1	230	7	VO-3
0526	1658880*	3	100	7	DPE-1
0528	-------	2	100	4	DH-2
0529	598120	2	230	7	VO-1, S-1
0532	236315	2	460	25	VO-9
0533	15356138	2	370	20	HWB-2, DH-1
0536	508110	2	260	27	DH-4
0538	3000	3	340	43	DH-1
0542	1614921	2	230	8	VO-4
0547	-------	2	490	---	VO-1
0548	-------	2	260	---	VO-1
0558	45351	2	490	7	VO-1
0560	942000	2	230	14	VO-2, S-1
0572	616000*	2	340	16	VO-1
0573	1536138	2	260	20	DPE-1