THE HYDROGEOCHEMISTRY OF AN AREA STRIP-MINED FOR COAL, NEAR McCURTAIN, HASKELL COUNTY, OKLAHOMA

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Location

The study area of this investigation includes the McCurtain No. 2 Federal Coal Mine, the Lone Star - Evans Coal Mine, and a nest of wells drilled by the United States Geological Survey (USGS) in 1980 for a study of the hydrology of an abandoned coal mining area. The study area is situated near the city of McCurtain in Haskell County, Oklahoma (Fig. 1). More specifically, the McCurtain No. 2 Mine is located in sections 14 and 15 of T. 8 N., R. 22 E. The Evans Mine is located just north of the McCurtain No. 2 Mine also in sections 14 and 15 of T. 8 N., R. 22 E. The mine areas are located approximately 0.75 miles north of Oklahoma State Highway 31 and 0.50 miles east of Oklahoma State Highway 26. The USGS well site is located in the SE/4 of Section 16 of T. 8 N., R. 22 E. The wells are located approximately 0.50 miles north of Oklahoma State Highway 31 and 0.50 miles west of Oklahoma State Highway 26 (Fig. 2).

The Hartshorne coal beds lie within the Hartshorne Formation, Krebs Group, Desmoinesian Series of the Pennsylvanian System. The McAlester Formation of the Krebs

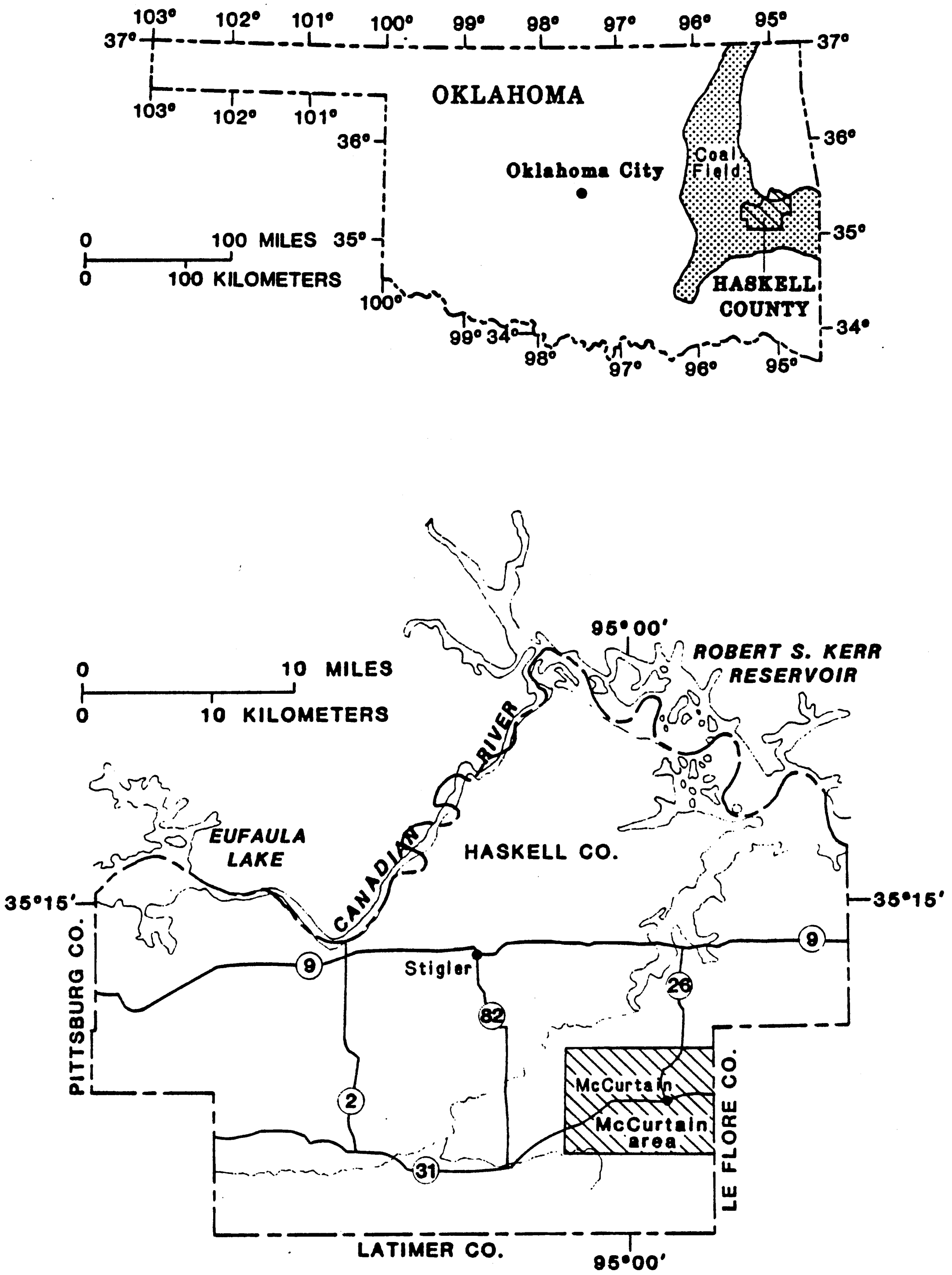

Figure 1. Location of Haskell County and the McCurtain Area

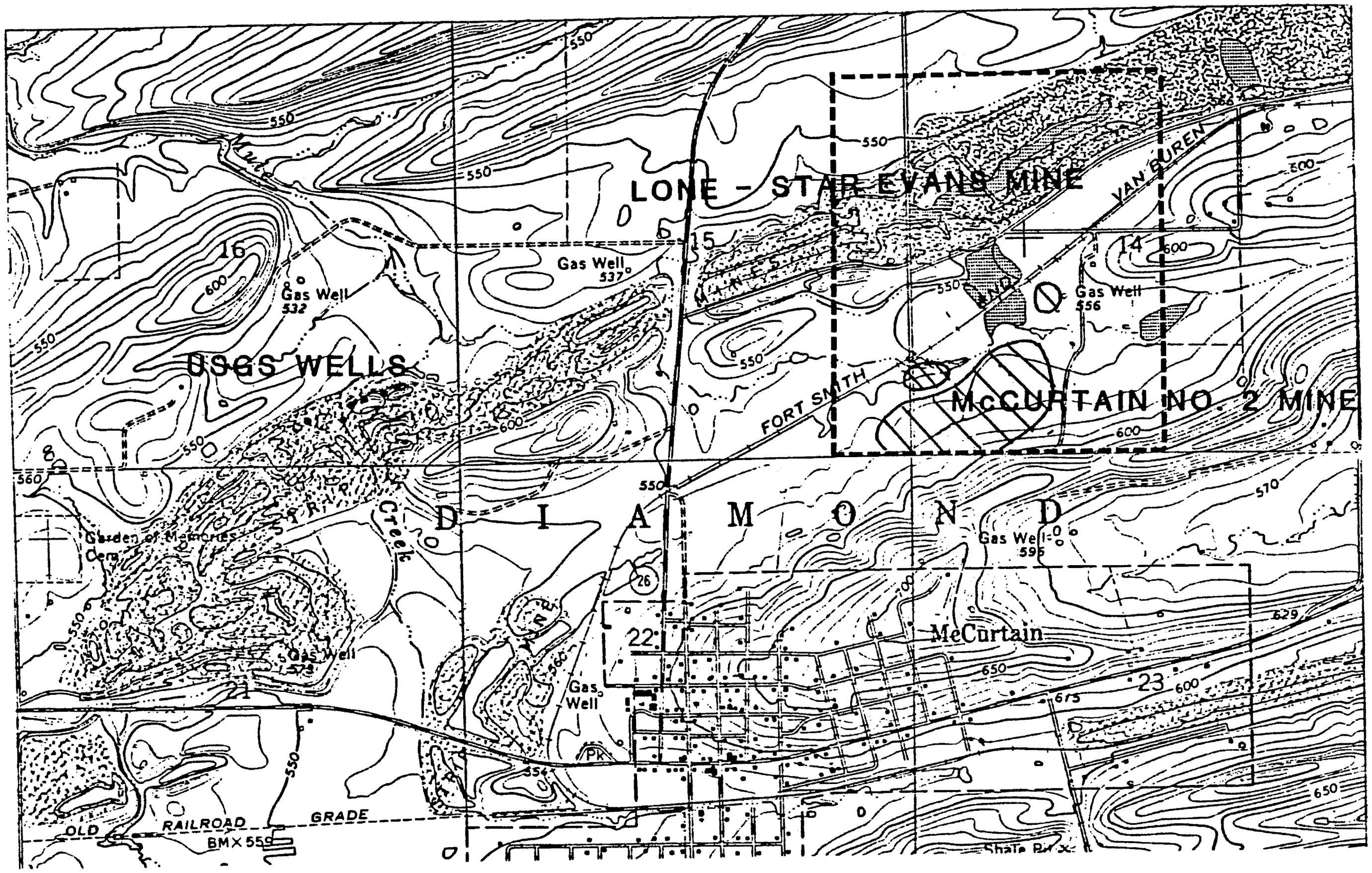

Figure 2. Location of Study Area: Sections 14, 15, and 16 of T8N, R22E

Group is the upper boundary of the Hartshorne Formation; the Atoka Formation of the Atokan Series is the lower boundary. Figure 3 illustrates the stratigraphic sequence of these formations as they occur within the Arkoma Basin.

Statement of the Problem

The principal objective of this investigation is to evaluate the effects of strip mining for coal on water quality. A secondary objective is to determine the geochemical interactions and processes which are occurring to produce the chemical characteristics of waters sampled from the ground-water wells and the coal mine surface pit impoundments.

Previous Investigations

Early investigations of coal resources in the Oklahoma-Arkansas coal basin were by Chance (1890), Drake (1897), and Taff and Adams (1900). Dane, Rothrock, and Williams (1938) described the geology and fuel resources of the southern part of the Oklahoma coal field. The mineral resources and geology of Haskell County were reported by Oakes and Knechtel (1948). Data on the coal resources of Oklahoma were summarized by Trumbull (1957) and Friedman (1974). Catalano (1978) described the geology of the Hartshorne coal in Haskell and LeFlore Counties.

Marcher (1969) described the availability and chemical quality of ground water and surface water in the Fort Smith Quadrangle of east-central Oklahoma. Marcher, Huntzinger,

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	BED
PENNSYLVANIAN	DESMOINESIAN	CABANISS	SENORA		
			STUART		
			THURMAN		
		KREBS	BOGGY	BLUEJACKET SS.	
			SAVANNA		
			McALESTER	WARNER SS.	STIGLER coal
			HARTSHORNE	TOBUCKSY SS.	UPPER HS. coal LOWER HS. coal
	ATOKAN		ATOKA		

Figure 3. Generalized Columnar Section, Arkoma Basin, Oklahoma

Stoner, and Blumer (1982) conducted a preliminary appraisal of the hydrology of the Stigler area in Haskell County. In 1983, a similar study was conducted by Slack on the hydrology of an abandoned coal mining area near McCurtain, in Haskell County. In 1984, Marcher, Bergman, Slack, Blumer, and Goemaat collaberated on an investigation into the hydrology of Area 41 of the western region of the Interior Coal Province (Oklahoma and Arkansas). A subsequent report was published by Slack and Blumer (1984) describing the physical and chemical characteristics of water in coal mine ponds of eastern Oklahoma.

CHAPTER II

PHYSIOGRAPHY AND GEOLOGY

The bituminous coal resources of eastern Oklahoma are in beds of Middle and Late Pennsylvanian age. They occur in an area in the southern part of the Western Region of the Interior Coal Province of the United States (Friedman, 1974). The McCurtain No. 2 and the Lone Star - Evans mines are located in sections 14 and 15 of T. 8 N., R. 22 E. in Haskell County approximately one-half mile north of the city of McCurtain. The McCurtain area is in the McAlester marginal hills geomorphic province (Johnson, et al., 1972) and is in the Arkoma geologic basin.

Topography

The McAlester marginal hills geomorphic province consists of folded rocks which form east-trending anticlines and synclines. The landscape is characterized by irregular hills and ridges capped with erosion-resistant sandstone and covered with scrubby trees and brush. The broad valleys were formed by the weathering and erosion of shales and are vegetated with native grasses, shrubs, wild flowers, and weeds.

The study area is located in sections 14, 15, and 16 of T. 8 N., R. 22 E., in the extreme eastern edge of

Haskell County. The total difference in elevation of the three sections is 134 feet. The surface elevation decreases from east to west and south to north. The stream and surface water runoff of the region flows northwesterly through the valley floors. All topographic features, both erosional and structural, generally trend southwest-northeast as parallel asymmetrical ridges.

The McCurtain No. 2 Mine lies in a small, gently sloping valley bordered on the south by a sharp, east-northeast trending ridge of the Milton anticline; and on the north by the one-quarter mile wide band of the abandoned and unreclaimed Lone-Star Evans Mine. The USGS well site is located in an abandoned mining area directly to west of the McCurtain No. 2 Mine. Four of the wells are located to the east of Mule Creek, Well 5 is located near the stream bed, and Well 6 is located to the west of Mule Creek.

Soils

Soils in the study area near the McCurtain No. 2 Mine are members of the Stigler Series. The Stigler series consists of nearly level or very gently sloping soils on uplands. These soils formed under a cover of tall and mid grasses and scattered hardwood trees in material derived from shale or clayey sediment.

In a representative profile the surface layer is 12 inches of dark grayish-brown silt loam and is strongly acidic (the degree of acidity or alkalinity of a soil, expressed in pH values is illustrated in Table 1). The subsurface layer extends to a depth of 21 inches and is brown silt loam which is also very strongly acidic. The subsoil extends to a depth of 78 inches and is yellowish-brown silty clay. The subsoil is very strongly acidic to medium acidic in the upper part and strongly acidic to mildly alkaline in the lower part. The lowest portion of

TABLE I

DEGREE OF ACIDITY OR ALKALINITY OF A SOIL

	pH
Extremely acid	Below 4.5
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Medium acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Mildly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	9.1 and higher

the subsoil ranges from strongly acidic to mildly alkaline (Brinlee, 1975).

Stigler soils are moderately well drained and have very slow permeability. Available water capacity is high. A seasonal perched water table is at a depth of 12 to 24 inches.

The representative profile of the Stigler silt loam (one to three percent slopes) is located 1800 feet west and 500 feet north of the SE corner of section 15, T. 9 N., R. 19 E. This description is listed in Appendix A.

Soils in the study area near the Lone-Star Evans Mine and the USGS well site are members of the Kanima series. The Kanima series consists of very gently sloping to steep soils on uplands. These soils formed under a sparse cover of trees and grasses in material weathered from shale that was displaced in strip-mining operations.

In a representative profile the surface layer is 6 inches of very dark grayish-brown shaly silty clay loam which is slightly acidic to moderately alkaline. The underlying material is very dark grayish-brown very shaly silty clay loam which is also slightly acidic to moderately alkaline (Brinlee, 1975).

Kanima soils are well drained and have moderate permeability. Available water capacity is low to moderate.

The representative profile of Kanima shaly silty clay loam (one to thirty percent slopes) is located 2100 feet south and 1300 feet west of the NE corner of section 8, T. 10 N., R. 22 E. This description is also listed in Appendix A.

Stratigraphy

Rock units within the study area are included within the Atokan and Desmoinesian Series of the Lower and Middle

Pennsylvanian age (Fig. 3). Pennsylvanian rocks units of the Arkoma Basin make up a thick sequence of shales, siltstones, sandstones, and minor limestones. The Pennsylvanian coal beds occur in the upper portion of the Hartshorne Formation of the Krebs Group of the Desmoinesian Series. The Atoka formation is the lowermost stratigraphic unit present at the surface in the study area. It outcrops in the NE/4 NE/4 SW/4 of Section 14 and continues into Section 22. The formation consists of a 600 - 7000 foot thick series of shales containing four major sandstone intervals averaging about 100 feet each in thickness.

The Hartshorne formation overlies the Atoka formation. It appears at the surface in an area approximately 20 acres in size in the S/2 SW/4 of Section 14. The Hartshorne formation is about 100 feet thick and consists of about 20 feet of firm gray shale overlain by another 20 feet of weathered shale. Two coal beds, the Lower and Upper Hartshorne beds, are present at the top of the formation. The two beds are separated by a few feet of shale in the area and are commonly combined and referred to as the Hartshorne coal (Fig. 4).

The McAlester formation overlies the Hartshorne formation and appears at the surface in the rest of the study area. The McAlester formation is about 2000 feet thick and consists of silty shales containing widely-spaced sandstone units and beds and lenses of coal, limestone, and clay ironstone. The Stigler coal is present in the McAlester formation, lying about 1100 feet

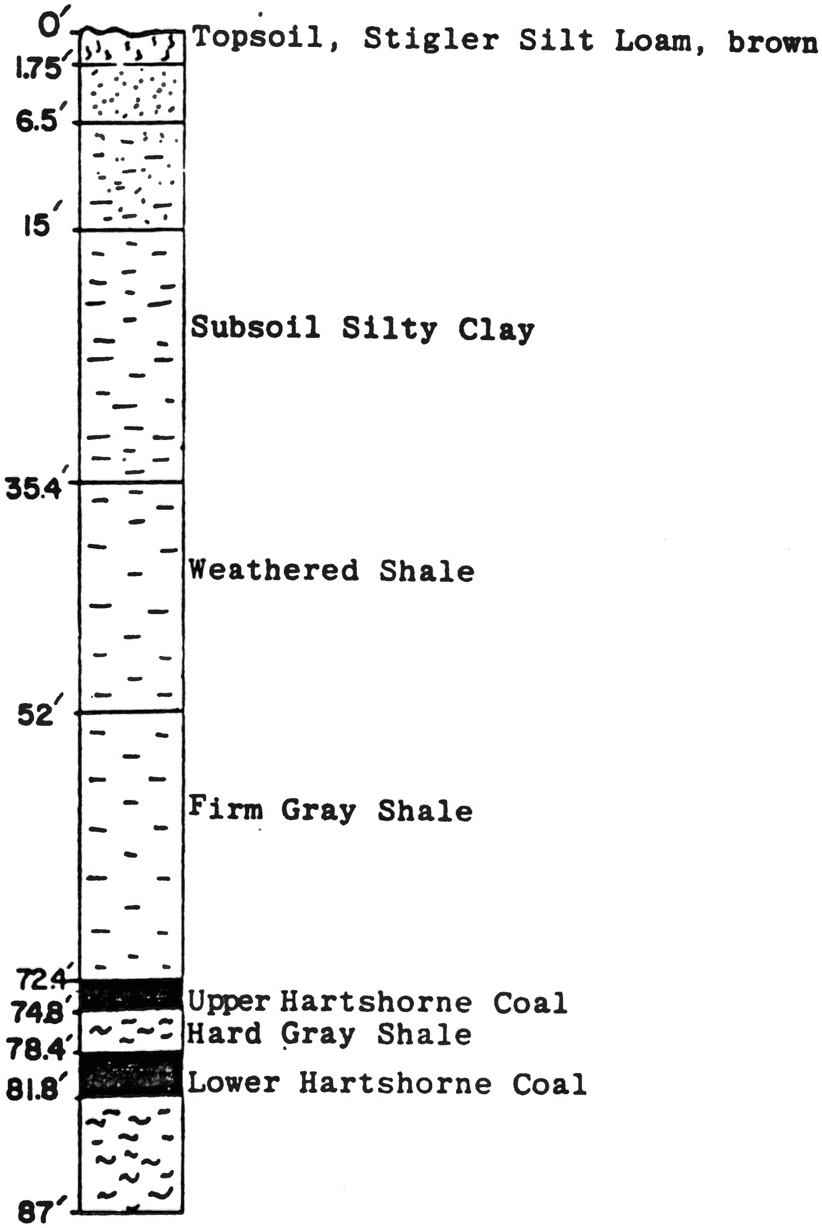

Figure 4. Typical Stratigraphic Column from the McCurtain No. 2 Federal Coal Lease

stratigraphically above the base of the formation. The Stigler coal crops out about 1.5 miles northwest of the study area.

Structure

The study area is located within the Arkoma Basin, which extends from north-central Arkansas to western Coal County in south-eastern Oklahoma (Branson, 1962). The Arkoma Basin is bounded on the north by the Ozark Uplift and the Northeast Oklahoma Platform, on the south by the Ouachita Mountains, and on the southwest by the Arbuckle Mountains (Catalano, 1978).

Stucturally, the study area is a large synclinorium comprised of synclines and faulted anticlines (Iannacchione, et al., 1979). The most prominent synclinal folds in the area include the Cavanal, Panther Mountain, and Sans Bois. Dominant anticlinal axes folds are the Milton, Backbone, and Kinta. There are large displacement faults paralleling the axes of the anticlines. The synclinal and anticlinal axes trend in easterly to northeasterly directions.

The two mines lie on the northern flank of the truncated, southwestward plunging Milton Anticline. Numerous small, closely spaced faults have severely deformed and displaced the strata in the vicinity. Strip mining on land adjacent to the study area has uncovered fault bounded blocks of coal-bearing strata. The Hartshorne coal beds within each block terminate abruptly against the fault planes on all sides of the block and are completely isolated from the main Hartshorne coal beds. Because of the deformation caused by the faulting, the dip of the strata in the the mining area ranges from 5 to 25 degrees.

CHAPTER III

HYDROLOGY

Climate

Precipitation records have been collected at McCurtain for 35 years and temperature records for 22 years. Both, precipitation and temperature records have been collected for 70 years at Eufala (35 miles west of McCurtain). These data are considered representative of the Haskell County climate (Holbrook, 1975).

The area has a warm temperate climate. Spring and autumn are usually mild, summers are hot. Winters are comparatively mild, although the temperature is less than 32F an average of 7 days each year. Temperatures recorded during sampling trips for this study ranged from a high of 108F in July of 1986 to 15F in January of 1987. Average annual precipitation is about 43 inches. On the average, 35% of the year's total moisture falls during the spring, 27% during summer, 23% during autumn, and 15% during winter (Holbrook, 1975). Much of the precipitation results from short duration thunderstorms of varying intensity which commonly occur during April to June, but can occur during any month. The last freeze in the spring occurs around March 30; the first freeze in autumn, about November 4.

Average annual lake evaporation is about 35 inches (Holbrook, 1975). Monthly precipitation data for the period from June 1986 to May 1987 was collected for the McCurtain area. Plots of the average monthly precipitation over time are illustrated in Figures 5 and 6. Precipitation for the study area ranged from a high of 6.98 inches in June of 1986 to a low of 1.52 inches in December of 1986.

Surface Water

The study area lies in the lower Arkansas River Basin. This basin has been subdivided into four segments by the Oklahoma Water Resources Board. The segment No. 220200 is named as the Arkansas River (below the Illinois River). The surface water from the mine area and vicinity flows through a network of ephemeral streams into Mule Creek. Mule Creek is a tributary of Sans Bois Creek which empties into the Robert S. Kerr Reservoir (Fig. 7). The study area is situated within a 757 acre watershed. Surface runoff from this watershed is a function of precipitation, soils, topography, and land use. Estimated streamflow from this watershed is influenced by ponds, which serve as detention reservoirs. Average discharge from this watershed is approximately 1.31 cfs. This amount includes water that runs off into ponds and water which falls on the ponds as precipitation. It also includes 19% of total precipitation as annual runoff, based on Oklahoma measured streamflow records. The closest gaged stream is Sallisaw

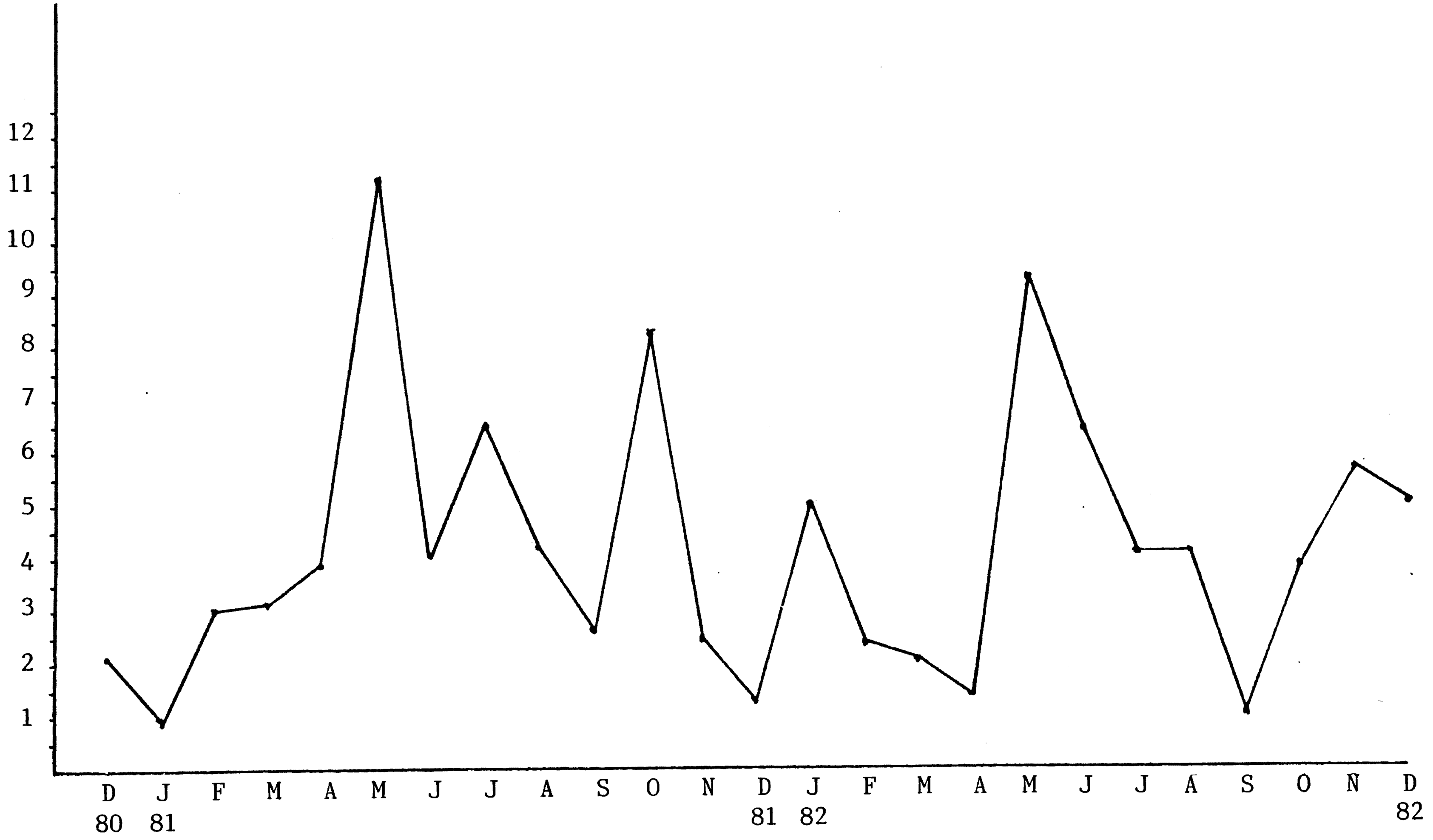

Figure 5. Average Monthly Precipitation for McCurtain, Oklahoma from December 1980 to December 1982 (in inches)

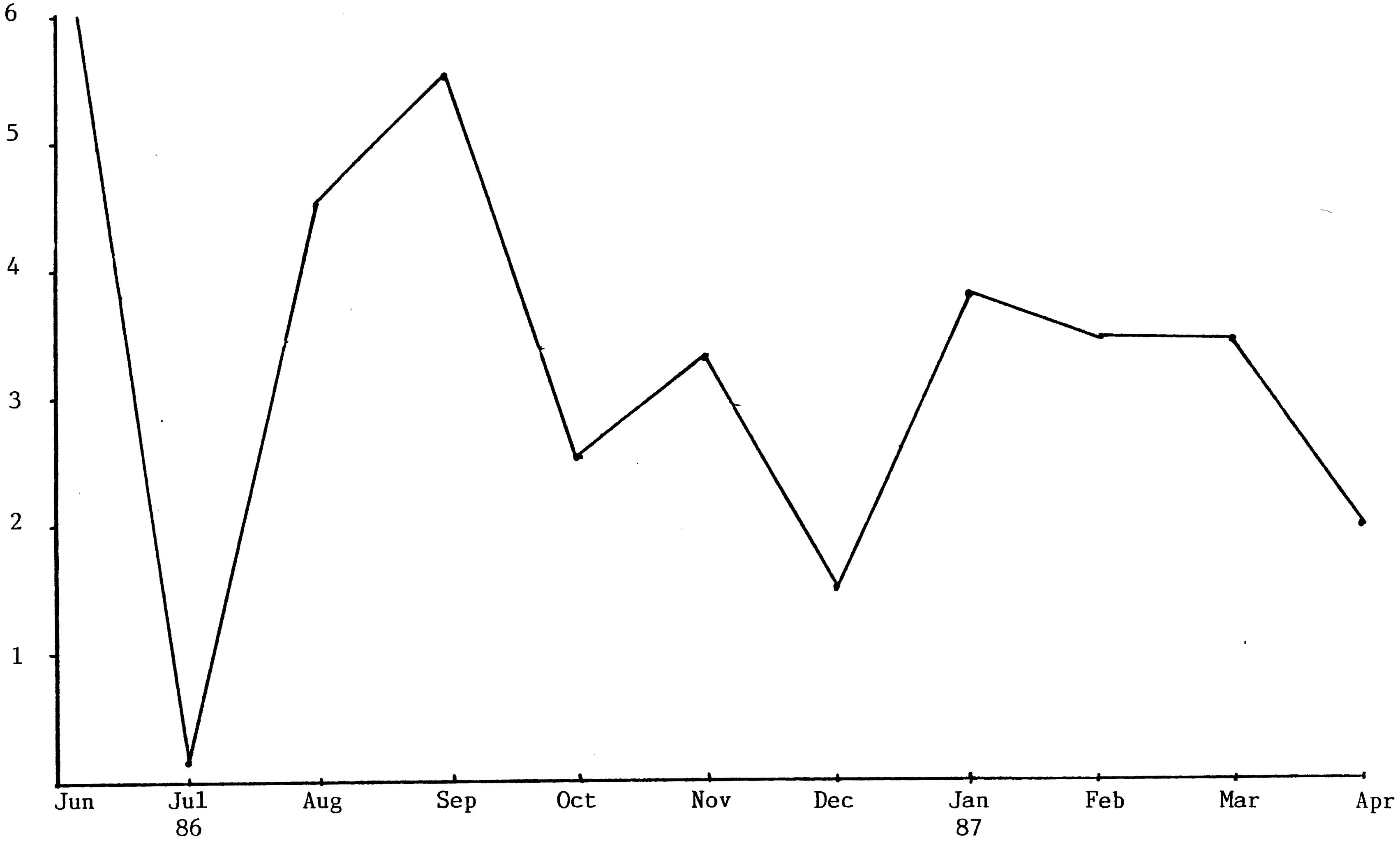

Figure 6. Average Monthly Precipitation for McCurtain, Oklahoma from June 1986 to April 1987 (in inches)

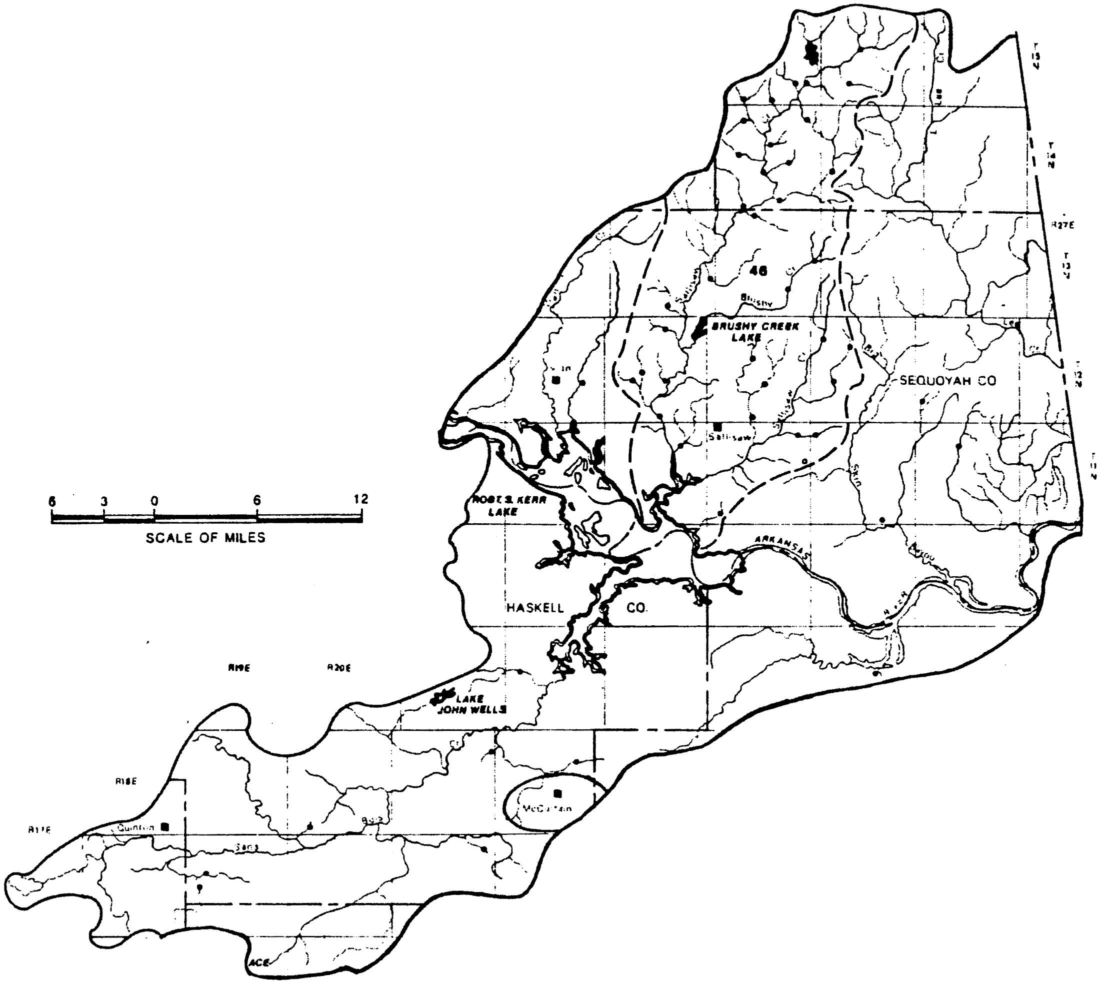

Figure 7. Regional Surface Water Drainage Basin

Creek near Sallisaw, Oklahoma in Section 34, T. 12 N., R. 23 E. Runoff occurs mainly in winter and fall months.

Several surface water impoundments exist within the study area. Surface impoundments at the McCurtain No. 2 Mine are: Basin A, Basin B, Slough, the final Pit impoundment, several small stock ponds, and ephemeral streams. The major surface water impoundments at the Lone - Star Mine area are the final pit impoundments from a succession of mining operations.

Basins A and B are settling basins designed to carry flow from a 10 year - 24 hour rainfall event and provide an inactive capacity of 0.1 acre feet per acre of disturbed area. Basin A is located in the SW/4, NE/4, SW/4 of Section 14, T. 8 N., R. 22 E. The dimensions of this impoundment are: 220' X 225' X 8' = 396,000 ft^3 = 9.1 acft. The effective area of the watershed contributing to discharge in Basin A is 20 acres. Basin B is located in the NW/4, SW/4, SW/4 of Section 14, T. 8 N., R. 22 E. The dimensions of this impoundment are: 500' X 250' X 11' = 1,375,000 ft^3 = 31.6 acft. The effective area of the watershed contributing to discharge in Basin B is 50 acres.

The Slough was created by a road enbankment and beaver dams. The Slough is located in the NW/4, SW/4 of Section 14, T. 8 N., R. 22 E., just to the west of Basin A and is dissected by the Ft. Smith and Van Buren Railroad. This impoundment serves as a catchment basin for water discharged from Basin B during peak storm events and water which runs off from the haul road enbankment. The average depth of the Slough is approximately five feet.

The final Pit impoundment of the McCurtain No. 2 Mine covers an approximate area of 140 acres. The tract of land is located in the S/2, NE/4, SW/4, S/2, SW/4 of Section 14 and SE/4, SE/4 of Section 15 of T. 8 N., R. 22 E. of Haskell County. Surface water depths vary within the impoundment from the shallow shoreline up to 50 feet in depth. The deepest portions of the Pit are located near the central portion of the impoundment.

The Lone Star - Evans Mine is located approximately one-half mile north of the McCurtain No. 2 Mine. The Evans Mine is a one-quarter mile wide band of abandoned, unreclaimed, steepsided spoil piles and strip pits. The Evans Mine extends from the center of Section 15, T. 8 N., R. 22 E. to the NW corner of Section 13, T. 8 N., R. 22 E. in Haskell County. The disturbed area is estimated to be approximately 300 acres in extent. Surface water impoundments within the disturbed area range in depth from the shallow shoreline upto 50 to 60 feet. The mine area directly north of the McCurtain No. 2 Mine in Section 14 is included in this study.

Ground Water

The USGS does not identify any major aquifers above, below, or within the coal seams of the study area. Limited aquifers exist in the fractured shale and sandstone above the coal seams. The occurrence, movement, and storage of ground water in the McCurtain area is largely controlled by the lateral and vertical distribution of rock units and their physical characteristics, especially permeability, and by geologic structure.

Water table conditions exist in bedrock and spoil. Bedrock in the area consists of tilted layers of thick shales, siltstone, and thin sandstone members of the McAlester, Hartshorne, and Atoka Formations. The sandstone members of the formations are usually fine grained and well cemented. Wells completed below the weathered bedrock zone are generally under artesian conditions. The main avenues of recharge to the bedrock are the exposed bedding-plane openings between layers of sandstone, partings between laminae of shale, overburden shattered and broken during surface mining, and fractures and joints developed during folding and faulting of the brittle rocks. Water levels are shallow in private wells in the McCurtain area. Three wells are located on the McCurtain No. 2 Mine property. Water level measurements for these wells are listed in Table 2.

Wells from which the USGS collected data during 1981 and 1982 were assigned site designations based on the grid system of latitude and longitude. The system provides the geographic location of the well and a unique number for each site. The number consists of fifteen digits: the first six digits denote degrees, minutes, and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits identify the wells within a one-second grid.

Four wells were drilled in the spoil piles on the east side of Mule Creek. The wells were drilled by the reverse air rotary method and cased with 4-inch diameter polystyrene: 10-foot sections of slotted casing were placed at the water-producing zone or at the bottom of each well. Well 5 was drilled on a peninsula of land on Mule Creek. A pre-existing well, Well 6, was discovered just north of spoil piles located on the west side of Mule Creek. Well records are summarized in Table 3.

TABLE II

RECORD OF WELLS - MC. 2 MINE

WELL #	LOCATION	WELL DEPTH FEET	DEPTH TO WATER (FEET BELOW LAND SURFACE) 11-2-86	(1-3-87)	(4-18-87)
GW 1	SE,SW SEC14 T8N R22E	76'	4.25'	4.25'	0.25'
GW 2	SE,NE SEC22 T8N R22E	120'	8.5'	9.5'	3.5'
GW 3	W/2, SW/4 SEC 13 T8N, R22E	161'	7.5'	6.75'	4.0'

TABLE III

RECORD OF USGS WELLS 1-6

WELL	DIAMETER (INCHES)	DATE (DRILLED)	WELL DEPTH (FEET)	LENGTH OF CASING (FEET)	SCREENED INTERVAL (FEET)	DEPTH TO WATER (FEET BELOW LAND SURFACE)
1	4	11-10-80	45	43	33 - 43	39-74
2	4	11-11-80	160	100	40 - 50 90 - 100	31.05
3	4	11-13-80	138	138	128 - 138	50.65
4	4	11-12-80	80	62.5	42 - 62	55.28
5	4	11-13-80	41	37.5	17 - 37	11.50
6	14	---	113	9	0	12.00

(USGS, 1982)

CHAPTER IV

COAL

Hartshorne Coal

The Hartshorne coal is stratigraphically the lowest exploited coal bed in Oklahoma for which resources have been determined. It is at the base of a 5,500 feet thick sequence of shales, sandstones, and thin coals in the Arkoma Basin. This coal is present at the top of the Hartshorne Sandstone of the Krebs Group, Desmoinesian Series, Pennsylvanian System.

At the southern edge of the coal region in Oklahoma the Hartshorne coal commonly is split into two beds by shale and sandstone 5 to 100 feet thick. These beds are known as the Upper and Lower Hartshorne coals, and they have been mined extensively. Both the Upper and Lower Hartshorne are present in the study area. The coal beds are approximately 40 to 26 inches thick, respectively, and are separated by approximately 26 to 84 inches of firm gray shale (Fig. 4). The beds dip to the northwest from 5 to 25 degrees.

The Hartshorne coalbed is a high-volatile, A-bituminous to medium-volatile bituminous coal, based on standards of the American Society for Testing and Materials

(ASTM) (Averitt, 1974). The Lower Hartshorne coalbed contains 0.4 - 5.1% sulfur and averages 1.0% raw (Friedman, 1974). The Upper Hartshorne coalbed contains 0.8 - 2.6% sulfur and averages 1.6% raw (Friedman, 1974). According to Catalano (1978), most of the Hartshorne coal in the study area contains less than 3% sulfur and is thus classified as intermediate (1-3%) and low sulfur (>1%) coal.

The sulfur content of coal is influenced by the depositional origin of the coal as well as by the diagenetic and post-diagenetic changes affecting the coal beds. Iannacchione (1979) proposed that the complex layers of coal, shale, siltstone, and sandstone sediments of the Hartshorne formation are part of a prograding deltaic complex that contains a distributary channel system, levee and overbank deposits, interdistributary bay sediments, crevasse splays, and peat swamps. In addition to the depositional environment and diagenetic changes, deep-lying bituminous coal beds tend to contain less sulfur than shallow-lying coal beds (Friedman, 1974).

Mineralogy of Coal

More than 95% of inorganic components of coal consists of five minerals: kaolinite, illite, calcite, pyrite (marcasite), and quartz (Bouska, 1981). Williams (1978) described the macroscopic accessories of the Lower Hartshorne coal as pyrite, shale, and calcite. Pyrite generally occurs as lenses, fine particles, in cleats, and occasionally in bands. Carbonaceous shale is present from distinct shale bands to a boney-coal-shale mixture. Calcite is described as rare and is found in the cleats. All coals, when burnt, leave some mineral residue known as ash. More than 95% of coal ash is formed by Al_2O_3, SiO_2, Fe oxides, and CaO. The remaining 5% is Mg, Na, K and Ti oxides and chlorides, sulfates, and phosphates of common elements (Bouska, 1981). A genetic classification (Svoboda and Benes, 1955) divides the inorganic substances found in coal as (a) internal ash matter (primary, proper) and (b) external ash matter (secondary, free). The first group is comprised of particles present in original plant bodies and trace elements of plants. The external ash matter is divided into syngenetic and postgenetic (Benes, 1954). Clayey and siliceous substances, pyrite, marcasite, siderite, ankerite, and other carbonates are syngenetic. They were formed during the cumulation of inorganic substances from dissolved salts, products of the decomposition of minerals transported into the peat bog from its environs, and products of the decay of organic substances such as carbonic acid. The postgenetic minerals originated mainly from later mineral solutions and from incrustations of fissures and joints in the adjacent rocks. Post genetic minerals are as follows: pyrite, marcasite, galena, sphalerite, arsenopyrite, halite, various sulfates, phosphates, and chlorides. FeS_2 usually forms during diagenesis by the reduction of sulfates by organic substance. Pyrite is the form of FeS2 usually associated with bituminous coal and anthracite (Bouska, 1981).

Generally, the higher the ash content in coal, the larger the amount of SiO2 and Al2O3 present. The composition of ash approaches the composition of the adjacent rocks with the increasing ash content in the coal. Hildebrand (1981) of the USGS, published a report on the chemical analyses of coal from the Krebs Group, Arkoma Basin, eastern Oklahoma. This report included samples of coal from the study area. Ash content for the Upper and Lower Hartshorne coalbeds ranged from 2.2 to 5.1%. This is consistent with analyses published by Catalano (1978), ash content of the Hartshorne coals from the study area ranged from 2.1 to 4.3%. Forms of sulfur identified from representative samples (Hildebrand, 1981) were sulfate, pyritic, and organic.

CHAPTER V

SURFACE MINING

The presence of coal in Oklahoma has been known since at least 1921, when Thomas Nuttall's journal of several excursions across the coalfield was published. Mining on a commercial scale did not begin until the Missouri-Kansas-Texas Railroad was built through McAlester in 1872 (Trumbull, 1957). Production of strip mining was not important in Oklahoma before 1920, when only 5% of the total state production was mined by that method.

Strip Mining Techniques

The surface mining operation consists of removing the topsoil and overburden by the cutting of successive trenches to expose the coal seam. The first cut is made at an outcropping seam in hilly terrain, or at the limit of the mine perimeter in level terrain. The overburden from the first cut is piled on the ground next to the area to be stripped (Fig. 8). In Oklahoma stripping regions, a large shovel and dragline work in parallel-tandem operations. In this type of operation the dragline removes most of the overburden, and the shovel actually exposes the coal seam. After the coal is drilled and blasted it is hauled off for washing and treatment prior to shipment to market.

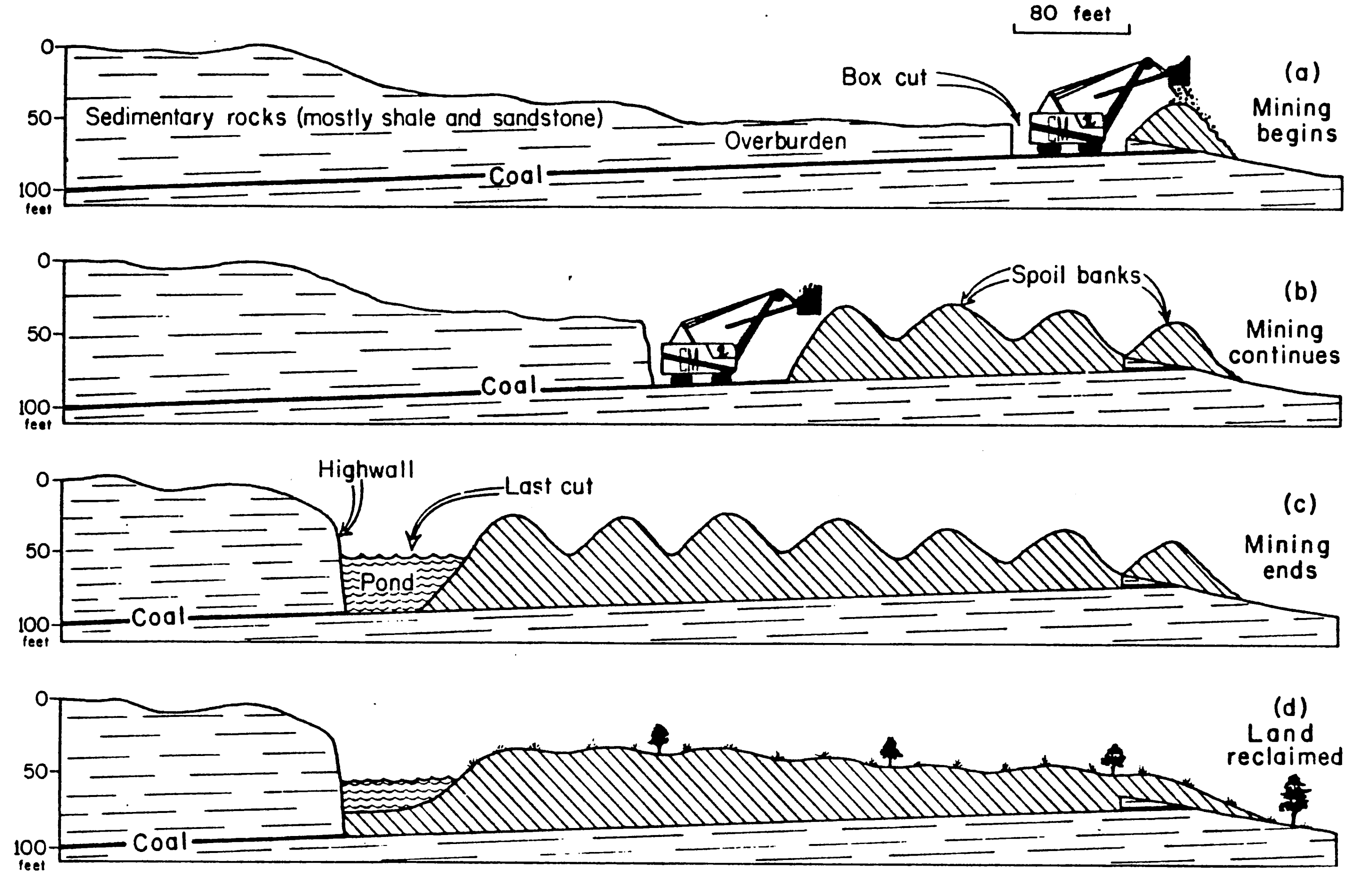

Figure 8. Stages of Surface Mining of Coal

The dragline operates continuously. At the end of the first cut, the direction is reversed, and a new cut is made parallel to the first. The overburden from this new cut is dumped into the cut from which the coal has been removed. This repetitive cut-and-fill sequence continues until the overburden thickness becomes so great that the coal can no longer be mined profitably.

Characteristics of Strip Mined Areas

Strip mining typically leaves the surface topography in a series of approximately parallel ridges and valleys. Disposal of the overburden alters the terrain more than is at first apparent because the spoil occupies a greater volume than did the original overburden (Doerr, 1961). Spoil actually covers a greater area than the total land area stripped.

Most Oklahoma pits are long and narrow. Coal strip mines on the contour in steeply dipping seams of the southern part of the Oklahoma coal province may be less than 100 feet in width, and many are less than 200 feet. Most of the stripped areas in southern Oklahoma are curvilinear in plan, because they follow the outcrop contour in an area. Continuous pits may be upto nine miles in length.

Soil textures and structures on exposed spoil are inferior to original topsoils. Various percentages of toxic materials may be present in the spoil, although generally lower pH readings are encountered in the northern part of the Oklahoma coalfield (Doerr, 1961). Widely varying soil conditions (both physical and chemical characteristics), climate, orientation of spoil ridges, steepness of slopes, presence or absence of toxic substances, and seed sources, all play a part in determining the rate of revegetation and the type of vegetation which succeeds in a given area.

Generally, weeds and grasses will appear in fresh spoil almost immediately, although some spoils are so toxic that they frustrate revegetation attempts for as long as five years or more (Doerr, 1961). Given a sufficient length of time, revegetation will proceed rapidly and excellent forests may develop. In the southern and eastern parts of the Oklahoma coalfield, forests are dominant, with oak, hickory, elm, hackberry, pine, dogwood, redbud, and walnut as the significant species. Normal replanting is the most efficacious method of achieving quick cover and a quality product.

One of the most significant features of strip mined areas is the presence of surface water impoundments in the last cut. The final cut leaves an open trench bounded by the last spoil pile on one side and the undisturbed highwall on the other. The final cut and other depressions partly fill with water from precipitation and ground-water seepage. These lakes are characteristically long and narrow and are usually always present. Depths of the lakes vary, but the typical strip pit lake is steep sided and deep.

The ultimate fate of all strip pit lakes is filling. The normal marsh ecological succession is speeded by slumping and wash from adjacent spoil. The scarcity of minerals useful to planktonic organisms restricts their growth and most waters are quite clear. Sunlight penetration to depths fosters the growth of bottom-rooted aquatic plants and filling is accelerated (Doerr, 1961).

Surface Mining and the Hydrologic Balance

Hydrologic balance is defined as the relationship between the quality and quantity of water inflow to, water outflow from, and water storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake or reservoir (Curtis, 1979). It encompasses the dynamic relationships among precipitation, runoff, evaporation, and changes in ground and surface water storage.

Disturbance of land during surface mining can have a significant effect on the water resource. A readily apparent change in the hydrologic system is the creation of additional water storage in the last mine cut. In addition to increasing the storage of water in mine ponds, other changes in the hydrologic system include changes in permeability and ground-water storage, changes in runoff and streamflow characteristics, changes in drainage patterns, changes in the chemical quality of water, and changes in the sediment loads of streams.

Overburden in the southern part of the Oklahoma coal field consists mainly of shale with some siltstone and sandstone; these rocks have minimal porosity and permeability. During mining, however, the overburden is broken and shattered to form spoil with many openings that may facilitate the entry, movement, and storage of water. Water stored in the spoil may move into adjacent bedrock, be slowly discharged to streams, and be used by plants. The volume of water entering the spoil is partly controlled by the permeability of the surface and near-surface material. Where that material consists of silt and clay, openings in the spoil may be plugged preventing or limiting the volume and rate of infiltration.

Observations in various parts of the Oklahoma coal field show that if appropriate reclamation procedures are used and climatic conditions are favorable, grasses on reclaimed spoil may be more lush and have denser growth than the original native vegetation. This denser plant growth tends to retard overland storm runoff so that it has more time to infiltrated into the soil and, as a consequence, less water reaches streams during times of normally high runoff. Conversely, water stored in the spoil, under some circumstances, may be slowly released to streams thereby sustaining streamflow during dry periods. The overall resulting change in streamflow would be to decrease peak discharges and to extend periods of low flow. Streamflow characteristics also may be affected by interception of runoff in mine ponds and depressions left in the reclaimed areas. In the study area, drainageways in parts of Sections 14 and 15, T. 8 N., R. 22 E. have been disrupted by mining and reclamation so that some of the overland flow is intercepted before it can reach Mule Creek. To prevent storm runoff from entering surface pits during mining operations, some diversions of stream channels may be necessary.

Minerals in the overburden and coal are in equilibrium with their environment as long as that environment is not changed. Mining, however, disturbs that equilibrium and the minerals react with various chemical components of their new environment such as water, oxygen, and plant acids. For example, pyrite, which is commonly associated with coal, reacts with water and oxygen to release iron and sulfate and to increase the acidity of the water. Other chemical reactions may result in the release of various trace elements, such as lead, copper, and zinc that may be present in the coal. As a consequence of these reactions, new and generally undesirable chemicals may be added to the hydrologic system.

Disruption of the land surface during mining and before the spoil is fully reclaimed will increase the quantity of sediment available to streams. However, if appropriate mining practices are followed, such as the use of settling ponds, the quantity of sediment added to streams can be decreased.

CHAPTER VI

METHODS AND MATERIALS

Data Sources

Data on the water quality of the McCurtain No. 2 Coal Mine and the Lone-Star Evans Coal Mine were obtained from actual sampling of the surface water impoundments on-site. These data consist of 33 chemical analyses from 5 surface water impoundments. A summary of these data are listed in Table 4. Data on the water quality of the USGS ground-water wells were obtained from published data supplied by the US Geological Survey. These data consist of 56 chemical analyses from 6 ground-water wells drilled in 1980. A summary of these data are listed in Table 5.

Sampling Procedures

Sampling of the surface water impoundments was conducted four times during the study period: July 1986, September 1986, January 1987, and April 1987. These sampling trips roughly coincided with seasonal climatic changes. Thermal stratification was evident in the pit impoundments of the McCurtain No. 2 and the Lone-Star Evans mines. Since a temperature gradient was present, the pit impoundments were sampled at staggered intervals. The

TABLE IV

CHEMICAL ANALYSES OF SURFACE WATER FROM McCURTAIN NO. 2 AND LONE-STAR EVANS MINES

McCURTAIN NO. 2 MINE PIT - 10 FEET

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
7-19-86	30	400	7.9	123	23	30	2	5	320	460	.06	<.01	---
9-13-86	25	1000	7.8	121	24	37	2	4	214	489	.06	<.01	---
1-3-87	5	800	7.2	181	58	56	0.2	6	229	547	<.01	<.01	---
4-18-87	1250	8.1	6.6	48	48	46	0.2	8	214	430	<.01	<.01	---

McCURTAIN NO. 2 MINE PIT - 20 FEET

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
7-19-86	23	990	7.0	176	30	56	2	6	540	631	.08	<.01	---
9-13-86	20	1200	6.9	200	31	58	2	6	336	726	.06	.29	---
1-3-87	5	1000	7.5	184	58	55	0.2	7	259	548	<.01	<.01	---
4-18-87	13	1250	8.0	181	54	50	0.4	8	244	451	<.01	<.01	---

TABLE IV (Continued)

McCURTAIN NO. 2 MINE PIT - 35 FEET

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
7-19-86	19	2200	6.8	323	45	76	3	9	714	1222	.07	2	2
9-13-86	16	2600	6.4	390	47	179	4	9	702	1586	.51	3.8	3
1-3-87	6	1800	6.8	226	76	72	.02	7	580	687	<.01	.09	1
4-18-87	13	1600	7.7	214	64	59	0.5	10	351	558	<.01	.31	0.3

McCURTAIN NO. 2 MINE POND A

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
7-19-86	31	360	5.9	11	34	10	2	7	160	171	.07	.55	2
9-13-86	26	260	6.0	9	31	7	2	5	52	126	.05	0.6	1
1-3-87	4.5	300	4.9	17	38	18	0.4	5	61	171	<.01	.01	1
4-18-87	25	345	7.9	14	34	17	1	3	61	143	.01	.07	0.1

TABLE IV (Continued)

McCURTAIN NO. 2 MINE POND B

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
7-19-86	32	400	7.5	131	26	34	2	7	359	487	.07	<.01	1
9-13-86	28	900	7.8	114	23	37	2	6	168	517	.07	<.01	0.3
1-3-87	4	540	7.2	164	52	50	0.2	7	244	507	<.01	.01	0.2
4-18-87	25	1165	8.1	165	48	45	0.4	7	336	419	<.01	<.01	---

McCURTAIN NO. 2 MINE SLOUGH

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
7-19-86	32	700	6.5	15	32	7	2	10	198	73	.09	.38	4
9-13-86	25	230	6.1	10	27	7	2	4	76	77	.18	.55	4
1-3-87	4	220	6.1	8	31	13	0.3	8	92	105	<.01	.01	0.6
4-18-87	25	220	8.3	9	21	11	0.1	3	76	69	.06	.02	0.6

TABLE IV (Continued)

LONE STAR-EVANS MINE PIT - 5 FEET

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO$_3$ (mg/l)	SO$_4$ (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO$_2$ (mg/l)
913-86	25	1000	7.3	225	43	55	2	3	458	647	.04	.06	---
1-3-87	6	900	7.8	299	106	77	0.2	7	540	730	<.01	.09	---
4-18-87	19	900	8.0	117	53	33	0	7	259	297	<.01	.04	1

LONE STAR-EVANS MINE PIT - 20 FEET

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO$_3$ (mg/l)	SO$_4$ (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO$_2$ (mg/l)
9-13-86	17	1500	6.8	287	45	81	2	5	564	917	.07	2.9	---
1-3-87	7	1000	7.7	289	106	76	0.2	7	568	726	<.01	.09	---
4-18-87	13	1400	7.7	183	73	47	0.1	8	381	439	<.01	.04	1.5

LONE STAR-EVANS MINE PIT - 35 FEET

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO$_3$ (mg/l)	SO$_4$ (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO$_2$ (mg/l)
9-13-86	16	2000	6.7	377	45	114	2	5	717	1144	.26	4.1	---
1-3-87	8	1250	6.9	333	119	88	0.2	7	656	870	<.01	.33	4
4-18-87	12	1700	7.7	248	89	60	0.1	9	488	536	<.01	.17	2.1

TABLE V

CHEMICAL ANALYSES OF GROUND WATER FROM USGS WELLS 1-6

350943094585701 WELL 1

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
1-27-81		3420	6.8	590	120	120	6	21	793	1100	.45	3.1	12
4-6-81		3590	7.2	590	210	180	7	27	659	1900	.19	3.3	46
5-6-81		---	---	660	220	220	7	20	683	2300	.40	1.1	10
6-23-81		---	7.2	600	210	220	5	8	244	2400	---	---	5
9-10-81		4000	7.4	630	190	200	7	21	610	1900	.19	1.2	12
12-2-81		4200	6.9	560	210	210	6	11	512	2100	.05	2.4	9
3-24-82		4700	6.8	690	270	310	6	6	305	3100	.17	1.4	5
6-23-82		3000	7.4	420	160	170	4	26	295	1700	.03	.61	5
12-1-82		3900	7.6	430	230	260	5	5	277	2200	.04	.29	4

TABLE V (Continued)

350943094585901 WELL 2

DATE	TEMP (C^o)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
12-23-80		2060	7.8	520	70	45	6	170	561	690	---	---	13
2-20-81		2800	8.0	680	22	9	2	95	744	840	.13	.31	11
4-8-81		2300	7.7	600	19	7	2	72	708	650	.32	.31	47
5-6-81		---	---	610	19	9	2	86	720	730	---	---	10
6-23-81		2500	7.9	580	16	6	2	78	695	620	.71	.23	11
9-9-81		2000	7.5	380	42	27	2	71	634	450	.02	.81	13
12-2-81		2800	7.4	620	16	5	2	96	720	680	.04	.18	11
3-23-82		7600	7.4	550	18	7	2	84	683	590	1.3	.18	10
6-23-82		3300	7.1	460	54	43	2	150	601	640	.03	1.7	12
9-2-82		3300	7.2	560	33	19	3	84	627	730	1.0	.61	9
12-1-82		3100	8.0	670	15	7	2	110	723	820	.47	.26	10

TABLE V (Continued)

350941094590301 WELL 3

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO (mg/l)	SO (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
2-18-81		2760	7.4	530	62	42	2	89	561	950	.29	.30	7
4-8-81		2500	7.5	540	67	41	2	90	427	940	.45	.34	6
5-6-81		---	---	600	64	4	2	76	537	860	---	---	6
7-9-81		2500	7.5	460	76	49	2	94	537	840	.41	.55	7
9-9-81		2800	7.6	510	75	62	3	60	525	1000	.48	.34	6
12-3-81		2700	7.5	460	76	52	3	120	464	810	.53	.54	7
3-23-82		2700	7.2	460	77	56	2	130	390	880	.03	.77	7
6-23-82		2400	7.0	450	70	49	2	120	550	710	.02	.93	9
9-2-82		3000	7.0	500	73	48	2	160	540	780	.08	.56	7
12-1-82		3000	8.0	240	92	82	2	30	510	660	1.2	3.4	12

TABLE V (Continued)

350941094590601 WELL 4

DATE	TEMP (C^o)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
4-7-81		2010	7.0	330	80	70	2	46	647	560	.03	.91	18
5-6-81		---	---	610	120	110	3	30	781	1300	---	---	12
7-9-81		2125	7.2	330	69	60	2	53	476	650	.02	.76	19
9-10-81		3150	7.4	500	86	85	2	36	671	980	.10	.62	11
3-24-82		3200	7.0	560	95	100	2	29	720	1200	.07	.51	10
6-23-82		2700	7.3	570	89	92	2	28	744	1200	.03	.47	11
9-1-82		3000	---	480	74	72	2	60	860	700	.02	.68	11
12-1-82		2800	7.3	450	89	94	2	33	429	1100	.03	.48	11

TABLE V (Continued)

350939094590501 WELL 5

DATE	TEMP (C^o)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
1-28-81		2500	7.5	400	42	47	2	42	512	720	.10	.46	11
2-19-81		2530	7.4	440	49	56	2	49	573	880	.02	.29	10
4-8-81		2250	7.6	440	44	46	2	44	561	720	.20	.22	39
5-6-81		---	---	420	44	56	1	44	561	820	---	---	10
7-9-81		2450	7.1	440	66	51	2	66	512	800	.04	.17	10
9-8-81		2450	7.6	430	50	56	1	50	573	780	.07	.27	10
12-2-81		2500	7.0	460	64	57	2	64	586	870	.01	.23	11
3-23-82		2370	7.4	400	55	49	2	55	500	710	.03	.31	9
6-24-82		2300	7.3	450	54	68	2	54	555	850	.08	.95	11
9-1-82		2900	---	450	68	60	3	68	693	720	.30	1.7	11
12-1-82		2400	7.3	440	93	45	2	93	600	680	1.1	.93	11

TABLE V (Continued)

350938094591201 WELL 6

DATE	TEMP (C°)	SPEF. COND. (UMHOS)	pH (STANDARD)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO_2 (mg/l)
3-2-81		2600	7.4	460	78	58	2	120	512	840	3.6	.19	6
4-7-81		2500	7.4	450	79	55	2	110	525	770	.06	.22	6
7-9-81		2500	7.5	440	92	67	3	120	561	840	.16	.25	6
12-3-81		2550	7.1	420	93	67	3	170	464	770	<.01	.24	6
3-24-82		1700	6.8	220	37	23	2	23	354	360	1.3	.73	14
6-24-82		1300	7.2	200	26	15	1	7	342	270	.02	.60	14
9-1-82		3300	7.2	470	100	68	2	190	443	850	.06	.76	6

sedimentation ponds and the slough were shallow (depths less than 5 feet) and no thermal stratification was observed. Therefore, only one surface water sample was taken from these impoundments for analysis during each sampling trip. The sampling routine was accomplished by launching a flat-bottomed boat into the pit impoundments. The pits were surveyed using sonar to aid in locating the deepest sections of the last cut. Once these areas were located, landmarks were identified in order to return to the approximate locations during subsequent sampling trips. The same procedure was used to locate the deepest portions of the sedimentation ponds and the slough.

One liter samples of surface water were collected from surface water impoundments in the study area for analysis of major ions. The samples were obtained by using an acrylic Kemmerer sampling bottle. The sampler was lowered to depths of 35, 20, and 10 feet for the McCurtain No. 2 pit; and to depths of 35, 20, and 5 feet for the Lone-Star Evans pit. The sedimentation ponds and the slough were sampled using the Kemmerer bottle at depths of approximately 3 feet.

Methods used in this study were conducted according to EPA standards and methods (1983). Once a sample was obtained, one liter of water was transferred into an acid-rinsed Nalgene collection bottle with an attempt to exclude all head space. One hundred milliliters of sample was reserved in order to analyze for the following field parameters: bicarbonate, pH, conductivity, and temperature.

After the field parameters were recorded, the sample bottles were placed on ice for preservation during transportation to the laboratory.

Approximately one quart of bottom sediment samples were obtained from each of the surface water impoundments at the approximate location where the water samples were taken. This was accomplished with the use of a brass Ekman dredge. The sediment samples were placed in glass Bell jars and placed on ice for preservation during transportation to the laboratory.

Upon arrival at the geochemical laboratory at Oklahoma State University, both the surface water and bottom sediment samples were refrigerated at 4°C for preservation according to EPA protocol (EPA, 1983). The samples were refrigerated no longer than the eight day holding period allowed by the EPA before the filtering process was initiated.

Sample Preparation

The water samples were taken from the refrigerator and filtered using a .45um Millipore filtering system to remove any sediment which may have been in suspension. The filtered samples were then transferred into clean acid-rinsed Nalgene bottles. Approximately one milliliter of concentrated HCl was added to the samples for preservation.

Bottom sediment samples were placed on plastic plates beneath a vented hood in order for the muck to dry. Once the samples were dried, they were powdered in a Spec-mill and ground down by hand with a mortar and pestle. The finely powdered specimens were mounted for bulk powder analysis by x-ray diffraction. Additional powdered samples were added to 250 ml of Calgon dispersent and placed in a shaker unit for 24 hours. The samples were then placed in 1000 ml graduated cylinders with double-distilled deionized water and thoroughly mixed. Once mixed, the cylinders and their contents were not disturbed for 18 hours. After the 18 hour settling period, the top 250 ml clay fractions of the sample-dispersent-water mixture were drawn off and collected. These fractions were used as slurries for clay mount production. Porcelain plate chips were mounted in a vacuum filtering system. Water and glass slivers were frosted onto the chips. The clay slurries were then added to the chip and the excess slurry was vacuumed off. One molar CaCl2 was filtered onto the chips as a sealant. The clay mounts were then allowed to dry for analysis by x-ray diffraction.

Sample Analysis

The surface water samples from the first two sampling trips (July and September, 1986) were analyzed by the Water Quality Research Laboratory at Oklahoma State University. Concentrations of the major cations sodium, calcium, magnesium, and potassium; and the minor trace elements of iron and manganese present in the samples were detected by the use of the Perkin-Elmer 5000 atomic absorption spectrometer. The water samples were then sent to the

Agronomic Services Laboratory at Oklahoma State University for the analysis of the two major anions chloride and sulfate. The ion chromatograph was utilized in the analysis of chloride. The inductively coupled plasma was utilized in the analysis of sulfate.

The surface water samples from the last two sampling trips (January and April, 1987) were sent to the Agronomic Services Laboratory for analysis. Concentrations of the major cations, trace elements, and the anion sulfate were determined by the use of the inductively coupled plasma. Concentrations for chloride were determined using the ion chromatograph.

Bulk powder and clay mounts of the bottom sediment from the impoundments were run on a Nicolet L11 Computerized Powder Diffractometer. The results from this analysis are listed in Table 6. X-ray diffraction patterns are presented in Appendix B. Minerals identified by x-ray diffraction from spoil-pile cuttings from USGS wells 1-6 are listed in Table 7.

Methods of Data Evaluation

Primary constituents of the waters sampled were analyzed graphically by means of a Piper diagram (Piper, 1944). A microcomputer version of Factor Analysis was utilized in order to determine the relationship among the large number of variables involved in the water analyses. The FORTRAN IV version of WATEQ, WATEQF (Plummer et al., 1976) was used to calculate the equilibrium distribution of

TABLE VI

MINERALS IDENTIFIED BY X-RAY DIFFRACTION FROM BOTTOM SEDIMENTS OF SURFACE WATER IMPOUNDMENTS

Smectites
Illite
Kaolinite
Quartz
K-feldspar
Plagioclase
Calcite
Pyrite

TABLE VII

MINERALS IDENTIFIED BY X-RAY DIFFRACTION FROM SPOIL-PILE CUTTINGS FROM USGS WELLS 1-6 (ANALYSES BY THE UNIVERSITY OF NORTH DAKOTA)

Smectites
Illite
Kaolinite
Chlorite
Quartz
K-feldspar
Plagioclase
Calcite
Gypsum
Siderite
Mica
Pyrite
Marcasite
Ferrous Sulfate
Magnetite

inorganic aqueous species of the major elements and the trace elements iron and manganese. BALANCE (Parkhurst, Plummer, and Thorstenson, 1982) a Fortran computer program designed to define and quantify chemical reactions between ground water and minerals, was used to determine the change in chemical compositions of collected water samples. Borehole geophysical logs, specifically neutron logs, were used to construct a simplified cross section along the ground-water well site.

Graphical Expression of Analyses

Piper plots of water analyses from the six ground-water wells are presented in Figures 9-14. A Piper plot of the analyses from the surface water impoundments is presented in Figure 15. The two lower triangles of the diagrams represent relative percentages of cations and anions in meq/l. Points plotted in the central diamond represent the total water analysis, and are a result of the intersection of lines projected from the corresponding cation and anion data points.

Multivariable Analyses

From a practical standpoint, factor analysis is a method whereby, the relations among a relatively large number of variables are redefined in terms of a lesser number of hypothetical variables called factors. Once these factors (groups of related variables) are obtained, a subjective interpretation of them is attempted.

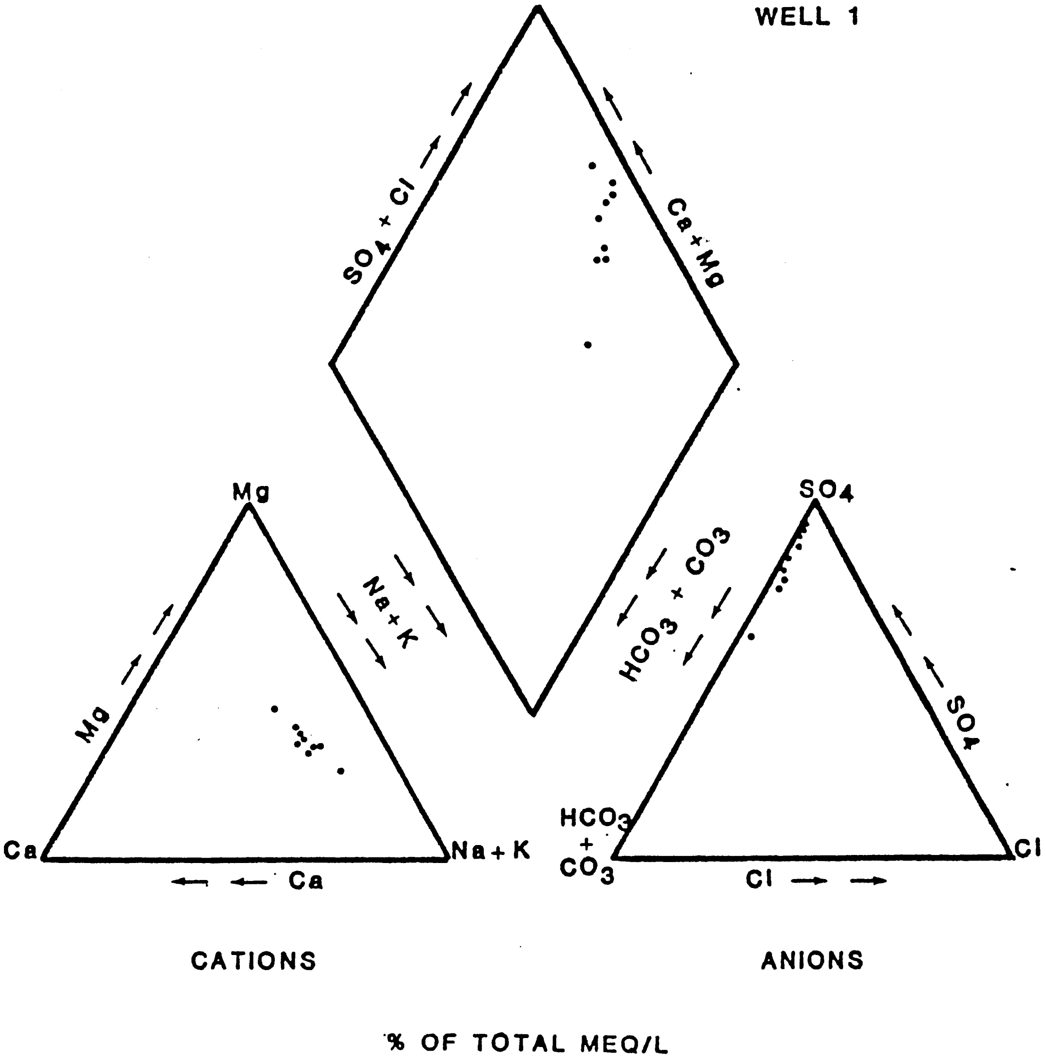

Figure 9. Piper Diagram of Well 1

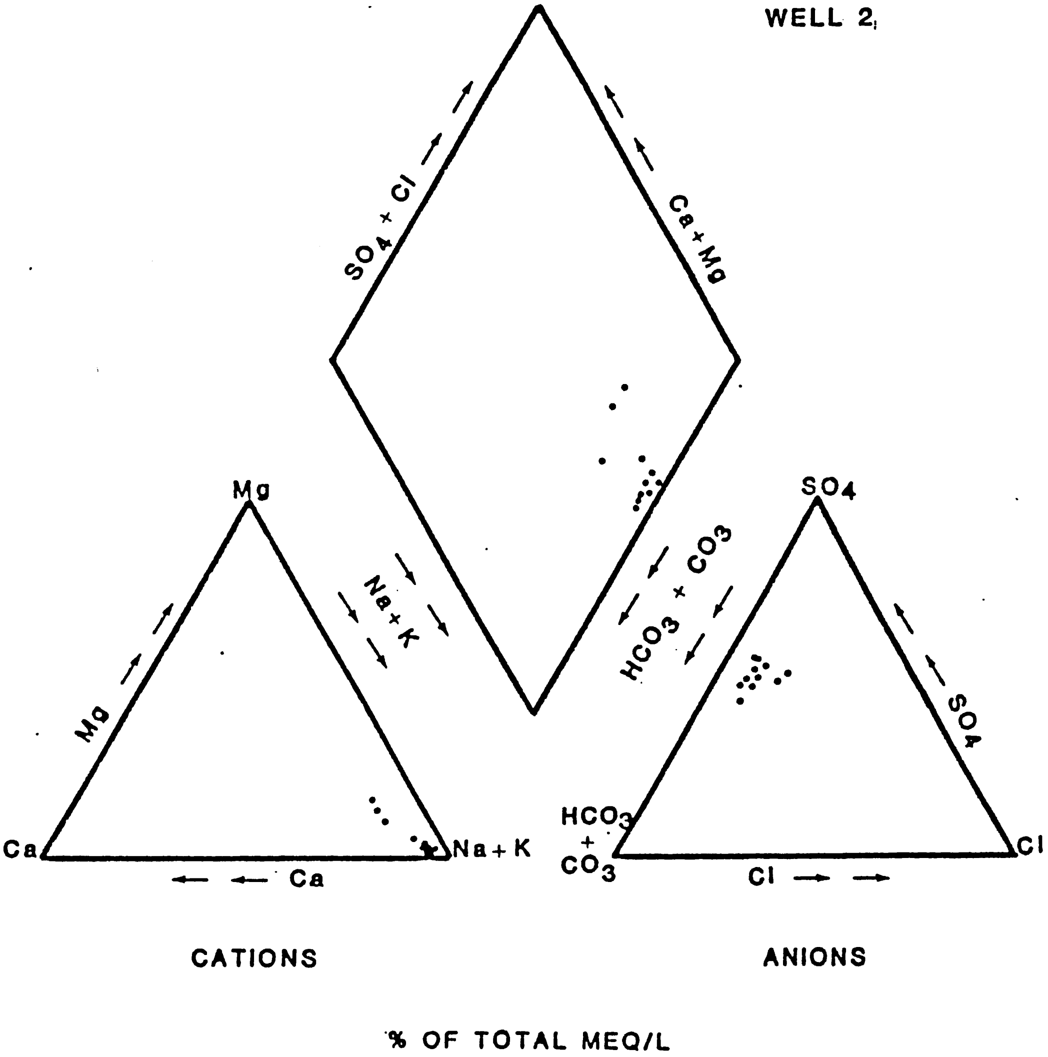

Figure 10. Piper Diagram of Well 2

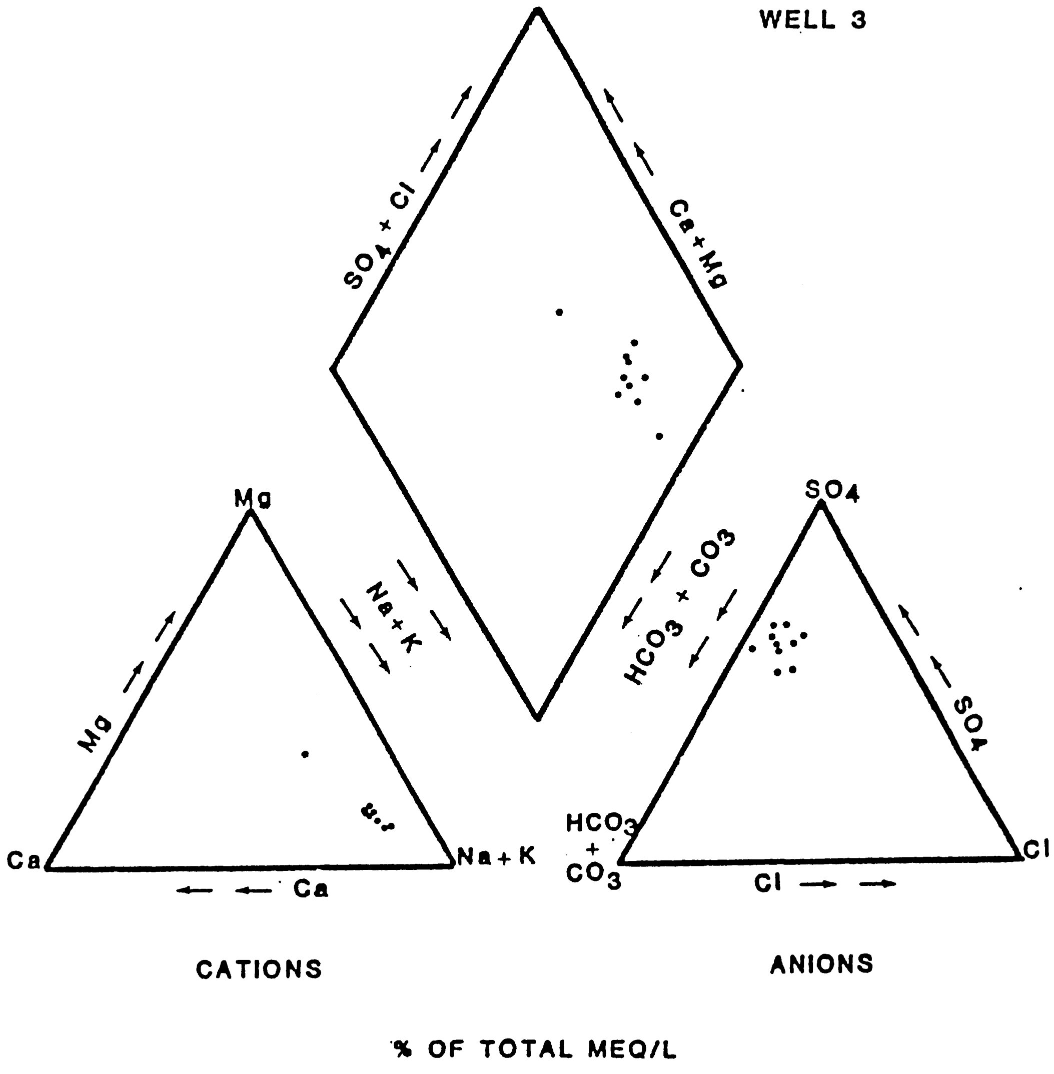

Figure 11. Piper Diagram of Well 3

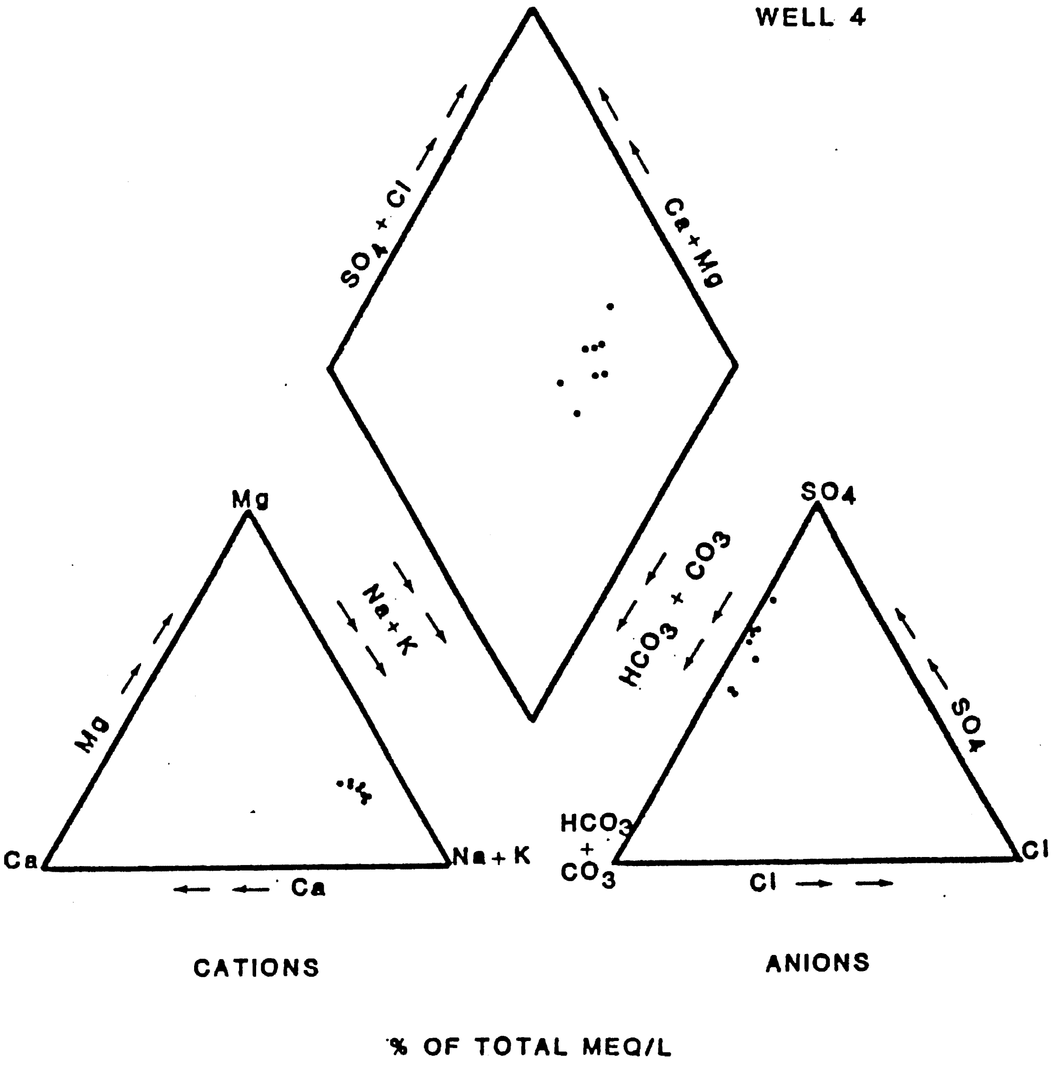

Figure 12. Piper Diagram of Well 4

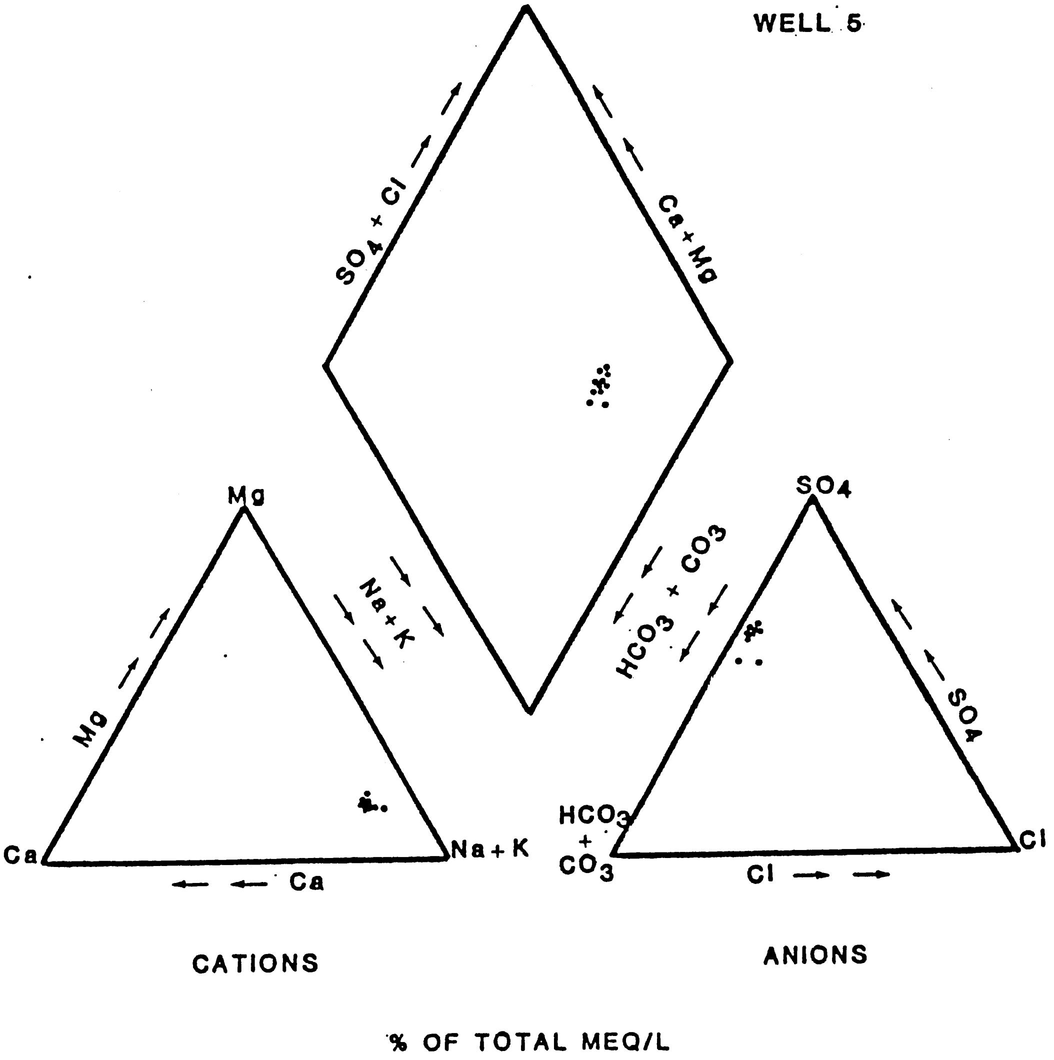

Figure 13. Piper Diagram of Well 5

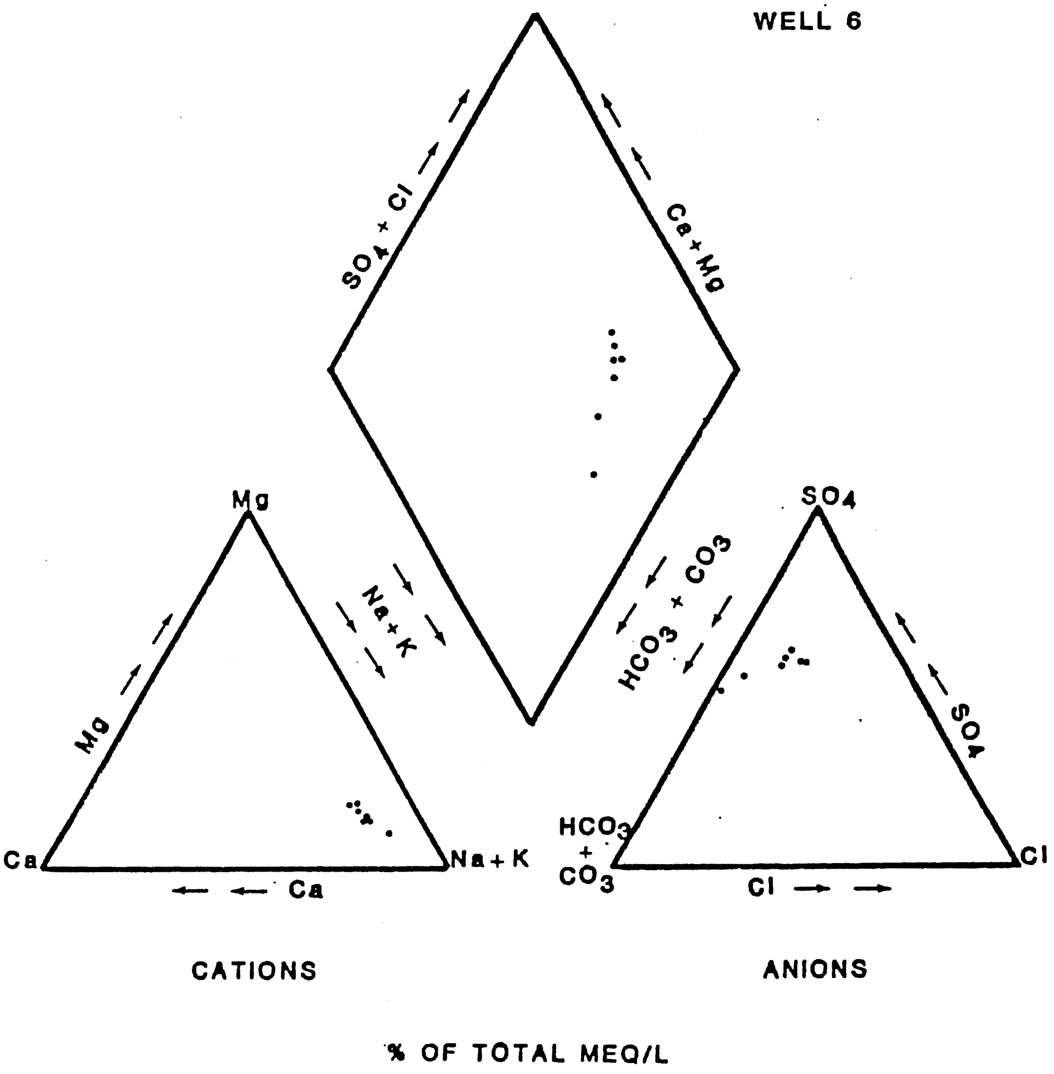

Figure 14. Piper Diagram of Well 6

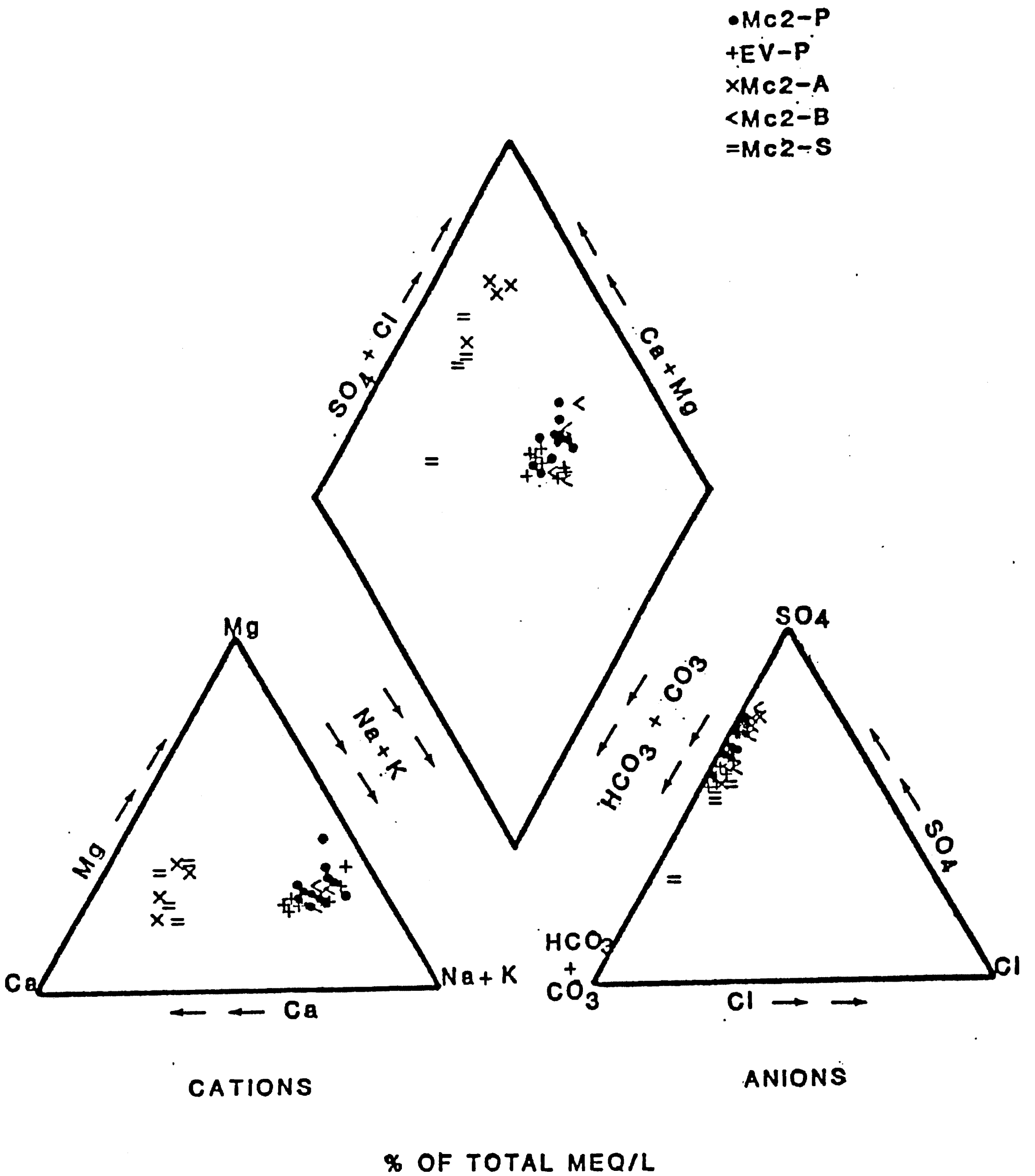

Figure 15. Composite Piper Diagram of Analyses from Surface Water Impoundments

Subsequently, a hypothetical variable representing each factor is derived for each sample; the original variables being weighted proportionally to their involvement in each factor. These derived variable values are standardized to a mean of zero and a standard deviation of one. The result is called a factor score matrix which shows the effect of each factor on each sample.

The Factor Analysis program was utilized to facilitate the simultaneous consideration of large numbers of variables in attempting to explain patterns of data correlation for the ground-water analyses and the surface water analyses. This tool was helpful in understanding the interrelationships between chemical constituents and properties of the ground water and was an important aid in the interpretation and identification of geochemical processes occurring in this system. The Factor Analysis statements are contained in Appendix C.

Equilibrium Considerations

The computer program, WATEQF requires the chemical analysis and in situ measurements of temperature, pH, and redox potential, to calculate the equilibrium distribution of inorganic aqueous species of major and important minor elements in natural waters. In order to determine the mineral phases with which the water is saturated, calculated activities of the dissolved ions are combined to produce an ion activity product (IAP). The log ratio of the IAP to the solubility product (KT) is known as the saturation index. If this ratio equals 0, then the solution is in equilibrium with the mineral. If IAP < KT (-), then the solution is undersaturated with respect to the mineral. If IAP > KT (+), then the solution is oversaturated with respect to the mineral and precipitation of that mineral may occur.

The WATEQF printout includes the total concentration of input species, the distribution of species, the mineral phases, activity products, solubility products, and the saturation index (log IAP/KT).

All available water quality data were initially run on WATEQF to provide a comprehensive data base that contained both the primary information of the water chemistry as well as some interpretations of this information. A sample WATEQF printout is listed in Appendix D.

Mass Balance

BALANCE (Parkhurst et al., 1982) is a USGS FORTRAN computer program designed to define and quantify reactions between ground water and minerals. A common application in water chemistry is the determination of the change in chemical composition of water samples between two points along a flow path. The program calculates the amounts of solid phases (minerals) entering or leaving the aqueous phase. The minerals to be considered and their chemical compositions, must be specified by the user on the basis of geology, hydrology, or mineralogy of the system. In addition to minerals, gaseous phases and ion exchange may be considered.

The simplest of the BALANCE options was run to help determine the ionic composition of the ground-waters sampled from the six USGS wells. A second BALANCE option requiring the input of a "final" water composition and two "end member" water compositions was run to determine if any mixing was occurring in the ground-water regime. Sample BALANCE runs are listed in Appendix E.

Borehole Geophysics

A simplified cross section across the six well-site was assembled using geophysical data logged by the USGS (Fig. 16). Although both gamma ray and neutron logs were available for the wells, the neutron logs were utilized in the cross-section assemblage. Neutron logs are porosity logs that measure the hydrogen ion concentration in a formation. In clean formations (ie. shale-free) where the porosity is filled with water or oil, the neutron log measures liquid-filled porosity.

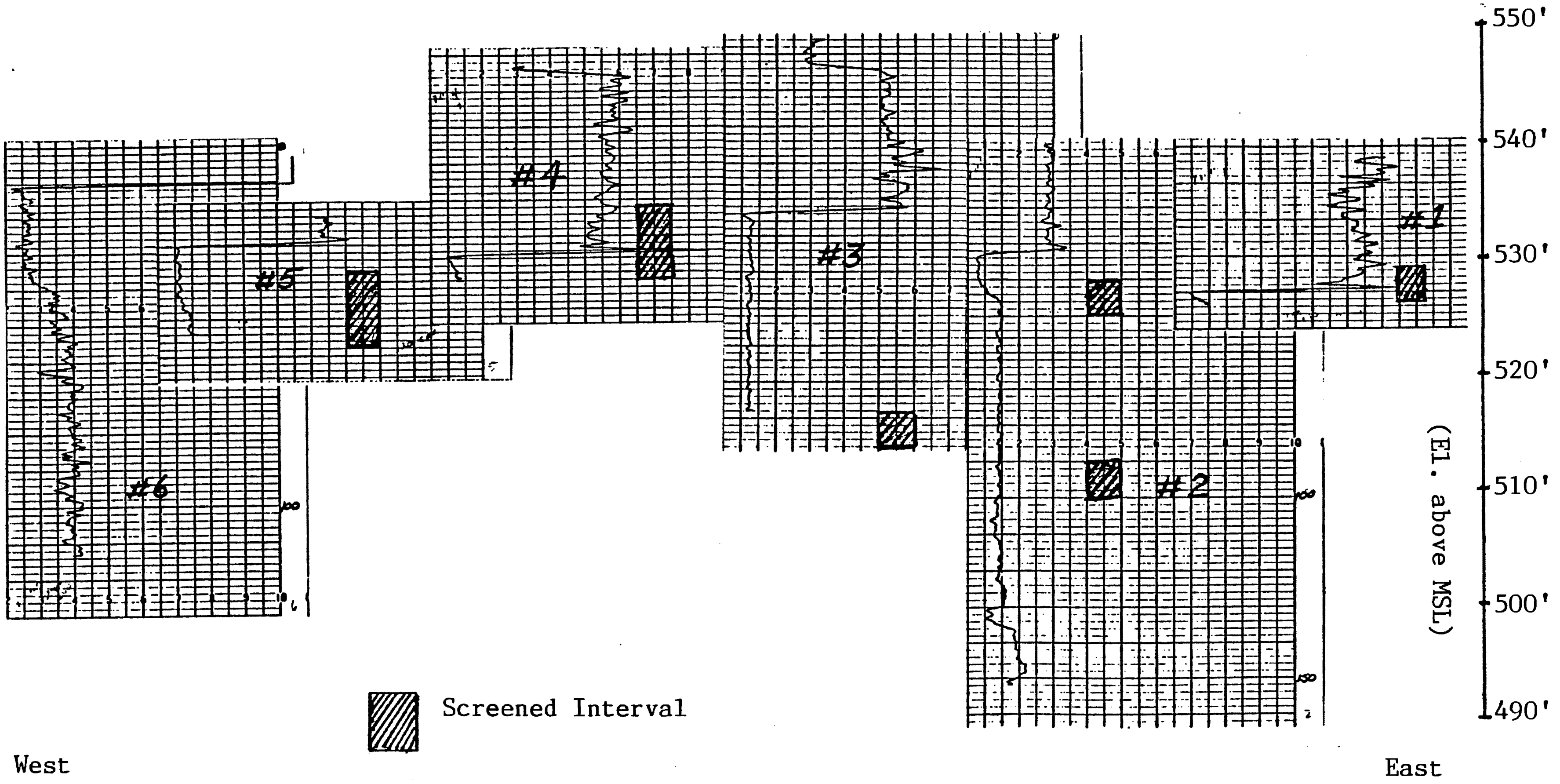

Figure 16. W-E Cross-section of Spoil Piles and USGS Ground-water Wells

CHAPTER VII

RESULTS AND DISCUSSION

The methods outlined in the previous chapter were utilized to describe the ground-water and surface-water chemistry of the study area. The subsequent determination of the geochemical processes which are occurring will aid in the development of a geochemical model to describe the evolution of the composition of both the surface and ground waters.

Chemical Processes

The first step in developing a geochemical model to explain the evolution of the water quality of the study area is to identify the minerals and processes that are controlling the chemical composition of the waters. Through x-ray diffraction studies of both bottom sediments and spoil cuttings the following minerals were identified: calcite, gypsum, pyrite, feldspars, quartz, and clays. Although not apparent on the x-ray runs, dolomite is a suspected constituent of the coal spoils.

Calcite was identified through x-ray diffraction as a constituent of the spoils. It is present as a matrix constituent of the Hartshorne sand (Kovach, 1987, personal communication), and as a macroscopic accessory of the Lower

Hartshorne coal (Williams, 1978). The presence of calcite in a hand sample of coal was confirmed by the effervescence of the calcite with cold, dilute hydrochloric acid. Calcite is readily soluble in dilute acids. It dissolves in the carbonic acid produced during the normal atmospheric weathering cycle:

$$CaCO_3 + CO_2 + H_2O <--> Ca^{++} + 2HCO_3^-$$

and in the sulfuric acid produced by the oxidation of pyrite which occurs in spoil piles:

$$CaCO_3 + H_2SO_4 <--> Ca^{++} + SO_4^{--} + H_2O + CO_2$$

The end result of the dissolution of calcite is neutralization of these acids and the production of calcium and bicarbonate. WATEQF results indicate oversaturation with respect to calcite in surface waters and waters producing from the spoil in the USGS wells. BALANCE runs also indicate that precipitation of calcite is possible from a mass balance stand point in the wells completed in the spoils.

Gypsum was identified as a constituent of the spoils by x-ray diffraction. Gypsum is a common constituent of marine shales. Gypsum also precipitates readily from solutions produced by the oxidation of pyrite coupled with the dissolution of calcite:

1) oxidation of pyrite

$$2FeS_2 + 15/2O_2 + 4H_2O <--> Fe_2O_3 + 4H_2SO_4$$

2) dissolution of calcite

$H_2SO_4 + CaCO_3 \longleftrightarrow Ca^{++} + SO_4^{--} + H_2CO_3$

3) precipitation of gypsum

$Ca^{++} + SO_4^{--} + 2H_2O \longleftrightarrow CaSO_4.2H_2O$

This reaction occurs readily in spoil piles (Hounslow, et al., 1978). WATEQF outputs indicate large amounts of gypsum are dissolving into solution, particularly in the wells completed in the spoil, and in the surface water impoundments.

Pyrite was identified as a constituent of the spoils by x-ray diffraction and by identification in hand samples of the Hartshorne coal. Pyrite is the principal sulfide present in nonlignitic coal seams. The oxidation and dissolution of pyrite with the liberation of sulfuric acid is responsible for acid mine drainage. The reaction:

$$2FeS_2 + 15/2O_2 + 4H_2O \longleftrightarrow Fe_2O_3 + 4H_2SO_4,$$

is reported to be catalyzed by microbial action (Hounslow, et al., 1978). However, the problem of acid mine drainage is not prevalent in the study area. The range of pH values of the ground-water samples ranged from 6.8 to 8.0. PH ranges for the surface water impoundments were from 6.0 to 8.3; with the exception of two lower values of 4.9 and 5.9 from Pond A.

Feldspars were also identified by x-ray diffraction in both the bottom sediments and spoil cuttings. Feldspars are common constituents of clastic sedimentary rocks. The common forms are potash feldspars ($KAlSi_3O_8$) and plagioclase ($NaAlSi_3O_8$ and $CaAl_2Si_2O_8$). Some sodium and potassium present in natural waters are likely the result of feldspar dissolution.

Quartz was identified through x-ray diffraction as a major constituent of the spoils and bottom sediments. Quartz is relatively insoluble, and is considered a stable constituent of spoil piles (Hounslow et at., 1978). WATEQF runs of selected surface and ground-water samples indicate oversaturation with respect to quartz.

Clay minerals were also identified as constituents of the spoils and bottom sediments through x-ray diffraction. Clay minerals are extremely fine-grained hydrous silicates which have the capacity to exchange cations in solution for cations which are adsorbed onto the mineral. BALANCE outputs suggest that cation exchange is occurring from a mass balance stand point, in both the ground-water and surface water systems. The BALANCE program utilizes the following reaction to calculate the exchange process: $Na_2X + Ca^{++} = 2Na^+ + CaX$. A positive value for the cation exchange process indicates the reaction is proceeding to the right; therefore, the calcium ions in solution are being adsorbed and sodium ions are released into solution. Clays identified in the study area are:

kaolinite, $Al_4[Si_4O_{10}](OH)_8$

illite, $K_{1-1.5}Al_4[Si_{7-6.5}Al_{1-1.5}O_{20}](OH)_4$

montmorillonite, $(1/2Ca,Na)_{0.7}(Al,Mg,Fe_4[Si,Al_8O_{22}]$
$(OH)_4.nH_2O$.

Kaolinite is the most common of the clay minerals and generally results from the alteration of feldspars in silicic rocks by acid solutions and under conditions of good drainage. Illite is a major constituent of many shales and mudstones. It is formed by the alteration of micas and feldspars under alkaline conditions. Montmorillonite is the principal constituent of bentonite clay deposits as well as being common in soils and shales. It results from the alteration of silica-poor rocks or volcanic material by alkaline solutions and its formation is favored by the availability of magnesium and calcium coupled with a deficiency of potassium. This last criteria is met in the ground-water and surface water analyses of the study area.

Dolomite is a suspected constituent of the spoil cuttings. WATEQF indicates oversaturation with respect to dolomite in both surface and ground waters. Perhaps, dolomite is a minor diagenetic constituent of the calcareous clastic matrix of the Hartshorne sandstone. From a mass balance approach, BALANCE runs of surface and ground water suggests saturation with respect to the dolomite phase. A second consideration from the BALANCE and WATEQF programs is the indication of calcite precipitation associated with high Mg:Ca ratios (1:1 to 2.5:1). One explanation for the precipitation of calcite is the process of dedolomitization. Dedolomitization explained simplistically, is the process whereby dolomite reverts back to calcite. As ground water moves through the coal spoils, calcite, dolomite, and gypsum which may be present are dissolved at varying rates. The system typically becomes saturated with respect to calcite first. Calcite precipitation is followed by dolomite saturation and precipitation. The dissolution of gypsum causes additional dissolution of dolomite. The calcium from the gypsum and the dolomite, and the carbonate from the dolomite combine to precipitate calcium carbonate. The dedolomitization process is outlined below:

1) dissolution of calcite

$H_2O + CO_{2s} + CaCO_3 \text{ ---> }$
$Ca_c^{+2} + 2HCO_{3s,c}^-$

2) dissolution of dolomite

$2H_2O + 2CO_{2s} + CaMg(CO_3)_2 \text{ ---> }$
$Ca_d^{+2} + Mg_2^{+2} + 4HCO_{3s,d}^-$

3) dissolution of gypsum

$CaSO_4 + 2H_2O \text{ ---> }$
$Ca_g^{+2} + SO_{4g}^{-2} + 2H_2O$

where c,d, and g represent ions from calcite, dolomite, and gypsum respectively; and s represents CO_2 from soil gas. When these three processes occur simultaneously, $CaCO_3$ will precipitate in the following manner:

4) $Ca_c^{+2} + Ca_d^{+2} + Ca_g^{+2} +$
$6HCO_{3c,d,s}^- \text{ ---> } 3Ca_{c,d,g}CO_{3c,d,s} +$
$3HCO_3^- + 3H^+$

(from Wheatcraft, 1987).

Ground-water Geochemistry

Graphical representation by Piper diagrams of the analyses from the ground-water wells (over time) demonstrates a trend of Ca-Mg-SO_4 composition in the shallow well 1. Well 4 of intermediate depth, indicates a progression away from the Ca-Mg-SO_4 composition towards the Na-HCO_3 ends of the triangular plots. Deep wells 2 and 3, demonstrate a trend of Na-HCO_3 composition. It can be inferred that two separate waters may be represented in this series of diagrams and that a certain degree of mixing between the two is also occurring. This theory can be supported by the use of the Factor Analysis program mentioned earlier. Fifty samples were entered into the Factor Analysis program and analyzed for the following variables: HCO_3, SO_4, Ca, Na, and Mg. Two factors were indicated by the varimax rotation analysis (Fig. 17). Factor 1 consists of the variables Ca, Mg, and SO_4. Factor 2 consists of the variables Na and HCO_3.

Neutron logs from the wells indicate the relative depths of the spoil piles from the abandoned coal mine area. The spoil piles are inferred to be the shaley-overburden components which can be measured from land surface (0 feet) to the top of the sand unit. The sand unit is defined as the "clean" kick towards the zero intensity measure of the log. The screened interval for each well is marked on each log. By inspection, shallow well 1 is screened predominantly in an interval of

```
VARIMAX ROTATION ANALYSIS.

 PCT          1          2
          64.2123    26.4081


 PCT          1          2          3          4          5
          76.6584    99.1952    94.9306    87.0555    95.2619


 V LO         1          2

   1       -.5092      .7122

   2        .9855      .1439

   3        .9726     -.0580

   4        .2887      .8873

   5        .9751     -.0429


 V WT         1          2

   1       -.1482      .5323

   2        .3094      .1237

   3        .3024     -.0295

   4        .1032      .6769

   5        .3034     -.0180
```

Figure 17. Ground-water Varimax Rotation Analysis

overburden spoil. Intermediate well 4 is screened in both the overburden and the sandstone unit. The deep wells 2 and 3 are screened solely in the sandstone unit. Although well 5 is shallow, it is screened only in the sand. Well 6 is a pre-existing private well and is unscreened (Slack, 1983).

Using the information obtained from the geophysical logs, two separate water types are occurring. Ca, Mg, and SO_4 are the main constituents of the spoil water. Na and HCO_3 are the main constituents of the water produced from the sandstone unit. Plotting a series of analyses from all six wells from June 23, 1982 on a Piper diagra (Fig. 18) indicates a linear relationship occurring within the diamond of the figure. The cations plotted in the left triangle follow a linear trend from Ca to Na, perhaps an indication of cation exchange. However, the anions in the right triangle plot in a scatter pattern. A linear trend between wells 1,4, and 6 exists, trending from SO_4 to HCO_3, suggesting sulfate reduction. The three remaining wells 2, 3, and 5 exhibit higher Cl values than any of the other wells. Since dissolution of halite is generally the only source of Cl in natural waters, a source of sodium chloride from outside the study area was suspected. Working on the assumption that wells 1 and 6 were probable end members, the Na and Cl values for the other four wells were adjusted by subtracting out an equivalent number of milliequivalents of Na and Cl from the original Na and Cl values. Percentages for each ion were adjusted using a volume

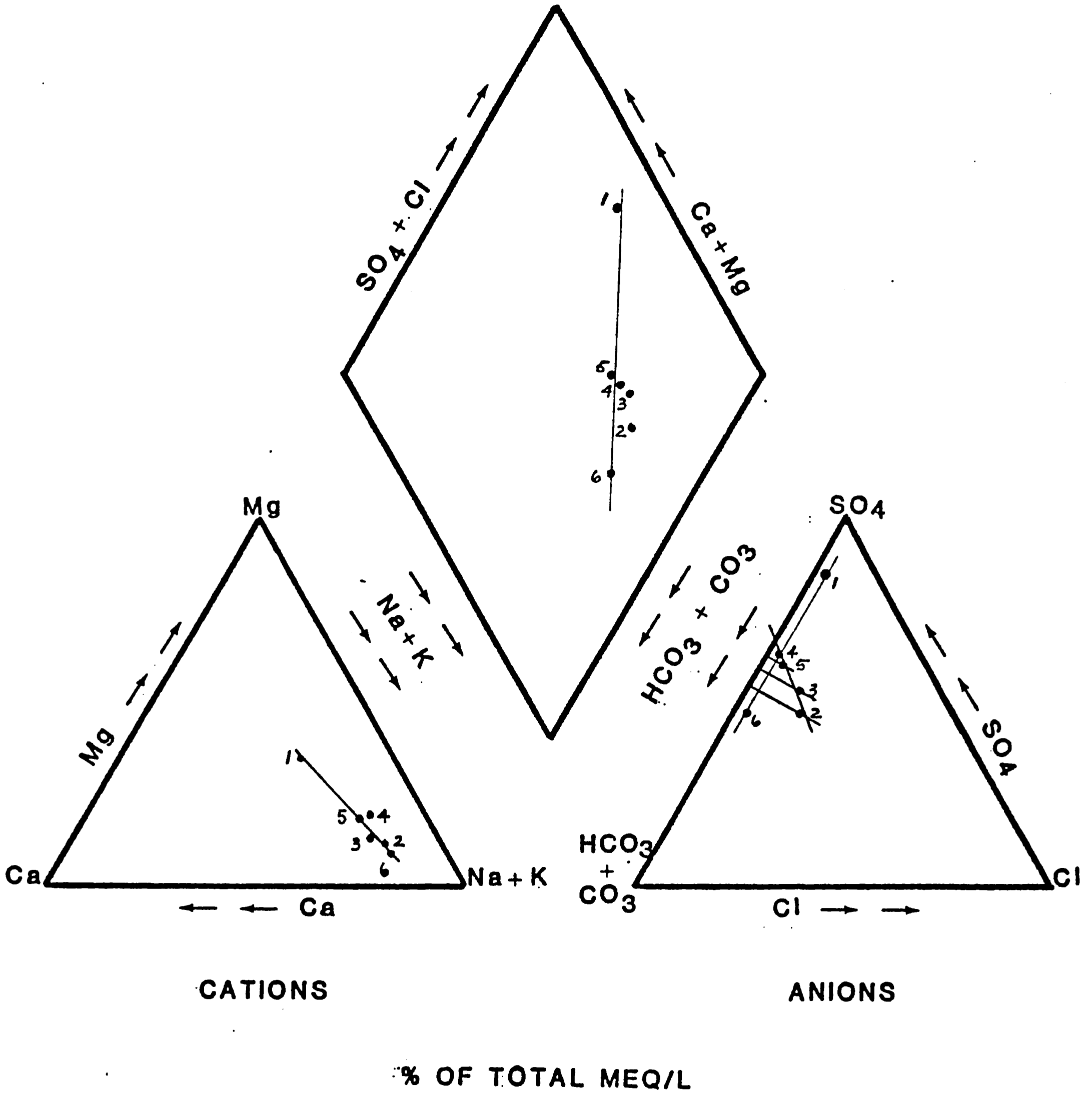

Figure 18. Piper Diagram of Wells 1-6 from June 23, 1982 Analyses

fraction program (Hounslow, 1987, personal communication). The new ion percentages for wells 2,3,4, and 5 were then replotted on a Piper diagram (Fig. 19). A linear trend of the anions from SO_4 to HCO_3 was now evident. Based on this information from the Piper diagram, the theory for the mixing of two end members, one Ca-Mg-SC_4 and two Na-HCO_3 is better supported.

It is interesting to note, that the wells with the highest Cl values were well 2, 3, and 5; all of which were completed in the sandstone unit. It is well documented that this region of the Arkoma Basin is intensely folded and faulted (Catalano, 1978). Mining around the McCurtain area commonly was instigated in areas where upthrown fault blocks had displaced coal beds to within an economically feasible range for strip mining. It is also interesting to note, that the study area is within the Kinta gas field. Gas wells are located to the north, east, and west of the ground-water well site. One possible explanation for the presence of excess Na and Cl in the ground water is that faults in the area may serve as conduits from the fresh water - salt water interface common in gas and oil bearing regions. A second possible explanation, is contamination by brines from the gas wells in the area. The author noticed recent drilling in the approximate study area. A third explanation could be the possible isolated point source contamination in the immediate area by the dissolution of halite from salt blocks placed in the pastured areas for the livestock and wildlife which are

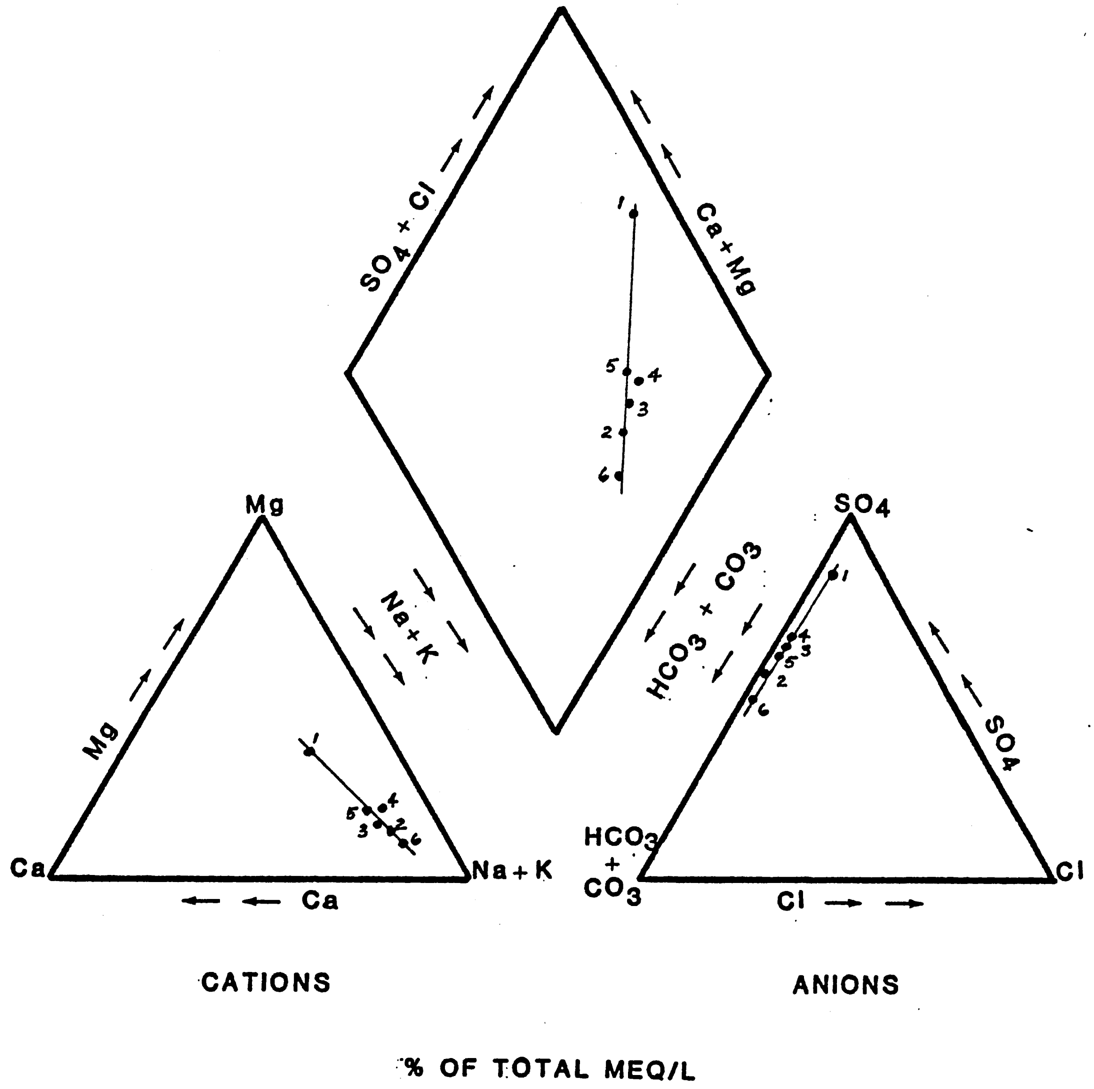

Figure 19. Piper Diagram of Wells 1-6 from June 23, 1982 Analyses Corrected Na and Cl Percentages

abundant in this region.

High Mg to Ca ratios (ranging from 1:1 to 2.5:1) are reported in the initial BALANCE runs for each of the six wells. Mg to Ca ratios greater than one are asociated with the precipitation of calcite ($CaCO_3$) in the ground water. This phenomenon is prevalent in the shallow wells screened partially in the spoil and becomes less so in the wells completed in the sand. Calcite precipitation is not evident in the deep well 2.

One explanation for the precipitation of calcite is the process of dedolomitization which was explained previously. Back et al. (1983) suggested that ground water, in the presence of gypsum, will be saturated or supersaturated with respect to calcite. This can be attributed to the common ion effect; the dissolution of gypsum contributes calcium ions to the solution resulting in the precipitation of calcite. As the calcite continues to precipitate the pH of the solution drops, causing the removal of carbonate from the solution, resulting in the dissolution of dolomite in an attempt to restore carbonate to the system. It is important to note that the dissolution of gypsum is the driving force for calcite precipitation. Gypsum is abundant in the spoils, mainly from the oxidation of pyrite.

Since calcite precipitation is not apparent in the deeper wells screened in the sandstone intervals, the process of ion (cation) exchange is a possible explanation for the high Mg:Ca ratios in these wells. An excess of Na

(Na >>> Cl) is indicated by inspection of the Piper diagrams as well as the raw data. Excess Na is released by clays due to preferential adsorption of Ca during the process of cation exchange. The dissolution of feldspars (common constituents of clastics) plays an important role in clay formation. BALANCE outputs suggest the process of ion exchange is occurring within this system.

Surface Water Geochemistry

A composite Piper diagram was constructed by graphing all of the surface water samples collected, for each sampling trip, on the same diagram. The graphical representation demonstrates that three of the surface water impoundments (Evans Pit, McCurtain No. 2 Pit, and Pond B) all plot predominantly as waters of Na-Mg-Ca-SO_4 composition. Pond A plots as a water with predominantly Ca-Mg-SO_4 composition. The Slough plots as a water with Ca-Mg-HCO_3 composition. From the mass balance approach, BALANCE outputs for the two Pits, Pond A, and Pond B all suggest precipitation of calcite and high values of dissolution for gypsum. The same processes which are occurring in the shallow wells of the spoil at the well site are also occurring here. Both Pits are bounded by spoil piles in various stages of vegetation. Pond B is located directly north of the McCurtain No. 2 Pit on the opposite side of the high-wall of the mine. Pond A is located near the coal pad, where coal was stacked and stored until shipment to market. The pH values of Pond A were the lowest recorded for the study area. Pond A had a pH of 5.9 on July 19, 1986 and 4.9 on January 3, 1987. Both of these dates correspond with low precipitation rates. It is apparent that these four impoundments are compositionally equivalent to the spoil waters from the well site. Factor Analysis computed for the 33 samples in this population indicated that only one factor was involved in these waters. Therefore, all constituents entered into the program (Ca, Mg, Na, HCO_3, and SO_4) were present in each surface water impoundment, in varying percentages. This reflects that the spoils from the mined area are influencing the impoundments in differing proportions, possibly due in part to differing rates of dilution by precipitation and surface runoff.

The composition of Pond A may be considered as a typical coal spoil water. High concentrations of Ca, Mg, and SO_4 coupled with the lowest pH values recorded for the area are contributed to the close proximity of the coal pad to this sedimentation pond. Oxidation of pyrite found in the Hartshorne coal, precipitation of gypsum in the spoil itself, leaching from precipitation, runoff into the pond, and dissolution of gypsum accounts for the precipitation of calcite, and subsequent dedolomitization process which has been described earlier. During periods of low precipitation the process of acid mine drainage is evident in this area. Periods of precipitation dilute the water composition in the pond, dissolve gypsum from the spoil pile, and runoff carries sediment into the pond. The influx of new material into the pond raises the pH to within neutral range.

The Pit impoundments have compositions similar to the the waters produced in the shallow ground-water wells. The average pit depth in these impoundments was approximately 35 feet. The pits were initially sampled at three depths due to thermal stratification (a decrease in temperature with depth) which was evident during the first sampling trip on July 19, 1986. This sampling scheme was continued throughout the rest of the study period. It is interesting to note that during the third sampling trip on January 3, 1987, the thermal stratification was reversed; the warmer water was found at the bottom of the pit with a succesion of cooler temperatures found near the surface. Along the same line as the thermal stratification, the following parameters generally changed with respect to depth: all ions analyzed increased, specific conductivity (and therefore, total dissolved solids) increased, while pH decreased. PH values for the Pit impoundments ranged from 6.4 to 8.0. The Pit impoundments are essentially of spoil composition in nature diluted by precipitation and surface runoff. BALANCE output suggests the process of ion exchange is occurring in the Pits.

The Slough composition is predominantly Ca-HCO_3-SO_4 in nature. The Slough is located the furthest from the original mining sites. The composition suggests that the

Slough is not as readily affected by the spoils as the other surface impoundments. The Slough primarily serves as a water retention pond for surface water runoff. Water was present in the Slough during all four sampling trips. This is attributed to the fact that beavers have dammed up the south end of the impoundment, therefore discharge into the ephemeral springs in the area is impossible.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been made from this study:

1. Two separate ground waters are occurring at the USGS well site area. One water type is essentially Ca-Mg-SO_4 in composition suggesting an origin in the spoil banks from previously mined areas. The second water type is essentially Na-HCO_3 in composition suggesting an origin from a sandstone aquifer which lies below the spoil piles. Mixing of the two ground waters results in intermediate compositions of varying proportions of both waters.

2. An outside source of NaCl is contaminating the wells completed in the sandstone unit. Possible sources for the contamination are faults intersecting the fresh water - salt water interface, previously existing gas wells in the area, and agricultural salting practices.

3. Surface waters from impoundments at the two mine sites are influenced by the spoils left from the strip mining procedure. Compositions of waters in direct contact with the spoils have essentially the same characteristics. The composition of these waters are influenced by dilution from direct precipitation and surface runoff.

4. Acid mine drainage is not a problem at this mining site for the following reasons:

a. the Hartshorne coal is a high-volatile, A-bituminous to medium-volatile bituminous coal with a sulfur content averaging less than 3%;

b. carbonates are present as matrix constituents of the clastics and shales, and calcite is present as a macroscopic accessory of the coal;

c. precipitation and surface runoff provide sufficient dilution mechanisms for surface water impoundments;

d. the formation of and subsequent dissolution of gypsum from the spoils, initiating the process of dedolomitization serves as a natural buffering system.

5. The major geochemical processes at work are dedolomitization, ion exchange, mixing, and dilution.

6. Except for elevated sulfate levels, and isolated iron and manganese levels, all other constituents are within EPA drinking water standards.

Recommendations

The following are the author's recommendations for further study:

1. A systematic study of the mineral and non-coal constituents of the Hartshorne coal.

2. An in-depth petrographic study of the area to determine the source of the suspected dolomite.

3. A subsurface mapping project to determine if faulting in the area is influencing NaCl contamination via fault-conduits.

4. Establishing control areas for comparison of areas unaffected to areas affected by strip mining for coal.

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APPENDIXES

APPENDIX A

SOIL PROFILES

STIGER SILT LOAM

A1-0 to 12 inches, dark grayish brown (10 YR 4/2) silt loam; few, fine, faint, yellowish-brown mottles; weak, medium, granular structure; friable, slightly hard, few iron-manganese concretions; strongly acid; gradual, wavy boundary.

A2-12 to 21 inches, brown (10YR 5/3) silt loam; few, fine, faint, yellowish-brown mottles; weak, medium, granular structure, friable, slightly hard; few iron-manganese concretions; strongly acid; clear wavy boundary.

B21t-21 to 33 inches, yellowish-brown (10YR 5/6) silty clay; many, medium and coarse, distinct, pale brown (10 YR 6/3), grayish-brown (10 YR 5/2), and yellowish-red (5 YR 4/6) mottles, moderate, medium, blocky structure; very firm; very hard; clay films on faces of peds; few iron-manganese concretions; medium acid; diffuse, wavy boundary.

B22t-33 to 65 inches, yellowish-brown (10 YR 5/6) silty clay; common, medium, distinct, light brownish-gray (10 YR 6/2) and dark yellowish-brown (10 YR 4/4) mottles, moderate, medium and coarse, blocky structure; extremely firm, extremely hard; clay films on faces of peds; few iron-manganese concretions and black streaks, neutral, diffuse, wavy boundary.

B3t-65 to 78 inches, yellowish-brown (10 YR 5/6) silty clay; common, distinct, light-gray (10 YR 6/1) mottles and black streaks; weak, medium, blocky structure; extremely firm, extremely hard, patchy clay films on faces of peds; neutral.

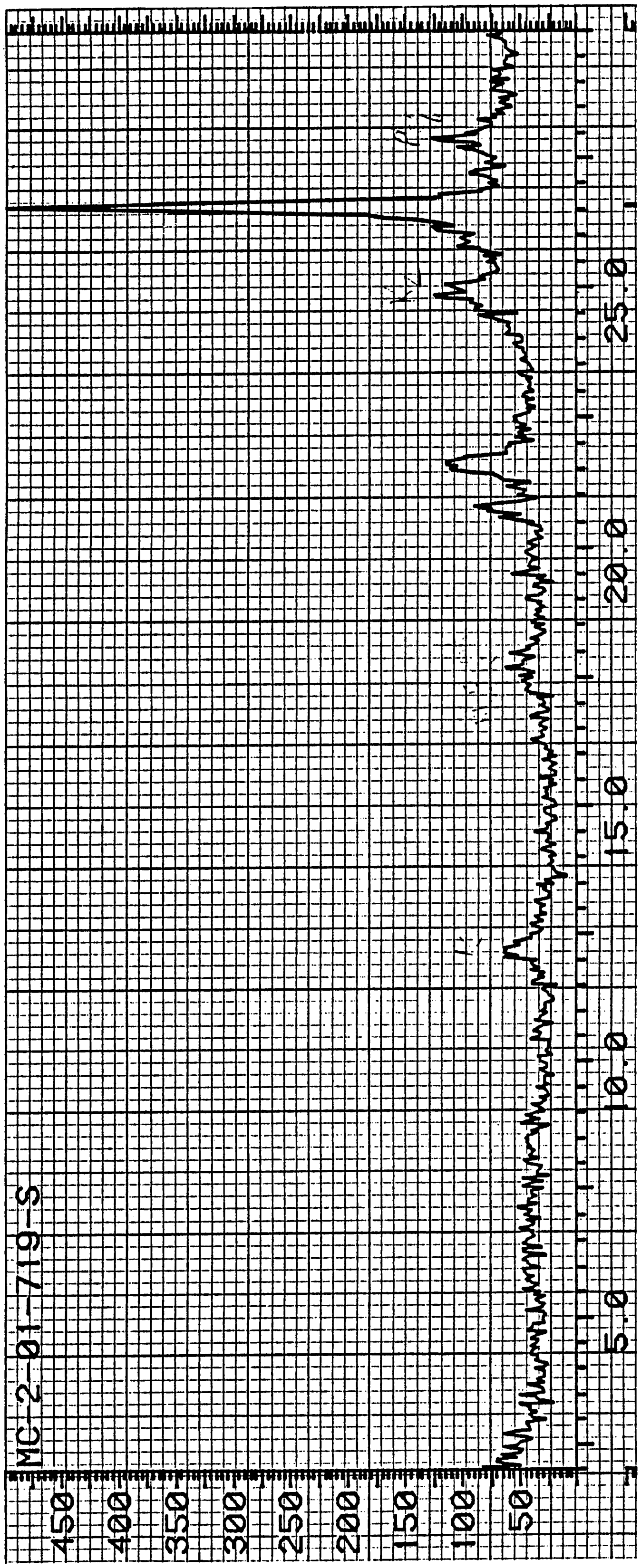
KANIMA SHALY SILTY CLAY LOAM

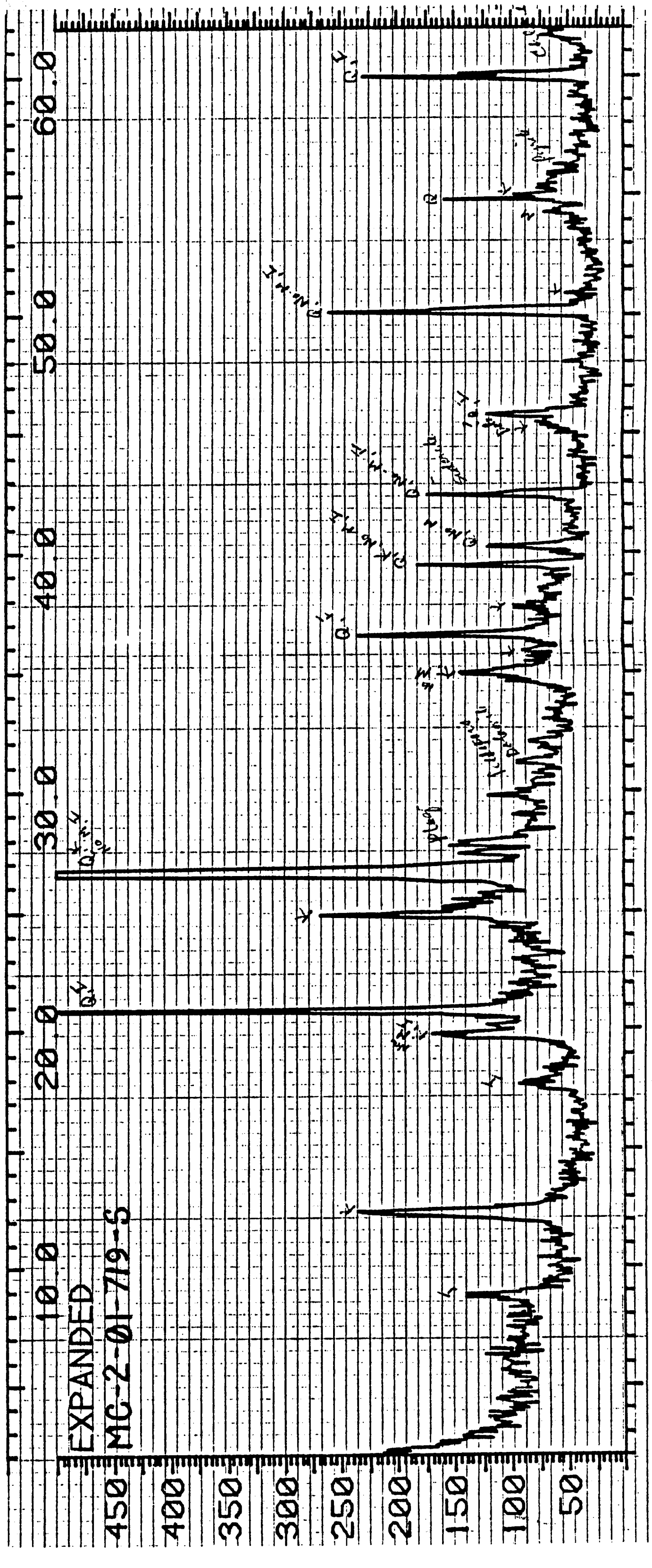
A1-0 to 6 inches, very dark grayish-brown (2.5 YR 3/2) shaly silty clay loam; massive; friable, hard; 20 percent shale fragments and 1 percent coal fragments; neutral; diffuse, wavy boundary; slightly acidic to modreately alkaline.

C-6 to 72 inches, very dark grayish-brown (2.5 YR 3/2) very shaly, silty clay loam; few fragments of very dark grayish-brown (10 YR 3/2) silt loam and yellowish-brown (10 YR 5/4) silty clay loam that has thin patchy clay films; massive; friable, hard; 70 percent very dark gray (N 3/0) shale fragments in the upper part and 85 percent shale and 2 percent coal fragments in the lower part; newtral.

APPENDIX B

SAMPLE X-RAY DIFFRACTION PATTERN


MC-2-01-719-S
450
400
350
300
250
200
150
100
50
5.0
10.0
15.0
20.0
25.0


EXPANDED
MC-2-01-719-S
10.0
20.0
30.0
40.0
50.0
60.0
450
400
350
300
250
200
150
100
50

APPENDIX C

SAMPLE FACTOR ANALYSIS PRINTOUT

```
1wells 1-6

 PARAMETERS
 COL  1 - 5 =     5
 COL 6 - 10 =    50
 COL 11 - 15 = 11100
 COL 16 - 20 =  1111
 COL 21 - 25 = 11100
 1               792.     1100.     120.     590.     120.
 2               659.     1900.     210.     590.     180.
 3               683.     2300.     220.     660.     220.
 4               244.     2400.     210.     600.     220.
 5               610.     1900.     210.     560.     200.
 6               512.     2100.     210.     560.     210.
 7               305.     3100.     270.     690.     310.
 8               295.     1700.     160.     420.     170.
 9               277.     2200.     230.     430.     260.
 10              561.      690.      70.     520.      45.
 11              744.      840.      22.     680.       9.
 12              708.      650.      19.     600.       7.
 13              720.      730.      19.     610.       9.
 14              695.      620.      16.     580.       6.
 15              634.      450.      42.     380.      27.
 16              720.      680.      16.     620.       5.
 17              683.      590.      18.     550.       8.
 18              601.      640.      54.     460.      43.
 19              627.      730.      33.     560.      19.
 20              723.      820.      15.     670.       7.
 21              561.      950.      62.     530.      42.
 22              427.      940.      67.     540.      41.
 23              537.      860.      64.     600.       4.
 24              537.      840.      76.     460.      49.
 25              525.     1000.      75.     510.      62.
 26              464.      810.      76.     460.      52.
 27              390.      980.      77.     460.      56.
 28              550.      710.      70.     450.      49.
 29              540.      780.      73.     500.      48.
 30              510.      660.      92.     240.      82.
 31              647.      560.      80.     330.      70.
 32              781.     1300.     120.     610.     110.
 33              476.      650.      69.     330.      60.
 34              671.      980.      86.     500.      85.
 35              720.     1200.      95.     560.     100.
 36              744.     1200.      89.     570.      92.
 37              860.      700.      74.     480.      72.
 38              429.     1100.      89.     450.      94.
 39              512.      720.      60.     400.      47.
 40              573.      880.      71.     440.      56.
 41              561.      720.      71.     440.      46.
 42              561.      820.      77.     420.      55.
 43              512.      800.      74.     440.      51.
```

```
44                 573.      780.       71.      430.      56.
45                 586.      870.       77.      460.      57.
46                 500.      710.       65.      400.      49.
47                 555.      850.       81.      450.      68.
48                 693.      720.       77.      450.      60.
49                 600.      680.       56.      440.      45.
50                 512.      840.       78.      460.      58.

INTERCORRELATION ANALYSIS.


 MEAN           1          2           3          4          5
            578.0000  1033.0000    89.1200   502.8000    77.8180


 SIGM           1          2           3          4          5
            133.8221   558.6277    60.9815    95.4367    70.1044


 R MA           1          2           3          4          5

   1          1.0000     -.4173     -.4422      .3113     -.4299

   2          -.4173     1.0000      .9368      .4240      .9471

   3          -.4422      .9368     1.0000      .1606      .9835

   4           .3113      .4240      .1606     1.0000      .1710

   5          -.4299      .9471      .9835      .1710     1.0000

PRINCIPAL AXIS ANALYSIS.

TRACE =    5.0000

 90.62 PCT. OF TRACE WAS EXTRACTED BY  2 ROOTS.


 EROO           1          2
              3.2127     1.3183


 PCT            1          2
             64.2542    26.3662
```

P LO	1	2
1	-.5326	.6949
2	.9802	.1766
3	.9740	-.0256
4	.2590	.8964
5	.9760	-.0105

P WT	1	2
1	-.1658	.5271
2	.3051	.1340
3	.3032	-.0194
4	.0806	.6799
5	.3038	-.0079

APPENDIX D

SAMPLE WATEQF PRINTOUT

```
                                                        ----------------
                                                        INITIAL SOLUTION
                                                        ----------------


TEMPERATURE =  20.00 DEGREES C   PH = ,  7.200ANALYTICAL EPMCAT =   51.307ANALYTICAL EPMAN =   51.305


   ***** OXIDATION - REDUCTION *****


DISSOLVED OXYGEN =    .000 MG/L
EH MEASURED WITH CALOMEL =  9.9000 VOLTS
MEASURED EH OF ZOBELL SOLUTION =  9.9000 VOLTS
CORRECTED EH =  9.9000 VOLTS
PE COMPUTED FROM CORRECTED EH = 100.000



  *** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

   TOTAL            LOG TOTAL          TOTAL
  SPECIES        MOLALITY           MOLALITY          MG/LITRE
  -------        --------           --------          --------

  CA        2     .525855E-02         -2.2791         .210000E+03
  MG        2     .743064E-02         -2.1290         .180000E+03
  NA        1     .257568E-01         -1.5891         .590000E+03
  K         1     .171969E-03         -3.7645         .670000E+01
  CL       -1     .764338E-03         -3.1167         .270000E+02
  SO4      -2     .198508E-01         -1.7022         .190000E+04
  HCO3     -1     .108394E-01         -1.9650         .659000E+03
  SIO2 TOT  0     .768365E-03         -3.1144         .460000E+02




   *** CONVERGENCE ITERATIONS ***

ITERATION    S1-ANALCO3      S2-SO4TOT        S3-FTOT         S4-PTOT         S5-CLTOT

  1        4.607085E-04    9.522641E-03    .000000E+00     .000000E+00     .000000E+00
  2        1.840778E-04    1.766849E-03    .000000E+00     .000000E+00     .000000E+00
  3       -8.651987E-07   -2.139807E-05    .000000E+00     .000000E+00     .000000E+00
  4        1.348555E-06    1.120754E-05    .000000E+00     .000000E+00     .000000E+00
  5        1.862645E-07    1.432374E-06    .000000E+00     .000000E+00     .000000E+00
```

```
                              ****DESCRIPTION OF SOLUTION ****

            ANALYTICAL  COMPUTED            PH              ACTIVITY H2O =   .9989
     EPMCAT    51.307      41.964          7.200            PCO2 =  3.236380E-02
     EPMAN     51.305      41.965                           LOG PCO2 =  -1.4899
                                         TEMPERATURE        PO2 =  9.351689E-17
     EH = 9.9000  PE =  10.000            20.00 DEG C       PCH4 =   .000000E+00
     PE CALC S =  1.000000E+02                              CO2 TOT =  1.205334E-02
     PE CALC DOX= 1.000000E+02           IONIC STRENGTH     DENSITY =   1.0000
     PE SATO DOX= 1.000000E+02           6.528176E-02       TDS =    3618.7MG/L

 IN COMPUTING THE DISTRIBUTION OF SPECIES, PE =  10.000     EQUIVALENT EH =   .582VOLTS



                                 -----------------------
                                 DISTRIBUTION OF SPECIES
                                 -----------------------

I  SPECIES          PPM          MOLALITY       LOG MOL     ACTIVITY       LOG ACT    ACT. COEFF.     LOG A COF

 1 CA        2   1.31906E+02    3.30302E-03    -2.4811    1.46130E-03    -2.8353    4.42413E-01      -.3542
 2 MG        2   1.20402E+02    4.97037E-03    -2.3036    2.26447E-03    -2.6450    4.55593E-01      -.3414
 3 NA        1   5.69274E+02    2.48520E-02    -1.6046    2.01046E-02    -1.6967    8.08976E-01      -.0921
 4 K         1   6.43881E+00    1.65265E-04    -3.7818    1.31540E-04    -3.8809    7.95936E-01      -.0991
64 H         1   7.51090E-05    7.47835E-08    -7.1262    6.30958E-08    -7.2000    8.43712E-01      -.0738
 5 CL       -1   2.70000E+01    7.64338E-04    -3.1167    6.08364E-04    -3.2158    7.95936E-01      -.0991
 6 SO4      -2   1.43968E+03    1.50415E-02    -1.8227    6.45261E-03    -2.1903    4.28988E-01      -.3676
 7 HCO3     -1   6.24554E+02    1.02729E-02    -1.9883    8.36681E-03    -2.0774    8.14459E-01      -.0891
18 CO3      -2   7.56992E-01    1.26604E-05    -4.8976    5.57086E-06    -5.2541    4.40024E-01      -.3565
86 H2CO3     0   7.73320E+01    1.25131E-03    -2.9026    1.27184E-03    -2.8956    1.01641E+00       .0071
27 OH       -1   2.31121E-03    1.36388E-07    -6.8652    1.08312E-07    -6.9653    7.94143E-01      -.1001
19 MGOH      1   1.88711E-03    4.58373E-08    -7.3388    3.77925E-08    -7.4226    8.24492E-01      -.0838
23 MGSO4 AQ  0   2.61591E+02    2.18105E-03    -2.6613    2.21408E-03    -2.6548    1.01515E+00       .0065
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22 MGHCO3     1   2.27458E+01      2.67533E-04       -3.5726      2.14002E-04       -3.6696     7.99907E-01         -.0970
21 MGCO3 AQ   0   9.22786E-01      1.09834E-05       -4.9593      1.11498E-05       -4.9527     1.01515E+00          .0065
29 CAOH       1   2.66473E-04      4.68476E-09       -8.3293      3.84182E-09       -8.4155     8.20069E-01         -.0861
32 CASO4 AQ   0   2.45816E+02      1.81215E-03       -2.7418      1.83959E-03       -2.7353     1.01515E+00          .0065
30 CAHCO3     1   1.33549E+01      1.32580E-04       -3.8775      1.08724E-04       -3.9637     8.20069E-01         -.0861
31 CACO3 AQ   0   1.02338E+00      1.02618E-05       -4.9888      1.04172E-05       -4.9822     1.01515E+00          .0065
44 NASO4     -1   9.60110E+01      8.09396E-04       -3.0918      6.59219E-04       -3.1810     8.14459E-01         -.0891
43 NAHCO3     0   7.79805E+00      9.31812E-05       -4.0307      9.45924E-05       -4.0241     1.01515E+00          .0065
42 NACO3     -1   1.63098E-01      1.97219E-06       -5.7051      1.60627E-06       -5.7942     8.14459E-01         -.0891
94 NACL       0   7.01598E-31      1.20485E-35      -34.9191      1.22309E-35      -34.9125     1.01515E+00          .0065
46 KSO4      -1   9.02588E-01      6.70199E-06       -5.1738      5.45850E-06       -5.2629     8.14459E-01         -.0891
95 KCL        0   5.85594E-33      7.88305E-38      -37.1033      8.00244E-38      -37.0968     1.01515E+00          .0065
63 HSO4      -1   4.13511E-03      4.27542E-08       -7.3690      3.44324E-08       -7.4630     8.05358E-01         -.0940
24 H4SIO4AQ   0   7.34504E+01      7.66964E-04       -3.1152      7.78580E-04       -3.1087     1.01515E+00          .0065
25 H3SIO4    -1   1.32747E-01      1.40082E-06       -5.8536      1.12053E-06       -5.9506     7.99907E-01         -.0970
26 H2SIO4    -2   4.22786E-06      4.50928E-11      -10.3459      1.98419E-11      -10.7024     4.40024E-01         -.3565



          MOL RATIOS FROM ANALYT MOLALITY      MOL RATIOS FROM COMP MOLALITY     LOG ACT RATIOS
          -------------------------------      -----------------------------     --------------

                CL/CA    =  1.4535E-01               CL/CA    =  2.3141E-01           LOG CA/H2 =   11.5647
                CL/MG    =  1.0286E-01               CL/MG    =  1.5378E-01           LOG MG/H2 =   11.7550
                CL/NA    =  2.9675E-02               CL/NA    =  3.0756E-02           LOG NA/H1 =    5.5033
                CL/K     =  4.4446E+00               CL/K     =  4.6249E+00           LOG K/H1  =    3.3191
                CL/AL    =  7.6434E+26               CL/AL    =  7.6434E+26           LOG AL/H3 =   21.6000
                CL/FE    =  7.6434E+26               CL/FE    =  7.6434E+26           LOG FE/H2 =   14.4000
                CL/SO4   =  3.8504E-02               CL/SO4   =  5.0815E-02           LOG CA/MG =    -.1902
                CL/HCO3  =  7.0514E-02               CL/HCO3  =  7.4404E-02           LOG NA/K  =    2.1842
                CA/MG    =  7.0768E-01               CA/MG    = 6.6454E-01
                NA/K     =  1.4978E+02               NA/K     =  1.5038E+02
```

```
      PHASE          IAP          KT        LOG IAP    LOG KT      IAP/KT     LOG IAP/KT     DELGR

  18 ANHYDRIT   9.4292E-06   3.1559E-05    -5.0255    -4.5009   2.9878E-01     -.52464      -.70376
  22 ARAGONIT   8.1407E-09   6.6373E-09    -8.0893    -8.1780   1.2265E+00      .08867       .11894
 151 ARTIN      1.3908E-25   4.1979E-19   -24.8567   -18.3770   3.3132E-07    -6.47976     -8.69197
  20 BRUCITE    2.6565E-17   3.7964E-12   -16.5757   -11.4206   6.9975E-06    -5.15506     -6.91502
  13 CALCITE    8.1407E-09   3.5807E-09    -8.0893    -8.4460   2.2735E+00      .35670       .47848
  98 CHALC      7.8035E-04   2.6261E-04    -3.1077    -3.5807   2.9716E+00      .47298       .63446
  21 CHRYSOTL                             -55.9420   -52.1449                 -3.79713     -5.09349
  30 CLENSTIT   2.0754E-20   1.1131E-17   -19.6829   -16.9534   1.8644E-03    -2.72945     -3.66130
 100 SILGEL     7.8035E-04   1.7031E-03    -3.1077    -2.7688   4.5819E-01     -.33895      -.45467
  29 DIOPSIDE                             -39.5560   -36.4838                 -3.07225     -4.12113
  12 DOLOMITE   1.0270E-16   1.2124E-17   -15.9885   -16.9164   8.4706E+00      .92791      1.24471
  28 FORSTRIT   5.5196E-37   6.7471E-29   -36.2581   -28.1709   8.1807E-09    -8.08721    -10.84822
  19 GYPSUM     9.4078E-06   1.7288E-05    -5.0265    -4.7623   5.4419E-01     -.26425      -.35446
  65 HALITE     1.2231E-05   3.7198E+01    -4.9125     1.5709   3.2880E-07    -6.48306     -8.69641
 118 HUNTITE    1.6343E-32   6.4869E-31   -31.7867   -30.1880   2.5194E-02    -1.59871     -2.14452
  39 HYDMAG                               -40.2745   -37.5010                 -2.77354     -3.72043
  99 MAGADI     3.6527E-19   5.0119E-15   -18.4374   -14.3000   7.2882E-05    -4.13738     -5.54990
  11 MAGNESIT   1.2615E-08   6.8726E-09    -7.8991    -8.1629   1.8356E+00      .26377       .35382
  67 MIRABI     2.5787E-06   4.4631E-02    -5.5886    -1.3504   5.7778E-05    -4.23824     -5.68519
  59 NAHCOL     1.6821E-04   2.5439E-01    -3.7741     -.5945   6.6124E-04    -3.17964     -4.26518
  61 NATRON     2.2263E-09   3.1057E-02    -8.6524    -1.5078   7.1684E-08    -7.14458     -9.58377
 150 NESQUE     1.2572E-08   7.2673E-06    -7.9006    -5.1386   1.7300E-03    -2.76196     -3.70491
 102 QUARTZ     7.8035E-04   8.2650E-05    -3.1077    -4.0828   9.4417E+00      .97505      1.30793
  37 SEPIOLIT                             -42.4752   -40.4317                 -2.04355     -2.74123
 101 SILGLAS    7.8035E-04   8.4624E-04    -3.1077    -3.0725   9.2214E-01     -.03520      -.04722
  38 TALC                                 -62.1569   -62.8534                   .69647       .93425
  66 THENAR     2.6081E-06   6.7321E-01    -5.5837     -.1718   3.8742E-06    -5.41182     -7.25944
  62 THRNAT     2.2492E-09   1.4455E+00    -8.6480      .1600   1.5559E-09    -8.80801    -11.81510
  32 TREMOLIT                            -141.2690  -141.4278                   .15885       .21309
  60 TRONA      3.7791E-13   2.6917E-01   -12.4226     -.5700   1.4040E-12   -11.85264    -15.89919
 154 SEP PT                               -42.4752   -37.2120                 -5.26324     -7.06013
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APPENDIX E

SAMPLE BALANCE PRINTOUT

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WELLS 3


  FINAL            INIT1     INIT2     HALITE    CALCITE   DOLOMITE  GYPSUM    CO2

 68.800  NA       45.300    77.200     1.000      .000      .000      .000      .000
 14.500  CA       19.800    11.500      .000     1.000     1.000     1.000      .000
 16.700  MG       34.700    11.000      .000      .000     1.000      .000      .000
  1.600  CL        1.800     1.600     1.000      .000      .000      .000      .000
 61.200  S        86.400    49.300      .000      .000      .000     1.000      .000
 37.300  C        11.800    49.100      .000     1.000     2.000      .000     1.000
  1.000  MIX       1.000     1.000      .000      .000      .000      .000      .000


                      DELTA PHASES

                  INIT1          .2617
                  INIT2          .7383
                  HALITE        -.0523
                  CALCITE       -.8617
                  DOLOMITE      -.5019
                  GYPSUM        2.1916
                  CO2           -.1738
WELLS  4


  FINAL            INIT1     INIT2     HALITE    CALCITE   DOLOMITE  GYPSUM    CO2

 67.300  NA       45.300    77.200     1.000      .000      .000      .000      .000
 12.100  CA       19.800    11.500      .000     1.000     1.000     1.000      .000
 20.500  MG       34.700    11.000      .000      .000     1.000      .000      .000
  2.100  CL        1.800     1.600     1.000      .000      .000      .000      .000
 65.800  S        86.400    49.300      .000      .000      .000     1.000      .000
 32.100  C        11.800    49.100      .000     1.000     2.000      .000     1.000
  1.000  MIX       1.000     1.000      .000      .000      .000      .000      .000


                      DELTA PHASES

                  INIT1          .3240
                  INIT2          .6760
                  HALITE         .4352
                  CALCITE      -8.3907
                  DOLOMITE      1.8215
                  GYPSUM        4.4801
                  CO2           -.1676
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VITA

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Judtih Erlene Ausmus

Candidate for the Degree of

Master of Science

Thesis: THE HYDROGEOCHEMISTRY OF AN AREA STRIP-MINED FOR COAL, NEAR McCURTAIN, HASKELL COUNTY, OKLAHOMA

Major Field: Geology

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