

**A mining research contract report  
DECEMBER 1983**

# **Results in Jefferson County, Ohio: Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining**

**Contract Nos. J0166054 and J0166055  
United States Department of Agriculture  
Agricultural Research Service**

**and**

**The Ohio State University  
Ohio Agricultural Research and  
Development Center, Wooster, Ohio**

Bureau of Mines Open File Report 209-84

**BUREAU OF MINES  
UNITED STATES DEPARTMENT OF THE INTERIOR**



---

**DISCLAIMER NOTICE**

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U. S. Government.

---

<b>REPORT DOCUMENTATION PAGE</b>		<b>1. REPORT NO.</b> BuMines OFR 209-84	<b>2.</b>	<b>3. Reporting Agency No.</b> PB85 1492767AS
<b>4. Title and Subtitle</b> Results in Jefferson County, Ohio: Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining			<b>5. Report Date</b> Dec. 1983	
<b>7. Author(s)</b> C.R. Amerman, J.V. Bonta, T.J. Harlukowicz, G.F. Hall, N.E. Smeck, W.A. Dick, J.R. Page, and A. C. Razem			<b>8. Performing Organization Report No.</b>	
<b>9. Performing Organization Name and Address</b> U.S. Department of Agriculture Agricultural Research Service Box 478 Coshocton, OH 43812			<b>10. Project/Task/Work Unit No.</b>	
Ohio State University Ohio Agricultural Research and Development Center Wooster, OH 44691			<b>11. Contract(s) or Grant(s) No.</b> (C) J0166054, J0166055 (G)	
<b>12. Sponsoring Organization Name and Address</b> Office of Assistant Director--Mining Research Bureau of Mines U.S. Department of the Interior Washington, DC 20241			<b>13. Type of Report &amp; Period Covered</b> Contract research, 1/76--12/83	
<b>14. Supplementary Notes</b> Approved for release November 2, 1984.				
<b>16. Abstract (Limit 200 words)</b> <p>Watershed J11 in Jefferson County, OH, was instrumented in 1977 as one of three watersheds established for the purpose of investigating surface mining and reclamation effects on local hydrology, sediment discharge, and sediment and water quality. Each watershed was less than 50 acres in size, and was in a different geologic setting within southeastern Ohio. Surface runoff and ground water levels were monitored. Samples were taken for sediment determination and chemical analysis prior to mining. Monitoring and sampling continued throughout the period of watershed disturbance caused by mining and reclamation activities that began in May 1980. A pseudo-postreclamation period followed the initial cessation of human-machine activity on the watershed. A second reclamation effort occurred in the fall of 1981. A true final postreclamation period was not monitored at this site because the erosion control practice failed after each reclamation.</p>				
<b>17. Descriptive Analysis &amp; Descriptors</b> Mining research                      Surface mining impacts                      Precipitation quality Hydrology                                      Runoff quality Water quality                                      Reclaimed soils Ground water Sediment quality <b>18. Identifiers/Ordering Terms</b>				
<b>a. COSATI Field/Group</b> 081				
<b>19. Availability Statement</b> Release unlimited by NTIS.			<b>20. Security Class (This Report)</b> Unclassified	<b>21. No. of Pages</b> 177
			<b>20. Security Class (This Page)</b> Unclassified	<b>22. Price</b>



## FOREWORD

This joint report was prepared by the USDA-Agricultural Research Service, North Appalachian Experimental Watershed, Coshocton, Ohio and The Ohio State University-Ohio Agricultural Research and Development Center, Wooster, Ohio under USBM Contracts J0166055 (USDA-ARS) and J0166054 (OSU-OARDC). The contracts were initiated under the Mining Environmental Research Program. They were administered under the technical direction of the Denver Mining Research Center with Ms. Deborah P. Sherer acting as the Technical Project Officer. Ms. Gladys S. Barrera is the contract administrator for the Bureau of Mines.

The site report for Watershed J11 concerns the entire project period, during which hydrology and water quality were monitored in the premine condition and through active mining and reclamation.

The contracts were awarded for conducting research as proposed in a document presented jointly by the USDA-ARS, North Appalachian Experimental Watershed and The Ohio State University-Ohio Agricultural Research and Development Center: A Research Proposal--Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining in May 1975. The U. S. Geological Survey, the Soil Conservation Service, the Muskingum Watershed Conservancy District, the Utah State University, and three private mining companies are participants in the studies.

## PREFACE

The organizations and individuals contributing technical information to this report are as follows:

### USDA-Agricultural Research Service

C. R. Amerman	Project management, surface-water
J. V. Bonta	hydrology, erosion, and sedimenta-
T. J. Harlukowicz	tion and instrumentation

### The Ohio State University-Ohio Agricultural Research and Development Center

G. F. Hall	Physical characteristics of soils
N. E. Smeck	and geologic cores
W. A. Dick	Surface-water quality
J. R. Page	

### U. S. Geological Survey

A. C. Razem	Ground-water hydrology and quality
-------------	------------------------------------

### Soil Conservation Service

Assistance was received from SCS personnel in soil survey and engineering design work from the Area Office, Coshocton, Ohio and State Office, Columbus, Ohio.

The coordinating committee for the joint project at the time of this report consisted of the following members:

Gary McIntosh Technical Project Officer Bureau of Mines U. S. Dept. of the Interior	Faz Haghiri OSU-OARDC Coordinator The Ohio State University- Ohio Agricultural Research and Development Center
C. Richard Amerman Project Leader North Appalachian Experimental Watershed U. S. Dept. of Agriculture- ARS	Allan C. Razem USGS Coordinator Geological Survey U. S. Dept. of the Interior
Deborah P. Sherer (effective April 4, 1983) Technical Project Officer Bureau of Mines U. S. Dept. of the Interior	

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	5
PREFACE	6
ABSTRACT	14
SUMMARY	16
I. INTRODUCTION	20
II. DESCRIPTION OF WATERSHED J11, ITS PHYSICAL CHARACTERISTICS, MINING HISTORY, AND DATA COLLECTION	24
A. Introduction .....	24
B. Premining Conditions .....	24
1. Premining Soils .....	30
2. Premining Geology .....	30
3. Premining Vegetation .....	30
C. Mining and Reclamation Operations .....	30
D. Postreclamation Conditions .....	42
1. Postreclamation Soils .....	48
a. Topsoil .....	48
b. Subsoil .....	50
2. Postreclamation Geology .....	50
E. Collection and Organization of Data .....	51
III. SURFACE-WATER HYDROLOGY	65
A. Introduction .....	65
B. Weather Data .....	65
C. Soil Moisture .....	77
D. Surface-Water Runoff .....	77
1. Runoff Volume .....	83
2. Runoff Intensity .....	91
E. Summary .....	102

	<u>Page</u>
IV. SURFACE-WATER QUALITY	107
A. Introduction .....	107
B. Precipitation and Surface-Water Quality .....	107
C. Duration Curves .....	107
D. Concentrations of Other Water-Quality Parameters .....	112
E. Flow Rate Relationships .....	112
F. Correlation Study Results .....	116
G. Sediment Quality .....	120
H. Conclusions .....	122
V. GROUND-WATER HYDROLOGY	123
A. Premining Data .....	123
B. Postreclamation Data .....	123
VI. GROUND-WATER QUALITY	132
A. Premining .....	132
B. Postreclamation .....	132
VII. EROSION AND SEDIMENTATION	144
A. Introduction .....	144
B. Watershed Conditions and Sources of Sediment .....	144
C. Summary and Discussion of Sediment Data .....	144
1. Summary of Data Collected .....	144
2. Regressions .....	146
3. Temporal Variations of the Flow, Sediment Concentraion, and Sediment Load and Data .....	146
4. Comparison of Phases 2 and 3a .....	149
5. Comparison of Phases 1, 2, and 3a .....	151
D. Maximum Concentrations .....	151
E. Summary .....	151
REFERENCES	156
APPENDIX	159

## FIGURES

<u>Number</u>	<u>Page</u>
1. Location of study watersheds.....	22
2. Premined topography of Watershed J11.....	26
3. Premining oblique aerial photograph of Watershed J11.....	28
4. Premining soils map for Watershed J11.....	31
5. Stratigraphic column for Watershed J11.....	33
6. Schematic cross section illustrating premining ground-water occurrence and flow at Watershed J11.....	34
7. Schematic sections illustrating stripmining process.....	36
8. Timber of economic value was removed from wooded sections in the central and eastern areas of Watershed J11.....	38
9. Topsoil was removed and stored in two large stockpiles in the western (and lower) area of the watershed.....	38
10. Looking northwest into the watershed during the early stages of mining shows one of the first mining cuts.....	39
11. A base of operations was maintained in the northern half of the watershed while mining continued in the southern half.....	39
12. An access road from the east central border of the watershed was left in place while mining operations were continued outside the watershed to the south.....	40
13. The erosion control system was completed with a complex network of diversions and removal of the access road.....	40
14. Watershed J11 in the fully reclaimed state.....	41
15. Progressive transformation of Watershed J11 from its undisturbed to reclaimed state.....	43
16. Topographic map of Watershed J11 during Phase 2d.....	46
17. Topographic map of Watershed J11 during Phase 3a.....	47
18. Postreclamation soil sampling sites for Watershed J11.....	49
19. Hydrogeologic sections showing changes resulting from surface mining at Watershed J11.....	52
20. Relationships between monthly climatological parameters at Steubenville, Ohio and Watershed J11.....	66

FIGURES (Cont'd)

<u>Number</u>	<u>Page</u>
21. Adjusted average monthly air temperature (°F) at Watershed J11 with respect to the logarithmic-normal distribution of average monthly air temperatures at Steubenville, Ohio.....	68
22. Representative "goodness-of-fit" for average monthly air temperature at Steubenville, Ohio fit to a logarithmic-normal distribution.....	70
23. Comparison of cumulative precipitation amounts measured with an unshielded gage and computed catch.....	72
24. Relationships between unshielded and dual gage storm rainfall catches at Watershed J11.....	73
25. Adjusted total monthly precipitation (in) at Watershed J11 with respect to the logarithmic-normal distributions of total monthly precipitation at Steubenville, Ohio.....	75
26. Average monthly relative humidities at Watershed J11.....	79
27. Soil moisture ranges measured at premined soil profile sites in Watershed J11.....	80
28. Schematic illustration of direct runoff determination from a storm hydrograph.....	84
29. Variability of Soil Conservation Service curve numbers with the progression of mining of Watershed J11.....	87
30. Watershed J11 - daily flow-duration curves.....	90
31. Distribution of daily precipitation on Watershed J11.....	92
32. Double mass plot of Watershed J11 runoff vs precipitation.....	93
33. Representative hydrographs observed at Watershed J11 prior to, during, and after mining.....	95
34. Relationship of rate of rapid response discharge rate to maximum average 10-minute rainfall intensity.....	99
35. Relationship of peak discharge to maximum average 5- and 10-minute rainfall intensities.....	103
36. Duration curves showing the percentage of water samples having concentrations of suspended solids, pH, manganese, and iron above specified limits at Watershed J11.....	111
37. Duration curves showing the percentage of water samples having concentrations of magnesium, calcium, sulfate, and dissolved solids above specified limits at Watershed J11.....	113

FIGURES (Cont'd)

<u>Number</u>	<u>Page</u>
38. Relationship between log flow rate and calcium, magnesium, strontium, sodium, sulfate, bicarbonate, dissolved solids, and suspended solids concentrations during the premine and the partially reclaimed periods at Watershed J11.....	117
39. Hydrographs of water levels from the top and middle aquifers and precipitation at Watershed J11.....	124
40. Premining potentiometric surface of the top aquifer at Watershed J11.....	125
41. Premining potentiometric surface of the middle aquifer at Watershed J11.....	126
42. Postreclamation top aquifer saturated thickness at Watershed J11, March 1982.....	129
43. Postreclamation potentiometric surface of the middle aquifer at Watershed J11.....	131
44. Stiff diagrams showing distribution of water types in the premining condition at Watershed J11.....	133
45. Variations with time of selected constituents in the top aquifer at Watershed J11.....	136
46. Variations with time of selected constituents in the middle aquifer at Watershed J11.....	137
47. Water-analysis diagram showing premining water-quality characteristics at Watershed J11.....	138
48. Stiff diagrams showing distribution of water types in the postreclamation condition at Watershed J11.....	139
49. Water-analysis diagram showing postreclamation water-quality characteristics at Watershed J11.....	140
50. Average monthly or period sediment concentrations and flow and load rates for Watershed J11.....	148
51. Sediment concentration - flow rate data for Watershed J11.....	153

TABLES

<u>Number</u>	<u>Page</u>
1. Chronology of operations at Watershed J11 .....	25
2. Legend for map symbols .....	27
3. Physical characteristics of Watershed J11 .....	29
4. Premining soils in Watershed J11 .....	32
5. Cover in Watershed J11 prior to mining .....	35
6. Hydrologic and recorded weather parameters, frequency of measurement, and periods of record at Watershed J11 .....	55
7. Premining well information at Watershed J11 .....	57
8. Postreclamation well information at Watershed J11 .....	58
9. Description of surface-water samples collected at the Watershed J11 outlet .....	59
10. Summary of analytical methods and detection limits for surface- water quality analyses .....	61
11. Description of suspended sediment samples collected at the Watershed J11 outlet .....	64
12. Summary of observed monthly mean air temperatures at Watershed J11 .....	69
13. Comparison of relationships between event totals of precipitation measured by an unshielded rain gage and a dual rain gage at Watershed J11 .....	74
14. Summary of observed monthly total precipitation at Watershed J11 .....	76
15. Comparison of annual precipitation at Watershed J11 and Steubenville, Ohio .....	78
16. Precipitation delimiters for defining Soil Conservation Service AMC .....	85
17. Summary of average SCS Curve Numbers .....	88
18. Summary of durations of the rising portions of rapid responses ...	96
19. Percentage of high intensity storms producing rapid responses ....	97

TABLES (Cont'd)

<u>Number</u>	<u>Page</u>
20. Summary of rapid response durations as measured by the time difference between the occurrences of the half-peak discharge rate .....	101
21. Summary of important surface-water quality data obtained at the Watershed J11 outlet .....	108
22. Chemical analysis of precipitation at Watershed J11 .....	110
23. Detection levels and maximum concentrations of parameters in surface-water samples collected from Watershed J11 .....	114
24. Relationships between flow rate (in log values) and concentration of water quality parameters at Watershed J11 .....	115
25. Relationships between suspended solids and water quality parameters .....	118
26. Relationships between dissolved solids and water quality parameters .....	119
27. Summary of suspended sediment quality in samples collected at the Watershed J11 outlet .....	121
28. Results of aquifer and underclay tests at Watershed J11 .....	127
29. Premining chemical analyses of ground water collected from Watershed J11, August 1976 - July 1980 .....	134
30. Postreclamation chemical analyses of ground water collected from Watershed J11, October 1980 - August 1982 .....	141
31. Distribution of sediment samples obtained at Watershed J11 .....	145
32. Average monthly sediment concentration, flow rate, and load rate for Watershed J11 .....	147
33. Watershed J11 Phases 2 and 3a period averages of sediment-related parameters .....	150
34. Period averages for Watershed J11 Phases 1, 2, and 3a using constrained sediment data sets .....	152
35. Maximum sampled sediment concentrations and flows at Watershed J11 .....	154

## ABSTRACT

Watershed J11 in Jefferson County, Ohio was instrumented in 1977 as one of three watersheds established for the purpose of investigating surface mining and reclamation effects upon local hydrology, sediment discharge, and sediment and water quality. Each watershed was less than 50-acres in size, and was in a different geologic setting within southeastern Ohio. Surface runoff and ground-water levels were monitored. Samples were taken for sediment determination and chemical analysis prior to mining. Monitoring and sampling continued through the period of watershed disturbance caused by mining and reclamation activities, which began in May 1980 at Watershed J11. A psuedo-postreclamation period followed the initial cessation of man-machine activity on the watershed. A second reclamation effort occurred in the fall of 1981 and was to be followed by a third in 1982 after observations ceased. A true final postreclamation period was not monitored at this site, because the erosion control practice (terrace diversions) failed after each reclamation.

Watershed J11 was a small pasture and wooded watershed with sandstone and shale above the mined coal seam prior to mining. A clay layer under the coal supported a perched saturated zone, termed the top aquifer for convenience. A lower underclay supported a second saturated zone called the middle aquifer. A lower perched aquifer had been dewatered by previous deep mining. After about three years of premine data and about two and one-half years of mining-reclamation and psuedo-postreclamation data, the following general observations may be made:

1. The mining-reclamation phase was very short, and the postmining period was characterized by erosion failures and remedial disturbances that kept the watershed condition and size in a state of change. It was impossible to collect sufficient data to confidently characterize the hydrologic-sediment-chemical aspects of the mining period or of a postreclamation period and, most importantly, of the future watershed after its various properties and characteristics have ceased adjusting to its severe disturbance and reconstitution.
2. A seeding of wheat followed by grasses and legumes was not a particularly successful reclamation practice in terms of stabilizing the new soil. Numerous rills and small gullies developed in spite of installed diversions.
3. Storm runoff rates and yields at the watershed outlet increased from the premine, (Phase 1) to the mining-reclamation (Phase 2) periods, and remained at or near the Phase 2 level through the postreclamation (Phase 3a) period.
4. The top aquifer changed in physical and chemical character as a result of mining and was becoming reestablished as the project drew to a close; but it is impossible to predict its final configuration or character.
5. Dewatering of the top aquifer resulted in a complete cessation of baseflow because the middle aquifer water table lay below the elevation of the watershed outlet.

6. The top and middle aquifers were merged in one area of the watershed where the upper coal underclay was disturbed.
7. Failure of the diversion terraces and their outlet obscured the effects of the reclamation practice upon sediment concentration and yields. There was little difference in sediment concentrations between Phases 2 and 3a.
8. Drinking water standards were met by surface waters throughout the period of observation except for two samples that exceeded the nitrate-N allowable level of 10 mg/l.
9. In all Phase 3 surface-water samples, iron concentrations were within the limits established by OSM, and manganese concentrations exceeded the regulation level only once. pH fell below the lower regulation level of 6.0 between 10% and 20% of the time.
10. The chemical quality of sediments was generally about the same after reclamation as before mining, with the exception of organic carbon, which decreased.

## SUMMARY

In 1976, the United States Department of Agriculture, Agricultural Research Service (USDA-ARS), The Ohio State University-Ohio Agricultural Research and Development Center (OSU-OARDC), and the United States Geological Survey (USGS) jointly undertook a quantitative investigation of the impact of surface mining for coal upon surface- and ground-water hydrology, upon the chemical constituents of both waters, and upon the quantities and chemical characters of sediments. This study was financed by the U. S. Bureau of Mines, U. S. Department of the Interior.

The project design specified the establishment of three research watersheds, designated C06, M09, and J11, on lands owned by private individuals, privately-owned utilities, or privately-owned surface mining companies. The letter in the watershed designation refers to the Ohio county in which located, Coshocton, Muskingum, or Jefferson. The non-zero digit refers to the regionally-used number of the coal bed to be mined. Each of the new watersheds was established, prior to mining, on a different geologic sequence, all of them being common to the southeastern Ohio coal mining area. The main gaging station for each watershed was constructed on a relatively impervious material immediately downstream of the anticipated lowest point of disturbance during mining and reclamation operations. Observation wells, soil water content observation facilities, and climatic instrumentation were established prior to mining and maintained and monitored to the extent practicable throughout the study. Observations were divided into three phases. The premine period was called Phase 1, the period of active disturbance (mining and reclamation activities) was called Phase 2, and Phase 3 was used to refer to the postreclamation period.

At Watershed J11, Phase 1 began May 1, 1977, and Phase 2 started May 20, 1980. Phase 3 was not fully implemented before data collection ceased June 30, 1982. Conditions during the period after the end of mining varied from time to time as described below. Data for the first year of Phase 1 were reported by U. S. Bureau of Mines (21). This report discusses all data and observations at Watershed J11 throughout the period of the project.

### Physical Description and Changes

Prior to mining, Watershed J11 contained 29.1 Ac of primarily pasture land with some woodland and exhibited 150 ft relief. Four soil mapping units were delineated, about 80% of the area being Gilpin. Dry-weather stream flow (base-flow) was continuously maintained by discharge from a zone of saturation perched on a shaley clay bed underlying the coal to be mined. This zone was called the top aquifer. The No. 11 coal of the Monongahela Formation lay within this aquifer. The next lower saturated zone was called the middle aquifer. It was founded on an underclay beneath the Meigs Creek (Sewickley) No. 9 coal bed of the Monongahela Formation. An even lower saturated zone had been dewatered years ago during deep mining of the Pittsburgh No. 8 coal of the Monongahela Formation. Figure 6 of the main text of this report schematically illustrates the relation of the saturated zones to each other and to the watershed surface. Figure 5 shows the premine sequence of strata between coals. Top aquifer pre-mining ground-water quality was of the calcium bicarbonate and calcium sulfate types with sodium bicarbonate and calcium bicarbonate types in the middle aquifer.

Mining and reclamation operations disturbed 94% of the original watershed area. As mining progressed and was followed by reclamation activities, the topography of the watershed drastically changed, and the drainage area was first reduced, then expanded. The minimum size reached was 11.4 Ac. The area not disturbed lay primarily along a public road on the eastern boundary. Mining along this boundary terminated in a high wall; some of the coal under the high wall was removed by augering.

Reclamation was accomplished in three stages, each about a year apart in time, with the final stage being accomplished after observations ceased. Final relief was 126 ft. In the fall of 1980, a portion of the watershed was reclaimed and seeded to wheat. A haul road remained in place on the watershed. The rest of the area was regraded and topsoiled, but not seeded. Terrace diversions were installed as erosion control for the wheat-seeded, reclaimed area. The second reclamation effort was applied to the entire watershed. The haul road was removed. A new, expanded set of terraces replaced the first set. Terrace expansion resulted in increasing the watershed area by about 40% during this second reclamation, much of the added drainage area being undisturbed by mining. The terrace systems installed during both reclamation efforts failed, both in the terraces themselves and in their outlets.

The postreclamation watershed soils were somewhat complex, but were predominantly of the Fairpoint soil series in reclaimed areas. Chemical and physical properties of the soil widely varied, with pH of the subsoil ranging from 3.7 to 8.2. All sampled sites had at least one subsoil horizon with 60% or more coarse aggregates. Enduring vegetative cover may be hard to establish in parts of the watershed, and rather poor vegetative cover was achieved during the first two years after mining.

The top aquifer was destroyed in the process of removing coal. The original, consolidated rock was converted to a mixed-rubble spoil except behind the high wall, and was dewatered in the process. Observation wells had been destroyed at the onset of mining and had to be redrilled after regrading during reclamation operations.

#### Hydrologic and Water Quality Results

Because of the frequent surficial changes after mining began at Watershed J11 and because of the absence of a stable Phase 3 period of any length, opportunities to statistically evaluate the impacts of surface mining and reclamation were limited. However, a number of comparisons were made.

The reader should consider these results in conjunction with those reported for Watersheds C06 and M09 in Coshocton and Muskingum Counties, Ohio, respectively. This investigation was much too brief to yield definitive documentation of the long-term impact of such a profound disturbance as surface mining and reclamation. Only the early impacts could be detected. The reclaimed systems were still obviously changing as this study drew to a close.

Climatic Experience: Normalcy of temperature and precipitation experienced during the study was assessed based on the assumption that the two data sets fit logarithmic-normal (log-normal) distributions. In the log-normal distribution, the average value is the anti-logarithm of the observation having a 50% probability of being exceeded. In the context of this report, normalcy is a term expressing the concept that for a given quantity that fluctuates randomly,

there is a range of fluctuation that is not considered to be unusual, i.e., considered to be normal. For this investigation, the normal range was defined as data magnitudes having at least a 5% and no more than a 95% probability of being exceeded. For example, an average temperature of 20.6° at Watershed J11 for the month of January will be exceeded during 95% of all Januaries, but an average January temperature of 38.9° will be exceeded in only 5% of all Januaries. Two of the 62 months covered by the study period experienced average temperatures low enough to be below the normal range of variation (both during Phase 1). There were also two abnormally warm months, both after mining began.

Precipitation was generally above the log-normal average, with 1980, the year of active mining, exhibiting the highest annual precipitation of the study period. The six months of active mining all experienced above average rainfall. August 1980 and April 1981 had abnormally large amounts of rainfall. January 1981 was an abnormally dry month.

Surface Runoff: The effect of mining upon surface runoff was expressed as increased direct storm runoff (total runoff minus baseflow when present), by a three to four times faster response, and by about an order of magnitude increase in peak rates. During the period following mining, the runoff parameters appeared to shift somewhat toward their Phase 1 magnitudes, but remained close to the Phase 2 values.

Prior to mining, baseflow was supported by discharge from a perched water table as explained in a discussion of the geology of the area below. Mining dewatered this zone and stopped baseflow altogether. Baseflow had not resumed before observations ceased.

Ground Water: Observations at the time of drilling indicated that the new top aquifer had begun to develop only in a very rudimentary and incomplete form. Later, it was observed to be redeveloping not only in its original position over the shaley clay bed (which was mostly undisturbed during mining), but also on top the original land surface where the latter was covered by spoil. (Refer to Figure 19 in the main text.) In some areas, the shaley clay was apparently pierced, and the top and middle aquifers merged.

Sediment: Repeated failures in the postreclamation diversion terraces and diversion outlet are presumed to be the reason why postreclamation sediment concentrations were no better than those observed during Phase 2. Maximum sediment concentrations were 6060, 184,000, and 149,000 mg/l, respectively, for Phases 1, 2, and 3.

Chemical Water Quality (Surface Water): Chemically, surface waters met drinking water standards most of the time. Two samples exceeded the regulation level for nitrate-N of 10 mg/l.

Sixty and 85%, respectively, of the Phase 1 and combined Phases 2 and 3 samples exceeded the Office of Surface Mining (OSM) suspended solids regulation level of 70 mg/l. For these same phase groupings, about 10% and 20% of the samples, respectively, had pH values below 6. One sample collected during mining exceeded the OSM manganese level of 4000 µg/ml. No sample had iron concentration above the regulation level of 7000 µg/ml.

Antimony, copper, cyanide, lead, phenols, phosphorus, and zinc were observed in 10 or less samples. Arsenic, chromium, cadmium, mercury, silver, and sulfide were not detected in any surface-water samples.

Chemical Water Quality (Ground Water): Postreclamation ground water in the new top aquifer is generally of the calcium sulfate type; one well yielded a sample classified as calcium bicarbonate type water. Water quality in the middle aquifer did not change during the study period except in an area where the top and middle aquifers merged as a result of apparent disturbance to the clay bed. In this area, the top/middle aquifer water was of the calcium sulfate type.

Chemical Quality of Sediments: Organic carbon, manganese, calcium, lead, strontium, and phosphorus concentrations in the sediment material removed from Watershed J11 surface-water samples were higher during the premine period than during the active mining and reclamation or the partially reclaimed periods. Sulfate and nickel concentrations were highest and pH levels and zinc concentrations were lowest during the active mining and reclamation period. During the partially reclaimed period, parameters which were increased in concentration compared to the premine or the active mining and reclamation periods were aluminum, iron, and magnesium. Copper and sodium concentrations generally remained constant in samples collected during the different phases. Cadmium and mercury were not detected in any of the sediment samples analyzed.

Interpretation of Results: The conclusions reached on the effect of mining and reclamation on water quality are based on observations made over less than a two-year period after mining had been completed. During this period, the watershed underwent two changes in surficial character and area drained. At the end of observations, a final reclamation effort was yet to be made, changes in concentrations of several parameters were still slowly changing, and the final equilibrium concentrations of surface-water parameters could not be estimated from the results of this study.

The top aquifer was still actively redeveloping at the end of observations. Whether it will eventually begin again to contribute drainage to baseflow is still open to question. An open question is whether the sulfate character of the top aquifer will extend into its components located in spoil over the old land surface and to what extent contamination of the middle aquifer will continue. There is potential for baseflow, if it redevelops, eventually also to take on a sulfate character.

## I. INTRODUCTION

At the time of the inception of this project, surface mining of coal and other minerals was regulated by numerous state laws. The national law later to be adopted as PL 95-87, Surface Mining Control and Reclamation Act of 1977, was then under consideration. There were few data available upon which to evaluate old regulations or to base new ones. There was little information on hydrologic and water quality monitoring techniques under surface mining and reclamation conditions, and potential costs of these activities were unknown. Experience was needed in the application of hydrologic models for predictive purposes in the context of mining and reclamation.

To address some of the above mentioned short-comings and needs, a proposal entitled "Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining" was prepared in 1975 and submitted to the Bureau of Mines, U. S. Department of the Interior. The objectives contained therein were modified slightly and adopted in a 1976 plan of work. The objectives of this project are reproduced here:

1. Obtain complete hydrologic and water quality data from at least three watersheds 40-80 acres in size, for four years with one year of data obtained prior to surface mining, and from erosion and treatment plots for three years, and analyze the data.
2. Characterize the study watersheds and plots, and obtain physical and chemical data for the soils and overburden materials prior to surface mining and for the replaced topsoil and underlying spoil material following surface mining.
3. Describe the hydrogeology of the watersheds and the water-quality characteristics of the aquifer systems for pre and postsurface mining conditions, and develop or adapt a ground-water chemical transport submodel for simulation of the ground-water flow conditions and movement of solutes for the pre and postsurface mining condition.
4. Develop or modify a computer model for simulation of the hydrologic and water quality regimes of the study watersheds for both pre and postsurface mined conditions by incorporating mathematical representations of submodels for the water flow components and sediment and chemical transport with emphasis on selection of model parameters that can be reasonably acquired for non-study areas within the physiographic region for application of the model.
5. Determine costs to obtain the necessary physical, chemical, and hydrologic data, including legal and administrative costs, as required for surface mining permits as well as costs for obtaining these data at alternate degrees of accuracy and completeness; and determine costs and benefits of alternative degrees of control of runoff, sediment, and water quality.

6. Submit semiannual status reports, study phase reports and a final project report with documentation of research data and results, and cooperate with the Bureau of Mines in interpreting such data and results.

Personnel and funding restraints forced a cut-back in the length of time that data could be collected from the erosion and treatment plots and reduced the number of plots. These same factors plus a state-of-the-art factor led to dropping sediment modeling and chemical considerations from both ground- and surface-water modeling.

As outlined in the first objective, the project was organized in three phases: 1) premine, 2) mining-reclamation, and 3) postreclamation. The premine, Phase 1 condition ended with initial disturbance of a watershed when Phase 2 began. The latter ended and Phase 3 began when reclaimed watershed surfaces were seeded after the spreading of topsoil.

Five watersheds were initially selected for study. One of them, Watershed A06, to be left in the unmined state as a control, was on the USDA-ARS, North Appalachian Experimental Watershed near Coshocton, Ohio. This watershed was subsequently dropped from the investigation when analyses revealed its weaknesses as a control (Appendices, U. S. Bureau of Mines, 23, 24). The others were selected and instrumented prior to the onset of mining at the sites of operating surface mines in three Ohio counties. Figure 1 shows the locations of all watersheds. The numbers contained in the watershed designations are the numbers commonly used to designate the coal beds in the region. The four watersheds to be mined were all associated with different coal beds, thus differed geologically from each other as well as in other respects.

Economic conditions led to earlier-than-planned mining of two watersheds and severely delayed the mining of two others. Watershed J08, in fact, was never mined and was dropped from the study before data accumulation began.

A Phase 1 report (U. S. Bureau of Mines, 21) extensively describes the project design and contains premining data in detail for three watersheds, but gives the complete premining data set only for the two watersheds (C06 and M09) mined at the time of the report. There is also a separate Phase 1 summary (U. S. Bureau of Mines, 22).

Earlier reports, (U. S. Bureau of Mines, 21, 22, 23, 24; Hamon et al., 9; Helgesen and Razem, 11) include descriptions of premining (Phase 1) ground-water hydrology and describe the mining-reclamation (Phase 2) ground-water conditions at Watersheds C06 and M09. Cooper (4) described ground-water quality conditions at Watershed A06. Helgesen et al. (12) and Weiss (29) described ground-water models applied to the study watersheds.

Separate Phase 2 and 3 reports were submitted for Watersheds C06 and M09 (U. S. Bureau of Mines, 23, 24, 25, 26). This report is the final report for Watershed J11 and focuses on all three phases of the study. Mining occurred too late in the study period to warrant separate phase reports.

This and other project reports contain a mixture of English and metric units. English units predominate because they are widely used in the mining industry. Metric units were generally used in discussions of chemical water quality because of their predominance in that context.

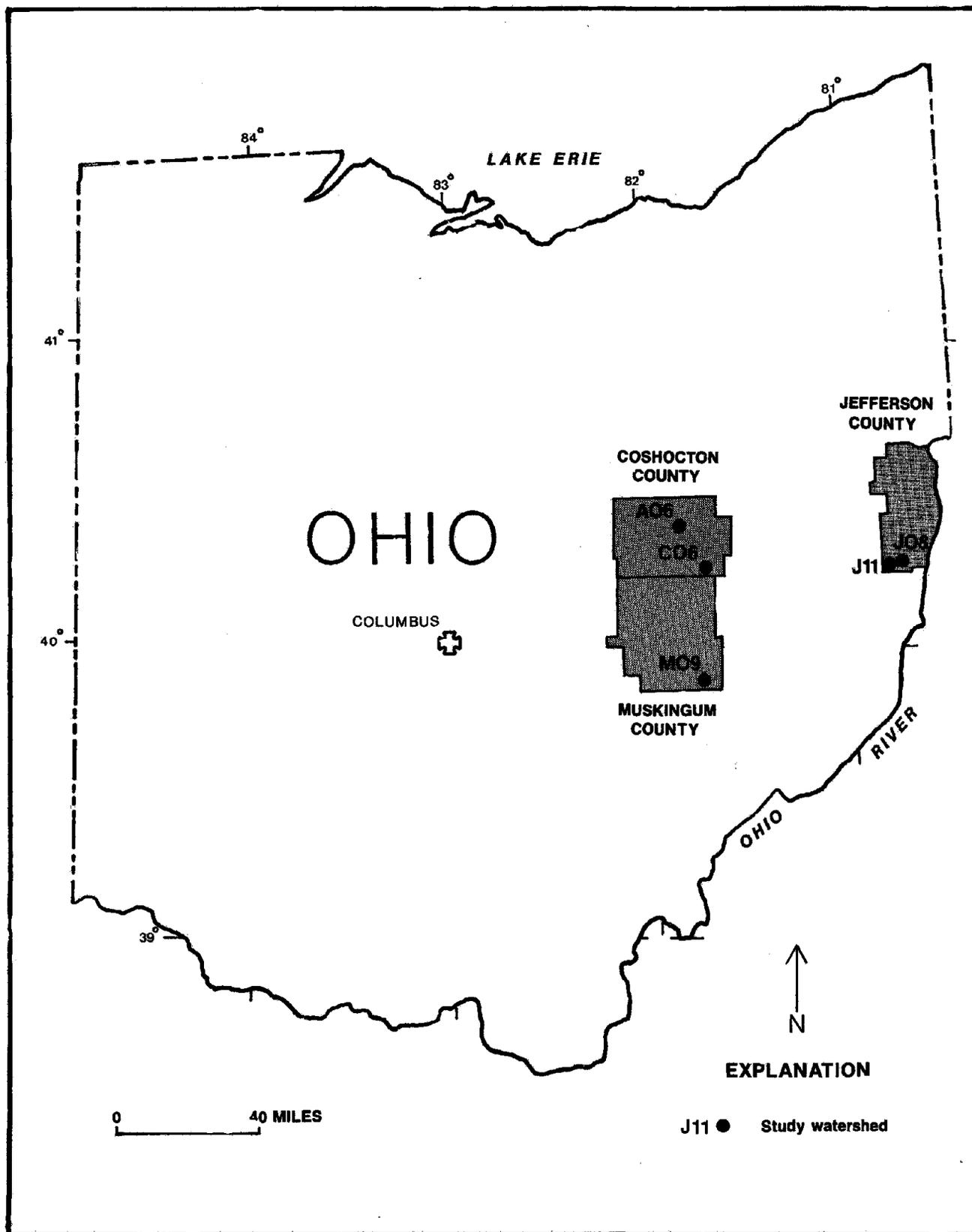


FIGURE 1. - Location of study watersheds.

For the convenience of those readers who prefer to use International System (Metric) units rather than inch-pound units, the conversion factors for terms used in this report are listed below:

TO CONVERT	TO	MULTIPLY BY
inch (in)	millimeter (mm)	25.4
foot (ft)	meter (m)	0.3048
mile (mi)	kilometer (km)	1.609
acre (Ac)	hectare (ha)	0.4047
gallon per minute (gal/min)	liter per second (l/s)	.06309
cubic foot per second (ft <sup>3</sup> /s)	cubic meter per second (m <sup>3</sup> /s)	.02832
micromhos per centimeter ( $\mu$ mho/cm)	microsiemens ( $\mu$ s)	1.0

## II. DESCRIPTION OF WATERSHED J11, ITS PHYSICAL CHARACTERISTICS, MINING HISTORY, AND DATA COLLECTION

### A. Introduction

Watershed J11 is located in the extreme southwest corner of Jefferson County, Ohio in Section 34 of Mt. Pleasant Township and was underlain by the Waynesburg (No. 11) coal of the Monongahela Formation. Prior to mining, the area experienced a long-term management practice limited to cattle grazing. An examination of soil cores taken within grassy areas showed evidence of a plow sole, and suggested the likelihood that tillage was part of the area's history.

Data collection at Watershed J11 commenced May 1, 1977 and was terminated for purposes of this report June 30, 1982. During that time, the watershed underwent profound disturbance as it was transformed from the undisturbed to the reclaimed condition.

As explained earlier in this report, the investigation was organized to analyze and compare data for three phases that may be roughly categorized as natural, disturbed, and reclaimed or, as generally designated in this report, premine, mining-reclamation, and postreclamation. Criteria for defining the beginning and ending of Phase 2 were given in Section I.

Table 1 shows the chronology of events on Watershed J11 and shows considerably more subdividing of data analysis/comparison periods than was originally visualized. The greater number of subdivisions was necessitated by interruptions in the reclamation schedule that resulted in there being two major reclamation efforts about a year apart in time. Unfortunately, final reclamation (removal of diversions) occurred after data collection for this report ceased, so the hydrology and water quality of the watershed in its final reclaimed state cannot be discussed herein. Phases 2d and 3a were characterized by a predominantly topsoiled, vegetated watershed surface, but also by diversions that affected both geometry of the watershed boundaries and surface-water flow patterns within the watershed. Erosion within the diversion channels and in the diversion outlets marked the effects of the reclamation practice during those periods.

The following sections describe the physical characteristics of the watershed before, during, and after mining; and the instrumentation employed to monitor the effects of mining on the hydrology and quality of ground water and surface runoff. An earlier report (U. S. Bureau of Mines, 21) gives somewhat more detail on premining conditions.

### B. Premining Conditions

A topographic map for the study site as it was prior to mining is shown in Figure 2. The legend of symbols used is shown in Table 2. An oblique aerial photograph of the watershed is shown in Figure 3. The natural/undisturbed column of Table 3 gives pertinent descriptive characteristics for the premining watershed.

The area was drained by a stream system which consisted of a well defined main channel, a less developed but major contributing ephemeral channel, and two poorly developed side channels that contributed intermittent flows. The main watercourse was borderline between ephemeral and continuous flow.

TABLE 1. - Chronology of operations at Watershed J11

Begin	Period End	Operation	Phase Designation
05/01/77		Data collection begins.	
05/01/77	05/19/80	Premine - pasture and wooded pasture.	1
05/20/80	08/22/80	Mine.	2a
08/23/80	10/03/80	Regrade; topsoil replacement, establish some diversions for erosion control.	2b
10/04/80	11/10/80	Fertilize and seed; some regrading and topsoil replacement continue.	2c
11/11/80	08/06/81	Stable period - partially reclaimed; haul road still in place; diversions and outlet significantly erode.	2d
08/07/81	09/28/81	Remove haul road, finish regrading, rework and extend existing diversions, and install new diversions. New seeding.	2e
09/29/81	06/30/82	Stable period, diversions in place; actively eroding diversions and outlets - some diversion terraces failed.	3a
06/30/82		Data collection ceases for purposes of this report.	

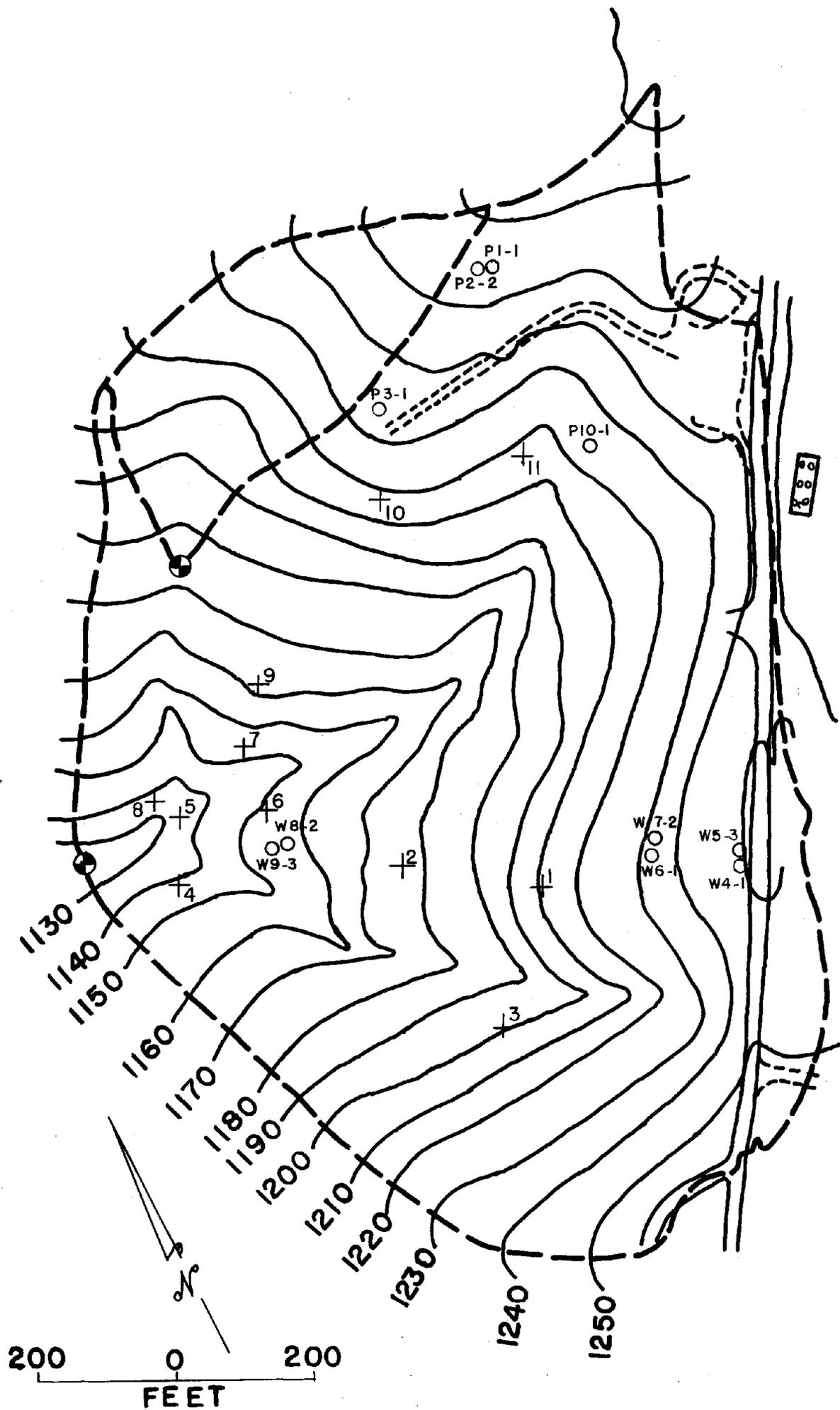
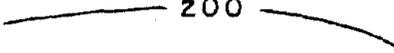


FIGURE 2. - Premined topography of Watershed J11. (See Table 2 for the legend.)

TABLE 2. - Legend for map symbols

---

INSTRUMENT PLOT	
CORE SITE	
OBSERVATION WELL (Last number represents aquifer numbered in sequence from top.)	<p data-bbox="1003 867 1094 892">W 8-2</p> 
GAGING STATION	
WATERSHED BOUNDARY	
INTERMITTENT STREAMS	
CONTOUR LINE	
COAL OUTCROP	
SOIL MOISTURE ACCESS TUBE	

---

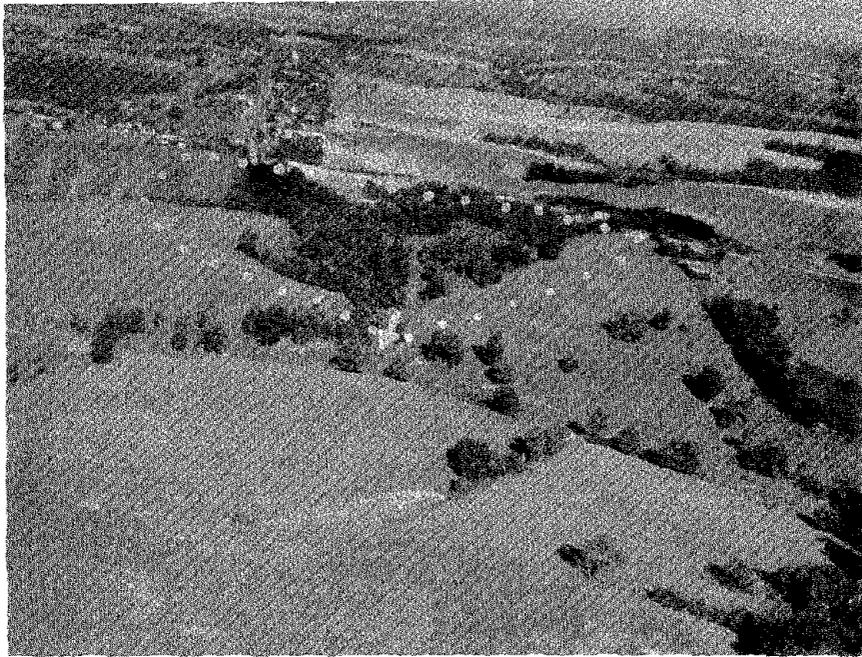


FIGURE 3. - Premining oblique aerial photograph of Watershed J11.

TABLE 3. - Physical characteristics of Watershed J11

Physical Characteristics	Watershed Condition			
	Natural/ Undisturbed	Actively Mined		Reclaimed
	Phase 1 <sup>1</sup>	Phase 2a,b,c	Phase 2d,e	Phase 3a
Area (Ac)	29.1	11.4 - 29.5	22.9 - 33.2	32.1
Aspect	W	W	W	W
Max. Elev. (ft) <sup>2</sup>	1285	1261	1261	1261
Min. Elev. (ft) <sup>2</sup>	1135	1135	1135	1135
Relief	150	126	126	126
Approx. Elev. of Coal (ft) <sup>2</sup>	1190	1190	1190	1190
Length of Main Watercourse (ft)	1140	300 - 1500	1500	1800
Max. Disturbance <sup>3</sup> (%)	0	91	82	76

<sup>1</sup>The time spans for each phase are shown in Table 1.

<sup>2</sup>Elevations are given with respect to sea level datum.

<sup>3</sup>Percent disturbance refers to the condition of land areas contributing runoff to the watershed outlet at a given time. Land shaping due to reclamation and the installation and later revision of diversions resulted in two separate instances of redirecting flows from undisturbed areas toward the outlet, with the percentage of included undisturbed land increasing during the second instance.

## 1. Premining Soils.

USDA-Soil Conservation Service personnel, using county and state soil legends, mapped Watershed J11 prior to mining. Figure 4 shows the distribution of these soils on the premined watershed. Table 4 identifies the soils, slope, and erosion and gives acreage.

Five sites were selected, and soils at these sites were sampled to characterize the watershed. Descriptions and data for the soils are given in the Appendix for the sites designated JF3-JF7. The locations are shown on Figure 4. Naming of the pedons sampled is based on the field descriptions and laboratory analysis. Naming of pedons does not in all cases agree with the field delineation. Remapping and reevaluation of the field delineations were not possible because the first stages of mining were underway by the time the laboratory characterization was completed.

## 2. Premining Geology.

Watershed J11 is in the unglaciated Allegheny Plateau region of southeastern Ohio. Stratigraphy (Figure 5) consisted of nearly flat-lying interbedded shale, sandstone, limestone, and coal of the Pennsylvanian and Permian system. Weathered rock and soil overlaid the bedrock in most places (U. S. Bureau of Mines, 21). The physical and chemical characteristics of the core taken at Watershed J11 are described in U. S. Bureau of Mines (21). The Waynesburg No. 11 coal bed of the Monongahela Formation cropped out near the middle of the watershed, whereas the No. 9 Meigs Creek (Sewickley) coal bed of the Monongahela Formation did not crop out in the watershed. The weir structure was founded on limestone at about the 130 ft level on Figure 5.

From a hydrologic standpoint, a pertinent aspect of the stratigraphy of the study area is that the coal beds are generally underlain by slowly permeable clays. Perched, saturated zones on these clays, resident in the fractures of the overlying coal and higher rock strata, discharge by leakage to lower zones and through springs and seeps to maintain dry-weather stream flow in the upland areas of the region. Figure 6 schematically illustrates the situation. At Watershed J11, the bed underlying the mined coal was a shaley clay.

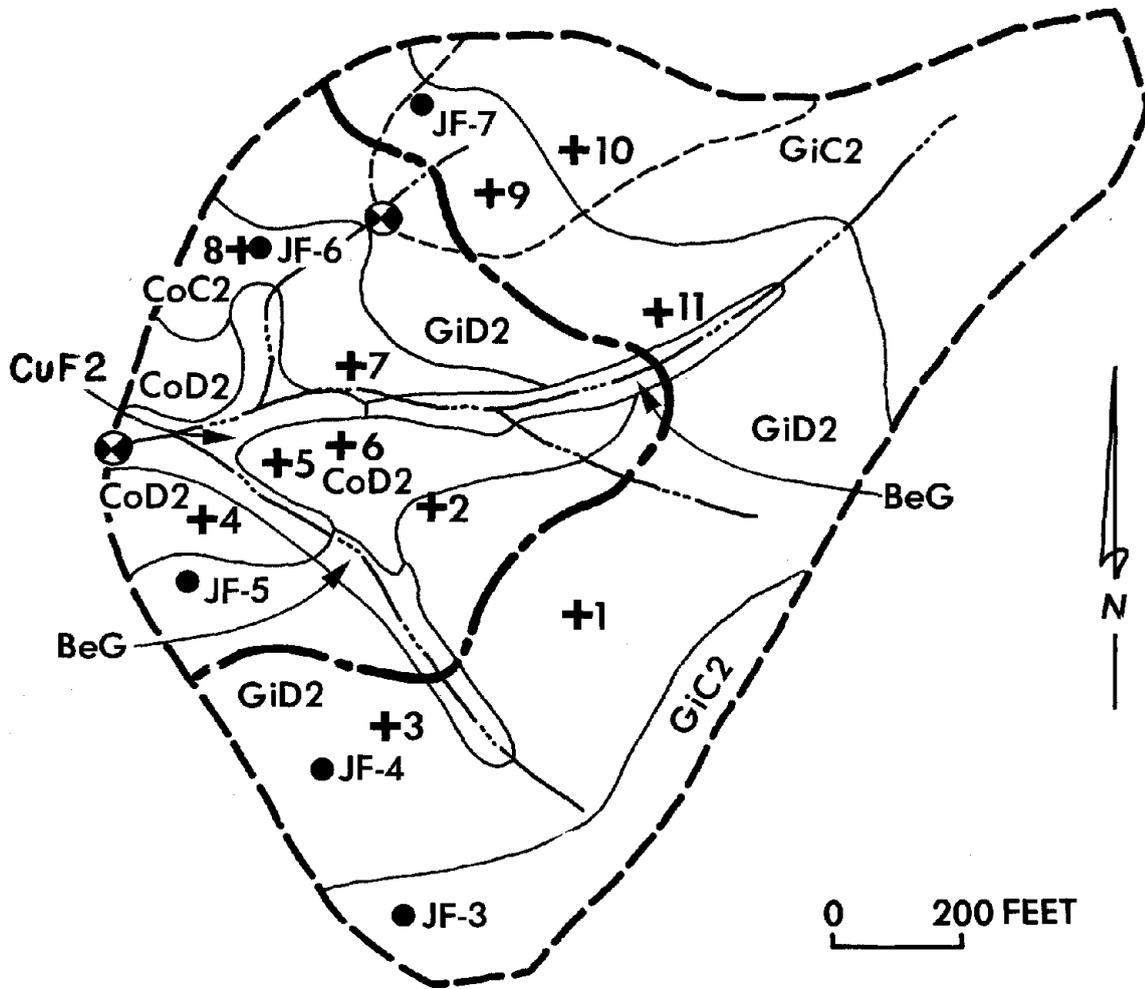
## 3. Premining Vegetation.

Much of the watershed was pasture or wooded. Tree species were all hardwoods. One small area was in cultivation. Vegetation was sampled at 11 sites; a summary of the results is given in Table 5.

## C. Mining and Reclamation Operations

Surface mining drastically altered this landscape. The topography and the upper geologic structure were destroyed as coal was extracted. During the active mining period, the shape and surficial characteristics of the watershed changed continuously. A haul-back method of mining was employed at the site after removing and stockpiling topsoil. In this method, a strip of coal was daylighted, and the coal was removed before proceeding into a new, adjoining strip. Spoil from each new pass was used to backfill cuts left in the wake of completed operations. Figure 7 illustrates the progression of events.

Portions of the unconsolidated material in the watershed were stockpiled and identified as "topsoil". No attempt was made to stockpile separate soil



- GiC2 Soil mapping unit
- JF-3 Soil sampling site
- +3 Soil moisture access tube
- ⊗ Weir
- - - Drainageway
- ~ Coal outcrop

FIGURE 4. - Premining soils map for Watershed J11.

TABLE 4. - Premining soils in Watershed J11

<u>Soil Code</u>	<u>Series</u>	<u>Slope-Erosion</u> <sup>1,2</sup> <u>Code</u>	<u>Hydrologic</u> <sup>3</sup> <u>Soil Class</u>	<u>Area</u> <u>(Ac)</u>
Be	Berks	G	C	1.1
Co	Coshocton	C2 D2	C	3.8
Cu	Culleoka	F2	C	0.9
Gi	Gilpin	C2 D2	C	23.3

<sup>1</sup>Slope Codes: C = 6-12%                      F = 25-35%  
                   D = 12-18%                      G = > 35%  
                   E = 18-25%

<sup>2</sup>Erosion Codes: 2 = plow layer has mixture of A and B horizons.  
                   No code present: Nearly level; no erosion.

<sup>3</sup>Hydrologic soil classification codes range from A to D where A pertains to soils of lowest runoff potential and D to soils of highest.

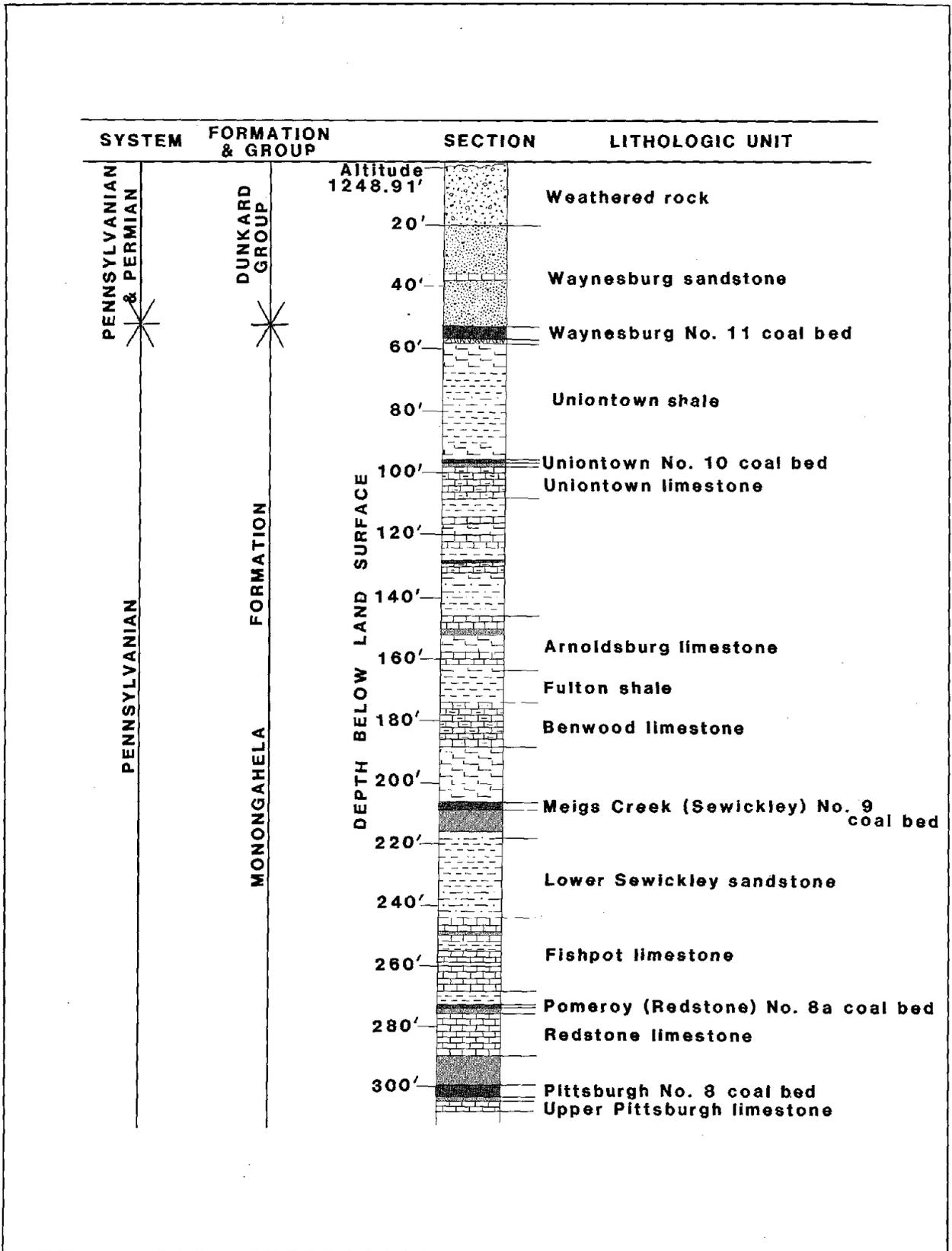


FIGURE 5. - Stratigraphic column for Watershed J11.

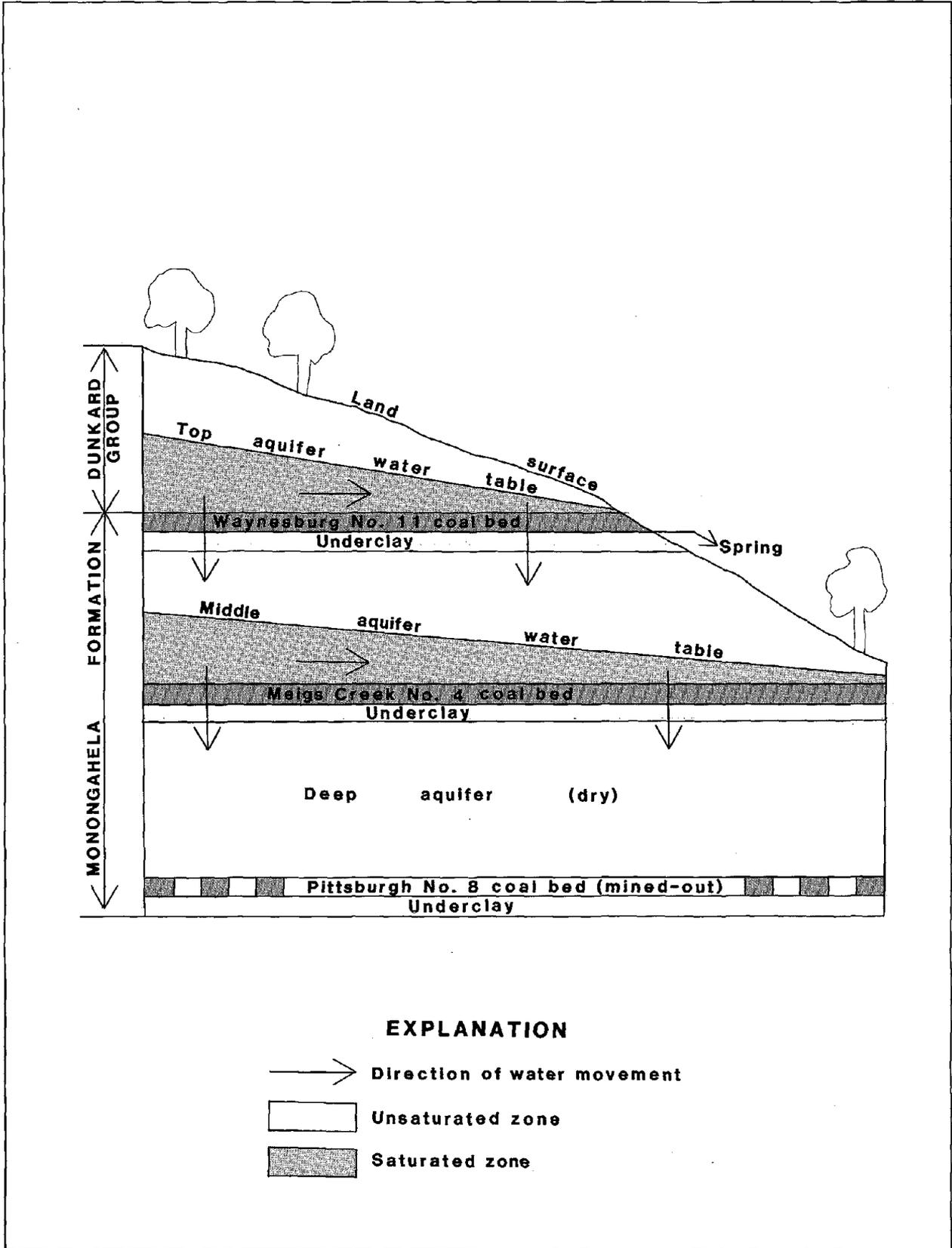


FIGURE 6. - Schematic cross section illustrating premining ground-water occurrence and flow at Watershed J11.

TABLE 5. - Cover in Watershed J11 prior to mining

Sawtimber <sup>1</sup> (>12" dbh)	Pole-Timber (6"-11" dbh)	Ground Cover				
		Woody Repro. (1"-5" dbh) No. Stems/Ac	Herbs % Woody % Duff %			
Net Volume Bd Ft/Ac (Doyle)	Net Volume Cords/Ac	Herbs %	Woody %	Duff %	Bare Soil and/or Rock %	
76	0.03	173	87	2	10	1

<sup>1</sup>Diameter at breast height.

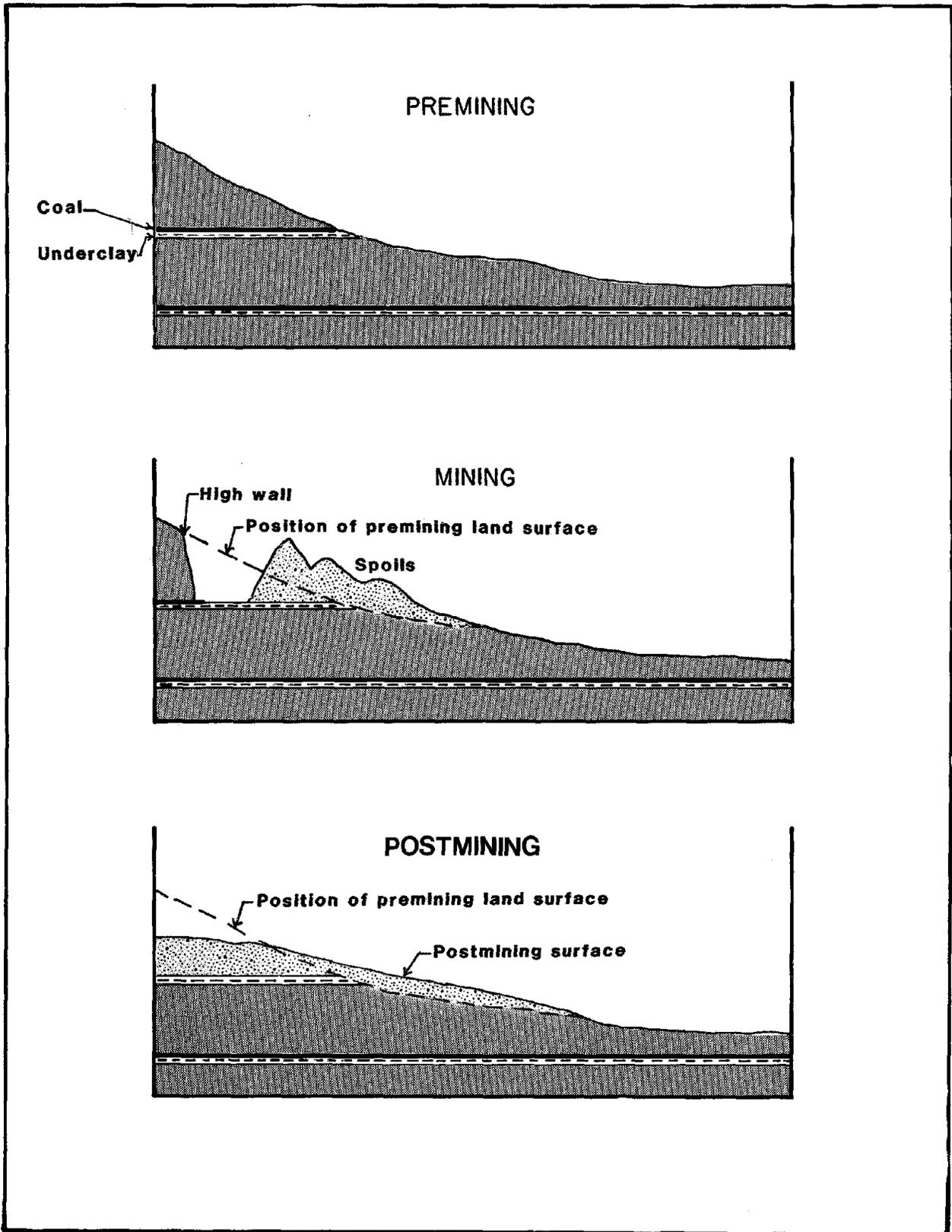


FIGURE 7. - Schematic sections illustrating stripmining process.

horizons. The surface materials in the watershed during mining consisted of piles of spoil materials made up of a mixture of preexisting soils and shattered bedrock. No attempt was made to determine the physical characteristics of these materials during Phase 2.

The spoil was later regraded to contours approximating the original watershed shape. Topsoil was spread; diversion terraces were built for erosion control purposes; and seed, fertilizer, and mulch were applied. Modifications were made to the erosion control diversion system during the two years following mining cessation.

The sequence of events that took place in the watershed during Phase 2 is shown in Figures 8-14, and is summarized as follows.

- a. Timber of economic value was removed from the undisturbed watershed. Activities associated with this operation were primarily confined to the heavily wooded areas along the drainage segment which extended from the central to the eastern fringe of the watershed (Figure 8).
- b. Topsoil was placed in two stockpiles, located to each side of the main drainage and below and to the west of the coal outcrop (Figure 9).
- c. The initial cut through the watershed was in an easterly direction, and bifurcated the watershed just to the north of the main drainage (Figure 10). The cut was terminated just west of the road forming the southeast boundary of the watershed. Mining proceeded in a northerly direction as the removal and stockpiling of topsoil was being completed in the southern half of the watershed (Figure 10).
- d. Coal removal was completed in the northern half of the watershed and adjoining areas further to the north (Figure 11). A temporary base of operations was maintained in the area as mining commenced in the southern half of the watershed.
- e. The mined watershed was partially reclaimed soon after all coal recovery operations were finished. An access road was left in place as a route to connect public roads with on-going surface mining activities to the south of the study site (Figure 12).
- f. Reclamation with an erosion control practice in place was completed with the removal of the access road and completion of the network of diversions (Figure 13).
- g. Final reclamation was completed with the removal of the system of diversions (Figure 14) shortly after data collection for this report ceased.

Five temporal-zonal classifications have been adopted in this study to describe the watershed status during the progression of mining and reclamation. The "natural" classification designates areas prior to the time when vegetation and topsoil removal began. The "disturbed" classification identifies areas during the times when they were partially or totally stripped of vegetation, subjected to vehicular or equipment traffic, and/or were stripped of topsoil. In these cases, the impact of mining on the physical features of the watershed was surficial. The "mined" classification applies to areas while they experienced complete destruction of the subsurface soil and geologic structures.



FIGURE 8. - Timber of economic value was removed from wooded sections in the central and eastern areas of Watershed J11.



FIGURE 9. - Topsoil was removed and stored in two large stockpiles in the western (and lower) area of the watershed.



FIGURE 10. - Looking northwest into the watershed during the early stages of mining shows one of the first mining cuts.



FIGURE 11. - A base of operations was maintained in the northern half of the watershed while mining continued in the southern half.

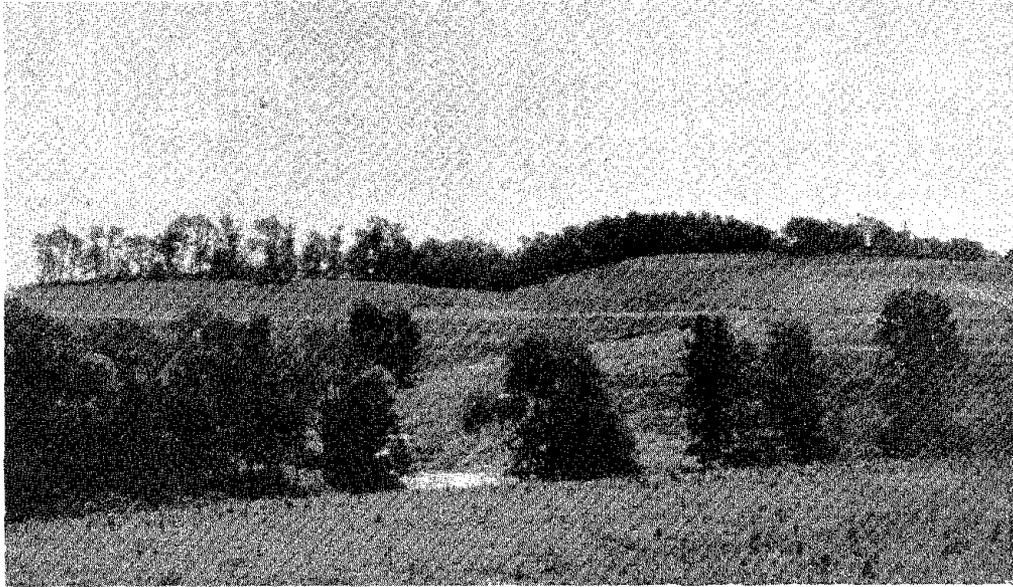


FIGURE 12. - An access road from the east central border of the watershed (starting at the upper left in the picture and running horizontally across the photograph) was left in place while mining operations were continued outside the watershed to the south (off the photograph to the right). The gaging station and sediment pond appear among the trees in the central foreground.



FIGURE 13. - The erosion control system was completed with a complex network of diversions and removal of the access road.



FIGURE 14. - Watershed J11 in the fully reclaimed state (viz. no diversions and final seeding).

Piles of spoil material, high walls, and irregular topography characterized these periods. The "graded" classification pertains to areas after coal removal had been completed and the spoil or topsoil material had been graded into what nearly constituted the reclaimed topography. Finally, the "reclaimed" classification designates areas after topsoil replacement, seeding, mulching, and fertilizing were completed.

The progressive transformation of the watershed from its natural condition through the mining and reclamation phases is shown as a series of maps in Figure 15. The delineations in the sequence were based primarily on field observations, and upon aerial photographs to a much lesser extent. Extensive field and aerial surveys were not attempted during the mining phase due to cost constraints and the rapidity of changes within the watershed. Consequently, the areas of the watershed and the zonal subdivisions in Figure 15 are approximate.

The watershed underwent drastic changes in runoff area during the mining and reclamation periods. Table 3 compares the ranges of physical characteristics observed during this period with those which described the natural state. Due to the uncertainty in the areal delineations, the term "probable runoff area" is used forthwith in place of "watershed area" whenever an areal delineation was not based on actual surveys.

For approximately two years following mining, the watershed experienced periods of partial reclamation. During the first year, diversions were installed to control erosion over the northern half of the watershed and a portion of the area to the south. An access road was left in place to accommodate traffic to other areas being mined to the south. Figure 16 is a topographic map of the study site during this period. Because of the extensive diversion network, the watershed included additional (natural and disturbed) acreage outside the boundary of the original natural watershed.

Removal of the access road and completion of the diversion network a year after mining ceased again changed the shape of the watershed and its drainage features. Figure 17 shows the impact on the topography. The drainage area again increased once the entire erosion control system was in place.

Removal of the terrace system and final reclamation occurred after data collection ceased.

Neither set of diversions was particularly effective for erosion control. Vegetative cover was generally poor, and rill erosion was evident in the areas between diversions. The diversion channels themselves eroded, and the outlet for the diversions, which discharged into the stream channel near the watershed outlet, severely eroded. The diversion terraces also overtopped on several occasions.

#### D. Postreclamation Conditions

Although a final postreclamation state was not actually achieved prior to the end of data collection, certain aspects of the postreclamation character of the watershed had been substantially established by the beginning of Phase 2c.

After the end of data collection for this report, the primary effects of further reclamation would be a reduction in size of the watershed, a redefinition of the watershed surface drainage pattern as the diversions are removed,

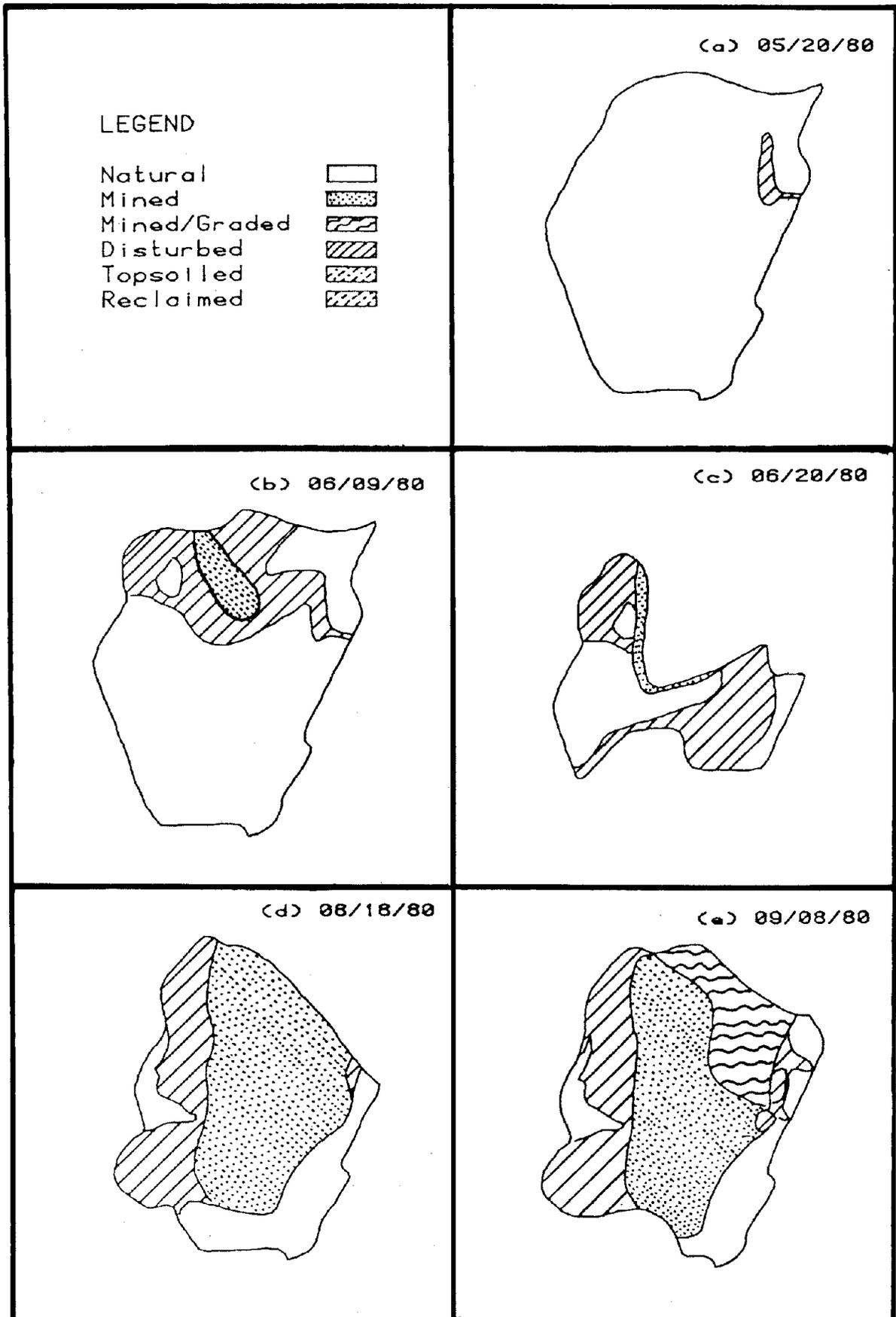


FIGURE 15. - Progressive transformation of Watershed J11 from its undisturbed to reclaimed state.

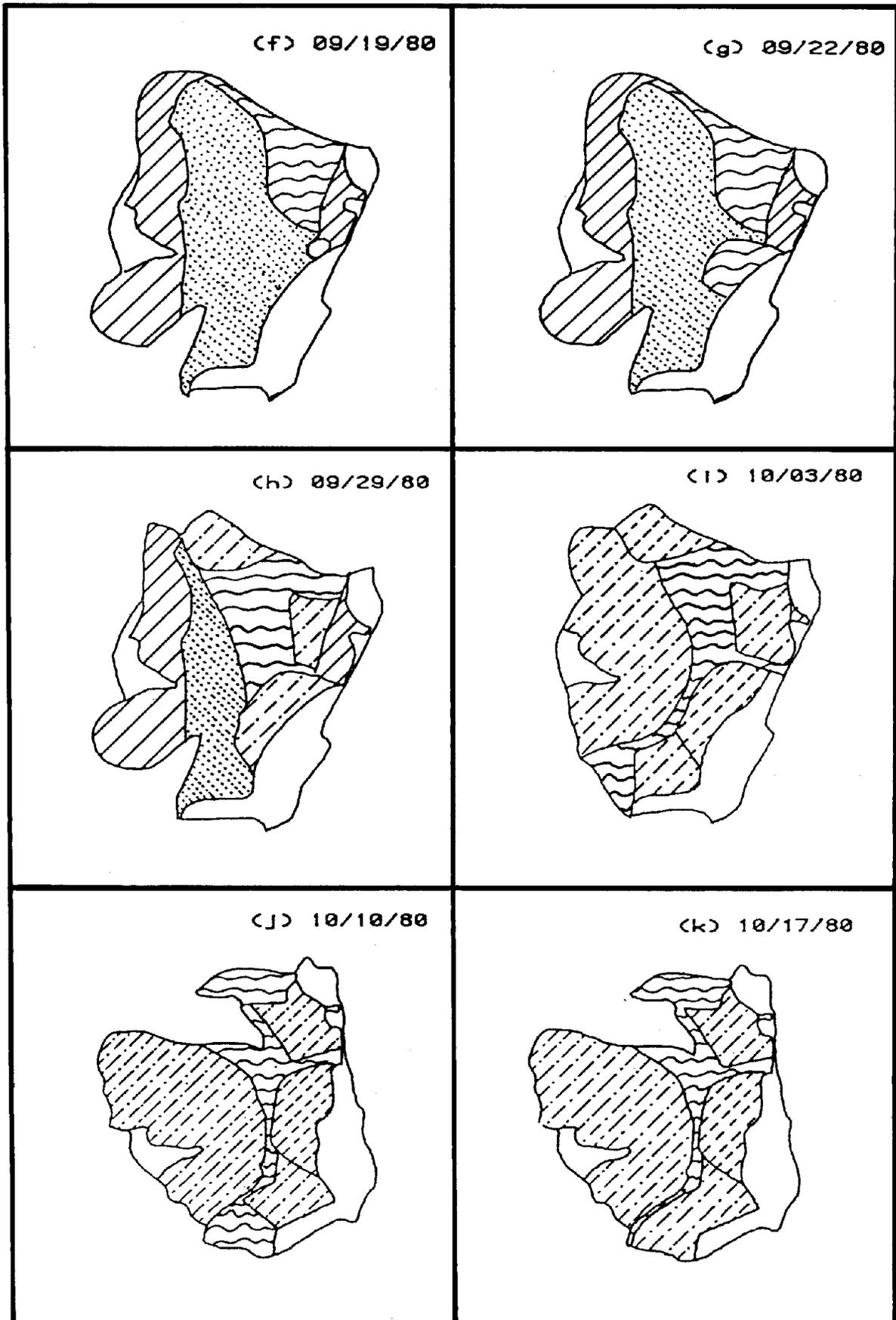


FIGURE 15. (Cont'd) - Progressive transformation of Watershed J11 from its undisturbed to reclaimed state.

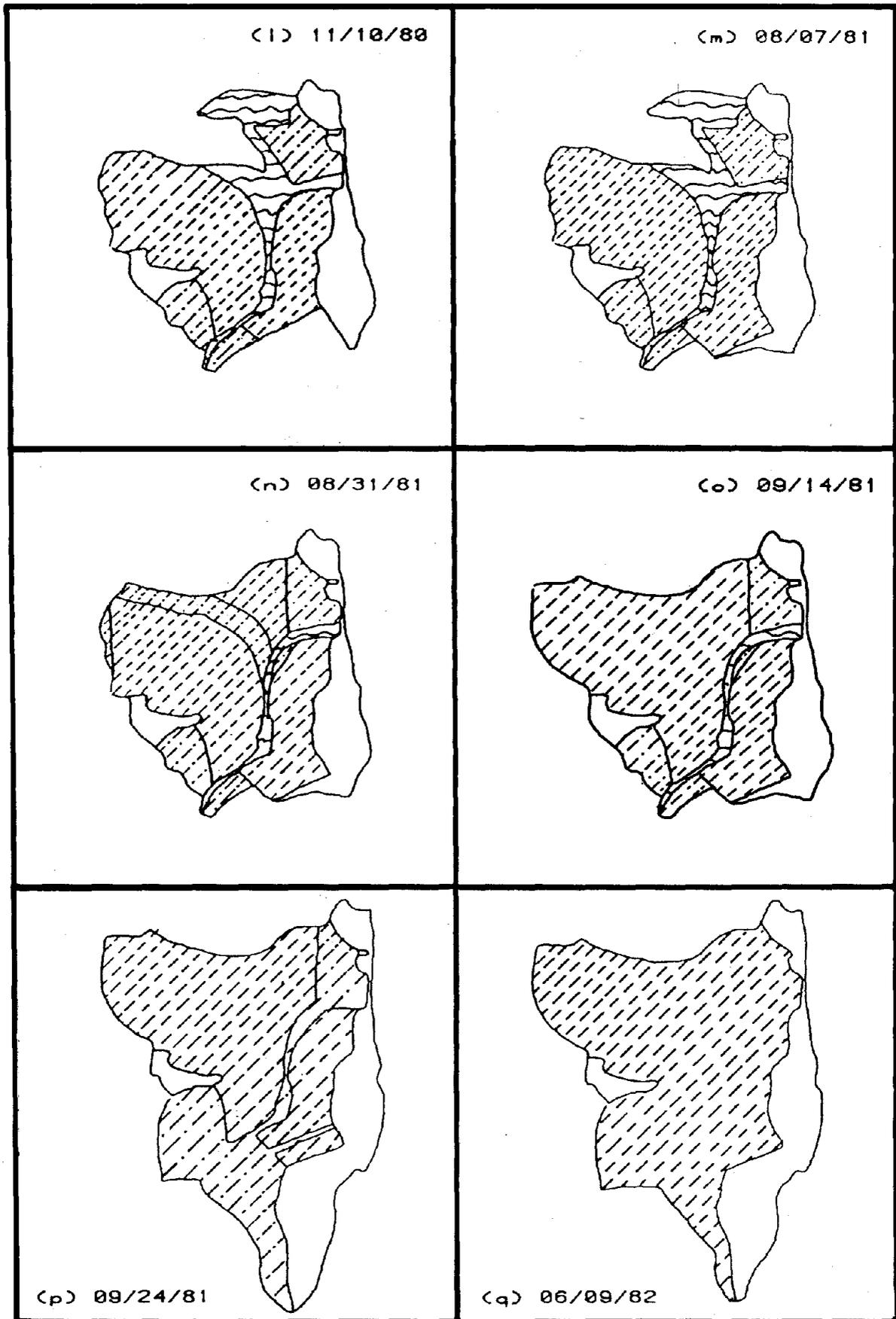


FIGURE 15. (Cont'd) - Progressive transformation of Watershed J11 from its undisturbed to reclaimed state.

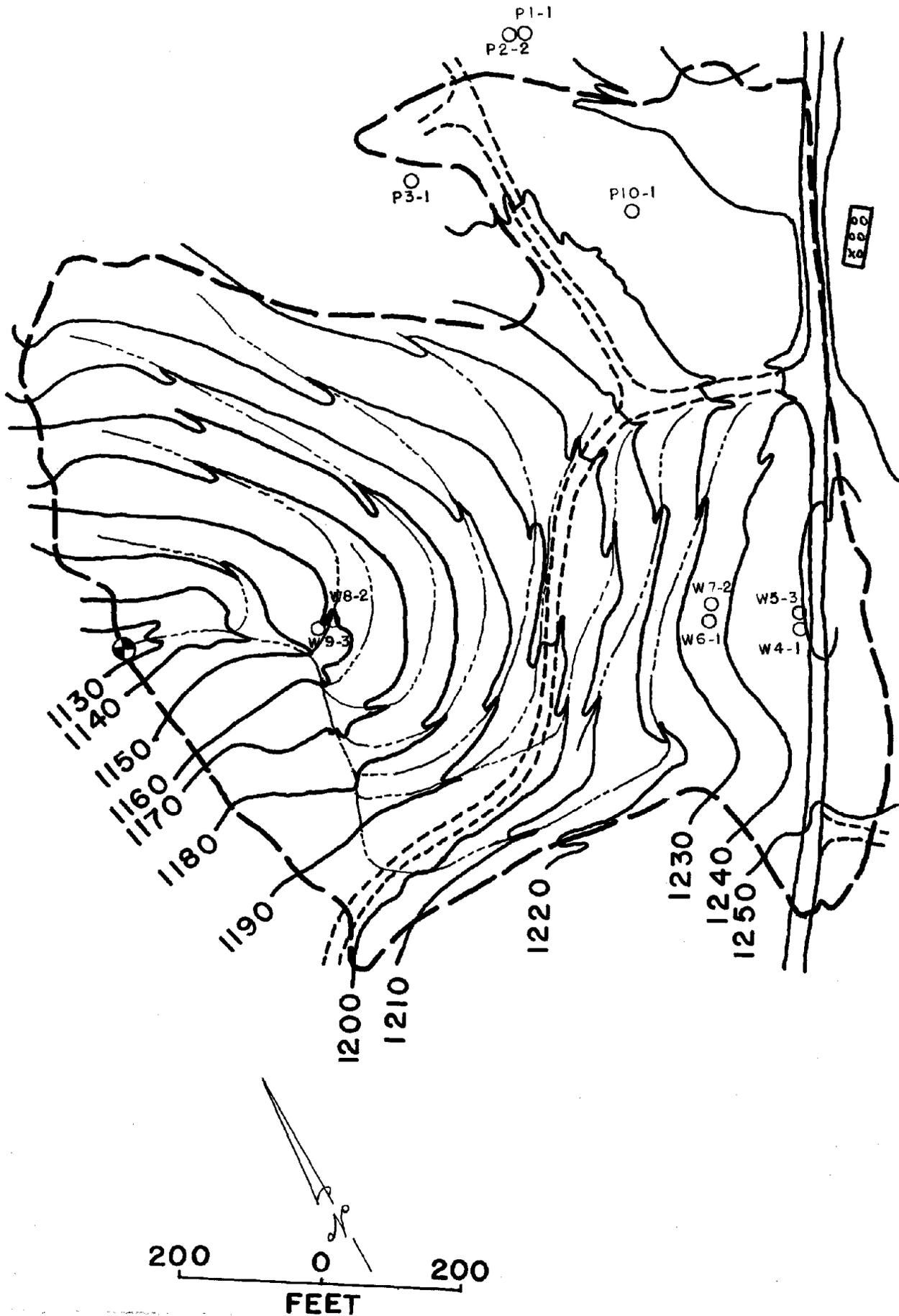


FIGURE 16. - Topographic map of Watershed J11 during Phase 2d.

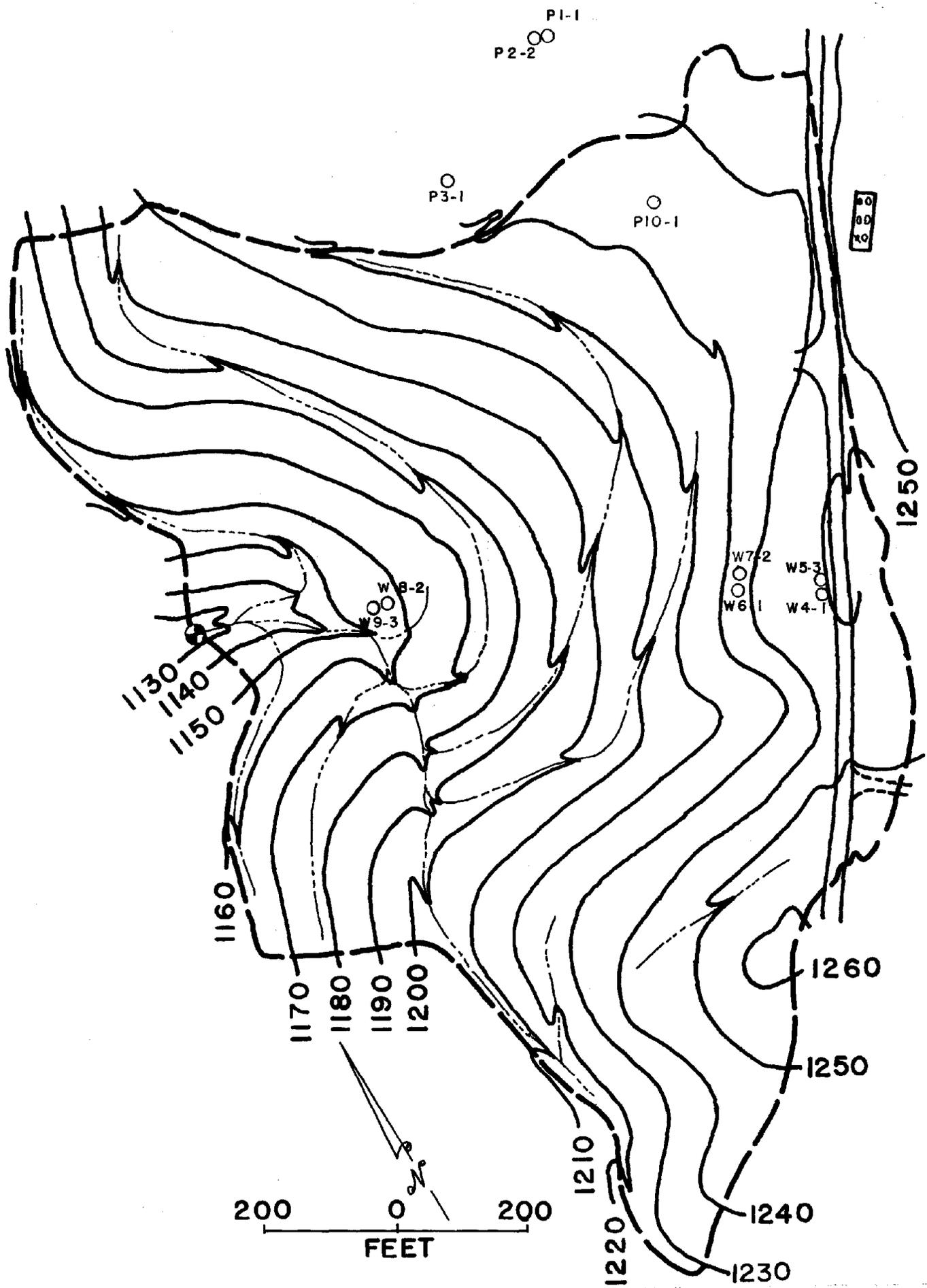


FIGURE 17. - Topographic map of Watershed J11 during Phase 3a.

and elimination of substantial sources of sediment. Thus, there is potential for considerable modification to surface runoff and water quality after final reclamation.

#### 1. Postreclamation Soils.

Following reclamation and topsoiling the soils in the watershed were mapped by personnel of the Ohio Department of Natural Resources (Division of Lands and Soils) using standard soil survey techniques. Soils in reclaimed stripmine areas in Ohio are identified as belonging to one of four soil series that have been established for mined areas and placed in the national series. These four soil series cover a full range from acid and toxic soils to mildly alkaline soils having free carbonate present in all horizons. From most alkaline to most acid, they are Morristown, Fairpoint, Bethesda, and Barkcamp, respectively.

Mapping of the watershed soils showed that there was a complex mixture of soil series. The dominant soil was Fairpoint with complex inclusions of Bethesda. Because the Bethesda soil areas were small and intricately mixed with the dominant Fairpoint, it was decided to identify the entire watershed as Fairpoint, but recognize that there were many inclusions of Bethesda. A few very small areas of Morristown may also be present in the watershed.

Following the mapping, four sites were selected to represent the various slopes and landscape positions in the reclaimed watershed (Figure 18). Pits were dug at the four sites, pedons described and samples taken for characterization. Descriptions and sampling were to a depth of 50-60 in, which exceeds the depth of rooting of most crops grown in the area. Evaluation of the field descriptions, plus the laboratory data from the pedons, led to the determination that two of the pedons could be classified as the Fairpoint series. The Fairpoint soil is a loamy skeletal, mixed, nonacid, mesic, Typic Udorthent. The other two pedons were classified in the Bethesda series. The Bethesda soil is a loamy skeletal, mixed, acid, mesic, Typic Udorthent. Descriptions and data for these four postmining pedons are given in the Appendix; identified as sites JF8-JF11.

Overall field mapping and sampling suggest that the soils of Watershed J11 are more variable than in the other two watersheds studied. In general the surface has a relatively high plant available moisture capacity. The surface pH values, though not high, are not low enough to hinder plant growth except for one site. Liming of the watershed after these samples were taken should have raised the pH levels to an even more desirable range. Subsoil horizons having large quantities of coarse skeletal material and lower pH values in places may limit plant growth.

##### a. Topsoil.

Topsoil thickness over the watershed appeared to be rather uniform. In the pedons sampled topsoil thickness ranged from 10 in at JF-10 and JF-11 to 13 in at JF-9. Surface textures ranged from silt loam to silty clay loam with a range in clay content from 22% to 28%. A range in clay content this narrow is considered unusual for mining topsoil. A wider range undoubtedly occurs over the watershed. Coarse skeletal (diameter greater than 2 mm) material was relatively high in all the soils sampled. Site JF-10 had 20% to 25% coarse material in the surface. This could create tillage problems; however, a portion of the material is shale and will disintegrate in a few years. Surface

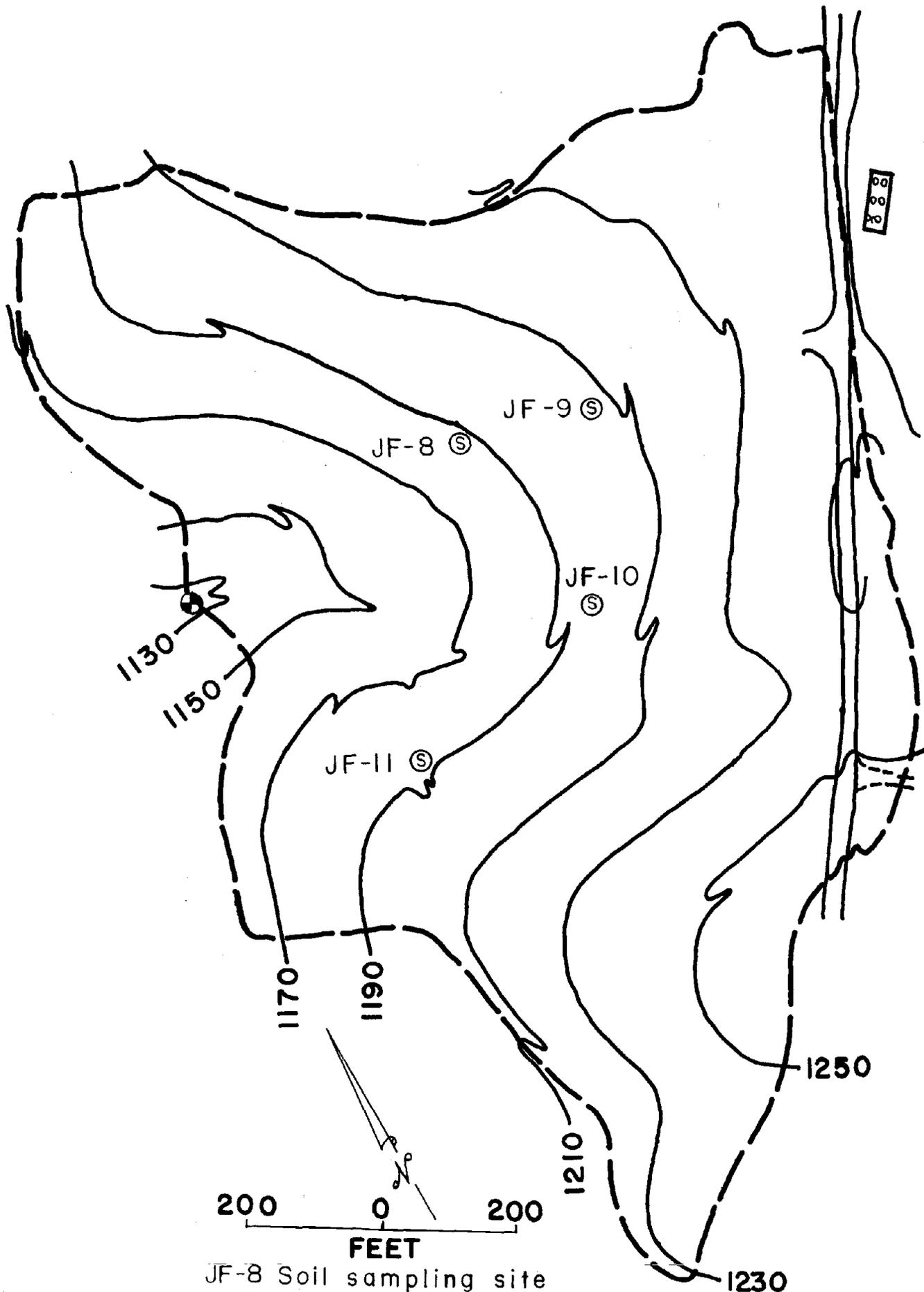


FIGURE 18. - Postreclamation soil sampling sites for Watershed J11.

pH's were lower than expected, ranging from 4.6 to 6.0 (1:1, H<sub>2</sub>O). This suggests that inadequate lime had been applied to the watershed prior to the time of sampling. The textures suggest that the plant-available moisture should be in the range of 0.12 to 0.16 in/in. These values are comparable to many natural topsoils in the area. Sulfur values were relatively low. The highest value for sulfur (0.14) was in the surface horizon with the lowest pH (4.6). Organic carbon contents in the surface were in the 0.5% to 0.8% range which is less than half that expected in many unmined soils, but is similar to contents found in reclaimed soils that includes an original topsoil component.

#### b. Subsoil.

Subsoil or spoil underlying the topsoil is highly variable in both physical and chemical properties. The most obvious variable property is the amount of material larger than 2 mm in diameter. Because of its size, it is difficult to sample and determine the actual percentage. The field estimates listed in the descriptions in the appendix are probably more accurate than the values shown in the laboratory data table. Field estimates for coarse skeletal material in the subsoil show a range from 20% to 75% by volume. Horizons with over 50% will limit rooting because of the physical impedance and a lowering of plant available moisture. At Watershed J11 all subsoil horizons had 45% or more coarse skeletal material. Texture of the less than 2 mm material was also highly variable. Textures ranged from silt loam (17% sand) to sandy loam (70% sand). Clay content in the 19 subsoil horizons sampled was, with one exception, always less than 28%. Silt content, which is positively correlated with available moisture holding capacity, ranged from 22% to 60%. As with all the other properties the subsoil pH had a wide range. The pH values (1:1, H<sub>2</sub>O) ranged from 3.5 in JF-10 to 8.2 in JF-11. Site JF-11, with carbonates in all but one subsurface horizon, comes very close to the Morristown soil in classification. Values for organic carbon are highly variable. This variability is attributed to mixing of the shale (and possibly coal) rather than from organic matter from the soils on the premining landscape. Sulfur values are not high; the highest value (0.64) is in JF-9 where it is associated with a horizon with 2.6% carbonate.

Of the sites studied in Watershed J11 the Fairpoint soil at site JF-9 would be the most desirable for revegetation. It has the lowest amount of coarse skeletal material, moderate pH values throughout, and a high content of silt down to 41 in. The poorest soil for revegetation would be the Bethesda at site JF-10. Root growth below the topsoil at this site will be very limited by the extremely acid (pH 3.7) and very coarse (50% CS) horizon immediately below the A1 horizon.

As a result of the complex distribution of soils on Watershed J11 and the variable physical and chemical properties of the soils, this watershed will probably present problems in long-term revegetation.

## 2. Postreclamation Geology.

Mining involved stripping the overburden, removing the coal, and replacing the overburden to the approximate premining configuration (Figure 7). The entire top aquifer was not destroyed, however, because nearby dwellings and roads restricted the mining area. In the vicinity of Wells W6-1 and W7-2, the coal was removed by augering, which did not disturb the overburden material. After mining, the stratigraphic section consisted of a top aquifer of spoils

material on top of the shaly underclay and undisturbed bedrock in the unmined and augered areas (Figure 19). The middle aquifer below the Waynesburg No. 11 coal bed of the Monongahela Formation was undisturbed, except that some areas downhill from the mined coal outcrop were covered with a layer of spoil material.

#### E. Collection and Organization of Data

The data collection system that was installed to quantify the impacts of surface mining on the hydrology, and quality of surface runoff and ground water before, during, and after mining was designed to provide the following information (Figure 2 shows the location of premining instrumentation).

- a. A continuous record of runoff at the watershed outlet. (Prior to mining, runoff from a 3.5-Ac area, located on one of the smaller tributaries to the main waterway was also continuously recorded.)
- b. A continuous record of precipitation on the watershed.
- c. Continuous records of temperature and relative humidity.
- d. Hourly average values of solar and net radiation.
- e. Ground-water level observations.
- f. Discrete samples of ground-water quality on a seasonal basis.
- g. Concentrations of suspended sediment during periods of storm runoff.
- h. Suspended sediment concentrations in baseflow.
- i. Concentrations of chemical constituents present in storm runoff and baseflow.
- j. Soil moisture profiles at discrete depths and times at various points within the watershed.

Originally, a 2.5-ft H-flume was used to gage flow at the watershed outlet. The design was in accordance with standard specifications (U. S. Department of Agriculture, 27). A water-level recorder recorded depth of flow as a function of time. Timer resolution was varied during the course of the study and ranged from 30 min per chart division to 7.5 min per chart division.

The 2.5-ft H-flume was replaced by a 1.2-ft drop-box weir on May 23, 1980. The design was a geometrically scaled-down version of a prototype described by Johnson et al., (16). The same water level recording device was used. Its timer resolution was varied during the remainder of the study and ranged from 7.5 min per chart division to 4.0 min per chart division.

Runoff from the 3.5-Ac premine watershed was gaged with a 0.8-ft drop-box weir. The same type of recording device as the one employed at the watershed outlet was used at this installation.

A pair of 8-in weighing bucket rain gages measured and recorded the time history of accumulated precipitation. One of the devices was equipped with a wind shield, designed to improve catch efficiency. Two sets of breakpoint

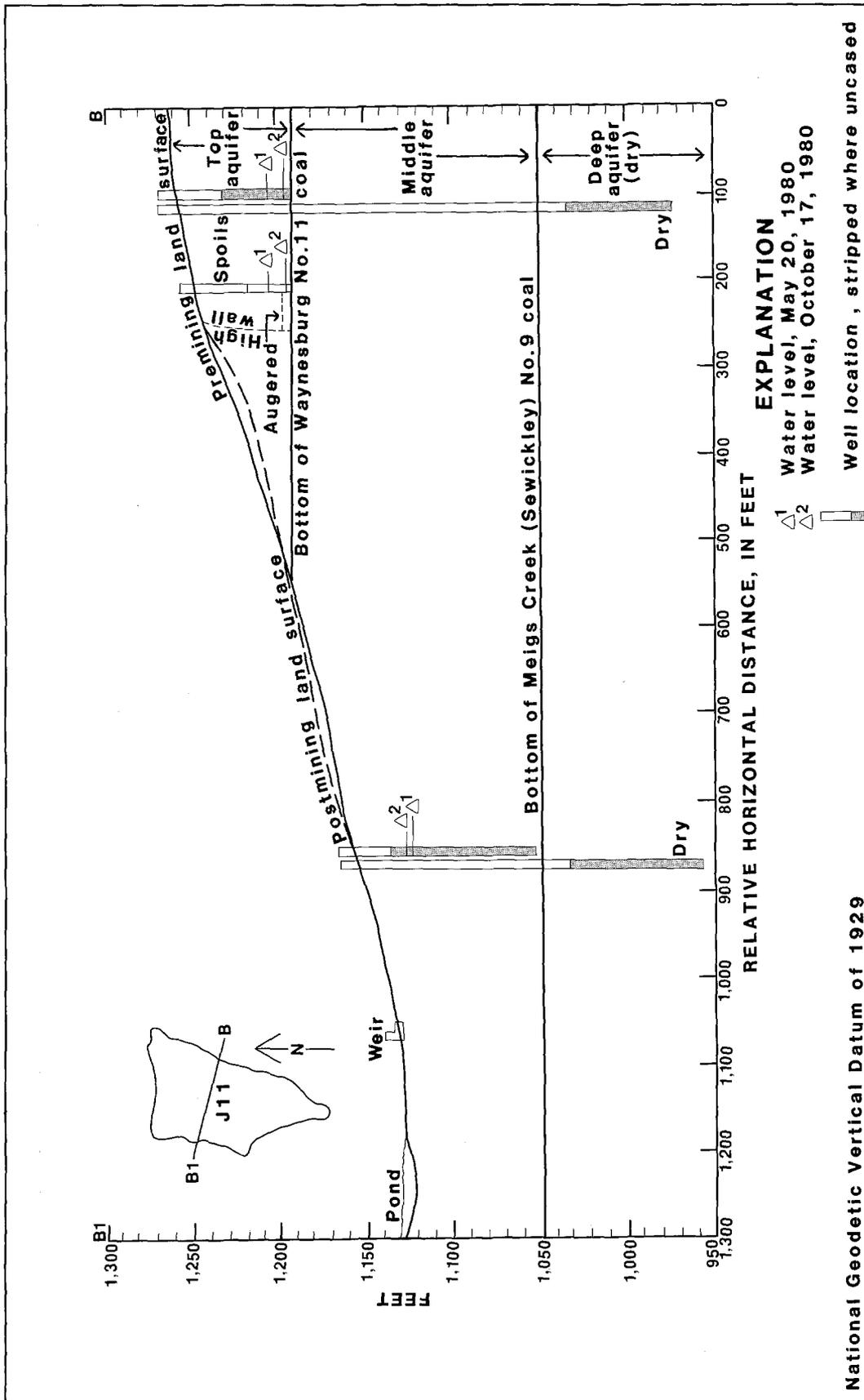


FIGURE 19. - Hydrogeologic sections showing changes resulting from surface mining at Watershed J11.

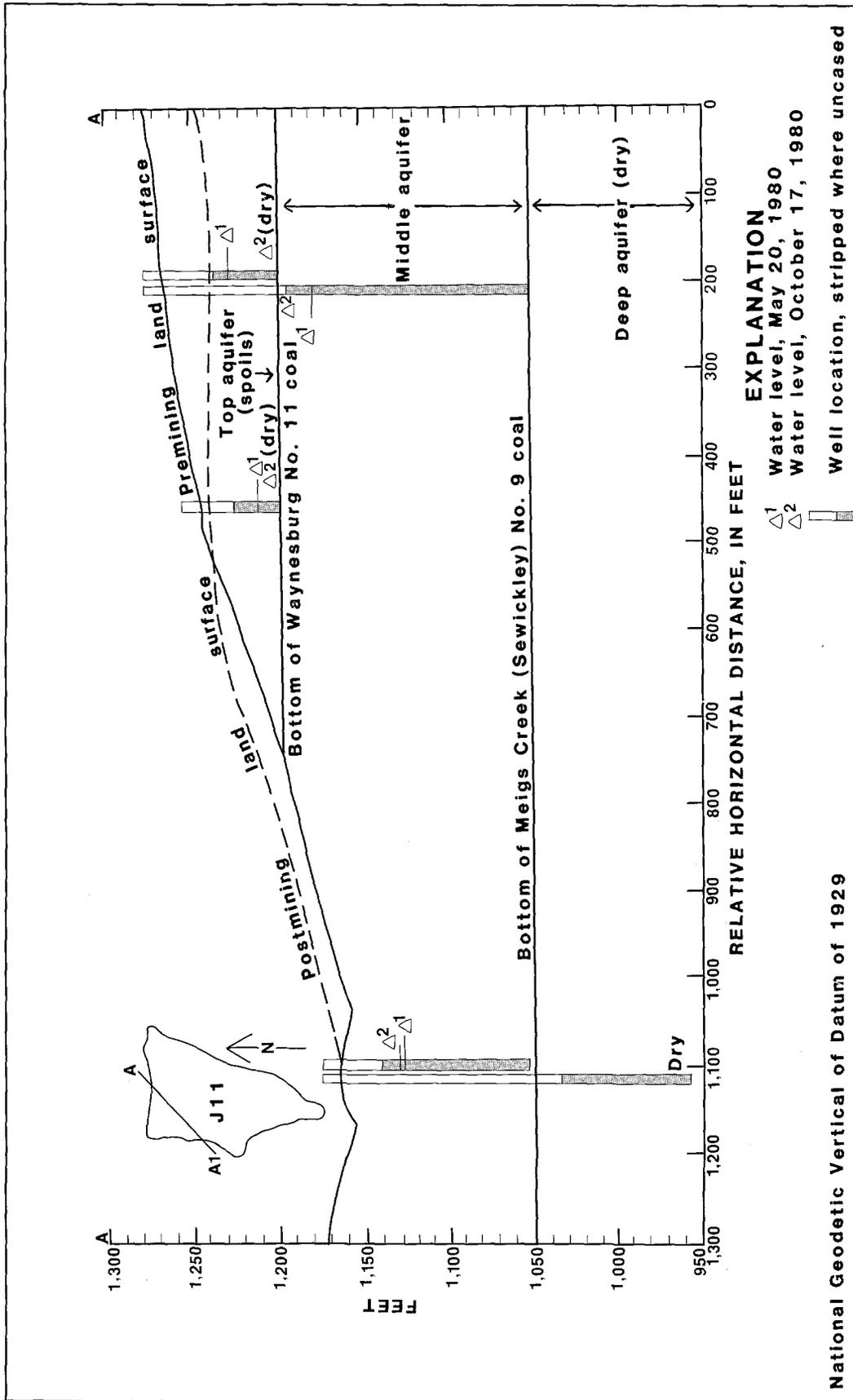


FIGURE 19. (Cont'd) - Hydrogeologic sections showing changes resulting from surface mining at Watershed J11.

precipitation intensities and totals of daily, monthly, and annual precipitation were derived from the measurements. The first set was based only on measurements taken with the unshielded gage. The second set was computed catches which were based on measurements taken using both gages. Precipitation amounts were calculated using an empirical formula proposed by Hamon (7). Differences between the unshielded and computed totals are noted and briefly discussed in Section III.

Continuous measurements of air temperatures and relative humidity were made with a hygrothermograph. Records were in the form of continuous ink tracings on strip charts.

Eppley Laboratory solar radiometers (Model 8-48)<sup>1</sup> and Micromet Instrument miniature net radiometers<sup>1</sup> were used to monitor incoming and outgoing radiation. The sensors were located at the study site's meteorologic station and were positioned 18 in above the ground surface. Sensor outputs were integrated by a Lintronic Mark V integrator, adapted to handle net outgoing radiation, to provide hourly totals.

Soil moisture access tubes were installed to depths of up to 51 in throughout the watershed. A neutron probe was used to measure soil moisture (% by volume) profiles at each tube site. Near surface soil moisture (% by volume) was determined from fixed-length core samples taken with a 1-1/2 in auger sampler.

Table 6 summarizes the hydrologic data collection scheme and shows how those data were grouped. For a discussion of hydrologic impacts, observations made during Phases 2a, b, and c were grouped into one set and those made during Phases 2d and e, in another. In this study, a watershed was not considered to be in a fully "reclaimed" state until topsoil replacement and reseeding were complete. At that time, the reconstructed topography was also more or less permanent, the land surface was stabilized, and erosion control systems were removed. These conditions were not fully realized before the study was concluded.

However, observations made after Phase 2e were considered to be a better representation of a reclaimed state than a mined state, and in the discussion that follows have been designated as belonging to Phase 3a.

Nine observation wells were installed before mining (Figure 2) during April and May 1976. Four wells were completed in the top aquifer, three in the middle, and two in the deep zone. The wells were drilled by the air-rotary method and each was cased so as to be open to only one of the three major zones. A continuous core was obtained in March 1976. Geophysical and drillers' logs were obtained from each well and the core hole.

Four observation wells were installed in March 1981 (Figure 16) to replace wells destroyed by mining. Three of the postreclamation wells were completed in the top aquifer (spoil) and one in the middle aquifer. The wells were drilled by the cable-tool method and cased so that they were open to only one of the aquifers. The three top aquifer (spoil) wells were finished with PVC

---

<sup>1</sup>Mention of the trade name of a proprietary product does not constitute a guarantee or warranty of the product by USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

TABLE 6. - Hydrologic and recorded weather parameters, frequency of measurement, and periods of record at Watershed J11

Component	Phase 1		Phase 2		Phase 3	
	Freq.	Dates <sup>2</sup>	Freq.	Dates	Freq.	Dates
Runoff (Watershed Outlet)	C	May 1, 1977 - May 19, 1980	C	May 20, 1980 Sept. 28, 1981	C	Sept. 29, 1981 June 30, 1982
Runoff (Small Watershed)	C	May 24, 1977 - May 19, 1980		May 20, 1980 May 28, 1981	N	
Precipitation	C	May 1, 1977 - May 19, 1980	C	May 20, 1980 Sept. 28, 1981	C	Sept. 29, 1981 June 30, 1982
Soil Moisture	P	June 3, 1977 - Dec. 29, 1979	N		N	
Solar Radiation	I	May 26, 1977 May 19, 1980	I	May 20, 1980 Sept. 28, 1981	I	Sept. 29, 1981 June 30, 1982
Net Radiation	I	May 26, 1977 May 19, 1980	I	May 20, 1980 Sept. 28, 1981	I	Sept. 29, 1981 June 30, 1982
Wind Speed	C <sup>3</sup>	Dec. 19, 1977 May 19, 1980	C <sup>3</sup>	May 20, 1980 Sept. 28, 1981	C <sup>3</sup>	Sept. 29, 1981 June 30, 1982
Air Temperature	C	Dec. 27, 1977 May 19, 1980	C	May 20, 1980 Sept. 28, 1981	C	Sept. 29, 1981 June 30, 1982
Relative Humidity	C	Dec. 27, 1977 May 19, 1980	C	May 20, 1980 Sept. 28, 1981	C	Sept. 29, 1981 June 30, 1982

<sup>1</sup>C-Continually; P-Periodic; I-Hourly integrated; N-Not collected.

<sup>2</sup>Inclusive dates.

<sup>3</sup>Record was collected, but not processed.

slotted casing and the middle aquifer well was constructed with steel casing to seal off the top aquifer and open hole below.

Water levels in the wells were measured monthly, and digital recorders obtained hourly data in selected wells. Table 7 lists the data obtained from each well. Aquifer tests (single-well pumping and slug tests) were made at premining wells to determine hydraulic properties before mining. Aquifer tests were not made at any of the postreclamation top aquifer (spoil) wells because the saturated thickness was too thin. Table 8 shows the postreclamation well information and data collected from each well. Tests of underclay permeability were done in the laboratory. Pumping tests were analyzed according to the method of Boulton (2), and slug tests were analyzed by the method described by Cooper et al. (3).

Forty-nine water samples were collected for premining water-quality analyses; 35 from top-aquifer wells and 14 from middle-aquifer wells. Twenty-five samples were collected after mining for water-quality analyses; 14 from top-aquifer (spoil) wells, and 11 from the undisturbed middle aquifer.

Samples were collected using an electrical submersible pump if the well yield permitted. A PVC bailer was used if the saturated thickness was small or well yield was low. Samples were collected after the well volume had been discharged two to three times and the specific conductance and temperature stabilized.

Temperature, specific conductance, pH, and alkalinity were determined in the field. Samples were filtered and treated in the field and chilled until laboratory analyses were made. Dissolved constituents were determined from samples that were filtered in the field with 0.45  $\mu\text{m}$  filters before treating. Samples were analyzed at the U. S. Geological Survey Laboratory in Doraville, Georgia.

The quality of surface water was monitored at the outlet of Watershed J11 for approximately 34 months before surface coal mining began, for 3 months during active mining and reclamation, and for 16 months during which the watershed lay in a partially reclaimed state. Runoff was automatically sampled (as composite samples) at the watershed outlet with an ISCO sampler. Samples were obtained above a practical threshold of 0.24 cfs at fixed time intervals through a screened intake placed in an area of high turbulence in the drop-box weir. Hamon et al. (8) describes the instrumentation in greater detail. Discrete samples were also manually collected.

The frequency of sampling varied depending on the number of runoff events. Table 9 gives a description of the 54 surface-water samples collected at the watershed outlet throughout the study period. The partially reclaimed period (10/4/80 - 6/30/82) corresponds to Phases 2 and 3, and a description of these phases was made previously in this report. This was a period during which the watershed remained in a relatively constant condition. However, there were two brief periods (approximately three months total) when reclamation processes such

---

<sup>1</sup>Mention of the trade name of a proprietary product does not constitute a guarantee or warranty of the product by USDA, and does not imply its approval to the exclusion of other products that may also be suitable.

TABLE 7. - Premining well information at Watershed J11

Local Number	Well Location Latitude Longitude	Altitude of Land Surface (ft)	Date Completed	Depth of Well (ft)	Depth Cased (ft)	Casing Diameter (in)	Remarks <sup>1</sup>
W1-1	401011N 0805216W	1259.5	4/1976	61	18	6	G, Q, L, K
W2-2	401011N 0805216W	1258.7	4/1976	211	64	6	G, Q, L, K
W3-1	401010N 0805218W	1235.2	4/1976	38	18	6	G, Q, L, K
W4-1	401002N 0805218W	1251.4	5/1976	60	18	6	G, Q, L, K
W5-3	401002N 0805218W	1251.7	5/1976	295	218	6	G
W6-1	401004N 0805219W	1237.4	5/1976	46	17	6	G, Q, L, K
W7-2	401004N 0805219W	1237.3	4/1976	192	53	6	G, Q, L
W8-2	401007N 0805224W	1156.7	4/1976	105	20	6	G, Q, L, K
W9-3	401007N 0805224W	1155	4/1976	198	120	6	G

<sup>1</sup>G = gamma log  
 Q = water quality  
 L = water levels  
 K = aquifer test

TABLE 8. - Postreclamation well information at Watershed J11

Local Number	Well Location Latitude Longitude	Altitude of Land Surface (ft)	Date Completed	Depth of Well (ft)	Depth Cased (ft)	Casing Diameter (in)	Remarks <sup>1</sup>
P1-1	401011N 0805216W	1236.2	3/1981	39	39	4	Q,L
P2-2	401011N 0805216W	1236.2	3/1981	187	46	6	Q,L
P3-1	401010N 0805218W	1236.7	3/1981	38	38	4	L
P10-1	401009N 0805215W	1236.1	3/1981	39	39	4	Q,L

<sup>1</sup>Q = water quality  
L = water levels

TABLE 9. - Description of surface-water samples collected at the Watershed J11 outlet

Sampling <sup>1</sup> Interval (Month/Day/Year)	Watershed Condition	Number of Samples Collected of the Type Indicated	
		Discrete	Composite
08/15/77-05/17/80	Premine	28	7
05/30/80-09/09/80	Active Mining and Reclamation	3	0
10/25/80-02/08/82	Partially Reclaimed	16	0

<sup>1</sup>These dates represent the dates on which were collected the first and last samples of a given period and do not indicate the beginning and ending dates for the period.

as grading and topsoiling occurred. Only one surface-water sample was collected during these periods of reclamation activity and that sample was eliminated from the statistical analyses of the partially reclaimed data. Concentrations of water quality parameters in this sample, however, were not greatly different from concentrations observed in other water samples collected during the partially reclaimed period.

Color and pH were measured in the field and all other parameters in the laboratory. Table 10 lists the analytical methods, with their lower detection limits, used to measure the various parameters in precipitation and surface-water samples. A complete schematic flow sheet of procedures used for sample preparation is reported in U. S. Bureau of Mines (21). A total of 59 precipitation samples were collected as monthly composite samples by means of an automatic precipitation collector and analyzed as described above for the surface-water samples.

Suspended sediment samples were obtained by continuous flow centrifugation of 12-15 liter surface-water samples collected at the watershed outlet. When the quantity of sediment from one sample was too small for analysis the sediment fractions from successive events were combined (Table 11). Sampling was performed primarily during runoff events when most of the sediment transport was taking place.

The sediment removed from the water sample as a result of centrifugation was freeze-dried, ground in a stainless steel mill, and stored in polyethylene bottles. Seventeen parameters were measured in the sediment samples. Metals (except mercury) and phosphorus concentrations were measured by pretreating the samples with 30%  $H_2O_2$  to destroy organic matter, heating the residue (68-70°C) in 0.3 N HCl for 30 min, and filtering using a 0.45  $\mu m$  membrane. The filtrate was analyzed using an inductively-coupled argon plasma atomic-absorption spectrometer (Garbarino and Taylor, 6). Mercury was measured by an atomic absorption cold vapor technique after a separate digestion procedure to remove interfering organic matter (Hatch and Ott, 10; Lindstedt, 17). Sulfate was extracted from the sediment with a 0.5 N ammonium acetate-0.25 N acetic acid mixture (sediment:extractant ratio, 1:2.5) and determined turbidimetrically (Bardsley and Lancaster, 1). pH was measured using a glass electrode (sediment:water ratio, 1:2) and organic C by an automatic carbon analyzer.

TABLE 10. - Summary of analytical methods and detection limits  
for surface-water quality analyses

Parameter <sup>1</sup>	Analytical Method	Method Reference	Lower Detection Limit
Acidity (meq/l)	Electrometric titration	3	0.01
Aluminum <sup>2</sup>	Inductive coupled argon plasma emission spectrometry (ICP)	4	.010
Ammonium-N	Specific ion electrode	5	.01
Antimony <sup>2</sup>	ICP	4	.025
Arsenic <sup>2</sup>	Atomic absorption/graphite furnace	6	.002
Barium <sup>2</sup>	ICP	4	.002
Bicarbonate (Alkalinity as CaCO <sub>3</sub> )	Electrometric titration	3	.4
Cadmium <sup>2</sup>	ICP	4	.003
Calcium <sup>2</sup>	ICP	4	.010

<sup>1</sup>All parameters reported as mg/l except where noted.

<sup>2</sup>Filtration by 0.45 µm membrane.

<sup>3</sup>U. S. Geological Survey. Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases, 1974.

<sup>4</sup>Garbarino, J. R. and H. E. Taylor. An Inductive-Coupled Plasma Atomic-Emission Spectrometric Method for Routine Water Quality Testing. Applied Spectroscopy, v. 33, 1979, pp. 220-226.

<sup>5</sup>Orion Specific Ion Electrode Instruction Manuals, Orion Research, Inc., Cambridge, Mass.

<sup>6</sup>Jarrell-Ash Methods Manual for Atomic Absorption Spectroscopy, Jarrell-Ash Division of Fisher Scientific Co., Waltham, Mass.

<sup>7</sup>American Public Health Association. Standard Methods for the Examination of Water and Wastewater, American Water Works Association, Water Pollution Control Federation, 14th ed., Washington, D. C., 1975.

<sup>8</sup>Olson, O. E., I. S. Palmer and E. E. Cary. Modification of the Official Fluorometric Method for Selenium in Plants. J. Assoc. Official Anal. Chem., v. 58, 1975, pp. 117-121.

TABLE 10. (Cont'd) - Summary of analytical methods and detection limits for surface-water quality analyses

Parameter <sup>1</sup>	Analytical Method	Method Reference	Lower Detection Limit
Carbon Dioxide	Calculation	3	0
Chloride	Potentiometric titration with Ag/S sp. ion electrode	5	0.1
Chromium VI <sup>2</sup>	Diphenylcarbazide spectrophotometric	3	.010
Color - Field (color units)	Color comparator	3	1
Copper <sup>2</sup>	ICP	4	0.003
Cyanide	Specific ion electrode	5	.01
Dissolved Oxygen	Membrane electrode	7	.1
Fluoride	Specific ion electrode	5	.02
Hardness	Calculation	7	0
Iron <sup>2</sup>	ICP	4	0.005
Lead <sup>2</sup>	ICP	4	.015
Magnesium <sup>2</sup>	ICP	4	.003
Manganese <sup>2</sup>	ICP	4	.001
Mercury <sup>2</sup> (total)	Atomic absorption/cold vapor	6	.002
Nickel <sup>2</sup>	ICP	4	.010
Nitrate-N	Specific ion electrode	5	.1
pH Runoff - Field Precipitation - Lab (standard units)	Electrometric	7	Undefined
Phenols	Chloroform extraction following distillation	7	0.004

<sup>1</sup>Ibid.

<sup>2</sup>Ibid.

TABLE 10. (Cont'd) - Summary of analytical methods and detection limits for surface-water quality analyses

Parameter <sup>1</sup>	Analytical Method	Method Reference	Lower Detection Limit
Phosphorus <sup>2</sup>	ICP	4	0.03
Selenium <sup>2</sup>	Fluorometric	8	.0001
Silver <sup>2</sup>	ICP	4	.003
Sodium <sup>2</sup>	ICP	4	.05
Specific Conductance ( $\mu$ mhos/cm)	Wheatstone bridge	7	0
Strontium <sup>2</sup>	ICP	4	0.002
Sulfate <sup>2</sup>	Turbidimetric	7	2
Sulfide	Specific ion electrode	5	0.01
Total Dissolved Solids <sup>2</sup>	Filtrable residue at 180° C (0.45 $\mu$ m filter)	7	1
Total Suspended Solids	Nonfiltrable residue	7	5
Zinc <sup>2</sup>	ICP	4	0.007

<sup>1</sup>Ibid.

<sup>2</sup>Ibid.

TABLE 11. - Description of suspended sediment samples collected at the Watershed J11 outlet

Sampling Interval (Month/Day/Year)	Watershed Condition	Sample Composition <sup>1</sup>	
		Number of Samples	Number of Events
11/30/77-04/14/80	Premine	5	26
05/30/80-09/09/80	Active Mining and Reclamation	3	3
10/25/80-01/23/82	Partially Reclaimed	12	13

<sup>1</sup>A "sample" means the sediment material analyzed. The "sample" may be a composite of the sediment fractions from one or more runoff events pooled to obtain sufficient material for analysis.

### III. SURFACE-WATER HYDROLOGY

#### A. Introduction

To assess the impacts of surface mining and reclamation on the hydrology of a small watershed in the North Appalachian Coal Region, hydrologic and meteorologic data were collected at the study watershed while in various stages of mining. Table 6 lists the parameters which were the basis for assessing these impacts.

The destruction of the subsurface soil and geologic structure, the near total removal of vegetative cover, and the stockpiling of loose and fragmented spoil affected the distribution of water mass in the watershed's hydrologic budget. The impact of these changes was not uniform over the mining period and was dependent on the series of disturbances caused by the sequence and scheduling of mining and reclamation operations as discussed in Section II. The continuous and nonuniform transformation of the watershed through the mining and reclamation phases, precluded the possibility of completely establishing cause and effect relationships for particular disturbances. Consequently, the hydrologic experience of Watershed J11 has been evaluated in the context of predominant disturbances at the times data were collected.

#### B. Weather Data

Climatological data are presented below. When possible, the conditions which prevailed during the study were first compared with average states, and the ranges of natural variability. In cases where observations could not be related to an historical record, the trend in the magnitude and variability of the parameter during the study has been described. The intent of this effort was to provide as much information as possible so that the surface and subsurface hydrologic observations presented in this report could be interpreted in the proper perspective. The extension of conclusions drawn from these observations is contingent on how representative were the natural driving forces during the three phases of the study. This was considered particularly pertinent to Phases 2 and 3 given the brevity of the collection periods and the frequency of physical alterations to the landscape.

Data for a nearby climatologic station were used to evaluate the normalcy of some conditions observed over the study period. The nearest reference station with a suitable long-term record was located at Steubenville, Ohio, approximately 19 miles northeast of the study site. Based on data that were collected between 1942 and 1981, log-normal distributions were computed for monthly mean air temperature, and monthly total precipitation. The normalcy of each observation made at the study site was evaluated according to the probability of occurrence as given by the distribution. In all cases, a normal condition was defined as having at least a 5% probability of being exceeded and at most a 95% probability of not being exceeded.

As a test of the representativeness of the long-term record, monthly mean temperatures and monthly total precipitation at Watershed J11 were linearly regressed on corresponding observations at Steubenville, Ohio. Figure 20a illustrates the relationships between the two sites.

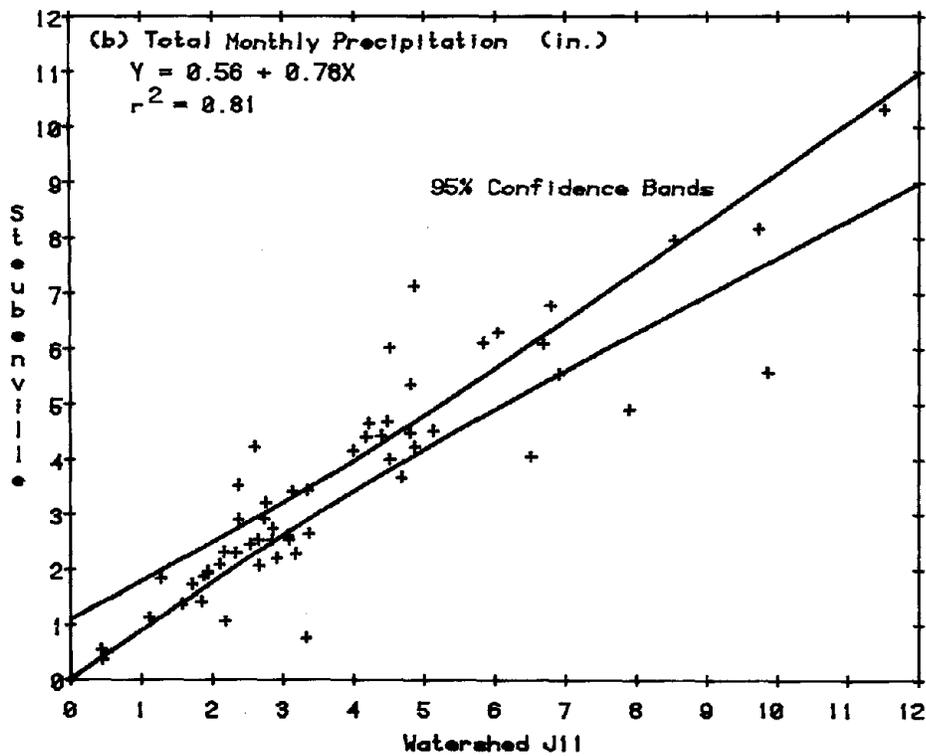
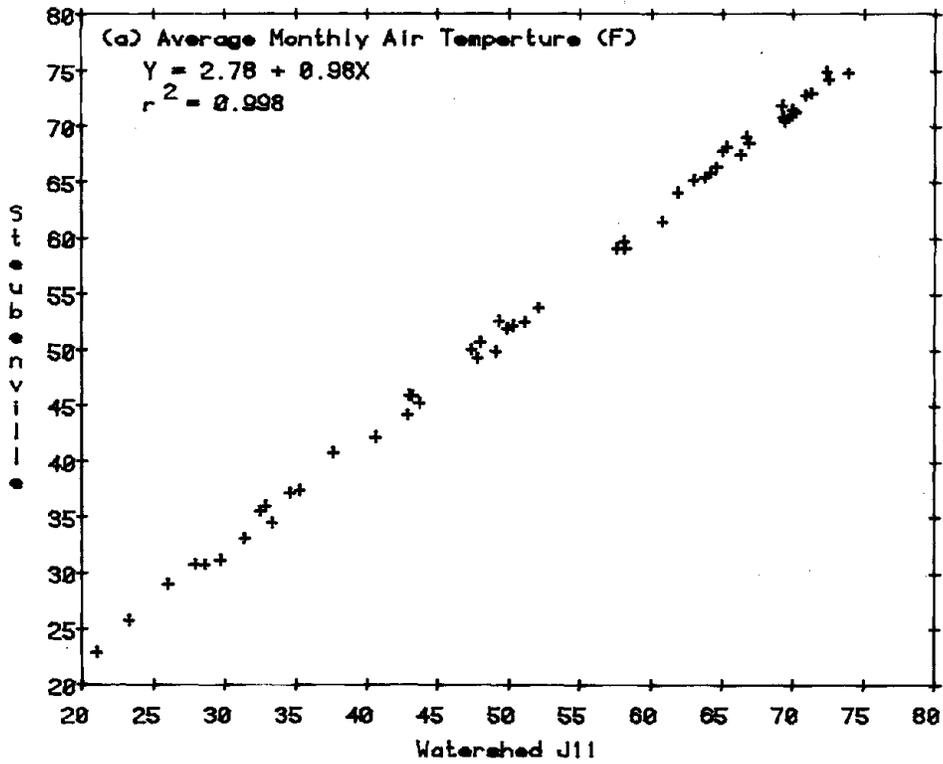


FIGURE 20. - Relationships between monthly climatological parameters at Steubenville, Ohio and Watershed J11.

The relationship developed for monthly mean air temperature was:

$$Y = 2.78^{\circ}\text{F} + 0.98X \quad (1)$$

where X = Watershed J11 observation

Y = Predicted values for Steubenville, Ohio (or, equivalently,  
Watershed J11 observations adjusted to conditions at  
Steubenville, Ohio)

As indicated by the slope constant and intercept Equation 1 shows the temperature differences were small. However, the Steubenville station consistently reported air temperatures approximately  $2.78^{\circ}\text{F}$  higher than those observed at Watershed J11. Whether this was due to site differences or instrument sensitivity is uncertain.

The relationship for total monthly precipitation (Figure 20b, Equation 2) was considerably less well defined:

$$Y = 0.58 \text{ in} + 0.78X \quad (2)$$

where X and Y are defined as above.

The distance between the observation points was most likely the principal factor for the scatter that is evident in the illustration. Summer month totals tended to fit the relationship least and reflected the highly localized nature of summertime convective thunderstorm activity. However, statistical analyses that were based on fall and winter, and spring and summer monthly totals did not yield better results than Equation 2.

The straight lines on Figure 21 are the log-normal fits of the average monthly air temperatures recorded at Steubenville, Ohio between 1942 and 1981. The strengths of these empirical relationships varied and were poorest for December, January, February, and March, average for October and November, and best for April through September. Figure 22 illustrates representative "goodness-of-fits."

In order to evaluate the normalcy of temperatures observed over the study period, monthly mean air temperatures at Watershed J11 were adjusted, using Equation 1, to equivalent values as measured at Steubenville. The relationship shown in Figure 20a was used to make the conversion. These adjusted values were superimposed on the straight lines of Figure 21, and the actual readings are listed in Table 12. On the basis of the empirically derived distributions and the criteria adopted for defining a normal condition, February 1978 and 1979 were colder and August 1980 and May 1982 were warmer than normal. Over the entire study period, prevailing monthly air temperatures were less than the long-term averages. Four of the last eight months of 1977; eight months of 1978, 1979, and 1980; nine months of 1981; and three of the first seven months of 1982 experienced lower than expected temperatures.

Precipitation was the only other climatic variable for which a long-term record was available. As noted earlier, measurements of accumulated precipitation were made with two standard recording rain gages; one was equipped with a wind shield to improve catch efficiency. Differences between the amounts measured with the unshielded gage and those computed using measurements from both gages (Hamon, 7) were presumed to be indicative of catch deficiencies

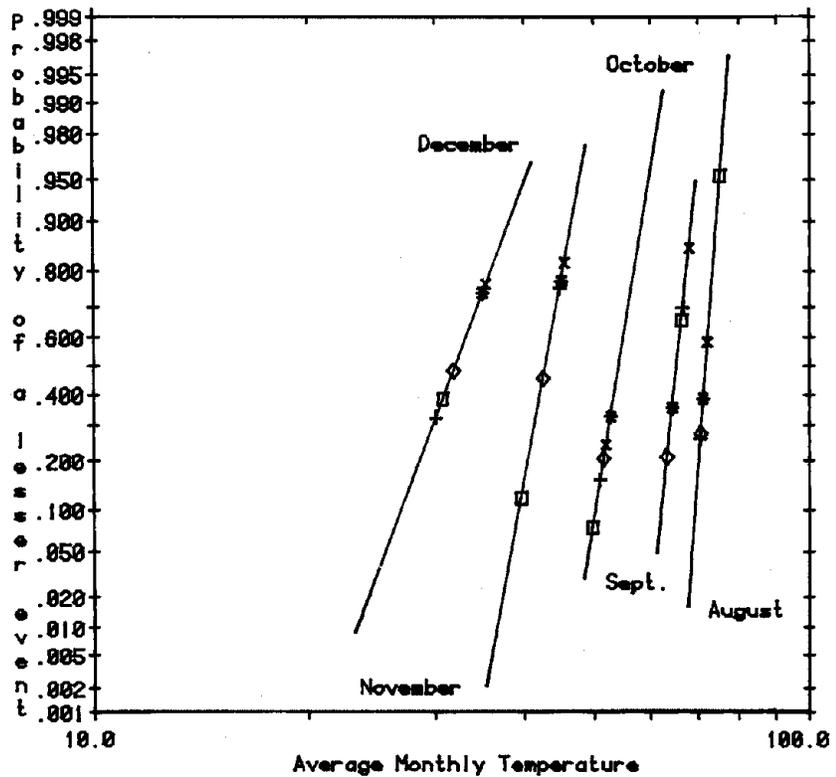
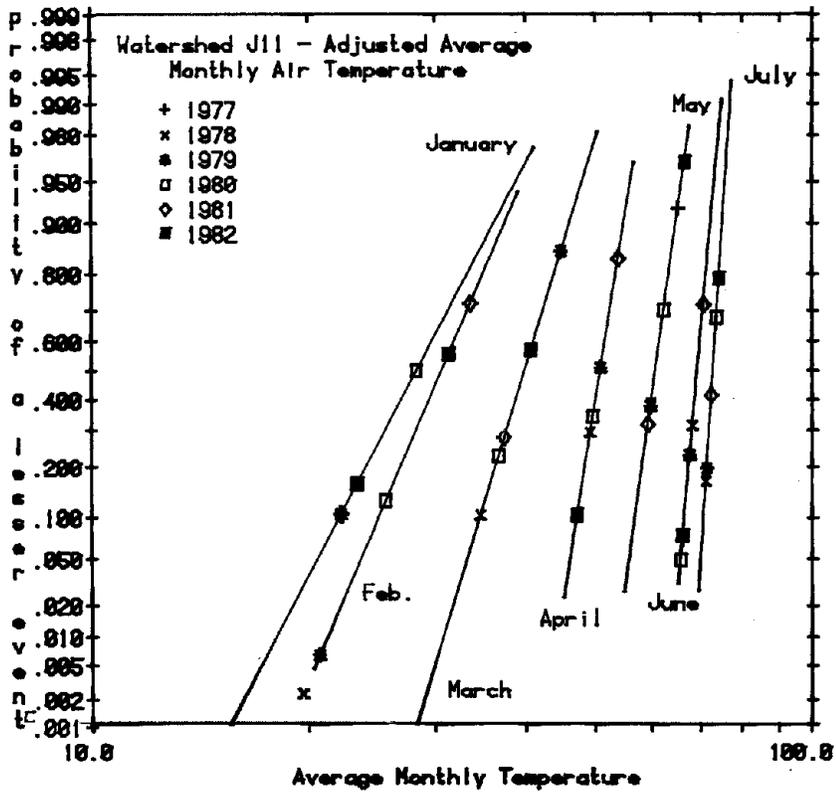


FIGURE 21. - Adjusted average monthly air temperature ( $^{\circ}$ F) at Watershed J11 with respect to the logarithmic-normal distribution of average monthly air temperatures at Steubenville, Ohio.

TABLE 12. - Summary of observed monthly mean air temperatures at Watershed J11

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1977	NM	NM	NM	NM	63.8	64.6	72.4	69.2	65.3	49.3	43.0	27.9
1978	19.8	17.2	32.5	47.4	58.2	66.9	70.0	70.9	66.7	50.3	43.7	33.3
1979	21.0	18.3	42.9	49.1	58.1	66.3	70.2	69.9	63.0	51.1	43.2	32.9
1980	26.0	23.3	34.6	47.8	60.8	64.2	72.5	73.9	65.0	48.0	37.6	28.6
1981	19.8	31.4	35.3	52.1	57.6	69.4	71.3	69.3	61.9	49.9	40.6	29.7
1982	21.0	29.1	38.7	45.3	65.2	64.7	73.1					

<sup>1</sup> NM No measurement

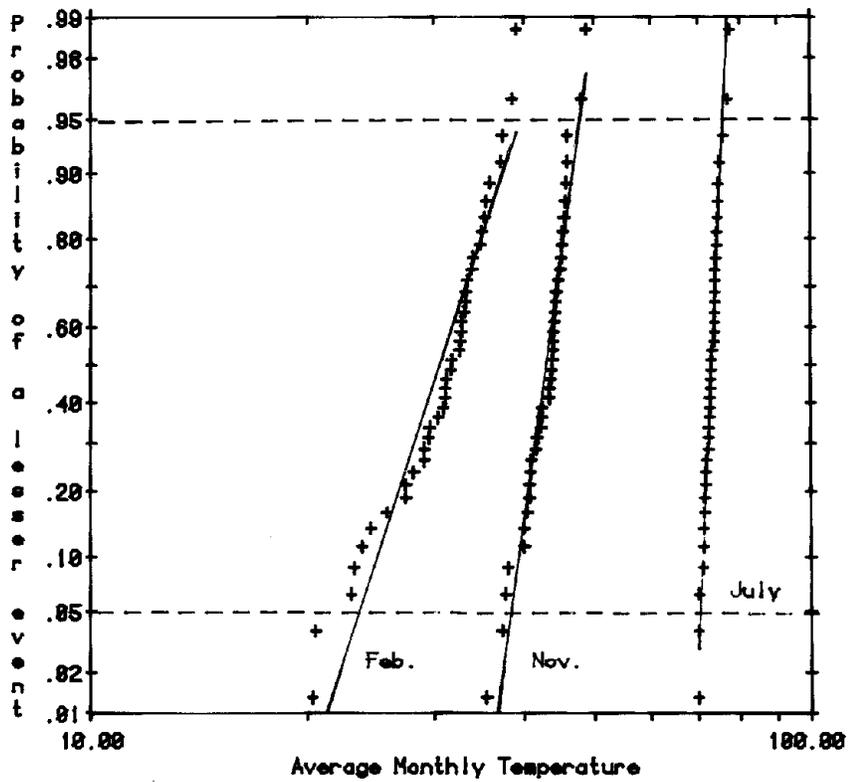


FIGURE 22. - Representative "goodness-of-fit" for average monthly air temperature at Steubenville, Ohio fit to a logarithmic-normal distribution. (1942 - 1981)

associated with the unshielded gage under windy conditions. Figure 23 plots the accumulated precipitation based on the two measurements and the line of equivalence. Precipitation values obtained by computation are referred to as "dual" gage measurements. As indicated by the curve slope, the catch of the unshielded gage system almost consistently decreased relative to the dual gage during the winter months. However, the relative catches after 1979 and during the summer months were unstable. Most of the rainfall-runoff events included in the analyses described in the following section occurred between early spring and late fall. Figure 24 plots the paired observations and their distribution about the line of equivalence. Prior to 1979, no significant bias was observed between the two measurement techniques. During the late summer months of 1979 and all months in 1980 and 1981, the unshielded gage measured more rainfall than the dual gage. This tendency was atypical of similar systems installed at two other sites (U. S. Bureau of Mines, 23, 24, 25, 26). The relative performance of the two systems changed again in 1982 as the dual gage measurements exceeded those of the unshielded gage.

A series of instrument replacements and repairs were suspected of significantly contributing to the changes in the relative performance of the two measuring devices. The equations listed in Table 13 quantify the periods and magnitudes of the variability detected over the study period. Because it could not be determined which was the more stable record, no effort was made to compensate for the variability. Consequently, differences in other hydrologic relationships that could be attributed to approximately a 10% error in the rainfall measurements made between Phase 1 and Phase 2; and a 20% error in those made between Phase 1 and Phase 3a should not be definitely attributed to mining. In the discussions that follow, individual storm volumes and intensities which have been cited were extracted from the dual raingage computed record. However, in checking the normalcy of Watershed J11 measurements with the long-term record for Steubenville, unshielded raingage data were used. The latter was deemed necessary since most, if not all, long-term precipitation records are based on unshielded rain gage measurements.

The computed log-normal distributions of total monthly precipitation at Steubenville, Ohio are plotted as solid lines on Figure 25. Generally, the quality of the fits was fair for monthly totals greater than 1 in and less than 6-7 in, and outside these limits it was poor. Notwithstanding the deficiencies, the results were used to detect deviations outside a normal range.

Equation 2 was used to estimate amounts at Steubenville based on monthly Watershed J11 precipitation totals. The probabilities of occurrence of the adjusted values are plotted on Figure 25; the actual monthly totals are listed in Table 14. As shown in Figure 20b, the relationship between total monthly precipitation at Watershed J11 and Steubenville was not nearly as precise as that for monthly mean air temperature. The 95% confidence bands for the postulated linear relationship (Equation 2) show a fairly broad range of uncertainty. Uncertainties that were associated with these predictions were not considered in the evaluations of the normalcy of the observations. Instead, an additional restriction was imposed on the normalcy criterion which required both the adjusted Watershed J11 and the corresponding Steubenville observations to fall outside the limits of normal variation. According to the empirical distributions, August 1980 and April 1981 were abnormally wet, and January 1981 was abnormally dry. Precipitation amounts for all other months were within the normal range of variation. Overall, precipitation in 21 of the 37 months prior to mining, all months of active mining, and 11 of the 22 months after mining was above average.



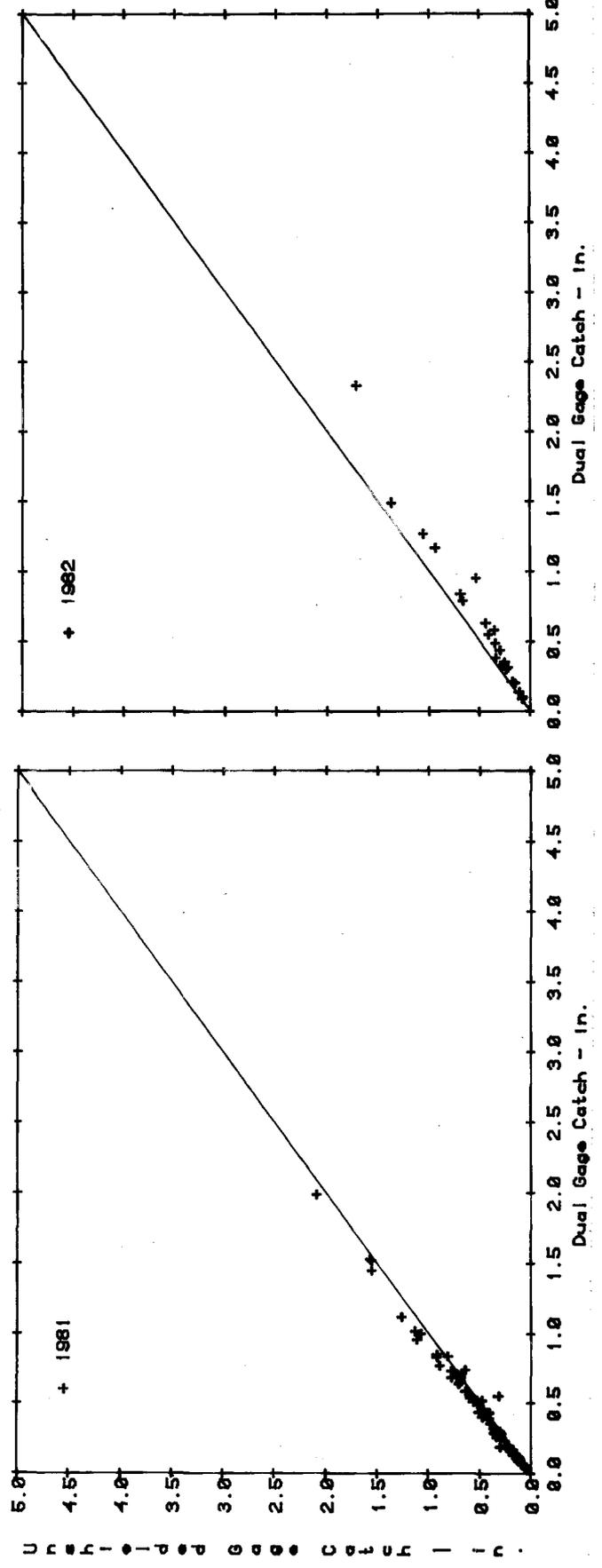
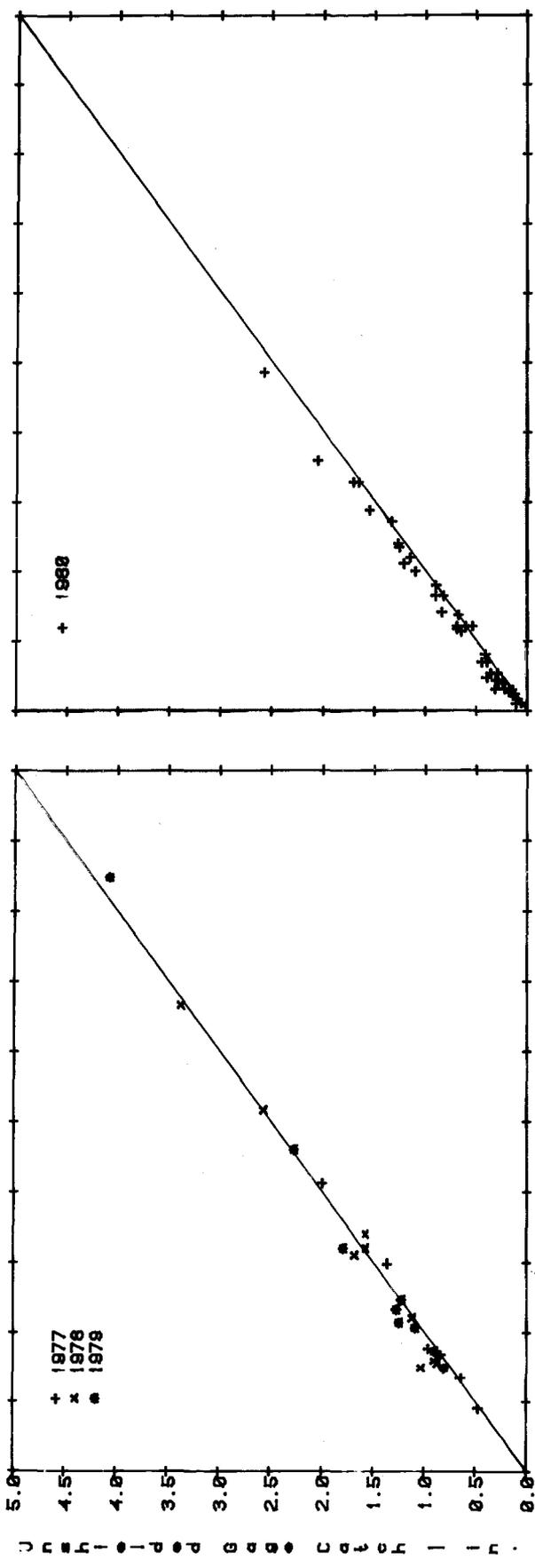


FIGURE 24. - Relationships between unshielded and dual gage storm rainfall catches at Watershed J11.

TABLE 13. - Comparison of relationships between event totals of precipitation measured by an unshielded rain gage and a dual rain gage at Watershed J11

Year		N	$r^2$
1977	$Y = 0.05 + 0.95 X$	5	0.99
1978	$Y = 0.15 + 0.94 X$	9	.98
1979	$Y = 0.16 + 0.93 X$	9	1.00
1980	$Y = 0.04 + 1.04 X$	41	0.99
1981	$Y = 0.01 + 1.04 X$	70	.99
1982	$Y = -0.01 + 0.78 X$	23	.97

<sup>1</sup>N = Number of observations

<sup>2</sup>X = Computed (dual) rain gage measurement

<sup>3</sup>Y = Unshielded rain gage measurement

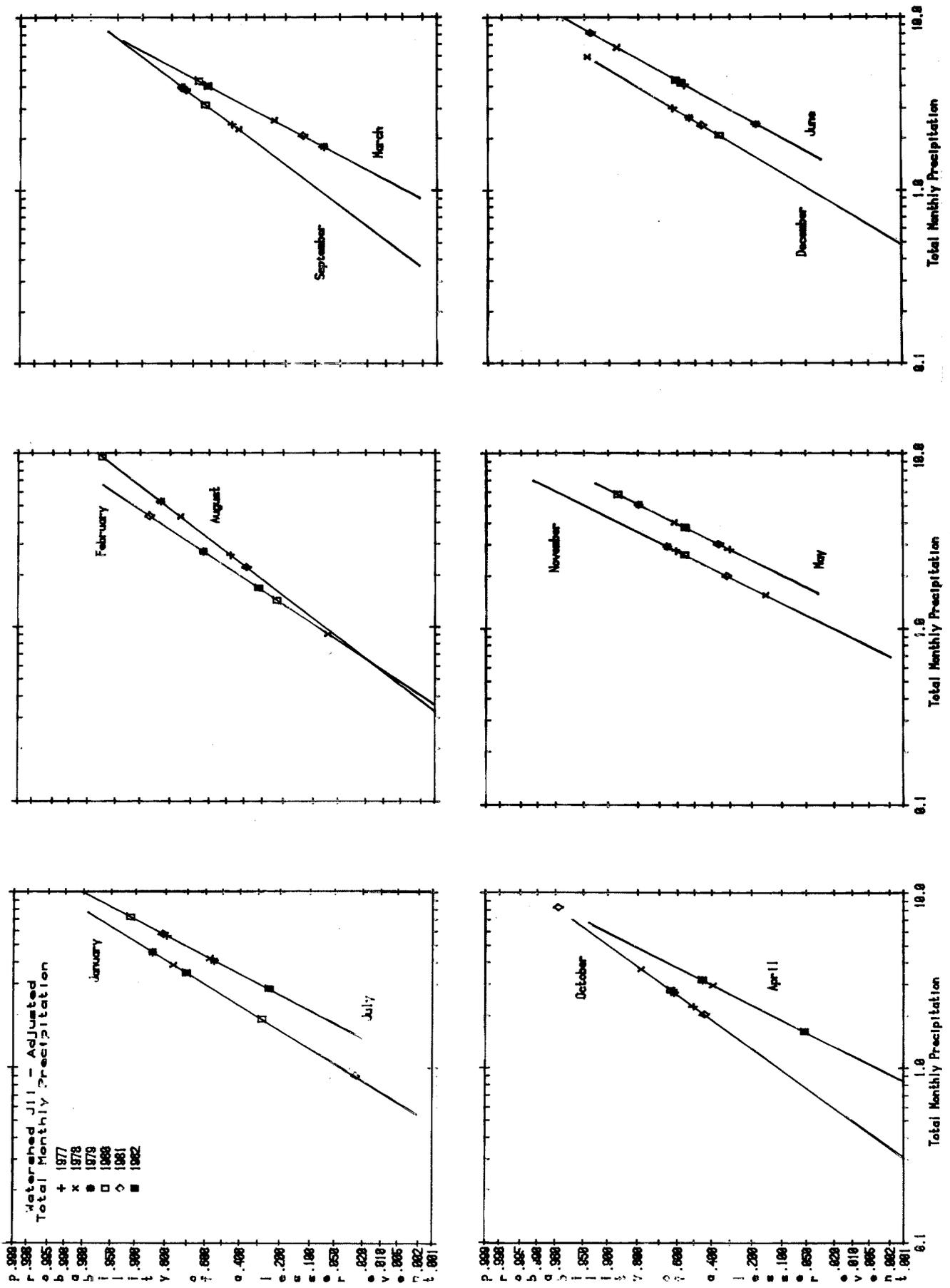


FIGURE 25. - Adjusted total monthly precipitation (in) at Watershed J11 with respect to the logarithmic-normal distributions of total monthly precipitation at Steubenville, Ohio.

TABLE 14. - Summary of observed monthly total precipitation at Watershed J11

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1977	NM	NM	NM	NM	2.92	4.53	6.52	2.61	2.38	2.17	2.86	3.15
1978	4.23	0.45	2.54	3.09	4.49	7.91	4.68	4.81	2.18	4.00	1.28	6.92
1979	5.14	2.77	1.58	3.36	5.85	2.38	4.52	6.05	4.40	2.74	3.07	2.67
1980	1.72	1.11	4.82	3.37	6.80	4.87	8.54	11.52	3.30	2.84	2.66	1.94
1981	0.44	4.88	1.94	9.87	3.18	9.74	6.70	2.11	4.19	1.88	1.85	2.34
1982	3.74	1.43	4.48	1.36	4.13	4.65	2.90					

<sup>1</sup>NM - No measurement.

Table 15 compares the amounts of annual precipitation that were measured at Watershed J11 and Steubenville, and ranks the years in order of decreasing amounts. Differences in totals for paired years were substantial and ranged from 0.64 to 8.21 in. The only agreement between the two sets of records was that precipitation (P) was greatest in 1980, the year of mining. Based on the unshielded totals at Watershed J11, precipitation in 1980 was approximately 4.4 in to 9.0 in more than in any other year of the study. A linear regression based on these few samples yielded Equation 3 and a coefficient of determination ( $r^2$ ) of only 0.51.

$$\text{Annual } P_{\text{Steu.}} = 1.05 \text{ in} + 0.75 * (\text{Annual } P_{\text{WS J11}}) \quad (3)$$

The limited data base in conjunction with the quality of the relationship was inadequate for an assessment of the normalcy of the annual observations at Watershed J11 based on these data and the long-term Steubenville record.

Average monthly relative humidity measurements are plotted in Figure 26. With the exceptions of the January 1970, and March and April 1981 averages, observations ranged from 62% to 83%. Some of this variation was due to instrument performance. Periodic comparisons of instrument records prior to and immediately after maintenance at times showed differences by as much as 10% relative humidity. Inasmuch as these devices are notoriously unreliable and the range of variation was only 23%, it was assumed that the observations were normal. The above evaluation of these data was considered sufficient since no effort has been made in this report to estimate evapotranspiration losses based on these data. Consequently, the impact of the extreme variations, observed for the three months previously cited, has not been addressed.

### C. Soil Moisture

Premining soil moisture data for Watershed J11 have been reported (U. S. Bureau of Mines, 21) as average discrete ranges for eight zones in the top 51 in of the soil profile. Each zonal range was computed as an unweighted average of all soil moisture data without regard to location. To illustrate premining soil moisture characteristics with respect to soil type, the data have been recompiled by site and are presented in Figure 27.

Measurements were taken in only two soils, Coshocton Silt Loam and Gilpin Silt Loam, and with the exception of the uppermost layer, soil moisture generally ranged from the high 20's (% by volume) to the mid 30's. A much wider variation was evident in the top 9 in and was indicative of the soil moisture response to the time sequences of meteorologic conditions. Differences within and among each series were not discernable.

Mining destroyed all the soil moisture access tubes within a brief period of time. No effort was made to reinstall tubes during Phases 2d and e, and Phase 3a inasmuch as surface activities (reseeding, harvesting, diversion installation, and repair) would have necessitated frequent replacements. Consequently, soil moisture data for the postmining periods are not available.

### D. Surface-Water Runoff

Surface-water runoff observations at the Watershed J11 outlet include 37 months of premining record, 4 months of intense mining and mining-reclamation record, and 21 months of postreclamation record. Data collected during the

TABLE 15. - Comparison of annual precipitation at Watershed J11 and Steubenville, Ohio

Year	Watershed J11		Steubenville	
	Unshielded Total (in)	Rank	Total (in)	Rank
1978	46.58	3	40.36	4
1979	44.53	4	43.89	2
1980	53.52	1	50.85	1
1981	49.12	2	40.91	3



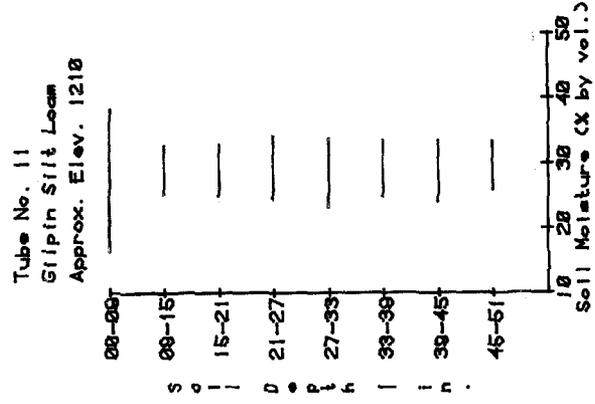
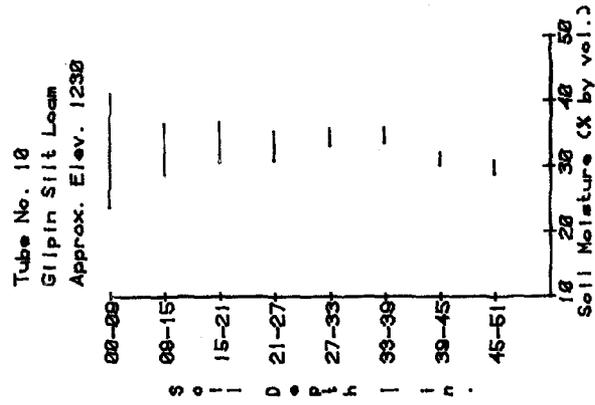
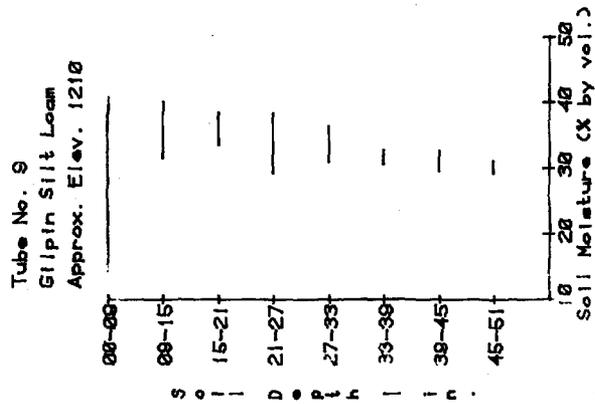
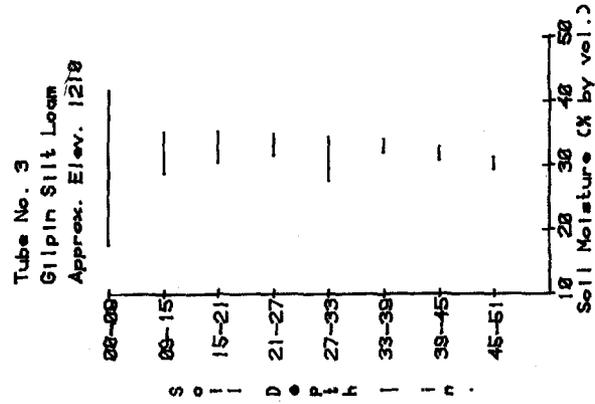
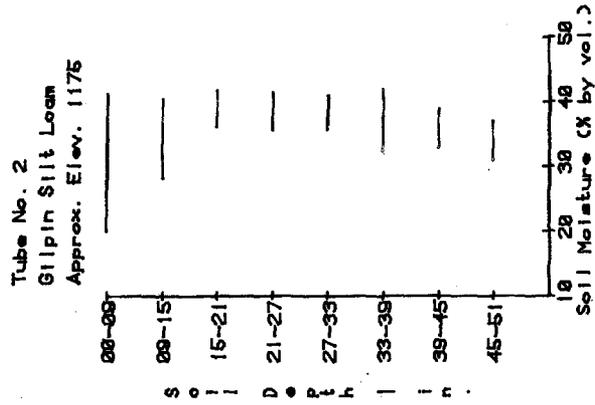
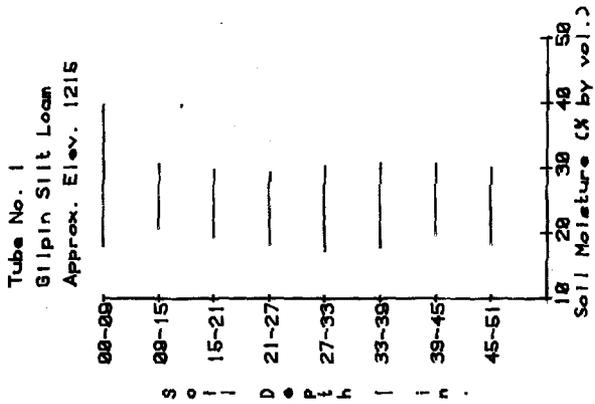


FIGURE 27. - Soil moisture ranges measured at premined soil profile sites in Watershed J11.

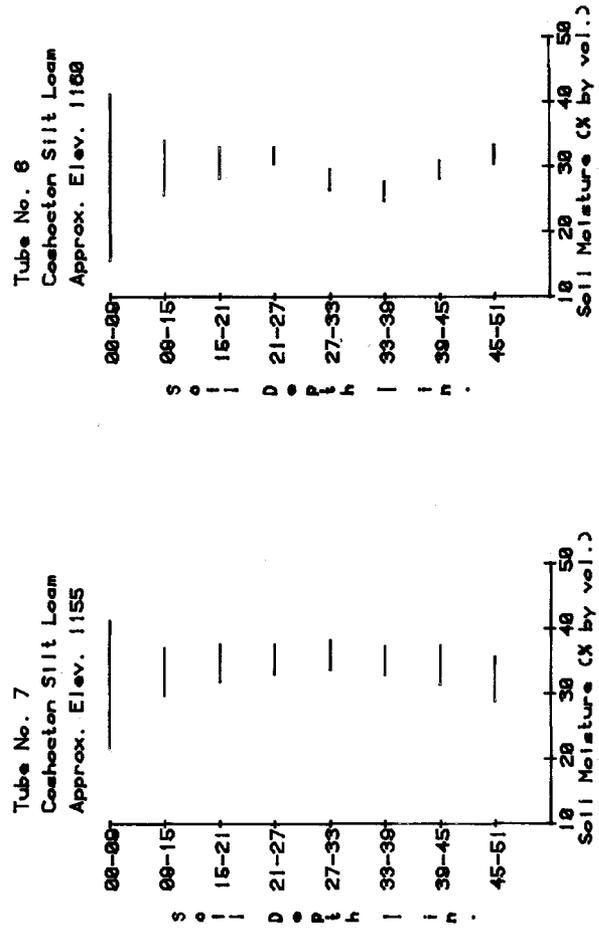
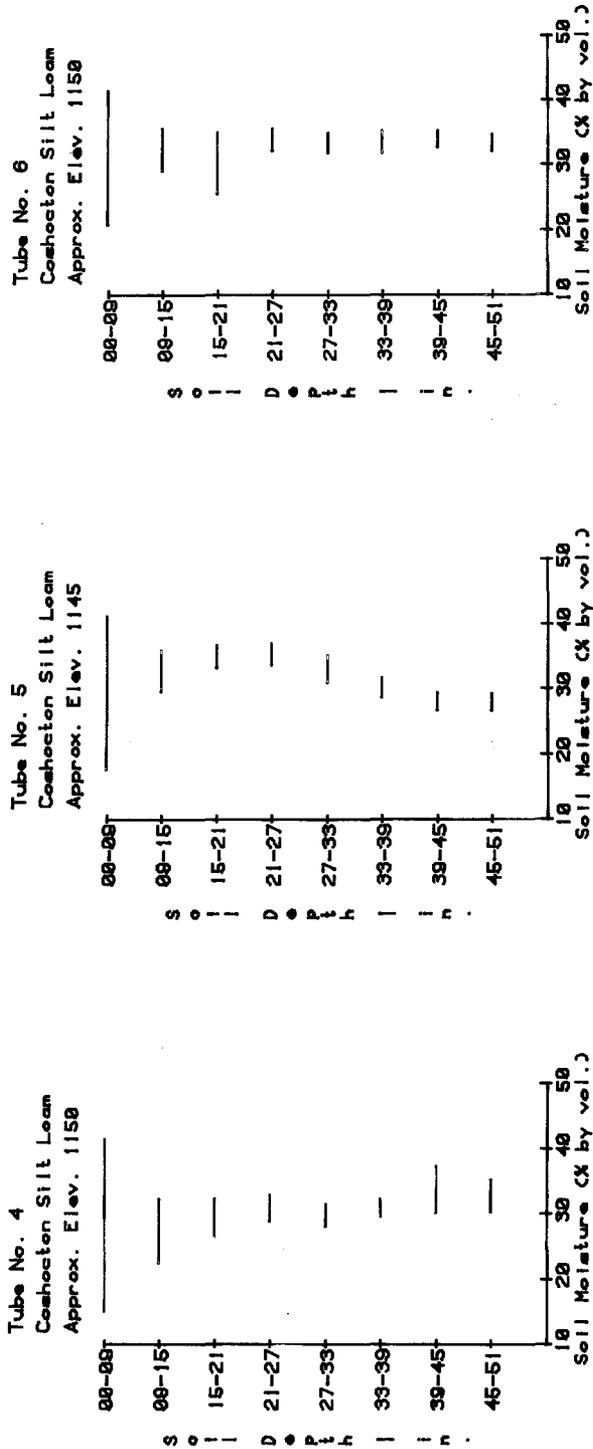


FIGURE 27. (Cont'd) - Soil moisture ranges measured at premined soil profile sites in Watershed J11.

three periods were the basis for evaluating the impacts of surface mining on surface-water runoff from the study watershed. Each period represented the watershed in a unique and readily identifiable physical condition. Watershed topography was the most prominent differentiating attribute. Figures 2, 16, and 17 illustrate differences for the original, intermediate, and final configurations. Vegetal cover was a second distinguishing characteristic. The study site was transformed from a pastured area with small patches of woods, to an area almost denuded of vegetation, and finally, to an area vegetated with a stand of grasses and legumes.

The remaining features which differentiated the data sets were the soils and underlying rock materials. Prior to mining, several locally common soils were identified in the watershed. These rested on a bedrock complex. Both soils and bedrock were destroyed over the upper part of the watershed and were replaced by ridges of spoil material with the onset of coal removal. Ultimately, soil comprised of previously undisturbed topsoil and some subsurface materials was substituted as the permanent replacement topsoil just prior to revegetation.

For comparison purposes, the runoff data were grouped into four sets. The first set characterized the watershed in the premined (undisturbed - Phase 1) state for the period May 1, 1977 to May 19, 1980. Observations made during Phases 2a, b, and c and Phases 2d and e were grouped into two separate sets. Intense mining and reclamation activities were prevalent during the earlier period, whereas few additional disturbances were made during Phases 2d and e. The fourth data set consisted of observations made during Phase 3a. As stated earlier, the watershed was nearly reclaimed during Phases 2d and e, but the reclamation included a partially completed erosion control system and an access road.

The physically distinct features associated with each data set suggested that the runoff response characteristics for each situation would be measurably different for similar transient meteorological inputs. Ideally, before observed differences can be quantified and attributed to a surface mining impact, an accounting should be made for variations arising from seasonal effects, as well as the normal range of meteorological inputs typically experienced. Because of the brevity of the observation periods, none of the groups contained sufficient data to seriously attempt such an effort.

An immediate consequence of this deficiency is that conclusions, derived from comparing data from the three groups, apply only to the combination of physical conditions and meteorological conditions that were experienced. The data sets do not allow latitude for interpretation as to what would have occurred had the watershed been revegetated with a different crop or been reforested; what effect warmer or cooler temperatures would have had on ET, moisture conditions, and runoff response; or how a different sequence of meteorological inputs might affect the conclusions derived from the available data. In addition, the data sets particularly lack information pertaining to snow and frozen soil hydrology. Consequently, this section excludes any reference to surface mining impacts over the winter period. Furthermore, runoff hydrographs suspected of having been influenced by snowmelt have been excluded from the analyses.

From a hydrologic perspective, the most obvious impacts of surface mining would be reflected in changes to the volumes and rates of runoff for comparative storm situations. In the analysis of the rainfall-runoff relationships that

follows, direct runoff (total runoff minus baseflow) is reported. Furthermore, only larger runoff events were considered. Generally, these had peak discharges in excess of 0.01 iph. A few exceptions were allowed when the hydrographs were single peaked, fairly well defined by a beginning and end time, and short in duration. By adopting this restriction, it was assumed that much of the variation induced by such lesser hydrologic components as interception would have been minimized. In addition, it was assumed that some variation induced by baseflow contributions would be attenuated. The procedure used to extract the direct runoff component from the total hydrograph is common to engineering practice (Linsley et al., 18) and is shown in Figure 28. The procedure requires that the curve segment of the hydrograph prior to the rise in runoff be linearly extended to a point just below the peak (line AB). From there, a line is drawn to some point on the recession limb (line BC). In this case, point C was arbitrarily selected as the tabulated gage height nearest 0.001 ft of the stage at the time of rise. The direct runoff is the volume bounded by the original hydrograph and curve ABC.

### 1. Runoff Volume.

The method selected in this report to relate runoff to rainfall is the Curve Number procedure developed by the Soil Conservation Service (SCS). The method is often applied in design engineering to estimate the volume of direct runoff from the total volume of precipitation on a catchment. It has received widespread acceptance because input parameters are easily derived from commonly available hydrologic and physical data. Details on the application of the procedure are well documented (SCS, 19).

Direct runoff is related to precipitation by the equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a)} + S \quad P > I_a \quad (4)$$

Where :

- Q = actual runoff (accumulated precipitation excess) in inches;
- P = potential maximum runoff (accumulated precipitation), in inches;
- $I_a$  = initial abstraction in inches;
- S = potential maximum retention at time when  $P = I_a$ , in inches (Hjelmfelt, 14).

Equation 5 expresses the relation between S and the SCS's curve number, CN.

$$S = \frac{1000}{CN} - 10 \quad (5)$$

CN is an empirical parameter which is a function of soil type, the SCS hydrologic classifications of soils, land use in the catchment, and antecedent moisture content (AMC). A qualitative estimate of the latter parameter is usually based on the total precipitation falling in the five-day period preceding an event. This total indicates a dry (AMC I), an intermediate (AMC II), or a wet (AMC III) antecedent moisture. When either a dry or wet AMC is estimated, an adjustment is made to the CN based on the watershed's physical characteristics and land management. Table 16 summarizes the ranges of total 5-day precipitation which delimit the three AMC's for the dormant and growing seasons.

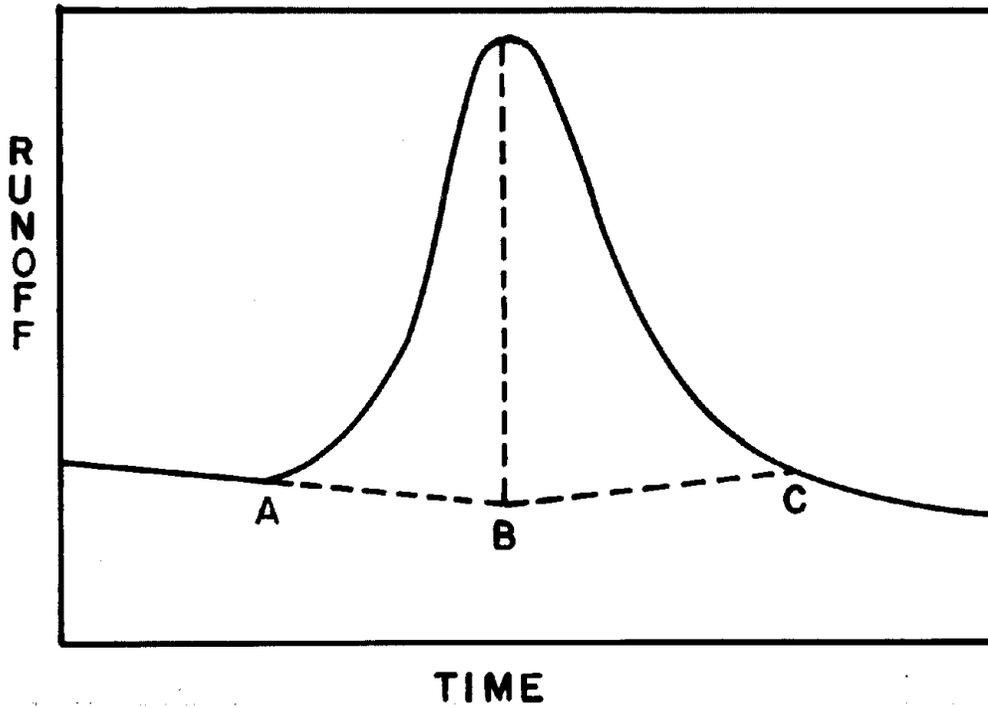


FIGURE 28. - Schematic illustration of direct runoff determination from a storm hydrograph.

TABLE 16. - Precipitation delimiters for  
defining Soil Conservation Service AMC

AMC No.	Total Five Day Precipitation	
	Growing Season <sup>1</sup>	Dormant Season <sup>2</sup>
I	$P < 1.4$ in	$P < 0.5$ in
II	$1.4 \leq P < 2.1$	$0.5 \leq P < 1.1$
III	$P \geq 2.1$	$P \geq 1.1$

<sup>1</sup>March 16 - September 15.

<sup>2</sup>September 16 - March 15.

One objective of the surface mining study was the determination of CN's for surface-mined lands. For this purpose, a reliable estimate of  $I_a$  was required. Unless sufficient data are available to justify otherwise,<sup>a</sup> the SCS recommends that Equation 6 be adopted to express the relationship between initial abstraction and potential maximum retention.

$$I_a = 0.2S \quad (6)$$

The equation was originally derived using analyses of natural rainfall on and runoff from watersheds less than 10 Ac in size. CN's presented in this report are based on this relationship although it would not be unreasonable to expect that Equation 6 might not apply during the active mining period given the continuous repositioning of spoils material, accidental and intentional impoundment of runoff, and the unnatural shape of stockpiled topsoils and spoils. Due to the paucity of data for the watershed in any one fixed state, no attempt was made to verify or modify Equation 6. Consequently, CN's predicted for Phase 2 are subject to an unquantifiable level of uncertainty. In the mostly reclaimed state, surface conditions were more readily identifiable with those that would be experienced for some common land management practices on natural watersheds. During the last months of 1980, for example, the surface conditions of the study site were predominantly what might be considered a combination of a poorly vegetated and a freshly tilled surface. An improving stand of legumes and grasses was experienced through 1981 and into 1982. Equation 6 is used by the SCS for these three conditions on natural watersheds.

Because the CN procedure relates direct runoff to soil types, vegetation, and land management through a single, lumped parameter, it cannot be analyzed in this study to determine the relative contribution of individual hydrologic and physical components to changes in the direct runoff-relationship. Instead, the composite effects of all changes are reflected in a single change to CN, provided the relationship of  $I_a$  to S remained constant. Thus, while most of the reclaimed study watershed was mapped as having a disturbed but uniform soil complex and a uniform vegetal cover, the effects of either characteristic alone on direct runoff (and hence CN) could not be differentiated on the basis of the data that were available. Notwithstanding this limitation Equations 4 and 5 were inverted and solved for CN for each of the rainfall-runoff events. Only events which occurred between April 15 and November 31 were included in the compilation. A few of these were combined when it was determined that the AMC for an event was markedly affected by its immediate predecessor. Storm and runoff events that occurred outside this period were excluded from consideration due to the likelihood of frozen soil conditions affecting CN.

Figure 29 plots CN vs total precipitation for each of the data sets described earlier. Substantial scatter is evident and only a weak association of points with respect to AMC is shown. These characteristics of the data sets are not surprising, given the accuracy associated with the procedure. Testimony to this is the discrepancy between computed and observed values for the watershed in the natural state. CN values of 54, 73, and 87 for AMC's I, II, and III, respectively, were estimated on the basis of the premining soils (Figure 4) and vegetation (Table 5) data. The estimate for AMC I is substantially less (54 vs 72) than that derived from the actual rainfall-runoff data (Table 17 - explained below).

A cursory study of the scatter diagrams of Figure 29 suggests an increase in the magnitude of CN with the commencement of mining activity and lasting through all of Phase 2. Thereafter, the persistence of the trend is less

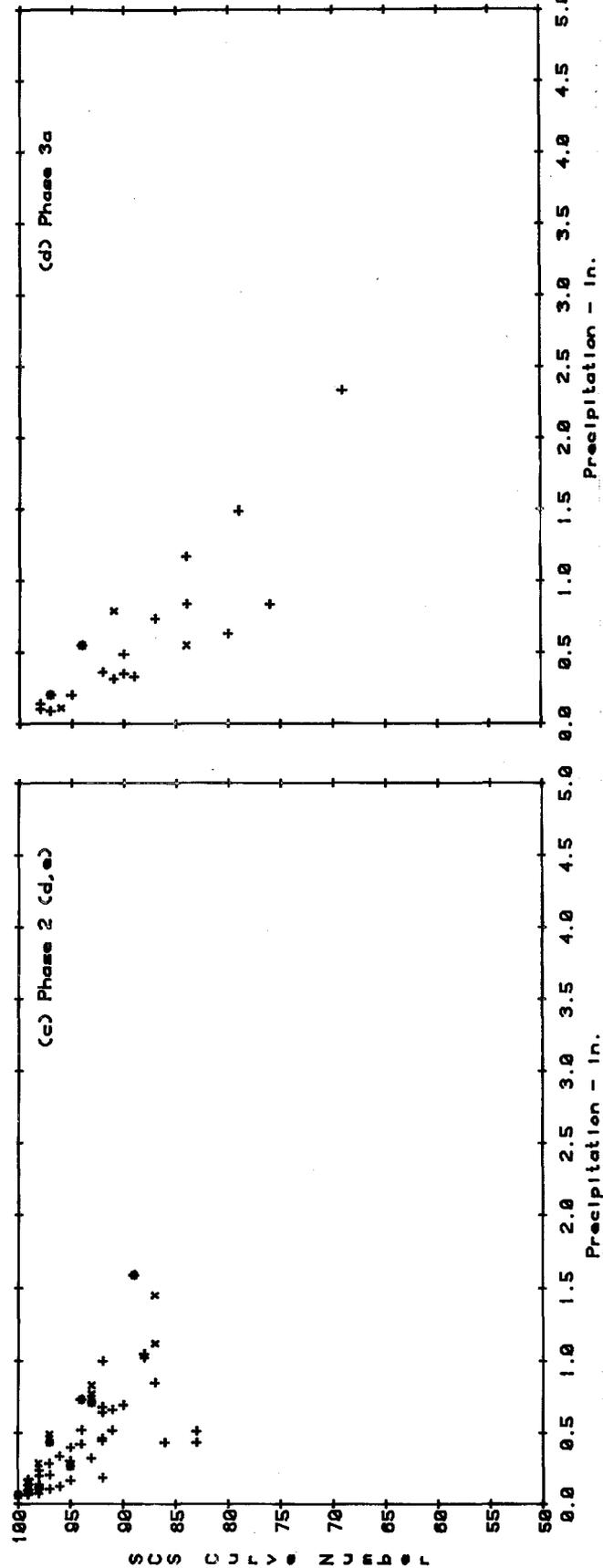
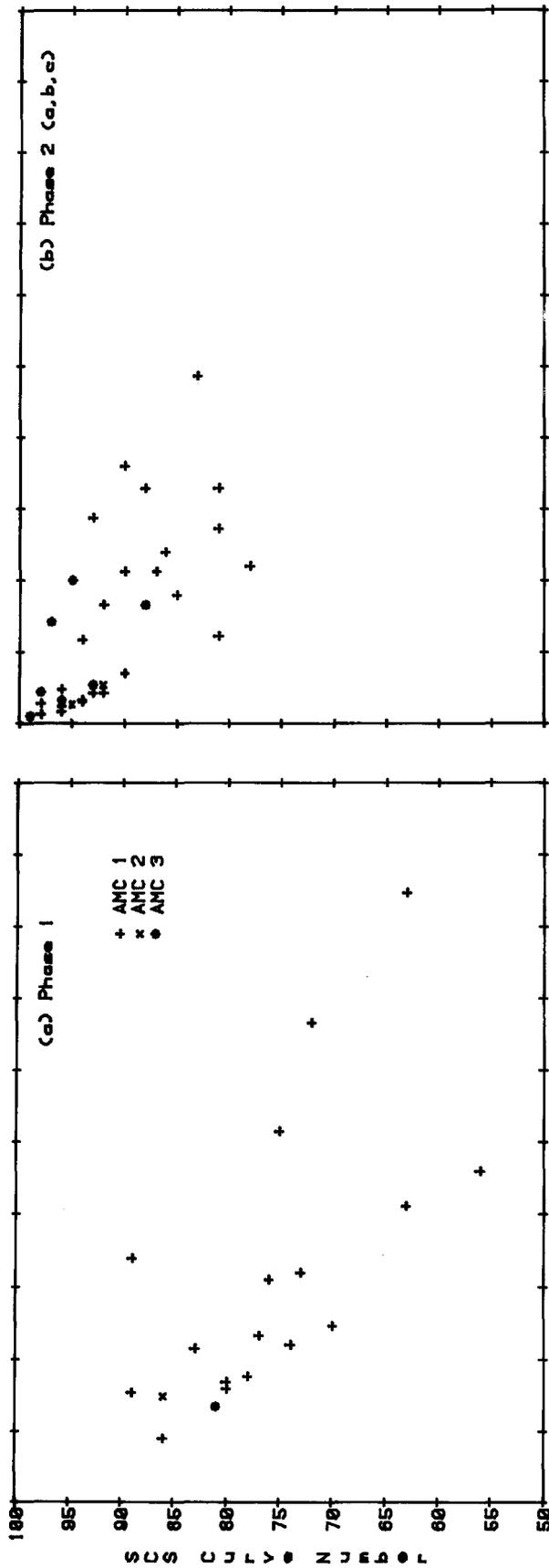


FIGURE 29. - Variability of Soil Conservation Service curve numbers with the progression of mining of Watershed J11.

TABLE 17. - Summary of average SCS Curve Numbers

Phase	AMC I		AMC II		AMC III		
	$\overline{CN}^{-1}$	$\overline{P}^{-2}$	$\overline{CN}$	$\overline{P}$	$\overline{CN}$	$\overline{P}$	No. Pts
1	72	1.63	86	0.74	81	0.67	1
2 (a,b,c)	87	0.81	93	.20	94	.46	7
2 (d,e)	91	.39	91	.82	93	.50	8
3	81	.65	89	.48	95	.38	2

$$1 \quad \overline{CN} = \frac{\sum_{i=1}^N (CN_i * P_i)}{\sum_{i=1}^N P_i}$$

$$2 \quad \overline{P} = \frac{\sum_{i=1}^N P_i}{N}$$

certain. CN values along the lower range of scatter for Phase 3a nearly envelope those for the premining period.

The convergence of points as P approaches zero was merely due to the structure of Equations 4 and 5 and partial area contributions. Given the extent of the scatter and the lesser significance of smaller events, weighted averages of CN's were computed for each of the periods in Figure 29. The results are presented in Table 17 and showed no significant difference among years after the commencement of mining. The overall representativeness of the average figure for 1978 Phases 2a, b, and c may be questioned in that it was based on highly transient physical configurations and topography within the watersheds. However, the degree of scatter that is depicted for the period is no less than that observed for the other periods. Consequently, they have been presented as a measure of change induced by surface mining.

A complete representation of the impacts of surface mining on the disposal of excess precipitation and ground water from the watershed is illustrated in the distribution of watershed outlet flow rates over time, and a double-mass curve plot of runoff versus rainfall. Figures 30a and b plot the daily-flow duration curves for the January through December and March through December periods of 1978, 1979, 1980, and 1981. The 10-month sequences were compiled to confirm that observed differences were not the result of snowmelt. Distributions for 1977 and 1982 were not computed since the records were incomplete. However, the partial record for 1977 was similar to records for 1978 and 1979 and the partial record for 1982 reflected watershed behavior that was observed in 1981.

One obvious difference among the four curves during either sequence of months is the progressive and marked diminution in the frequency and magnitude of low flows (viz. runoff less than 0.025 in/day) with the commencement of mining. As shown by the 1978 and 1979 curves, discharge from the watershed prior to mining was continuous nearly 100% of the time. During the first stage of reclamation, the frequency of zero runoff daily occurrences in 1981 had increased to approximately 50% and the overall distribution of daily flows tended to be sharply divided between storm runoff and brief periods of low (possibly base) flow. The latter characteristic indicated that the "reconstructed" aquifer was probably recharging slowly and/or not releasing storage. The flow duration curve for 1980 was a transition between the two extremes and was a composite representation of natural response and surface mining impacts. Until mining disturbances were incurred, there were no days of zero runoff. Thereafter and until the end of 1980, days of no runoff were observed more than 35% of the time, with the frequency of no flow observations increasing with the progression of Phases 2a, b, and c. It should be noted that activities related to the replacement of the runoff measuring device, as reported in Section II, affected the runoff duration results for 1980. The frequencies of zero runoff days as presented in Figures 30a and b are excessive. Replacement of the H-flume by the drop box weir in May 1980 resulted in approximately 30 days of lost record. In the flow duration compilation, zero runoff was assumed although baseflow was observed during the operation. Based on the number and magnitude of storms observed during this period (April 22 - May 22), and earlier runoff records, the principal impact on the flow duration curve was most likely confined to the 0.0 - 0.25 in/day range. The fractions of time that zero daily runoff were observed in 1980 probably ranged from 0.26 - 0.34 in Figure 30a, and 0.31 - 0.41 in Figure 30b.

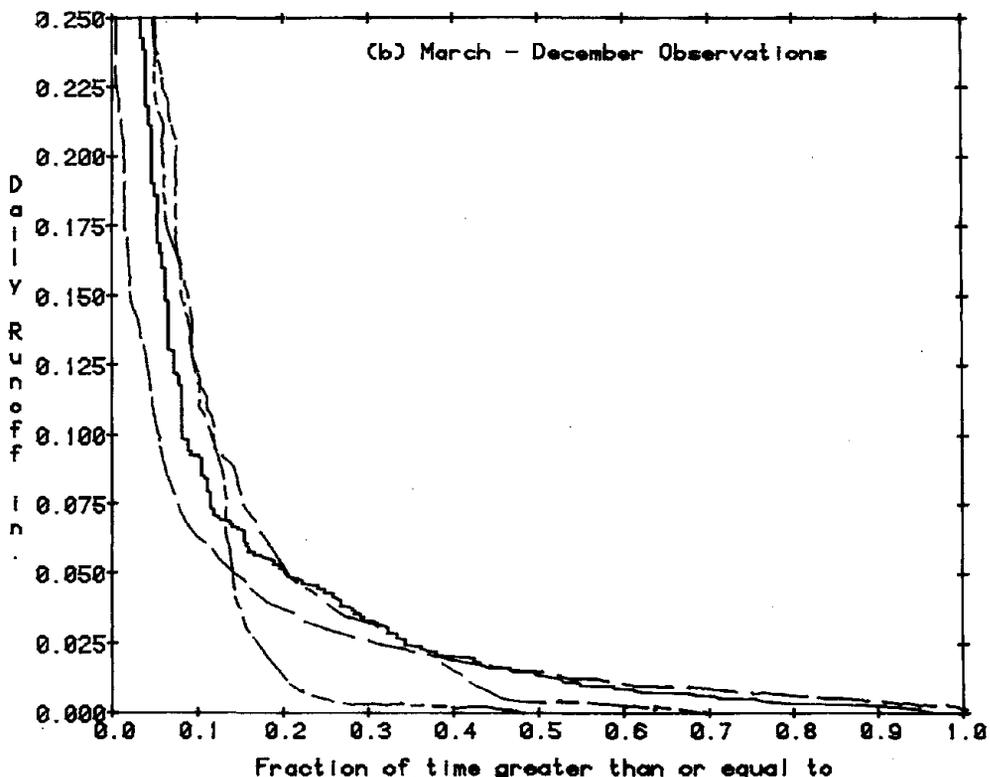
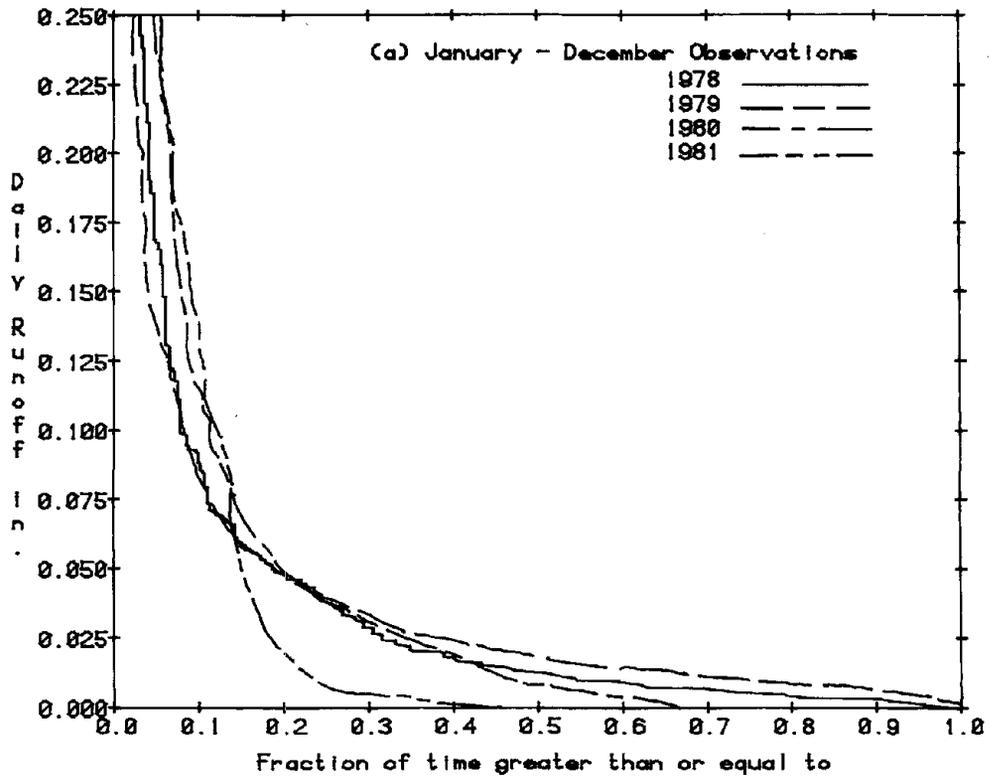


FIGURE 30. - Watershed J11 - daily flow-duration curves.

The frequencies of daily precipitation inputs (Figures 31a and b) were similar particularly for the smaller sized storms. In conjunction with the distribution of monthly precipitation inputs, it is unlikely that the differences among the runoff duration curves were solely the result of climatic factors. While some sensitivity was exhibited to the exclusion of January and February daily runoffs in 1979, the distribution shapes were relatively constant with respect to each other. Thus, surface mining decreased the tendency for Watershed J11 to sustain a continuous low (base) flow and enhanced more frequent and greater daily runoff. As noted below, these impacts were reflected in the storm hydrographs and included higher peak flow rates and shorter recession limb periods relative to those observed prior to mining.

A double mass plot of cumulative runoff vs cumulative precipitation is exhibited in Figure 32. The origin and terminal points of the trace correspond to the first and last days of the study period. The first days of intermediate months are scored on the time axis directly above the corresponding accumulations on the x-axis for that day. Although this does not provide an absolute time scale, it is a reference for isolating monthly contributions to the total record. Thus, for example, the more closely spaced are two adjacent scores on the time axis, the less is the contribution of daily precipitation to the total accumulation for that period.

Strong seasonal trends in the relationship were observed during Phase 1. Average runoff yields during the late spring and summer months (Curve Segments AB, CD, and EF) were substantially less than those depicted for other months (Curve Segments BC, DE, and FG). Phases 2a and b were limited to the summer and early fall of 1980 and were too brief to reflect any seasonal variability. A comparison of the Phase 2 average runoff yield (Curve Segment G'H) with Phase 1 observations indicate a significant net increase in runoff during the mining period. The increase is evident by a comparison of the curve slope of segment G'H with those of segments AB, CD, EF. The relative difference is an estimate at best, since catchment delineations of probable runoff areas were based primarily on field inspections.

Sharp attenuations and amplifications of Phase 3a average runoff yields with changes from growing to dormant season, and vice versa, were not as apparent as they were in Phase 1. Despite the reclamation and establishment of a vegetal cover, Phase 3a summertime runoff yields were greater than those during Phase 1, while dormant season runoff yields were noticeably less than those observed prior to mining. Overall, seasonal variability was not reflected as much in the precipitation-runoff relationship during Phase 3a as it was in Phase 1.

A possible contributing factor may be related to the cause for the enhancement of the ephemeral characteristics of the flow regime. That factor is the inability of the reclaimed soil to infiltrate water. Reductions in hydrograph recession times relative to premining observations and lack of ground-water recharge as discussed later are evidence to that end. Consequently, it may be speculated that the available water storage in the soil was somehow reduced by mining, and antecedent moisture levels were not as variable in the reclaimed watershed. However, there are no data with which to test this hypothesis.

## 2. Runoff Intensity.

In addition to the volume of excess precipitation discharged from the watershed, surface mining and reclamation affected the discharge rates. A common

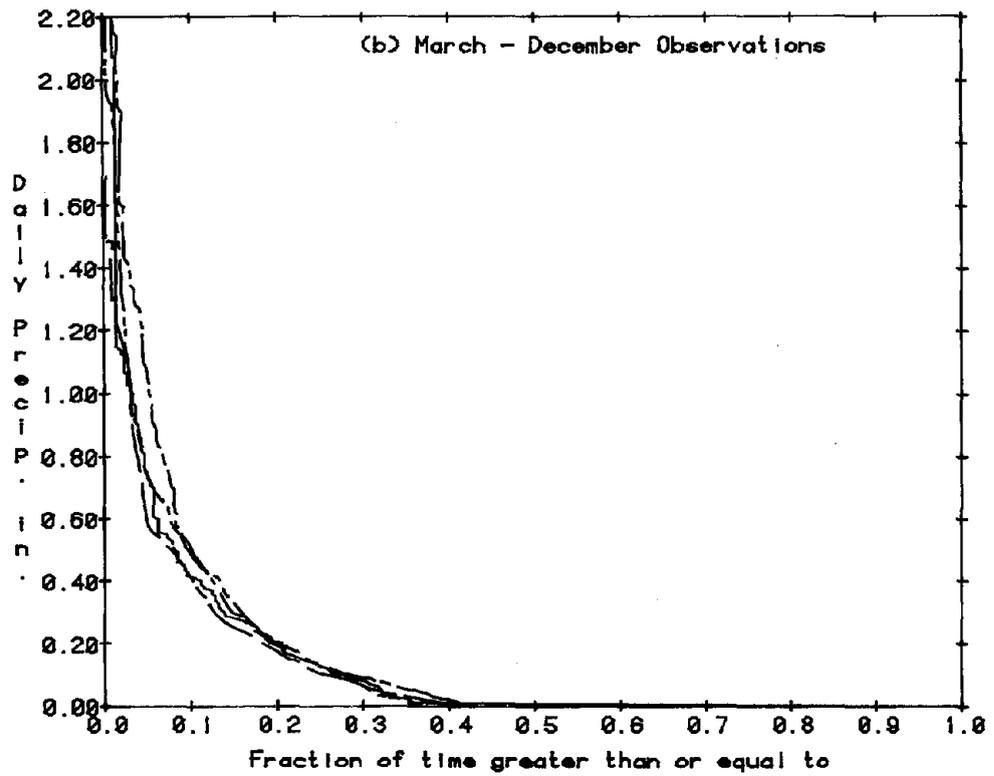
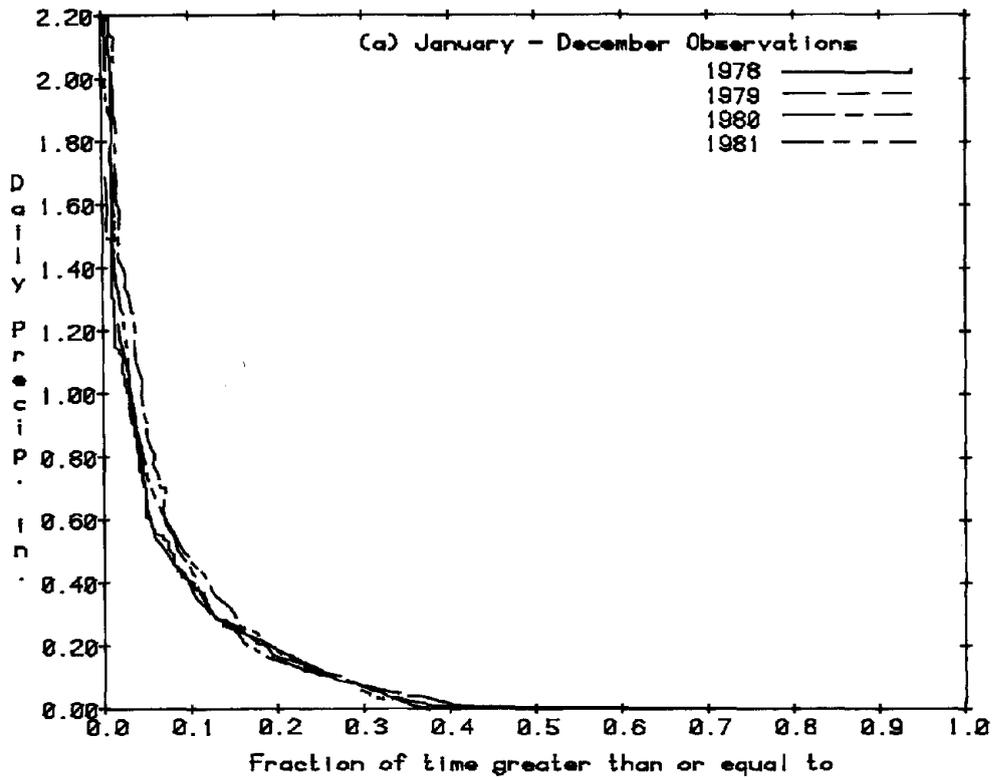


FIGURE 31. - Distribution of daily precipitation on Watershed J11.

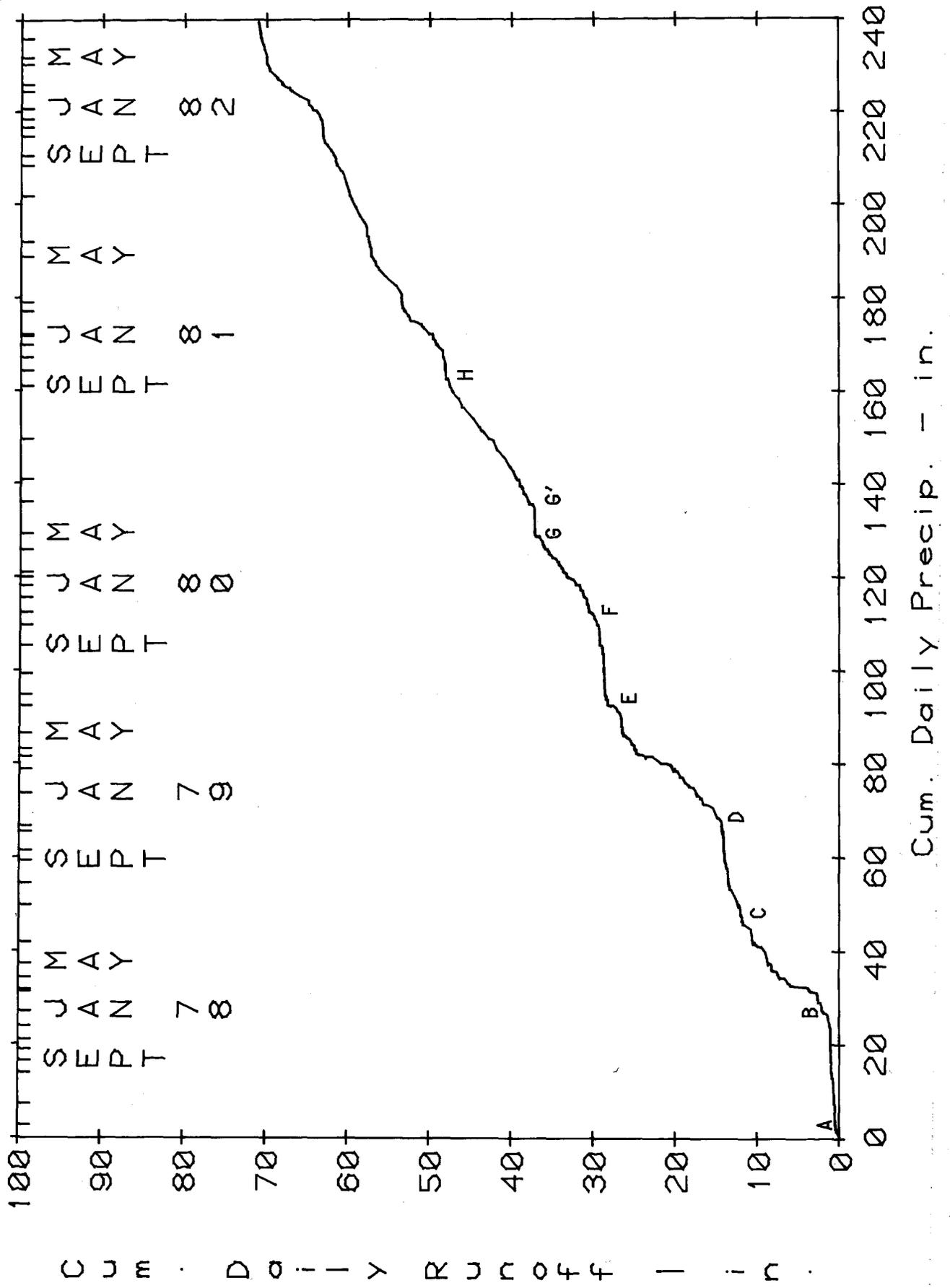


FIGURE 32. - Double mass plot of Watershed J11 runoff vs precipitation.

characteristic of the spring and summer month hydrographs observed before, during, and after mining was the apparent coexistence of slow and rapid responses. The latter were often superimposed on the slow responses and were typified by rapid rates of rise and fall. These rates were nearly linear with time, and strongly resembled triangularly-shaped discharge functions. The slower responses tended to be more frequent and more variable. Figures 33a to d compare representative responses observed during each study period. While the functional forms of the rapid responses were similar, distinct differences were observed among their descriptive parameters (time to peak, rate of rise, response durations, and peak flow) for the watershed in the natural, mined and reclaimed states. How surface mining changed the magnitudes of each of these parameters is discussed below. In the examples shown in Figure 33, the rate of rapid rise was most dramatic and the peak flows were greatest in the Phases 2a, b, and c, and Phases 2d and e hydrographs. At the same time, the maximum average 5-minute rainfall intensity associated with these two responses were least (viz. 2.04 iph and 4.60 iph, respectively, vs 5.80 iph for Phase 1 and 5.38 iph for Phase 3a).

In the discussion that follows, the descriptive parameters (noted above) which document differences among the premining, mining and postmining runoff responses are quantified. For these purposes, it was assumed that the triangular unit hydrograph concept was valid. On that basis, discharge rates for a given convolution interval (unit hydrograph duration) increase proportionally to the excess precipitation intensity (rainfall intensity less infiltration rate averaged over the convolution interval).

One significant difference between the premining hydrographs and the mining and postmining hydrographs was a decrease in the time to peak for comparative ranges of rainfall intensities. In comparing the various responses observed during the study, minor contributions to the overall response were ignored and the time to peak was approximated as the duration,  $T_D$ , of the steepest linear segment of the rising limb. According to unit-hydrograph theory,  $T_D$  varies with the durations of the average maximum storm intensities. To approximate representative values of  $T_D$ , all major runoff responses were identified and grouped according to phase. Only those events with clearly identifiable and relatively rapid linear discharge rates were selected. Furthermore, only those portions of the responses associated with sustained periods of relatively elevated rainfall intensity were considered. Table 18 summarizes some properties of the data base, and shows a 4 - 5 fold decrease in  $T_D$  with the progression of mining reclamation.

The downward trend in  $T_D$  from the natural to reclaimed state could not be traced to differences in precipitation characteristics. Table 19 summarizes the number of individual storms having average maximum 5-, 10-, and 15-minute intensities greater than 1.0, 2.0, and 3.0 in per hour (iph). Some storms having these characteristics were not included in the compilation. In a few instances, instrument malfunctions were responsible for responses not being recorded. In other cases, variable rainfall intensities generated runoff responses that were too complex for consideration.

On the average, and relative to the other phases, the natural watershed was more effective in absorbing higher rainfall intensities. On a percentage basis, rapid responses were observed least often during the premining period. Their frequency of observation increased with average maximum rainfall intensity and, generally, the duration of the intensity. Elements of the premining

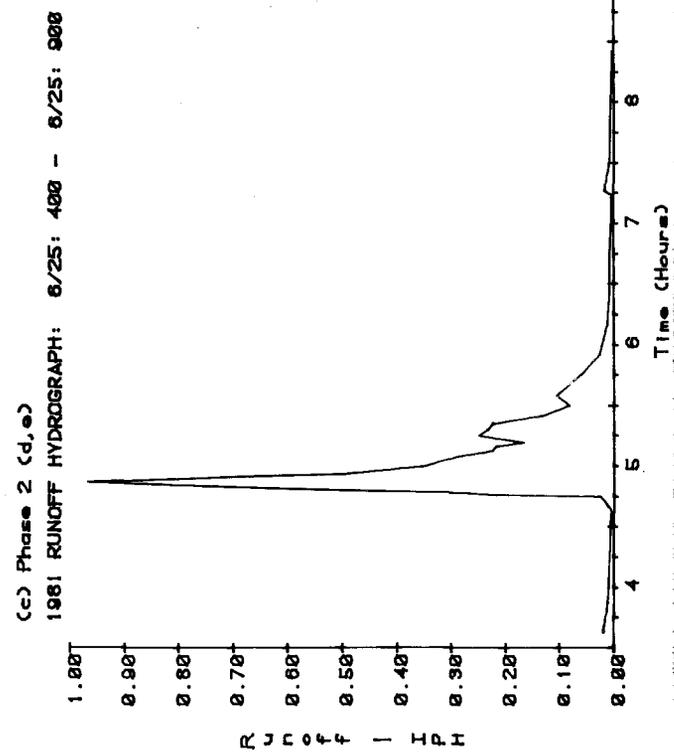
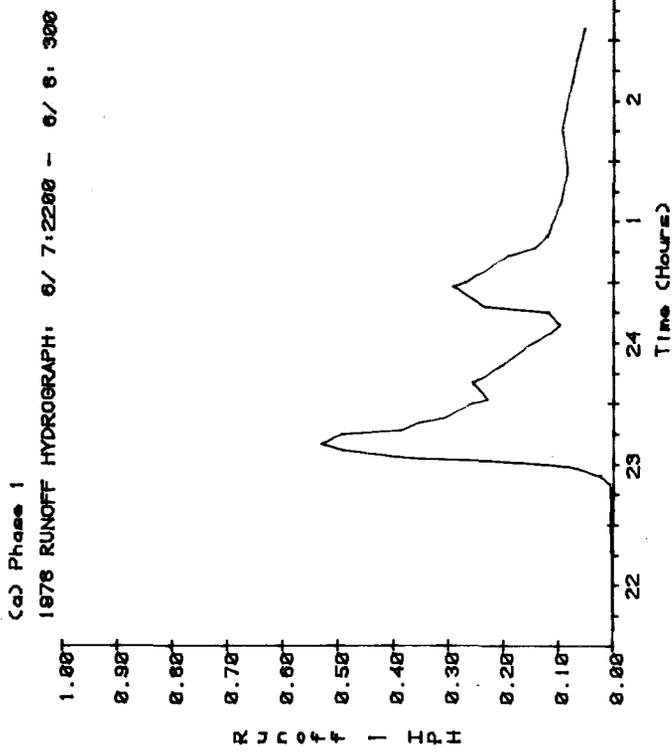
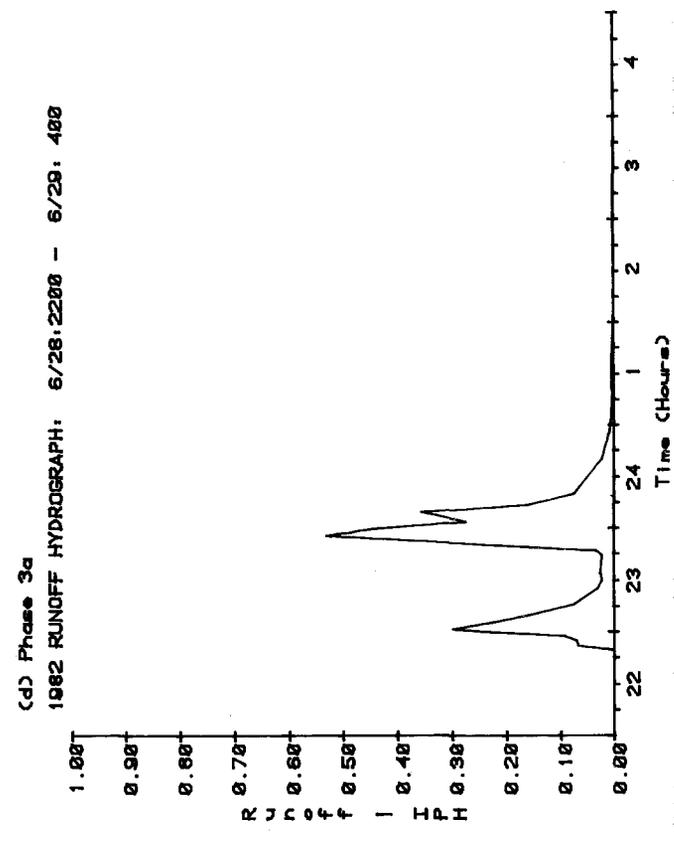
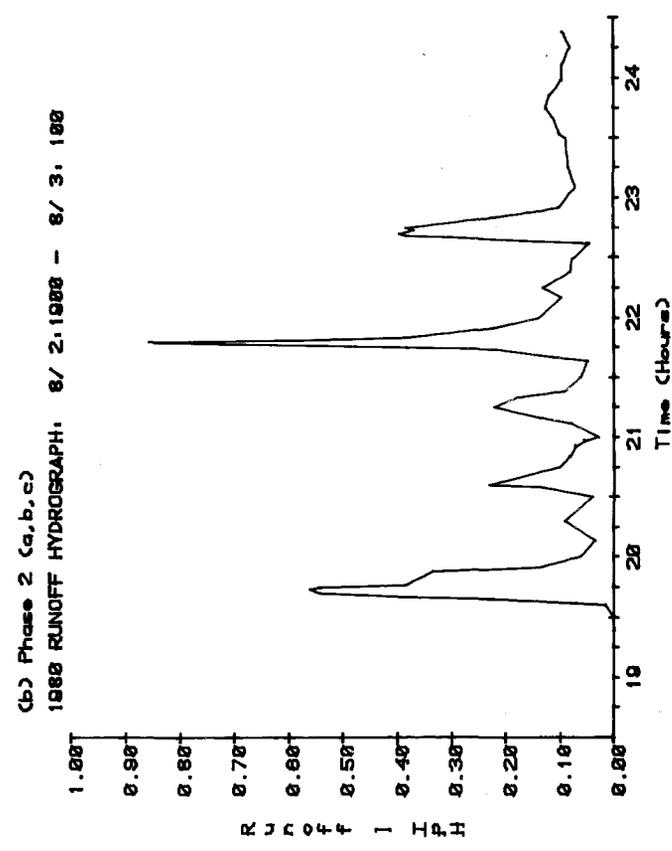


FIGURE 33. - Representative hydrographs observed at Watershed J11 prior to, during, and after mining.

TABLE 18. - Summary of durations of the rising portions of rapid responses

Data Base Period	No. of Responses Considered	T <sub>D</sub> -Duration of Rapid Rise-Minutes		
		Mean	Stand. Dev.	Coef. of Var.
Natural & Disturbed (Phase 1)	28	36	27	.75
Active Mining (Phase 2a,b,c)	27	11	8	.73
Mining (Reclamation) (Phase 2d,e)	65	7	5	.71
Reclaimed (with erosion control practice) (Phase 3a)	25	8	4	.50

TABLE 19. - Percentage of high intensity storms producing rapid responses

Data Set	5-Minute Duration			10-Minute Duration			15-Minute Duration		
	>1 iph N <sup>1</sup> U <sup>2</sup>	>2 iph N U	>3 iph N U	>1 iph N U	>2 iph N U	>3 iph N U	>1 iph N U	>2 iph N U	>3 iph N U
Phase 1	64 5%	24 53%	11 73%	41 19%	15 37%	7 100%	27 40%	12 67%	3 100%
Phase 2 a, b, c	22 21%	13 100%	9 100%	17 100%	10 100%	3 100%	13 100%	6 100%	1 100%
Phase 2 d, e	34 33%	13 100%	9 100%	24 100%	10 100%	5 100%	18 100%	5 100%	1 100%
Phase 3a	16 13%	8 100%	5 100%	11 100%	4 100%	2 100%	10 100%	3 100%	0 100%

<sup>1</sup>N = Number of storms.

<sup>2</sup>U = Percentage of storms which produced a rapid response.

matrix with the smallest percentages of observation (5% and 19%) were the 5- and 10-minute duration of 1 iph, respectively. After mining, however, virtually every storm with at least an average maximum rainfall intensity of 1 iph, lasting no less than 5 minutes produced a rapid response. However, as indicated by the standard deviation of  $T_D$  in Table 18, the response characteristics were quite variable. Similar statistics for the active mining and reclaimed periods were 3 to 5 times less than those for the natural watershed. The tendency for quick, high intensity and short-lived response persisted after the first stage of reclamation was completed.

A second measurable difference among the runoff responses prior to, during and after mining was in the rates of increasing discharge. This was indicated qualitatively in Figure 33 where the slope of the rising limbs of the mining and postmining hydrographs were greater than that for the premining hydrograph. To quantify these differences, the average slope of the rising limb over  $T_D$ ,  $\dot{Q}$ , was computed for each rapid response.

For a triangular shaped unit hydrograph,  $\dot{Q}$  is proportional to a uniform burst of excess rainfall intensity over some specific period  $P$ . The basis for comparing  $\dot{Q}$  for the various study periods, therefore, was a linear relationship between  $\dot{Q}$  and  $I_P$ , where  $I_P$  is the average maximum  $P$ -minute rainfall intensity. Because of the limited number of significant runoff producing storms which occurred during the study and the unavailability of some background data, the manner in which this relationship was subsequently used is somewhat liberal. First, the lack of adequate infiltration data for computing storm losses necessitated the use of actual rather than excess rainfall intensities. Second,  $\dot{Q}$  was not corrected for contributions from slow responses or rainfall preceeding rapid responses. Third, a single rainfall averaging period ( $P=10$  minutes) was used for all phases of the study despite differences in  $T_D$  values. Ideally, the averaging period for the input (rainfall) function would be consistent with the averaging period for the response (runoff) to insure proper application of the unit-hydrograph concept. Notwithstanding the differences among the  $T_D$ 's, the 10-minute interval was selected for computing an average maximum rainfall intensity on the basis that it corresponded closely with the mean values of  $T_D$  for the actively mined and reclaimed period, and was within one standard deviation of the average for the natural watershed.

A plot of  $\dot{Q}$  vs the maximum average 10-minute rainfall intensity,  $I_{10}$  is shown in Figure 34. Considerable scatter is evident, particularly among Phase 2 observations. Several factors contributed to the variability. The responses for many Phase 2 and 3 events were so rapid that the durations of the rising stage were less than 1 time division on the recording media. Considerable judgement was used to interpolate beginning and ending times. Omission of infiltration losses and deficiencies associated with the application of unit-hydrograph theory contributed, too. The estimated delineations of watershed area during periods of frequent and intense disturbances (Phases 2a, b, c) were yet another source of variability.

Mining and reclamation markedly increased  $\dot{Q}$  with respect to  $I_{10}$ . Assuming a linear relationship of the form:

$$\dot{Q} = k * I_{10} \quad (7)$$

the proportionality constant  $k$  increased from 3.6 for Phase 1, to 20.1 for Phases 2a, b, and c and to 34.7 for Phase 2d and e. During Phase 3a, the

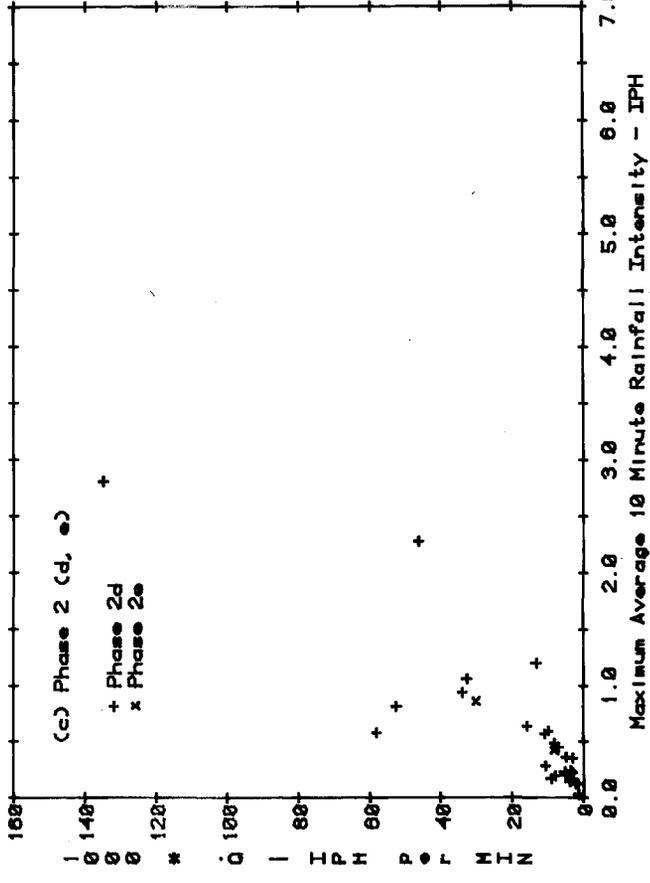
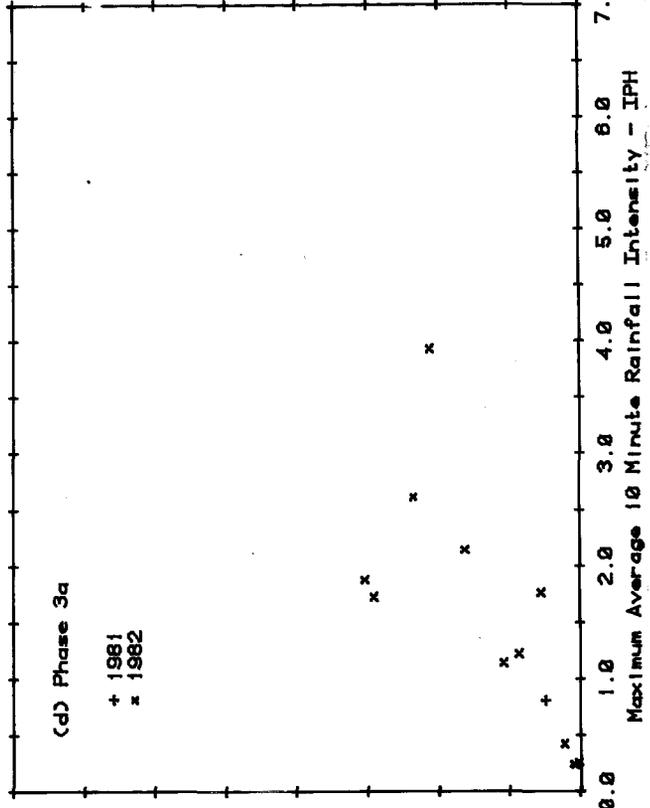
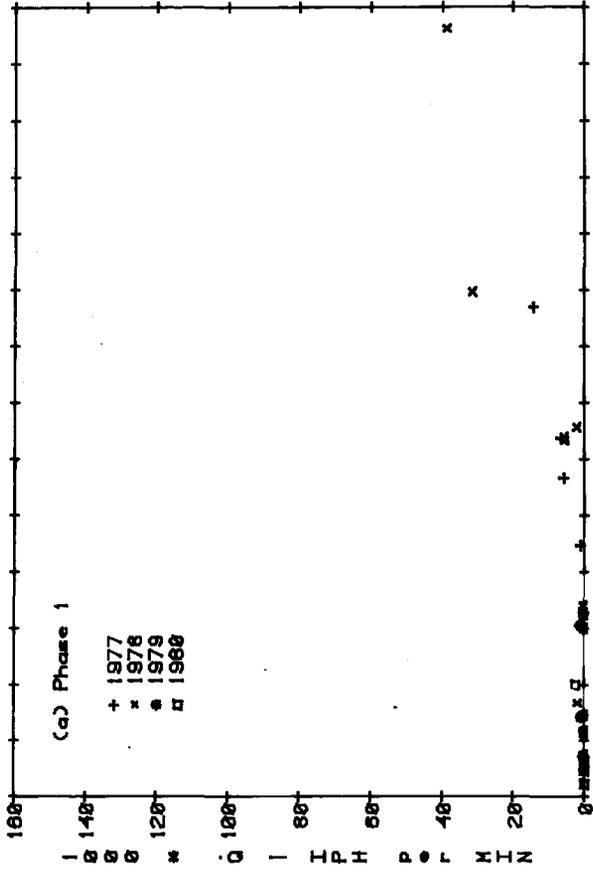
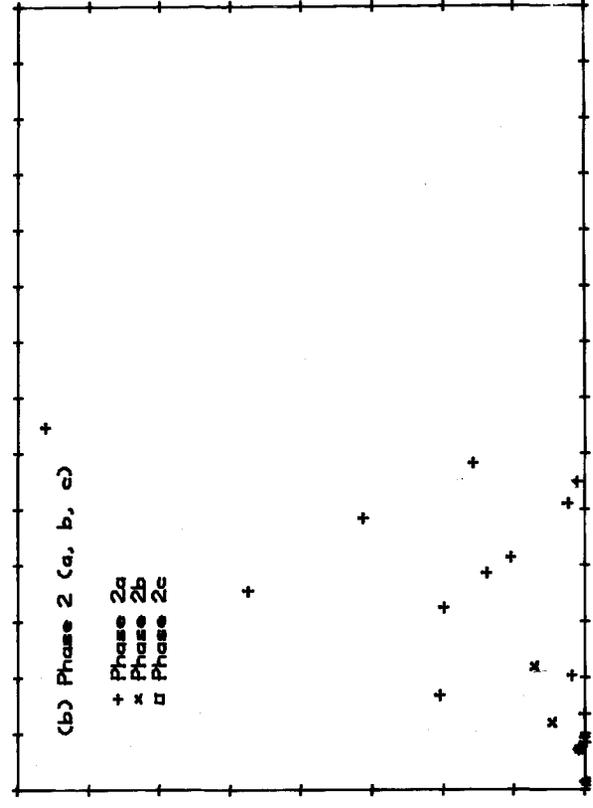


FIGURE 34. - Relationship of rate of rapid response discharge rate to maximum average 10-minute rainfall intensity.

durations of the rapid responses remained unchanged on the average (Table 18), but intensities were not sustained, and  $k$  decreased to 16.2. The strengths of these relationships as measured by the coefficient of determination,  $r^2$ , were fair and varied from 0.79 for Phase 1, to 0.56 for Phases 2a, b, and c, to 0.85 for Phases 2d and e, and to 0.73 for Phase 3a.

More than anything else, the near 50% reduction in  $k$  from Phases 2d and e to Phase 3a was most likely related to reestablishment of a vegetal cover. The general topography of the study site during these two periods differed primarily in areas adjacent to the access road. Removal of the road and completion of the erosion control system altered the contributing area but that change was confined to the southeastern quadrant, and was far away from the watershed outlet. A more important difference was the quality and density of vegetation on the remaining 75% of the watershed. The Phases 2d and e reclamation efforts yielded a very weak stand of vegetation. Reseeding of large tracts was required and vegetation on the watershed during Phase 3a was much improved.

A third impact of surface mining that was reflected in changes to the shapes of the runoff hydrographs was associated with the total duration of the rapid response. Total rapid response durations also tended to be shorter in the mining and reclamation years. As a measure of this condition, time intervals between the occurrences of the rising and falling limb half-peak discharge rates were computed for single-peaked, triangularly shaped hydrographs. Only responses with peak discharges greater than 0.01 iph and occurring between May 1 and October 31 were considered. The latter criterion was adopted inasmuch as the summer months were most common to all the study groups, and seasonal effects were strongly exhibited in the Phase 1 observations.

The results could not be correlated with observed peak flows, although the Phase 2 data sets indicated a very weak inverse relationship between duration and peak flow. Table 20 summarizes the properties of the data set. As indicated by the 3 - 5 fold reduction in the duration, a more "flashy" runoff response was characteristic of Phases 2 and 3a, with no substantial difference between the mining and reclamation periods. The relative variability of the response duration, as quantified by the coefficient of variation, however, was more or less constant.

The fourth characteristic of Watershed J11 hydrographs affected by surface mining was peak discharge rate. Surface mining drastically amplified peak discharge rates from the watershed. One means to quantify an impact of this nature is a comparison of peak discharges vs a suitable set of independent parameters; a second is a comparison of unit-hydrographs for conditions within and among the various phases of mining. The latter is more desirable because it provides such useful engineering information as time to unit-peak and unit-runoff duration for effective-rainfall durations, and reduces the runoff responses for the various mining phases and random shapes of the rainfall hyetograph to a standard norm.

A prerequisite for such an analysis is the availability of data bases that consist of sufficient numbers of samples with direct runoff being a large fraction of total storm input. The norm that was adopted for this condition was direct runoff in excess of 1 in. Too few events occurred within the respective study periods which met this criterion. Consequently, an assessment of changes to the watershed's runoff response characteristics during the study

TABLE 20. - Summary of rapid response durations as measured by the time difference between the occurrences of the half-peak discharge rate

Period	Number of Samples	Average Duration (min)	Coefficient of Variation
Phase 1	14	47	.6
Phase 2 (a,b,c)	17	12	.7
Phase 2 (d,e)	22	10	.5
Phase 3a	11	15	.7

was limited to comparisons among sets of peak discharges. The independent variables used as the second parameter in the relationships were the maximum average 5- and 10-minute rainfall intensities. Figure 35 plots the results. An extension of the exercise to include maximum average rainfall intensities lasting more than 10 minutes did not enhance the relationship. The primary differences between these results and those presented in the illustration were increasing reductions in the dispersion of data points, but with little change in relative positions among the observations. Furthermore, averaging beyond the 10-minute interval showed some peak discharges approaching maximum average precipitation intensities.

The presentation of Figures 35 (a to h) is not intended to suggest that an exact relationship exists among the two variables. Hjelmfelt (15) has shown for the simple case of rainfall on an impermeable surface that peak discharge varied measurably with time to equilibrium. In the case of the study watershed, AMC, the complexity of the topography, non-uniform soil properties, and shape of the rainfall hyetograph radically affected the peak flows, too.

The disturbances associated with preparing the site for coal removal and actual mining operations effected an immediate increase in peak discharges. Phases 2a, b, and c maxima (Figures 35c and d) were as much as an order of magnitude greater than those observed during Phase 1 (Figures 35a and b) over a comparable range of average precipitation intensities. The same relationship persisted in Phases 2d and e, but with substantial decrease in variability (Figures 35e and f). More accurate determination of watershed area, and less frequent and more uniform smaller scale disturbances probably contributed to this characteristic. An attenuation of peak discharges was observed with the improvement of a vegetal cover during Phase 3a (Figures 35g and h). These maxima were approximately 2 to 3 times less than those observed during all of Phase 2 but were still substantially greater than those measured during Phase 1.

#### E. Summary

Observations related to the surface hydrology of the study site were grouped into four periods: Phase 1; Phases 2a, b, and c; Phases 2d and e; and Phase 3a. May 1, 1977 and June 30, 1982 delimited the overall study period and defined the first and last days of Phase 1 and Phase 3a, respectively. The commencement dates of Phases 2a, b, and c and Phases 2d and e were May 20, 1980 and November 11, 1980, respectively. Each period corresponded to a predominant condition or activity within the watershed. Natural-undisturbed conditions typified Phase 1; active, severe disturbance typified Phases 2a, b, and c; a long stable period of few and minor disturbances on a partially but mostly reclaimed watershed identified Phases 2d and e; and total reclamation with an erosion control practice in place characterized Phase 3a. No observations were made for "final" reclaimed condition inasmuch as the study terminated prior to the realization of that state.

Meteorologic components affecting the surface hydrology were generally within a subjectively defined normal range of variation. Observations having at least a 5% probability of being exceeded and a 95% probability of not being exceeded were deemed normal. Based on logarithmic-normal distributions fit to monthly observations made at Steubenville, Ohio and adjustments to Watershed J11 observations for site differences, February 1978 and 1979 were the only abnormally cold months; and August 1980 and May 1982 were the only abnormally



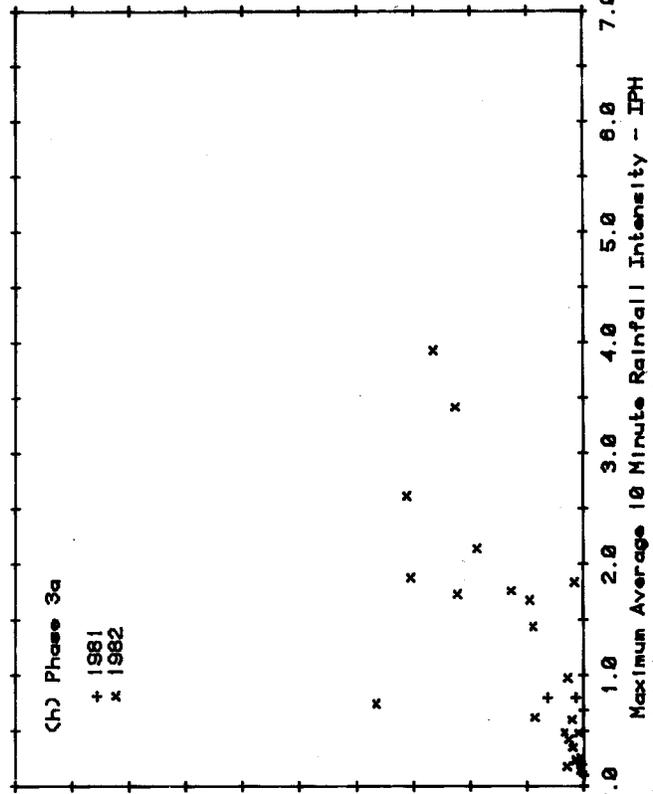
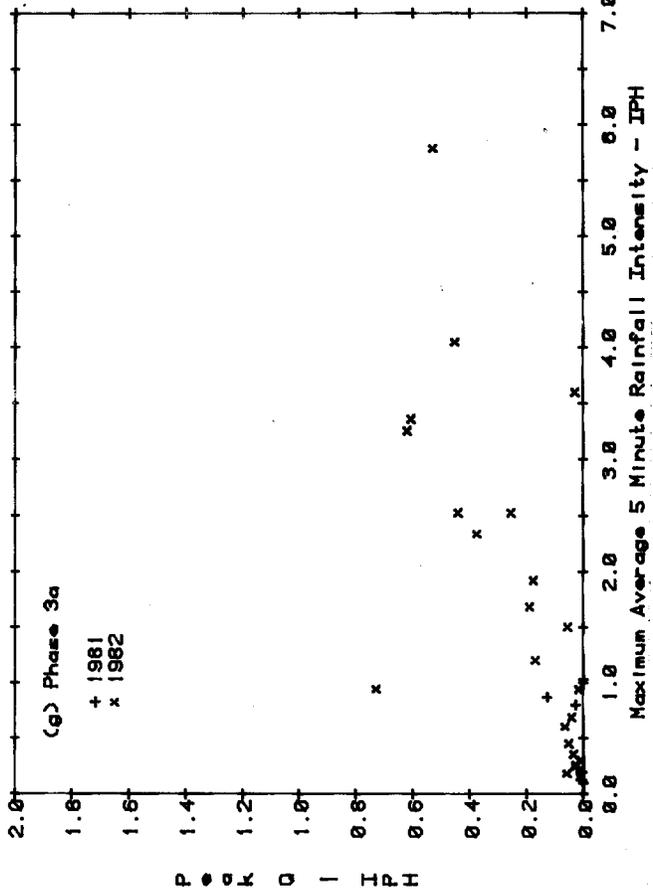
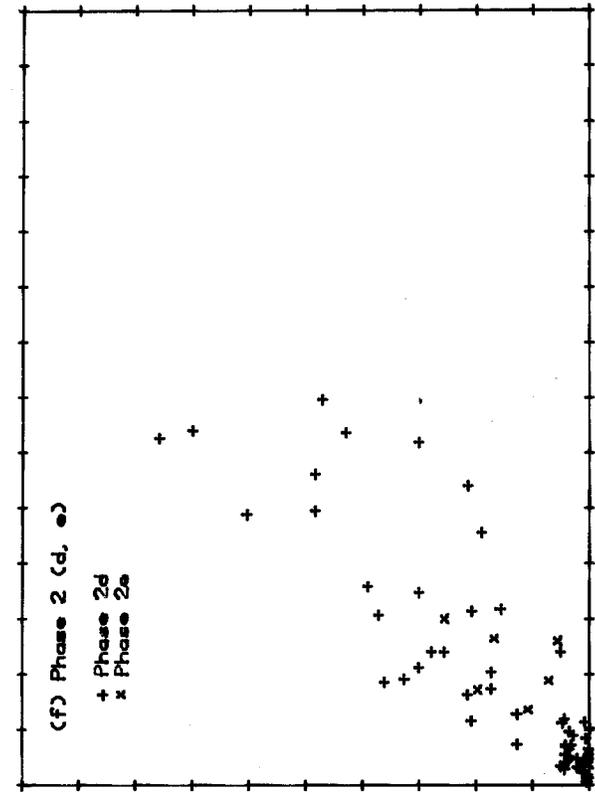
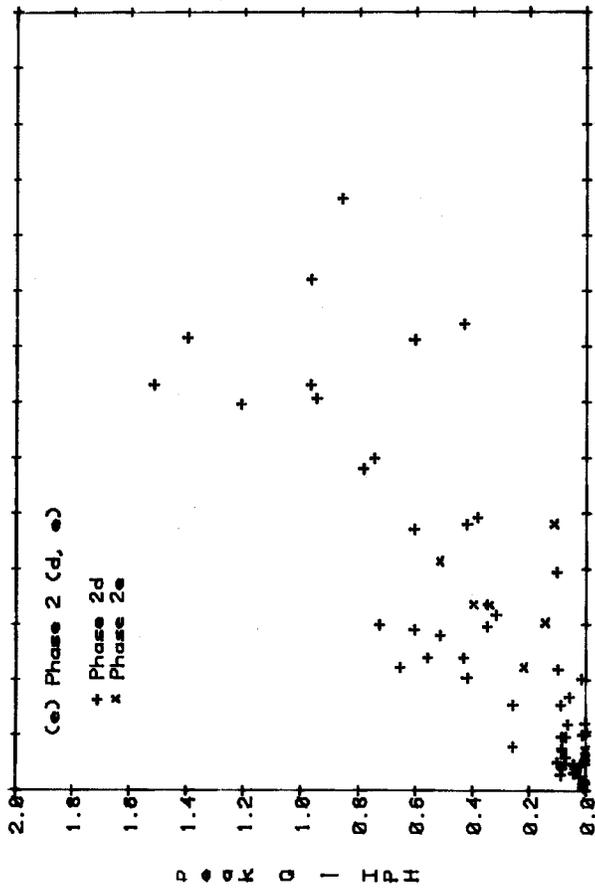


FIGURE 35. (Cont'd) - Relationship of peak discharge to maximum 5- and 10-minute rainfall intensities.

warm months. Generally, mean monthly air temperatures were cooler than expected. Four of the eight months of 1977; eight months each of 1978, 1979, and 1980; nine months of 1981; and three of the six months of 1982 experienced mean monthly air temperatures below the long-term averages.

August 1980 and April 1981 were the only abnormally wet months and January 1981 was the only abnormally dry month. Total precipitation in 21 of the 37 months prior to mining; all months of active mining (Phases 2a, b, c); and 11 of the 22 remaining was above average. The annual total for 1980, the year of mining, was greatest and exceeded other years by 4.4 to 9.0 inches.

Direct runoff increased with the commencement of mining, and the increase was sustained through the early stages of reclamation. A subsequent decrease was observed with the re-establishment of vegetation on reclaimed areas. Average AMC 1 SCS curve numbers, weighted with respect to storm size, varied from 72 for Phase 1, to 87 for Phases 2a, b, and c, to 91 for Phases 2d and e, and to 81 for Phase 3a. Average storm sizes for these averages were 1.63, 0.81, 0.39, and 0.65, respectively. Inasmuch as the SCS curve number has been observed to decrease with storm size, the increase as depicted by the above averages may not be as significant as indicated. However, over a range of similar-sized storms, increases to the extent just cited were evident.

Despite quite similar distributions of the frequency of daily precipitation on the watershed, the annual distribution of storm and base flows changed with the progress of the mining operations. Discharge from the watershed was nearly continuous in 1978 and 1979 and remained so until mid-1980 when mining began. Thereafter, the frequency of zero runoff days increased as mining progressed. The trend persisted into Phase 3a and 1982. In 1981 days of no runoff were observed 50% of the time. This indicated that the "reconstructed" upper aquifer was probably recharging slowly. The same distributions showed more frequent higher volume daily return flows in the mining and postmining years, and support the previously cited finding that surface mining increased direct runoff.

Surface mining also attenuated response times and amplified the magnitudes of the rapid responses of runoff to rainfall. The average durations of the linear segment of the rising limb of a rapid response decreased from 36 minutes for Phase 1, to 11, 7, and 8 minutes for Phases 2a, b, and c, Phases 2d and e, and Phase 3a, respectively. The coefficient of variation was approximately 0.7 for all but Phase 3a. The figure for the latter was 0.5. As a measure of changes in the magnitude of the responsiveness, the slope of the rising limb,  $Q$  (iph/min), was related to the maximum average 10-minute rainfall intensity  $I_{10}$ . Based on a linear relationship of the form  $Q = kI_{10}$ ,  $k$  ( $\text{min}^{-1}$ ) increased from 3.6 for Phase 1, to 20.1 for Phases 2a, b, and c, and to 34.7 for Phases 2d and e. The coefficient decreased to 16.2 for Phase 3a. Improvement to the vegetative cover was suspected to have been a major contributing factor for the reversal.

Differences in the response characteristics between Phase 1 and the other study periods were not related to differences in storm intensities. With the commencement of mining, virtually every storm having maximum average rainfall intensities of 1, 2, and 3 iph lasting more than 5 minutes produced a rapid response. While more of these storms were sampled during Phase 1, not nearly as many generated a response. Least effective were the 5- and 10-minute 1 iph maximum intensities. The only Phase 1 storms which consistently caused a response were those having at least a 3 iph average intensity over a 10-minute period.

Comparisons of peak discharge rate with maximum 10-minute average rainfall intensity supported trends in runoff response durations and magnitudes. Over a comparable range of rainfall intensity, peak discharges during Phases 2a, b, and c, and Phases 2d and e) were as much as an order of magnitude greater than those observed during Phase 1. Phase 3a maximum flows were two to three times smaller than those observed during all of Phase 2, but were still substantially above Phase 1 maxima.

#### IV. SURFACE-WATER QUALITY

##### A. Introduction

A summary of the surface-water quality data for samples collected from the watershed outlet is given in Table 21. The samples are divided into the three major time intervals described in Table 9 and also by flow rate, i.e. baseflow vs runoff. The results and discussion presented are derived from the analyses of the data in Table 21, precipitation quality data, and sediment quality data.

##### B. Precipitation and Surface-Water Quality

Twenty-two parameters in precipitation were measured in samples collected over a 59-month period from July 1977 to July 1982 (Table 22). The amount of sampled precipitation received in a month ranged from a high of 11.54 in to a low of 0.24 in with the average being 3.90 in. Aluminum, calcium, iron, magnesium, sodium, and zinc were found in all samples, analyzed and copper, manganese, nitrate-N, and sulfate were detected in the majority of the precipitation samples. Antimony, barium, bicarbonate, cadmium, lead, nickel, phosphorus, silver, strontium, and sulfide were not detected or only rarely detected. Precipitation pH values ranged from 3.6 to 5.8 with an average of 4.2. Specific conductance was also measured in the precipitation samples and ranged from 1.4 to 70  $\mu$ mhos/cm with an average of 25  $\mu$ mhos/cm.

Several parameters had concentrations in precipitation samples which equaled or exceeded the concentrations of corresponding parameters in runoff water. These parameters included aluminum, copper, and zinc. A significant amount of the iron and nitrate-N levels in runoff water also seemed to have been derived from precipitation. Only a small percentage of the calcium, magnesium, barium, manganese, sodium, and specific conductance in runoff water, however, seemed to be a result of precipitation influences.

##### C. Duration Curves

Duration curves for the watershed effluent parameters regulated by the Office of Surface Mining Reclamation and Enforcement (OSM) were prepared for the premine, the combined active mining and reclamation, and the partially reclaimed periods (Figure 36). The parameters that are regulated are pH, iron, manganese, and total suspended solids. The regulation levels indicated for each parameter in Figure 36 conform to the levels published on September 18, 1978 by OSM (Federal Register, 5). The results show that 60% of the samples collected during the premine period and 85% of the samples collected during the combined mining and reclamation and the partially reclaimed periods exceeded the OSM regulation level for suspended solids (70 mg/l). Two samples had suspended solids concentrations greater than 40,000 mg/l and were collected when removal of the overburden was occurring or when regrading and topsoiling was being done to accomplish reclamation. Data are not available, however, to determine suspended solids concentrations after reclamation had been completed.

Figure 36 also shows that approximately 10% and 20% of the surface-water samples collected during the two period designations were below the pH regulation level of 6. The premine samples which had pH levels below 6 were collected in January, 1980. The ground had already frozen over when a 0.90 in precipitation event occurred. Very little interaction of the precipitation and runoff with the topsoil was possible because of the frozen conditions so

TABLE 21. - Summary of important surface-water quality data obtained at the Watershed J11 outlet

Parameter	Unit	Flow Type <sup>1</sup>	Premine		Mining and Reclamation		Partially Reclaimed			
			n <sup>2</sup>	Range	Mean	n	Range	n	Range	Mean
Acidity	meq/l	RO	28	0.03 - 0.17	0.09	2	0.13 - 0.94	14	0.03 - 0.16	0.09
Alkalinity	mg/l	BF	7	0.10 - 0.27	0.17	1	0.14	2	0.17 - 0.20	0.19
		RO	28	7 - 66	33	2	0 - 1	14	3 - 26	10
Aluminum	µg/l	BF	7	84 - 128	103	1	115	2	57 - 118	88
		RO	28	<10 - 36	<16	2	<10 - 3330	14	<10 - 104	29
Ammonium-N	mg/l	BF	7	<10 - 16	<12	1	<10	2	14 - 23	19
		RO	26	<0.01 - 0.21	0.05	2	0.86 - 2.0	14	0.05 - 3.10	0.77
Barium	µg/l	BF	7	<.01 - .03	0.02	1	.01	2	.02 - 0.16	0.09
		RO	28	18 - 40	29	2	48 - 71	14	13 - 58	34
Bicarbonate	mg/l	BF	7	21 - 50	32	1	33	2	41 - 43	42
		RO	28	8 - 80	40	2	0 - 2	14	3 - 32	12
Calcium	mg/l	BF	7	102 - 156	125	1	140	2	69 - 144	107
		RO	28	12.8 - 39.2	23.1	2	32 - 133	14	16.5 - 88.0	35
Carbon Dioxide	mg/l	BF	7	37.4 - 54.7	45.4	1	46.1	2	43.4 - 118	81
		RO	28	3 - 100	21	2	0 - 28	14	3 - 20	10
Chloride	mg/l	BF	7	13 - 85	38	1	11	2	12 - 18	15
		RO	28	0.7 - 13.3	6.3	2	0.8 - 2.1	14	2.5 - 28.9	9.8
Color	PCU	BF	7	8.5 - 13.8	11.4	1	9.1	2	2.3 - 7.4	4.9
		RO	27	10 - 5000	610	2	3000 - 15000	11	5 - 8000	2080
Diss. Oxygen	mg/l	BF	6	0 - 500	180	1	5	2	5 -	5
		RO	9	10.1 - 13.0	11.5	2	8.6 - 9.9	8	7.3 - 13.2	9.9
Diss. Solids	mg/l	BF	2	8.3 - 10.6	9.5	1	7.3	2	4.2 - 10.0	7.1
		RO	28	63 - 272	130	2	172 - 851	14	105 - 459	206
Flow Rate <sup>3</sup>	CFS	BF	7	182 - 260	218	1	205	2	251 - 573	412
		RO	21	0.0158 - 3.2900	0.7157	2	0.1310 - 5.1388	14	0.0960 - 8.8230	1.3321
Fluoride	mg/l	BF	7	.0038 - .0350	0.0156	1	.0340	2	.0005 - .0015	0.0010
		RO	28	.08 - .16	0.11	2	.04 - 0.38	14	.04 - .22	0.10
		BF	7	.08 - .13	0.11	1	.12	2	.10 - .18	0.14

<sup>1</sup>RO - Runoff BF - Baseflow.

<sup>2</sup>n - number of samples.

<sup>3</sup>Flow rates are given only for discrete samples.

<sup>4</sup>NA - Not Available.

TABLE 21. (Cont'd) - Summary of important surface-water quality data obtained at the Watershed J11 outlet

Parameter	Unit	Flow Type <sup>1</sup>	Premine		Mining and Reclamation		Partially Reclaimed			
			n <sup>2</sup>	Range	Mean	n	Range	n	Range	Mean
Hardness	mg/l	RO	28	43 - 137	78	2	113 - 510	14	57 - 343	130
		BF	7	139 - 192	162	1	165	2	156 - 416	286
Iron	mg/l	RO	28	<5 - 55	18	2	14 - 380	14	<5 - 59	16
		BF	7	<5 - 12	7	1	<5	2	8 - 10	9
Magnesium	mg/l	RO	28	2.60 - 9.52	4.8	2	8.11 - 43.0	14	3.82 - 29.8	10.2
		BF	7	9.5 - 14.4	11.9	1	12.0	2	11.5 - 29.5	20.5
Manganese	mg/l	RO	28	2 - 172	38	2	1430 - 17000	14	310 - 3020	1210
		BF	7	12 - 201	72	1	60	2	120 - 780	450
Nitrate-N	mg/l	RO	24	0.6 - 5.3	2.8	2	1.0 - 25.0	14	0.5 - 12.1	2.9
		BF	7	0.1 - 5.8	1.8	1	5.3	2	.8 - 1.2	1.0
pH		RO	27	5.2 - 7.8	7.0	2	4.1 - 5.4	11	6.2 - 7.5	6.7
		BF	7	6.9 - 7.9	7.3	1	8.1	2	6.6 - 6.9	6.8
Selenium	µg/l	RO	27	0.1 - 0.6	0.3	2	1.2 - 2.2	1	NA <sup>4</sup>	1.0
		BF	6	.2 - .4	0.3	0	NA	0	NA	NA
Sodium	mg/l	RO	28	1.01 - 5.99	3.33	2	1.3 - 4.41	14	1.08 - 5.95	2.57
		BF	7	3.48 - 8.46	6.82	1	7.44	2	2.47 - 3.93	3.20
Sp. Cond.	µmhos/cm	RO	15	70 - 180	129	2	500 - 1200	11	130 - 650	295
		BF	4	120 - 475	318	1	410	1	NA	360
Strontium	µg/l	RO	28	58 - 215	107	2	111 - 478	14	49 - 278	117
		BF	7	226 - 339	263	1	268	2	147 - 411	279
Sulfate	mg/l	RO	28	18 - 62	37	2	129 - 573	14	31 - 232	103
		BF	7	53 - 64	59	1	60	2	103 - 298	201
Susp. Solids	mg/l	RO	28	13 - 6060	454	2	5730 - 54100	14	391 - 41200	8360
		BF	7	25 - 74	54	1	58	2	10 - 16	13

<sup>1</sup>Ibid.

<sup>2</sup>Ibid.

<sup>4</sup>Ibid.

TABLE 22. - Chemical analysis of precipitation at Watershed J11<sup>1</sup>

Precipitation	Units	Range	Average
Aluminum	µg/l	11 <sub>2</sub> - 1100	74
Antimony	µg/l	<25 <sup>2</sup> - 44	<25 (48) <sup>3</sup>
Barium	µg/l	<2 - 6	3
Bicarbonate	mg/l	<0.4 - 6.9	<0.4 (58)
Cadmium	µg/l	<3 - 11	<3
Calcium	mg/l	0.04 - 4.20	0.88
Copper	µg/l	<3 - 39	7.3
Iron	µg/l	5 - 83	29
Lead	µg/l	<15 - 83	<15
Magnesium	mg/l	0.01 - 0.82	0.16
Manganese	µg/l	<1 - 100	17
Nickel	µg/l	<10 - 37	<10
Nitrate-N	mg/l	<0.1 - 3	0.61
pH		3.6 - 5.8	4.2
Phosphorus	mg/l	<0.03 - 0.05	<0.03
Silver	µg/l	<3 - 5	<3
Sodium	mg/l	0.04 - 0.81	0.18
Sp. Conductance	µmhos/cm	1.4 - 70	25
Strontium	µg/l	<2 - 16	<2
Sulfate	mg/l	<2 - 11	5 (58)
Sulfide	mg/l	<0.01	<0.01 (29)
Zinc	µg/l	7 - 150	28
Rainfall	in	0.24 - 11.54	3.90

<sup>1</sup>Fifty-nine monthly composite samples were collected between July 1977 to July 1982.

<sup>2</sup>The less than sign (<) signifies that the value of the parameter was below the detection limit. Lower detection limits are given in Table 10.

<sup>3</sup>In parentheses are the number of samples analyzed when less than 59.



that the runoff closely reflected the natural pH of the precipitation which averaged 4.2 (Table 22). The samples which exhibited a pH of less than 6 in the combined mining and reclamation and the partially reclaimed periods were collected during the removal of overburden material and the stripping of the coal.

Manganese and iron are known to become soluble under acidic conditions. The sample collected during mining which had the lowest pH (4.1), also exhibited the highest manganese and iron levels. The manganese concentration in this sample was 17,000  $\mu\text{g/ml}$  which greatly exceeded the OSM regulation level of 4000  $\mu\text{g/ml}$ . All other samples, however, were in compliance with the OSM regulation level for manganese. Concentrations of dissolved iron were found to be below OSM regulation levels for iron in all samples collected at the watershed outlet during this study.

Duration curves for magnesium, calcium, sulfate, and dissolved solids are shown in Figure 37. For each of these parameters, higher levels were observed during the combined active mining and reclamation and the partially reclaimed periods than during the premine period. This change was observed even though the average flow rate during the premine period was lower than for the combined periods. Generally the lower the flow rate the higher the concentration of parameters in the runoff water.

#### D. Concentrations of Other Water-Quality Parameters

Several parameters of potential importance in surface waters were either not detected or only rarely detected. Table 23 lists these parameters with their lower detection levels, the number of samples which had concentrations greater than the detection level and the maximum concentration found. Many of these parameters were only measured in every third or fourth sample as a check on concentration changes that may have occurred with time. Arsenic, chromium, cadmium, mercury, silver, and sulfide were not detected in any of the samples collected during this study. Antimony, copper, cyanide, lead, phenols, phosphorus, and zinc were detected in 10 or less samples. Selenium, observed in almost all samples analyzed, exhibited very low concentrations with the highest concentration found being 2.2 parts per billion.

Water quality from Watershed J11 evaluated in terms of the U.S. EPA National Interim Drinking Water Regulations (U.S. EPA, 28) met water criteria for maximum contaminant levels for 9 of the 10 inorganic chemicals regulated (arsenic, barium, cadmium, chromium, fluoride, lead, mercury, selenium, and silver). Two samples exceeded the EPA regulation level for nitrate-N of 10 mg/l. One sample (25 mg/l) was collected during active mining, and it is difficult to determine the cause for the high nitrate-N level. The second sample was collected during the partially reclaimed period and may be due to the application of fertilizer to aid in the establishment of vegetation on the mine site.

#### E. Flow Rate Relationships

An important parameter controlling the concentrations of many parameters in surface water is flow rate. Table 24 describes the relationships between the logarithm (log) of flow rate and the parameters which account for most of the change in the water samples, and dissolved solids and suspended solids. Calcium, magnesium, sodium, strontium, bicarbonate, sulfate, chloride, and dissolved solids were significantly ( $P < 0.01$ ) but negatively correlated

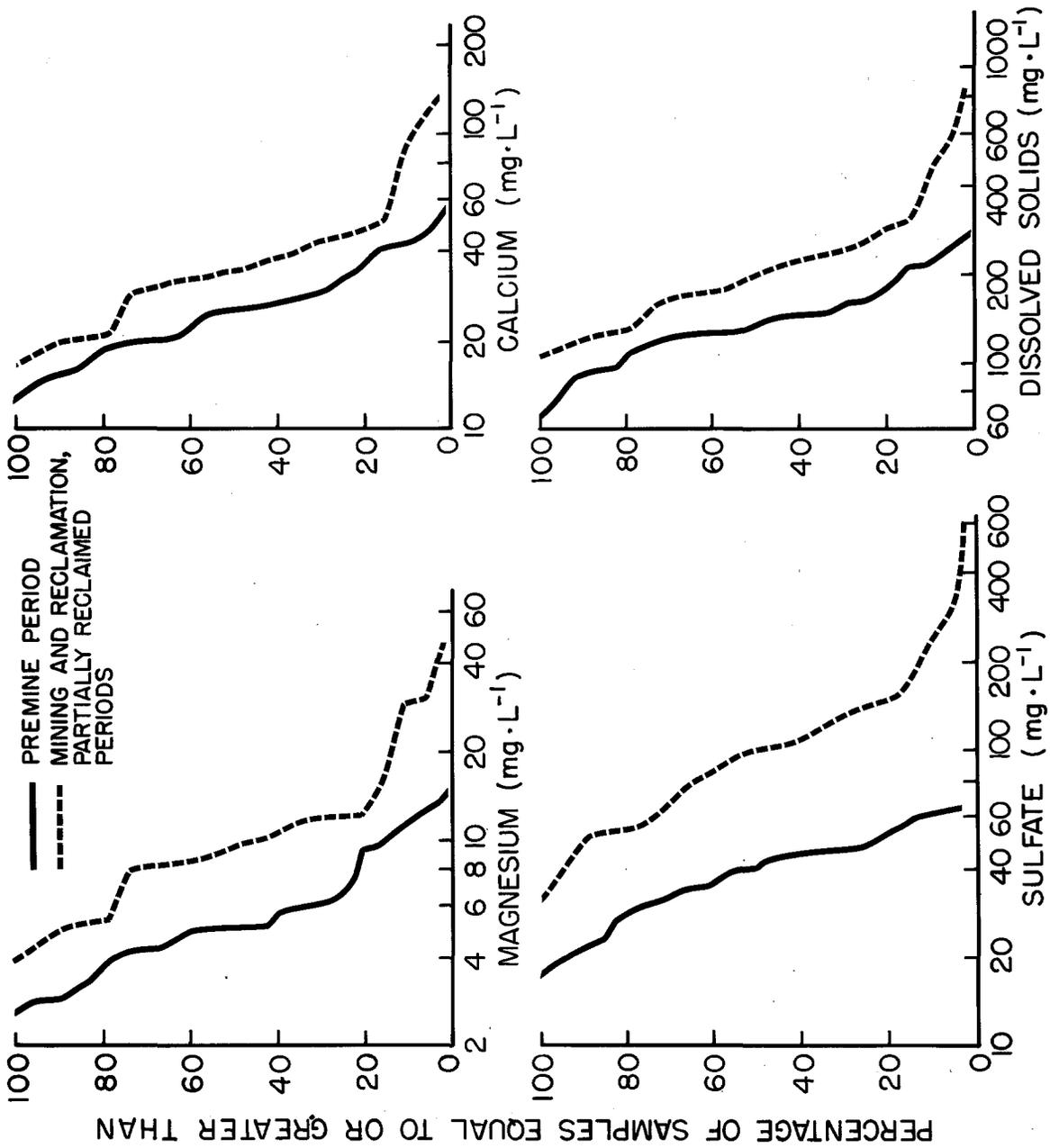


FIGURE 37. - Duration curves showing the percentage of water samples having concentrations of magnesium, calcium, sulfate, and dissolved solids above specified limits at Watershed J11.

TABLE 23. - Detection levels and maximum concentrations of parameters in surface-water samples collected from Watershed J11

Parameter	Detection Level (mg/l)	Number of Samples Analyzed <sup>1</sup>	Number of Samples Which Exceeded the Detection Level	Maximum Concentration Found
Antimony	0.025	49	2	0.032
Arsenic	.002	15 <sup>2</sup>	0	ND <sup>3</sup>
Cadmium	.003	54	0	ND
Chromium	.01	25 <sup>2</sup>	0	ND
Copper	.003	54	9	.010
Cyanide	.01	24 <sup>2</sup>	1	.02
Lead	.015	54	6	.28
Mercury	.002	15 <sup>2</sup>	0	ND
Phenols	.004	18 <sup>2</sup>	9	.008
Phosphorus	.03	54	6	.11
Selenium	.0001	36 <sup>2</sup>	35	.0022
Silver	.003	54	0	ND
Sulfide	.01	25 <sup>2</sup>	0	ND
Zinc	.007	54	10	.037

<sup>1</sup>The total number of water samples collected during this study was 54.

<sup>2</sup>Analyses were performed on randomly selected samples to check for any changes in concentration with time. In most cases the concentrations remained near or below the detection limit.

<sup>3</sup>ND - Not Detected.

TABLE 24. - Relationships between flow rate (in log values) and concentration of water quality parameters at Watershed J11

Parameter	Simple Correlation Coefficient (r) <sup>1</sup>	
	Premine	Partially Reclaimed
<b>Cations:</b>		
Calcium	-0.90**	-0.70**
Magnesium	-0.88**	-0.62*
Manganese	-0.36	-0.00
Sodium	-0.60**	-0.41
Ammonium-N	0.29	0.09
Strontium	-0.90**	-0.72**
<b>Anions:</b>		
Bicarbonate	-0.92**	-0.83**
Sulfate	-0.82**	-0.62*
Chloride	-0.51**	-0.02
Nitrate-N	0.51**	0.06
Dissolved Solids	-0.85**	-0.69**
Suspended Solids	0.40*	0.59*

<sup>1</sup>The simple correlation coefficients describe results obtained when 28 samples collected during the premine period and 16 samples collected during the partially reclaimed period were statistically analyzed.

\* - 5% level of significance.

\*\* - 1% level of significance.

with log flow rate during the premine period. The negative correlation occurred when precipitation increased the total flow volume and diluted the concentration of the parameters in the resultant runoff.

Nitrate-N and suspended solids concentrations were significantly and positively correlated with log flow rate values ( $P < 0.01$  and  $< 0.05$ , respectively). A significant positive correlation between suspended solids concentrations and flow rate values is commonly observed and is due to the greater kinetic energy rapidly flowing water imparts to soil sediment particles causing dislodgement and transport. The positive correlation for nitrate-N occurs because a large percentage of this parameter in surface waters is derived from precipitation, and once the nitrate-N comes in contact with the soil it is readily taken up by the soil biota. When large precipitation events occur, the amount of interaction between the soil and precipitation is much less relative to that occurring for baseflow or for small precipitation events. As a result the nitrate-N concentrations at low flows are less than at high flows.

During the partially reclaimed period the relationships between the various parameters and log flow rate were not as strong, i.e. there were fewer parameters significantly correlated at the 5% or 1% level and the correlation coefficients were lower (Table 24). However, the data indicate that during the partially reclaimed period, Watershed J11 had returned to an approximation of an equilibrium condition, and concentrations of parameters as a result of disturbance of the mine site were no longer changing.

Concentrations of parameters in water samples collected at similar flow rates during the partially reclaimed period compared to the premine period were investigated. Figure 38 shows the regression lines for concentrations of calcium, magnesium, strontium, bicarbonate, dissolved solids, and suspended solids in water samples collected during these two periods. Calcium, magnesium, sulfate, dissolved solids, and suspended solids concentrations were all increased in the water samples collected during the partially reclaimed period compared to the premine period. Sodium and bicarbonate concentrations were decreased and there was essentially no change in strontium concentrations during the partially reclaimed period. For most of the parameters, the slope of the regression line was not greatly changed during the partially reclaimed period compared to the premine period. This indicates that even though concentrations may have been altered significantly, the rate of change of parameter concentrations as influenced by flow rate was not greatly affected. An exception was noted for suspended solids concentrations where changes in concentrations with flow rate were much greater during the partially reclaimed period than during the premine period.

#### F. Correlation Study Results

Eight parameters were significantly correlated ( $P < 0.05$ ,  $< 0.01$ , or  $< 0.001$ ) with suspended solids concentrations either during the premine period or when the data for the premine and partially reclaimed periods were combined (Table 25). Only color, however, was very highly significantly correlated ( $P < 0.001$ ) and only color was significantly correlated with suspended solids concentrations during the partially reclaimed period. Table 26 shows the relationship between dissolved solids and water quality parameters. Fourteen parameters were significantly ( $P < 0.05$ ,  $< 0.01$ , or  $< 0.001$ ) correlated with dissolved solids when measurements made during the premine period or the partially reclaimed period were analyzed separately or combined. Most of the parameters listed were very

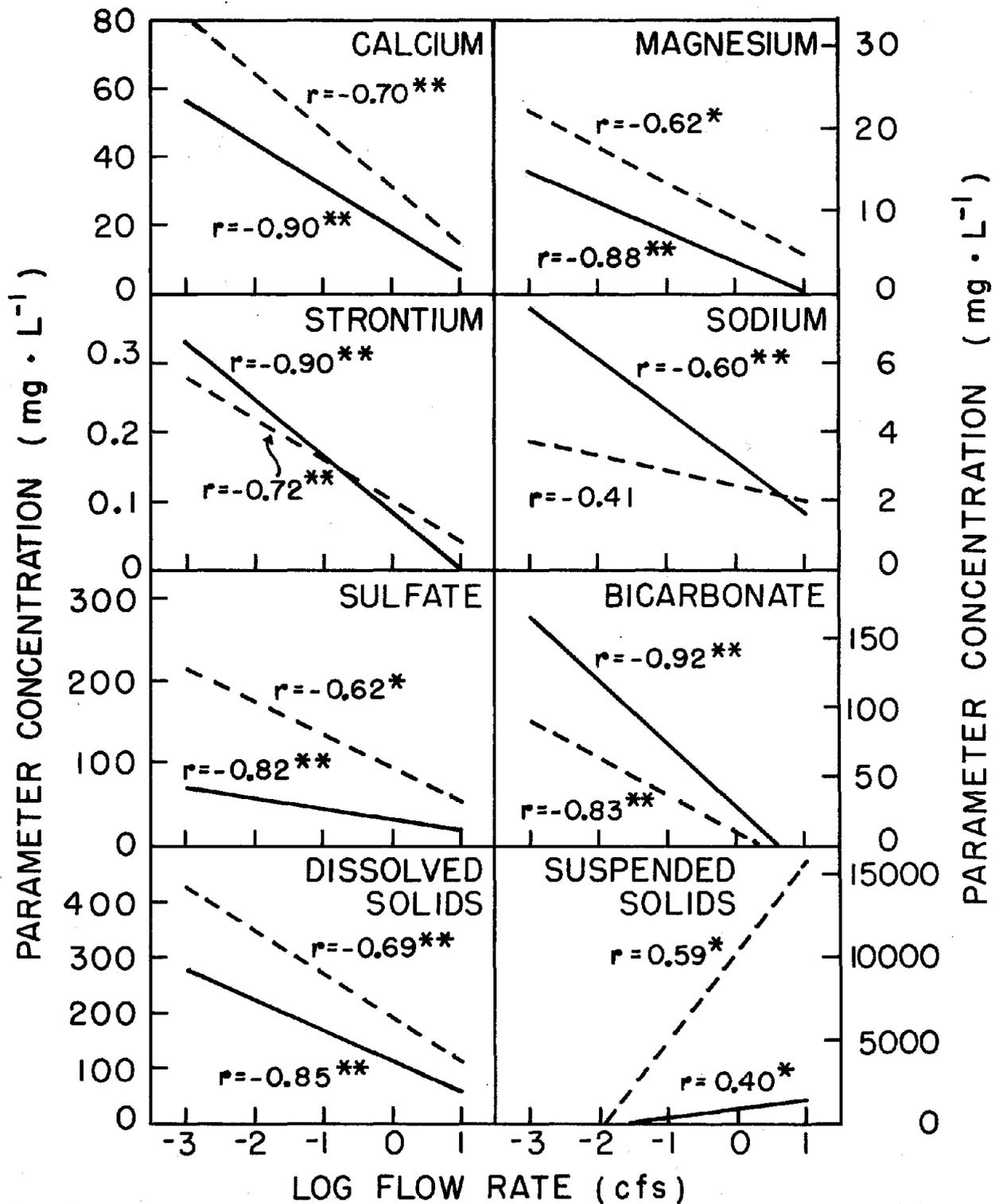


FIGURE 38. - Relationship between log flow rate and calcium, magnesium, strontium, sodium, sulfate, bicarbonate, dissolved solids, and suspended solids concentrations during the premine (—) and the partially reclaimed (---) periods at Watershed J11. \* = 5% level of significance and \*\* = 1% level of significance.

TABLE 25. - Relationships between suspended solids and water quality parameters

Suspended Solids vs.	Premine		Partially Reclaimed		Combined Periods	
	n <sup>1</sup>	r <sup>2</sup>	n	r	n	r
Alkalinity					47	-0.35*
Barium	34	-0.38*				
Bicarbonate					47	-0.35*
Color	33	0.96***	13	0.94***	46	0.89***
Dissolved Solids	34	-0.37*				
Fluoride	34	0.53**			47	-0.37*
Manganese					47	0.29*
Sodium					47	-0.35*

<sup>1</sup>Number of samples.

<sup>2</sup>Correlation coefficient. \* = 5% level of significance, \*\* = 1% level of significance, and \*\*\* = 0.1% level of significance.

TABLE 26. - Relationships between dissolved solids and water quality parameters

Suspended Solids vs.	Premine		Partially Reclaimed		Combined Periods	
	n <sup>1</sup>	r <sup>2</sup>	n	r	n	r
Acidity					47	0.34*
Alkalinity	34	0.79***	13	0.64*	47	.33*
Barium			13	.68*	47	.60***
Bicarbonate	34	.79***	13	.64*	47	.33*
Calcium	34	.80***	13	.99***	47	.94***
Chloride	34	.62***			47	.41**
Color	33	-0.39*				
Hardness	34	0.80***	13	.99***	47	.94***
Magnesium	34	.78***	13	.97***	47	.94***
Manganese					47	.59***
Sodium	34	.59***				
Strontium	34	.80***	13	.98***	47	.76***
Sulfate	34	.66***	13	.96***	47	.60***
Suspended Solids	34	-0.37*				

<sup>1</sup>Number of samples.

<sup>2</sup>Correlation coefficient. \* = 5% level of significance, \*\* = 1% level of significance, and \*\*\* = 0.1% level of significance.

highly ( $P < 0.001$ ) positively correlated indicating they are important contributors to the dissolved solids levels in surface waters coming from Watershed J11. Calcium, magnesium, sodium, and strontium are all basic cations and their removal from the watershed in the dissolved form could forecast problems with increased acidity in the future unless the weathering processes and other sources of input can replace these cations at a sufficient rate to compensate their loss.

Concentrations of certain parameters in mine drainage water, particularly metals, are often dependent upon pH. There were no significant ( $P < 0.05$ ) correlations observed, however, between pH and parameter concentrations during the premine period, the partially reclaimed period, or when the periods were combined. This is probably because the pH in most of the water samples was 6.5 or greater and the range in pH was small, generally being 1 to 1.5 units. Only four samples had pH values below 6, and the solubility of most metals is not greatly affected until the sample pH descends below this value.

#### G. Sediment Quality

The chemical quality of the suspended sediment was monitored at the outlet of Watershed J11 because it affects several surface-water parameters and influences the environment where it is redeposited downstream from the mine site. As mining occurred on the watershed, the amount of suspended sediment in surface runoff greatly increased and the source material for the suspended sediment material also changed from that previously available during the premining period. A description of the sampling procedures and analyses for the sediment samples was given earlier in this report.

Concentration ranges and means for the 17 parameters measured in suspended sediment samples during the three study periods are given in Table 27. The parameter which exhibited the greatest change in concentration from the premine period was organic carbon. This is due to the changing source material contributing to the suspended sediment fraction. The premine material was primarily surface soil material which had a higher organic carbon level than the fragmented geologic bed materials eroded during the other periods. Manganese, calcium, lead, strontium, and phosphorus concentrations were also elevated in the premine period compared to the active mining and reclamation period or the partially reclaimed period. During the active mining and reclamation period, sulfate concentrations were double those found during the other two periods. Mining exposed pyritic material which began to oxidize and to produce soluble sulfate. This in turn produced a more acidic sediment material, as shown by the lower pH during the active mining and reclamation period. An analysis of the relationships between sediment pH and concentrations of parameters in the sediment material for samples collected during the partially reclaimed period showed a significant ( $P < 0.001$ ) negative correlation between sediment pH and sulfate concentrations. This indicates that as the sulfate concentrations in the sediment increased, the pH of the sediment decreased. However, for calcium and strontium a positive correlation ( $P < 0.01$ ) was observed so that concentrations of these parameters were found to decrease with a decrease in sediment pH. The parameters which had the highest concentrations during the partially reclaimed period compared to the other periods were aluminum, iron, and lead. Cadmium and mercury were not found in any of the sediment samples analyzed.

TABLE 27. - Summary of suspended sediment quality in samples collected at the Watershed J11 outlet

Parameter	Concentration of Parameter During Period Specified, mg/l					
	Premine		Active Mining and Reclamation		Partially Reclaimed	
	Range <sup>1</sup>	Mean	Range	Mean	Range	Mean
Aluminum	6.15 - 8.22	7.10	7.28 - 8.04	7.55	7.10 - 13.4	9.66
Cadmium	>0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium	3.12 - 4.53	3.69	1.13 - 2.23	1.68	2.19 - 2.76	2.42
Copper	0.014 - 0.021	0.017	0.012 - 0.018	0.016	0.014 - 0.033	0.020
Iron	13.7 - 16.4	15.0	14.9 - 15.9	15.3	14.5 - 25.7	19.3
Lead	0.018 - 0.042	0.028	0.010 - 0.023	0.017	0.003 - 0.029	0.019
Magnesium	1.64 - 2.49	2.03	2.54 - 3.00	2.72	2.70 - 4.84	3.71
Manganese	0.954 - 1.30	1.11	0.426 - 0.649	0.568	0.498 - 0.870	0.660
Mercury	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Nickel	0.016 - 0.026	0.021	0.022 - 0.068	0.051	0.027 - 0.050	0.034
Organic Carbon	24.4 - 31.5	27.3	4.9 - 5.3	5.1	5.0 - 9.4	7.1
pH	6.5 - 7.3	6.8	4.2 - 6.3	5.3	5.6 - 7.0	6.4
Phosphorus	0.482 - 0.642	0.564	0.204 - 0.223	0.210	0.190 - 0.400	0.270
Sodium	.04 - .06	.05	.04 - .06	.05	.05 - .08	.06
Strontium	.021 - .028	.024	.011 - .014	.013	.014 - .018	.016
Sulfate	.156 - .294	.225	.146 - 1.10	.532	.110 - .290	.200
Zinc	.058 - .082	.069	.046 - .056	.050	.048 - .088	.066

<sup>1</sup>Five, 3, and 12 samples were analyzed during the premine, active mining and reclamation, and the partially reclaimed periods, respectively.

## H. Conclusions

1. Concentrations of aluminum, copper, and zinc were higher in precipitation samples than in surface runoff from Watershed J11. A significant amount of iron and nitrate-N also seemed to have been derived from precipitation.
2. Duration curves for the 4 parameters regulated by OSM (pH, suspended solids, iron, and manganese) showed that 60% of the premine period samples and 85% of the combined mining and reclamation and partially reclaimed period samples exceeded the suspended solids regulation level of 70 mg/l. Approximately 10% and 20% of the water samples collected for the same periods had pH values below 6, the lower OSM regulation level. Only one sample, collected during mining, exceeded the regulation level for manganese (4000  $\mu\text{g/ml}$ ) and all samples were below the regulation level for iron (7000  $\mu\text{g/ml}$ ).
3. Arsenic, chromium, cadmium, mercury, silver, and sulfide were not detected in any surface-water samples collected from Watershed J11. Antimony, copper, cyanide, lead, phenols, phosphorus, and zinc were detected in 10 or less samples.
4. Water quality evaluated in terms of the EPA National Interim Drinking Water Regulations met water criteria for maximum contaminant levels for 9 of the 10 inorganic chemicals regulated (arsenic, barium, cadmium, chromium, fluoride, lead, mercury, selenium, and silver). Two samples exceeded the EPA regulation level for nitrate-N of 10  $\mu\text{g/l}$ .
5. Concentrations of suspended solids, dissolved solids, and the cations and anions that account for most of the change in the surface-water samples were significantly correlated with log flow rate. Comparisons of parameter concentrations in samples collected at similar flow rates during the premining period and the partially reclaimed period showed calcium, magnesium, sulfate, dissolved solids, and suspended solids concentrations were increased during the partially reclaimed period. Sodium and bicarbonate concentrations were decreased and strontium concentrations remained unchanged.
6. Organic carbon, manganese, calcium, lead, strontium, and phosphorus concentrations in the sediment material removed from Watershed J11 surface-water samples were higher during the premine period than during the active mining and reclamation or the partially reclaimed periods. Sulfate and nickel concentrations were highest and pH levels and zinc concentrations were lowest during the active mining and reclamation period. During the partially reclaimed period, parameters which were increased in concentration compared to the premine or the active mining and reclamation periods were aluminum, iron, and magnesium. Copper and sodium concentrations generally remained constant in samples collected during the different phases. Cadmium and mercury were not detected in any of the sediment samples analyzed.

## V. GROUND-WATER HYDROLOGY

### A. Premining Data

Relatively impermeable, shaley clay beds that underlaid the major coal seams formed bases for two local perched saturated zones. The saturated zones are referred to as "aquifers" for convenience, even though the wells typically yield less than 1 gal/min.

The top aquifer was above the shaly clay that underlaid the Waynesburg No. 11 coal bed of the Monongahela Formation. Recharge was from direct precipitation within the watershed. Figure 39 shows the close relationship between precipitation and water-level rises. Recharge to the middle aquifer is indirectly related to precipitation.

Movement of water in the top aquifer (Figure 40) was from the watershed divide toward the coal outcrop where it discharged as spring flow, seepage, and evapotranspiration. Spring flow was the major contributor to stream baseflow. The remainder of the discharge was downward leakage through the underclay.

The middle aquifer is above the shaly clay that underlies the Meigs Creek (Sewickley) No. 9 coal bed of the Monongahela Formation. Recharge to the middle aquifer is by leakage through the overlying underclay and by precipitation where the underclay is absent. Movement of water in the middle aquifer (Figure 41) is from the watershed divide toward the mouth of the watershed where it discharges as underflow. Additional discharge is downward leakage through the underclay.

The two deepest wells (W5-3 and W9-3), which are dry, penetrated mined-out openings in the Pittsburgh No. 8 coal bed of the Monongahela Formation. Much of the No. 8 coal bed had been previously removed by underground mining and is apparently drained down gradient from the watershed. Aquifers below the No. 8 coal bed were not monitored.

Ground water is stored and transmitted within open spaces in the rock. The permeability is primary (intergranular pore space) and secondary (fractures and bedding-plane openings). Most of the ground-water movement in undisturbed rock is probably controlled by fracture-flow hydraulics. Values for the aquifer horizontal hydraulic conductivity were obtained by slug tests and single-well aquifer tests. Underclay vertical hydraulic conductivity was measured by obtaining a sample from the field and experimentally determining the value in a laboratory. The laboratory-determinations were obtained by The Ohio State University, Department of Agronomy. Table 28 shows that the hydraulic conductivities of the aquifers were extremely low. The underclay value was about 200 times lower in hydraulic conductivity than the aquifer.

### B. Postreclamation Data

Topographic and water-table elevations within the watershed suggest that the ground-water divides for the top and middle aquifers reflect the new drainage divide. The postreclamation top aquifer consists of spoil in the strip-mined area and bedrock in the augered and undisturbed area. The top aquifer is above the shaley clay that underlaid the Waynesburg No. 11 coal bed of the Monongahela Formation and above the premining land surface where the clay does not exist (Figure 19).

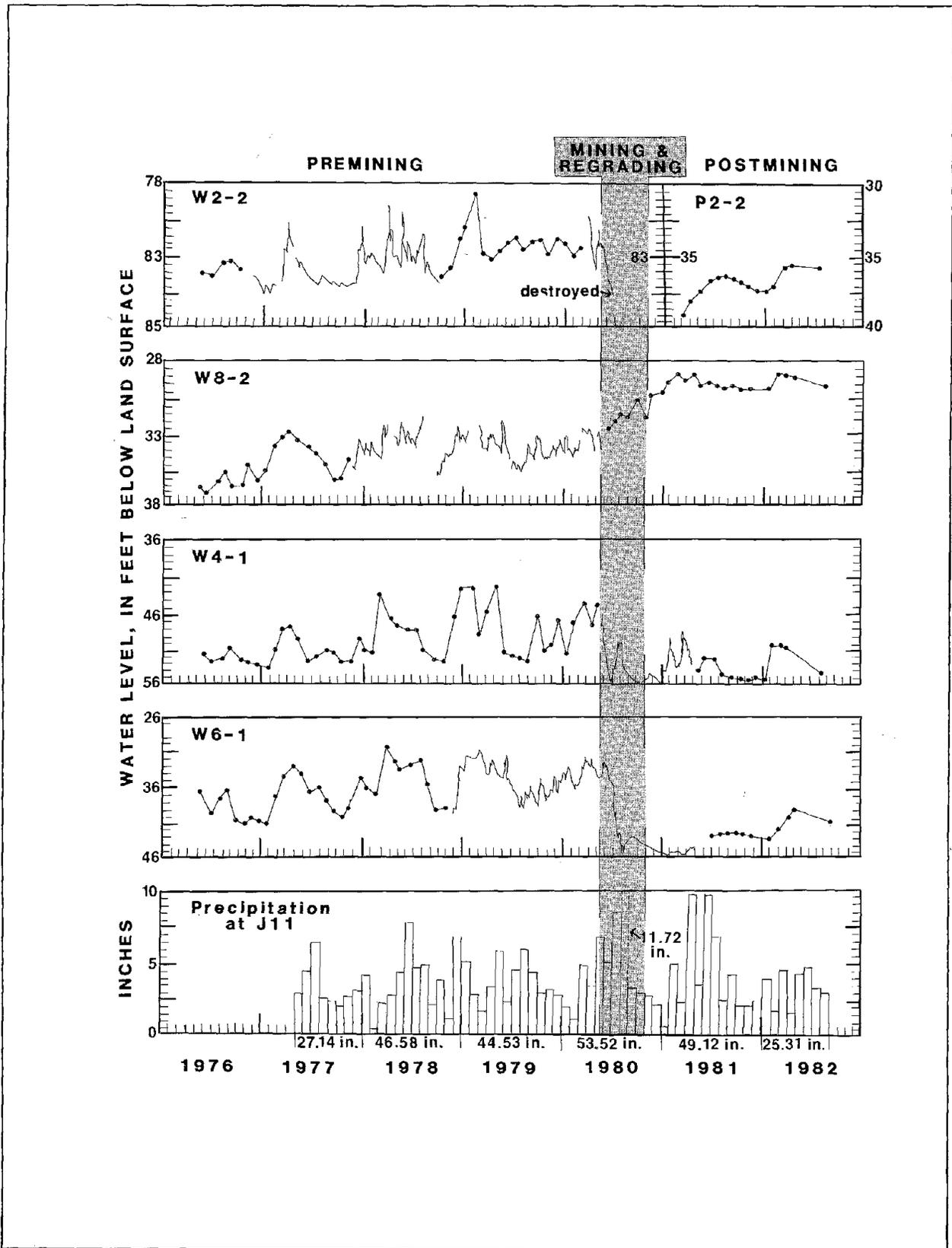


FIGURE 39. - Hydrographs of water levels from the top and middle aquifers and precipitation at Watershed J11. Last digit in well number represents aquifer; 1=top, 2=middle. Solid circles connected by lines are monthly measurements; continuous lines represent continuous recorder data.

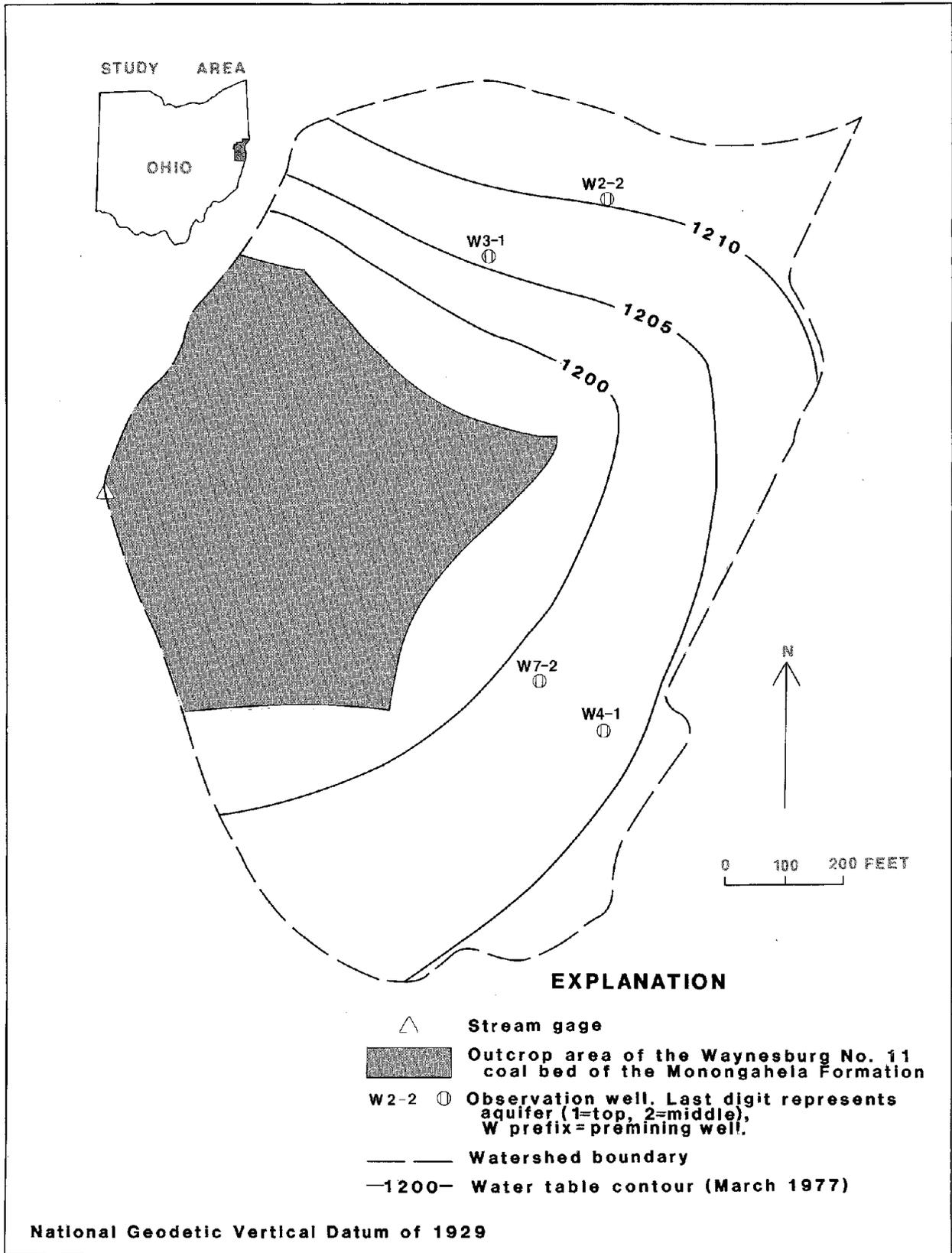


FIGURE 40. - Premining potentiometric surface of the top aquifer at Watershed J11.

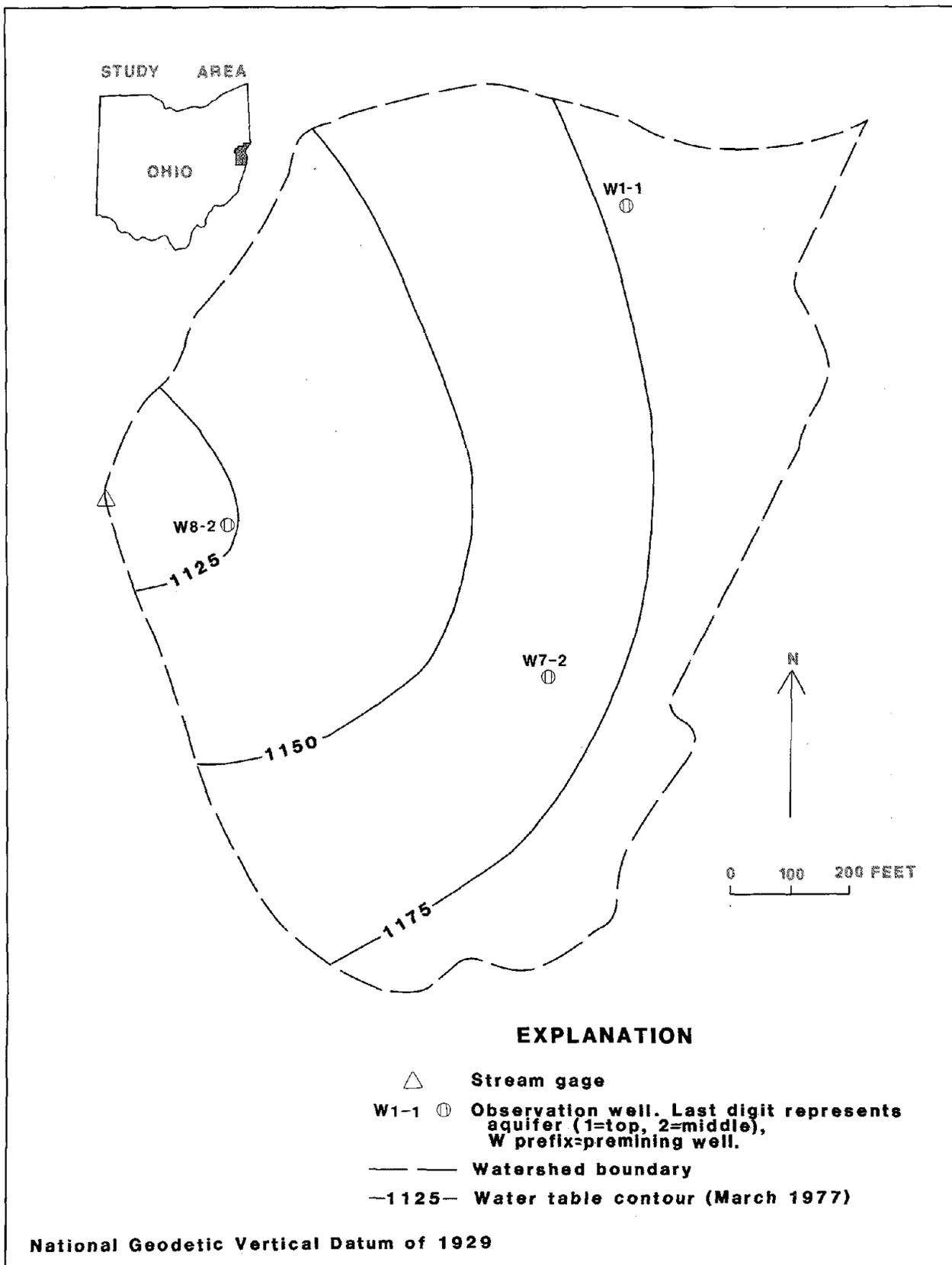


FIGURE 41. - Premining potentiometric surface of the middle aquifer at Watershed J11.

TABLE 28. - Results of aquifer and underclay tests at Watershed J11

Hydraulic Conductivity (ft/d)				
<u>Well</u>	<u>Slug Test</u>	<u>Single-well Pumping Test</u>	<u>Laboratory Test</u>	<u>Saturated Thickness (ft)</u>
W1-1	0.12			13
W3-1	.096			8
W4-1	.302			10
W6-1	.058			9
Average for top aquifer	.144			10
W2-2	0.48	0.017		123
W8-2	.04	.33		65
Average for middle aquifer	.26	.174		94
Underclay			.00038	
Underclay			.00035	
Underclay			.00207	
Average for Underclay			.00093	

As in the premining condition, the postreclamation top aquifer receives recharge from precipitation that infiltrates to the saturated zone. However, preliminary artificial infiltration tests suggest that the recharge rates in the area covered by spoil have decreased. This decrease has been caused by the destruction of soil structure and compaction of the soil. With time, the recharge rate should increase as soil structure develops.

The middle aquifer receives recharge from precipitation where it is exposed, leakage through the overlying shaley clay bed and percolation through the overlying spoils material where the clay is absent.

Discharge from the top aquifer includes downward leakage to the middle aquifer in the areas where sufficient head has developed. Discharge from the top aquifer has decreased substantially in the postreclamation condition. No springs or seeps have been observed, and stream flow is solely the result of direct runoff following precipitation. Discharge from the middle aquifer occurs as downward leakage and underflow out of the western part of the watershed, as in the premining condition.

Water is stored and transmitted in the intergranular pore spaces of the spoil material and in openings, fractures, and bedding planes in the middle aquifer and that part of the top aquifer that was not disturbed. After mining and reclamation, all of the wells reinstalled in March 1981 in the spoils material were initially dry. In March 1982, Well P3-1 was still dry and Wells P1-1 and P10-1 contained only 4 ft and 3 ft of water, respectively (Figure 42). The slow development of a saturated zone in the spoil is a result of increased storage capacity and increased hydraulic conductivity. The development of the saturated zone is also slowed because the spoil material was partially dried. In the part of the top aquifer not disturbed by mining near Wells W4-1 and W6-1, the amount of water in storage has been less than during premining. This can be best seen by comparing premining and postreclamation water levels (Figure 39).

Water levels responded almost immediately to the mining operation. Water-level declines were seen in all wells soon after mining began, except in W8-2, which is in the middle aquifer in an area not subjected to mining and reclamation activity (Figure 39). The water-level decline resulted directly from mining, as evidenced by the magnitude of the declines, because no other stresses were occurring, and because precipitation during July and August 1980 was significantly higher than in the same periods in 1978-82 (Figure 39).

As under premining conditions, two major perched saturated zones exist in the area not disturbed by mining (near Wells W6-1 and W4-1). However, in the spoils material (near Wells P1-1 and P10-1), there is no longer an unsaturated zone between the top aquifer (spoil) and the middle aquifer. Water levels in Well P2-2 in the second aquifer are up to 40 ft higher than during premining, and are equal to those in Well P1-1. This, along with the discovery that the shaley underclay was not observed during drilling after mining, indicates that either the aquifers are directly connected or that only one aquifer now exists in this area.

Water in the postreclamation top aquifer moves along a nearly flat gradient from the watershed divide toward the buried highwall that separates the bedrock from the spoils (Figure 19). Discharge from the top aquifer to the middle aquifer probably occurs at the point of the buried highwall because the underclay is absent. Water in the middle aquifer moves from the watershed divide

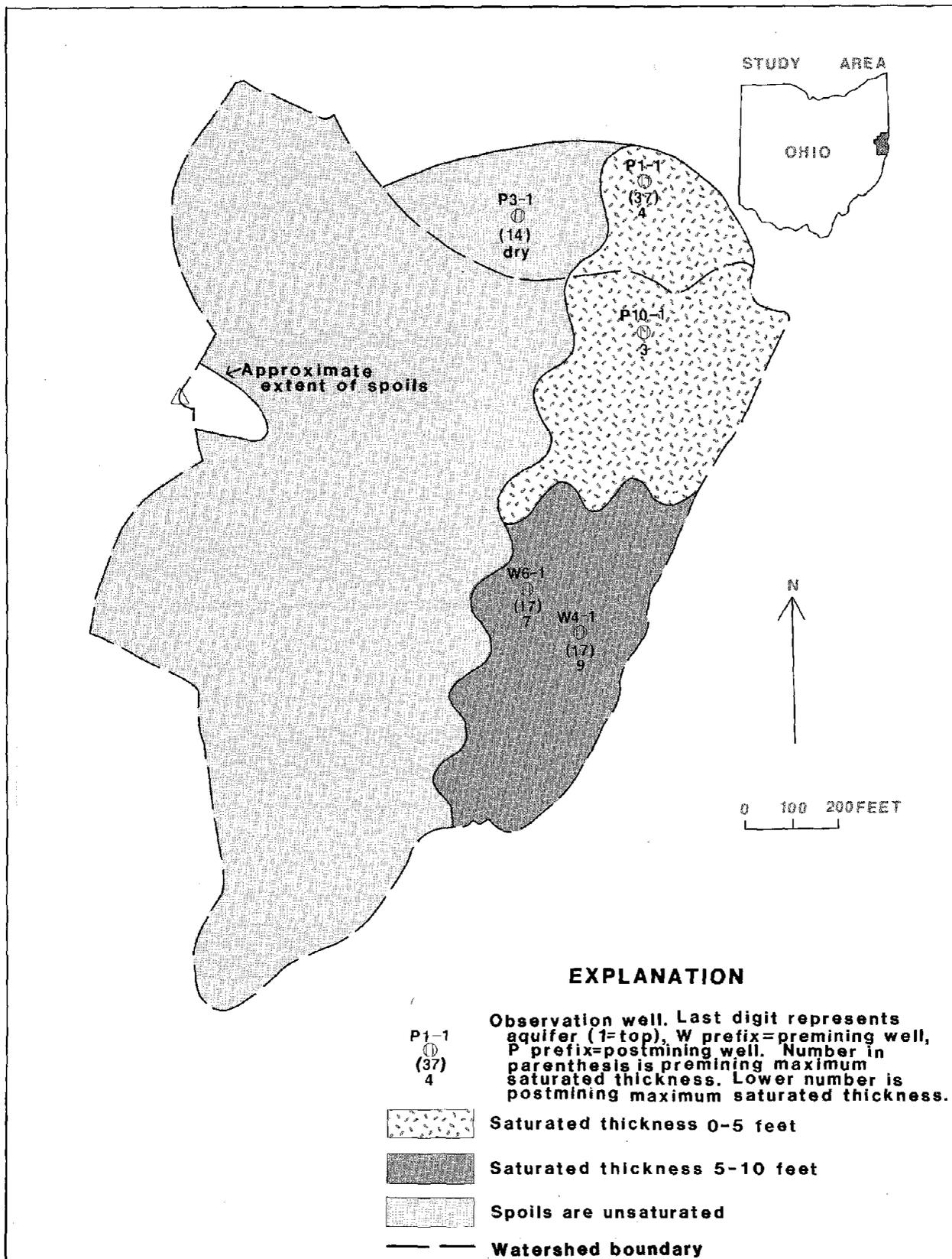


FIGURE 42. - Postreclamation top aquifer saturated thickness at Watershed J11, March 1982.

toward the mouth of the watershed, the same as during the premining condition (Figure 43). However, the gradient has increased slightly as a result of the water level rise in Well P2-2 (Figure 39). The deep zone remains dry, as it was during the premining condition.

Aquifer testing in the spoil material has not been possible because the saturated zone has been too thin. Indications from bailing during water-quality sampling are that the spoils material yield is higher than during premining, but still on the order of 1 to 2 gal/min. This presents a situation where the hydraulic conductivity of the down-gradient top aquifer material (spoil) is probably one to two orders of magnitude higher than the hydraulic conductivity of the up-gradient bedrock. This will retard or prevent the top aquifer water levels from rebounding to the premining levels because the material of higher hydraulic conductivity will drain faster than the water level rises in the lower hydraulic-conductivity material. That is, a new steady-state situation will be attained that results in lower water levels in the bedrock part of the top aquifer. Aquifer tests were not feasible in the bedrock part of the top aquifer because of the low yields and the thin saturated zone, but aquifer characteristics should be the same as before mining. Postreclamation aquifer tests were not conducted in the middle aquifer because the material was undisturbed by mining. However, because of the increased saturated thickness (30-ft), the transmissivity has increased about 20%. Observations during postreclamation drilling and water-quality sampling suggested primary permeability is the major factor controlling water movement in the spoils part of the top aquifer. As in the premining condition, secondary permeability controls water movement in the bedrock part of the top aquifer and in the middle aquifer after mining.

Storage capacity has increased in the spoils because the handling and breaking of the overburden material has created many more openings, pores, and voids than were present in the premining consolidated rocks. The quantity of water in storage in the bedrock part of the top aquifer has decreased because the extent of the bedrock aquifer has decreased, and the saturated thickness of the remaining bedrock is thinner than under premining conditions. This decrease in storage is a result of the partial removal of coal by augering. The augering has created large drains that have lowered the water table.

The mining operation did not visually disturb the material below the underclay beneath the Waynesburg No. 11 Coal bed of the Monongahela Formation. Thus, the hydrologic properties of the middle aquifer are not expected to have changed. However, blasting and heavy equipment traffic could have fractured or stressed the aquifer.

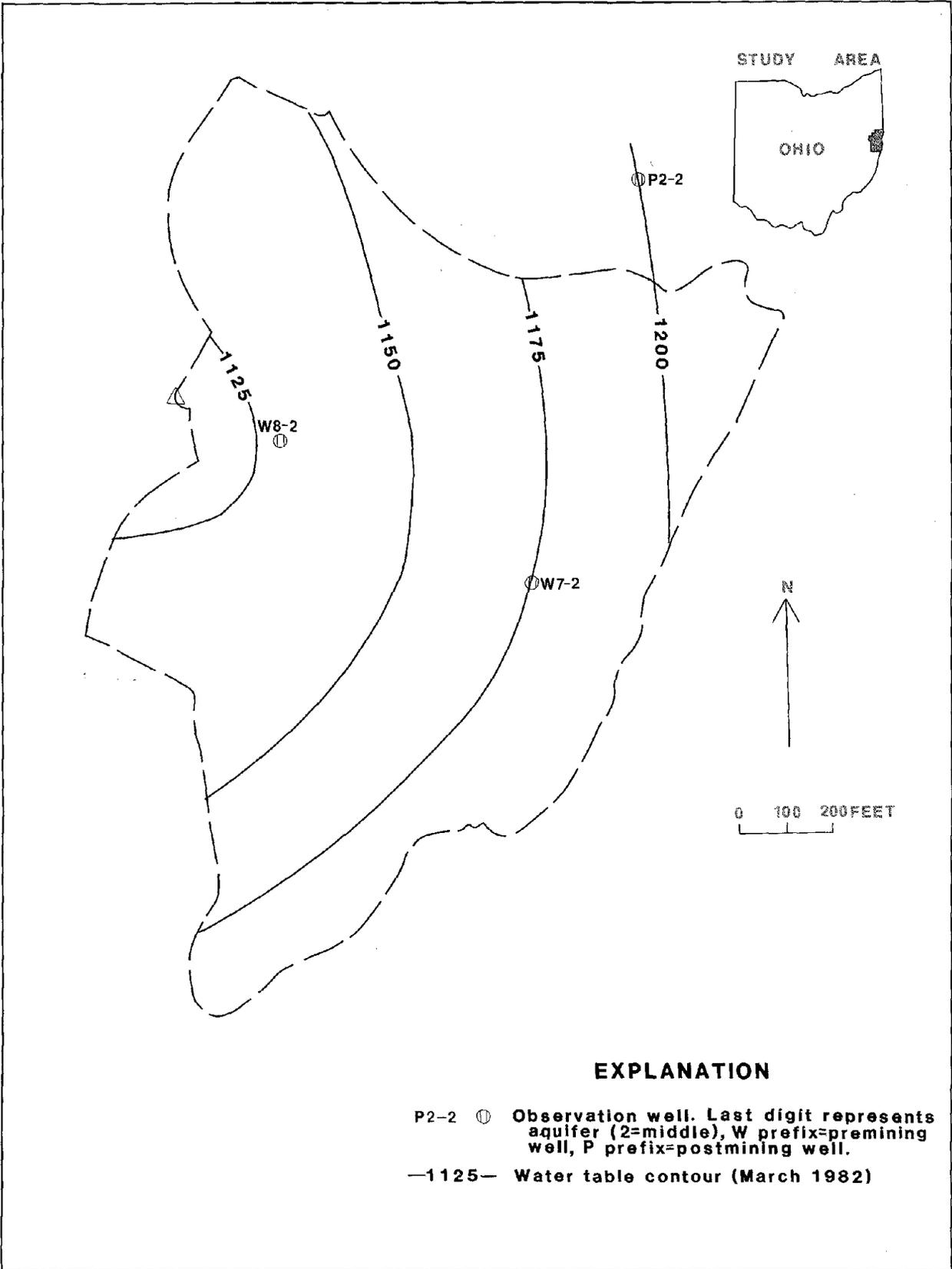


FIGURE 43. - Postreclamation potentiometric surface of the middle aquifer at Watershed J11.

## VI. GROUND-WATER QUALITY

### A. Premining

The top aquifer at Watershed J11 contained water of the calcium bicarbonate and calcium sulfate types (Figure 44). Water from the middle aquifer was sodium bicarbonate and calcium bicarbonate. Results of chemical analyses are shown in Table 29.

The premine variations in chemical constituents were the result of the local geology, paths of flow, and seasonal variations. Local geology was responsible for the high percentage of sulfate in water from the top aquifer wells, W3-1 and W6-1 (Figure 44). The local geology and the paths of ground water movement cause water from Well W7-2 to have sodium as the dominant cation and water from Well W8-2 to have calcium as the dominant cation (Figure 44). This was because water recharging the vicinity of Well W7-2 had to pass through the coal and an underclay which resulted in cation exchange between sodium and calcium and a net increase of sodium in the water. In the vicinity of Well W8-2, water recharged directly from precipitation, and calcium was the dominant cation.

Chloride changes occur seasonally in Wells W4-1, W6-1, and W8-2 (Figures 45 and 46). Well W4-1, which is close to a county road that is salted during the winter, shows increases in chloride content every spring. Wells W6-1 and W8-2, which are farther from the county road, show lesser increases. However, the increases take place during late summer because the chloride moves with the ground water and travels farther before arriving at Wells W6-1 and W8-2.

The water-quality diagram (Figure 47) shows that the baseflow water quality and top aquifer water quality closely resemble each other. This indicates that premining baseflow was entirely supplied by spring discharge from the top aquifer. The water level in the middle aquifer was 18 ft below the stream bottom and could not have been supplying water to the stream.

### B. Postreclamation

Water in the postreclamation top aquifer is a calcium sulfate type, except at Well W4-1 which yielded calcium bicarbonate-type water (Figures 48 and 49). Although water types have not changed much between premining and postreclamation (Figure 49), the median concentrations of most of the individual constituents have increased (compare Table 30 with Table 29). These increases are the result of the mining operation that shattered the bedrock, exposing spoil of material susceptible to solution. Top aquifer constituents whose median concentrations increased significantly from premining to postmining conditions are dissolved iron (0.03 mg/l to 0.15 mg/l), dissolved manganese (0.03 mg/l to 0.4 mg/l), dissolved sulfate (84 mg/l to 200 mg/l), dissolved chloride (13 mg/l to 41 mg/l), and noncarbonate hardness (96 mg/l to 225 mg/l). Only the median concentration of dissolved manganese exceeds the recommended limit for drinking water of 0.05 mg/l (U. S. Environmental Protection Agency, 28). However, concentrations of some constituents at specific well sites did exceed recommended limits, as can be seen in the range from Table 30.

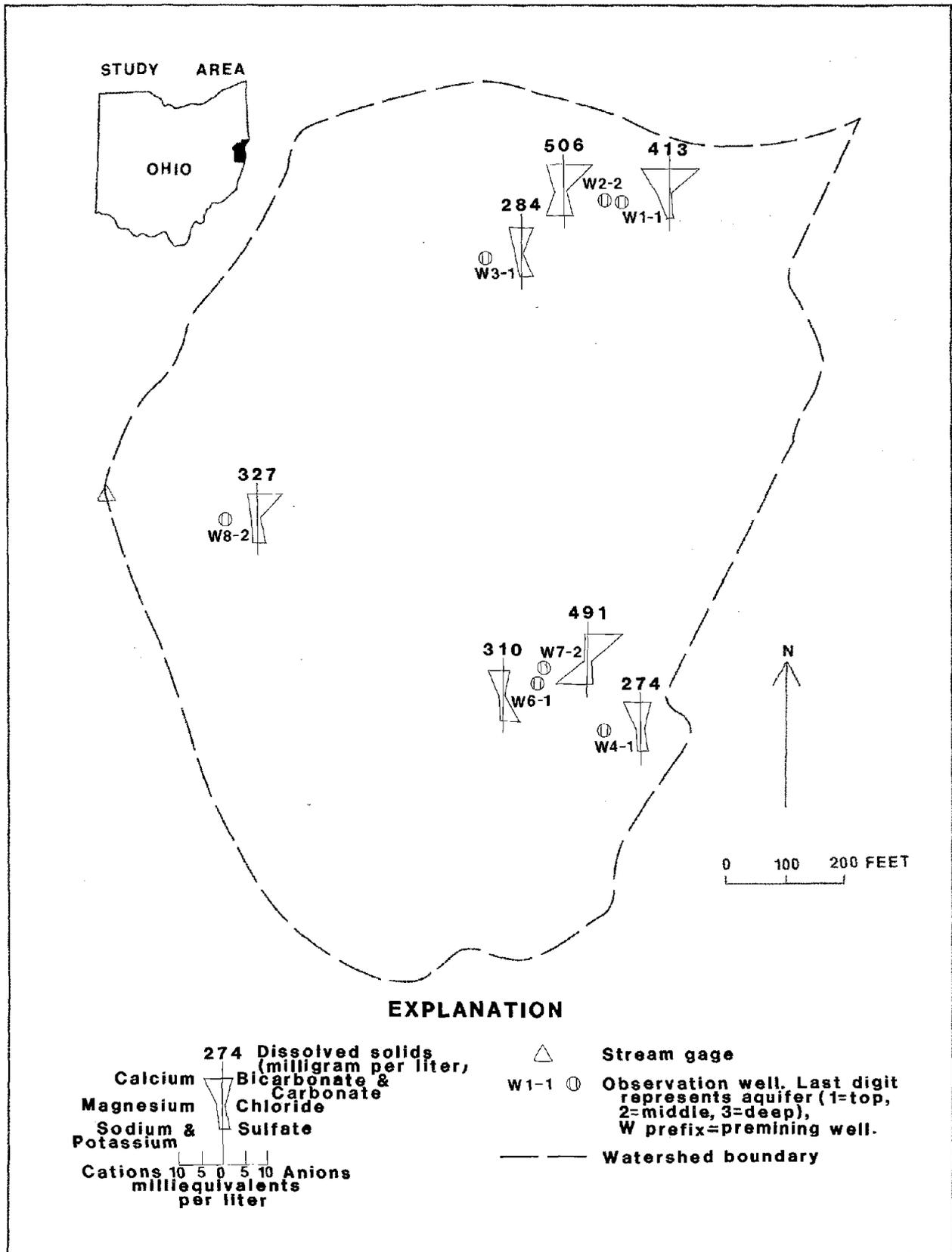


FIGURE 44. - Stiff (20) diagrams showing distribution of water types in the premining condition at Watershed J11.

TABLE 29. - Premining chemical analyses of ground water collected from Watershed J11, August 1976 - July 1980

Constituents or Properties	Unit	Number of Samples	Concentration or Other Measurement, Top Aquifer	
			Range	Median
Specific Conductance	µmhos/cm	35	320 - 830	550
pH		35	5.8 - 7.7	7.0
Alkalinity, (as CaCO)	mg/l	35	16 - 346	148
Bicarbonate, (as HCO)	mg/l	35	20 - 422	180
Nitrogen, (Dissolved)	mg/l	11	0.8 - 11	2.8
Nitrogen, NH (Dissolved)	mg/l	18	0 - 8	0.02
Nitrogen, NH (Total)	mg/l	13	0.01 - 0.21	.01
Nitrogen, Organic (Dissolved)	mg/l	18	0 - 1.9	.14
Nitrogen, NO + NO (Dissolved)	mg/l	18	0.01 - 11	1.35
Phosphorus (Dissolved)	mg/l	18	0 - 0.71	0.01
Carbon, Organic (Total)	mg/l	17	2.1 - 9.2	5.4
Hardness, (as CaCO)	mg/l	35	140 - 430	270
Hardness, Noncarbonate	mg/l	35	12 - 210	96
Calcium (Dissolved)	mg/l	35	39 - 120	80
Magnesium (Dissolved)	mg/l	35	9.1 - 3.1	16
Sodium (Dissolved)	mg/l	35	5.4 - 13	7.9
Sodium Adsorption Ratio		35	0.1 - 0.4	0.2
Percent Sodium		35	3 - 13	8
Potassium (Dissolved)	mg/l	35	1 - 3.2	1.6
Chloride (Dissolved)	mg/l	35	7.5 - 55	13
Sulfate (Dissolved)	mg/l	35	24 - 190	84
Fluoride (Dissolved)	mg/l	35	0.1 - 0.2	0.1
Silica (Dissolved)	mg/l	31	10 - 19	15
Iron (Dissolved)	µg/l	35	10 - 17,000	30
Manganese (Dissolved)	µg/l	35	3 - 1400	30
Strontium (Dissolved)	µg/l	14	150 - 470	300
Zinc (Dissolved)	µg/l	14	20 - 60	30
Phenols	µg/l	34	0 - 44	0.5
Solids, Sum of Constituents, (Dissolved)	mg/l	31	222 - 471	335

TABLE 29. (Cont'd) - Premining chemical analyses of ground water collected from Watershed J11, August 1976 - July 1980

Constituents or Properties	Unit	Number of Samples	Concentration or Other Measurement, Middle Aquifer	
			Range	Median
Specific Conductance	$\mu\text{mhos/cm}$	30	475 - 910	680
pH		30	6.8 - 8.2	7.5
Alkalinity, (as CaCO)	mg/l	30	254 - 417	324
Bicarbonate, (as HCO)	mg/l	30	310 - 508	395
Nitrogen, (Dissolved)	mg/l	9	0.1 - 1.1	0.3
Nitrogen, NH (Dissolved)	mg/l	15	0.01 - 0.21	.01
Nitrogen, NH (Total)	mg/l	11	0.01 - 0.27	.03
Nitrogen, Organic (Dissolved)	mg/l	15	0 - 0.75	.12
Nitrogen, NO + NO (Dissolved)	mg/l	15	0.03 - 0.45	.2
Phosphorus (Dissolved)	mg/l	15	0 - 0.02	0.01
Carbon, Organic (Total)	mg/l	17	1.7 - 8.5	5.4
Hardness, (as CaCO)	mg/l	30	56 - 390	250
Hardness, Noncarbonate	mg/l	30	0 - 55	0
Calcium (Dissolved)	mg/l	30	13 - 100	61
Magnesium (Dissolved)	mg/l	30	5.5 - 34	23
Sodium (Dissolved)	mg/l	30	11 - 230	48.5
Sodium Adsorption Ratio		30	0.3 - 13	1.35
Percent Sodium		30	8 - 90	28.5
Potassium (Dissolved)	mg/l	30	1.2 - 2.7	2
Chloride (Dissolved)	mg/l	30	8.8 - 49	14
Sulfate (Dissolved)	mg/l	30	22 - 87	47
Fluoride (Dissolved)	mg/l	30	0.1 - 2.6	0.25
Silica (Dissolved)	mg/l	27	9.4 - 18	11
Iron (Dissolved)	$\mu\text{g/l}$	30	0 - 290	10
Manganese (Dissolved)	$\mu\text{g/l}$	30	1 - 40	10
Strontium (Dissolved)	$\mu\text{g/l}$	10	720 - 1900	1140
Zinc (Dissolved)	$\mu\text{g/l}$	10	0 - 80	20
Phenols	$\mu\text{g/l}$	30	0 - 68	0
Solids, Sum of Constituents, (Dissolved)	mg/l	27	338 - 588	405

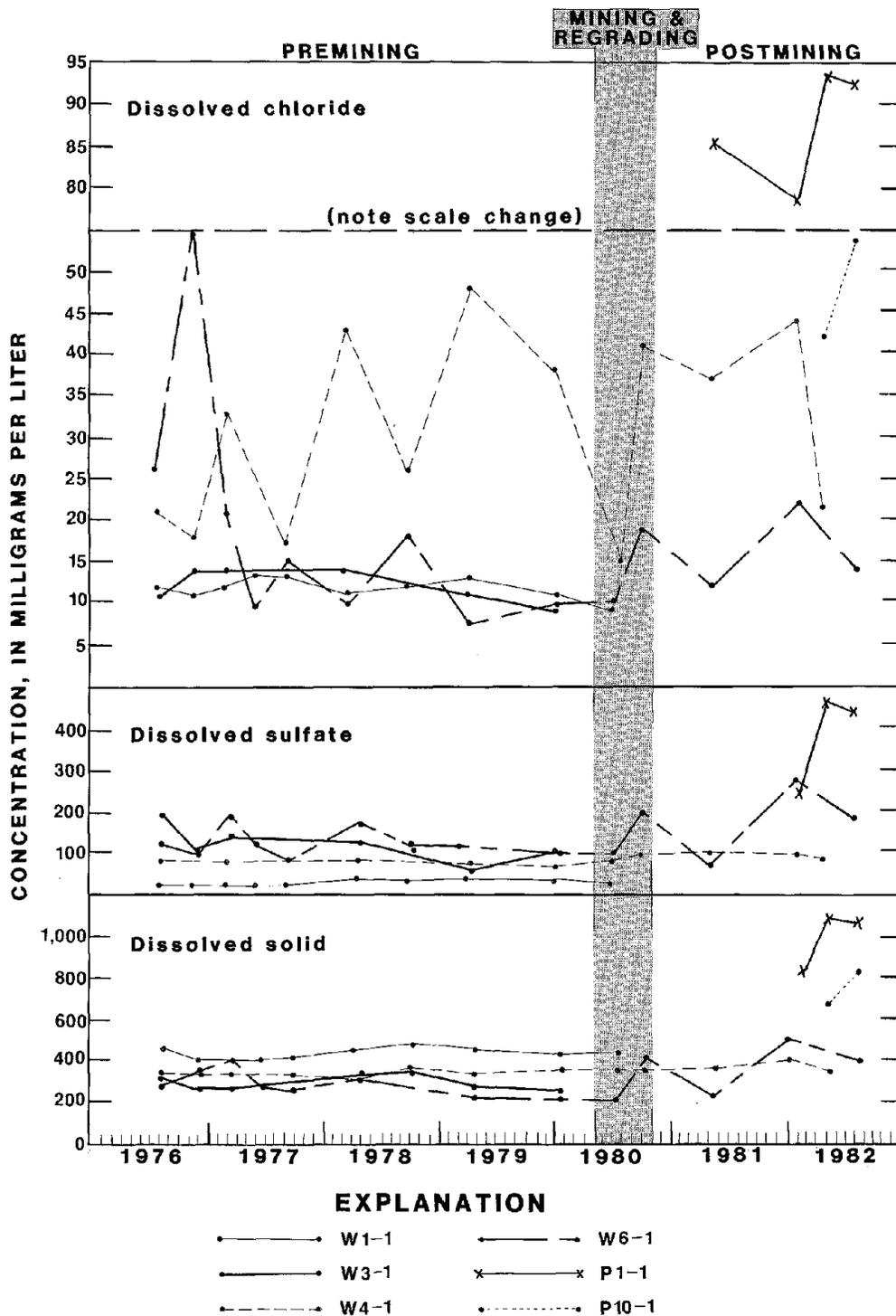


FIGURE 45. - Variations with time of selected constituents in the top aquifer at Watershed J11. (W prefix = premining well; P prefix = postreclamation well.)

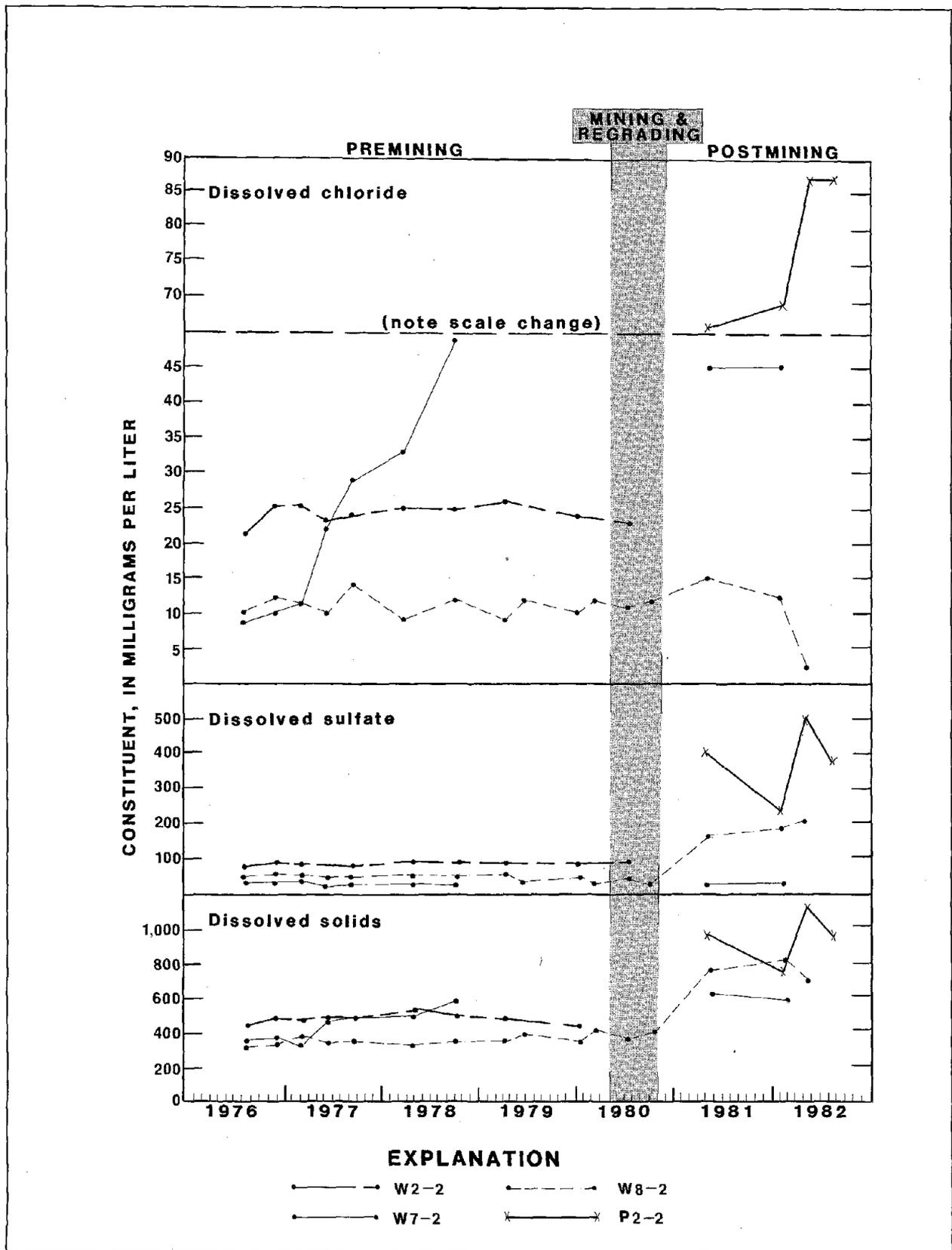


FIGURE 46. - Variations with time of selected constituents in the middle aquifer at Watershed J11. (W prefix = premining well; P prefix = postreclamation well.)

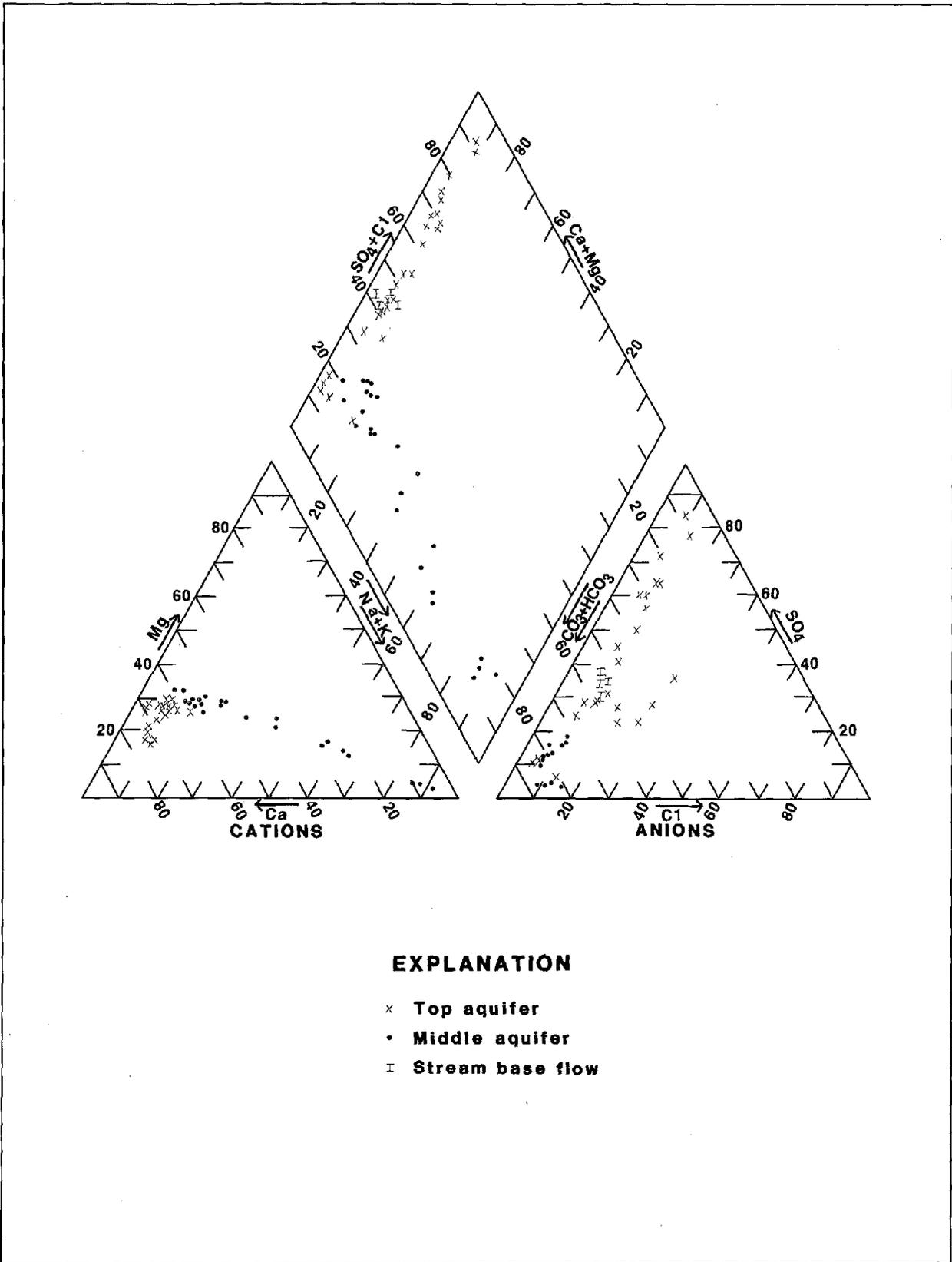


FIGURE 47. - Water-analysis diagram showing premining water-quality characteristics at Watershed J11.

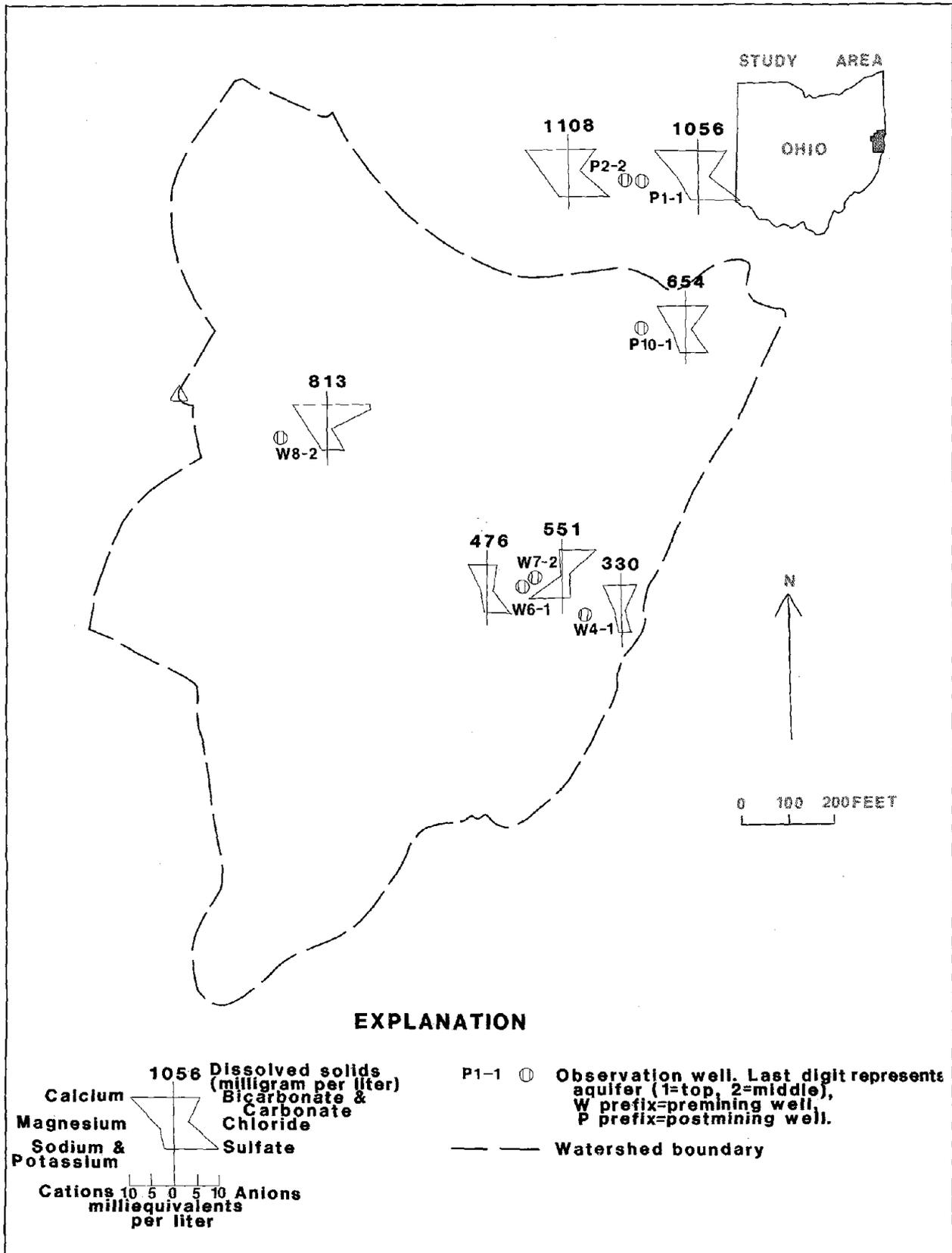


FIGURE 48. - Stiff (20) diagrams showing distribution of water types in the postreclamation condition at Watershed J11.

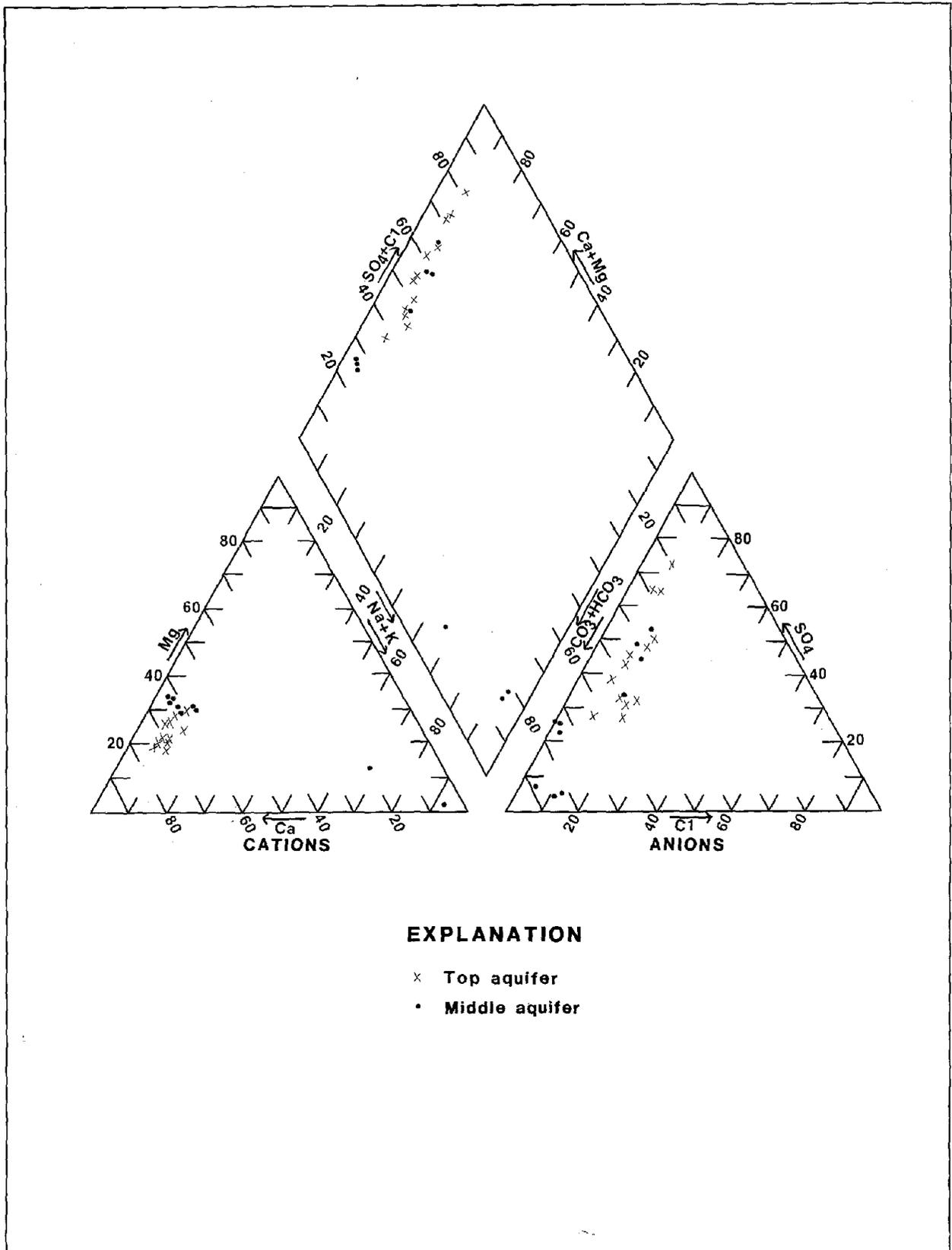


FIGURE 49. - Water-analysis diagram showing postreclamation water-quality characteristics at Watershed J11.

TABLE 30. - Postreclamation chemical analyses of ground water collected from Watershed J11, October 1980 - August 1982

Constituents or Properties	Unit	Number of Samples	Concentration or Other Measurement, Top Aquifer	
			Range	Median
Specific Conductance	$\mu\text{mhos/cm}$	14	374 - 1500	716.5
pH		14	6.6 - 7.1	6.85
Alkalinity, (as CaCO)	mg/l	14	72 - 394	196
Bicarbonate, (as HCO)	mg/l	14	88 - 480	239
Nitrogen, (Dissolved)	mg/l	10	0.17 - 10	0.63
Nitrogen, NH (Dissolved)	mg/l	11	.03 - 10	.19
Nitrogen, Organic (Dissolved)	mg/l	11	0 - 0.57	.14
Nitrogen, NO + NO (Dissolved)	mg/l	11	.01 - 1.5	.1
Phosphorus, (Dissolved)	mg/l	11	.01 - 0.68	.01
Carbon, Organic, (as C)	mg/l	14	1.2 - 26	3.3
Hardness (as CaCO)	mg/l	14	170 - 770	335
Hardness, Noncarbonate	mg/l	14	63 - 440	225
Calcium, (Dissolved)	mg/l	14	53 - 210	103.5
Magnesium, (Dissolved)	mg/l	14	8.9 - 61	18.5
Sodium, (Dissolved)	mg/l	14	8 - 32	14
Sodium Adsorption Ratio		14	0.2 - 0.6	0.3
Percent Sodium		13	6 - 11	8
Potassium (Dissolved)	mg/l	13	1.4 - 3.6	1.8
Chloride (Dissolved)	mg/l	14	12 - 92	41
Sulfate, (Dissolved)	mg/l	13	71 - 460	200
Fluoride, (Dissolved)	mg/l	14	0 - 0.2	0.1
Silica, (Dissolved)	mg/l	13	11 - 20	14
Iron, (Dissolved)	$\mu\text{g/l}$	13	11 - 4300	150
Manganese, (Dissolved)	$\mu\text{g/l}$	14	39 - 910	400
Strontium, (Dissolved)	$\mu\text{g/l}$	14	250 - 1000	490
Zinc, (Dissolved)	$\mu\text{g/l}$	2	30 - 80	55
Phenols	$\mu\text{g/l}$	14	0 - 20	1
Solids, Sum of Constituents, (Dissolved)	mg/l	13	236 - 1070	405

TABLE 30. (Cont'd) - Postreclamation chemical analyses of ground water collected from Watershed J11, October 1980 - August 1982

Constituents or Properties	Unit	Number of Samples	Concentration or Other Measurement, Middle Aquifer	
			<u>Range</u>	<u>Median</u>
Specific Conductance	µmhos/cm	10	702 - 1600	1185
pH		10	6.8 - 7.8	7.05
Alkalinity, (as CaCO)	mg/l	10	333 - 591	402
Bicarbonate, (as HCO)	mg/l	10	406 - 720	490
Nitrogen, (Dissolved)	mg/l	7	0.2 - 2.2	0.5
Nitrogen, NH (Dissolved)	mg/l	9	0.03 - 0.46	.11
Nitrogen, Organic (Dissolved)	mg/l	9	0 - 0.38	.21
Nitrogen, NO + NO (Dissolved)	mg/l	9	0.01 - 1.5	.05
Phosphorus, (Dissolved)	mg/l	9	0.01 - 0.06	.01
Carbon, Organic, (as C)	mg/l	9	1 - 5.2	1.8
Hardness (as CaCO)	mg/l	10	37 - 810	640
Hardness, Noncarbonate	mg/l	10	0 - 470	94.5
Calcium, (Dissolved)	mg/l	10	9.3 - 216	166
Magnesium, (Dissolved)	mg/l	10	3.2 - 66	53.5
Sodium, (Dissolved)	mg/l	10	11 - 250	32
Sodium Adsorption Ratio		10	0.2 - 17	0.6
Percent Sodium		10	3 - 93	9.5
Potassium (Dissolved)	mg/l	10	1.2 - 3.5	2.2
Chloride (Dissolved)	mg/l	10	2.4 - 86	45
Sulfate, (Dissolved)	mg/l	10	21 - 500	190
Fluoride, (Dissolved)	mg/l	10	0.1 - 3	0.2
Silica, (Dissolved)	mg/l	10	8.3 - 15	12.5
Iron, (Dissolved)	µg/l	10	3 - 1500	18
Manganese, (Dissolved)	µg/l	10	5 - 1500	220
Strontium, (Dissolved)	µg/l	10	430 - 2000	1600
Zinc, (Dissolved)	µg/l	1	0 - 0	0
Phenols	µg/l	10	0 - 1	1
Solids, Sum of Constituents, (Dissolved)	mg/l	10	404 - 1120	770

Water in the second aquifer is a sodium bicarbonate type (W7-2), calcium bicarbonate type (W8-2), and a calcium sulfate type (P2-2) (Figures 48 and 49). The types of water from Wells W8-2 and W7-2 are the same as during premining, though the median of the total dissolved solids content of water at Well W8-2 has increased from 358 mg/l to 765 mg/l. The water-quality changes at Well W7-2 are small in comparison to Wells W8-2 and P2-2 because this area was not disturbed by mining and the well location is up-gradient (Figure 17) from the mining activity. Water-quality changes in the middle aquifer were most dramatic at P2-2, which has changed from calcium bicarbonate type to calcium sulfate type. This site was in the middle of the mining activity and the shaley underclay was disturbed. The similarities in water quality (Figure 48) and water levels in Wells P1-1 and P2-2 show that the top aquifer and middle aquifers react as one in the area of the spoils material.

Concentrations of some constituents at specific well sites exceeded recommended limits for drinking water, as can be seen in the ranges in Table 30. Dissolved manganese and dissolved solids are the only constituents whose median concentrations exceed recommended limits of 0.05 mg/l and 500 mg/l (U. S. Environmental Protection Agency, 28). Although few constituents in the middle aquifer exceed recommended limits, many increased significantly from premining to postreclamation conditions. Some of the median concentrations of constituents in the middle aquifer that increased are hardness (250 mg/l to 640 mg/l), noncarbonate hardness (0 mg/l to 94.5 mg/l), calcium (61 mg/l to 166 mg/l), magnesium (23 mg/l to 53.5 mg/l), sulfate (47 mg/l to 190 mg/l), manganese (10 µg/l to 220 µg/l), dissolved solids (405 mg/l to 770 mg/l), and chloride (14 mg/l to 45 mg/l). Oddly, even though chloride increased, the median concentration of sodium decreased from 48.5 mg/l to 32 mg/l.

The increases of median concentrations of constituents in the top aquifer (spoil) result from more surface area along mineral-water contacts, which allows for more mineral dissolution. Dissolution of limestones and carbonate cements caused the rise in calcium, magnesium, bicarbonate, and hardness. Manganese is derived from oxides and hydroxides in the soil and rock; sulfates and iron are derived from reduced minerals, particularly pyrite. Breaking and disintegration of the marine shales has released chlorides that were entrapped in the fine-grained sediments when they were deposited.

The introduction of oxygen, in contact with reduced minerals (pyrite), will cause dissolution of these minerals to yield iron and sulfates. The increase in concentrations of constituents in the middle aquifer is the result of leakage from the overlying spoils and introduction of oxygen from the oxygenated spoils. When springs and seeps eventually return, the baseflow of the stream will probably be considerably reduced in quality compared to that before mining.

In the premining condition, median concentrations of dissolved iron and dissolved manganese were equal for both the top and middle aquifers. In the postreclamation condition, the median values of dissolved manganese are many times higher than dissolved iron, which is unusual for most ground waters (Hem, 13). This imbalance is caused by the dissolution of reduced minerals in the presence of oxygen; iron will tend to go into solution. However, the iron-bearing water will go into solution from the pyrite dissolution, but then precipitate out in the presence of oxygen. On the other hand, manganese goes into solution and stays in solution even in the presence of oxygen (Hem, 13). The net result is that both dissolved iron and manganese increase, with manganese increasing much more.

## VII. EROSION AND SEDIMENTATION

### A. Introduction

Sediment and related flow data collected at the Watershed J11 outlet are summarized in this section. While recognizing the importance of precipitation characteristics in the erosion process, only the variation of sediment concentration with channel flow measured at the outlet will be considered herein. The variable flow rate has features of a climatological index variable since it responds to, among other factors, precipitation patterns.

The final reclaimed landscape, consisting of a dense stand of grass without diversions, was not realized until after the end of the monitoring cut-off date (June 30, 1982) for this report. Therefore, comparisons with Phase 3 data reported herein are actually with the initial Phase 3 period (Phase 3a) as mentioned in Section II, and not those of the final reclaimed landscape. A "period" is defined as a time interval within a phase.

The term "water quality" in this section is used in the context of sediment concentration only.

### B. Watershed Conditions and Sources of Sediment

Watershed conditions during the periods of data collection are discussed in Section II. Watershed disturbance maps are presented in Figure 15. The periods of disturbance are summarized in Table 1. Briefly, the periods during which the overland flow areas were protected with vegetation were Phase 1, the latter part of Phase 2e, and part of Phase 3a. Some of these areas supported only a sparse vegetative cover, contributing sediment sampled at the watershed outlet. Additionally, field observations during Phase 2 and Phase 3a, indicated that the diversions, and main stream channels were being scoured. This process contributed much of the sediment sampled at the watershed outlet. The relative magnitude of the contribution of the channel and overland sources is not known.

### C. Summary and Discussion of Sediment Data

#### 1. Summary of Data Collected.

The data base used in this section consisted of 44 Phase 1, 641 Phase 2, and 559 Phase 3 samples, totalling 1244 samples. Most samples were collected automatically, and some were collected manually.

The distributions of samples collected according to hydrograph position at the time of sampling, and the sources of runoff are shown in Table 31. Two categories of the latter were considered, runoff derived from rainfall only and runoff derived from snowmelt. The table shows that falling limbs were sampled most frequently, and that valleys and baseflows were sampled least during Phases 2 and 3a. However, falling limbs and baseflows were sampled most frequently, and rising limbs were sampled least during Phase 1. Snowmelt affected about 23% of Phases 1 and 2 samples, while it affected 51% of those of Phase 3.

TABLE 31. - Distribution of sediment samples obtained at Watershed J11

<u>Category</u>	<u>Phase 1</u>		<u>Phase 2</u>		<u>Phase 3a</u>	
	<u>Total</u>	<u>% of Total</u>	<u>Total</u>	<u>% of Total</u>	<u>Total</u>	<u>% of Total</u>
1. Hydrograph Position						
a. Rising Limb	6	14	209	33	175	31
b. Peak	12	27	94	15	59	10
c. Falling Limb	13	30	296	46	295	53
d. Valley	0	0	32	5	28	5
e. Baseflow	13	30	10	2	2	<1
2. Source of Runoff						
a. Rainfall Only	34	77	497	78	272	49
b. Snowmelt Affected	10	23	144	22	287	51
3. Totals	44	100	641	100	559	100

## 2. Regressions.

Regressions of sediment concentration upon flow rate were performed on their logarithmic transformations, using subsets of data listed in Table 31. These subsets were formed in order to attempt to reduce unexplained variability found in a plot of these data. The subsets were created by grouping the data by phase and period, runoff source (snowmelt only, combined snowmelt and rainfall, and rainfall only), and by position on the hydrograph at the time of sampling (Table 31). The results showed marginal, but insignificant improvements in unexplained variability in sediment data by grouping by runoff source in about 50% of the regressions, and improvement in about 30% of the regressions by grouping by hydrograph position. However, about 60% of the regressions by falling limb positions experienced a decrease in unexplained variability. Two of the more noticeable improvements were made by such a grouping. The coefficient of determination ( $r^2$ ) was increased from 0.40 (sample size = 44) to 0.71 (sample size = 13) for Phase 1 samples, and from 0.71 (sample size = 70) to 0.83 (sample size = 41) for Phase 2e samples. The next highest  $r^2$  values in the falling limb group were two values of 0.56.

## 3. Temporal Variations of the Flow, Sediment Concentration, and Sediment Load and Data.

In order to trace the variation of sediment concentrations and loads with time, the monthly average concentrations and flows, and associated average load rates were computed. The results are in Table 32. Flow rate is expressed in terms of in per hour (iph) to account for the effects of known and probable changes in the runoff area. The ratios of the monthly average flows, sediment concentrations, and load rates to the respective monthly maximum averages plotted in Figure 50 show the magnitude of change occurring during the entire period of record with respect to the maximum of each parameter (the month in which the ratio equals 1.0). Because flow rate is being used as a climatological index variable, the trends of the concentration and load rate ratio curves with respect to that of the flow ratio curve are indicators of the effects upon concentrations and load rates due to surface activities and disturbances.

Figure 50 shows the phase and period designations listed in Table 1 embedded in the plots of the ratio of flow, concentration, and load rate. The presence of a monthly value (or plot symbol for flow ratio) on this plot indicates a sample size of 5 or more (Table 32). Where the sample size is too small, the average of all the data in the period is presented as a horizontal line. The figure shows that the maximum average concentrations and load rates occurred toward the end of Phase 3a with one of the higher monthly flows. The maximum average flow occurred during Phase 2e with a relatively small concentration (August, 1981).

There are two periods evident in this graph that show deteriorating surface conditions. The first is in Phase 2d (March - June 1981). Field notes indicate that the haul road crossing the watershed was a major sediment source, and that the vegetative stand was poor on some of the seeded areas during this time. Small gullies had begun to carve the surface. As early as December 1980, field notes also indicated that the grass stand was poor, and that small, normally dry detention dams installed in one of the main waterways were deteriorating. The overland flow areas and channels contributed greatly

TABLE 32. - Average monthly sediment concentration, flow rate, and load rate for Watershed J11

Month	Year	No. of Samples	Average Sed. Concentration (mg/l)	Average Flow Rate (iph)	Average Load Rate (tons/day)	
1	1980	5	144	0.0035	0.065	
2		6	51	.0033	.025	
3		14	248	.0093	.29	
9		5	33,600	.074	430	
10		32	12,700	.026	23	
11		49	6800	.028	23	
12		36	12,600	.023	21	
1		1981	30	4060	0.041	11
2			134	8970	.028	24
3			13	8930	.0084	6.7
4			58	20,700	.031	70
5			51	17,500	.028	43
6	95		18,300	.074	110	
7	56		23,600	.077	150	
8	6		30,800	.11	290	
9	70		14,500	.091	150	
12	123		7510	.032	29	
1	1982		176	7740	0.032	48
2			122	9270	.019	22
3		105	24,600	.034	140	
4		11	28,100	.014	51	
5		21	78,100	.058	470	

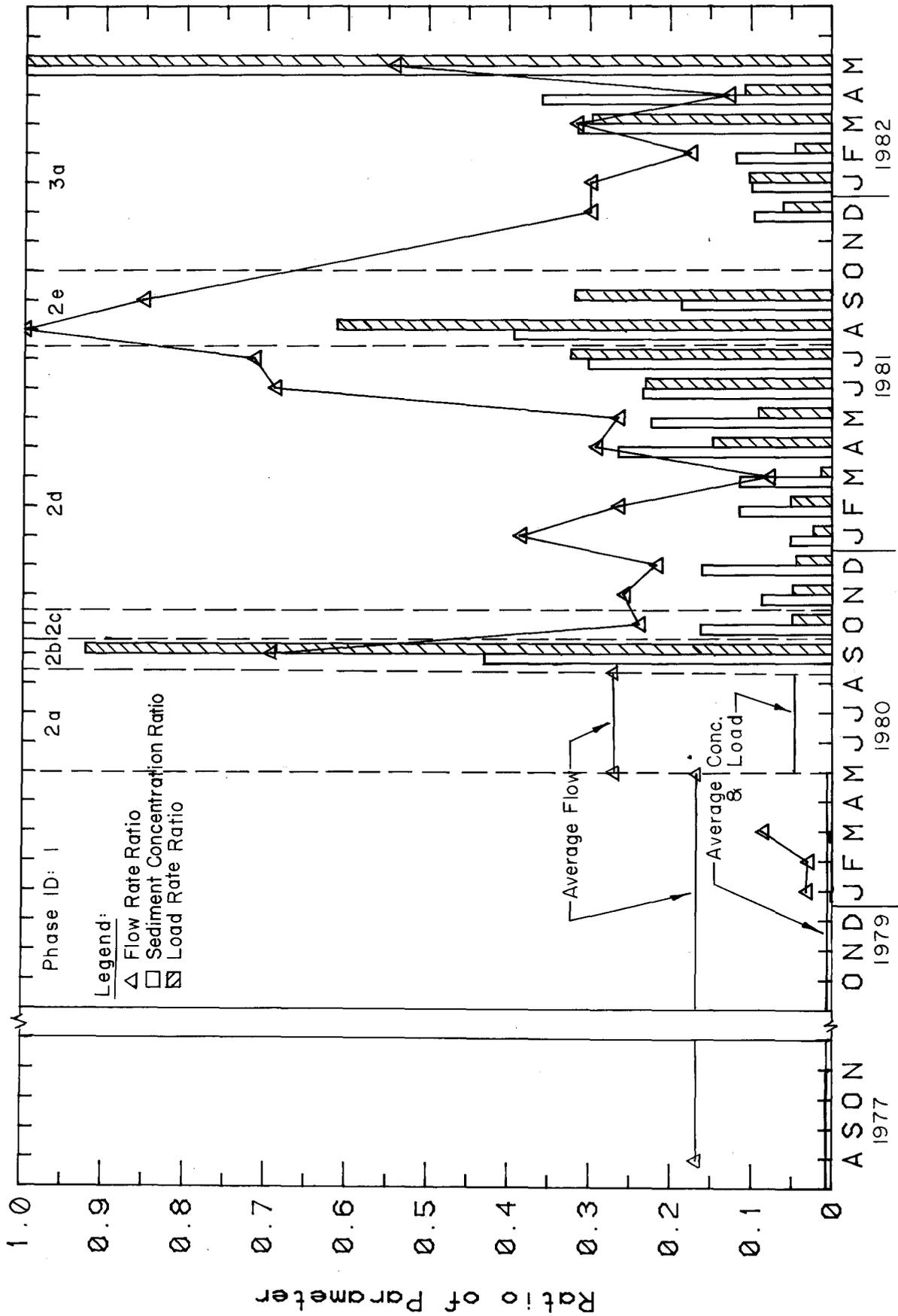


FIGURE 50. - Average monthly or period sediment concentrations, and flow and load rates for Watershed J11.

to the sediment yield of the watershed. Also, sediment was observed to be rapidly depositing in the approach area of the weir (from March - June 1981).

The second time deteriorating conditions were apparent is during Phase 3a (March - May 1982). After September 1981, a month of active reclamation, the concentrations and load rates were depressed for flows nearly equal to or greater than those observed in the prior period. This showed a positive impact of the reclamation activities in September. However, in March 1982, the concentration and load rate increased relative to those in Phase 2d, eventually reaching the maximum of the record close to the reporting cutoff date. Field notes did not indicate any new man-made surface disturbance on the watershed during this time; however, there were active gullies and diversion terrace failures, and some areas supported a sparse vegetative cover.

The data from the other periods do not show any reportable trends except during Phase 2b. Here the average flow and load rates were high, but the average concentration was low. The averages are the result of a sample size of only 5, consisting of two high flow rates, three low flow rates, and associated high and low sediment concentrations. A larger sample size would be more representative.

#### 4. Comparison of Phases 2 and 3a.

With the exception of Phase 1, averages were computed for the sediment concentration and for flow and load rate data for each period identified in Table 1; the results are presented in Table 33. Flow rates are expressed in terms of in per hour to account for the effects of the changing watershed areas. The statistical sample sizes for Phases 2a and b were too small to use in comparisons with the other periods. The ratios with respect to Phase 3a show that the average sediment concentrations for Phases 2d, e, and 3a did not change with the type of disturbance. However, the concentration data combined with the average flow rates do show an effect due to the type of disturbance. The average Phase 2e sampled flow rate was 3 times that of Phase 3a, but the average concentration was practically the same for the two periods. The average flow for Phase 2d was 1.4 times that of Phase 3a, but the average concentration remained unchanged. It appears that the Phase 3a surface conditions caused a decrease in water quality compared to those of Phase 2e. However, Phase 2e activities resulted in better water quality than those of Phase 2d.

The Phase 2c flows and concentrations were both lower than those of Phase 3a. The effect of the type of disturbance cannot be separated from the effect upon concentrations due to lower flow rates that were sampled during Phase 2c.

The average load rates of Phases 2e and 3c reveal that in spite of the apparent improvement in the quality of the water during Phase 2e, the load rate then was the greatest of all periods, due mainly to the higher sampled flows. Load rates were less for Phases 2c and d.

When the pooled Phase 2 data are compared with Phase 3c, sediment concentration and load rate remained unchanged, but the sampled flow rate was 60% higher during Phase 2 compared to that of Phase 3a. This suggests that the watershed reclamation practice deteriorated during Phase 3a, a period during which there was minimal surface activity by man, and when the watershed was in a partially reclaimed condition with diversions, poor cover in some areas, and active gullies.

TABLE 33. - Watershed J11 Phases 2 and 3a period averages  
of sediment-related parameters

Phase/ Period	Number of Samples	Sediment Concentration		Flow Rate		Load Rate	
		Average (mg/l)	Ratio <sup>1</sup>	Average (iph)	Ratio <sup>1</sup>	Average (tons/day)	Ratio <sup>1</sup>
Phase 2							
a	5	4300	NC <sup>2</sup>	.029	NC	25	NC
b	6	28,000	NC	.062	NC	362	NC
c	32	12,700	.89	.026	.87	23.2	.33
d	528	14,300	1.0	.043	1.4	61.3	.86
e	70	14,500	1.0	.091	3.0	150	2.1
Entire Phase 2	641	14,300	1.0	.047	1.6	71.7	1.0
Phase 3a	559	14,200	1.0	.030	1.0	71.3	1.0

<sup>1</sup>Ratio with respect to Phase 3a.

<sup>2</sup>NC - Not calculated due to small sample size.

## 5. Comparison of Phases 1, 2, and 3a.

The number of samples collected during Phase 1 did not span the range of flow rates experienced during Phases 2 and 3a. In order to eliminate the influence of higher flow rates causing higher sediment concentrations in comparisons between the 3 Phases, modified data sets composed of samples collected at flows less than or equal to the maximum sampled Phase 1 flow of 3.3 cfs were created. Period averages were computed using these data sets. The results are presented in Table 34.

The data in Table 34 show that the sediment concentrations and load rates of Phase 3 did not recover to the Phase 1 levels, however, the average sampled flow rates were also higher. The effect of type of disturbance is noticeable in Table 34. Except for Phase 2e, the concentrations were about 27 times those of Phase 1. The flows experienced an increase, and then decreased after Phase 2e, while the sediment concentration dipped during Phase 2e. This indicates the reclamation efforts of Phase 2e were effective in attenuating the sediment concentration.

Figure 51 is a plot of all the flow-sediment data collected in each phase. The Phases 2 and 3a data were initially plotted with different symbols. However, the two sets of data were practically indistinguishable, so only one symbol was used in the figure. The envelope in the figure shows the lower limit of sediment concentration for Phase 2, except for an isolated outlier. All point symbols plotted below this envelope are Phase 3a data. This small region of Phase 3a data of lower sediment concentration was obtained early during the phase. They show the improvement of the water quality experienced early in Phase 3a. Later in Phase 3a, the water quality became poorer, eventually becoming worse than in Phase 2e, as previously shown. The plus symbols in the figures show the premining data. These samples lie noticeably below those of Phases 2 and 3a. The noticeable degradation of the water quality during Phases 2 and 3a is evident from this illustration. The concentration of points at about 0.24 cfs reflects the automatic sample threshold.

### D. Maximum Concentrations

Table 35 lists the maximum concentrations sampled and the associated flow and load rates for each phase. The table shows that the maximum concentrations occurred at lower flows than those measured at the maximum flow rate samples for Phases 2 and 3a. The highest concentration of 184,000 mg/l was measured during Phase 2. The highest Phase 3a concentration was measured in a relatively small flow on a rapidly rising hydrograph. The variability of the flow-concentration data that is evident here was exhibited also in the earlier discussion of regression results.

### E. Summary

The 1244 sediment samples collected from the outlet of Watershed J11 were grouped according to predominant surface activities. A total of six periods were identified, Phase 1, Phases 2a, b, c, d, e, and Phase 3a. The watershed erosion control practice consisted of diversions that were occasionally removed and reinstalled and that eroded and failed.

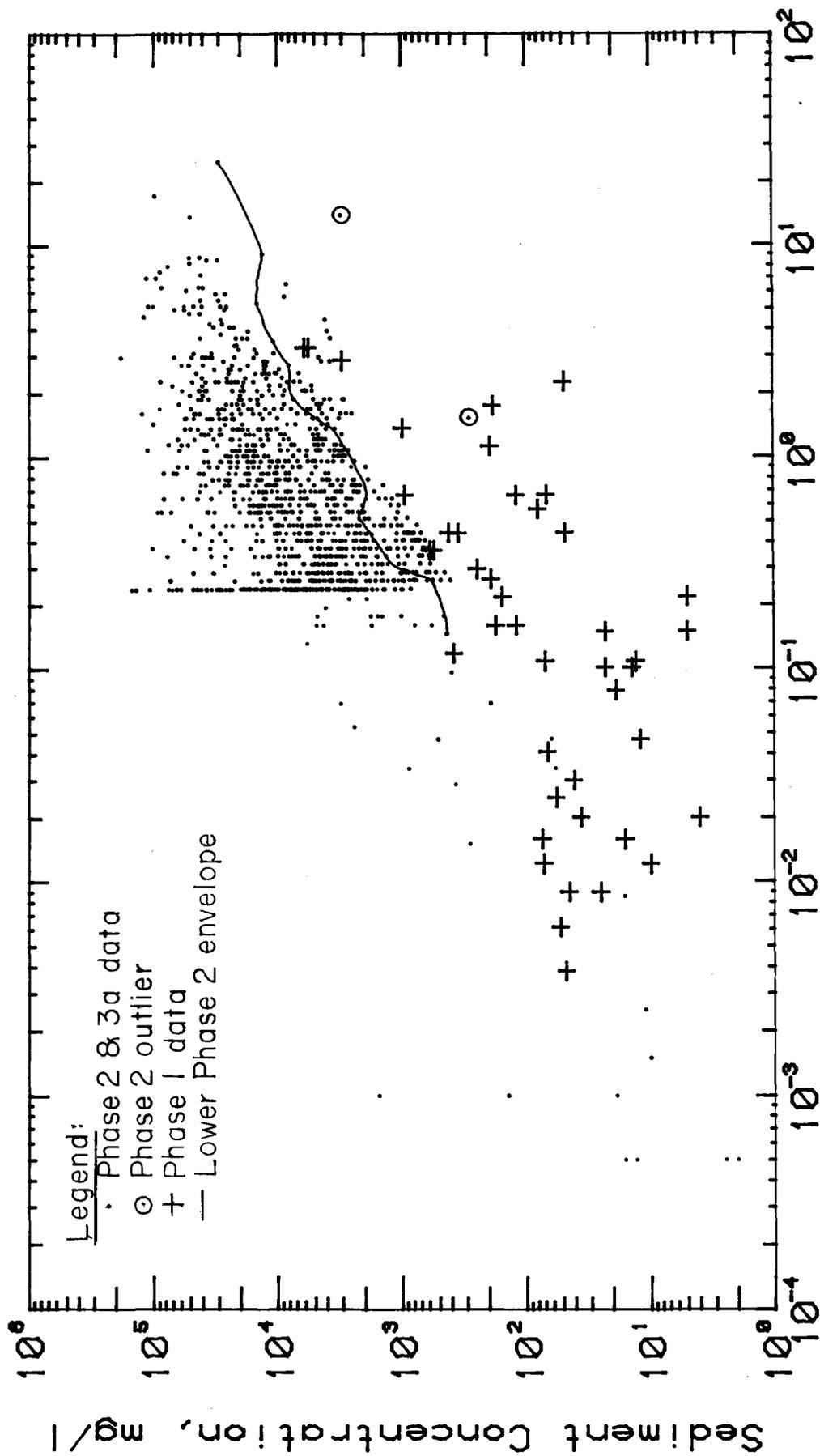
Regressions of sediment concentration upon flow rate were performed, using the logarithmic transformation of these variables. Data were grouped according

TABLE 34. - Period averages for Watershed J11 Phases 1, 2, and 3a using constrained sediment data sets

Phase/ Period	Number of Samples	<u>Sediment Concentration</u>		<u>Flow Rate</u>		<u>Load Rate</u>	
		Average (mg/l)	Ratio <sup>1</sup>	Average (iph)	Ratio <sup>1</sup>	Average (tons/day)	Ratio <sup>1</sup>
Phase 1	44	485	1.0	0.018	1.0	3.13	1.0
Phase 2							
a	5	4320	NC <sup>2</sup>	.029	NC	24.5	NC
b	4	2820	NC	.0022	NC	0.738	NC
c	32	12,700	26	.026	1.4	23.2	7.4
d	511	13,700	28	.033	1.8	39.9	13
e	51	8500	18	.045	2.5	34.7	11
Entire Phase 2	603	13,100	27	.033	1.8	38.2	12
Phase 3a	540	12,700	26	.025	1.4	37.2	12

<sup>1</sup>Ratios are with respect to Phase 1.

<sup>2</sup>NC - Not calculated due to small sample size.



Flow Rate, cfs

FIGURE 51. - Sediment concentration - flow rate data for Watershed J11.

TABLE 35. - Maximum sampled sediment concentrations and flows at Watershed J11

Item	Phase 1	Phase 2	Phase 3a
Maximum Sediment Concentrations, mg/l	6060	184,000	149,000
Associated Flow, cfs	3.29	2.97	.237
Load Rate, tons/day	53.8	1470	95.2
Date	4/14/80	6/25/81	5/28/82
Maximum Flow, cfs	3.29	25.0	17.2
Associated Sediment Concentrations, mg/l	6060	29,800	98,000
Load Rate, tons/day	53.8	2010	4550
Date	4/14/80	7/28/81	3/16/82

to position on the hydrograph at the time of sampling, source of runoff, and type of disturbance. The results showed that no practical improvements in the explainable variation of the sediment data were made by such groupings. The four highest coefficients of determination (0.83, 0.71, 0.56, 0.56) were found in falling limb groups.

A plot of the temporal variation of the ratios of the average monthly sediment concentrations, and flow and load rate to the respective maximum of each variable was constructed (Figure 50). The plot shows two short periods of deteriorating water quality (with respect to sediment concentration) when the vegetative cover over part of the watershed was sparse and gullies were active. Reclamation efforts during a short time between these two periods appeared to have improved water quality for a while. However, by grouping the data into periods by type of disturbance, and by computing for each period average sediment concentration, and flow and load rate, the apparent improvement in water quality at the beginning of Phase 3a was masked by the higher concentrations experienced at the end of Phase 3a, apparently as the diversion-channel system again deteriorated.

A comparison of Phases 2 and 3a showed that during Phase 2e, a period of reclamation efforts, the average period flow was greatest, but the average period concentration did not change much. Overall, Phase 3a concentrations were about the same as those of the entire Phase 2 period, but the flow was about 38% less than that of Phase 2, indicating that in fact a decrease in water quality occurred during the temporary Phase 3a reclamation period.

A comparison of Phases 1, 2, and 3a was made with data sets in which sampled flows greater than 3.3 cfs, the maximum premine sampled flow, were deleted. The results show that the average Phase 2 and Phase 3a concentrations were about 26 times and load rates 12 times those of Phase 1. However, the flow rates were 1.8 and 1.4 times that of Phase 1 for Phases 2 and 3a, respectively. The data suggest that the Phase 2 water quality was better than the Phase 3a water quality, but both were much worse than that of Phase 1.

The maximum measured Phases 1, 2, and 3a concentrations were 6060, 184,000, and 149,000 mg/l, respectively. The maximum Phases 2 and 3a concentrations were sampled in flows less than the maximum sampled flows for each period.

## REFERENCES

1. Bardsley, C. E. and J. D. Lancaster. Sulfur. In C. A. Black (ed.) *Methods of Soil Analysis, Part 2*, American Society of Agronomy, Madison, Wisconsin, v. 9, 1965, pp. 1102-1116.
2. Boulton, N. W. Analysis of Data from Nonequilibrium Pumping Tests Allowing for Delayed Yield from Storage. *Institute of Civil Engineers Proc.* v. 26, no. 6693, 1963, pp. 469-482.
3. Cooper, H. H., Jr., J. D. Bredehoeft, and I. S. Papadopoulos. Response of a Finite-Diameter Well to an Instantaneous Charge of Water. *Water Resources Research*, v. 3, no. 1, 1967, pp. 263-269.
4. Cooper, S. C. Ground-Water Quality Variations in a Small Watershed, Coshocton County, Ohio. M.S. Thesis, The Ohio State University, Columbus, 1982, 152 pp.
5. Federal Register. Office of Surface Mining Reclamation and Enforcement, Surface Coal Mining and Reclamation Operations. Proposed Rules for Permanent Regulatory Program, 1978, pp. 41661-41940.
6. Garbarino, J. R. and H. E. Taylor. An Inductively-Coupled Plasma Atomic-Emission Spectrometer Method for Routine Water Quality Testing. *Applied Spectroscopy*, v. 33, 1979, pp. 200-226.
7. Hamon, W. R. Computing Actual Precipitation. Proceedings Symposium on Distribution of Precipitation in Mountainous Areas, Geilo, Norway, 31 July - 5 August, 1972, WMO/OMM No. 326, World Meteorological Organization, Geneva, Switzerland, v. 1, 1972, pp. 159-175.
8. Hamon, W. R., Faz Haghiri, and Darwin Knochenmus. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Proceedings Fifth Symposium on Surface Mining and Reclamation: National Coal Association, Bituminous Coal Research Coal Conference and Expo IV, Louisville, Kentucky, October 18-20, 1977, pp. 37-40.
9. Hamon, W. R., J. V. Bonta, Faz Haghiri, and J. O. Helgesen. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining: I. Premining Hydrologic and Water Quality Conditions. Proceedings Symposium on Surface Coal Mining and Reclamation: Coal Conference and Expo V, Louisville, Kentucky, October 23-25, 1979, pp. 70-98.
10. Hatch, W. R. and W. L. Ott. Determination of Sub-Microgram Quantities of Mercury by Atomic Absorption Spectrophotometry. *Analytical Chemistry*, v. 40, 1968, pp. 2085-2087.
11. Helgesen, J. O. and A. C. Razem. Preliminary Observation of Surface-Mine Impacts on Ground Water in Two Small Watersheds in Eastern Ohio. Proceedings Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. Lexington, Kentucky, 1980, pp. 351-360.
12. Helgesen, J. O., S. P. Larson, and A. C. Razem. Model Modifications for Simulation of Flow Through Stratified Rocks in Eastern Ohio: U. S. Geological Survey Water-Resources Investigations 82-4019, 1982, 109 pp.

13. Hem, J. D. Study and Interpretation of the Chemical Characteristics of Natural Water. U. S. Geological Survey Water Supply Paper 1473, 1970, 363 pp.
14. Hjelmfelt, A. T. Curve-Number Procedure as Infiltration Method. Journal of Hydraulics Division, ASCE, v. 106, no. 6, 1980, pp. 1107-1111.
15. Hjelmfelt, A. T. Overland Flow from Time-Distributed Rainfall. Journal of the Hydraulics Division, ASCE, v. 107, no. HY-2, 1981, pp. 227-238.
16. Johnson, C. W., A. D. Copp, and E. R. Tinney. Drop-Box Weir for Sediment-Laden Flow Measurements. Journal of the Hydraulics Division, v. 95, no. HY5, 1966, pp. 165-190.
17. Lindstedt, G. A Rapid Method for the Determination of Mercury in Urine. Analyst, v. 95, 1970, pp. 264-271.
18. Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus. Applied Hydrology. McGraw-Hill Book Company, New York, 1949.
19. Soil Conservation Service. National Engineering Handbook, Section 4, Hydrology. U. S. Department of Agriculture, Washington, D.C., 1972.
20. Stiff, H. A. The Interpretation of Chemical Water Analysis by Means of Patterns. Journal of Petroleum Technology Techniques Notes, v. 84, no. 3, 1951, 15 pp.
21. U. S. Bureau of Mines. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Phase 1: Premining Hydrologic and Water Quality Conditions. U. S. Bureau of Mines Open-File Report 88-80, 1978, 347 pp.
22. U. S. Bureau of Mines. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Phase 1: Premining Hydrologic and Water Quality Conditions. Summary Report, Open-File Report 31-80, 1979, 40 pp.
23. U. S. Bureau of Mines. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Phase 2: Hydrologic and Water Quality Conditions During Mining and Reclamation in a Small Watershed in Coshocton County, Ohio. U. S. Bureau of Mines Open-File Report (In Press), 1982, 146 pp.
24. U. S. Bureau of Mines. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Phase 2: Hydrologic and Water Quality Conditions During Mining and Reclamation in a Small Watershed in Muskingum County, Ohio. U. S. Bureau of Mines Open-File Report (In Press), 1982, 138 pp.
25. U. S. Bureau of Mines. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Phase 3: Hydrologic and Water Quality Conditions After Reclamation in a Small, Mined Watershed, Coshocton County, Ohio. U. S. Bureau of Mines Open-File Report (In Press), 1983, 177 pp.

26. U. S. Bureau of Mines. Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining. Phase 3: Hydrologic and Water Quality Conditions After Reclamation in a Small, Mined Watershed, Muskingum County, Ohio. U. S. Bureau of Mines Open-File Report (In Press), 1983, 196 pp.

27. U. S. Department of Agriculture, Field Manual for Research in Agricultural Hydrology, Agricultural Handbook Number 224, 1979, 98 pp.

28. U. S. Environmental Protection Agency. National Interim Primary Drinking Water Regulations. EPA-570/9-76-003, 1977.

29. Weiss, J. C. Digital Model Analysis of the Effects of Strip Mining for Coal on Localized Ground-Water Flow Systems in Eastern Ohio. M.S. Thesis, The Ohio State University, Columbus, 1982, 56 pp.

APPENDIX

Field and Laboratory Reports  
for Sampled Soil Pedons Before  
Mining and After Reclamation

SOIL TYPE: HUNTERFIELD SILT LOAM COUNTY: JEFFERSON SITE: JF-3  
 PEDON CLASSIFICATION: FINE MIXED, MESIC, TYPIC, HUMID 9.  
 LOCATION: 200 FT. N. AND 200 FT. W. CENTER OF SEC. 34 T. 7N R. 3W  
 PHYSIOGRAPHY: SUMMIT ELEVATION: 1235'  
 TOPOGRAPHY: GENTLY SLOPING % SLOPE: 8 ASPECT: NW  
 DRAINAGE: WELL VEGETATION: PASTURE  
 COLLECTORS: AMBA/SMECK/HALL DATE: 7/31/78  
 PARENT MATERIALS: COLLUVIUM, SILTSTONE

HORIZON	DEPTH IN	DESCRIPTION
AP1	0-3	10YR4/3-SILT LOAM; STRONG MEDIUM GRANULAR STRUCTURE; VERY FRIABLE; MANY FINE ROOTS; 0% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
AP2	3-8	10YR4/3-SILT LOAM; MODERATE COARSE GRANULAR STRUCTURE; FRIABLE; COMMON FINE ROOTS; COMMON 10YR5/4 WORM CASTS IN CHANNELS; 5% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
B1	8-10	10YR5/5-SILT LOAM; MODERATE FINE SUBANGULAR BLOCKY PARTING TO WEAK MEDIUM PLATY STRUCTURE; FRIABLE; COMMON FINE ROOTS; 20% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B21T	10-17	10YR5/5-SILT LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE; COMMON FINE ROOTS; THIN VERY PATCHY 10YR4/6 ARGILLANS ON FACES; 20% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
B22T	17-22	10YR5/5-SILT LOAM; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; COMMON FINE ROOTS; THIN VERY PATCHY 10YR4/6 ARGILLANS ON FACES; FEW 10YR2/1 FERRO-MANGANS ON FACES; 20% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
IIB23T	22-26	10YR6/4-GRAVELLY SILT LOAM; FEW FINE FAINT 10YR5/6 AND FEW FINE FAINT 10YR6/3 MOTTLES; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; THIN VERY PATCHY 10YR5/6 ARGILLANS ON FACES; MEDIUM CONTINUOUS 10YR6/3 ARGILLANS SUBCUTANEOUSLY; FEW 10YR2/1 FERRO-MANGANS ON FACES; 40% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIB24T	26-32	10YR5/4-GRAVELLY LOAM; COMMON MEDIUM FAINT 10YR5/6 MOTTLES; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; MEDIUM PATCHY 10YR5/4 ARGILLANS ON FACES; MEDIUM CONTINUOUS 10YR6/3 ARGILLANS SUBCUTANEOUSLY; FEW 10YR2/1 FERRO-MANGANS ON FACES; 60% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIB25T	32-36	10YR5/4-GRAVELLY CLAY LOAM; COMMON MEDIUM FAINT 10YR5/6 AND COMMON MEDIUM DISTINCT 10YR5/2 MOTTLES; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; MEDIUM PATCHY 10YR5/4 ARGILLANS ON FACES; MEDIUM CONTINUOUS 10YR6/3 ARGILLANS SUBCUTANEOUSLY; FEW 10YR2/1 FERRO-MANGANS ON FACES; 75% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
IIB26T	36-44	10YR5/2-SILTY CLAY LOAM; MANY COARSE PROMINANT 10YR6/1 AND FEW FINE DISTINCT 10YR5/6 MOTTLES; STRONG MEDIUM ANGULAR BLOCKY STRUCTURE; FIRM; THIN CONTINUOUS 10YR6/4 ARGILLANS ON FACES; THIN CONTINUOUS 10YR6/1 ARGILLANS ON FACES; 5% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
IIB27T	44-49	10YR5/2-SILTY CLAY; COMMON MEDIUM FAINT 10YR6/1 AND COMMON MEDIUM PROMINANT 10YR5/6 MOTTLES; STRONG COARSE ANGULAR BLOCKY STRUCTURE; FIRM; THIN CONTINUOUS 10YR6/4 ARGILLANS ON FACES; THIN CONTINUOUS 10YR6/1 ARGILLANS ON FACES; 10% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
IIB31T	49-58	10YR5/4-SILTY CLAY LOAM; COMMON COARSE DISTINCT 10YR6/1 AND COMMON COARSE FAINT 10YR5/6 MOTTLES; WEAK MEDIUM PLATY STRUCTURE; FIRM; THIN VERY PATCHY 10YR6/4 ARGILLANS ON HORIZONTAL FACES; 5% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
IIB32	58-77	10YR5/4-SILTY CLAY LOAM; FEW FINE FAINT 10YR5/2 AND COMMON MEDIUM FAINT 10YR5/6 MOTTLES; WEAK MEDIUM PLATY STRUCTURE; FRIABLE; 10% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
R	77-	

NOTE: THE TOP MATERIAL IS LOESS INFLUENCED BY COLLUVIUM.

SOIL SERIES: WOODSFIELD  
SITE: JF-3

COUNTY: JEFFERSON  
DATE: 7/31/78

DEPTH IN	HORIZON	CO FRAG Z>2mm	PARTICLE SIZE DISTRIBUTION (%C <sub>2mm</sub> )										TEXT CLASS	
			VC.C		SAND				SILT			CLAY		
			M	FI	VF	TOT	FI	VF	TOT	FI	TOT			
0-3	AP1	12.0	6.2	1.2	4.0	7.4	18.8	47.0	12.3	61.3	4.5	19.7	SIL	
3-8	AP2	6.5	6.2	1.1	4.0	8.7	20.0	44.6	12.4	59.9	3.8	20.1	SIL	
8-10	B1	17.2	7.9	1.3	5.3	10.3	24.8	33.8	11.8	55.3	5.3	19.9	SIL	
10-17	B21T	17.8	7.1	1.5	5.4	9.4	23.4	36.8	10.5	54.1	6.1	22.5	SIL	
17-22	B22T	5.7	8.0	1.5	6.6	12.9	29.0	29.5	7.5	49.0	7.1	22.0	L	
22-26	IIB23T	32.2	8.9	1.5	6.9	16.0	33.3	27.0	7.7	47.8	4.8	18.9	L	
26-32	IIB24T	46.9	10.4	1.5	5.6	14.0	31.5	20.9	4.9	47.1	5.3	21.4	L	
32-36	IIB25T	20.1	12.7	2.0	8.4	17.3	40.4	18.8	6.5	32.5	10.5	27.1	CL	
36-44	IIB26T	10.4	6.5	0.9	1.7	3.0	12.1	31.2	17.8	37.7	15.0	50.2	C	
44-49	IIB27T	9.9	7.3	0.9	1.1	1.5	10.8	37.5	14.3	48.8	13.8	40.4	SIC	
49-58	IIB31T	9.0	9.4	1.4	1.7	4.3	16.8	39.8	12.1	60.1	6.4	23.1	SIL	
58-67	IIB32	18.0	9.6	1.2	2.4	9.6	22.8	35.0	12.5	56.1	5.6	21.1	SIL	
67-77	IIB32	50.9	8.3	1.3	4.3	13.4	27.3	33.5	12.9	53.1	5.3	19.6	SIL	

DEPTH IN	pH		ORG C	EQ.%			EXCH CATIONS MEQ/100s				BASE SAT.%	
	HAT	CaCl		CALC	DOLO	CARB	H	Ca	Mg	K		SUM
0-3	5.9	5.6	2.76				8.1	6.7	1.5	0.89	17.2	53
3-8	6.3	5.9	1.98				6.0	6.3	1.3	0.58	14.2	58
8-10	5.3	4.8	0.42				4.6	3.2	0.8	0.34	8.9	49
10-17	4.7	4.2	0.29				7.0	2.3	0.8	0.24	10.3	32
17-22	4.6	4.1	0.21				7.2	2.6	0.9	0.19	10.9	34
22-26	4.7	4.2	0.20				6.6	2.9	1.0	0.17	10.7	38
26-32	4.7	4.1	0.10				7.4	3.3	1.7	0.16	12.6	41
32-36	4.7	4.2	0.13				7.3	4.9	2.9	0.20	15.3	52
36-44	4.7	4.3	0.15				6.7	8.7	5.3	0.31	21.0	68
44-49	5.8	5.6	0.24				2.3	8.2	4.6	0.31	15.4	85
49-58	6.7	6.3	0.11				2.2	6.4	3.2	0.20	12.0	82
58-67	6.9	6.5	0.04				2.3	8.3	3.5	0.20	14.3	84
67-77	7.0	6.7	0.09				2.0	7.2	2.7	0.18	12.1	83

SOIL TYPE: WESTMORELAND SILT LOAM COUNTY: JEFFERSON SITE: JF-4  
 PEDON CLASSIFICATION: COARSE-LOAMY MIXED MESIC ULTIC HAPLUDALF  
 LOCATION: 270 FT. N. AND 810 FT. W. OF CENTER OF SEC. 34 T. 7N R. 3W  
 PHYSIOGRAPHY: SIDESLOPE, BACKSLOPE ELEVATION: 1217'  
 TOPOGRAPHY: STRONGLY SLOPING % SLOPE: 24 ASPECT: NW  
 DRAINAGE: WELL VEGETATION: PASTURE  
 COLLECTORS: AMBA/SMECK/HALL DATE: 7/31/78  
 PARENT MATERIALS: COLLUVIUM, SILTSTONE

HORIZON	DEPTH IN	
AP1	0-3	10YR4/3-SILT LOAM; STRONG FINE GRANULAR STRUCTURE; VERY FRIABLE; MANY FINE ROOTS; 5% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
AP2	3-7	10YR4/3-SILT LOAM; COMMON MEDIUM DISTINCT 10YR4/4 MOTTLES; MODERATE MEDIUM GRANULAR STRUCTURE; FRIABLE; COMMON FINE ROOTS; 10% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
B1	7-10	10YR4/4-SILT LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE; COMMON FINE ROOTS; COMMON 10YR4/3 WORM CASTS IN PORES; 20% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B21T	10-15	10YR4/4-LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; COMMON FINE ROOTS; THIN VERY PATCHY 10YR4/4 ARGILLANS ON FACES; 25% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
IIB22T	15-20	10YR4/4-LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; COMMON FINE ROOTS; THIN VERY PATCHY 10YR4/4 ARGILLANS ON FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 40% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
IIB23T	20-27	10YR4/4-LOAM; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; THIN PATCHY 10YR4/4 ARGILLANS ON FACES; FEW 10YR2/1 FERRO-MANGANS ON FACES; 75% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
IIB24T	27-32	10YR5/4-SILTY CLAY LOAM; FEW FINE FAINT 10YR5/6 AND FEW FINE FAINT 10YR5/1 MOTTLES; MODERATE COARSE SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; THIN VERY PATCHY 10YR4/4 ARGILLANS ON FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 25% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIIB25T	32-42	10YR5/4-SILTY CLAY LOAM; FEW MEDIUM FAINT 10YR5/6 AND FEW FINE FAINT 10YR5/1 MOTTLES; MODERATE COARSE SUBANGULAR BLOCKY STRUCTURE; FIRM; MEDIUM CONTINUOUS 10YR5/4 ARGILLANS ON FACES; FEW 10YR2/1 FERRO-MANGANS ON FACES; 10% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIIB26T	42-55	10YR5/4-SILTY CLAY LOAM; FEW MEDIUM FAINT 10YR5/6 AND COMMON MEDIUM FAINT 10YR5/4 MOTTLES; MODERATE COARSE SUBANGULAR BLOCKY STRUCTURE; FIRM; MEDIUM CONTINUOUS 10YR5/4 ARGILLANS ON FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 25% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIIB3T	55-70	2.5Y5/4-CLAY LOAM; WEAK MEDIUM PLATY STRUCTURE; FIRM; MEDIUM PATCHY 10YR4/4 COATINGS ON HORIZONTAL FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 60% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
R	70-80	5Y5/3-CLAY LOAM; MEDIUM PATCHY 10YR5/4 COATINGS ON ROCK FRAGMENTS;

NOTE: UPPER PART IS LOESS/COLLUVIUM..C.FRAGS ARE II-SANDST.III-SILTSTONE. TAXADJUNCT.;

SOIL SERIES: WESTMORELAND  
 SITE: JF-4

COUNTY: JEFFERSON  
 DATE: 7/31/78

DEPTH IN	HORIZON	CO FRAG >2mm	PARTICLE SIZE DISTRIBUTION (%<2mm)									TEXT CLASS	
			SAND			SILT			CLAY				
			VC.C	M	FI	VFI	TOT	FI	VF	TOT	FI		TOT
0-3	A1	12.5	8.0	1.5	5.7	8.0	23.2	42.8	10.9	57.9	4.1	18.9	SIL
3-7	A2	5.2	7.9	1.4	5.0	5.9	20.2	45.0	13.0	68.2	1.6	11.6	SIL
7-10	B1	9.4	8.1	1.6	6.3	8.6	24.6	41.5	11.8	60.9	1.9	14.5	SIL
10-15	B21T	15.3	8.8	1.6	6.9	10.2	27.5	36.8	10.6	54.6	3.8	17.9	SIL
15-20	II B22T	22.4	12.1	2.5	10.8	13.0	38.4	28.7	8.2	44.5	3.9	17.1	L
20-27	II B23T	59.9	13.4	3.5	16.8	13.7	47.4	24.4	7.3	35.4	4.4	17.2	L
27-32	II B24T	25.4	5.9	1.3	5.5	11.1	23.8	32.6	10.1	55.5	4.2	20.7	SIL
32-42	III B25T	31.1	3.1	0.8	2.2	6.1	12.2	37.8	12.3	63.7	5.4	24.1	SIL
42-55	III B26T	35.8	5.1	0.9	3.5	10.1	19.6	33.4	10.8	57.1	6.4	23.3	SIL
55-62	III B3T	49.9	10.8	4.4	18.1	16.5	49.8	18.8	6.3	33.5	5.3	16.7	L
62-70	III B3T	62.6	5.7	0.5	1.1	7.3	14.6	39.4	12.6	65.0	4.5	20.4	SIL
70-80	R	83.9	0.4	0.0	0.3	1.8	2.5	54.0	18.2	76.5	4.0	21.0	SIL

DEPTH IN	pH		ORG C	EQ. %			EXCH CATIONS MEQ/100g				BASE SAT. %	
	WAT	CaCl		CALC	DOLO	CARB	H	Ca	Mg	K		SUM
0-3	6.4	6.0	1.83				5.8	7.4	1.6	0.41	15.2	62
3-7	7.1	6.4	1.42				3.6	6.8	1.3	0.30	12.0	70
7-10	7.3	6.8	0.92				3.1	6.3	1.2	0.27	10.9	71
10-15	7.1	6.6	0.34				2.7	4.4	1.1	0.15	8.3	68
15-20	7.0	6.5	0.26				3.0	4.4	1.2	0.14	8.7	66
20-27	6.3	5.9	0.17				3.1	4.1	1.1	0.12	8.4	63
27-32	5.2	4.7	0.13				4.2	5.2	1.6	0.17	13.2	53
32-42	4.8	4.4	0.11				8.1	5.4	3.2	0.21	16.9	52
42-55	4.9	4.5	0.16				8.3	5.3	4.1	0.20	17.9	54
55-62	5.0	4.5	0.12				6.4	4.6	3.5	0.17	14.7	56
62-70	5.1	4.6	0.13				6.2	5.8	4.8	0.21	17.0	64
70-80	5.1	4.7	0.15				4.5	7.0	4.8	0.29	16.6	73

SOIL TYPE: CLARKSBURG SILT LOAM COUNTY: JEFFERSON SITE: JF-5  
 PEDON CLASSIFICATION: FINE-LOAMY, MIXED, MESIC, AQUIC, FRAGIUDALF.  
 LOCATION: 470 FT. N. AND 825 FT. W. OF CENTER, SEC. 34 T. 7N R. 3W  
 PHYSIOGRAPHY: SIDESLOPE, FOOTSLLOPE ELEVATION: 1180  
 TOPOGRAPHY: STRONGLY SLOPING % SLOPE: 18 ASPECT: NW  
 DRAINAGE: MODERATELY WELL VEGETATION: PASTURE  
 COLLECTORS: AMBA/SPECK/HALL DATE: 8/1/78  
 PARENT MATERIALS: COLLUVIUM, SHALE

HORIZON	DEPTH IN	
AP1	0-3	10YR4/3-SILT LOAM; STRONG MEDIUM GRANULAR STRUCTURE; VERY FRIABLE; 5% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
AP2	3-8	10YR4/3-SILT LOAM; FEW MEDIUM DISTINCT 10YR5/4 MOTTLES; MODERATE FINE SUBANGULAR BLOCKY STRUCTURE; FRIABLE; MANY FINE ROOTS; 10% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
B1	8-10	10YR5/4-SILT LOAM; MODERATE FINE SUBANGULAR BLOCKY STRUCTURE; FRIABLE; COMMON FINE ROOTS; COMMON 10YR4/3 WORM CASTS ON FACES; 20% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B21T	10-14	10YR5/4-HEAVY SILT LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE; COMMON FINE ROOTS; THIN PATCHY 10YR4/4 ARGILLANS ON FACES; 30% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B22T	14-20	10YR5/6-CLAY LOAM; FEW FINE FAINT 7.5YR5/6 AND FEW FINE DISTINCT 10YR5/2 MOTTLES; MODERATE COARSE SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; MEDIUM PATCHY 10YR4/4 ARGILLANS ON FACES; FEW 10YR2/1 FERRO-MANGANS ON FACES; 45% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B23T	20-27	10YR5/5-CLAY LOAM; MANY FINE FAINT 7.5YR5/6 AND FEW FINE DISTINCT 10YR5/2 MOTTLES; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE; FEW FINE ROOTS; MEDIUM PATCHY 10YR4/4 ARGILLANS ON FACES; MANY 10YR2/1 FERRO-MANGANS ON FACES; 25% COARSE FRAGMENTS; CLEAR WAVY BOUNDARY.
IIBX1	20-27	10YR4/4-CLAY LOAM; MANY FINE DISTINCT 5YR5/6 AND COMMON FINE DISTINCT 10YR5/2 MOTTLES; WEAK VERY COARSE PRISMATIC PARTING TO MODERATE MEDIUM PLATY STRUCTURE; BRITTLE; THICK CONTINUOUS 2.5Y6/3 SILTANS ON VERTICAL FACES; MANY 10YR2/1 FERRO-MANGANS ON FACES; 20% COARSE FRAGMENTS; CLEAR WAVY BOUNDARY.
IIBX2	27-34	2.5Y5/4-SILTY CLAY LOAM; FEW FINE PROMINANT 5YR5/6 AND MANY MEDIUM DISTINCT 10YR5/1 MOTTLES; WEAK VERY COARSE PRISMATIC PARTING TO WEAK COARSE SUBANGULAR BLOCKY STRUCTURE; BRITTLE; MEDIUM PATCHY 5YR4/4 ARGILLANS ON FACES; MANY 10YR2/1 FERRO-MANGANS ON FACES; THICK CONTINUOUS 2.5Y6/3 SILTANS ON VERTICAL FACES; 40% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIBX3	34-43	10YR5/4-SILTY CLAY LOAM; COMMON FINE PROMINANT 5YR4/6 AND FEW FINE PROMINANT 10YR5/1 MOTTLES; WEAK VERY COARSE PRISMATIC PARTING TO WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; BRITTLE; MANY 10YR2/1 FERRO-MANGANS ON FACES; MEDIUM CONTINUOUS 10YR5/2 SILTANS ON VERTICAL FACES; THICK CONTINUOUS 10YR5/1 ARGILLANS ON VERTICAL FACES; 40% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIC1	43-51	10YR4/4-SILTY CLAY LOAM; MANY MEDIUM PROMINANT 5YR4/6 AND FEW FINE DISTINCT 10YR5/1 MOTTLES; MASSIVE; FIRM; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 35% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
IIIC2	51-58	N2/0-CLAY LOAM; MASSIVE; FIRM; 0% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
IVC3	58-64	10YR5/4-CLAY; FEW MEDIUM DISTINCT 10YR5/1 AND FEW FINE FAINT 10YR5/6 MOTTLES; MASSIVE; FIRM; MANY 10YR2/1 FERRO-MANGANS ON FACES; 0% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
VC4	64-72	2.5Y5/4-CLAY; FEW COARSE DISTINCT 10YR5/6 AND FEW COARSE DISTINCT 10YR5/2 MOTTLES; MASSIVE; FIRM; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 0% COARSE FRAGMENTS; STRONG EFFERVESCENCE; ABRUPT SMOOTH BOUNDARY.
VCS	72-→	10YR5/4-CLAY; COMMON MEDIUM FAINT 2.5Y5/4 AND FEW COARSE DISTINCT 10YR5/6 MOTTLES; MASSIVE; FIRM; 0% COARSE FRAGMENTS; SLIGHT EFFERVESCENCE; GRADUAL SMOOTH BOUNDARY.

NOTE: TAXAD. ... SEEM OF COAL 51-58 INCHES. STONELINE AT 27 INCHES.

SOIL SERIES: CLARKSBURG  
 SITE: JF-5

COUNTY: JEFFERSON  
 DATE: 8/1/78

DEPTH IN	HORIZON	CO	FRAG >2mm	PARTICLE SIZE DISTRIBUTION (%<2mm)										TEXT CLASS
				SAND				SILT			CLAY			
				VC.C	M	FI	VFI	TOT	FI	VF	TOT	FI	TOT	
0- 3	AP1	0.6	4.1	1.3	4.2	3.7	13.3	48.3	11.6	62.9	6.5	23.8	SIL	
3- 8	AP2	2.8	4.3	1.4	4.6	4.2	14.5	51.9	15.6	69.8	3.0	15.7	SIL	
8- 10	B1	3.2	5.2	1.3	4.1	3.5	14.1	42.7	12.5	62.8	6.6	23.1	SIL	
10- 14	B21T	8.3	5.8	1.6	5.4	4.5	17.3	38.7	10.2	59.1	7.8	23.6	SIL	
14- 20	B22T	6.0	5.4	1.8	6.3	5.1	18.6	32.1	6.9	55.2	11.3	26.2	SIL	
20- 27	B23T	3.0	4.6	1.9	7.3	6.4	20.2	30.9	6.8	54.5	10.2	25.3	SIL	
20- 27	IIBX1	3.9	6.1	2.2	8.3	7.7	24.3	29.0	6.5	50.9	10.5	24.8	SIL	
27- 34	IIBX2	9.5	5.4	1.5	5.9	9.4	22.2	30.9	9.9	49.9	9.4	27.9	CL	
34- 43	IIBX3	8.2	6.2	1.7	6.9	10.2	25.0	26.7	9.8	48.1	8.2	26.9	L	
43- 51	IIC1	11.8	10.5	1.3	3.5	7.3	22.6	28.3	8.9	51.4	6.9	26.0	SIL	
51- 58	IIC2	0.0	4.4	4.0	16.5	9.4	34.3	28.0	9.7	34.5	11.1	31.2	CL	
58- 64	IVC3	0.0	0.1	0.2	3.3	4.6	8.2	27.7	9.6	37.0	27.6	54.8	C	
64- 72	VCA	0.0	1.1	0.1	0.6	1.0	2.8	45.9	18.4	55.5	12.6	41.7	SIC	
72- 82	VCS	2.6	2.5	0.5	1.3	2.2	6.5	56.0	23.4	61.3	6.5	32.2	SICL	

DEPTH IN	PH		ORG C	EQ. %			EXCH CATIONS MEQ/100s				BASE SAT. %	
	WAT	CaCl		CALC	DOLO	CARB	H	Ca	Mg	K		SUM
0- 3	5.9	5.4	2.18				7.2	7.0	1.4	0.86	16.5	56
3- 8	6.3	5.8	1.20				5.4	5.7	1.2	0.42	12.7	58
8- 10	6.3	5.8	0.38				4.3	5.3	1.4	0.22	11.2	62
10- 14	5.9	5.4	0.31				4.5	5.7	1.5	0.18	11.9	62
14- 20	4.9	4.4	0.28				7.2	4.8	1.3	0.19	13.5	47
20- 27	4.5	4.0	0.18				9.6	3.3	1.2	0.18	14.3	33
20- 27	4.4	3.9	0.17				10.7	3.0	1.4	0.20	15.3	30
27- 34	4.4	3.9	0.12				12.0	3.3	1.3	0.19	16.8	29
34- 43	4.4	3.9	0.12				10.5	4.0	1.5	0.18	16.2	35
43- 51	4.7	4.3	0.35				7.6	6.0	1.6	0.16	15.4	51
51- 58	5.9	5.4	22.99				32.5	50.1	8.4	0.27	91.3	64
58- 64	6.9	6.8	0.39				2.1	19.2	4.0	0.54	25.8	92
64- 72	8.0	7.6		13.0	1.5	14.6						
72- 82	7.8	7.5		2.7	2.1	4.9						

The control section was considered to be between 10 and 27 inches  
 Weighted average SAND: 14.6 SILT: 60.4 CLAY: 25

SOIL TYPE: CULLEOKA SILT LOAM COUNTY: JEFFERSON SITE: JF-6  
 PEDON CLASSIFICATION: FINE-LOAMY, MIXED, MESIC, TYPIC, HAPLUDALF.  
 LOCATION: 1050' N. AND 900' W. OF CENTER OF SEC. 34 T. 7N R. 3W  
 PHYSIOGRAPHY: SIDESLOPE, SHOULDER ELEVATION: 1160'  
 TOPOGRAPHY: MODERATELY SLOPING % SLOPE: 9 ASPECT: SOUTHWEST  
 DRAINAGE: WELL VEGETATION: PASTURE  
 COLLECTORS: SNECK/HALL/AMBA DATE: 8/1/78  
 PARENT MATERIALS: COLLUVIUM

HORIZON	DEPTH IN	
AP1	0 -2	10YR4/3-SILT LOAM; STRONG MEDIUM GRANULAR STRUCTURE; VERY FRIABLE; MANY FINE ROOTS; 10% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
AP2	2 -6	10YR4/3-SILT LOAM; COMMON MEDIUM DISTINCT 10YR5/4 MOTTLES; MODERATE FINE SUBANGULAR BLOCKY PARTING TO MODERATE COARSE GRANULAR STRUCTURE; FRIABLE; COMMON FINE ROOTS; 15% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
B1	6 -9	10YR5/4-SILT LOAM; FEW FINE FAINT 10YR5/6 MOTTLES; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE; COMMON FINE ROOTS; COMMON 10YR4/3 WORM CASTS IN PORES; 10% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B21T	9 -18	10YR5/6-SILT LOAM; FEW FINE FAINT 7.5YR5/6 MOTTLES; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; COMMON FINE ROOTS; THIN PATCHY 10YR5/4 ARGILLANS ON FACES; FEW 10YR2/1 FERRO-MANGANS ON FACES; 25% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B22T	18-25	10YR5/6-LOAM; COMMON MEDIUM FAINT 7.5YR5/6 MOTTLES; WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; THIN PATCHY 7.5YR5/4 ARGILLANS ON FACES; MEDIUM CONTINUOUS 10YR6/3 SILANS ON VERTICAL FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 37% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
IIB23T	25-32	7.5YR5/6SILTY CLAY LOAM; MANY COARSE PROMINANT 5Y6/1 MOTTLES; MASSIVE; FIRM; FEW FINE ROOTS; MEDIUM PATCHY 10YR6/3 SILANS ON VERTICAL FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 55% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
IIB24T	32-39	7.5YR5/6-SILTY CLAY LOAM; MANY COARSE PROMINANT 5Y6/1 MOTTLES; MASSIVE; FIRM; THIN PATCHY 10YR6/3 SILANS ON VERTICAL FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 60% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
IIB3T	39-48	2.5Y5/4-GRAVELLY SILTY CLAY LOAM; MANY MEDIUM PROMINANT 7.5YR5/6 MOTTLES; MASSIVE; FIRM; THICK CONTINUOUS 10YR6/1 COATINGS ON FACES; MANY 10YR2/1 FERRO-MANGANS ON FACES; 90% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.

NOTE: SOLID ROCK AT 30 INCHES THE MATERIAL DESCRIBED FILLED JOINTS.

SOIL SERIES: CULLEOKA  
SITE: JF-6

COUNTY: JEFFERSON  
DATE: 8/1/78

DEPTH IN	HORIZON	CO FRAG >2mm	PARTICLE SIZE DISTRIBUTION (%<2mm)										TEXT CLASS	
			VC.C	M	SAND			SILT			CLAY			
					FI	VFI	TOT	FI	VF	TOT	FI	TOT		
0-	2	AP1	7.2	5.1	0.9	3.2	3.8	13.0	46.7	10.2	69.2	5.5	17.8	SIL
2-	6	AP2	12.0	5.2	1.2	3.6	3.3	13.3	46.1	11.4	74.1	2.4	12.6	SIL
6-	9	B1	1.3	3.0	0.7	2.2	3.0	8.9	42.7	9.7	71.4	6.2	19.7	SIL
9-	18	B21T	6.0	5.5	1.1	3.3	4.7	14.6	33.1	7.0	61.5	9.9	23.9	SIL
18-	25	B22T	47.4	8.6	1.3	5.4	8.0	23.3	30.7	6.7	52.3	9.5	24.4	SIL
25-	32	IIB23T	33.6	6.4	1.4	5.8	10.5	24.1	29.0	8.0	49.0	10.7	26.9	L
32-	39	IIB24T	34.0	7.9	1.1	4.1	10.8	23.9	29.2	8.7	50.6	8.3	25.5	SIL
39-	48	IIB3T	37.1	9.3	0.8	1.5	5.5	17.1	38.7	10.5	58.9	6.5	24.0	SIL

DEPTH IN	pH		ORG C	EQ. %			EXCH CATIONS MEQ/100g				BASE SAT. %		
	WAT	CaCl		CALC	DOLO	CARB	H	Ca	Mg	K		SUM	
0-	2	6.8	6.4	1.97				2.8	9.2	1.6	0.16	13.3	80
2-	6	7.0	6.6	1.04				2.6	6.8	1.0	0.12	10.5	73
6-	9	6.8	6.4	0.36				2.7	6.2	0.9	0.14	9.9	73
9-	18	6.4	5.9	0.28				3.9	7.4	1.2	0.21	12.7	69
18-	25	4.9	4.4	0.18				8.1	5.0	1.4	0.22	14.7	45
25-	32	4.7	4.3	0.12				8.6	6.6	2.8	0.27	18.3	53
32-	39	4.9	4.5	0.13				6.8	8.2	3.4	0.24	18.6	64
39-	48	6.2	5.9	0.13				3.7	11.3	4.1	0.21	19.3	81

SOIL TYPE: WESTMORELAND SILT LOAM COUNTY: JEFFERSON SITE: JF-7  
 PEDON CLASSIFICATION: FINE-LOAMY MIXED MESIC ULTIC HAPLUDALF.  
 LOCATION: 1100 FT. N. AND 500 FT. W. OF CTR. OF SEC. 34 T. 7N R. 3W  
 PHYSIOGRAPHY: HEADSLOPE, BACKSLOPE ELEVATION: 1210'  
 TOPOGRAPHY: MODERATELY SLOPING % SLOPE: 19 ASPECT: SOUTHWEST  
 DRAINAGE: WELL VEGETATION: PASTURE  
 COLLECTORS: HALL/NORTON/LAMB DATE: 8/1/79  
 PARENT MATERIALS: COLLUVIUM

HORIZON	DEPTH IN	
AP1	0 -2	10YR4/3-SILT LOAM; MODERATE MEDIUM GRANULAR STRUCTURE; FRIABLE; MANY FINE ROOTS; 5% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
AP2	2 -6	10YR4/3-SILT LOAM; WEAK FINE SUBANGULAR BLOCKY PARTING TO WEAK FINE GRANULAR STRUCTURE; FRIABLE; COMMON FINE ROOTS; FEW 10YR5/5 NODULES IN THE MATRIX; 5% COARSE FRAGMENTS; ABRUPT SMOOTH BOUNDARY.
B1T	6 -11	10YR5/5-SILT LOAM; WEAK MEDIUM SUBANGULAR BLOCKY PARTING TO WEAK FINE SUBANGULAR BLOCKY STRUCTURE; FIRM; COMMON FINE ROOTS; COMMON 10YR4/3 WORM CASTS IN THE MATRIX; 10% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B21T	11-16	10YR5/5-CHANNERY LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; COMMON FINE ROOTS; THIN PATCHY 10YR5/4 COATINGS ON FACES; FEW 10YR2/1 FERRO-MANGANS ON FACES; 20% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B22T	16-24	10YR5/5-CHANNERY LOAM; MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; THIN PATCHY 10YR5/4 COATINGS ON FACES; MANY 10YR2/1 FERRO-MANGANS ON FACES; 40% COARSE FRAGMENTS; CLEAR SMOOTH BOUNDARY.
B3T	24-33	10YR5/4-CHANNERY LOAM; FEW FINE DISTINCT 7.5YR5/6 AND FEW FINE DISTINCT 10YR5/2 MOTTLES; WEAK COARSE SUBANGULAR BLOCKY STRUCTURE; FIRM; FEW FINE ROOTS; THIN PATCHY 7.5YR5/4 ARGILLANS ON FACES; COMMON 10YR2/1 FERRO-MANGANS ON FACES; 60% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
C1	33-51	10YR5/6-CHANNERY SANDY LOAM; FEW MEDIUM DISTINCT 7.5YR5/6 MOTTLES; MASSIVE; FRIABLE; 80% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.
C2	51-68	10YR5/6-CHANNERY SANDY LOAM; FEW MEDIUM DISTINCT 7.5YR5/6 MOTTLES; MASSIVE; FRIABLE; 80% COARSE FRAGMENTS; GRADUAL SMOOTH BOUNDARY.

NOTE: THE COARSE FRAGMENTS ARE WEAKLY CEMENTED SANDSTONE.

SOIL SERIES: WESTMORELAND  
 SITE: JF-7

COUNTY: JEFFERSON  
 DATE: 8/1/78

DEPTH IN	HORIZON	CO FRAG X>2mm	PARTICLE SIZE DISTRIBUTION (%<2mm)										TEXT CLASS	
			VC	C	M	SAND		SILT		CLAY				
						FI	VFI	TOT	FI	VF	TOT	FI	TOT	
0-	2	AP1	1.4	2.3	2.7	1.4	2.3	8.7	53.6	13.0	68.5	5.3	22.8	SIL
2-	6	AP2	2.3	2.9	0.8	2.1	2.5	8.3	59.7	16.4	77.8	1.9	13.9	SIL
6-	11	B1T	38.1	4.8	0.8	2.4	6.3	14.3	47.8	13.1	67.5	2.2	18.2	SIL
11-	16	B21T	52.1	11.9	1.5	4.7	10.1	28.2	34.3	11.2	51.3	4.4	20.5	SIL
16-	24	B22T	44.8	10.8	2.8	9.1	13.5	36.2	25.7	8.4	43.6	5.6	20.2	L
24-	33	B3T	51.0	20.0	9.0	25.3	9.1	63.4	16.7	5.2	23.2	4.3	13.4	SL
33-	41	C1	46.3	20.7	9.7	27.2	9.3	66.9	14.7	5.6	20.2	4.0	12.9	SL
41-	51	C1	56.2	23.5	11.0	27.4	7.2	69.1	14.5	6.5	19.5	3.0	11.4	SL
51-	68	C2	29.7	27.5	14.1	28.1	4.8	74.5	11.0	4.5	14.6	3.0	10.9	CSL

DEPTH IN	PH		ORG C	EQ. %			EXCH CATIONS MEQ/100g				BASE SAT. %		
	HAT	CaCl		CALC	DOLO	CARB	H	Ca	Mg	K		SUM	
0-	2	6.4	6.2	2.61				5.5	8.8	1.9	0.47	16.7	67
2-	6	7.1	6.6	1.13				3.0	7.4	1.0	0.45	11.9	75
6-	11	6.7	6.0	0.53				4.0	5.8	1.0	0.33	11.1	64
11-	16	5.6	5.0	0.33				5.6	5.7	1.2	0.26	12.8	56
16-	24	4.8	4.3	0.15				8.4	3.7	1.1	0.23	13.4	37
24-	33	4.9	4.3	0.09				4.9	2.9	1.4	0.18	9.4	48
33-	41	5.0	4.4	0.07				4.0	2.6	1.5	0.18	8.3	52
41-	51	5.1	4.6	0.09				2.9	2.4	1.4	0.15	6.9	58
51-	68	5.2	4.7	0.10				2.5	2.1	1.2	0.14	5.9	58

SOIL TYPE: Bethesda clay loam                      COUNTY: Jefferson                      SITE: JF-8  
 PEDON CLASSIFICATION: loamy-skeletal mixed acid mesic Typic Udorthent  
 LOCATION: Section 34, Mt. Pleasant Twp.  
 PHYSIOGRAPHY: headslope, backlope                      ELEVATION: 1180                      DATE: 9/28/82  
 TOPOGRAPHY: strongly sloping                      % SLOPE: 16                      ASPECT: SW  
 DRAINAGE: well                      VEGETATION: pasture  
 COLLECTORS: Sneek/Hall/Jaynes  
 PARENT MATERIALS: sandstone and shale

<u>HORIZON</u>	<u>DEPTH IN</u>	
A1	0-6	10YR 5/4-clay loam; few medium faint 10YR 5/6 mottles; moderate medium angular blocky parting to moderate fine angular blocky structure; friable; common fine roots; 15% coarse fragments; pH 5.6; clear wavy boundary.
A2	6-11	10YR 5/4-clay loam; few medium faint 10YR 5/6 mottles; massive parting to platy structure; firm; common fine roots; 15% coarse fragments; pH 5.6; abrupt wavy boundary.
C1	11-17	30% 10YR 5/4; 25% 10YR 4/2; 20% 10YR 6/6; 15% 10YR 5/6; 10% 10YR 4/1-loam; massive; firm; few fine roots; 60% coarse fragments; pH 5.4; clear wavy boundary.
C2	17-29	70% 10YR 6/6; 30% 10YR 4/2-loam; few fine faint 10YR 5/6 mottles; massive; firm; 40% coarse fragments; pH 5.1; abrupt wavy boundary.
C3	29-35	60% 10YR 5/4; 30% 5Y 4/1; 10% N/2-loam; few medium distinct 10YR 5/6 and few medium faint 5Y 4/2 mottles; massive; firm; 20% coarse fragments; pH 6.4; abrupt wavy boundary.
C4	35-48	50% 10YR 5/4; 50% N/2-loam; few medium faint 10YR 5/6 and few medium distinct 5Y 5/2 mottles; massive; firm; 25% coarse fragments; pH 5.2; clear wavy boundary.
C5	48-60	60% 10YR 5/4; 25% 5Y 5/2; 5% N/2; 5% 10YR 5/6; 5% 10YR 6/4-loam; massive; firm; 50% coarse fragments; pH 5.2;

NOTE: In the sixth horizon (35-48), the material occurs as bands. In the surface horizon, the platy structure is the result of compaction. Some true mottling is present in this profile, but most of the colors are due to the various colors of the materials that were mixed together when the land was reclaimed. This soil was described on watershed J11 as part of the stripmine reclamation study Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining sponsored by the U.S. Bureau of Mines.

SOIL SERIES: Bethesda  
SITE: JF-8

COUNTY: Jefferson  
DATE: 9/28/81

OSU LAB. NUMBERS: 24732 - 24737

DEPTH	HORIZON	CO. FRAG. >2mm	PARTICLE SIZE DISTRIBUTION (% < 2mm)										TEXT. CLASS			
			SAND			SILT (um)				CLAY (um)						
in			VC	C	M	F	VF	TOTAL	50-20	20-5	5-2	TOTAL	2-.2	<.2	TOTAL	
0- 11	A1	19.5	1.2	2.4	2.4	9.0	7.5	22.5	16.0	27.2	9.9	53.1	18.7	5.7	24.4	SIL
11- 17	C1	37.9	2.9	5.6	9.8	23.9	6.9	49.1	11.0	14.9	8.1	34.0	9.8	7.1	16.9	L
17- 29	C2	39.8	4.1	4.6	4.3	14.0	9.0	36.0	13.7	22.5	9.0	45.2	12.6	6.2	18.8	L
29- 35	C3	26.1	3.5	4.9	6.2	15.0	6.9	36.5	11.8	22.7	9.5	44.0	11.2	8.3	19.5	L
35- 48	C4	25.7	2.2	5.2	6.7	20.0	10.0	44.1	8.2	19.4	9.5	37.1	11.3	7.5	18.8	L
48- 60	C5	42.4	2.0	5.5	8.3	21.6	8.6	46.0	10.3	17.6	8.9	36.8	10.6	6.6	17.2	L

DEPTH	1:1	.01M	ORG.	CAL-	DOLO-	CARB-	EXTRACTABLE CATIONS					BASE	-E.C.-	TOTAL	
	WATER	CaCl2	C	CITE	MITE	ONATE	H	Ca	Mg	K	Na	SUM	SAT.	mehos/	SULFUR
in	pH		%	Eq. %			meq/100g					%	ca	%	
0- 11	5.1	4.8	0.70				6.6	7.1	2.0	0.24		15.9	59	1.50	0.06
11- 17	4.1	4.0	1.28				5.9	5.5	2.0	0.19		13.6		3.20	0.17
17- 29	4.9	4.4	1.08				6.4	5.1	3.0	0.24		14.7	57	0.57	
29- 35	4.6	4.2	2.56				9.7	5.6	3.1	0.25		18.7	48	1.35	0.33
35- 48	5.0	4.5	11.97				35.7	19.5	7.1	0.22		62.5	43	0.39	
48- 60	5.2	4.5	5.93				18.5	10.4	3.9	0.22		33.0	44	0.37	0.11

THE PARTICLE SIZE FAMILY CONTROL SECTION WAS CONSIDERED TO BE BETWEEN 10 AND 40 INCHES.  
WEIGHTED AVERAGE: 75-.1MM WHOLE SOIL %= 54.4      <2 MICRON FINE EARTH %= 18.7

SOIL TYPE: Fairpoint SiCL COUNTY: Jefferson SITE: JF-9  
 PEDON CLASSIFICATION: loamy-skeletal mixed nonacid mesic Typic Udorthent  
 LOCATION: section 34, Mt. Pleasant Twp.  
 PHYSIOGRAPHY: headslope, backslope ELEVATION: 1220 DATE: 9/28/81  
 TOPOGRAPHY: moderately sloping % SLOPE: 7 ASPECT: SSW  
 DRAINAGE: well VEGETATION: pasture  
 COLLECTORS: Smeck/Hall/Jaynes  
 PARENT MATERIALS: sandstone and shale

<u>HORIZON</u>	<u>DEPTH IN</u>	
A1	0-6	10YR 5/6 silty clay loam; weak medium subangular blocky parting to weak fine subangular blocky structure; friable; common fine roots; 10% coarse fragments; pH 5.4; clear smooth boundary.
A2	6-13	10YR 5/6-silty clay loam; massive parting to weak medium subangular blocky structure; firm; few fine roots; 10% coarse fragments; pH 5.2; clear smooth boundary.
C1	13-22	10YR 5/4-clay loam; few fine distinct 10YR 5/8 mottles; massive; firm; few fine roots; 35% coarse fragments; pH 7.2; gradual wavy boundary.
C2	22-31	10YR 5/4-loam; few fine distinct 10YR 5/8 and few fine distinct 5Y 5/2 mottles; massive; firm; 20% coarse fragments; pH 7.2; gradual smooth boundary.
C3	31-41	80% 10YR 5/4; 10% 10YR 4/1; 10% 5Y 5/2-loam; massive; firm; 20% coarse fragments; pH 7.3; abrupt wavy boundary.
C4	41-55	10YR 5/1-loam, massive; firm; 60% coarse fragments; pH 7.3;

NOTE: Some true mottling is present in this profile, but the various colors in the C3 horizon are due to the many colors of the materials that were mixed together when the land was reclaimed. This soil was described as part of the stripmine reclamation study "Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining" sponsored by the U.S. Bureau of Mines. This soil was described on the J11 watershed.

SOIL SERIES: FAIRPOINT  
SITE: JF-9

COUNTY: JEFFERSON  
DATE: 9/28/81

OSU LAB. NUMBERS: 24738 - 24743

DEPTH	HORIZON	CO. FRAG. >2mm	PARTICLE SIZE DISTRIBUTION (% < 2mm)											TEXT.			
			SAND			SILT (um)			CLAY (um)								
			VC	C	M	F	VF	TOTAL	50-20	20-5	5-2	TOTAL	2-.2	<.2	TOTAL	CLASS	
in																	
0-	6	A11	15.4	2.4	2.4	1.5	5.7	6.7	18.7	15.6	27.3	10.5	53.4	18.6	9.3	27.9	SI CL
6-	13	A12	17.7	2.3	2.5	1.6	5.4	6.5	18.3	17.4	26.1	11.1	54.6	16.9	10.2	27.1	SI CL
13-	22	C1	44.4	2.6	2.4	1.4	4.9	10.7	22.0	19.1	24.7	9.6	53.4	17.1	7.5	24.6	SIL
22-	31	C2	43.2	3.9	2.9	1.7	5.9	13.8	28.2	22.4	20.2	9.9	52.5	11.0	8.3	19.3	SIL
31-	41	C3	32.9	3.5	2.5	1.1	3.9	11.5	22.5	20.0	24.7	10.6	53.3	13.2	9.0	22.2	SIL
41-	55	C4	58.1	4.7	4.7	3.1	16.6	18.5	47.6	15.5	17.0	6.3	38.8	8.7	4.9	13.6	L

DEPTH	1:1 WATER	.01M CaCl2	ORG. C	CAL-CITE	DOLD-MITE	CARBONATE	EXTRACTABLE CATIONS					BASE SAT.	-E.C.- mmhos/cm	TOTAL SULFUR %	
							H	Ca	Mg	K	Na				SUM
in															
0-	6	5.4	4.9	0.70			6.7	7.9	2.6	0.35	17.5	62	0.71	0.04	
6-	13	5.2	4.6	0.55			7.4	7.4	2.8	0.31	17.9	59	0.40		
13-	22	6.4	6.0	0.18			3.6	11.2	3.1	0.26	18.2	80	0.47	0.03	
22-	31	6.2	5.9	0.17			3.2	9.0	3.0	0.23	15.4	79	0.53		
31-	41	6.5	6.2	0.32			3.7	9.9	3.1	0.25	17.0	78	0.86		
41-	55	7.4	7.2	1.24		2.6	0.6	5.7	1.7	0.20	8.2		2.20	0.64	

THE PARTICLE SIZE FAMILY CONTROL SECTION WAS CONSIDERED TO BE BETWEEN 10 AND 40 INCHES.  
WEIGHTED AVERAGE: 75-.1MM WHOLE SOIL %= 45.5 <2 MICRON FINE EARTH %= 22.5

SOIL TYPE: Bethesda silt loam                      COUNTY: Jefferson                      SITE: JF-10  
 PEDON CLASSIFICATION: loamy-skeletal mixed acid mesic Typic Udorthent  
 LOCATION: section 34, Mt. Pleasant Twp.  
 PHYSIOGRAPHY: headslope, backslope                      ELEVATION: 1210                      DATE: 9/28/81  
 TOPOGRAPHY: moderately sloping                      Z SLOPE: 7                      ASPECT: SW  
 DRAINAGE: well                      VEGETATION: pasture  
 COLLECTORS: Hall/Smeck/Jaynes  
 PARENT MATERIALS: sandstone and shale

<u>HORIZON</u>	<u>DEPTH IN</u>	
A	0-10	10YR 5/4-silt loam; common medium faint 10YR 5/8 mottles; moderate medium subangular blocky parting to moderate fine subangular blocky structure; friable; common fine roots; 20% coarse fragments; pH 5.2; abrupt smooth boundary.
C1	10-19	10YR 4/3-clay loam many colors of small extent, 10YR 4/1, 10YR 5/8, 10YR 6/1, 10YR 3/3; massive; firm; few fine roots; 50% coarse fragments; pH 4.7; clear wavy boundary.
C2	19-26	75% 10YR 4/4; 15% 10YR 5/6; 10% H2/-clay loam; massive; firm; 25% coarse fragments; pH 5.2; clear wavy boundary.
C3	26-39	10YR 4/3-clay loam; massive; friable; 20% coarse fragments; pH 4.9; clear wavy boundary.
C4	34-49	10YR 5/6-clay loam; few medium distinct 10YR 4/2 and a few medium distinct 10YR 6/8 mottles; massive; friable; 60% coarse fragments; pH 5.2; clear wavy boundary.
C5	49-65	10YR 4/4-sandy loam; common 10YR 6/8 and 10YR 7/1 soft coarse fragments; massive; very friable; 75% coarse fragments; pH 4.3.

NOTE: Clay loams in the C1, C2, C3, and C4 horizons have a slippery (micaceous) feel. Clay percentages may be much less. This soil was described as part of the stripmine reclamation study "Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining" sponsored by the U.S. Bureau of Mines. This soil was described on the J11 watershed.

SOIL SERIES: BETHESDA  
SITE: JF-10

COUNTY: JEFFERSON  
DATE: 9/28/81

OSU LAB. NUMBERS: 24744 - 24749

DEPTH	HORIZON	CO. FRAG. >2mm	PARTICLE SIZE DISTRIBUTION (%<2mm)											TEXT. CLASS		
			SAND					SILT(um)				CLAY(um)				
			VC	C	M	F	VF	TOTAL	50-20	20-5	5-2	TOTAL	2-.2	<.2	TOTAL	
in																
0-10	A1	25.0	2.0	2.6	2.0	8.6	8.2	23.4	17.3	26.5	10.4	54.2	17.4	5.0	22.4	SIL
10-19	C1	54.6	6.4	6.6	2.4	5.1	7.1	27.6	18.0	26.0	10.1	54.1	14.6	3.7	18.3	SIL
19-26	C2	35.2	5.6	6.1	3.9	11.6	8.5	35.7	14.4	20.6	9.5	44.5	14.3	5.5	19.8	L
26-39	C3	43.0	7.4	7.0	2.4	5.2	7.5	29.5	19.5	22.6	10.7	52.8	14.4	3.3	17.7	SIL
39-49	C4	36.2	3.8	5.4	6.9	19.8	9.5	45.4	11.4	18.9	8.1	38.4	12.6	3.6	16.2	L
49-65	C5	51.2	2.7	5.9	10.9	37.8	11.5	68.8	8.1	8.8	5.5	22.4	5.6	3.2	8.8	SL

DEPTH	1:1 WATER	.01M CaCl2	ORG. C	CAL- CITE	DOL- MITE	CARB- ONATE	EXTRACTABLE CATIONS					BASE SAT.	-E.C.- mmhos/	TOTAL SULFUR
							H	Ca	Mg	K	Na			
in	PH		%	Eq.%			meq/100g					%	cm	%
0-10	4.6	4.5	0.81				9.0	6.8	3.1	0.24	19.1		3.75	0.14
10-19	3.7	3.7	1.72				10.9	10.2	3.9	0.23	25.2		4.15	0.26
19-26	4.7	4.2	3.30				13.6	7.1	3.5	0.22	24.4	44	0.95	
26-39	4.9	4.3	0.91				9.1	5.9	3.1	0.24	19.3	50	0.41	0.07
39-49	4.3	4.0	0.96				8.1	4.1	2.4	0.18	14.8	45	1.85	
49-65	3.5	3.5	2.17				7.1	4.6	1.6	0.12	13.4		3.70	0.18

THE PARTICLE SIZE FAMILY CONTROL SECTION WAS CONSIDERED TO BE BETWEEN 10 AND 40 INCHES.  
WEIGHTED AVERAGE: 75-.1MM WHOLE SOIL %= 57.5 <2 MICRON FINE EARTH %= 18.3

SOIL TYPE: Fairpoint silty clay loam      COUNTY: Jefferson      SITE: JF-11  
 PEDON CLASSIFICATION: loamy-skeletal, mixed, nonacid, mesic Typic Udorthent  
 LOCATION: section 34, Mt. Pleasant Twp.  
 PHYSIOGRAPHY: headslope, backslope      ELEVATION: 1190      DATE: 9/30/82  
 TOPOGRAPHY: moderately sloping      % SLOPE: 10      ASPECT: N  
 DRAINAGE: well  
 COLLECTORS: Hall/Smeck/Jaynes  
 PARENT MATERIALS: sandstone and shale

<u>HORIZON</u>	<u>DEPTH IN</u>	
A	0-10	75% 10YR 5/6; 25% 10YR 4/3-silty clay loam; common fine distinct 10YR 6/2 mottles; massive; firm; 15% coarse fragments; pH 5.4; abrupt smooth boundary.
C1	10-18	2.5Y 4/2-clay loam; common medium distinct 10YR 4/1 and common medium distinct 10YR 5/8 mottles; massive; firm; 45% coarse fragments; pH 7.3; clear wavy boundary.
C2	18-25	65% 2.5Y 6/4; 35% 5Y 5/1-clay loam; common medium prominent 10YR 5/8 mottles; massive; firm; 65% coarse fragments; pH 7.2; clear wavy boundary.
C3	25-36	2.5Y 6/4-clay loam; common medium distinct 10YR 5/8 mottles; massive; firm; 70% coarse fragments; pH 7.3; strong effervescence; clear wavy boundary.
C4	36-47	2.5Y 5/4-clay loam; common medium distinct 10YR 5/8 and common medium distinct N2/ mottles; massive; firm; 60% coarse fragments; pH 7.3; slight effervescence; clear wavy boundary.
C5	47-56	5Y 5/3-clay loam; few fine distinct 10YR 5/4 and few fine distinct 10YR 4/2 mottles; massive; firm; 60% coarse fragments; pH 7.3; slight effervescence;

NOTE: This soil was reclaimed just prior to sampling and hence had no vegetative cover. This soil was described on the J11 watershed as part of the stripmine reclamation project "Research on the Hydrology and Water Quality of Watersheds Subjected to Surface Mining" sponsored by the U.S. Bureau of Mines.

SOIL SERIES: FAIRPOINT  
SITE: JF-11

COUNTY: JEFFERSON  
DATE: 9/29/81

OSU LAB. NUMBERS: 24750 - 24755

DEPTH	HORIZON	CO. FRAG. >2mm	PARTICLE SIZE DISTRIBUTION (% < 2mm)											TEXT. CLASS		
			SAND			SILT (um)				CLAY (um)						
			VC	C	M	F	VF	TOTAL	50-20	20-5	5-2	TOTAL	2-.2	.2	TOTAL	
in																
0-10	A1	18.8	2.4	2.8	1.5	5.9	9.6	22.2	18.1	24.2	11.4	53.7	17.0	7.1	24.1	SIL
10-18	C1	45.4	2.7	2.6	1.0	2.8	3.3	12.4	9.7	29.4	17.2	56.3	27.0	4.3	31.3	SICL
18-25	C2	49.6	5.3	3.8	1.4	3.0	4.4	17.9	12.6	26.0	16.1	54.7	23.0	4.4	27.4	SICL
25-36	C3	59.7	4.1	3.4	1.2	2.7	5.5	16.9	18.2	26.1	15.5	59.8	19.0	4.3	23.3	SIL
36-47	C4	46.2	3.1	2.9	1.2	3.2	5.3	15.7	15.5	26.5	14.8	56.8	21.4	6.1	27.5	SICL
47-56	C5	49.5	3.9	2.9	1.3	3.6	5.6	17.3	15.1	28.3	13.5	56.9	20.0	5.8	25.8	SIL

DEPTH	1:1 WATER	.01M CaCl2	ORG. C	CAL-CITE	DOLO-MITE	CARBONATE	EXTRACTABLE CATIONS					BASE SAT. %	-E.C.- mmhos/cm	TOTAL SULFUR %
							H	Ca	Mg	K	Na			
in	pH		%	Eq. %			meq/100g							
0-10	6.0	5.7	0.51				5.8	6.4	2.1	0.30	14.6	60	0.95	0.04
10-18	6.8	6.7	0.79				2.9	14.6	4.2	0.45	22.2		2.65	0.22
18-25	7.4	7.2	0.08			3.1	1.9	14.1	4.6	0.33	20.9	91	1.95	
25-36	8.2	7.8	0.04			5.3	0.1	19.9	6.0	0.25	26.3	100	0.68	
36-47	7.9	7.6	0.40			3.9	1.5	16.2	4.9	0.31	22.9	93	1.10	
47-56	7.8	7.5	0.54			3.7	1.3	13.8	4.5	0.29	19.9	93	1.20	0.24

THE PARTICLE SIZE FAMILY CONTROL SECTION WAS CONSIDERED TO BE BETWEEN 10 AND 40 INCHES.  
WEIGHTED AVERAGE: 75-.1MM WHOLE SOIL % = 57.1      <2 MICRON FINE EARTH % = 27

