CLASSIFICATION OF STREAM BASINS IN SOUTHEASTERN OHIO ACCORDING TO EXTENT OF SURFACE COAL MINING

By C. J. Oblinger Childress

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E R R A T U M

p. 40 -- The following citation was omitted from the references section:

"Buchanan, T. J., and Somers, W. P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A8, 65 p."

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CONVERSION FACTORS

For the benefit of readers who prefer to use the International System of units (SI), conversion factors for terms used in this report are listed below:

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometers (km^2)
acre (ac)	0.4047	square hectometer (hm^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

Water-quality data were collected from streams draining 35 basins in the southeastern-Ohio coal region to evaluate and categorize the effect of surface coal mining on stream quality. The study area is underlain by rocks of Pennsylvanian age, the most important coal-producing formations of which are the Allegheny and Monongahela Formations.

The study area contains 276 data-collection sites, each of which was sampled four times over a 3-year period. Water and bed-material samples were collected. Each site was classified as "abandoned," "reclaimed," "unmined," or "mixed," depending on the proportion of the drainage basin disturbed by mining, and if mined, on the present condition of the mine. Of the 130 sites in the Monongahela Formation, 18 percent were classified as abandoned, 2 percent as reclaimed, 10 percent as unmined, and 70 percent as mixed. Of the 146 sites in the Allegheny Formation, 14 percent were classified as abandoned, 11 percent as unmined, and 75 percent as mixed.

Streams draining the carbonate-bearing Monongahela Formation have a significantly greater buffering capacity than streams draining the Allegheny Formation. There are significant differences in specific conductance; pH; alkalinity; acidity; hardness; total and dissolved iron, manganese, and aluminum; dissolved nickel, zinc, and sulfate; and dissolved solids among mining-disturbance types in the Allegheny Formation. However, in streams draining the Monongahela Formation, only hardness, sulfate, dissolved solids, and dissolved manganese are significantly different among mining-disturbance types.

Discriminant-function analysis of water-quality data was used to classify each "mixed" site into one of four categories: Abandoned, reclaimed, unmined, or uncertain. In addition, observations in each of the first three categories were classified as strongly, moderately, or weakly characteristic of that category. The discriminant function was based on specific conductance, pH, acidity, dissolved sulfate, dissolved aluminum, and dissolved manganese in streams draining the Allegheny Formation, and was based on specific conductance, dissolved sulfate, and alkalinity for streams draining the Monongahela Formation.

Of the "mixed" sites in the Monongahela Formation, 46 percent were reclassified as abandoned, 11 percent as reclaimed, 18 percent a unmined, and 24 percent as uncertain. One site was not classified because of insufficient data. Of the "mixed" sites in the Allegheny Formation, 27 percent were reclassified as abandoned, 57 percent as unmined, and 15 percent as uncertain. Four sites were not classified because of insufficient data.

INTRODUCTION

Surface mining accounts for more than 60 percent of the coal extracted in Ohio (Collins, 1976). Before 1972, surface mines usually were abandoned when further extraction was no longer economical. The gob piles, highwalls, and ponds that remained were unreclaimed, and, in many cases, remain unreclaimed today. Ohio has an estimated 450,000 acres of unreclaimed surface mines that affect the water quality of 2,500 miles of streams (Ohio Department of Natural Resources, Division of Reclamation, written commun., 1980).

Purpose and Scope

The purpose of this report is to classify basins according to impact of abandoned surface mines. Selected basins were classified based on percentage of abandoned-mine, reclaimed, and unmined areas in each basin. Basins containing a mixture of mined, reclaimed, and unmined areas were reclassified into one of ten categories based on statistical analysis of water-quality data.

The study area included much of the southeastern-Ohio coal region. Water-quality samples were collected during low flow at 276 sites in this region between 1980 and 1982.

Geologic and Physiographic Setting

The study area is located in the unglaciated southeastern part of Ohio (fig. 1). The coal beds are present in a 30-county area along the western edge of the Appalachian Plateaus physiographic province (Fenneman, 1938). The area is underlain by rocks of Pennsylvanian and Permian age. The Pennsylvanian system comprises four formations; the Pottsville Formation is overlain by the Allegheny, Conemaugh, and Monongahela Formations. The Permian System comprises the Dunkard Group.

Fifty-two coal beds are recognized and named in Ohio, but most are thin and discontinuous. Most of the coals that can be economically mined are in the Allegheny and Monongahela Formations. All are highly volatile bituminous coals, most of which fall in the medium (1.1 to 3.0 percent) to high (greater than 3.0 percent) sulfur range (Collins, 1978).

Rock types are present in sequences of (with increasing depth) coal, freshwater limestone, calcareous shale, sandstone, and marine limestone (Brant, 1960). The proportion of sandstone strata increases with age. The Allegheny Formation is 40 percent sandstone; the remainder is shale and clay. The Monongahela consists of shale, limestone, and not more than 15 percent sandstone strata (Stout and others, 1943).

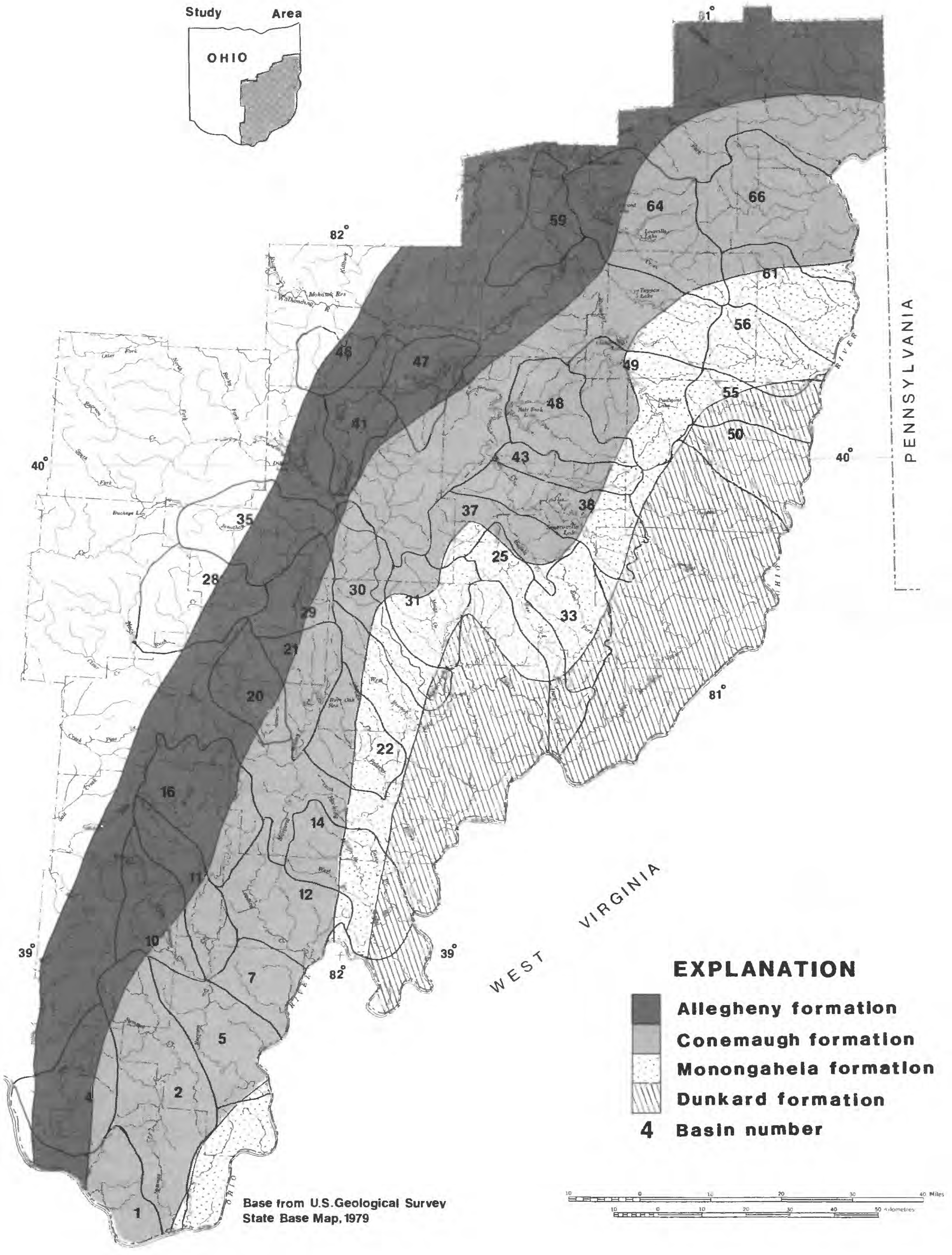


Figure 1.--Geologic formations and basins in the study area.

The area is drained by four major drainage systems (Hocking River, Raccoon Creek, Duck Creek, and the Muskingum River) and by drainage local to the Ohio River.

METHODS OF STUDY

Thirty-five drainage basins in southeastern Ohio have been given high or medium priority for reclamation by the Ohio Board on Unreclaimed Strip Mined Lands (1974). The Ohio Department of Natural Resources, Division of Reclamation, selected 276 sampling sites within these 35 basins (fig. 2). Each site was given a number corresponding to the basin in which it is located, followed by a unique site number corresponding to its location in the basin in downstream order (for example: 35-5, table 1).

Sites were located along the main stem and tributaries of each basin to measure the immediate impact of acid mine drainage and the downstream extent of the impact. The number of sites in each basin ranges from 1 to 17. Drainage areas range from 0.6 to 7,196 square miles. The sites are listed in downstream order in table 1.

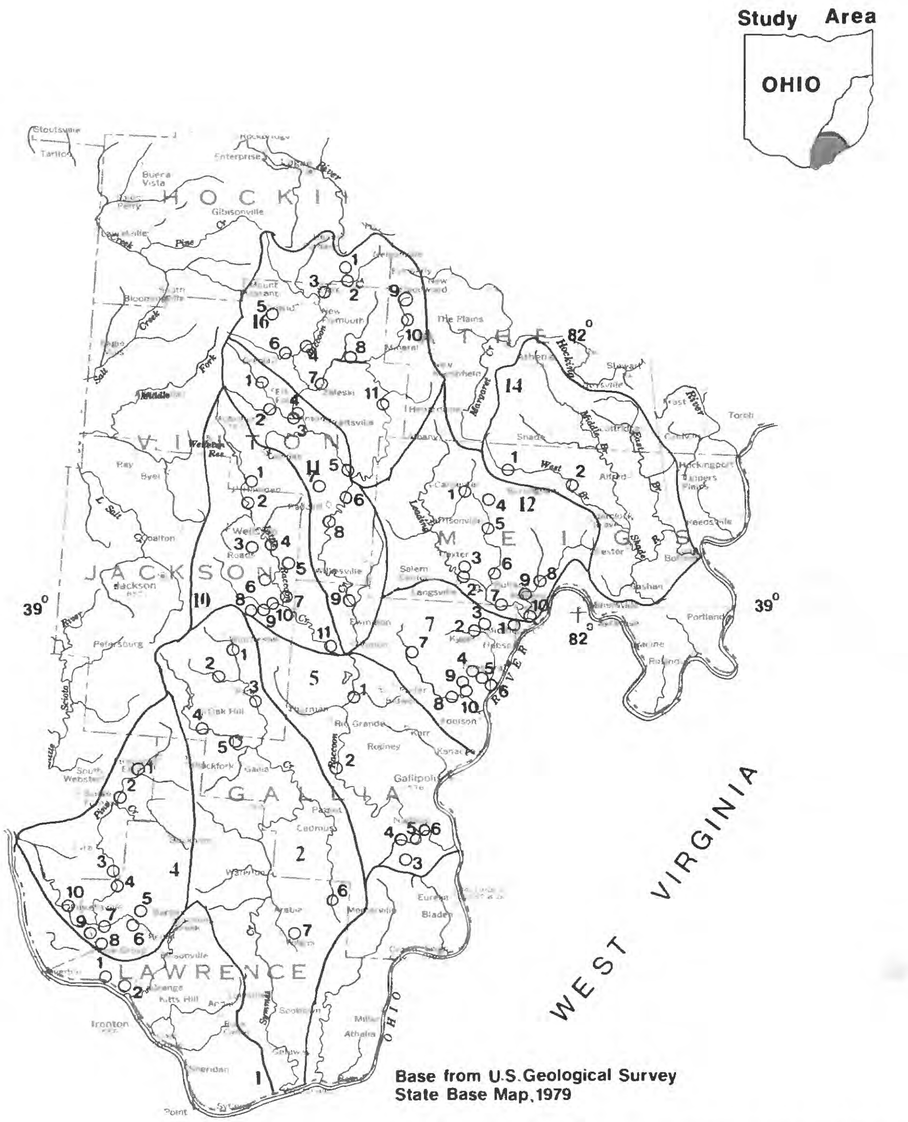
Sampling Schedule

On-site measurements of discharge, specific conductance, pH, temperature, alkalinity, and acidity were made. Water samples were collected during low flow at 67 sites in the autumn of 1980, and during low flow at all 276 sites in autumn of 1981 and 1982. All water samples collected prior to the autumn of 1982 were analyzed for concentrations of total and dissolved aluminum, iron, and manganese; dissolved nickel and zinc; and hardness, sulfate, and dissolved solids.

In the autumn of 1982, samples of bed material were collected and analyzed for concentrations of recoverable aluminum, iron, manganese, nickel, and zinc at sites where pH was greater than 5.0. Water samples were collected and analyzed for sulfate, chloride, and dissolved solids. At sites where pH was less than 5.5, water samples were collected and analyzed according to the same schedule used prior to autumn 1982.

Sampling and Analytical Techniques

Discharge was measured by the methods of Buchanan and Somers (1969). Dissolved oxygen, pH, specific conductance, temperature, and alkalinity were determined by the methods of Skougstad and others (1979). Acidity was determined using the hot-peroxide-treatment method (American Public Health Association, 1975). Water samples for chemical analysis were collected using the equal-transit rate/equal-width increment method (U.S. Geological Survey, 1977) for all streams greater than about 0.5 foot deep. These were composited in a churn splitter from which subsamples were drawn.



EXPLANATION

—— **Basin divide**

4 **Basin number**

$\circ^7$ **Within-basin site location and number**

Scale 1:1,000,000

Figure 2.--Site locations-southern third of the study area.

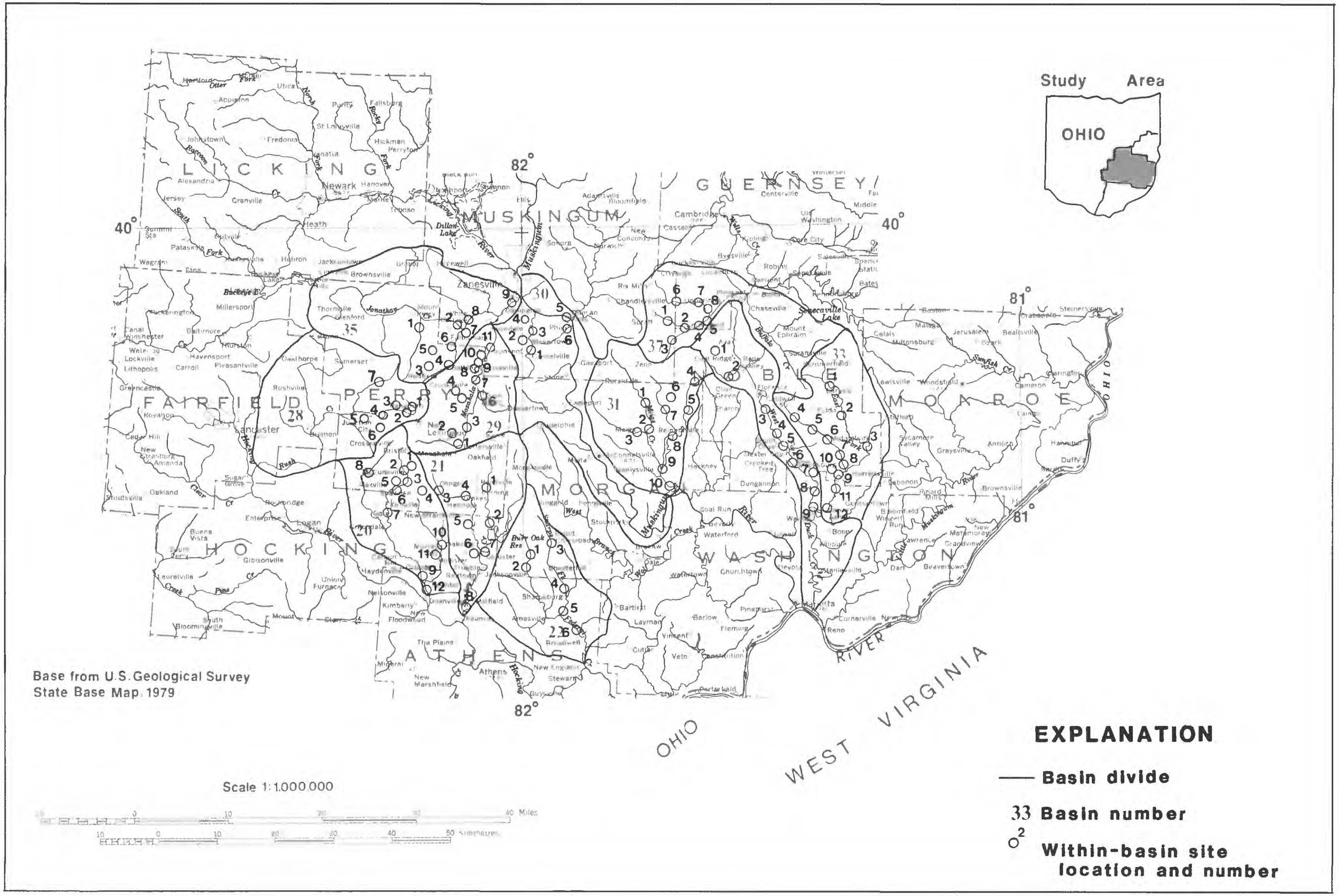


Figure 2.--Site locations-middle third of the study area--continued

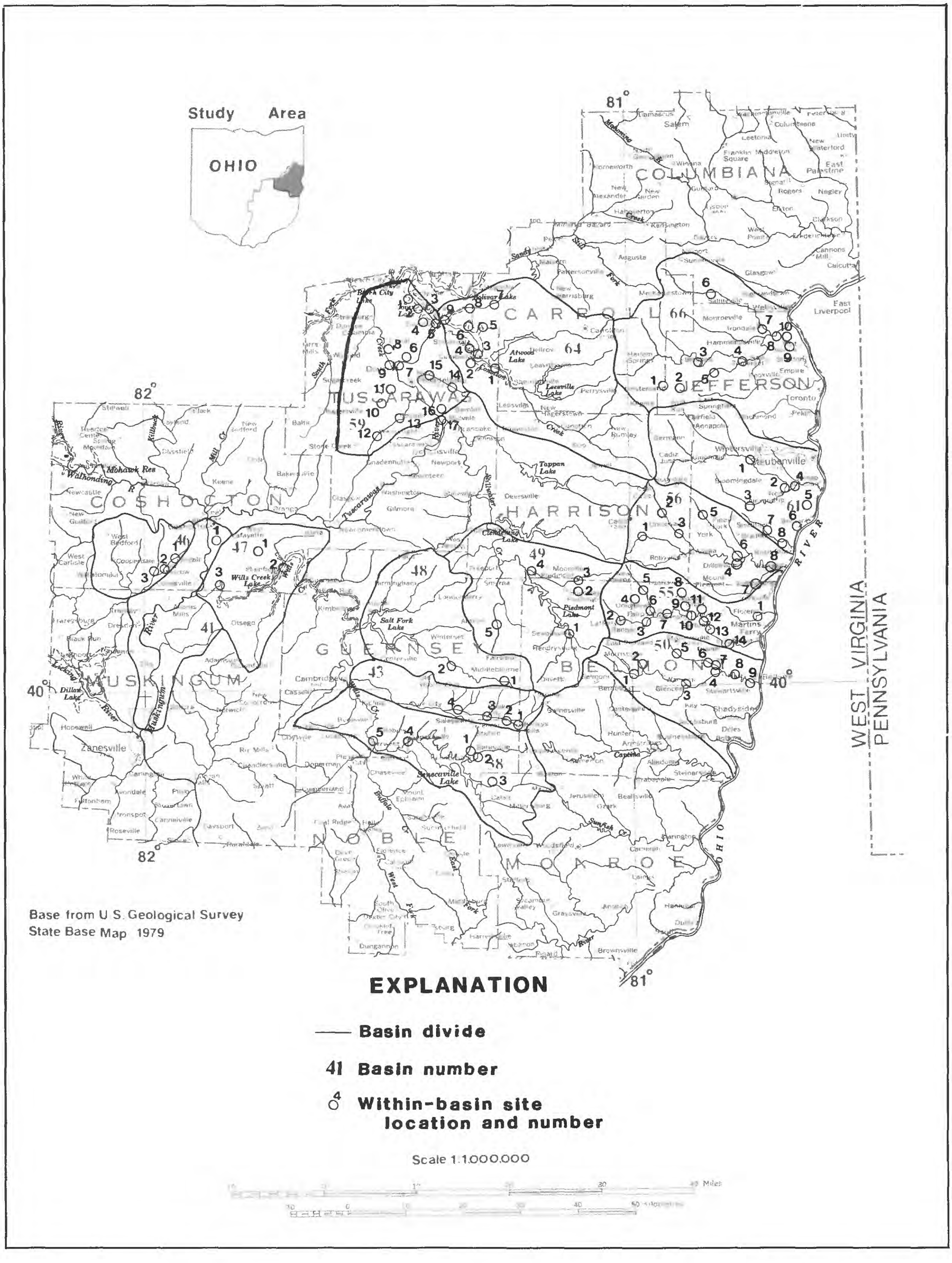


Figure 2.--Site locations-northern third of the study area--continued

Table 1.--List of data-collection sites

[AB, abandoned; AL, Allegheny; C, creek; F, fork; L, little; M, middle; MO, Monongahela; MX, mixed; NR, near; RC, reclaimed; RN, run; TR, tributary; UM, unmined; UNAM, unnamed. Drainage areas are in square miles]

STATION NAME	DRAINAGE AREA	FORMATION	MINING DISTURBANCE, (PERCENT OF BASIN) ABANDONED SURFACE MINE	RECLAIMED SURFACE MINE	SUBSURFACE MINE	CLASSIFICATION
OHIO RIVER LOCAL DRAINAGE						
YELLOW C (66-1)[a] AT AMSTERDAM OH	19.80	AL	1	3	0	UM
WOLF RN (66-2) NR AMSTERDAM OH	2.50	AL	15	1	0	MX
YELLOW C (66-3) NR BERGHOLZ OH	82.40	AL	3	1	5	MX
YELLOW C (66-4) NR NEW SOMERSET OH	106.00	AL	3	1	5	MX
LONG RN (66-5) NR E SPRINGFIELD OH	4.20	AL	5	0	0	UM
N F YELLOW C (66-6) NR SALINEVILLE OH	40.30	AL	3	3	10	MX
N F YELLOW C (66-7) AT HAMMONDSVILLE OH	58.00	AL	3	3	5	MX
YELLOW C (66-8) AT HAMMONDSVILLE OH	225.00	AL	-	-	-	MX
HOLLOW ROCK RN (66-9) NR NEW SOMERSET OH	5.60	AL	16	16	0	MX
HOLLOW ROCK RN (66-10) NR HAMMONDSVILLE OH	9.20	AL	14	11	0	MX
CROSS C (61-1) NR WINTERSVILLE OH	71.80	MO	1	3	1	MX
CROSS C (61-2) NR NEW ALEXANDER OH	88.80	MO	3	1	1	MX
MCINTYRE C (61-3) NR SMITHFIELD OH	14.30	MO	3	53	5	RC
CROSS C (61-4) NR MINGO JUNCTION OH	118.00	MO	10	25	2	MX
GEORGES RN (61-5) NR MINGO JUNCTION OH	2.60	MO	5	19	5	MX
SALT RN (61-6) NR RUSH RN OH	5.40	MO	7	16	5	MX
RUSH RN (61-7) NR RUSH RN OH	5.90	MO	7	9	65	AB
RUSH RN (61-8) AT RUSH RN OH	9.70	MO	10	10	50	AB
SHORT C						
SALLY BUFFALO C (56-1) NR CADIZ OH	9.50	MO	16	44	0	MX
N F SHORT C (56-2) AT UNIONVALE OH	10.60	MO	3	19	5	MX
N F SHORT C (56-3) NR ROBYVILLE OH	17.70	MO	3	30	5	MX
SHORT C (56-4) AT DILLONVALE OH	84.20	MO	5	35	25	MX
PINEY F (56-5) NR PINEY FORK OH	11.30	MO	1	30	10	MX
PINEY F (56-6) AT DILLONVALE OH	22.24	MO	1	41	42	MX
L SHORT C (56-7) NR TILTONSVILLE OH	14.30	MO	5	11	95	MX
SHORT C (56-8) NR RAYLAND OH	127.00	MO	3	30	30	MX
GLENNS RN (55-1) NR FLORENCE OH	8.20	MO	5	0	75	AB
WHEELING C (55-2) AT LAFFERTY OH	11.80	MO	19	8	20	MX
WHEELING C (55-3) AT BANNOCK OH	24.40	MO	15	15	60	MX
CRABAPPLE C (55-4) AT UNIONTOWN OH	10.10	MO	47	13	37	AB
CAMPBELL RN (55-5) NR UNIONTOWN OH	3.40	MO	38	16	49	MX
CRABAPPLE C (55-6) NR FAIRPOINT OH	19.60	MO	65	10	60	AB
WHEELING C (55-7) AT FAIR POINT OH	50.30	MO	4	10	60	AB
COX RN (55-8) NR MAYNARD OH	5.50	MO	40	5	90	AB
COX RN (55-9) AT MAYNARD OH	7.10	MO	34	6	45	AB
WHEELING C (55-10) AT MAYNARD OH	68.80	MO	45	15	70	AB
FALL RN (55-11) NR BARTON OH	4.00	MO	6	23	95	MX
WHEELING C (55-12) NR BARTON OH	82.50	MO	30	15	70	MX
WHEELING C (55-13) AT BARTON OH	88.60	MO	35	15	70	MX
WHEELING C (55-14) AT BLAINE OH	97.70	MO	35	15	70	MX
MCMAHON C (50-1) NR WARNOCK OH	12.40	MO	5	5	5	MX
BRUSH RN (50-2) NR WARNOCK OH	4.00	MO	8	11	0	MX
MCMAHON C (50-3) AT GLENCOE OH	36.70	MO	5	5	10	MX
MCMAHON C (50-4) AT NEFFS OH	62.80	MO	5	5	25	MX
L MCMAHON C (50-5) NR ST CLAIRSVILLE OH	3.80	MO	12	0	50	AB
L MCMAHON C (50-6) NR NEFFS OH	12.40	MO	11	4	75	AB
L MCMAHON C (50-7) AT NEFFS OH	14.20	MO	10	4	65	AB
MCMAHON C (50-8) NR BELLAIRE OH	80.00	MO	5	5	30	MX
MCMAHON C (50-9) AT BELLAIRE OH	89.50	MO	5	5	30	MX
DUCK CREEK BASIN						
W F DUCK C						
COAL RN (25-1) NR COAL RIDGE OH	4.10	MO	9	31	0	MX
UNAM TR TO W F DUCK C (25-2) NR BELLEVLY OH	7.80	MO	8	13	0	MX
W F DUCK C (25-3) NR CALDWELL OH	60.30	MO	3	3	1	UM
WARREN RN (25-4) AT SOUTH OLIVE OH	2.90	MO	47	0	0	AB
W F DUCK C (25-5) AT DEXTER CITY OH	75.40	MO	3	3	1	MX
W F DUCK C (25-6) AT MACKSBURG OH	84.40	MO	5	3	1	MX
UNAM TR TO W F DUCK C (25-7) AT ELBA OH	3.80	MO	53	0	1	AB
W F DUCK C (25-8) NR ELBA OH	97.70	MO	6	3	1	MX
W F DUCK C (25-9) AT WARNER OH	106.00	MO	7	2	1	MX
E F DUCK C (33-1) AT CARLISLE OH	31.70	MO	5	5	0	UM
E F DUCK C (33-2) NR MIDDLEBURG OH	42.50	MO	15	5	0	MX
E F DUCK C (33-3) NR HARRIETSVILLE OH	58.90	MO	12	5	0	MX
M F DUCK C (33-4) NR SOUTH OLIVE OH	9.80	MO	5	1	0	UM
M F DUCK C (33-5) NR MIDDLEBURG OH	15.30	MO	36	1	0	MX
M F DUCK C (33-6) AT MIDDLEBURG OH	20.50	MO	42	1	0	AB
M F DUCK C (33-7) NR HARRIETSVILLE OH	24.10	MO	41	1	0	AB

Table 1.--List of data-collection sites--Continued

STATION NAME	DRAINAGE AREA	FORM-ATION	MINING DISTURBANCE, (PERCENT OF BASIN) ABAN-DONED SURFACE MINE	RE-CLAIMED SURFACE MINE	SUB-SURFACE MINE	CLASS-IFICA-TION
M F DUCK C (33-8) NR GERMANTOWN OH	26.48	MO	42	1	0	AB
E F DUCK C (33-9) NR HARRIETSVILLE OH	100.00	MO	30	1	1	MX
UNAM TR TO E F DUCK C (33-10) NR ELBA OH	4.10	MO	67	0	0	AB
E F DUCK C (33-11) NR LOWER SALEM OH	106.00	MO	30	1	1	MX
E F DUCK C (33-12) AT LOWER SALEM OH	135.00	MO	30	1	1	MX
DUCK C (25-10) AT MARIETTA OH	286.00	MO	15	5	1	MX
MUSKINGUM RIVER BASIN						
TUSCARAWAS R						
WOLF RN (59-1) NR ZOAR OH	3.50	AL	35	1	0	MX
UNAM TR (59-2) TO TUSCARAWAS R NR ZOAR OH	1.80	AL	22	6	0	MX
MIDDLE RN						
UNAM TR (59-3) TO SM MIDDLE RN NR ZOAR OH	1.20	AL	17	15	0	MX
MIDDLE RN (59-4) AT ZOAR OH	2.30	AL	30	5	1	MX
CONOTTON C (64-1) NR NEW CUMBERLAND OH	68.50	AL	3	3	1	UM
DOG RN (64-2) AT NEW CUMBERLAND OH	2.80	AL	5	10	10	MX
CONOTTON C (64-3) AT NEW CUMBERLAND OH	246.00	AL	-	-	-	MX
UNAM TR (64-4) CONOTTON C NR NW CUMBRLND OH	5.50	AL	5	5	30	MX
BEGGAR RN (64-5) NR NEW CUMBERLAND OH	1.80	AL	42	21	5	AB
UNAM TR (64-6) TO CONOTTON C NR SOMERDALE OH	1.40	AL	8	37	5	MX
HUFF RN (64-7) NR MINERAL CITY OH	8.20	AL	10	5	5	MX
HUFF RN (64-8) NR MINERAL CITY OH	10.60	AL	15	5	7	MX
CONOTTON C (64-9) AT ZOARVILLE OH	285.00	AL	-	-	-	MX
TUSCARAWAS R (59-5) AT ZOARVILLE OH	1115.00	AL	-	-	-	MX
UNAM TR (59-6) TO TUSCARAWAS R AT DOVER OH	2.70	AL	0	25	1	MX
TUSCARAWAS R (59-7) AT DOVER OH	1772.00	AL	-	-	-	MX
SUGAR C						
GOETTGE RN (59-8) AT DOVER OH	4.40	AL	11	16	0	MX
SUGAR C (59-9) AT DOVER OH	348.00	AL	-	-	-	MX
STONE C (59-10) NR NEW PHILADELPHIA OH	21.30	AL	2	3	1	UM
STONE C (59-11) NR NEW PHILADELPHIA OH	25.20	AL	3	3	1	UM
OLDTOWN C (59-12) NR STONE CREEK OH	4.70	AL	0	1	1	UM
OLDTOWN C (59-13) NR WAINWRIGHT OH	10.80	AL	5	10	1	MX
BEAVERDAM C (59-14) NR MIDVALE OH	3.70	AL	5	5	25	MX
BEAVERDAM C (59-15) NR NEW PHILADELPHIA OH	12.80	AL	9	10	20	MX
PIKE RN (59-16) AT MIDVALE OH	6.30	AL	4	11	20	MX
STILLWATER C (49-1) NR HENDRYSBURG OH	37.60	MO	12	30	5	MX
BOGGS F						
TRAIL RN (49-2) AT HOLLOWAY OH	6.40	MO	28	29	10	MX
BOGGS F (49-3) AT HOLLOWAY OH	12.70	MO	3	63	1	RC
BOGGS F (49-4) AT PIEDMONT OH	36.50	MO	5	20	1	MX
SKULL F (49-5) NR ANTRIM OH	14.60	MO	7	23	1	MX
STILLWATER C (59-17) NR UHRICHSVILLE OH	485.00	AL	-	-	-	MX
ROBINSON RN (41-1) NR TYNDALL OH	3.70	AL	14	8	30	MX
WILLS C						
BUFFALO F						
MAYS F (37-1) NR CUMBERLAND OH	3.40	MO	49	24	0	AB
MILLER C (37-2) AT CUMBERLAND OH	11.90	MO	27	42	0	MX
COLLINS F (37-3) NR CUMBERLAND OH	6.90	MO	29	16	0	MX
BUFFALO F (37-4) AT CUMBERLAND OH	27.80	MO	25	30	0	MX
BUFFALO F (37-5) NR CUMBERLAND OH	32.60	MO	25	30	0	MX
YOKER C (37-6) NR CUMBERLAND OH	6.70	MO	19	45	0	MX
YOKER C (37-7) NR CUMBERLAND OH	16.20	MO	15	30	0	MX
YOKER C (37-8) NR CUMBERLAND OH	23.00	MO	10	15	0	MX
BUFFALO C (37-9) AT PLEASANT CITY OH	49.90	MO	5	1	1	UM
SENECA F						
YOKER C (38-1) NR BATESVILLE OH	2.40	MO	2	0	0	UM
BEAVER C (38-2) NR BATESVILLE OH	16.80	MO	8	0	1	UM
UNAM TR SENECA F WILLS C(38-3) NR CALAIS OH	1.80	MO	15	0	0	MX
SENECA F WILLS C (38-4) NR SENECAVILLE OH	118.00	MO	5	1	1	MX
WILLS C (38-5) AT BUFFALO OH	275.00	MO	-	-	-	MX
LEATHERWOOD C (43-1) AT BAILEYS MILLS OH	8.00	MO	12	1	10	MX
LEATHERWOOD C (43-2) AT SPENCER STATION OH	17.70	MO	10	1	1	MX
LEATHERWOOD C (43-3) AT QUAKER CITY OH	26.90	MO	10	1	1	MX
LEATHERWOOD C (43-4) NR SALESVILLE OH	35.70	MO	10	1	1	MX
SALT F (48-1) NR BARNESVILLE OH	4.00	MO	37	4	1	MX
SALT F (48-2) NR MIDDLEBOURNE OH	31.50	MO	10	2	1	MX
WILLS C						
BACON RN (47-1) NR PLAINFIELD OH	3.20	AL	48	19	15	AB
WILLS C (47-2) AT PLAINFIELD OH	771.00	AL	-	-	-	MX

Table 1.--List of data-collection sites--Continued

STATION NAME	DRAINAGE AREA	FORMATION	MINING DISTURBANCE, (PERCENT OF BASIN) ABANDONED SURFACE MINE	RECLAIMED SURFACE MINE	SUBSURFACE MINE	CLASSIFICATION
WILLS C (47-3) NR CONESVILLE OH	850.00	AL	-	-	-	MX
WAKATOMIKA C						
MILL F (46-1) NR NEW MOSCOW OH	4.50	AL	4	45	5	RC
MILL F (46-2) NR NEW MOSCOW OH	9.60	AL	9	41	5	RC
MOSCOW BK (46-3) NR NEW MOSCOW OH	7.20	AL	17	26	5	MX
MOXAHALA C						
MOXAHALA C (29-1) AT MOXAHALA OH	7.40	AL	28	0	15	MX
UNAM TR TO MOXAHALA C (29-2) AT MOXAHALA OH	5.60	AL	57	0	40	AB
MOXAHALA C (29-3) NR MOXAHALA OH	18.10	AL	37	1	15	MX
UNAM TR TO MCLUNEY C (29-4) NR ROSE FARM OH	1.40	AL	95	0	10	AB
MCLUNEY C (29-5) NR ROSE FARM OH	6.20	AL	73	0	10	AB
BLACK F (29-6) NR CROOKSVILLE OH	28.50	AL	5	2	10	MX
MOXAHALA C (29-7) AT CROOKSVILLE OH	40.20	AL	20	5	5	MX
UNAM TR TO MOXAHALA C (29-8) AT ROSEVILLE OH	4.20	AL	73	0	5	AB
PORTER RN (29-9) AT ROSEVILLE OH	3.40	AL	31	1	1	MX
UNAM TR MOXAHALA C (29-10) NR ROSEVILLE OH	2.20	AL	65	0	1	AB
MOXAHALA C (29-11) NR AVONDALE OH	98.00	AL	15	3	3	MX
JONATHAN C						
TURKEY RUN (35-1) NR MT PERRY OH	10.20	AL	14	0	1	MX
JONATHAN C (35-2) AT FULTONHAM OH	125.00	AL	2	1	2	MX
UNAM TR TO BUCKEYE (35-3) AT REDFIELD OH	1.40	AL	65	0	1	AB
BUCKEYE F (35-4) AT SALTILLO OH	7.30	AL	71	0	5	AB
UNAM TR TO BUTCHERKNIFE (35-5) NR SALTILO OH	2.00	AL	44	0	1	AB
BUTCHERKNIFE C (35-6) NR FULTONHAM OH	7.10	AL	38	0	1	MX
BUCKEYE F (35-7) NR WHITE COTTAGE OH	23.10	AL	35	1	5	MX
JONATHAN C (35-8) AT WHITE COTTAGE OH	150.00	AL	7	1	3	MX
MOXAHALA C (35-9) NR DARLINGTON OH	301.00	AL	-	-	-	MX
BRUSH C (30-1) AT CHANNELVILLE OH	11.50	AL	5	1	5	MX
TURKEY RN (30-2) AT STOVERTOWN OH	2.10	AL	66	12	5	AB
BRUSH C (30-3) NR PHILO OH	18.57	AL	15	5	18	MX
UNAM TR TO BRUSH C (30-4) NR STOVERTOWN OH	2.30	AL	40	0	10	AB
MUSKINGUM R (30-5) AT DUNCAN FALLS OH	7196.00	AL	-	-	-	MX
DUNCAN RN (30-6) AT PHILO OH	7.40	AL	5	1	5	MX
MEIGS C (31-1) NR MEIGS OH	31.30	MO	1	5	1	UM
MEIGS C (31-2) NR MEIGS OH	35.70	MO	5	5	1	MX
MANS F (31-3) NR MEIGS OH	28.00	MO	5	15	1	MX
DYES F (31-4) NR ZENO OH	5.40	MO	10	38	0	MX
DYES F (31-5) NR REINERSVILLE OH	16.70	MO	5	35	0	MX
BRANNONS F (31-6) NR REINERSVILLE OH	5.00	MO	65	0	0	AB
HORSE RN (31-7) NR MCCONNELSVILLE OH	4.50	MO	3	53	0	RC
DYES F (31-8) NR REINERSVILLE OH	38.10	MO	20	55	1	MX
DYES F (31-9) NR HACKNEY OH	45.00	MO	20	55	1	MX
MEIGS C (31-10) NR NEELYSVILLE OH	136.00	MO	10	20	1	MX
HOCKING RIVER BASIN						
UNAM TR TO RUSH C (28-1) AT REHOBOTH OH	1.60	AL	64	0	1	AB
RUSH C (28-2) AT NEW LEXINGTON OH	9.40	AL	50	0	5	AB
UNAM TR TO RUSH C (28-3) AT NEW LEXINGTON OH	4.70	AL	21	0	0	MX
RUSH C (28-4) NR JUNCTION CITY OH	28.10	AL	20	1	15	MX
DRY RN (28-5) NR JUNCTION CITY OH	3.00	AL	11	0	0	MX
TURKEY RN (28-6) NR JUNCTION CITY OH	4.70	AL	20	0	5	MX
CTR B RUSH C (28-7) NR SOMERSET OH	6.70	AL	1	5	0	UM
MONDAY C (20-1) AT MCCUNEVILLE OH	3.50	AL	27	1	30	MX
UNAM TR TO MONDAY C (20-2) AT MCCUNEVILLE OH	3.40	AL	42	5	15	AB
MONDAY C (20-3) NR SHAWNEE OH	7.70	AL	30	5	20	MX
SHAWNEE C (20-4) AT SHAWNEE OH	1.40	AL	30	0	30	MX
UNAM TR TO MONDAY C (20-5) NR SHAWNEE OH	3.40	AL	25	15	5	MX
MONDAY C (20-6) NR SHAWNEE OH	17.80	AL	28	15	15	MX
MONDAY C (20-7) AT OREVILLE OH	27.00	AL	25	15	15	MX
L MONDAY C (20-8) NR MAXVILLE OH	4.80	AL	35	0	0	MX
MONDAY C (20-9) NR BUCHTEL OH	85.00	AL	15	10	5	MX
SNOW F (20-10) AT MURRAY CITY OH	12.10	AL	15	0	10	MX
BRUSH F (20-11) AT ORBISTON OH	4.80	AL	24	0	95	AB
MONDAY C (20-12) AT DOANVILLE OH	114.00	AL	15	8	5	MX
SUNDAY C (21-1) AT CORNING OH	8.90	AL	5	0	0	UM
SUNDAY C (21-2) NR OAKDALE OH	21.50	AL	1	0	0	UM
W B SUNDAY C						
PINE RN (21-3) AT HEMLOCK OH	4.40	AL	10	2	45	AB
W B SUNDAY C (21-4) NR HEMLOCK OH	9.90	AL	10	1	45	AB
JOHNSON RN (21-5) NR GLOUSTER OH	4.20	AL	2	5	1	UM

Table 1.--List of data-collection sites--Continued

STATION NAME	DRAINAGE AREA	FORMATION	MINING DISTURBANCE, (PERCENT OF BASIN) ABANDONED SURFACE MINE	RECLAIMED SURFACE MINE	SUBSURFACE MINE	CLASSIFICATION
MUD F (21-6) AT GLOUSTER OH	7.30	AL	0	0	1	UM
SUNDAY C (21-7) AT GLOUSTER OH	104.00	AL	2	2	1	MX
SUNDAY C (21-8) AT CHAUNCEY OH	139.00	AL	1	1	1	MX
FEDERAL C						
MINERS F (22-1) NR SHARPSBURG OH	3.50	MO	10	0	1	MX
MINERS F (22-2) NR SHARPSBURG OH	7.10	MO	1	3	0	UM
SHARPS F (22-3) NR SHARPSBURG OH	11.80	MO	5	0	0	UM
SHARPS F (22-4) AT SHARPSBURG OH	21.10	MO	7	0	0	UM
SHARPS F (22-5) NR AMESVILLE OH	35.70	MO	5	0	0	UM
FEDERAL C (22-6) AT BROADWELL OH	107.00	MO	5	1	1	MX
OHIO RIVER LOCAL DRAINAGE						
W B SHADE R (14-1) NR BURLINGHAM OH	10.20	MO	35	2	0	MX
W B SHADE R (14-2) AT BURLINGHAM OH	29.80	MO	25	1	0	MX
LEADING C						
MUD F (12-1) NR HARRISONVILLE OH	3.50	MO	20	1	0	MX
LEADING C (12-2) NR LANGSVILLE OH	80.80	MO	15	1	1	MX
UNAM TRIB TO LEADING C (12-3) NR RUTLAND OH	0.60	MO	37	0	0	MX
UNAM TRIB TO LEADING C (12-4) AT HARRISON OH	1.30	MO	46	0	0	AB
L LEADING C (12-5) NR HARRISONVILLE OH	5.50	MO	20	0	0	MX
L LEADING C (12-6) AT RUTLAND OH	21.60	MO	35	0	5	MX
LEADING C (12-7) NR RUTLAND OH	89.30	MO	15	1	1	MX
THOMAS F (12-8) NR POMEROY OH	21.10	MO	10	0	10	MX
THOMAS F (12-9) NR MIDDLEPORT OH	29.20	MO	20	0	10	MX
LEADING C (12-10) AT MIDDLEPORT OH	150.00	MO	15	1	1	MX
STORYS RN (7-1) NR MIDDLEPORT OH	3.10	MO	34	0	23	MX
KYGER C (7-2) AT KYGER OH	7.90	MO	23	0	1	MX
JESSIE C (7-3) AT KYGER OH	3.40	MO	35	0	10	MX
L KYGER C (7-4) NR KYGER OH	2.70	MO	68	0	2	AB
L KYGER C (7-5) NR ADDISON OH	5.50	MO	58	0	5	AB
KYGER C (7-6) NR ADDISON OH	30.80	MO	35	1	10	MX
CAMPAIGN C						
L WHITE OAK C (7-7) NR PORTER OH	5.00	MO	35	0	0	MX
CAMPAIGN C (7-8) NR ADDISON OH	35.00	MO	5	0	0	UM
L CAMPAIGN C (7-9) NR ADDISON OH	2.30	MO	29	0	0	MX
L CAMPAIGN C (7-10) NR ADDISON OH	4.40	MO	21	0	0	MX
RACCOON CREEK BASIN						
UNAM TR TO E B RACCOON C (16-1) NR STARR OH	2.30	AL	68	0	0	AB
E B RACCOON C (16-2) NR STARR OH	6.40	AL	47	2	0	AB
E B RACCOON C (16-3) AT STARR OH	13.70	AL	29	3	5	MX
RACCOON C (16-4) NR ZALESKI OH	56.30	AL	10	1	5	MX
BRUSHY F (16-5) NR MT PLEASANT OH	4.80	AL	2	0	0	UM
BRUSHY C (16-6) NR CREOLA OH	33.70	AL	2	2	0	UM
RACCOON C (16-7) NR ZALESKI OH	114.00	AL	3	1	5	MX
RACCOON C (16-8) NR ZALESKI OH	122.00	AL	3	1	5	MX
HEWETT F (16-9) NR KIMBERLY OH	7.80	AL	13	0	35	MX
HEWETT F (16-10) NR MINERAL OH	11.80	AL	10	5	30	MX
RACCOON C (16-11) NR MINERAL OH	194.00	AL	3	1	2	MX
ELK F 11-1) NR MCARTHUR OH	8.60	AL	7	0	5	MX
PUNCHEON F (11-2) AT MCARTHUR OH	6.30	AL	10	0	1	MX
ELK F (11-3) NR MCARTHUR OH	26.40	AL	8	5	5	MX
UNAM TRIB TO ELK F (11-4) NR PRATTSVILLE OH	2.40	AL	21	0	0	MX
ELK F (11-5) NR RADCLIFF OH	59.50	AL	5	5	5	MX
RACCOON C (11-6) NR RADCLIFF OH	296.00	AL	-	-	-	MX
PIERCE RN (11-7) NR RADCLIFF OH	5.20	AL	20	4	5	MX
RACCOON C (11-8) NR WILKESVILLE OH	306.00	AL	-	-	-	MX
RACCOON C (11-9) AT EWINGTON OH	347.00	AL	-	-	-	MX
L RACCOON C						
SUGAR RN (10-1) AT HAMDEN OH	5.00	AL	26	10	5	MX
L RACCOON C (10-2) NR WELLSTON OH	47.70	AL	5	1	1	UM
UNAM TRIB TO L RACCOON C (10-3) NR ROADS OH	1.80	AL	63	0	5	AB
L RACCOON C (10-4) NR ROADS OH	67.50	AL	15	5	1	MX
BUFFER RN (10-5) NR ROADS OH	1.80	AL	20	0	30	MX
TARCAMP RN (10-6) NR ROADS OH	2.90	AL	10	0	5	MX
L RACCOON C (10-7) NR EWINGTON OH	99.70	AL	18	3	5	MX
DICKASON RN						
DIXON RN (10-8) NR WINCHESTER OH	1.20	AL	34	0	5	MX
DIXON RN (10-9) NR EWINGTON OH	4.00	AL	37	0	5	MX
DICKASON RN (10-10) NR EWINGTON OH	26.90	AL	17	1	1	MX
L RACCOON C (10-11) NR VINTON OH	154.00	AL	16	1	5	MX

Table 1.--List of data-collection sites--Continued

STATION NAME	DRAINAGE AREA	FORM-ATION	MINING DISTURBANCE, (PERCENT OF BASIN) ABAN-DONED SURFACE MINE	RE-CLAIMED SURFACE MINE	SUB-SURFACE MINE	CLASS-IFICA-TION
RACCOON C (5-1) NR RIO GRANDE OH	560.00	AL	-	-	-	MX
RACCOON C (5-2) NR PATRIOT OH	607.00	AL	-	-	-	MX
BULLSKIN C (5-3) NR MERCERVILLE OH	4.50	MO	18	0	0	MX
L BULLSKIN C (5-4) NR MERCERVILLE OH	3.30	MO	19	2	0	MX
BULLSKIN C (5-5) NR MERCERVILLE OH	13.10	MO	17	3	0	MX
RACCOON C (5-6) NR EUREKA OH	661.00	MO	-	-	-	MX
OHIO RIVER LOCAL DRAINAGE						
SYMMES C (2-1) NR PYRO OH	11.00	AL	10	1	0	MX
UNAM TR TO SYMMES C (2-2) AT PYRO OH	12.60	AL	13	6	5	MX
SYMMES C (2-3) NR THURMAN OH	27.40	AL	7	4	1	MX
BLACK F (2-4) NR GALLIA OH	37.70	AL	6	3	1	UM
BLACK F (2-5) AT GALLIA OH	46.40	AL	6	3	1	UM
SAND F (2-6) NR WILGUS OH	8.90	MO	15	3	0	MX
BUCKEYE F (2-7) AT WILGUS OH	4.10	MO	1	0	1	UM
L STORMS C (1-1) NR TRENTON OH	5.20	AL	28	0	5	MX
OSBORNE RN (1-2) NR IRONTON OH	3.10	AL	29	10	5	MX
PINE C						
HALES C (4-1) NR EIFORT OH	14.40	AL	9	3	5	MX
HALES C (4-2) NR S WEBSTER OH	31.90	AL	5	1	3	UM
PINE C (4-3) NR BARTLES OH	88.00	AL	5	1	5	MX
PINE C (4-4) NR PEDRO OH	95.00	AL	5	1	5	MX
L PINE C (4-5) AT PEDRO OH	8.90	AL	10	0	10	MX
ELLISONVILLE C (4-6) AT PEDRO OH	8.60	AL	5	1	5	MX
L PINE C (4-7) NR PEDRO OH	29.22	AL	20	0	5	MX
SPERRY F (4-8) NR PINE GROVE OH	5.20	AL	20	29	10	MX
SPERRY F (4-9) NR PINE GROVE OH	9.90	AL	11	31	5	MX
PINE C (4-10) NR POWELLSVILLE OH	148.00	AL	12	1	5	MX

[a]Site identification number; basin number precedes within-basin site number.

Water samples were analyzed by standard methods (American Public Health Association, 1975) in the autumn of 1980 and spring of 1981 by the Ohio Department of Health and in the autumn of 1981 by a private laboratory. Samples collected in the autumn of 1982 were analyzed by the U.S. Geological Survey central laboratory in Atlanta, Ga., by methods described by Skougstad and others (1979). Quality assurance was maintained by submitting blind samples to assess reproducibility, samples spiked with known concentrations of specific constituents to assess percent recovery, and standard reference water samples to assess accuracy. If a laboratory outside the U.S. Geological Survey was performing the analyses, replicate samples were also sent to the U.S. Geological Survey laboratory to provide a comparison between laboratory results.

Bed-material samples were collected by a method described by Jenne and others (1980). Material scooped off the top few centimeters of the streambed with a plastic freezer container was sieved through successively smaller nylon screens (2 millimeter, 200 micrometers, and 62 micrometers) and washed through the screens with native water. This slurry was chilled and returned to the U.S. Geological Survey Ohio District laboratory.

Material smaller than 20 micrometers was isolated using the following method. The slurry was brought to room temperature (about 22 degrees Celsius), mixed, then poured into a polyvinyl chloride settling tube that had three withdrawal ports positioned 10 centimeters apart. The first port was opened to bring the material to the correct starting level. The slurry was remixed, then settled for a fixed period dependent on temperature (Jackson, 1956). The top 10 centimeters was drawn off through the second port, the sample remixed, and the procedure repeated using the bottom port. The sediment-water mixture was centrifuged at 2,200 revolutions per minute for approximately 20 minutes and the supernatant poured off. This entire procedure was repeated until sufficient bed material (at least 10 milligrams wet weight) was obtained for analysis. The sample was chilled and sent to the U.S. Geological Survey Atlanta laboratory for analysis.

Statistical Procedures

All statistical procedures were performed by means of the Statistical Analysis System (SAS) version 82.3 (Statistical Analysis System Institute, 1982). The data set included all low-flow samples collected at each site. Because parametric tests assume normally distributed data, each constituent was tested for normality using the Kolmogorov-Smirnov test and normal probability plots. A significance level of 0.01 was chosen to minimize the probability of rejecting the null hypothesis when the data were normally distributed (Snedecor and Cochran, 1980). If the null hypothesis was rejected, a log transformation of the data was tested. The following constituents were neither normally nor log-normally distributed: Alkalinity (as $CaCO_3$); total manganese, iron, and aluminum; and dissolved manganese, iron, and aluminum. As a result, a rank transformation was chosen for all constituents when using the parametric statistical tests that follow (Conover and Iman, 1976; Conover and Iman, 1981). In order to rank transform the data, the observations are arranged in ascending order according to the value of the variable being transformed. The lowest value receives a 1 and the highest the value N, where N is the number of observations. The rank replaces the original value in subsequent statistical testing. A significance level of 0.05 was selected.

One-way analysis of variance (ANOV) for unbalanced designs was used to test for differences among mining-disturbance types and formations. ANOV is a statistical procedure that provides a comparison of grouped data. ANOV tests the null hypothesis that the group means are equal. Rejection of the null hypothesis indicates that a significant difference exists among those means. When a rank transformation is used, the means of the ranks are tested. If the number of groups tested was greater than two and the ANOV null hypothesis was rejected, Tukey's studentized range test was used to determine which of the differences among means were significant. If no difference was detected at the 0.05 level of significance, the significance level was increased to 0.10. Tukey's studentized range test is designed to control type I error, which results in a loss of power. Because a significant difference was already shown with ANOV, it is acceptable to increase the power of the test (B level) by increasing the significance level (Snedecor and Cochran, 1980).

CLASSIFICATION OF BASINS BY PERCENTAGE OF AREA DISTURBED BY MINING

Ohio Capability Analysis Program (OCAP) 7.5-minute land-use maps were used to estimate the percentage of abandoned and reclaimed surface-mine land contributing to the drainage area of each basin. OCAP is a computer data base containing land-use information that was compiled by the Ohio Department of Natural Resources. Information on abandoned mine lands was provided for those maps from data collected in 1975.

A series of 7.5-minute underground-mine maps, prepared by the Ohio Department of Natural Resources, Division of Geological Survey, was used to estimate the percentage of each basin underlain by subsurface mines above major drainage. No effort was made to confirm drainage patterns of seeps from subsurface mines; therefore, the percentage of underground-mined land represents only a potential source of acid mine drainage.

Drainage basins smaller than 70 square miles (mi^2) were classified by type of mining disturbance. This size was selected to maximize the number of sites that were classified (79 percent of the sites had basins less than 70 mi^2) while at the same time minimizing the number of sites with highly heterogeneous land use. If 40 percent or more of a drainage basin was disturbed by either abandoned surface or subsurface mines and 25 percent or less by reclaimed surface mines, then it was classified as "abandoned." If 40 percent or more of a drainage basin was disturbed by reclaimed surface mines, 10 percent or less by abandoned surface mines, and 10 percent or less by subsurface mines, it was classified "reclaimed." If reclaimed surface mines, abandoned surface mines, or subsurface mines covered 10 percent or less of a drainage basin, it was classified as "unmined." If the drainage basin did not meet the criteria for an "abandoned," "reclaimed," or "unmined" classification or if the drainage area was greater than 70 mi^2, it was classified "mixed." As a result, 44 sites were classified abandoned, 5 were classified reclaimed, 30 were classified unmined, and 197 were classified mixed.

Each basin also was classified by predominant geologic formation (Allegheny or Monongahela). The geologic classifications were based on the state geologic map published by the Ohio Department of Natural Resources, Division of Geological Survey (Bownocker, 1947). Table 1 lists the percentages of each basin covered by each mining-disturbance type, the disturbance classification, and the predominant geologic formation for each site.

COMPARISON OF MINED AND UNMINED BASINS

Differences in Water Quality Based on Geology

Samples collected from streams draining unmined basins in the Allegheny and Monongahela Formations were examined for differences in surface-water chemistry. Results of ANOV are shown in table 2. Significantly different concentrations among streams draining different geologic formations were found for: pH, alkalinity, bicarbonate alkalinity, acidity, dissolved sulfate, and dissolved solids.

Table 3 shows ranges, first and third quartiles, and median concentrations for unmined basins by geologic formation. Alkalinity and bicarbonate concentrations are highest in streams draining the Monongahela Formation. Acidity is significantly higher and pH significantly lower in streams draining the Allegheny Formation than in streams draining the Monongahela Formation. These data reflect the greater number of carbonate-bearing strata in the Monongahela Formation and, therefore, a potentially greater capacity to assimilate acidic discharges from mined areas. A stream's capacity for assimilating acid mine drainage is a function of the amount of calcareous material available in the strata to neutralize acidity (Caruccio and others, 1977). In the Allegheny Formation, the median alkalinity is 53 milligrams per liter (mg/L) compared with 180 mg/L in the Monongahela Formation.

Dissolved-solids and dissolved-sulfate concentrations are significantly higher in streams draining the Monongahela Formation than in those draining the Allegheny Formation. These data suggest a difference in mineralogy and geochemical processes in the two formations.

Table 2.--Results of analysis of variance between unmined basins in the Allegheny and Monongahela Formations

Property or constituent	Number of obser- vations	[1]F statistic	[2]Probability of a greater F
Specific conductance (μS/cm)	87	1.80	0.18
pH	86	12.10	.00
Alkalinity, as $CaCO_3$ (mg/L)	88	11.26	.00
Bicarbonate, as HCO_3 (mg/L)	83	4.90	.03
Acidity, as $CaCO_3$ (mg/L)	83	26.73	.00
Hardness, as $CaCO_3$ (mg/L)	42	3.18	.08
Noncarbonate hardness, as $CaCO_3$ (mg/L)	37	0.90	.35
Iron, total recoverable (μg/L)	46	1.37	.25
Iron, dissolved (μg/L)	46	.07	.79
Manganese, total recov- erable (μg/L)	46	.00	.95
Manganese, dissolved (μg/L)	45	.17	.68
Aluminum, total recov- erable (μg/L)	46	.51	.48
Aluminum, dissolved (μg/L)	46	.26	.62
Nickel, dissolved (μg/L)	46	.16	.70
Zinc, dissolved (μg/L)	46	.68	.41
Sulfate, dissolved (mg/L)	71	4.35	.04
Solids, dissolved (mg/L)	70	4.04	.05

[1]Null hypothesis: $\mu_1 = \mu_2$

[2]Mean values are significantly different at the 95-percent level if the probability is less than 0.05.

Table 3.--Summary of univariate statistics for observations grouped by disturbance type in the Allegheny and Monongahela Formations

Geologic formation; property or constituent	Statistics for abandoned mine lands: Number	Median	First quartile	Third quartile	Minimum	Maximum
Allegheny Formation						
Specific conductance (µS/cm)	63	1,680	1,300	2,240	560	3,690
pH	63	3.3	3.0	4.3	2.6	7.7
Hardness, carbonate (mg/L)	24	880	610	1,200	340	1,800
Hardness, noncarbonate (mg/L)	6	920	640	1,600	390	1,700
Acidity (mg/L)	63	220	50	430	0	840
Bicarbonate (mg/L)	27	0	0	14	0	220
Alkalinity (mg/L as $CaCO_3$)	62	0	0	0	0	180
Sulfate, dissolved (mg/L)	45	920	640	1,440	370	2,100
Dissolved solids (mg/L)	45	1,470	1,110	2,220	601	3,420
Aluminum, total (µg/L)	43	13,000	4,800	29,000	75	48,000
Aluminum, dissolved (µg/L)	43	13,000	3,900	27,000	75	41,000
Aluminum, bed material (µg/g)	3	3,300	3,200	6,800	3,200	6,800
Iron, total (µg/L)	43	11,000	2,300	30,000	490	170,000
Iron, dissolved (µg/L)	43	7,000	1,500	24,000	30	140,000
Iron, bed material (µg/g)	3	7,000	5,200	23,000	5,200	23,000
Manganese, total (µg/L)	43	15,000	5,400	25,000	950	52,000
Manganese, dissolved (µg/L)	43	15,000	4,900	23,000	5	52,000
Manganese, bed material (µg/g)	3	690	270	190,000	270	190,000
Nickel, dissolved (µg/L)	43	300	100	470	20	700
Nickel, bed material (µg/g)	3	40	10	80	10	80
Zinc, dissolved (µg/L)	43	440	140	700	20	980
Zinc, bed material (µg/g)	3	86	46	90	46	90
Monongahela Formation						
Specific conductance (µS/cm)	69	1,520	1,110	2,000	510	2,800
pH	71	7.4	6.6	7.9	3.4	8.8
Hardness, carbonate (mg/L)	27	860	590	1,130	320	1,890
Hardness, noncarbonate (mg/L)	22	680	450	900	200	1,800
Acidity (mg/L)	70	0	0	6	0	300
Bicarbonate (mg/L)	63	170	69	300	0	410
Alkalinity (mg/L as $CaCO_3$)	70	120	35	230	0	340
Sulfate, dissolved (mg/L)	52	800	560	1,100	83	2,000
Dissolved solids (mg/L)	50	1,450	1,050	1,980	377	2,990
Aluminum, total (µg/L)	31	800	270	6,700	75	28,000
Aluminum, dissolved (µg/L)	31	200	76	1,600	50	28,000
Aluminum, bed material (µg/g)	19	3,700	2,700	7,600	1,200	18,000
Iron, total (µg/L)	33	1,100	390	5,400	10	68,000
Iron, dissolved (µg/L)	33	60	36	840	10	51,000
Iron, bed material (µg/g)	19	14,000	5,600	29,000	4,900	70,000
Manganese, total (µg/L)	33	500	270	9,300	5	34,000
Manganese, dissolved (µg/L)	33	460	180	7,000	5	31,000
Manganese, bed material (µg/g)	19	1,100	310	2,500	120	4,200
Nickel, dissolved (µg/L)	31	100	20	340	12	650
Nickel, bed material (µg/g)	19	30	20	40	10	80
Zinc, dissolved (µg/L)	31	42	11	200	10	640
Zinc, bed material (µg/g)	19	71	44	110	30	200

Table 3.--Summary of univariate statistics for observations grouped by disturbance type in the Allegheny and Monongahela Formations--Continued

Geologic formation; property or constituent	Statistics for reclaimed mine lands					
	Number	Median	First quartile	Third quartile	Minimum	Maximum
Allegheny Formation						
Specific conductance (μS/cm)	6	1,670	1,380	1,790	1,320	1,900
pH	6	6.7	6.4	7.2	6.3	7.3
Hardness, carbonate (mg/L)	2	--	--	--	1,000	1,200
Hardness, noncarbonate (mg/L)	2	--	--	--	1,000	1,200
Acidity (mg/L)	6	0	0	11	0	12
Bicarbonate (mg/L)	5	52	42	54	38	54
Alkalinity (mg/L as $CaCO_3$)	5	43	35	44	31	44
Sulfate, dissolved (mg/L)	4	1,000	940	1,100	920	1,200
Dissolved solids (mg/L)	4	1,680	1,600	1,870	1,570	1,930
Aluminum, total (μg/L)	2	--	--	--	850	3,500
Aluminum, dissolved (μg/L)	2	--	--	--	75	2,000
Aluminum, bed material (μg/g)	2	--	--	--	3,300	4,100
Iron, total (μg/L)	2	--	--	--	1,400	19,000
Iron, dissolved (μg/L)	2	--	--	--	47	12,000
Iron, bed material (μg/g)	2	--	--	--	14,000	15,000
Manganese, total (μg/L)	2	--	--	--	240	7,200
Manganese, dissolved (μg/L)	2	--	--	--	200	6,900
Manganese, bed material (μg/g)	2	--	--	--	510	3,200
Nickel, dissolved (μg/L)	2	--	--	--	20	20
Nickel, bed material (μg/g)	2	--	--	--	20	20
Zinc, dissolved (μg/L)	2	--	--	--	19	100
Zinc, bed material (μg/g)	2	--	--	--	47	74
Monongahela Formation						
Specific conductance (μS/cm)	9	1,710	1,200	1,830	1,050	2,100
pH	11	7.9	7.5	8.2	7.3	8.2
Hardness, carbonate (mg/L)	4	1,200	880	1,200	790	1,200
Hardness, noncarbonate (mg/L)	4	960	710	990	630	1,000
Acidity (mg/L)	11	0	0	0	0	0
Bicarbonate (mg/L)	11	220	190	250	180	260
Alkalinity (mg/L as $CaCO_3$)	11	180	160	210	150	220
Sulfate, dissolved (mg/L)	9	940	540	960	400	1,000
Dissolved solids (mg/L)	7	1,560	1,090	1,640	1,060	1,800
Aluminum, total (μg/L)	4	260	120	460	75	520
Aluminum, dissolved (μg/L)	4	83	75	170	75	200
Aluminum, bed material (μg/g)	3	2,600	1,500	4,600	1,500	4,600
Iron, total (μg/L)	6	490	360	590	310	760
Iron, dissolved (μg/L)	6	40	25	300	10	310
Iron, bed material (μg/g)	3	7,500	4,000	16,000	4,000	16,000
Manganese, total (μg/L)	6	370	170	560	29	690
Manganese, dissolved (μg/L)	6	160	23	440	16	600
Manganese, bed material (μg/g)	3	3,300	3,200	4,800	3,200	4,800
Nickel, dissolved (μg/L)	4	20	20	80	20	100
Nickel, bed material (μg/g)	3	10	10	60	10	60
Zinc, dissolved (μg/L)	4	17	11	28	10	30
Zinc, bed material (μg/g)	3	36	12	93	12	93

Table 3.--Summary of univariate statistics for observations grouped by disturbance type in the Allegheny and Monongahela Formations--Continued

Geologic formation; property or constituent	Statistics for unmined lands					
	Number	Median	First quartile	Third quartile	Minimum	Maximum
Allegheny Formation						
Specific conductance (µS/cm)	49	510	350	913	160	5,480
pH	49	6.8	6.2	7.4	3.3	8.0
Hardness, carbonate (mg/L)	26	200	130	350	72	770
Hardness, noncarbonate (mg/L)	21	120	68	240	23	500
Acidity (mg/L)	46	0	0	17	0	1,700
Bicarbonate (mg/L)	45	76	40	100	0	170
Alkalinity (mg/L as $CaCO_3$)	50	53	20	79	0	140
Sulfate, dissolved (mg/L)	43	110	84	260	34	4,200
Dissolved solids (mg/L)	42	292	218	501	45	6,690
Aluminum, total (µg/L)	30	720	140	2,000	75	35,000
Aluminum, dissolved (µg/L)	30	200	130	1,700	75	21,000
Aluminum, bed material (µg/g)	13	3,500	2,600	5,000	2,000	8,800
Iron, total (µg/L)	30	1,700	640	4,800	130	960,000
Iron, dissolved (µg/L)	30	220	160	2,900	30	930,000
Iron, bed material (µg/g)	13	12,000	8,600	20,000	5,100	26,000
Manganese, total (µg/L)	30	2,000	720	4,200	72	18,000
Manganese, dissolved (µg/L)	30	1,200	520	3,800	5	18,000
Manganese, bed material (µg/g)	13	1,400	860	2,000	800	4,900
Nickel, dissolved (µg/L)	30	100	20	100	10	600
Nickel, bed material (µg/g)	13	20	15	20	10	50
Zinc, dissolved (µg/L)	30	30	28	140	10	870
Zinc, bed material (µg/g)	13	75	45	120	21	170
Monongahela Formation						
Specific conductance (µS/cm)	38	600	488	685	290	900
pH	37	7.6	7.1	7.8	6.5	8.7
Hardness, carbonate (mg/L)	16	380	270	430	140	510
Hardness, noncarbonate (mg/L)	16	190	100	248	49	360
Acidity (mg/L)	37	0	0	0	0	12
Bicarbonate (mg/L)	38	220	170	240	84	460
Alkalinity (mg/L as $CaCO_3$)	38	180	140	200	69	380
Sulfate, dissolved (mg/L)	28	140	98	220	37	260
Dissolved solids (mg/L)	28	445	315	505	188	644
Aluminum, total (µg/L)	16	230	150	330	23	500
Aluminum, dissolved (µg/L)	16	100	75	210	75	330
Aluminum, bed material (µg/g)	12	2,600	1,800	3,600	640	5,700
Iron, total (µg/L)	16	430	190	610	10	760
Iron, dissolved (µg/L)	16	50	24	140	10	430
Iron, bed material (µg/g)	12	8,000	4,100	11,000	1,400	14,000
Manganese, total (µg/L)	16	180	100	410	50	1,200
Manganese, dissolved (µg/L)	15	84	30	270	5	1,300
Manganese, bed material (µg/g)	12	980	760	1,600	220	3,400
Nickel, dissolved (µg/L)	16	21	20	78	20	100
Nickel, bed material (µg/g)	12	10	10	20	10	40
Zinc, dissolved (µg/L)	16	10	10	29	10	57
Zinc, bed material (µg/g)	12	37	19	48	9	83

The data were separated and examined within geologic formation. To determine if a significant difference in water chemistry exists among mining-disturbance types within a particular geologic formation, one-way ANOV for unbalanced designs and Tukey's studentized range test were performed on sites to which a mining disturbance classification of abandoned, reclaimed, or unmined had been assigned. When the number of observations classified as reclaimed was less than three for a particular constituent, those observations were not included in the analysis.

Differences in Water Quality Based on Type of Mining Disturbance, Allegheny Formation

Concentrations of all constituents tested were significantly different for streams draining mining-disturbance types in the Allegheny Formation (tables 4 and 5). The values of pH and concentrations of alkalinity are higher in streams draining reclaimed and unmined sites than in streams draining abandoned sites (fig. 3). The concentrations of acidity are lower in streams draining reclaimed and unmined sites than in streams draining abandoned sites. The higher acidity found in streams draining abandoned-mine areas is a result of pyrite oxidation, which produces acidity. The net effect is measured directly as acidity and indirectly as loss of alkalinity and decrease in pH.

The concentrations of dissolved and total iron, dissolved and total manganese, dissolved zinc, dissolved nickel, and dissolved and total aluminum are lower at unmined sites than at abandoned sites (fig. 4). This is a result of acid production during pyrite oxidation. High concentrations of dissolved trace metals are symptomatic of acid mine drainage. Acidity increases the weathering intensity on surrounding rock surfaces and releases trace metals to surface water.

Trace-metal solubility varies with pH and Eh. The solubility of ferric iron is very low when the pH is above 4.8. Manganese is soluble at relatively high pH; it precipitates above pH 8.0, or within the normal Eh range for surface waters. Aluminum is most soluble at the extreme pH ranges. Minimum solubility is at a pH of about 6.0. At a neutral pH, zinc concentrations of 1,000 ug/L can be chemically stable (Hem, 1970). In addition, ferric and manganese hydroxides, which are in high concentration in acid mine drainage due to the dissolution of parent rock, control the concentrations of some trace metals released by acid mine drainage through adsorption and precipitation (Jenne, 1968).

Carbonate and noncarbonate hardness are lower in streams draining unmined areas than in streams draining abandoned-mine areas (fig. 3). Hardness can be attributed to a number of constituents. In natural waters, it is generally attributed to calcium and magnesium, and is expressed in milligrams per liter, calcium carbonate equivalent (mg/L as $CaCO_3$). Other divalent cations, such as iron, manganese, zinc, and aluminum, contribute to hardness when present in high concentrations. A proportion of

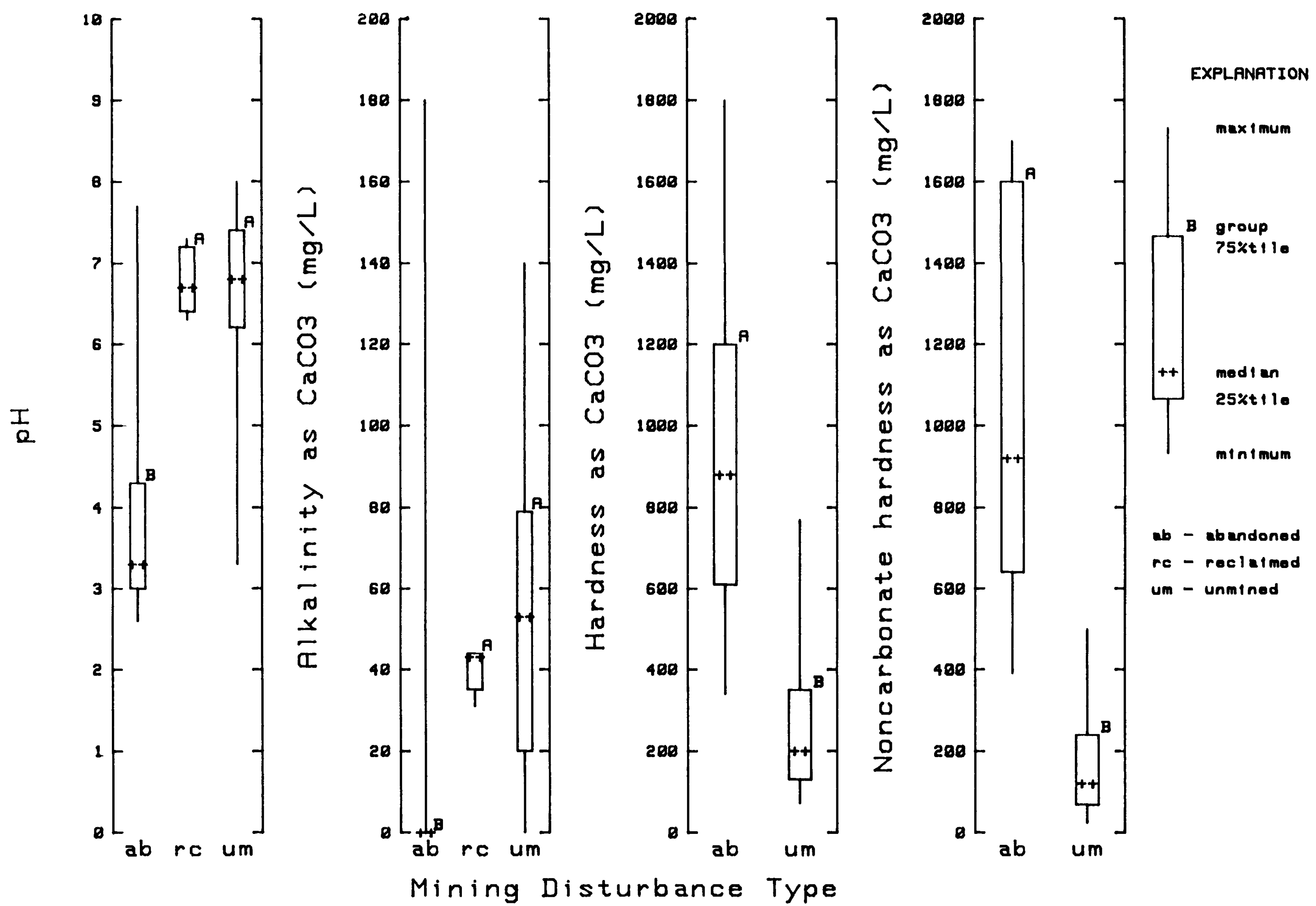


Figure 3.--Ranges, quartiles, and median concentrations of selected nonmetals and pH for sites grouped by mining-disturbance type in the Allegheny Formation. (Groups with different letters are significantly different.)

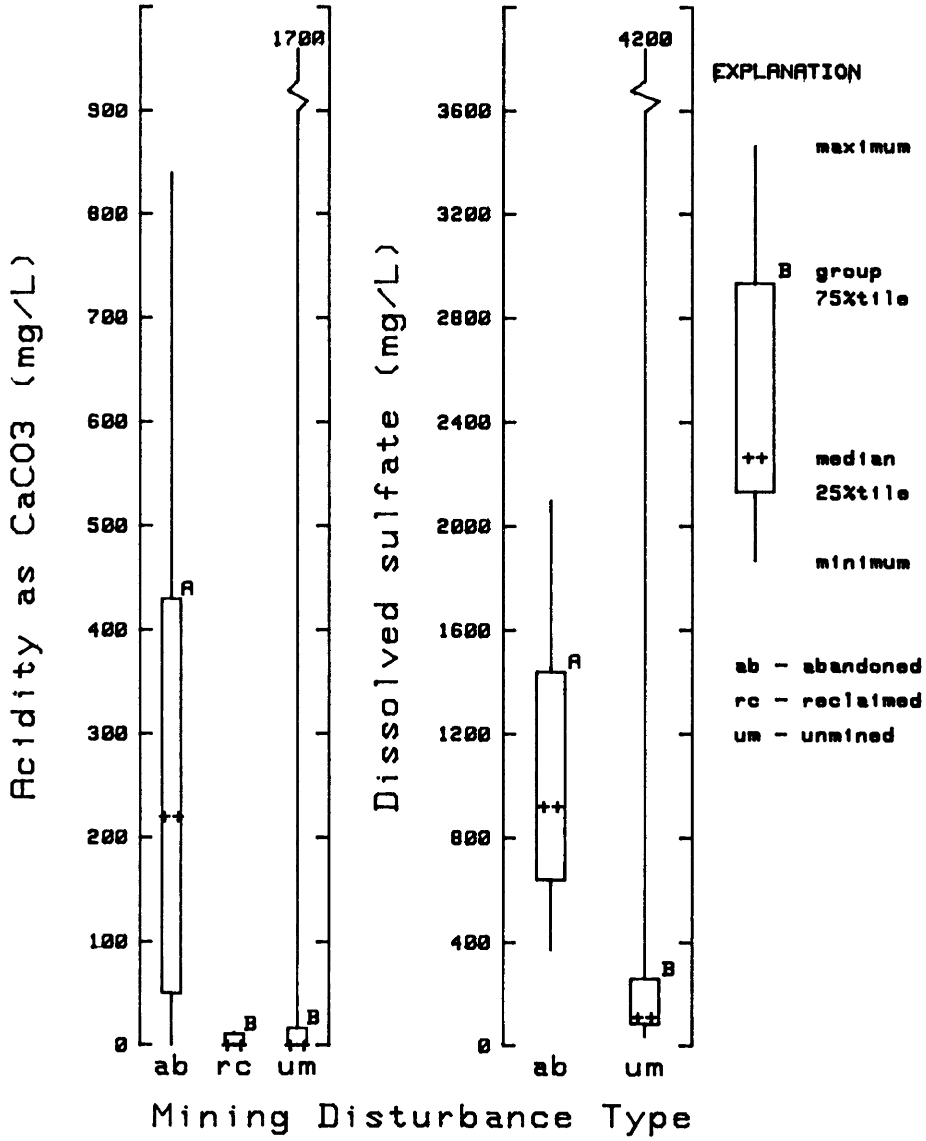


Figure 3.--Ranges, quartiles, and median concentrations of selected nonmetals and pH for sites grouped by mining-disturbance type in the Allegheny Formation.--Continued

Table 4.--Results of analysis of variance between mining disturbance types within the Allegheny and Monongahela Formations

Constituent or property	Allegheny Formation			Monongahela Formation		
	Number of observations	[1]F statistic	[2]Probability of a greater F	Number of observations	[1]F statistic	[2]Probability of a greater F
Specific conductance (µS/cm)	118	38.2	0.00	116	80.5	0.00
ph	118	54.5	.00	119	4.5	.01
Alkalinity, as $CaCO_3$ (mg/L)	117	47.2	.00	119	2.79	.06
Bicarbonate, as HCO_3 (mg/L)	77	16.8	.00	112	1.26	.29
Acidity, as $CaCO_3$ (mg/L)	115	37.9	.00	118	5.43	.00
Hardness, as $CaCO_3$ (mg/L)	[3]50	75.1	.00	47	37.65	.00
Noncarbonate hardness, as $CaCO_3$ (mg/L)	[3]27	23.7	.00	42	41.08	.00
Iron, total recoverable (µg/L)	[3]73	12.3	.00	55	6.20	.00
Iron, dissolved (µg/L)	[3]73	24.1	.00	55	1.24	.30
Manganese, total recoverable (ug/L)	[3]73	57.8	.00	55	3.91	.03
Manganese, dissolved (µg/L)	[3]73	52.5	.00	54	5.98	.00
Aluminum, total recoverable (µg/L)	[3]73	34.0	.00	51	5.82	.00
Aluminum, dissolved (µg/L)	[3]73	55.0	.00	51	2.55	.09
Nickel, dissolved (µg/L)	[3]73	30.7	.00	51	2.07	.14
Zinc, dissolved (µg/L)	[3]73	33.8	.00	51	7.22	.00
Sulfate, dissolved (mg/L)	92	56.7	.00	89	62.64	.00
Solids, dissolved (mg/L)	91	43.0	.00	85	64.32	.00

[1]Null hypothesis: $\mu_{reclaimed} = \mu_{abandoned} = \mu_{unmined}$

[2]At least one mean value is significantly different from others at the 95-percent level when the probability is less than 0.05.

[3]Reclaimed group not included because the number of observations = 2.

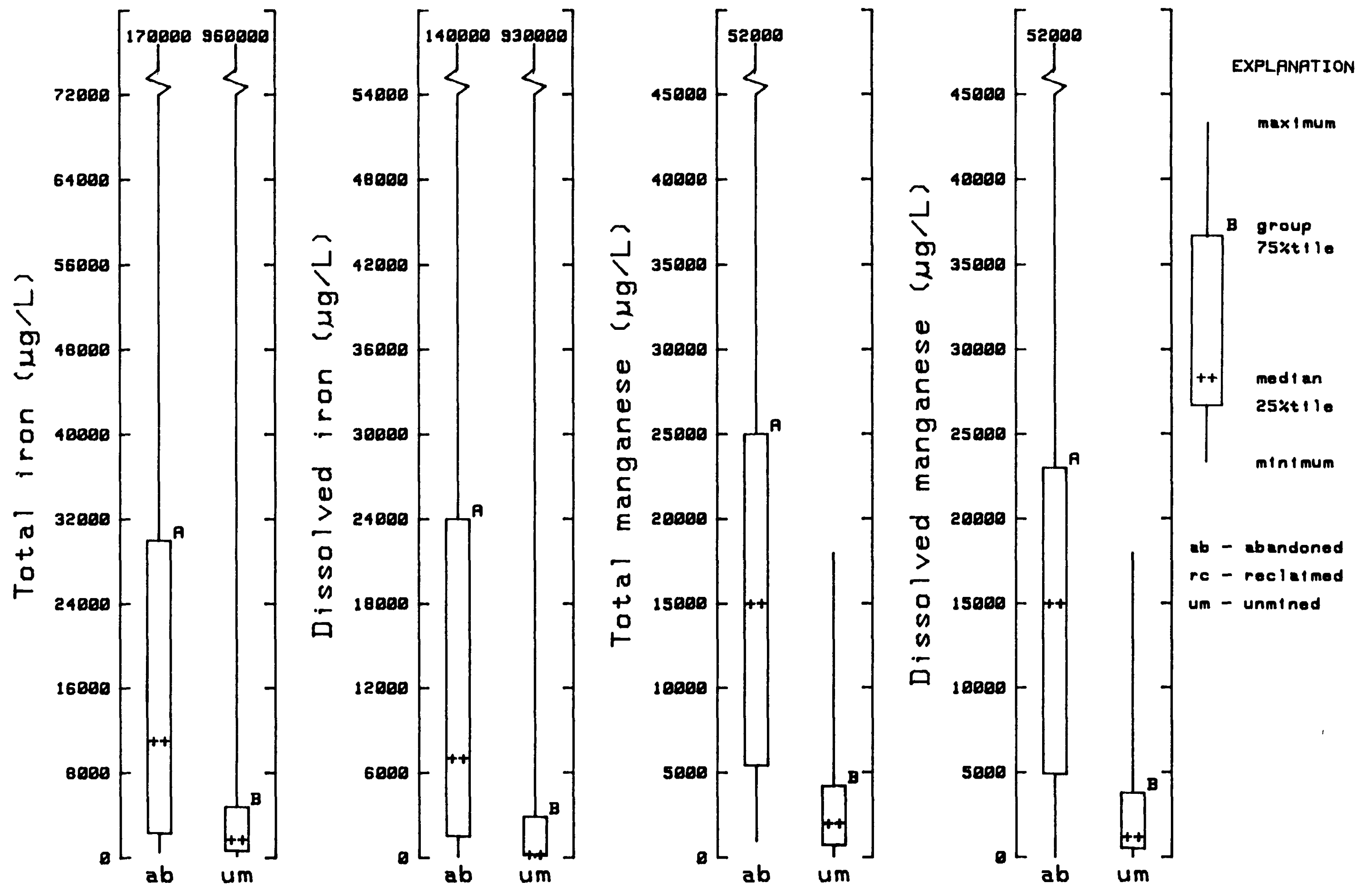
Table 5.--Results of Tukey's studentized range test for differences among the three mining disturbance types within the Allegheny and Monongahela Formations

Constituent or property	Type of disturbance	Allegheny Formation: Number of observations	Allegheny Formation: Median	Allegheny Formation: [1]Grouping	Monongahela Formation: Number of observations	Monongahela Formation: Median	Monongahela Formation: [1]Grouping
Specific conductance (µS/cm)	abandoned	63	1680	A	69	1520	A
	reclaimed	6	1670	A	9	1710	A
	unmined	49	510	B	38	600	B
ph	abandoned	63	3.3	B	71	7.4	B
	reclaimed	6	6.7	A	11	7.9	A
	unmined	49	6.8	A	37	7.6	AB
Alkalinity, as $CaCO_3$ (mg/L)	abandoned	62	0	B	[3]--	--	--
	reclaimed	5	43	A	--	--	--
	unmined	50	53	A	--	--	--
Bicarbonate, as HCO_3 (mg/L)	abandoned	27	0	B	[3]--	--	--
	reclaimed	5	52	BA	--	--	--
	unmined	45	76	A	--	--	--
Acidity, as $CaCO_3$ (mg/L)	abandoned	63	220	A	70	0	A
	reclaimed	6	0	B	11	0	B
	unmined	46	0	B	37	0	AB
Hardness, as $CaCO_3$ (mg/L)	abandoned	[2]--	--	--	27	860	A
	reclaimed	--	--	--	4	1200	A
	unmined	--	--	--	16	380	B
Noncarbonate hardness, as $CaCO_3$ (mg/L)	abandoned	[2]--	--	--	22	680	A
	reclaimed	--	--	--	4	960	A
	unmined	--	--	--	16	190	B
Iron, total recoverable (µg/L)	abandoned	[2]--	--	--	33	1100	A
	reclaimed	--	--	--	6	490	AB
	unmined	--	--	--	16	430	B
Iron, dissolved (µg/L)	abandoned	[2]--	--	--	[3]--	--	--
	reclaimed	--	--	--	--	--	--
	unmined	--	--	--	--	--	--
Manganese, total recoverable (µg/L)	abandoned	[2]--	--	--	33	500	[4]A
	reclaimed	--	--	--	6	370	AB
	unmined	--	--	--	16	180	B

Table 5.--Results of Tukey's studentized range test for differences among the three mining disturbance types within the Allegheny and Monongahela Formations--Continued

Constituent or property	Type of disturbance	Allegheny Formation: Number of observations	Allegheny Formation: Median	Allegheny Formation: [1]Grouping	Monongahela Formation: Number of observations	Monongahela Formation: Median	Monongahela Formation: [1]Grouping
Manganese, dissolved (µg/L)	abandoned	[2]--	--	--	33	460	[4]A
	reclaimed	--	--	--	6	160	AB
	unmined	--	--	--	15	84	B
Aluminum, total recoverable (µg/L)	abandoned	[2]--	--	--	31	800	[4]A
	reclaimed	--	--	--	4	260	AB
	unmined	--	--	--	16	100	B
Aluminum, dissolved (µg/L)	abandoned	[2]--	--	--	[3]--	--	--
	reclaimed	--	--	--	--	--	--
	unmined	--	--	--	--	--	--
Nickel, dissolved (µg/L)	abandoned	[2]--	--	--	[3]--	--	--
	reclaimed	--	--	--	--	--	--
	unmined	--	--	--	--	--	--
Zinc, dissolved (µg/L)	abandoned	[2]--	--	--	31	42	[4]A
	reclaimed	--	--	--	4	17	AB
	unmined	--	--	--	16	10	B
Sulfate, dissolved (mg/L)	abandoned	45	920	A	52	800	A
	reclaimed	4	1000	A	9	940	A
	unmined	43	110	B	28	140	B
Solids, dissolved (mg/L)	abandoned	45	1470	A	50	1450	A
	reclaimed	4	1680	A	7	1560	A
	unmined	42	292	B	28	445	B

[1]Groups with different letters have significantly different mean ranks at the .05 significance level.
[2]Multiple comparison not done since reclaimed sites were not used.
[3]Multiple comparison not done since ANOV null hypothesis was not rejected.
[4] α = 0.10.



Mining Disturbance Type

Figure 4.--Ranges, quartiles, and median concentrations of selected metals for sites grouped by mining-disturbance type in the Allegheny Formation. (Groups with different letters are significantly different.)

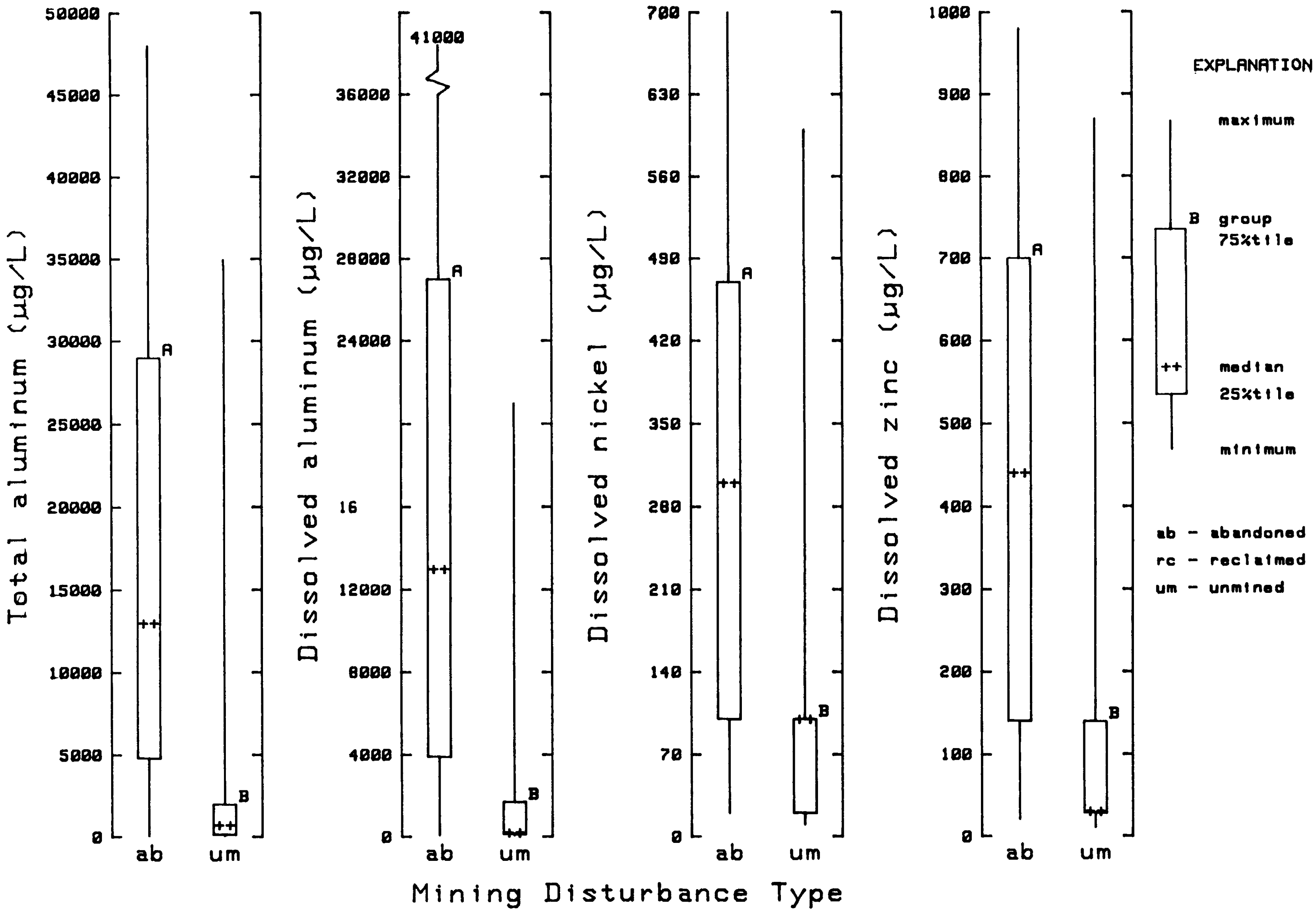


Figure 4.--Ranges, quartiles, and median concentrations of selected metals for sites grouped by mining-disturbance type in the Allegheny Formation.--Continued

total hardness equal to alkalinty is called carbonate hardness. Any remaining hardness (that is, hardness that exceeds alkalinity) is called noncarbonate hardness. High noncarbonate hardness in streams affected by acid mine drainage is likely due to high concentrations of dissolved metals combined with low concentrations of alkalinity.

Specific conductance and dissolved-solids concentration are also significantly higher in streams draining reclaimed and abandoned mines than in streams draining unmined areas. Sulfate, a conservative product of pyrite oxidation, is significantly higher at abandoned and reclaimed sites than at unmined sites (fig. 3). Pfaff and others (1981) reported that sulfate concentrations remained as high in Ohio streams draining reclaimed mines as in those draining abandoned mines.

Differences in Water Quality Based on Type of Mining Disturbance, Monongahela Formation

In streams draining the Monongahela Formation, as in streams draining the Allegheny Formation, specific conductance and concentrations of dissolved solids, carbonate hardness, and noncarbonate hardness are significantly higher in streams draining abandoned or reclaimed mines than in streams draining unmined areas (fig. 5). This is probably due to high metals concentrations. In contrast to streams draining the less calcareous Allegheny Formation, a significant difference in pH was not detected between abandoned and unmined sites. pH was significantly higher in streams draining reclaimed mines than in streams draining abandoned areas. Materials such as limestone are commonly used for reclamation and could account for the higher pH.

Dissolved manganese and zinc concentrations are significantly higher at abandoned-mine sites than unmined sites. This is not true for dissolved iron or aluminum (fig. 6). Manganese is soluble at relatively high pH. By contrast, iron and aluminum are insoluble at the nearly neutral pH conditions commonly found in streams draining all three mining-disturbance types.

Total aluminum, iron, and manganese concentrations are significantly higher in streams draining abandoned-mine areas than in streams draining unmined areas. The higher total metals concentrations probably represent material that is adsorbed to suspended sediment.

Sulfate concentrations are significantly higher in areas of abandoned and reclaimed mines than in unmined areas (fig. 5). After production by pyrite oxidation, sulfate persists in solution in normal surface water regardless of pH.

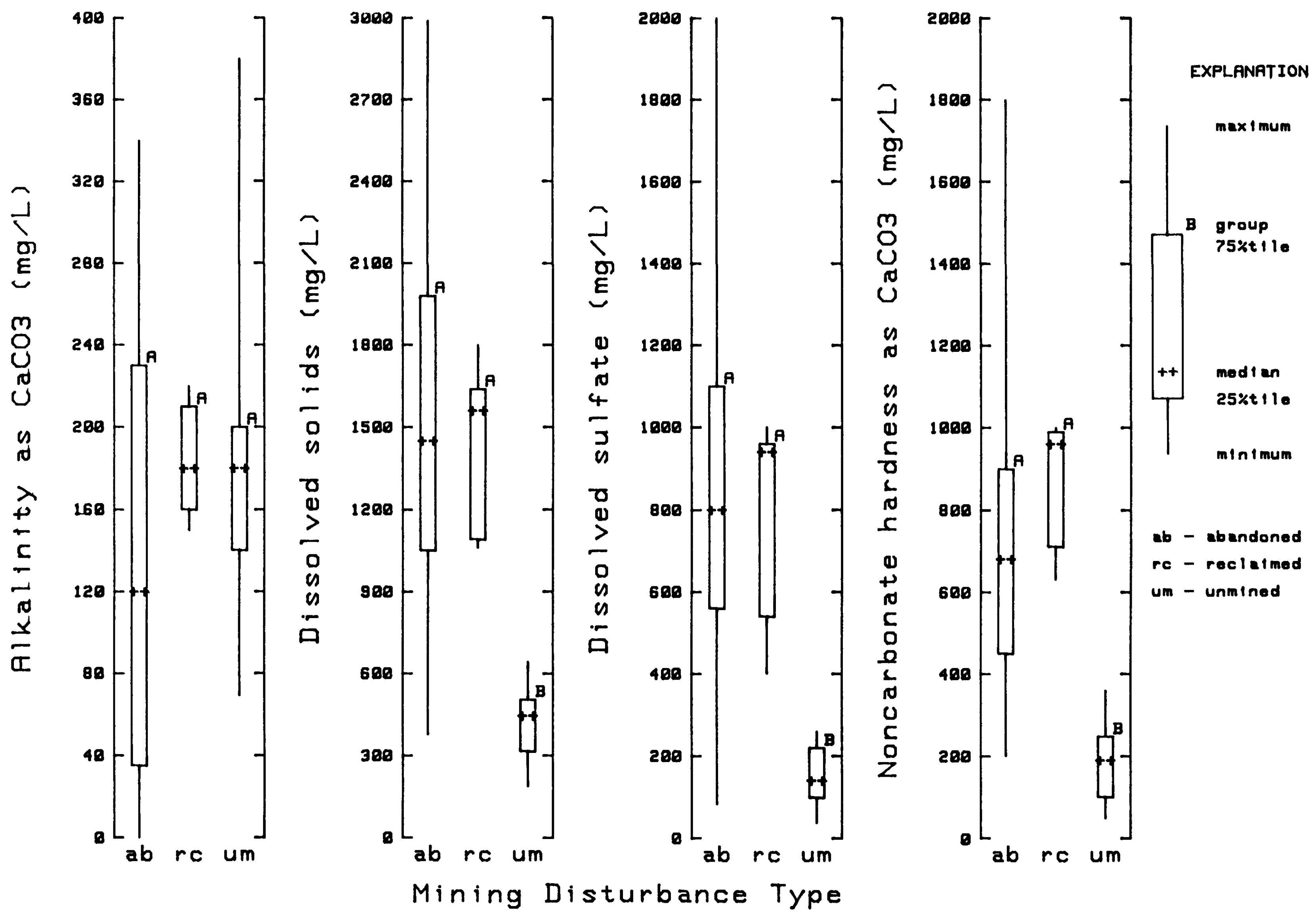


Figure 5.--Ranges, quartiles, and median concentrations for selected nonmetals and pH grouped by mining-disturbance type for sites in the Monongahela Formation. (Groups with different letters are significantly different.)

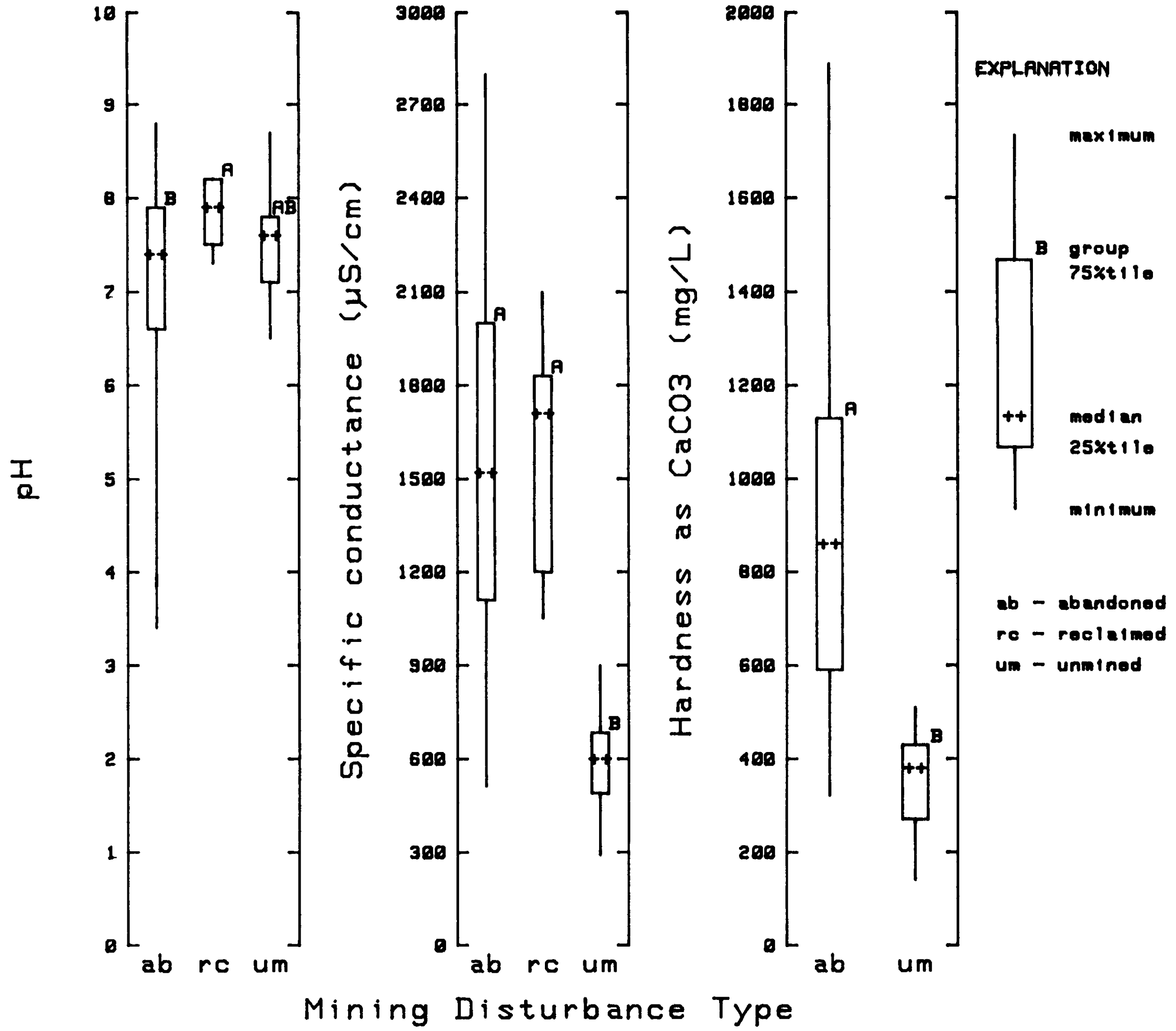


Figure 5.--Ranges, quartiles, and median concentrations for selected nonmetals and pH grouped by mining-disturbance type for sites in the Monongahela Formation.--Continued

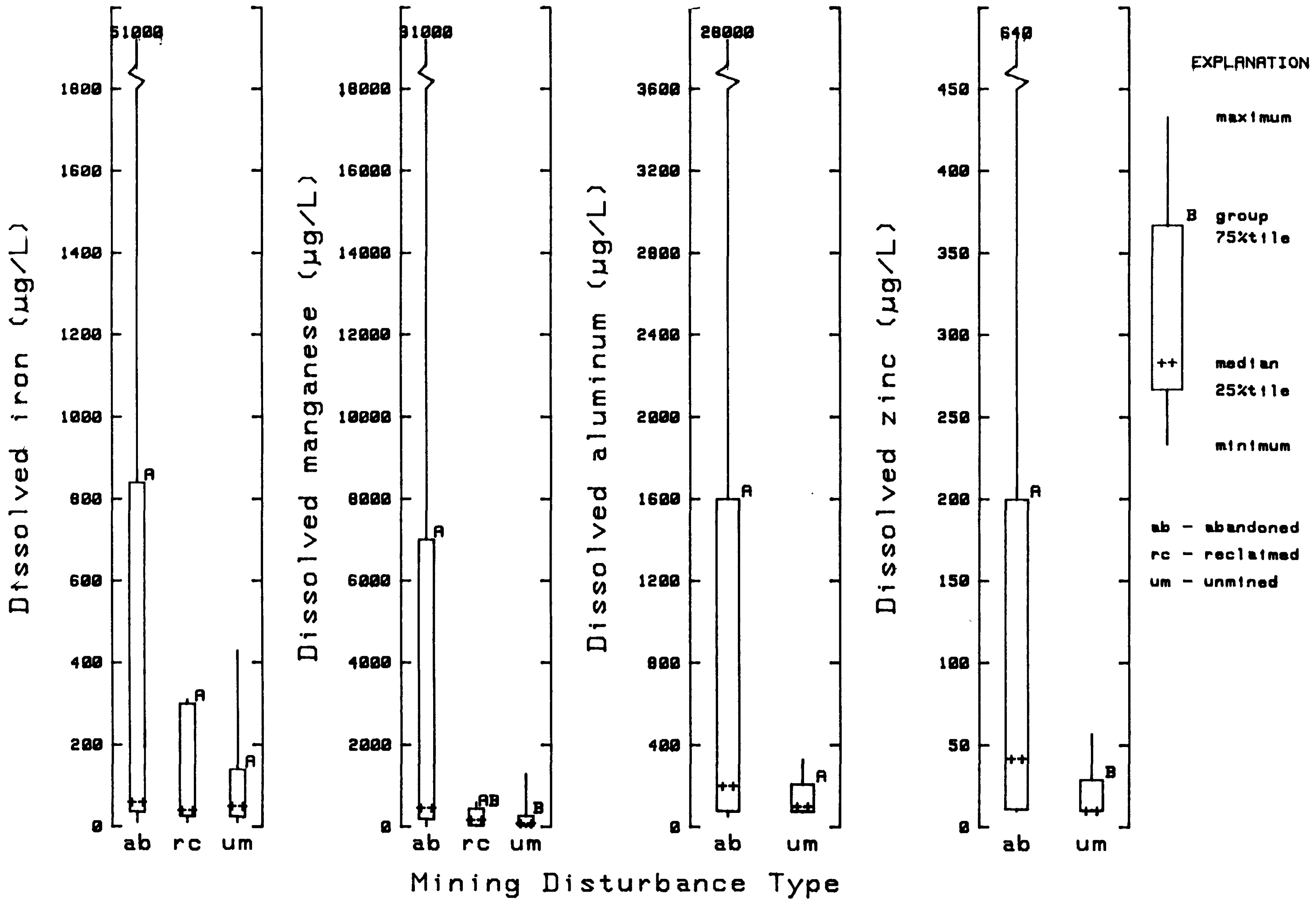


Figure 6.--Ranges, quartiles, and median concentrations of selected metals for sites grouped by mining-disturbance type in the Monongahela Formation. (Groups with different letters are significantly different.)

Table 6.--Results of analysis of variance between abandoned-mine and unmined areas in the Monongahela Formation for metals recoverable from bottom material

Constituent	Number of observations	[1]F statistic	[2]Probability of a greater F
Aluminum------	31	6.72	0.01
Iron----------	31	5.91	.02
Manganese-----	31	0.79	.38
Nickel--------	31	10.79	.00
Zinc----------	31	11.30	.00

[1]Null hypothesis: $\mu_{abandoned} = \mu_{unmined}$

[2]Mean ranks are significantly different at the 95-percent level when the probability is less than 0.05.

Differences in Bed Material Based on Type of Mining Disturbance

There are two conditions under which a water sample collected from the study area during low flow might not show the presence of acid mine drainage in the basin. The first is if carbonate-bearing strata in the Monongahela Formation buffer acidity produced by pyrite oxidation during low flow. The second is if pyrite-oxidation products are delivered to the stream primarily as a slug in runoff. This runoff causes a temporary increase in acidity, a drop in pH, and an increase in metal concentrations; these changes were observed at several sites during high flows.

When iron and manganese are oxidized to insoluble ferric and manganese hydroxides, trace metals adsorb and coprecipitate (Jenne, 1968). Therefore, the concentration of metals in bed material might be a more appropriate means of evaluating the impact of mining in those basins where acid mine drainage is intermittent or is neutralized by the calcareous strata. To test this, bed-material samples were collected at sites in both formations if the pH was greater than 5.5.

Data collected from sites classified as abandoned and unmined in the Monongahela Formation were examined for differences in bed-material quality using ANOV (table 6). Concentrations of aluminum, iron, nickel, and zinc are significantly higher at abandoned sites than at unmined sites. Concentrations of manganese are not significantly different. As noted previously, manganese does not precipitate as readily as iron, and trace metals such as zinc and nickel coprecipitate with the ferric hydroxides.

Bed-material data collected in the Allegheny Formation were not analyzed because of insufficient numbers of samples collected from abandoned sites.

Use of Comparisons

The results of these comparisons were used to select constituents for potential use in calibrating a discriminant function. The discriminant function reclassified "mixed" sites into a specific type of mining disturbance -- abandoned, reclaimed, or unmined -- based on which type best approximated the water quality at that site. In addition, the ANOV results show that the effect of acid mine drainage on water quality in the Allegheny and Monongahela Formations differs so that each requires a separate discriminant function calibrated with a different suite of constituents.

RECLASSIFICATION OF "MIXED" MINING-DISTURBANCE TYPES

Discriminant-function analysis is a multivariate statistical procedure that is used to assign a qualitative classification to a quantitative multivariate observation (Rao, 1952; Rao, 1966; Kendall and Stuart, 1966; Kendall, 1980; Kachigan, 1982). Consider a sample with two variables and two classification groups. When all of the observations are plotted in a scatter plot, observations from each classification occupy a generally different space with some overlap. The purpose of the discriminant function is to define a separation for the two groups (by a line in the case of the two-variate, two-group example) such that the number of misclassified observations is minimized. The method can be expanded to more than two variables and more than two classification groups.

The SAS "DISCRIM" procedure develops either a linear or quadratic generalized squared-distance function. Both assume normal distributions; therefore, rank transformations of the data were used (Conover and Iman, 1980). The linear discriminant function assumes homogeneous covariance matrices among the classification groups. The quadratic discriminant function does not require equal covariance matrices and is mathematically more complex. The SAS procedure includes a chi-square test of the hypothesis of equal covariance matrices and chooses the linear or quadratic function accordingly.

A classified sample was used to develop either a linear or quadratic generalized squared-distance function. Classification is based on the smallest generalized squared distance from an observation to a group mean. The probability of an observation belonging to a group (posterior probability) is the ratio of the generalized squared distance of that group to the sum of the generalized squared distances to all groups. The observation is reclassified into the group yielding the highest probability.

The discriminant function was used to reclassify the preclassified data set (based on land use) as a means of verification. An observation was considered misclassified whenever a new classification did not agree with the corresponding preclassification.

Unless the group distributions are completely distinct (and if this were the case, there would be no problem of discrimination), there is an area where observations from two or more groups overlap. An observation that falls in this area, referred to here as an area of uncertainty, will have nearly equal probability of belonging to more than one group. When the posterior probability of an observation belonging to any group was not greater than 65 percent, then the observation was not classified into any group but instead was designated "uncertain." A percentage of preclassified observations are expected to be in this area of uncertainty after verification.

This method of verification introduces two types of biases that work in opposite directions. First, the discriminant function developed from a preclassified sample is an estimate of the "true" discriminant function developed from the population. This results in a greater number of misclassifications than would be expected from the "true" function. Second, the preclassified sample was evaluated against a discriminant function developed from the identical sample. This results in a lower number of misclassifications than when evaluated against the "true" discriminant function (Kendall and Stuart, 1966; Kendall, 1980).

Constituents for potential use in the discriminant-function analysis were first selected by examining the ANOV results. Those constituents that were significantly different by disturbance type were tested. The combination of constituents that resulted in the fewest misclassified observations was chosen.

Sites that had been classified as "mixed" on the basis of land-use maps were reclassified by the calibrated discriminant function. Since the discriminant function had been calibrated with data that had been rank transformed, the "mixed" data set also had to be rank transformed. This was accomplished by assigning to each constituent the rank corresponding to a constituent with the same concentration in the calibration data set (Conover and Iman, 1980). When there was no exact corresponding concentration in the calibration set, a rank was assigned by interpolating between the next highest and next lowest concentration and corresponding rank. A concentration that was higher or lower than any in the calibration set was assigned the highest or lowest rank, respectively, in the calibration set. There must be no missing value for any constituent in order to enter an observation into the discriminant function. If an observation contained missing data, it was dropped from the analysis.

Constituents Used in Discriminant Analysis

Water Quality

The Allegheny Formation is characterized by generally small amounts of calcareous material, which results in poorly buffered drainage. Constituents that produced the best discriminant function were pyrite oxidation products (acidity and sulfate), products associated with high acidity and low pH (dissolved manganese and aluminum), and indicators of these products (pH and specific conductance). Sites preclassified as abandoned were reclassified abandoned in 90.5 percent of the cases. Unmined sites were 96.1 percent correctly reclassified. Because there were only two reclaimed sites, they were not entered into the discriminant function. Therefore, no mixed sites could be classified as reclaimed for the Allegheny Formation.

In the Monongahela Formation, specific conductance, dissolved sulfate, and dissolved manganese and alkalinity provided the best discriminant function among streams draining unmined, reclaimed, and abandoned sites. By means of this discriminant function, 97 percent of the observations preclassified as abandoned and 100 percent of the observations preclassified as reclaimed or unmined were correctly reclassified. The total number of misclassifications was 2 percent. Sulfate (a pyrite oxidation product) and manganese (an indirect product of acid mine drainage) remain in solution even at relatively high pH. Both are good indicators of past mining disturbance, and both differentiate between reclaimed and unmined areas for the well-buffered streams associated with this formation. Specific conductance is essentially an indirect measure of sulfate and manganese, as well as other dissolved constituents.

Good separation between the abandoned-mine group and the reclaimed-mine or unmined groups is not attained when alkalinity is removed from the discriminant function. Only 18 percent of the preclassified observations were correctly reclassified. Furthermore, all of the misclassifications are observations that were preclassified in the abandoned group. Clearly, alkalinity is an important factor in distinguishing basins classified as abandoned from those classified as unmined and reclaimed. The differences in alkalinity among the three disturbance types are significant at the 0.06 level (table 4), barely above the 0.05 criterion previously used.

Although the best discriminant function was attained by including dissolved manganese, there are a large number of observations, particularly from samples collected in 1982, for which dissolved manganese was not measured. For that reason, discriminant function analysis was also performed using only dissolved sulfate, alkalinity, and specific conductance. Reclassification of the data set resulted in a slight increase in misclassifications. All of the increase occurred for observations preclassified as abandoned (from 3.3 to 10 percent of the abandoned observations or from 2 to 6 percent of the total). Four percent of the observations from the abandoned-mine areas (2 percent of the total) were not classified because the posterior probability for each group was less than 65 percent. The increased error rate was acceptable, as removal of dissolved manganese from the discriminant function allowed an additional 85 observations of mixed disturbance type to be classified. Observations in the "mixed" data set were classified using both discriminant functions, and the results were compared. Only 15 percent of the observations classified using dissolved manganese were classified into a different group when dissolved manganese was removed. When observations with less than a 65 percent posterior probability of membership in a group were considered to be of uncertain classification rather than misclassified, only 4 percent were misclassified.

Bed Material

Discriminant functions were also developed from bed-material data as combinations of aluminum, iron, manganese, nickel, and zinc. The best discriminant function was achieved with manganese, nickel, and zinc. Addition of aluminum did not appreciably improve discrimination. Out of 31 sites used to develop the discriminant function, 77 percent were correctly reclassified. An additional 13 percent of the observations had posterior probabilities less the 65 percent and were therefore not classifiable. The bed-material data were not used in the final stream classification because use of the water-quality data resulted in better discrimination (that is, there were fewer misclassifications).

Results of Analysis

Each observation of each "mixed" site was reclassified by the following scheme according to the results of the discriminant function for the formation in which the site is located:

Probability of being abandoned, reclaimed, or unmined (in percent)	Mining impact	Classification
≥90	Strongly characteristic of abandoned, reclaimed, or unmined lands	Ab1, Rc1, or Um1, respectively
80-90	Moderately characteristic of abandoned, reclaimed, or unmined lands	Ab2, Rc2, or Um2, respectively
65-79	Weakly characteristic of abandoned, reclaimed, or unmined lands	Ab3, Rc3, or Um3, respectively
<65	Cannot be classified	Uncertain

Furthermore, a summary classification was assigned to each site by averaging the probability associated with the reclaimed, abandoned, or unmined categories for all observations within a site and applying the classification scheme described above to the average probability.

There were an insufficient number of sites preclassified as reclaimed in the Allegheny Formation for use in the discriminant function; therefore, none of the "mixed" sites in that formation were reclassified "Rc."

The results are shown in tables 7 and 8 (at back of report) for sites in the Allegheny Formation and in the Monongahela Formation, respectively. The basin maps in figure 7 (at back of report) show the summary classification assigned to each site based on the discriminant function.

Because sites in the Monongahela and Allegheny Formations were evaluated separately, equal classifications do not imply equivalent water quality if the sites in question are not from the same geologic formation. As stated earlier, there are real differences in the effect of abandoned surface mines on surface-water quality in the two formations because of the greater number of carbonate-bearing strata in the Monongahela Formation.

Table 9 compares the 75 percentiles, medians, and 25 percentiles for constituents used in the discriminant-function analysis. They are grouped both by geologic formation and by classification. This provides a qualitative means of comparing the water quality of observations that have the same classification but are in different formations. For example, the median dissolved aluminum concentration of observations classified as AB in the Allegheny Formation is 10,250 μg/L. In the Monongahela Formation, the median dissolved aluminum concentration for observations classified as AB is 201 μg/L, about the same as for sites classified as UM in the Allegheny Formation. Furthermore, median pH for the classification AB in the Monongahela Formation is 7.3 whereas median pH is less than 7.0 for all classifications in the Allegheny Formation. Therefore, based on pH and dissolved aluminum, a site classified as AB in the Allegheny Formation has poorer water quality than a site classified as AB in the Monongahela Formation.

SUMMARY AND CONCLUSIONS

Water-quality samples were collected at 276 sites in Ohio's coal region four times over a 3-year period. The sites represent 35 basins underlain by either of two geologic formations (Allegheny and Monongahela). Samples were analyzed for dissolved and total iron, manganese, and aluminum; dissolved zinc and nickel; sulfate; dissolved solids; specific conductance; pH; alkalinity; and acidity. In addition, bed-material samples were collected at selected sites in 1982 and analyzed for total recoverable iron, manganese, aluminum, nickel, and zinc.

Maps showing areas of underground mines and of abandoned, partially reclaimed, and reclaimed surface mines were used to determine the percentage of each study basin disturbed by mining. On the basis of these data, each site was classified into one of four mining disturbance types (abandoned, reclaimed, unmined, or mixed). In the Allegheny Formation, 14 percent were classified abandoned, 11 percent unmined, and 75 percent mixed. In the Monongahela Formation, 18 percent were classified abandoned, 2 percent as reclaimed, 10 percent as unmined, and 70 percent as mixed.

Ranks of concentrations of each constituent were calculated for the abandoned, reclaimed, and unmined disturbance categories. Analysis of variance and Tukey's studentized range test were used to determine whether differences in mean rank were significant among mining-disturbance categories. Water-quality data collected from sites that were preclassified as "abandoned," "reclaimed," and "unmined," were used to calibrate a discriminant function. Each site preclassified as "mixed" was then assigned a new classification (abandoned, reclaimed, or unmined) by the discriminant function. The results were used to classify each site according to impact from acid mine drainage. The ten classifications are: Strongly characteristic of (1) abandoned, (2) reclaimed, or (3) unmined areas; moderately characteristic of (4) abandoned, (5) reclaimed, or (6) unmined areas; weakly characteristic of (7) abandoned, (8) reclaimed, or (9) unmined areas; or (10) cannot be classified. In the Allegheny Formation, 57 percent of the "mixed" sites were reclassified as "unmined," 27 percent as "abandoned," and 15 percent as "uncertain." Four sites were not classified because there were insufficient data. In the Monongahela Formation, 18 percent of the "mixed" sites were reclassified as "unmined," 46 percent as "abandoned," 11 percent as "reclaimed," and 24 percent as "uncertain."

Streams draining unmined basins in the Allegheny and Monongahela Formations differ significantly in the concentrations of alkalinity, bicarbonate, acidity, dissolved sulfate, dissolved solids, and values of pH. There are more carbonate-bearing strata in the Monongahela Formation than in the Allegheny Formation. The result is a greater buffering capacity in streams draining the Monongahela Formation and, therefore, a greater capacity to assimilate acid mine drainage.

The concentrations of all constituents tested in streams draining the Allegheny Formation were significantly different among mining-disturbance types tested. In the Monongahela Formation, specific conductance, dissolved solids, pH, sulfate, dissolved manganese, hardness, and noncarbonate hardness were significantly different among streams draining different mining-disturbance types.

For streams draining the Allegheny Formation, the best discriminators among mining-disturbance types are acidity, pH, sulfate, dissolved manganese, and dissolved aluminum. For streams draining the Monongahela Formation, the best discriminators are specific conductance, dissolved sulfate, and alkalinity.

This report provides the Ohio Department of Natural Resources with a mechanism for identifying and ranking basins in need of reclamation, identifies the critical characteristics of areas having potential for adverse impact from surface mining, and identifies the extent of impact downstream from the mining site.

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Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation

[Sites marked with an asterisk were preclassified and were used to calibrate the discriminant function. "Unc" stands for "uncertain".]

Basin number	Site number	Year sampled	Percent probability Abandoned	Percent probability Unmined	Classification by observation	Summary classification	Preclassification
1	1	80	93.5	6.5	AB1	unc	
		81	81.9	18.1	AB2		
		82	16.3	83.7	UM2		
	2	80	98.2	1.8	AB1	AB2	
		81	76.6	23.4	AB3		
2	1	80	0.1	99.9	UM1	UM1	
		81	1.2	98.8	UM1		
	2	80	2.9	97.1	UM1	UM3	
		81	33.3	66.7	UM3		
	3	80	26.1	73.9	UM3	UM2	
		81	8.5	91.5	UM1		
	*4	80	.4	99.6	UM1	UM1	UM
		81	.1	99.9	UM1		
	*5	80	.1	99.9	UM1	UM1	UM
		81	.1	99.9	UM1		
4	1	80	4.2	95.8	UM1	UM1	
		81	1.4	98.6	UM1		
	*2	80	.3	99.7	UM1	UM1	UM
		81	.1	99.9	UM1		
	3	80	2.2	97.8	UM1	UM1	
		81	0	100.0	UM1		
	4	80	2.1	97.9	UM1	UM1	
		81	.2	99.8	UM1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability		Classification by observation	Summary classification	Preclassification
			Abandoned	Unmined			
4	5	80	97.8	2.2	AB1	unc	
(cont.)		81	1.5	98.5	UM1		
	6	80	81.2	18.8	AB2	AB3	
		81	52.1	47.9	unc		
	7	80	29.4	70.6	UM3	UM2	
		81	6.7	93.3	UM1		
	8	80	87.9	12.1	AB2	unc	
		81	62.8	37.2	unc		
		82	32.8	67.2	UM3		
	9	80	30.2	69.8	UM3	UM3	
		81	11.9	88.1	UM2		
	10	80	4.2	95.8	UM1	UM1	
		81	11.4	88.6	UM1		
5	1	80	2.5	97.5	UM1	UM1	
		81	2.1	97.9	UM1		
	2	80	7.0	93.0	UM1	UM1	
		81	.7	99.3	UM1		
10	1	80	27.7	72.3	UM3	AB3	
		81	89.4	10.6	AB2		
		82	99.2	0.8	AB1		
	*2	80	5.0	95.0	UM1	UM1	UM
	*3	80	99.5	.5	AB1	AB1	AB
		81	100.0	0	AB1		
		82	99.9	.1	AB1		
	4	80	1.6	98.4	UM1	UM2	
		81	32.6	67.4	UM3		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
10 (cont.)	5	80	89.6	10.4	AB2	AB1	
		81	99.7	.3	AB1		
		82	100.0	0	AB1		
	6	81	0.1	99.9	UM1	UM1	
	7	80	7.5	92.5	UM1	UM2	
		81	17.3	82.7	UM2		
		82	33.8	66.2	UM3		
	8	80	82.0	18.0	AB2	unc	
		81	4.4	95.6	UM1		
	9	80	23.6	76.4	UM3	unc	
		81	44.6	55.4	unc		
		82	48.9	51.1	unc		
	10	80	2.6	97.4	UM1	UM1	
		81	1.9	98.1	UM1		
	11	80	10.1	89.9	UM2	UM2	
		81	22.2	77.8	UM3		
		82	13.6	86.4	UM2		
11	1	81	0.2	99.8	UM1	UM1	
	2	Insufficient data----------------					
	3	80	6.7	93.3	UM1	UM1	
		81	2.5	97.5	UM1		
	4	81	.1	99.9	UM1	UM1	
	5	80	4.8	95.2	UM1	UM1	
	6	80	2.8	97.2	UM1	UM1	
		81	.1	99.9	UM1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
11 (cont.)	7	80	9.2	90.8	UM1	UM2	
		81	22.0	78.0	UM3		
		82	16.2	83.8	UM2		
	8	80	1.3	98.7	UM1	UM1	
		82	5.8	94.2	UM1		
	9	80	1.4	98.6	UM1	UM1	
		81	.9	99.1	UM1		
16	*1	81	99.6	0.4	AB1	AB1	AB
		82	100.0	0	AB1		
	*2	81	89.5	10.5	AB2	AB1	AB
		82	99.9	.1	AB1		
	3	82	99.9	.1	AB1	AB1	
	4	80	59.8	40.2	unc	UM3	
		81	9.8	90.2	UM1		
		82	2.4	97.6	UM1		
	*5	80	3.9	96.1	UM1	UM1	UM
	*6	80	0.5	99.5	UM1	UM2	UM
		81	.7	99.3	UM1		
		82	38.9	61.1	unc		
	7	80	50.1	49.9	unc	UM2	
		81	0	100.0	UM1		
		82	3.8	96.2	UM1		
	8	80	39.0	61.0	unc	UM3	
		81	56.9	43.1	unc		
		82	4.9	95.1	UM1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
16 (cont.)	9	80	17.6	82.4	UM2	UM2	
		81	23.0	77.0	UM3		
		82	6.1	93.9	UM1		
	10	80	90.1	9.9	AB1	AB2	
		81	99.8	.2	AB1		
		82	66.3	33.7	AB3		
	11	80	16.8	83.2	UM2	UM3	
		81	8.3	91.7	UM1		
		82	46.1	53.9	unc		
20	1	81	98.3	1.7	AB1	AB2	
		82	76.6	23.4	AB3		
	*2	82	45.3	54.7	unc	unc	AB
	3	81	0.7	99.3	UM1	UM1	
		82	16.6	83.4	UM2		
	4	81	5.2	94.8	UM1	UM1	
	5	82	22.1	77.9	UM3	UM3	
	6	81	1.0	99.0	UM1	UM2	
		82	31.8	68.2	UM3		
	7	81	12.5	87.5	UM2	UM2	
		82	26.8	73.2	UM3		
	8	81	6.6	93.4	UM1	UM1	
		82	1.6	98.4	UM1		
	9	81	50.7	49.3	unc	unc	
		82	21.7	78.3	UM3		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
20 (cont.)	10	81	94.0	6.0	AB1	unc	
		82	31.4	68.6	UM3		
	*11	81	100.0	0	AB1	AB1	AB
		82	100.0	0	AB1		
	12	81	99.0	1.0	AB1	AB1	
		82	92.8	7.2	AB1		
21	*1	81	2.6	97.4	UM1	UM1	UM
	*2	81	91.4	8.6	AB1	unc	UM
		82	18.0	82.0	UM2		
	*3	81	15.3	84.7	UM2	UM3	AB
		82	32.5	67.5	UM3		
	*4	81	11.2	88.8	UM2	UM3	AB
		82	48.4	51.6	unc		
	5	Insufficient data----------------------------					
	*6	81	0	100.0	UM1	UM1	UM
		82	0	100.0	UM1		
	7	81	0	100.0	UM1	UM1	
		82	0.6	99.4	UM1		
	8	81	97.6	2.4	AB1	AB1	
		82	96.1	3.9	AB1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
28	*1	81	99.9	.1	AB1	AB1	AB
		82	99.9	.1	AB1		
	*2	81	99.7	.3	AB1	AB1	AB
		82	99.9	.1	AB1		
	3	81	4.9	95.1	UM1	UM1	
	4	81	98.5	1.5	AB1	AB1	
		82	98.8	1.2	AB1		
	5	Insufficient data----------------------------					
	6	81	43.0	57.0	unc	unc	
		82	35.1	64.9	unc		
	*7	81	0.1	99.9	UM1	UM1	UM
29	1	81	73.8	26.2	AB3	unc	
		82	51.5	48.5	unc		
	*2	81	100.0	0	AB1	AB1	AB
		82	100.0	0	AB1		
	3	81	76.1	23.9	AB3	AB2	
		82	97.2	2.8	AB1		
	*4	81	100.0	0	AB1	AB1	AB
		82	100.0	0	AB1		
	*5	81	100.0	0	AB1	AB1	AB
		82	98.8	1.2	AB1		
	6	81	99.3	6.8	AB1	AB1	
		82	95.0	5.0	AB1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
29 (cont.)	7	81	99.6	0.4	AB1	AB1	
		82	94.9	5.1	AB1		
	*8	81	98.9	1.1	AB1	AB1	AB
		82	90.3	9.7	AB1		
	9	Insufficient data-----------------------------					
	*10	81	99.0	1.0	AB1	AB1	AB
	11	82	98.8	1.2	AB1	AB1	
30	1	81	51.5	48.5	unc	unc	
		82	42.5	57.5	unc		
	*2	81	1.1	98.9	UM1	unc	AB
		82	99.7	0.3	AB1		
	3	81	86.1	13.9	AB2	AB3	
		82	69.1	30.9	AB3		
	*4	80	100.0	0	AB1	AB1	AB
		81	91.6	8.4	AB1		
		82	99.9	.1	AB1		
	5	80	.4	99.6	UM1	UM1	
		81	.1	99.9	UM1		
	6	81	4.7	95.3	UM1	UM1	
35	1	81	33.4	66.6	UM3	UM3	
	2	81	0	100.0	UM1	UM1	
	*3	81	99.9	0.1	AB1	AB1	AB
		82	81.1	18.9	AB2		
	*4	81	99.8	.2	AB1	AB1	AB
		82	99.0	1.0	AB1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
35	*5	81	95.4	4.6	AB1	AB2	AB
(cont.)		82	73.1	26.9	AB3		
	6	81	7.3	92.7	UM1	unc	
		82	69.5	30.5	AB3		
	7	81	99.4	.6	AB1	AB1	
		82	94.8	5.2	AB1		
	8	81	3.6	96.4	UM1	UM1	
	9	81	10.9	89.1	UM2	UM3	
		82	35.8	64.2	unc		
41	1	81	93.0	7.0	AB1	AB3	
		82	48.6	51.4	unc		
46	1	81	100.0	0	AB1	AB1	
	2	81	100.0	0	AB1	AB1	
	3	81	100.0	0	AB1	AB1	
47	*1	80	99.8	.2	AB1	AB1	AB
		81	97.2	2.8	AB1		
	2	80	0.9	99.1	UM1	UM1	
		81	.1	99.9	UM1		
	3	80	1.7	98.3	UM1	UM1	
		81	11.2	88.8	UM2		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
59	1	80	100.0	0	AB1	AB1	
		81	100.0	0	AB1		
		82	100.0	0	AB1		
	2	80	100.0	0	AB1	AB1	
		81	99.7	.3	AB1		
	3	80	100.0	0	AB1	AB1	
		81	100.0	0	AB1		
		82	100.0	0	AB1		
	4	80	99.9	0.1	AB1	AB1	
		81	98.3	1.7	AB1		
		82	99.2	.8	AB1		
	5	80	10.8	89.2	UM2	UM1	
		81	0.1	99.9	UM1		
	6	80	23.2	76.8	UM3	UM2	
		81	6.4	93.6	UM1		
	7	80	0	100.0	UM1	UM1	
		81	.3	99.7	UM1		
	8	80	95.1	4.9	AB1	AB1	
		81	99.3	.7	AB1		
		82	100.0	0	AB1		
	9	80	.6	99.4	UM1	UM1	
		81	3.5	96.5	UM1		
	*10	80	3.6	96.4	UM1	UM1	UM
	*11	80	5.0	95.0	UM1	UM2	UM
		81	20.1	79.9	UM3		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
59 (cont.)	*12	80	4.5	95.5	UM1	UM1	UM
		81	0	100.0	UM1		
	13	80	83.1	16.9	AB2	unc	
		81	5.9	94.1	UM1		
	14	81	.3	99.7	UM1	UM1	
	15	80	0	100.0	UM1	UM1	
		81	13.5	86.5	UM2		
	16	80	0	100.0	UM1	unc	
		81	59.3	40.7	unc		
		82	100.0	0	AB1		
	17	80	9.0	91.0	UM1	UM1	
		81	.8	99.2	UM1		
64	*1	80	.8	99.2	UM1	UM1	UM
		81	.1	99.9	UM1		
	2	80	7.2	92.8	UM1	UM1	
		81	1.0	99.0	UM1		
	3	80	.2	99.8	UM1	UM1	
		81	.2	99.8	UM1		
	4	80	63.0	37.0	unc	unc	
		81	20.2	79.8	UM2		
	*5	80	100.0	0	AB1	AB1	AB
		81	100.0	0	AB1		
	6	80	100.0	0	AB1	unc	
		81	100.0	0	AB1		
		82	2.0	98.0	UM1		

Table 7.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Allegheny Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
64 (cont.)	7	80	79.7	20.3	AB3	unc	
		81	2.2	97.8	UM1		
	8	80	100.0	0	AB1	AB1	
		81	100.0	0	AB1		
		82	99.5	0.5	AB1		
	9	80	3.4	96.6	UM1	UM1	
		81	2.2	97.8	UM1		
66	*1	81	0.9	99.1	UM1	UM1	UM
	2	81	100.0	0	AB1	AB1	
		82	100.0	0	AB1		
	3	80	3.0	97.0	UM1	UM1	
		81	1.7	98.3	UM1		
	4	80	10.0	90.0	UM1	UM1	
		81	.4	96.0	UM1		
	*5	81	0	100.0	UM1	UM1	UM
	6	80	4.6	95.4	UM1	UM1	
		81	.2	99.8	UM1		
	7	80	23.0	77.0	UM3	UM2	
		81	1.1	98.9	UM1		
	8	80	19.4	80.6	UM2	UM1	
		81	0.2	99.8	UM1		
	9	81	13.7	86.3	UM2	UM2	
	10	81	1.0	99.0	UM1	UM1	

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation

[Sites marked with an asterisk were preclassified and were used to calibrate tne discriminant function. "Unc" stands for "uncertain".]

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
2	6	80	99.2	0.8	0	AB1	AB1	
		81	83.4	0	16.6	AB2		
		82						
	*7	81	0.5	0	99.5	UM1	UM1	UM
		82	1.7	0	98.3	UM1		
5	3	80	97.8	1.4	0.9	AB1	AB1	
		81	99.1	.6	0.3	AB1		
		82	99.7	.1	.2	AB1		
	4	80	8.5	.1	91.5	UM1	UM1	
		81	4.0	.1	95.9	UM1		
		82	1.2	1.0	97.7	UM1		
	5	80	95.8	0	4.2	AB1	AB1	
		81	99.3	0	0.7	AB1		
		82	77.0	0	23.0	AB3		
	6	80	1.5	0	98.5	UM1	UM1	
		81	1.3	0	98.7	UM1		
		82	10.5	0	89.5	UM2		
7	1	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		
	2	81	72.5	0	27.5	AB3	unc	
		82	56.3	0	43.7	unc		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
7	3	81	100.0	0	0	AB1	AB1	
(cont.)		82	100.0	0	0	AB1		
	*4	80	100.0	0	0	AB1	AB1	AB
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
	*5	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	6	80	100.0	0	0	AB1	AB1	
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
	7	80	100.0	0	0	AB1	AB1	
		81	100.0	0	0	AB1		
	*8	80	17.5	0	82.5	UM2	UM1	UM
		81	0.5	0.1	99.4	UM1		
		82	.3	0	99.7	UM1		
	9	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		
	10	81	100.0	0	0	AB1	AB1	
12	1	81	35.6	0	64.4	unc	unc	
		82	30.5	0	69.5	unc		
	2	81	99.8	0	0.1	AB1	AB1	
		82	100.0	0	0	AB1		
	3	Insufficient data------------------------------						
	*4	81	57.1	31.5	11.4	unc	unc	AB
		82	.7	.1	99.2	UM1		
	5	81	.6	0	99.4	UM1	UM1	

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
12 (cont.)	6	81	45.2	0	54.8	unc	AB3	
		82	96.3	3.7	0	AB1		
	7	81	99.3	0.7	0	AB1	AB1	
		82	91.2	8.8	0	AB1		
	8	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		
	9	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		
	10	80	99.1	.2	0.7	AB1	AB1	
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
14	1	81	3.8	0	96.2	UM1	UM1	
		82	3.0	0	97.0	UM1		
	2	81	3.4	0	96.6	UM1	UM1	
		82	2.0	0	98.0	UM1		
22	1	81	2.1	0.1	97.8	UM1	UM1	
		82	0.5	.2	99.2	UM1		
	*2	81	11.6	0	88.4	UM2	UM1	UM
		82	1.1	.1	98.8	UM1		
	*3	81	.1	0	99.9	UM1	UM1	UM
		82	.1	0	99.9	UM1		
	*4	81	2.1	1.6	96.2	UM1	UM1	UM
		82	.2	0	99.8	UM1		
	*5	81	2.9	0	97.1	UM1	UM1	UM
		82	.4	0	99.6	UM1		
	6	81	3.8	0	96.2	UM1	UM1	
		82	.6	0	99.4	UM1		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Reclaimed	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
25	1	81	30.3	69.9	0	unc	RC3	
		82	21.2	78.8	0	RC3		
	2	81	64.4	18.3	17.3	unc	unc	
		82	0.7	0	99.3	UM1		
	*3	81	3.4	0	96.6	UM1	UM1	UM
		82	14.8	0	85.2	UM2		
	*4	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	5	81	3.5	0.6	95.9	UM1	UM1	
		82	1.1	0	98.9	UM1		
	6	81	24.9	64.8	10.3	unc	unc	
		82	33.5	.6	65.9	UM3		
	*7	81	99.2	0	0.8	AB1	AB1	AB
		82	99.4	.6	0	AB1		
	8	81	85.9	12.2	1.9	AB2	AB3	
		82	58.0	22.5	19.5	unc		
	9	81	91.6	6.9	1.4	AB1	AB3	
		82	47.1	2.6	50.3	unc		
	10	80	39.4	58.4	2.1	unc	unc	
		81	22.1	.2	77.8	UM3		
		82	25.0	0	75.0	UM3		
31	*1	81	3.0	0	97.0	UM1	UM1	UM
		82	3.4	0	96.6	UM1		
	2	81	14.8	0	85.2	UM2	UM2	
		82	8.1	0	91.9	UM1		
	3	81	99.8	0.2	0	AB1	AB3	
		82	30.1	0	69.9	UM3		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Percent probability: Reclaimed	Percent probability: Unmined	Classification by observation	Summary classification	Preclassification
31 (cont.)	4	81	9.1	87.5	3.4	RC2	RC3	
		82	33.8	66.2	0	RC3		
	5	81	26.0	73.6	0.4	RC3	RC3	
		82	25.4	73.4	1.2	RC3		
	*6	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	*7	81	13.7	86.1	.2	RC2	RC2	RC
		82	14.5	84.8	.6	RC2		
	8	81	99.9	0.1	0	AB1	AB1	
		82	99.8	.2	0	AB1		
	9	81	100.0	0	0	AB1	AB1	
		82	99.9	.1	0	AB1		
	10	81	10.6	89.4	0	RC2	RC2	
		82	22.2	76.4	1.4	RC3		
33	*1	81	.2	0	99.8	UM1	UM1	UM
		82	.1	0	99.9	UM1		
	2	81	1.7	0	98.3	UM1	UM1	
		82	.2	0	99.8	UM1		
	3	81	1.8	1.8	96.5	UM1	UM1	
		82	.6	.1	99.3	UM1		
	*4	81	3.0	0	97.0	UM1	UM1	UM
		82	.5	0	99.5	UM1		
	5	81	100.0	0	0	AB1	AB1	
		82	98.5	0	1.5	AB1		
	*6	81	99.5	0	0.5	AB1	AB1	AB
		82	99.9	0	.1	AB1		

8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
33	*7	81	100.0	0	0	AB1	AB1	AB
(cont.)		82	100.0	0	0	AB1		
	*8	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	9	81	99.7	0	3.1	AB1	unc	
		82	1.6	2.4	96.0	UM1		
	*10	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	11	81	79.8	0.1	20.2	AB3	unc	
		82	4.7	2.4	92.9	UM1		
	12	81	56.8	9.8	33.4	unc	unc	
		82	9.1	1.2	89.7	UM1		
37	*1	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	2	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		
	3	81	100.0	0	0	AB1	unc	
		82	25.8	74.2	0	unc		
	4	81	99.7	.3	0	AB1	AB3	
		82	30.6	69.4	0	RC3		
	5	81	100.0	0	0	AB1	AB1	
		82	99.2	.8	0	AB1		
	6	81	51.6	48.4	0	unc	unc	
		82	41.7	58.2	.1	unc		
	7	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
37	8	81	98.6	1.4	0	AB1	AB1	
(cont.)		82	100.0	0	0	AB1		
	*9	81	0.6	0	99.4	UM1	UM1	UM
		82	.1	0	99.9	UM1		
38	*1	81	1.4	0	98.6	UM1	UM1	UM
		82	.1	0	99.9	UM1		
	*2	80	.6	0	99.4	UM1	UM1	UM
		81	.5	0	99.5	UM1		
		82	.6	0	99.4	UM1		
	3	80	.2	0	99.8	UM1	UM1	
		81	.1	0	99.9	UM1		
		82	.4	0	99.6	UM1		
	4	80	.3	0	99.7	UM1	UM1	
		81	.2	0	99.8	UM1		
		82	.2	0	99.8	UM1		
	5	80	5.2	94.5	0.3	RC1	RC3	
		81	44.4	55.0	.7	unc		
		82	31.1	68.9	0	RC3		
43	1	81	93.1	4.3	2.6	AB1	unc	
		82	18.3	44.1	37.6	unc		
	2	82	69.5	28.2	2.3	AB3	AB3	
	3	81	67.8	12.6	19.6	AB3	AB3	
		82	87.4	11.4	1.2	AB2		
	4	81	89.8	.1	10.1	AB2	AB2	
		82	73.6	24.9	1.5	AB3		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
48	1	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		
	2	80	28.9	66.4	4.7	RC3	unc	
		81	7.7	26.0	66.3	UM3		
		82	15.5	31.6	52.9	unc		
49	1	80	96.3	3.7	0	AB1	AB2	
		81	63.0	37.0	0	unc		
		82	97.6	0	2.4	AB1		
	2	80	6.8	93.2	0	RC1	unc	
		81	6.3	93.7	0	RC1		
		82	95.5	4.5	0	AB1		
	*3	80	8.4	91.6	0	RC1	RC2	RC
		81	6.9	93.1	0	RC1		
		82	28.1	71.9	0	RC3		
	4	82	58.4	41.6	0	unc	unc	
	5	80	100.0	0	0	AB1	AB1	
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
50	1	81	.6	0	99.4	UM1	UM1	
		82	20.2	0	79.8	UM3		
	2	82	99.9	0	0.1	AB1	AB1	
	3	80	1.2	0	98.8	UM1	UM1	
		81	.3	0	99.7	UM1		
		82	2.0	0	98.0	UM1		
	4	80	19.6	6.1	74.3	UM3	unc	
		81	2.2	1.3	96.5	UM1		
		82	28.1	66.9	5.0	RC3		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
50 (cont.)	*5	81	100.0	0	0	AB1	AB1	AB
		82	84.3	15.7	0	AB2		
	*6	81	80.5	19.5	0	AB2	AB1	AB
		82	100.0	0	0	AB1		
	*7	81	91.1	8.9	0	AB1	AB1	AB
		82	99.5	0.5	0	AB1		
	8	80	28.1	67.8	4.1	RC3	unc	
		81	19.3	7.6	73.1	UM3		
		82	31.2	65.7	3.1	RC3		
	9	80	28.3	68.2	3.6	RC3	unc	
		81	25.3	25.7	49.1	unc		
		82	32.1	67.6	0.3	RC3		
55	*1	81	100.0	0	0	AB1	AB1	AB
		82	100.0	0	0	AB1		
	2	81	30.2	69.8	0	RC3	RC3	
		82	28.1	71.9	0	RC3		
	3	80	100.0	0	0	AB1	AB1	
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
	*4	81	5.2	94.8	0	RC1	unc	AB
		82	85.4	14.6	0	AB2		
	5	81	19.2	80.8	0	RC2	RC3	
		82	28.2	71.8	0	RC3		
	*6	80	31.1	68.9	0	RC3	unc	AB
		81	25.6	74.4	0	RC3		
		82	98.4	1.6	0	AB1		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
55 (cont.)	*7	80	76.9	23.1	0	AB3	AB2	AB
		81	92.3	7.7	0	AB1		
		82	90.7	9.3	0	AB1		
	*8	81	99.8	0	.2	AB1	AB1	AB
		82	99.6	0	.4	AB1		
	*9	81	99.8	0	.2	AB1	AB1	AB
		82	100.0	0	0	AB1		
	*10	80	99.5	.5	0	AB1	AB1	AB
		81	99.2	.8	0	AB1		
		82	100.0	0	0	AB1		
	11	81	7.9	92.1	0	RC1	unc	
		82	100.0	0	0	AB1		
	12	80	90.6	9.4	0	AB1	AB2	
		81	68.8	31.2	0	AB3		
		82	94.1	5.9	0	AB1		
	13	80	91.8	8.1	0	AB1	unc	
		81	6.4	93.6	0	RC1		
		82	11.8	88.2	0	RC2		
	14	80	20.6	79.4	0	RC3	RC3	
		81	9.0	91.0	0	RC1		
		82	54.4	45.6	0	unc		
56	1	81	14.0	86.0	0	RC2	RC3	
		82	45.8	54.2	0.1	unc		
	2	81	100.0	0	0	AB1	AB1	
		82	100.0	0	0	AB1		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
56 (cont.)	3	81	22.1	77.9	0	RC3	unc	
		82	100.0	0	0	AB1		
	4	80	25.0	75.0	0	RC3	AB3	
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
	5	81	99.2	0	0.8	AB1	AB1	
		82	97.1	2.9	0	AB1		
	6	81	98.2	0	1.8	AB1	AB1	
		82	99.2	0	.8	AB1		
	7	81	96.7	3.3	0	AB1	AB1	
		82	99.6	.4	0	AB1		
	8	80	23.6	76.4	0	RC3	unc	
		81	50.0	50.0	0	unc		
		82	67.4	32.6	0	AB3		
61	1	80	27.3	67.4	5.3	RC3	RC3	
		81	29.1	67.3	3.6	RC3		
		82	27.0	66.4	6.6	RC3		
	2	80	40.5	58.9	0.5	unc	unc	
		81	38.5	59.2	2.3	unc		
		82	30.8	66.0	3.2	RC3		
	*3	81	0.9	99.1	0	RC1	RC2	RC
		82	25.6	74.4	0	RC3		
	4	80	100.0	0	0	AB1	AB1	
		81	100.0	0	0	AB1		
		82	100.0	0	0	AB1		
	5	81	99.7	.3	0	AB1	AB1	
		82	97.8	0	2.2	AB1		

Table 8.--Discriminant-function analysis of preclassified and "mixed" disturbance type sites in the Monongahela Formation--Continued

Basin number	Site number	Year sampled	Percent probability: Abandoned	Reclaimed	Unmined	Classification by observation	Summary classification	Preclassification
61	6	81	40.3	0	59.7	unc	UM3	
(cont.)		82	20.0	0	80.0	UM2		
	*7	81	100.0	0	0	AB1	AB1	AB
		82	97.5	2.5	0	AB1		
	*8	81	37.3	62.7	0	unc	unc	AB
		82	90.9	9.0	0.1	AB1		

Table 9.--Median, 75 percentile, and 25 percentile of observations classified as unmined, reclaimed, and abandoned by discriminant-function analysis

[AB, abandoned; RC, reclaimed; UM, unmined; n, number of observations]

Percentile and number of observations	AB		RC		UM	
	Allegheny	Monongahela	Allegheny	Monongahela	Allegheny	Monongahela
Specific conductance						
75	2,206	1,912	--	1,998	1,050	726
50*	1,700	1,510	--	1,610	675	625
25	1,300	1,100	--	1,100	468	506
n	104	138	--	44	154	76
pH						
75	4.3	7.9	--	8.1	7.4	8
50*	3.4	7.3	--	7.9	6.6	7.6
25	3.0	6.5	--	7.6	5	7.1
n	104	137	--	44	154	75
Alkalinity						
75	0	182	--	223	82	180
50*	0	111	--	179	46	154
25	0	39	--	149	0	104
n	104	138	--	44	152	76
Acidity						
75	292	0	--	0	30	0
50*	166	0	--	0	0	0
25	70	0	--	0	0	0
n	104	135	--	44	154	75
Dissolved sulfate						
75	1,200	980	--	1,110	396	235
50*	890	730	--	835	215	168
25	640	478	--	530	138	110
n	104	138	--	44	154	76
Dissolved aluminum						
75	18,830	490	--	244	1,100	200
50*	10,250	201	--	200	200	103
25	2,375	<75	--	107	154	<75
n	104	87	--	28	154	41
Dissolved manganese						
75	21,750	6,935	--	310	3,514	327
50*	13,000	560	--	221	2,046	100
25	6,260	218	--	51	576	30
n	104	87	--	28	154	39

* 50 percentile = median

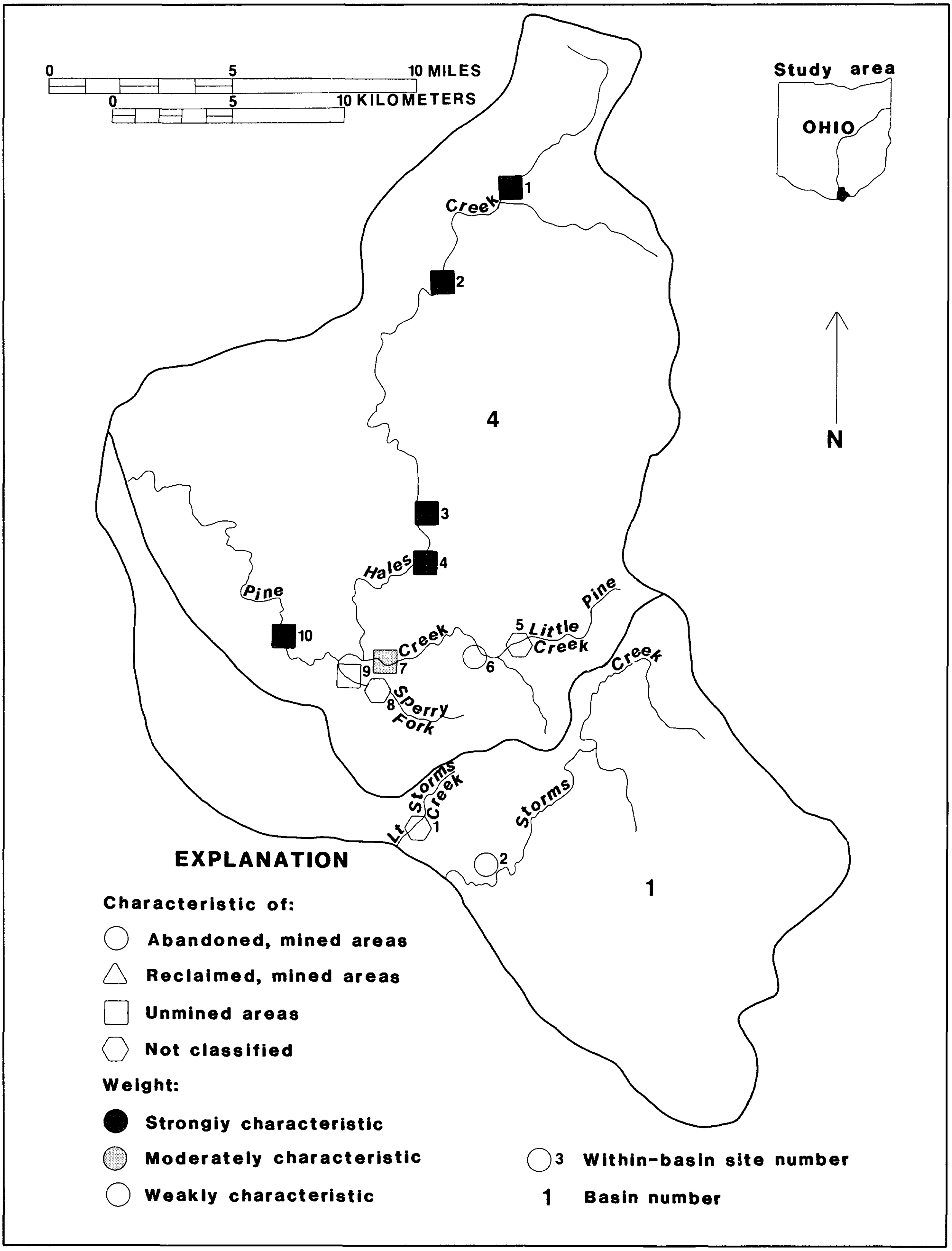

Figure 7.--Results of discriminant-function classification for basin.

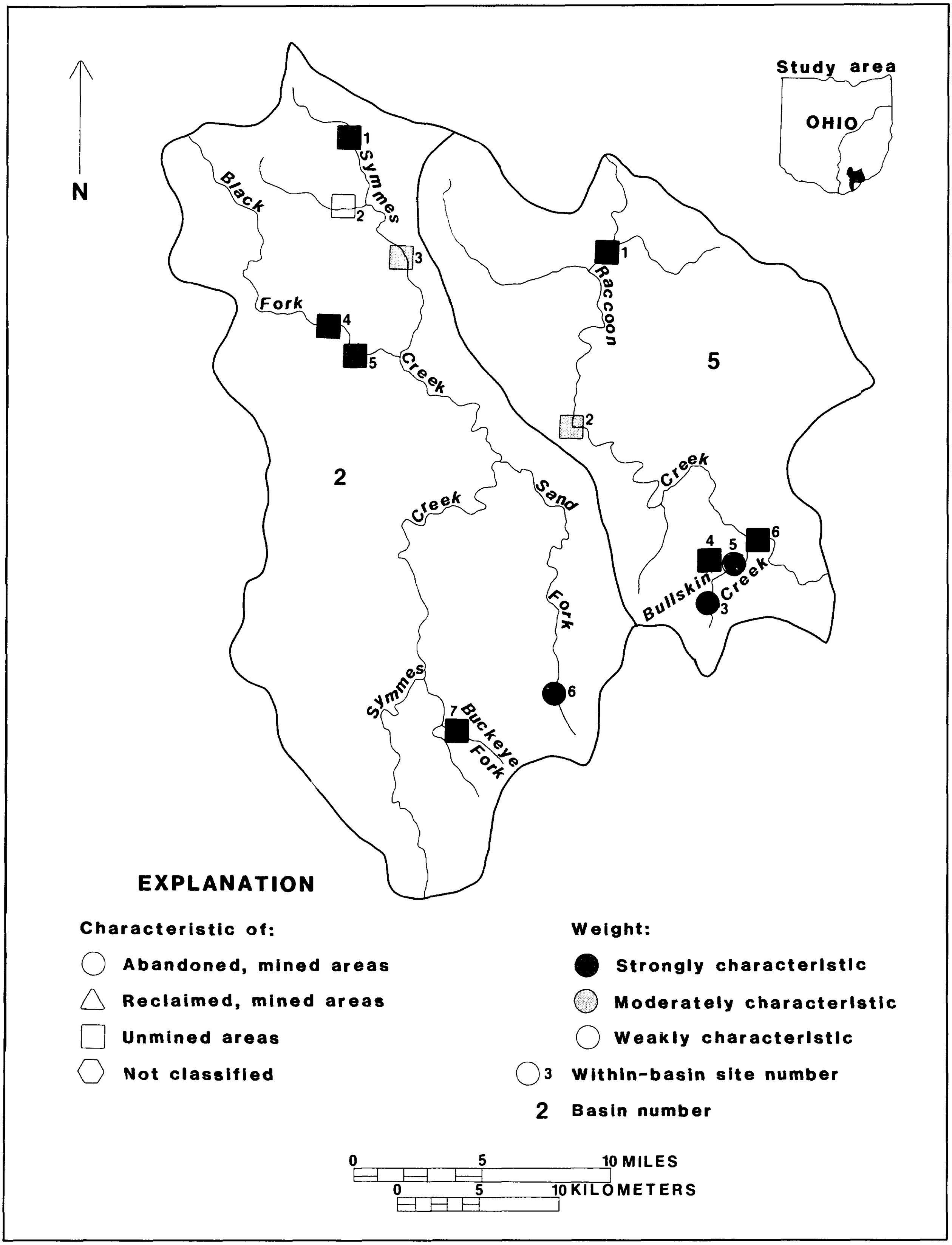

Figure 7.--Results of discriminant-function classification for basins--continued.

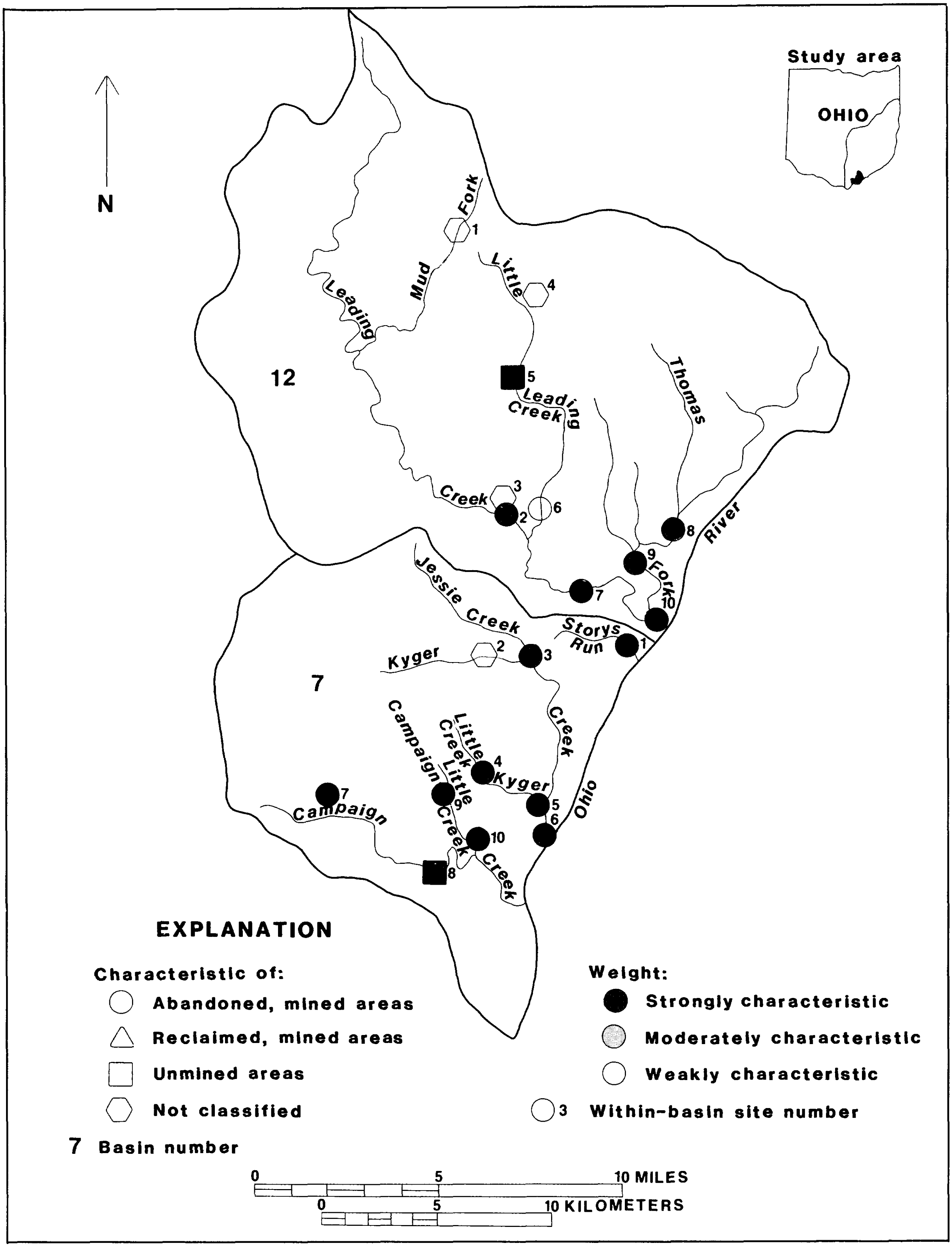

Figure 7.--Results of discriminant-function classification for basins--continued.

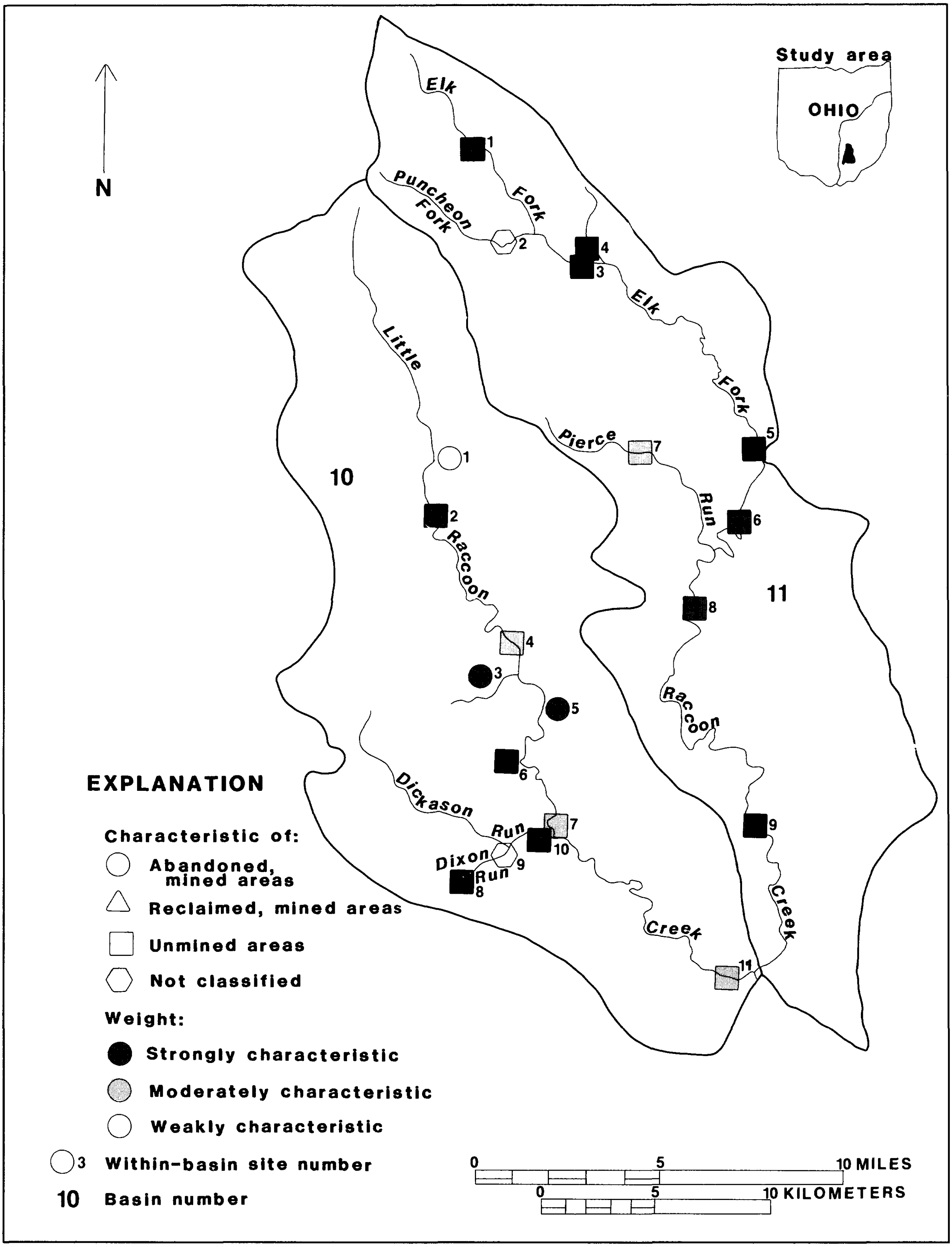

Figure 7.--Results of discriminant-function classification for basin--continued.

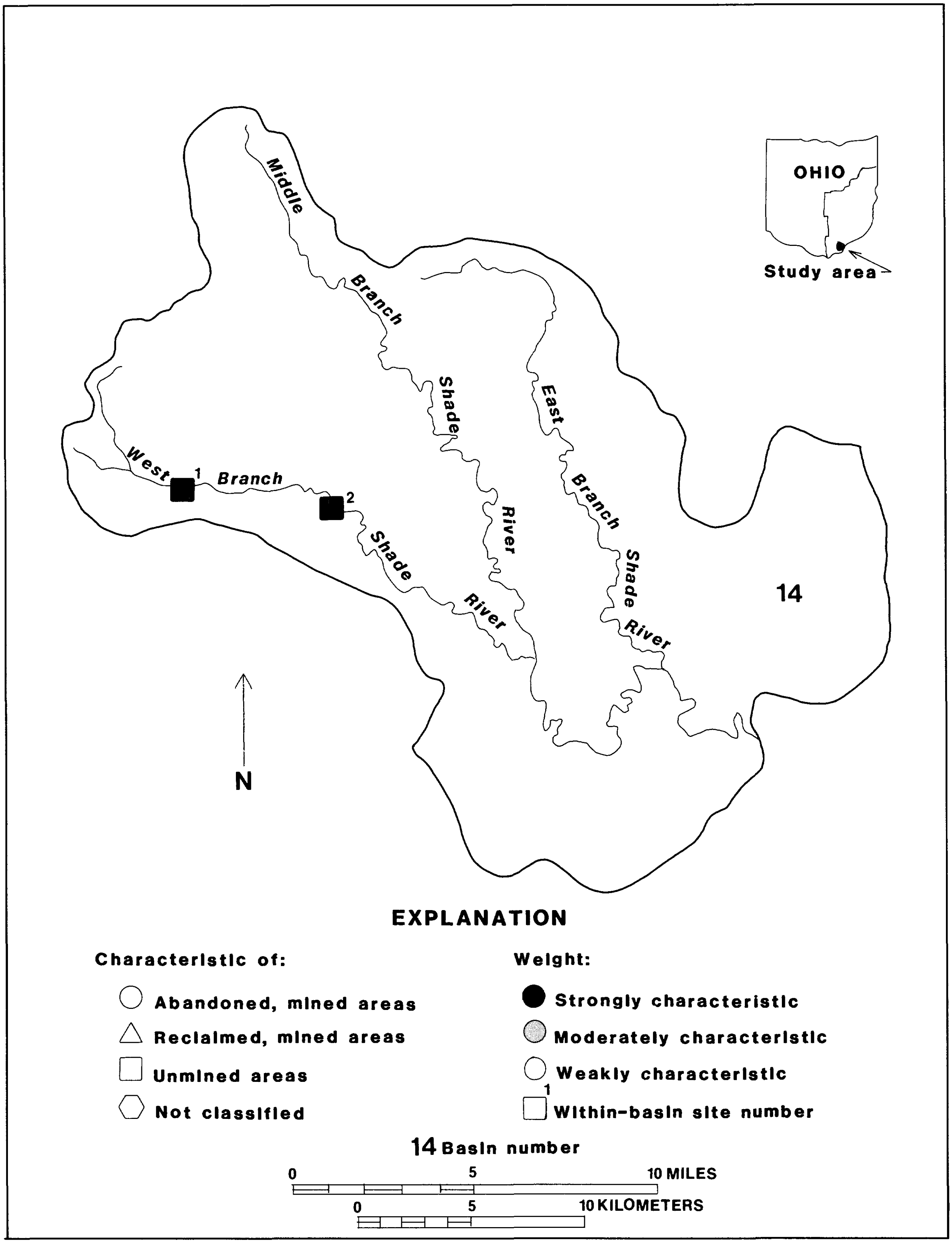

Figure 7.--Results of discriminant-function classification for basins--continued.

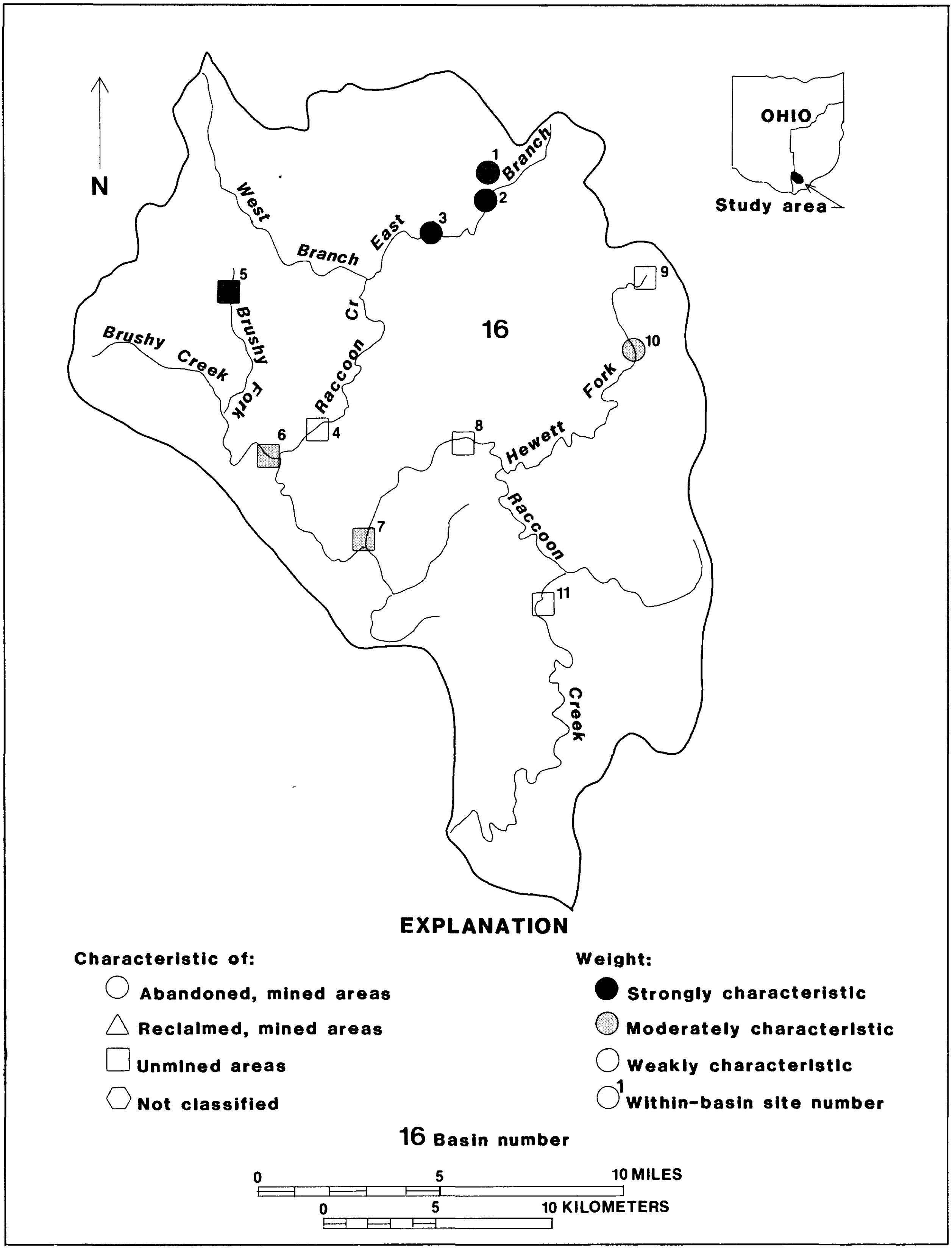

Figure 7.--Results of discriminant-function classification for basins --continued.

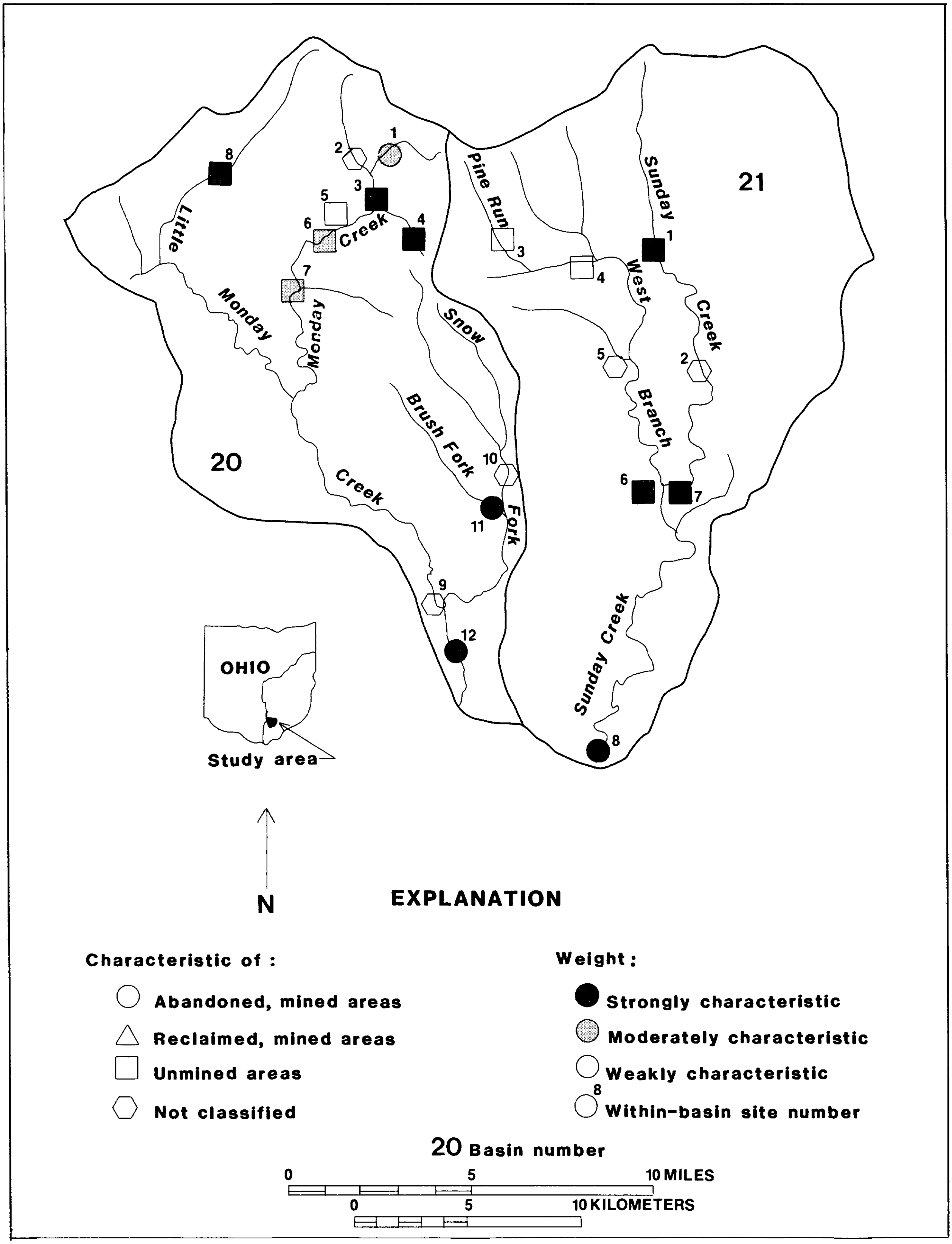

Figure 7.--Results of discriminant-function classification for basins--continued.

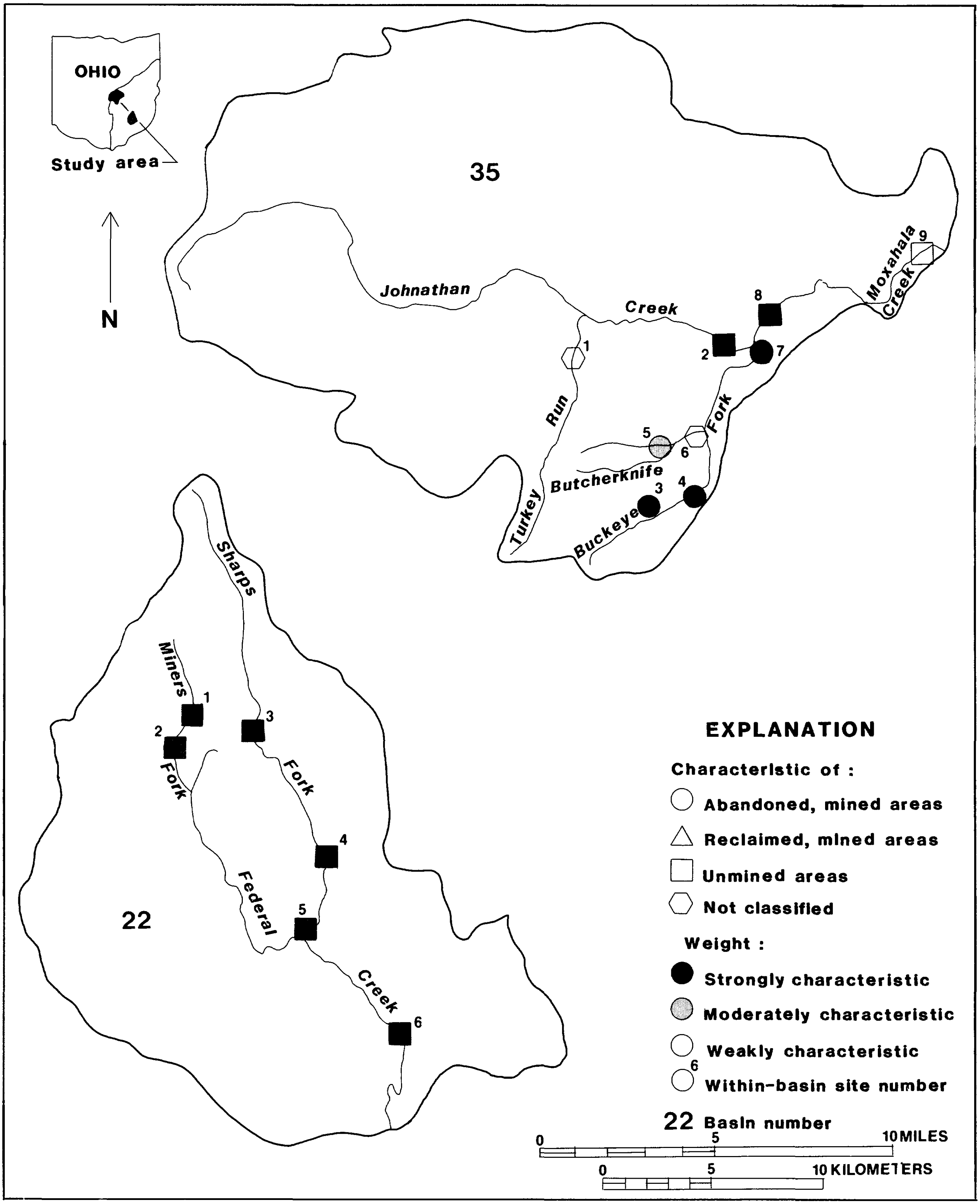

Figure 7.--Results of discriminant-function classification for basins--continued.

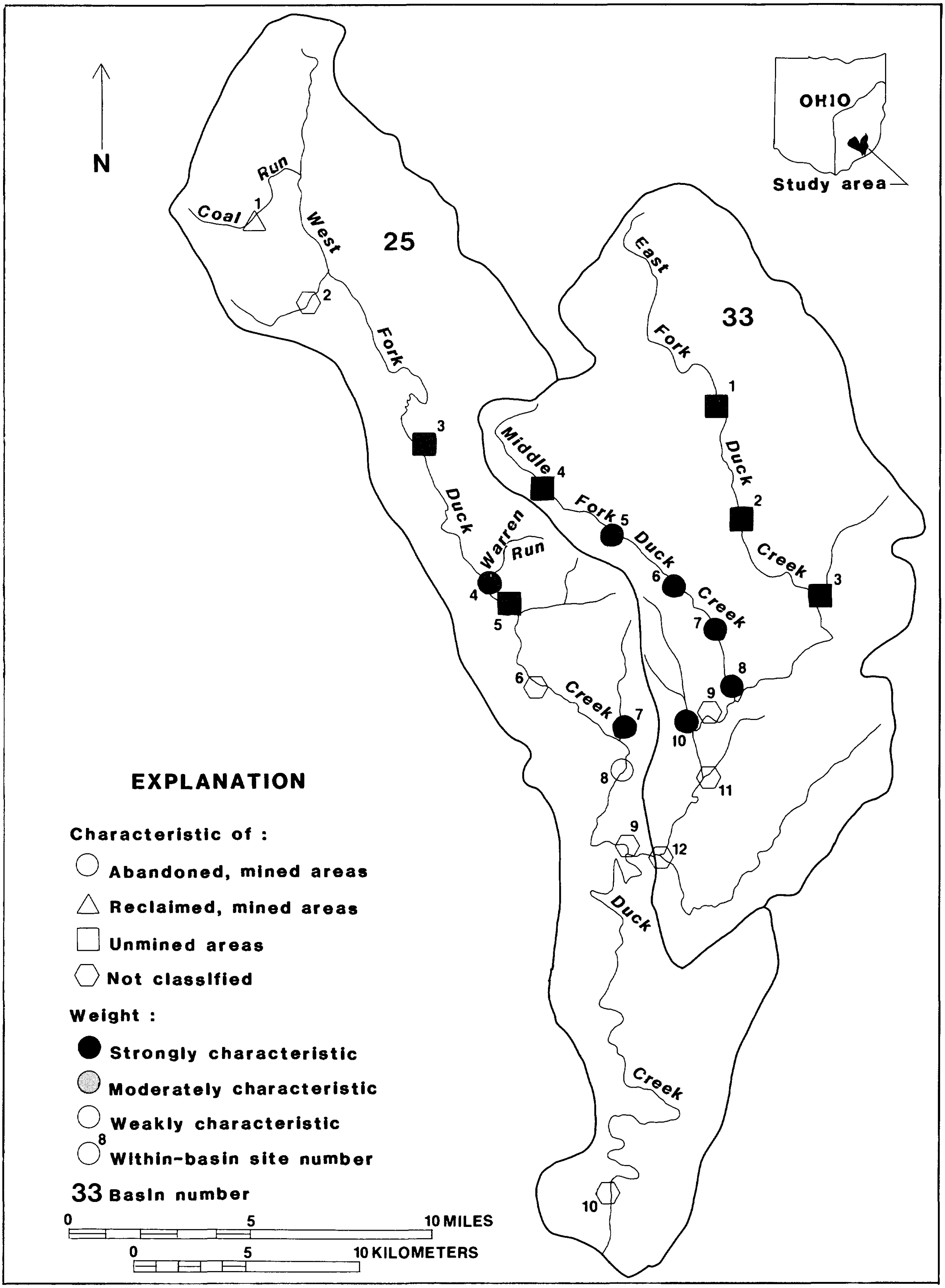

Figure 7.--Results of discriminant-function classification for basins--continued.

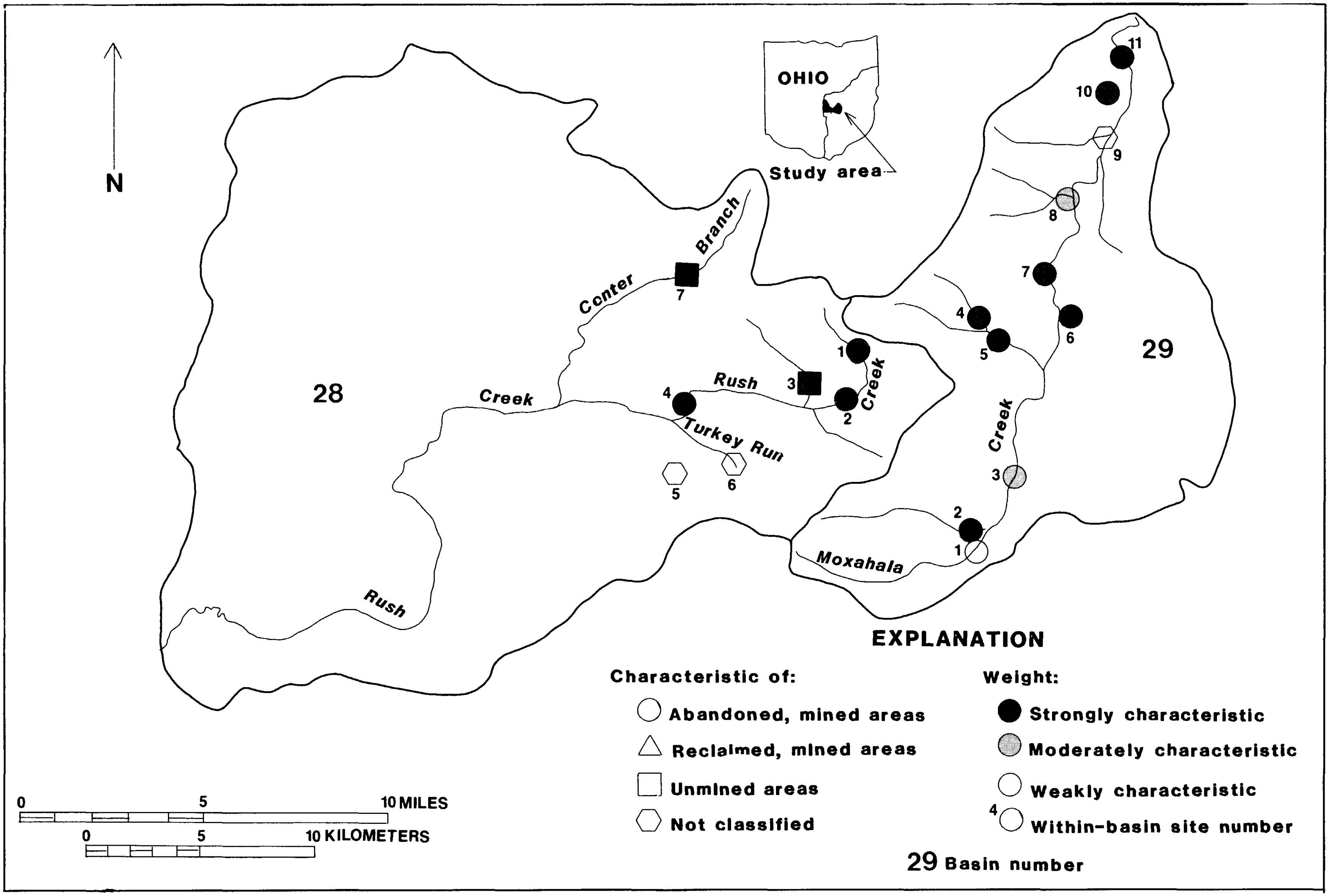

Figure 7.--Results of discriminant-function classification for basins--continued.

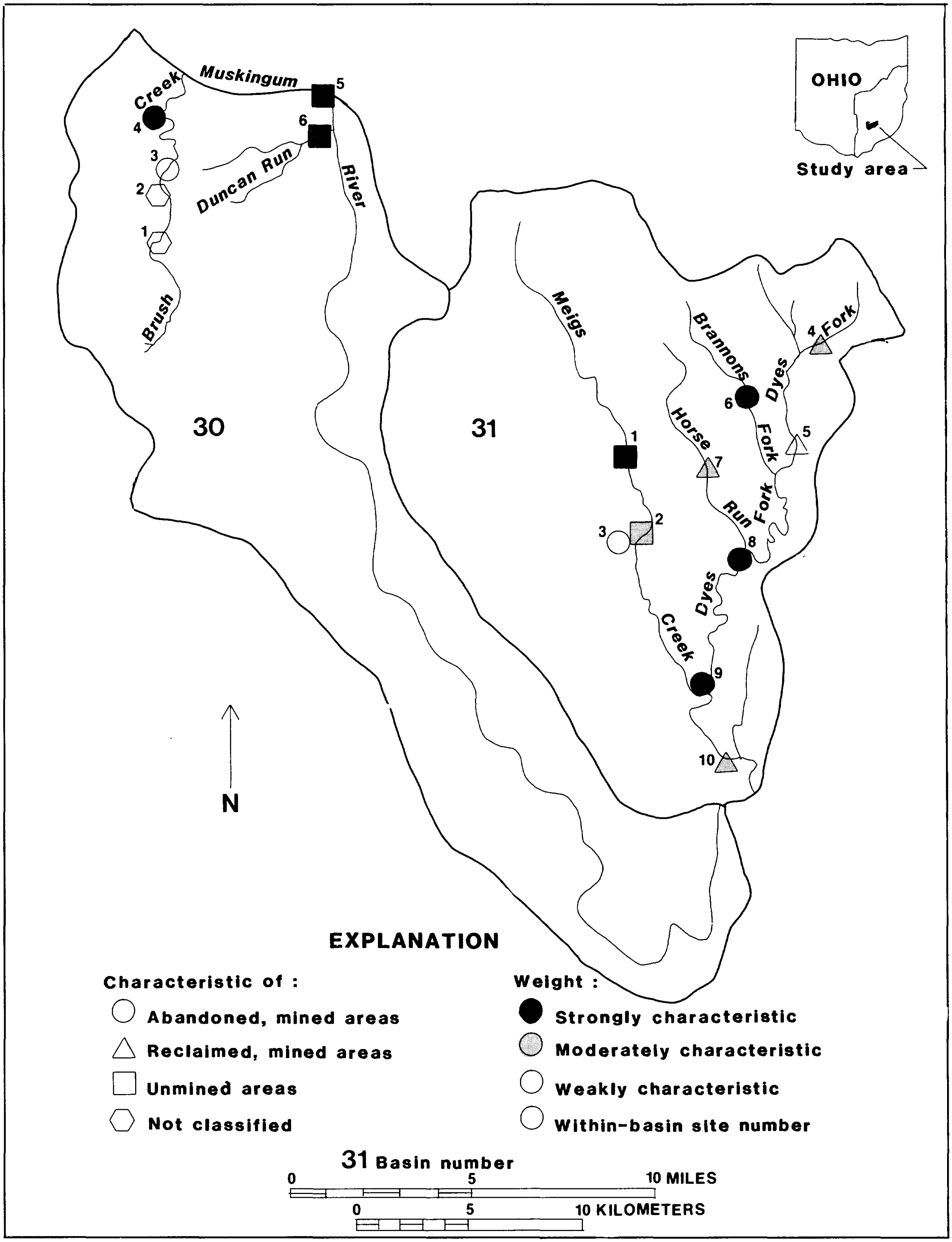

Figure 7.--Results of discriminant-function classification for basins--continued.

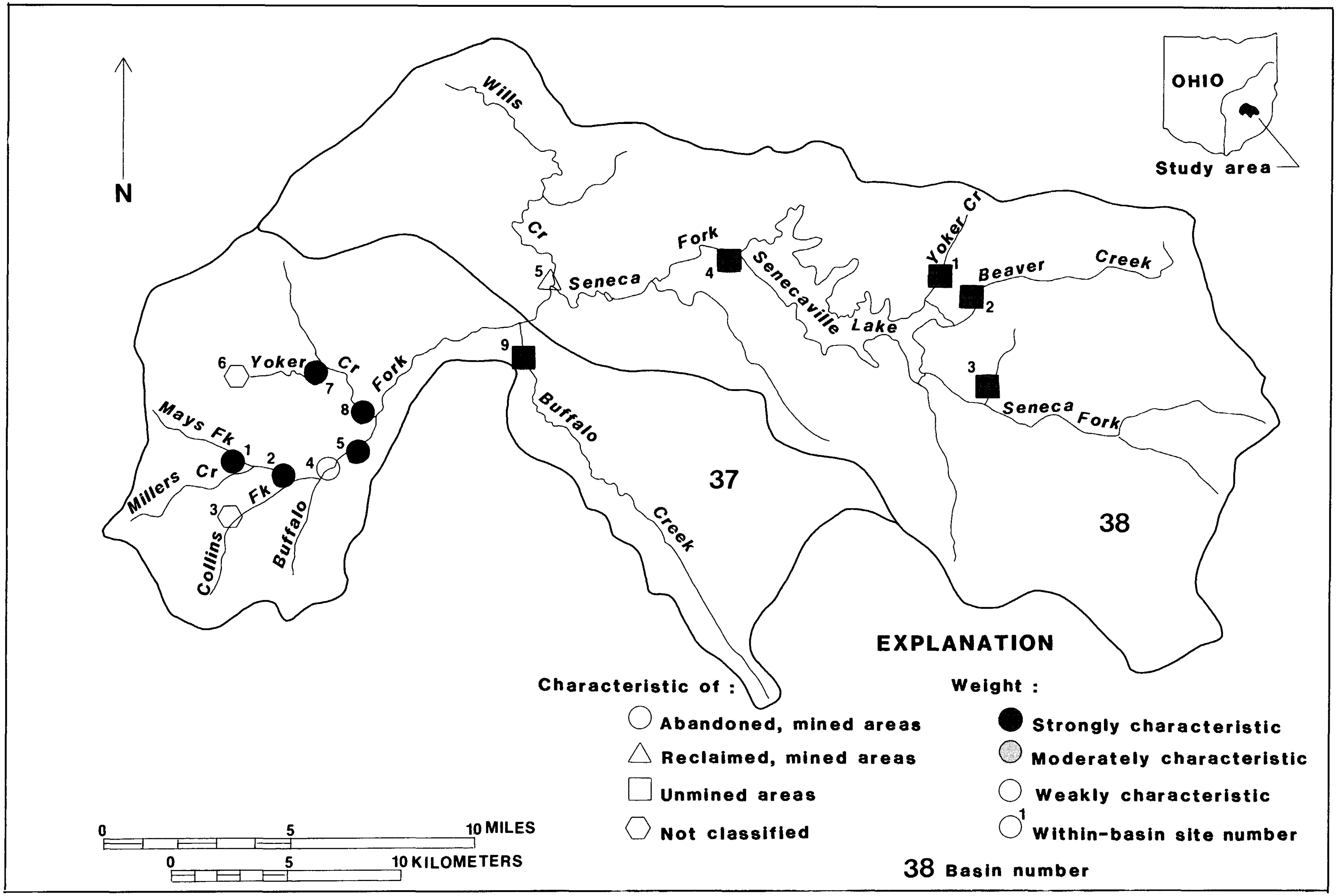

Figure 7.--Results of discriminant-function classification for basins--continued.

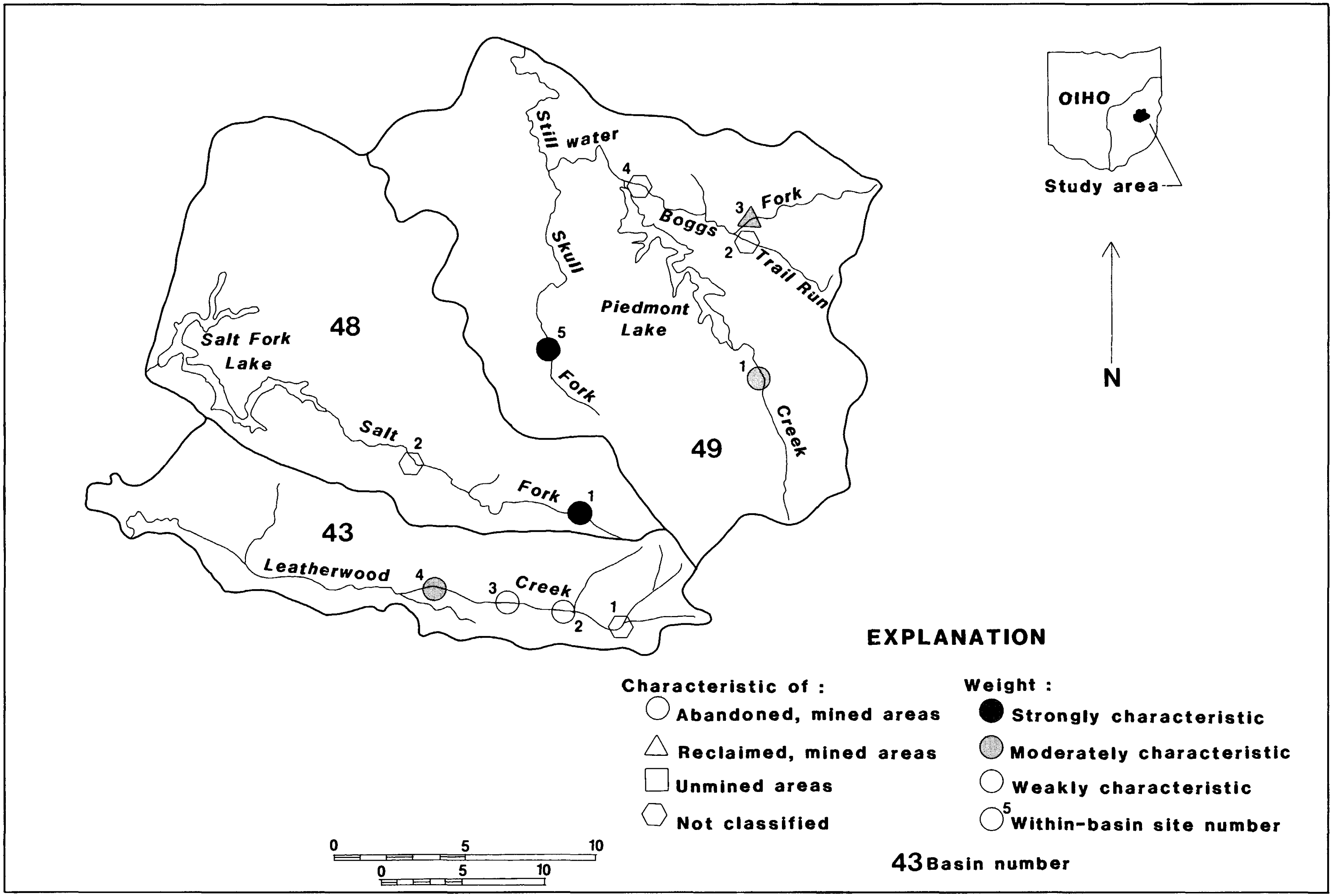

Figure 7.--Results of discriminant-function classification for basins--continued.

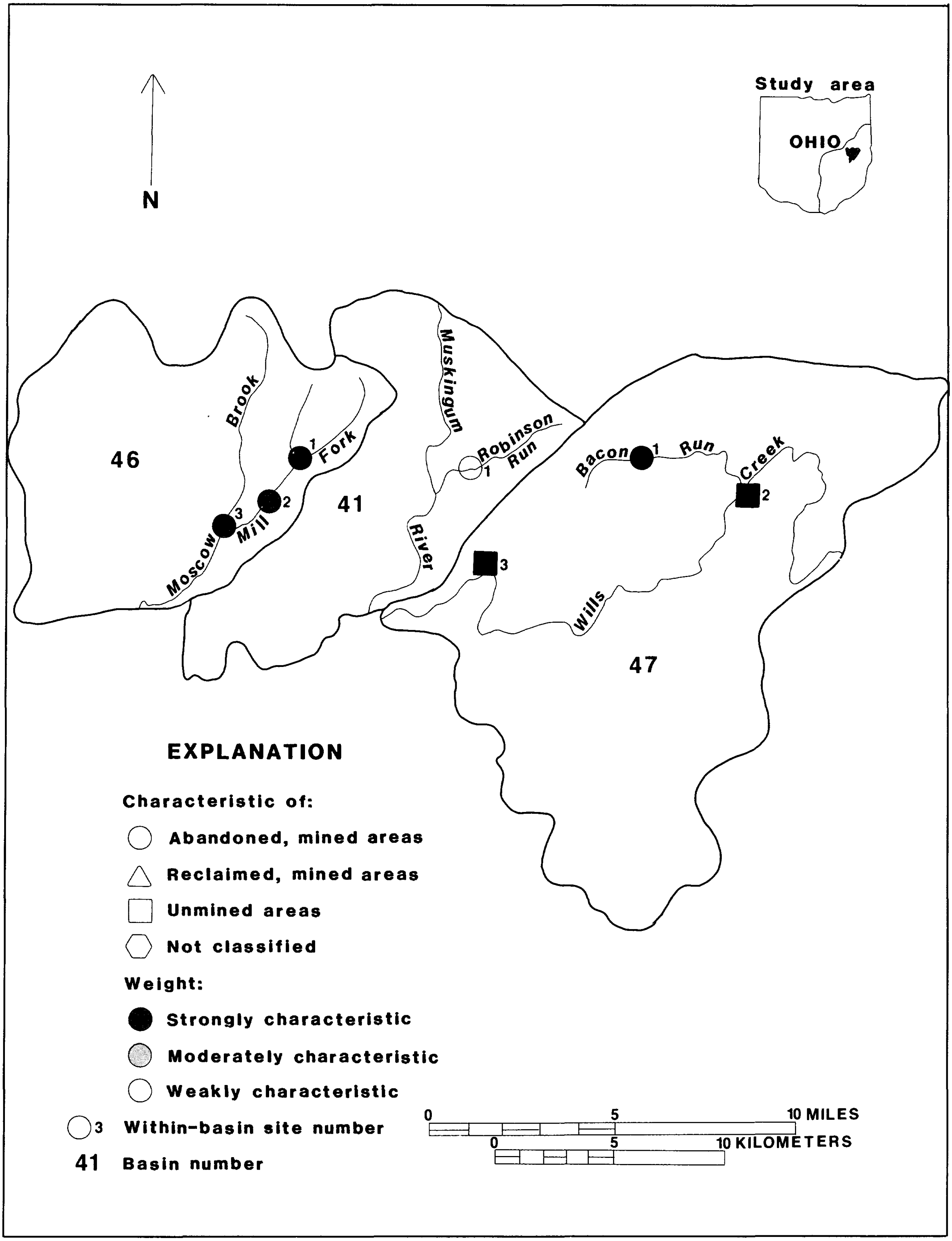

Figure 7.--Results of discriminant-function classification for basins--continued.

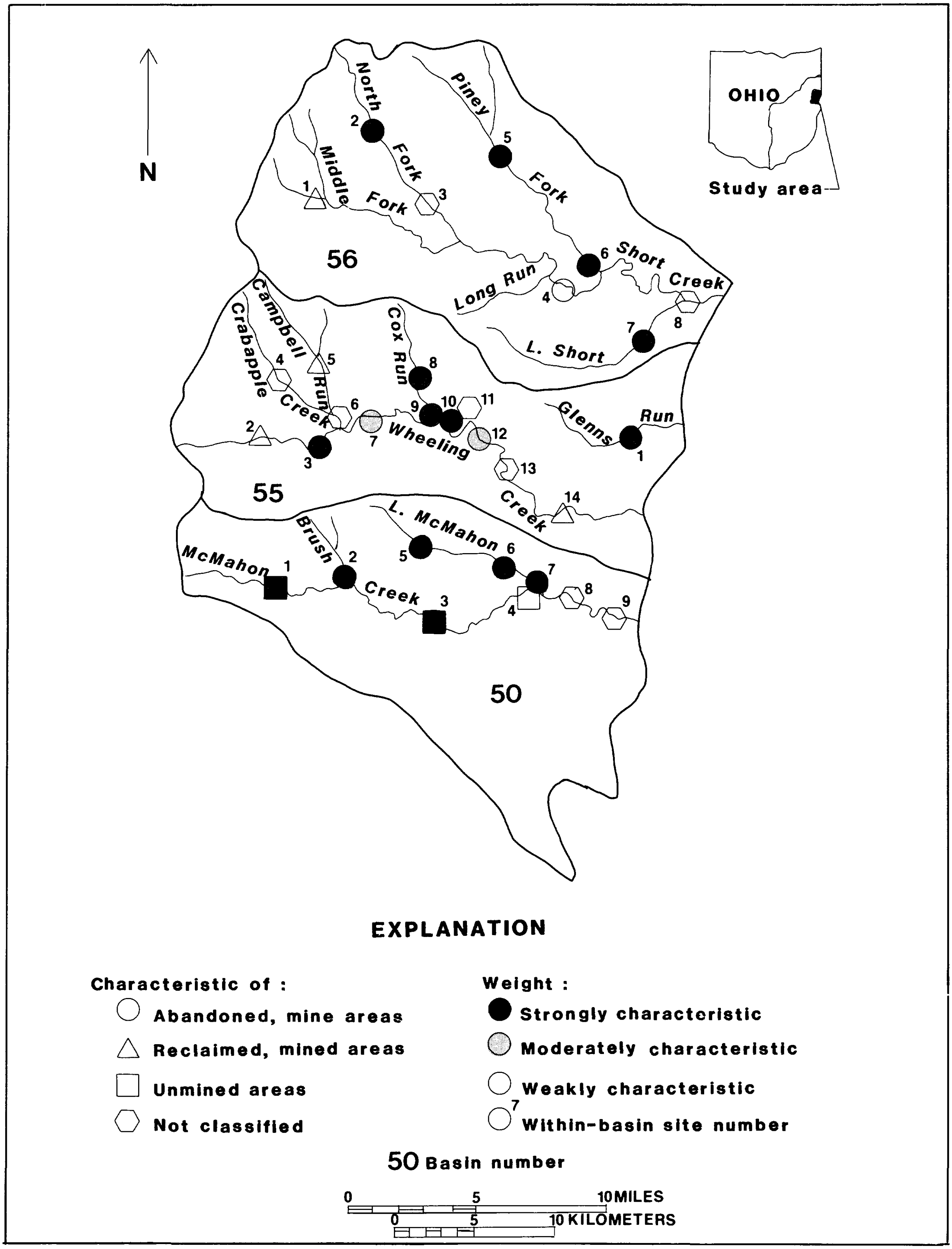

Figure 7.--Results of discriminant-function classification for basins--continued.

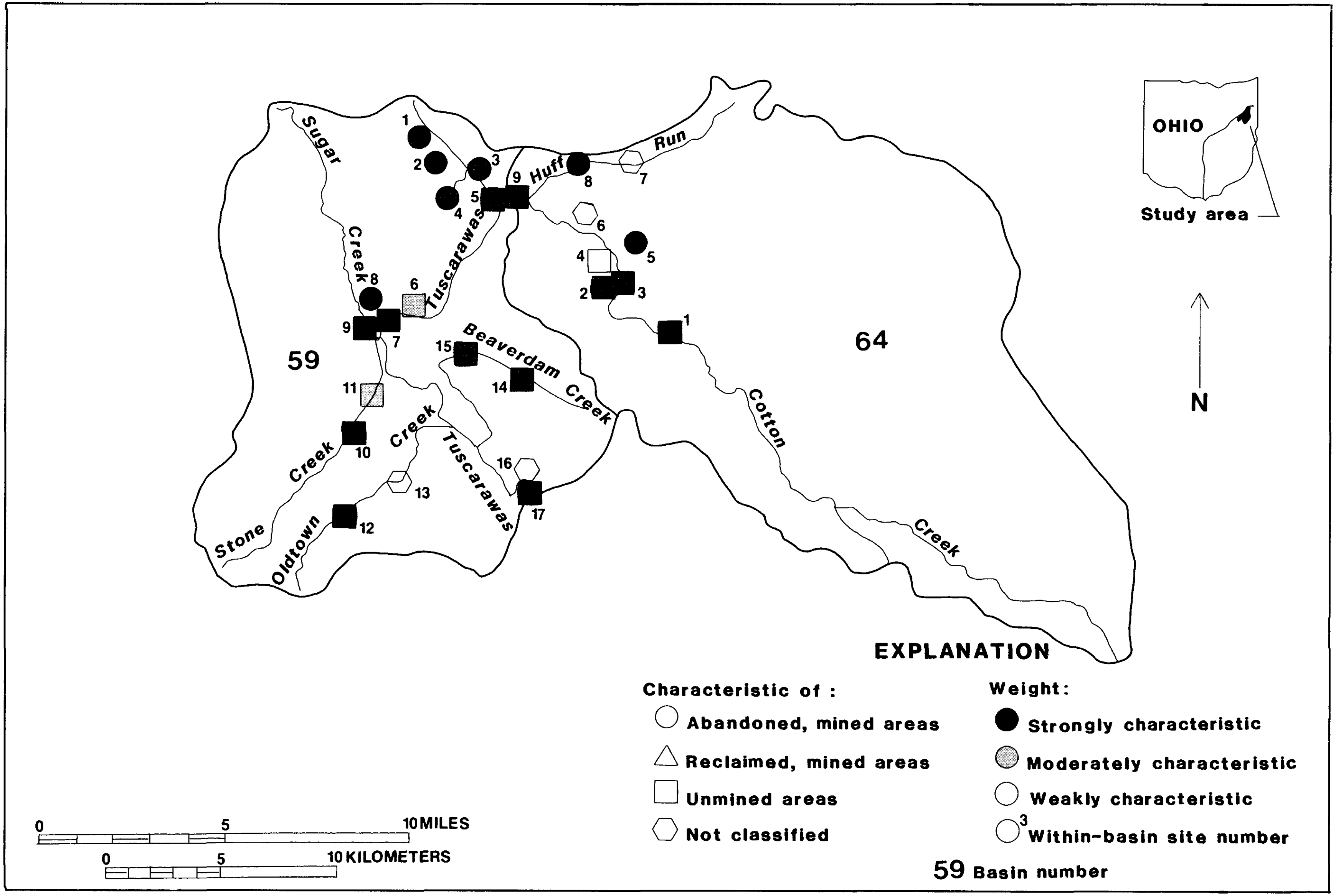

Figure 7.--Results of discriminant-function classification for basins--continued.

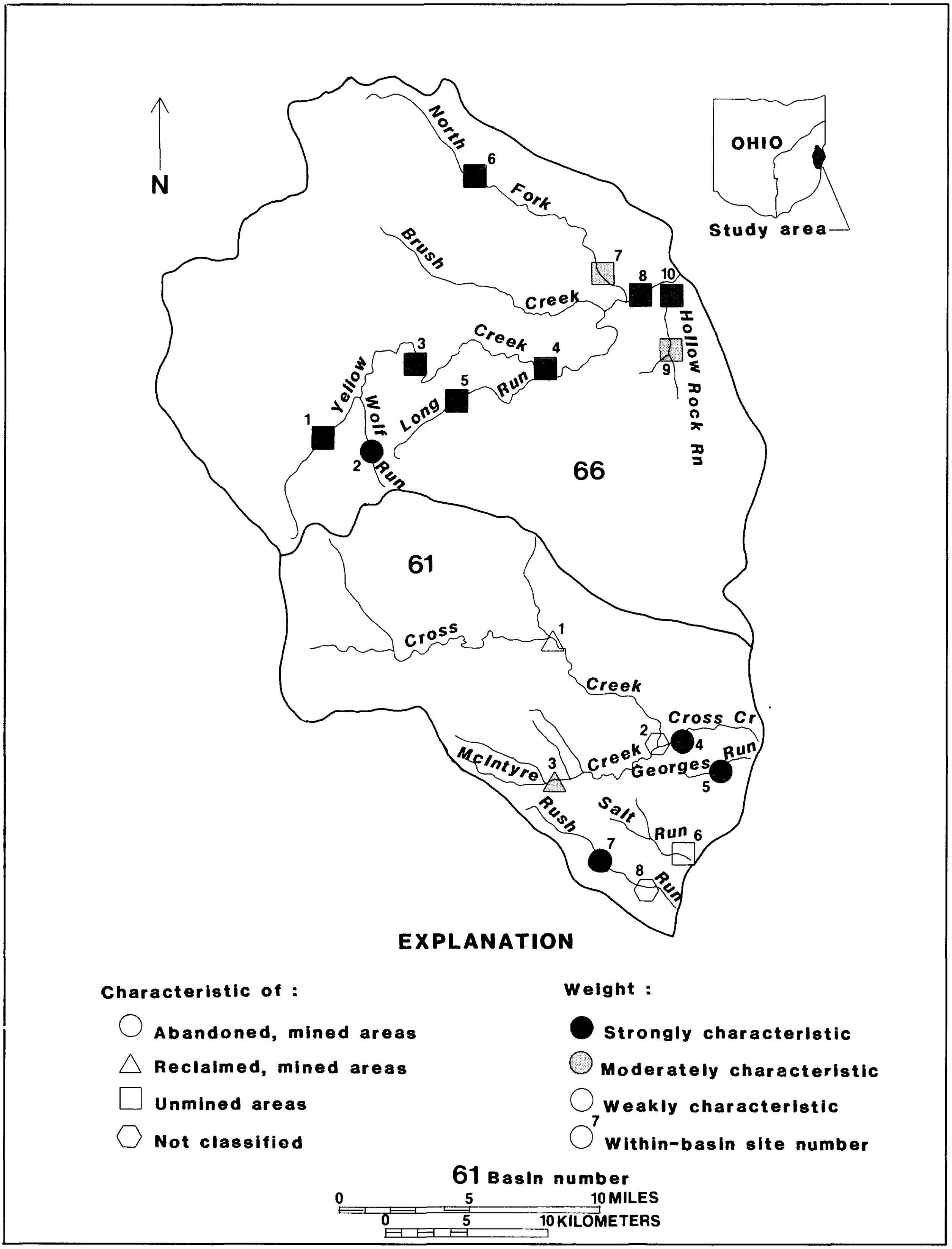

Figure 7.--Results of discriminant-function classification for basins--continued.