APPLICATION OF REMOTE-SENSING TECHNIQUES TO HYDROLOGIC STUDIES IN SELECTED COAL-MINED AREAS OF SOUTHEASTERN KANSAS

by

J. F. Kenny and J. R. McCauley

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WILLIAM P. CLARK, Secretary

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Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
1950 Constant Avenue - Campus West
University of Kansas
Lawrence, KS 66044-3897
[Telephone: (913) 864-4321]

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Inch-pound units of measurement used in this report may be converted to the International System (SI) of units by using the following factors:

To convert from inch-pound unit	To SI unit	Multiply by
inch	centimeter	2.54
foot	meter	0.3048
mile	kilometer	1.609
square mile	square kilometer	2.590
foot per mile	meter per kilometer	0.1894
cubic foot per second	cubic meter per second	0.02832
micromho per centimeter	microsiemens per centimeter	1.000

APPLICATION OF REMOTE-SENSING TECHNIQUES TO HYDROLOGIC STUDIES IN SELECTED COAL-MINED AREAS OF SOUTHEASTERN KANSAS

by

J. F. Kenny, Hydrologist, U.S. Geological Survey

and

J. R. McCauley, Geologist, Kansas Geological Survey

ABSTRACT

Disturbances of the land, water, and vegetation in the Cherry Creek basin of southeastern Kansas have resulted from intensive underground and strip mining for coal. Causal relationships among these disturbances were identified by comparing color and color-infrared aerial photography of Cherry Creek basin with water-quality data from simultaneously acquired samples. Imagery was used to determine the type and extent of vegetative cover on strip-mined lands and the extent and success of reclamation practices. Drainage patterns, point sources of acid mine drainage, and recharge areas for underground mines also were located for onsite inspection.

Comparison of remote-sensing interpretations to water-quality data proved especially useful in detecting and resolving anomalies in various reaches of Cherry Creek. Contamination in the eastern part of the basin is due largely to circulation of water from unreclaimed strip mines and collapse features through the network of shallow underground mines and subsequent discharge of acidic drainage through seeps. Contamination in the western part of the basin is caused primarily by runoff and seepage from strip-mined lands in which surfaces frequently have been graded and limed but generally are devoid of mature stands of soil-anchoring vegetation.

The successful use of aerial photography in the study of Cherry Creek basin indicates the potential of using remote-sensing techniques in studies of other coal-mined regions.

INTRODUCTION

A century of coal mining in southeastern Kansas has brought mineral wealth to the surface and degradation of the land and water resources of the region. Previous studies in the area have investigated the disruption of the hydrologic system and described the gross effects of contamination on stream quality. In particular, a water-quality investigation of streams draining coal-mined areas of southeastern Kansas, conducted by the U.S. Geological Survey in cooperation with the Kansas Department of Health and Environment, has provided a large data base of chemical characteristics from surface waters in five drainage basins affected by extensive surface and underground mining. Data collected for this previous study are published in the annual Water-Data Reports of the U.S. Geological Survey for the years 1976 through 1980 (U.S. Geological Survey, 1977-81) and in two U.S. Geological Survey open-file reports (Bevans, 1980; Bevans and Diaz, 1980).

Objectives

The purpose of this remote-sensing investigation, cooperatively undertaken by the U.S. Geological Survey, the Kansas Geological Survey, and the Kansas Department of Health and Environment, was to use aerial imagery in conjunction with hydrologic data to further examine the surface and hydrologic disturbances in a selected drainage basin. By allowing synoptic coverage over an entire project area, remote-sensing techniques provided a valuable tool in the quantitative measurement of mined land, reclamation efforts, and stream-quality degradation. The objectives of this study were to:

1. Use aerial imagery of a coal-mined basin to accurately describe the drainage patterns, surface features, and extent of mining;

2. Evaluate the effects of mined-land reclamation on the hydrologic environment by identifying areal changes in vegetative type and vigor and areas of active erosion;

3. Implement these interpretations of remotely sensed data, along with water-quality data collected within the basin, in detecting point sources of contamination to streams; and

4. Assess the usefulness of remote-sensing techniques in this study and for application to other studies of coal-mined areas.

Location of Study Area

The area chosen for the remote-sensing study was that part of Cherokee County drained by Cherry Creek and its tributaries in southeastern Kansas. This stream basin includes undisturbed, primarily agricultural land, as well as the remains of many surface and underground coal mines. The deleterious effects of mining activities are evident in the poor quality of surface waters in this basin, a condition documented by available data from previous investigations of southeastern Kansas (see "References").

The location of the study area is shown in figure 1. Cherry Creek and its two major branches, referred to in this report as Big Cherry and Little Cherry, drain an area of about 114 square miles in central Cherokee County. The two major coal seams cropping out in this area are the Weir-Pittsburg and the Mineral coals, as indicated in figure 1. The location of water-quality sampling sites and the extent of aerial photography also are shown.

Previous Investigations

Many previous investigations have dealt with the coal fields of southeast Kansas and the environmental repercussions of mining them. As early as 1911, the deleterious effects of mine drainage were discussed by E. H. S. Bailey in U.S. Geological Survey Water-Supply Paper 273, "Preliminary Report on Stream Pollution by Mine Waters in Southeastern Kansas" (Bailey, 1911). Valuable information on the nature of the coal seams mined was provided by W. G. Pierce and W. H. Courtier in the Kansas Geological Survey Bulletin 24, "Geology and Coal Resources of the Southeastern Kansas Coal Field" (1937), and by G. E. Abernathy in the Kansas Geological Survey Bulletin 52, "Mined Areas of the Weir-Pittsburg Coal Bed" (1944). Specific research into the problems of Cherry Creek was undertaken by the Division of Sanitation of the Kansas State Board of Health during 1958 (Metzler and others, 1958). This "Cherry Creek Stream Survey Report" documented water-quality problems in the basin and included a discussion of various abatement techniques. The "Kansas Water Quality Management Plan" prepared by the Kansas Department of Health and Environment (1978) contains a technical report on mineral-resource activities in the State and investigate' related water-quality problems and abatement alternatives.

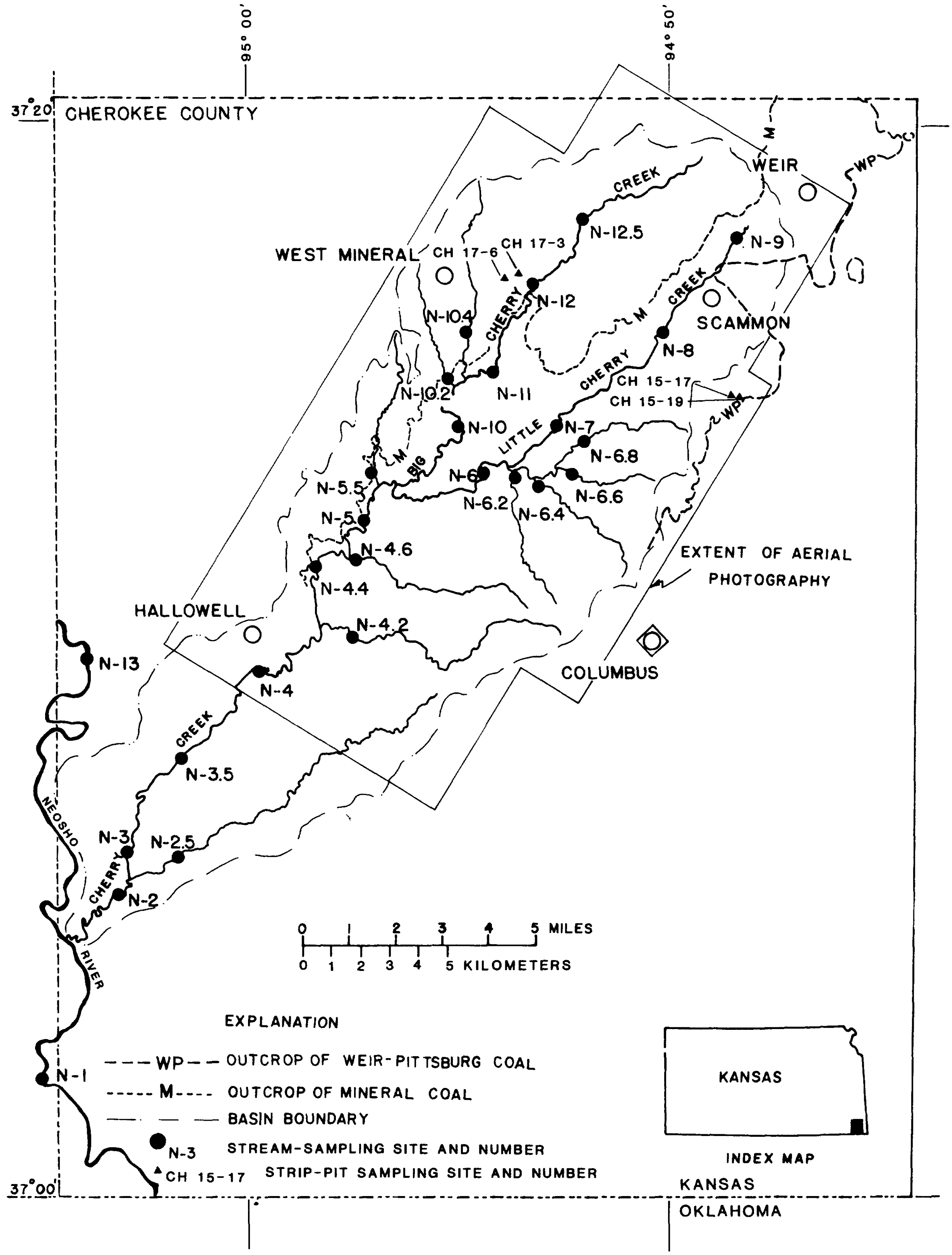


Figure 1.--Location of sampling sites and coal outcrops, and extent of aerial photography in Cherry Creek study area.

BACKGROUND INFORMATION

Geology and Coal Resources

The Cherry Creek basin lies within the Central Lowlands physiographic province. The land surface is gently rolling and slopes to the northwest at about 10 feet per mile. Surficial rocks in the basin are part of the Krebs and Cabaniss Formations of the Cherokee Group of Pennsylvanian age. Because these consolidated rocks dip northwesterly at about 20 feet per mile, progressively older units are exposed from west to east (Seevers, 1975, p. 2). Unconsolidated silt, clay, sand, and gravel of Quaternary age occur in the stream valleys of Cherry Creek and its tributaries.

History of Mining

The earliest mining of coal was conducted where the overburden of soil, clay, and soft shale was thin. Wagon-pit mines along the creek banks and drift mining of coal near the surface were common techniques. Underground mining of the relatively thick Weir-Pittsburg coal was possible where this seam was overlain by sufficient depth of overburden. Extensive deep-mine operations flourished after the first successful sinking of a shaft near the town of Scammon in 1874. The abundant hardwood timber growing along the stream banks was used for shoring in these mines, while the large numbers of immigrants to this valley supplied the labor. Underground mining of the Weir-Pittsburg coal became so prosperous a venture that in 1898 Erasmus Haworth noted, "At present this whole northeastern part of Cherokee County is one coal mining area, it being difficult to find a position from which no coal mining shaft can be seen." (Haworth and Crane, 1898, p. 120). Depth to the Weir-Pittsburg coal ranges from less than 20 feet near Scammon to more than 150 feet near West Mineral. The clustering of underground mines near these towns is shown in figure 2. However, the precise extent of tunneling is unknown, as many records were destroyed in a fire and others were never made. Hydraulic connections between closely spaced mines and between the mines and the land surface are likely due to the presence of mine-drainage shafts. These shafts were sunk to the west, or downdip, of underground mines in order to drain the tunnels of standing water (Metzler and others, 1958, p. 4).

The rocks of the Krebs and Cabaniss Formations of the Cherokee Group consist of shales, sandstones, sandy shales, limestone, and numerous thin seams of high-quality bituminous coal. Of primary importance in the Cherry Creek basin are the Weir-Pittsburg coal of the Cabannis Formation, lying about 250 feet above the base of the Cherokee Group, the Mineral coal, which occurs about 80 feet above the Weir-Pittsburg, and the Fleming and Croweburg coals, which occur above the Mineral. The Weir-Pittsburg coal, the most uniform of these seams, averages about

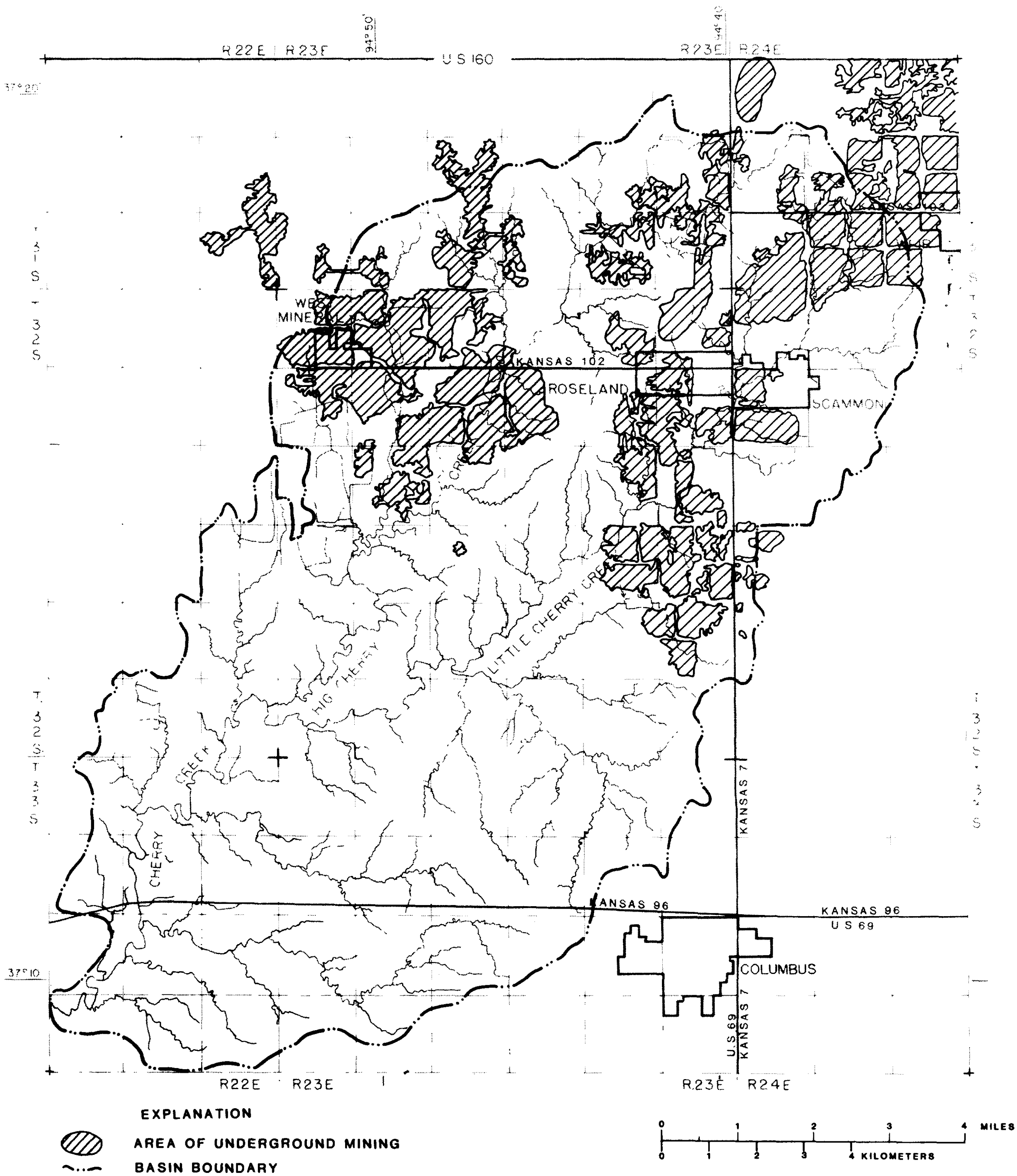


Figure 2.--Extent of underground mining in study area (from Abernathy, 1944).

3 feet in thickness. However "horsebacks," or clay veins, displace the coal in some areas. Sandstone, grey sandy shale, and scattered black shale overlie this coal (Abernathy, 1944, p. 220). The Mineral coal ranges from 17 to 24 inches in thickness and is capped by either a black fossiliferous limestone or black shale. Above this are several grey shales and the discontinuous Fleming and Croweburg coals. Near the town of West Mineral, the Fleming coal is about 19 feet above the Mineral coal and is 12- to 18-inches thick. Where present, the Croweburg coal lies about 25 feet above the Mineral coal. The Croweburg seam is about 1-foot thick and can be identified by the succession of strata above it. These strata include, in ascending order, grey shales, 3 feet of fissile black shale containing siliceous limestone concretions, and the Verdigris Limestone Member (Pierce and Courtier, 1937, p. 71-75). These rocks associated with the coal beds in the Cherry Creek basin have been variably disturbed during extraction of the different coals.

By 1930, stripping had become the dominant method of coal mining in southeastern Kansas. In the Cherry Creek basin, stripping of the remaining shallow measures of the Weir-Pittsburg coal near Scammon occurred first. Extraction of the thinner Mineral, Fleming, and Croweburg seams near West Mineral followed. The Mineral coal was strip mined extensively along the western side of the basin; the Fleming and Croweburg seams were mined only locally or in conjunction with the more economically important Mineral coal. The extent of strip mining is mapped in figure 3, The terrain in these stripped areas ranges from steep embankments in abandoned mines to leveled surfaces in reclaimed mines. Drainage from both types of terrain collects in depressions of various sizes and shapes, known as strip pits.

A third method used to extract coal was "dinkey" mining. Common during the depression years, this practice was carried out in existing strip and underground mines. In the strip mines, short tunnels were driven into the coal seam from the exposed sides of an open pit. In the underground mines, supporting coal pillars were removed (Metzler and others, 1958, p. 4) These "dinkey" mining techniques served to promote short-term fuel gain but at the expense of subsurface concavity.

No present day (1983) mining is being conducted in the Cherry Creek basin, yet the disturbances caused by previous activities remain. Problems related to the hydrologic environment include acid mine drainage, surface subsidence, waste piles, and sedimentation.

Hydrologic Problems

Acid mine drainage is the term for water draining from mines that has been in contact with rocks containing pyrite (FeS_2) and oxygen. Weathering of pyrite produces sulfuric acid, which lowers the pH of the water and perpetuates the following reactions:

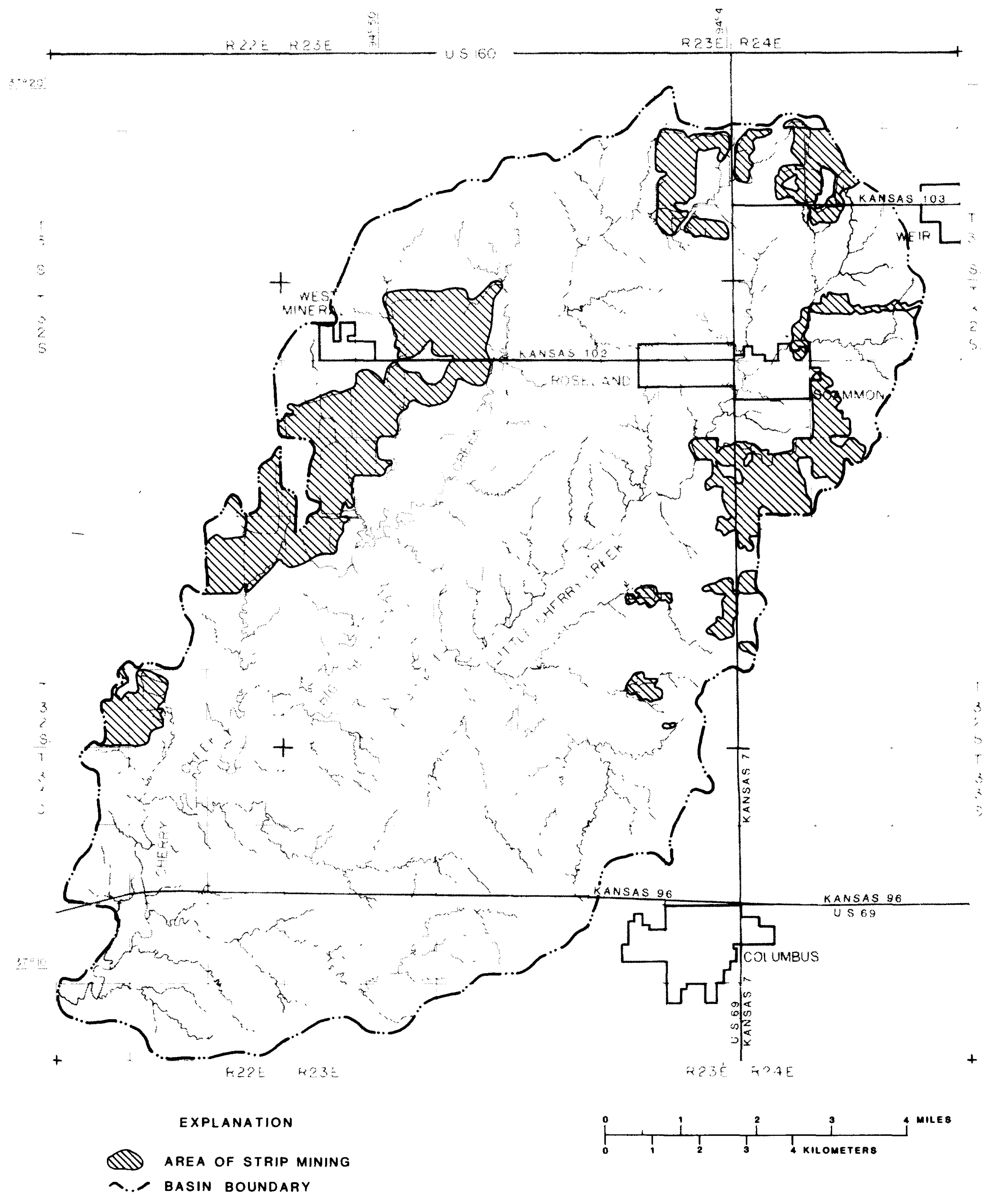


Figure 3.--Extent of strip mining in study area.

$$FeS_2 + {}^{7}/{}_{2}\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4{}^{2-} + 2H^+ \quad (a)$$

$$Fe^{2+} + {}^{1}/{}_{4}\ O_2 + H^+ \rightarrow Fe^{3+} + 1/2\ H_2O \quad (b)$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 \downarrow + 3H^+ \quad (c)$$

$$FeS_2 + 14Fe^{3+} + 8\ H_2O \rightarrow 15Fe^{2+} + 2SO_4{}^{2-} + 16H^+. \quad (d)$$

The ferrous iron released by reaction a is subsequently oxygenated to the ferric form, reaction b. Ferric iron can either undergo hydrolysis, as in reaction c, or oxidize more pyrite, reaction d (Stumm and Morgan, 1970, p. 540-541). Freshly precipitated "ferric hydroxide," $Fe(OH)_3$ in equation c above, is actually amorphous ferric oxyhydroxide that is less stable than the crystalline forms of FeOOH and Fe_2O_3. The amorphous precipitate may age with time to poorly crystalline ferric oxyhydroxides and oxides. Ferric oxyhydroxide precipitates commonly coat streambeds in the Cherry Creek basin; the color of the precursors to ferrous oxides are characteristically red and that of the precursors to oxyhydroxides, yellow to brown (Krauskopf, 1967, p. 108-109; Langmuir and Whittemore, 1971).

In acid solutions, iron may be dissolved as Fe^{2+}, Fe^{3+}, $FeOH^{2+}$, $Fe(OH)_2{}^+$, and polymeric forms (Hem, 1970, p. 116-118). Dissolved iron in most acid mine drainage is mainly Fe^{2+}. Also, the solubility of other potentially toxic metals, such as aluminum, lead, manganese, and zinc, is increased when the pH is lowered by acid mine drainage. Lowered pH and increased concentrations of metals may impair the ability of a stream to support aquatic life and may limit certain uses of the water.

Surface subsidence of the land over relatively shallow underground mines is a continuing problem in some areas of southeastern Kansas. Subsidence may be due to rotted shoring, collapse of the sandy units adjacent to the Weir-Pittsburg coal, or the removal of pillars during "dinkey" mining. The resulting sinkholes not only pose a hazard but also allow water to drain into underground mine workings.

Scattered throughout the study area are piles of waste material at the sites of former tipples for underground mines. These "gob" piles, as they are often called, are composed of fractured rock and unmarketable coal waste that were rejected as the coal was separated. Because they contain abundant pyrite and other minerals, these waste piles are sources of acid mine drainage and stream degradation when in contact with water.

Erosion of these waste piles and of unprotected spoil banks in strip mines can increase the sediment loads of streams and strip pits in the Cherry Creek basin. The increased turbidity caused by sediment transport is detrimental to aquatic life. Erosion also retards the establishment of a soil profile on disturbed land.

Reclamation Efforts

Reclamation efforts in the Cherry Creek basin have been confined to certain strip-mined lands. The earliest reclamation practices included reforestation, development of pasture or cropland, and establishment of recreational and wildlife preserves. With the passage of the Kansas Mined Land Reclamation and Conservation Act in 1968, mining companies were required to restore areas stripped after January 1, 1969, to original conditions. Lands mined after this date in the Cherry Creek basin lie primarily along the western edge of the study area where the most recent mining has been conducted. These lands have been regraded to eliminate spoil ridges, and the drainage channeled into large strip pits. Revegetation with grasses and legumes has been attempted, with mixed success.

Rapid establishment of vegetative cover reduces the rate of acid generation by providing a barrier to pyrite oxidation. Respiring roots and decaying organic matter increase the carbon dioxide concentration and decrease the oxygen concentration in soil pores. The improved water-holding capacity of soil enriched by decomposing vegetation also aids an effective oxygen barrier (Doyle, 1976, p. 145). Successful vegetation also provides protection against wind and water erosion. Dense ground covers of grasses and legumes are more immediately effective in erosion control than are trees, which require many years to establish (Kansas Department of Health and Environment, 1978, p. 51). However, vigorous forage growth is dependent on repeated application of lime and fertlizer, as well as continuous grazing and clipping management (Doyle, 1976, p. 171).

The condition of mine spoil also affects revegetation efforts. Although the breakdown of some shales releases valuable plant nutrients, highly pyritic shales are toxic to plant life and inhibit vegetation unless large quantities of neutralizing material are utilized. The presence of coarsely broken rock fragments also can inhibit successful establishment of ground cover. Topsoil replacement greatly enhances the ability of strip-mined land to support healthy vegetation but was not required by the Kansas Mined Land Reclamation Act until 1975. Strip-mining activities in the Cherry Creek basin ceased at about this time.

Any future mining and reclamation must be conducted according to the mandates of the Federal Surface Mining Control and Reclamation Act of 1977. This law establishes a permit program and strict environmental protection standards for all strip-mining operations. It also provides funding to reclaim and restore land and water resources adversely affected by past mining. Sites to be reclaimed under the 1977 Act must meet certain eligibility requirements and must not require continuous maintenance unless a commitment exists to bear indefinite costs.

METHODS OF INVESTIGATION

The use of remote-sensing techniques in the study of the Cherry Creek basin entailed several coordinated efforts. Data acquired on April 25-26, 1978, consisted of water-quality samples and four types of aerial imagery. Data acquisition was followed by interpretation and mapping of surface features and correlation with chemical characteristics. Onsite checking of certain surface features was warranted in some instances.

Data Acquisition

An important aspect of sensing a dynamic system such as a river basin is the timeliness of the data. Therefore, water-quality samples were collected simultaneously with daytime low-altitude overflights. Data collection was conducted during low-flow stream conditions in the spring in order to maximize the usefulness of both types of information. Water sampling during low-flow conditions allowed a reasonably accurate approximation of base flow, while aerial photography taken during the spring allowed observation of vegetation before leafing obscured land and water surfaces.

The 26 stream-sampling sites established for this study are shown in figure 1. Twenty sites were located in areas covered by aerial imagery, and four others were located on downstream reaches of Cherry Creek. In addition, two sites were sampled on the Neosho River, upstream and downstream from the mouth of Cherry Creek. Because the study area lies within the drainage basin of the Neosho River, the letter N precedes the identification number of each site. Streamflow measurements and water-quality samples were obtained at each of the 26 sites. Water-quality charactersistics determined at the time of sample collection were pH, water temperature, specific conductance, dissolved oxygen, acidity, and alkalinity. Water-quality samples for subsequent laboratory analysis included both raw samples and those filtered through a 0.45-micrometer filter pad.

Water samples also were collected at selected strip pits (fig. 1) that were considered representative of the different types of impounded waters present in the strip-mined land. Pits CH 17-3 and CH 17-6 are located between West Mineral and Big Cherry Creek. Pits CH 15-17 and CH 15-19 lie southeast of Scammon and Little Cherry Creek. Pit numbers are those used by the Kansas Fish and Game Commission to designate lakes and ponds in the Strip Pits Wildlife Management Areas and refer to the county and tract of land in which the pits are located.

Water samples were analyzed by the Kansas Department of Health and Environment for total and dissolved concentrations of major cations, major anions, and trace metals, according to "Standard Methods for the Examination of Water and Wastewater" (American Public Health Association, 1975). The sum of all dissolved constituents was used to compute total dissolved solids, expressed in milligrams per liter. Selected results of these chemical analyses are summarized in table 1. Because very little suspended material is present during low-flow stream conditions, the dissolved concentrations were used in describing the chemical composition of Cherry Creek, with the exception of lead for which only total concentrations were determined.

The results shown in table 1 were used to describe the quality of water in the study area at low streamflow when aerial imagery was acquired and also to illustrate water quality in smaller reaches that have not been sampled regularly. Data collected from October 1976 through April 1979 by the U.S. Geological Survey provided additional information on the chemical quality of Cherry Creek. Statistical summaries of selected physical properties and chemical constituents for the three routinely sampled stream sites N-4, N-6, and N-10 are given in table 2 (Bevans and Diaz, 1980, table 2). These data indicate the ranges in the magnitude and chemical quality of streamflow in Cherry Creek, Little Cherry Creek, and Big Cherry Creek.

Integration of these selected water-quality charactersistics into a synoptic view of the study area was made possible through the use of aerial imagery, which was acquired by private contract. Color and color-infrared photography of Cherry Creek basin were delivered as 9-inch transparencies, with a scale of 1:10,000. Stereo coverage was achieved through 60-percent end lap and 30-percent side lap on successive frames. Multi-spectral-scanner imagery of the study area was acquired in the spectral bands blue, green, red, and near infrared, as well as thermal infrared. The scanner data were delivered in roll form as 5-inch black and white transparencies at a scale of 1:21,000 and as computer-compatible tapes suitable for signal enhancement. The photography and most of the multi-spectral-scanner data were obtained during the late morning and early afternoon, with the exception of the thermal-infrared imagery which was flown in the predawn hours of the same day.

Data Interpretation

Aerial color photography was selected primarily because it produces images of landforms and hydrologic features that are easily recognized and interpreted. The most important advantage of viewing color photography over a coal-mined area was the ease with which acid mine drainage could be detected. The yellow to red color of ferric oxide and oxyhydroxide precipitates on streambeds, vegetation, waste piles, and ephemeral drainages from mine shafts clearly contrasted with the colors of the surrounding terrain.

TABLE 1.--Chemical analyses of samples from streams, strip pits, and seeps at selected sites in study area

[Analyses by U.S. Geological Survey and Kansas Department of Health and Environment. Discharge given in cubic feet per second (ft^3/s); specific conductance in micromhos per centimeter at 25°C (μmhos); and chemical constituents in milligrams per liter (mg/L) or micrograms per liter (μg/L). Sample sites shown in figures 1 and 4]

Site	Streamflow, instantaneous (ft^3/s)	Specific conductance (μmhos)	pH (units)	Oxygen, dissolved (mg/L)	Acidity, as H+ (mg/L)	Acidity, as $CaCO_3$ (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)	Aluminum, dissolved, as Al (μg/L)	Iron, dissolved, as Fe (μg/L)	Manganese, dissolved, as Mn (μg/L)	Zinc, dissolved, as Zn (μg/L)	Lead, total recoverable, as Pb (μg/L)	Sulfate, dissolved, as SO_4 (mg/L)	Calcium, dissolved, as Ca (mg/L)	Magnesium, dissolved, as Mg (mg/L)	Solids, sum of constituents, dissolved (mg/L)
BIG CHERRY CREEK BASIN, APRIL 25-26, 1978																
N-12.5	0.53	2,000	8.1	--	0.1	4.9	180	0	40	450	0	0	1,000	230	120	1,540
N-12	.52	1,800	7.8	--	.2	8.0	160	0	10	620	0	0	920	210	120	1,430
N-11	1.4	2,050	7.4	10.6	.3	13	160	0	30	660	0	0	1,000	240	110	1,550
N-10.4	.82	1,700	6.9	--	.1	5.9	120	0	140	1,900	0	0	800	190	73	1,230
N-10.2	.56	2,500	7.8	--	.4	20	180	0	20	2,400	0	0	1,400	350	130	3,000
N-10	4.1	2,200	7.6	9.0	.2	10	160	0	10	1,200	0	0	1,100	260	120	1,680
CH 17-3[1/]	--	332	7.9	12.6	.7	34	250	0	0	0	0	0	1,900	410	220	2,780
CH 17-6[2/]	--	--	6.0	10.2	.2	8.0	130	0	20	2,000	340	0	1,700	440	150	2,360
CH 17-6[3/]	--	--	5.3	--	.5	24	110	0	20	2,700	600	0	1,800	450	153	2,560
LITTLE CHERRY CREEK BASIN, APRIL 25-26, 1978																
N-9	0.08	1,810	7.8	9.0	0.1	7.0	120	0	10	290	10	0	980	200	130	1,430
N-8	1.4	1,050	6.6	11.1	.1	5.0	12	0	10	3,700	130	0	500	85	43	739
N-7	9.3	1,490	4.0	15.3	1.0	52	0	4,400	1,100	6,300	180	0	820	190	46	1,160
N-6.8	0.01	328	7.5	15.0	.1	7.0	87	0	500	1,800	0	10	56	26	5.5	184
N-6.6	.04	670	7.2	8.3	.1	6.0	48	0	0	800	0	10	270	63	21	422
N-6.4	.08	428	7.7	10.9	0	2.0	55	0	50	170	0	10	130	34	12	245
N-6.2	.02	403	7.1	10.5	.1	6.0	52	0	230	680	0	10	120	26	11	232
N-6	10	1,440	4.2	9.9	.8	38	0	4,100	400	6,200	180	10	780	180	45	1,110
CH 15-17	--	--	3.6	9.3	2.3	116	0	8,200	8,600	38,000	170	0	870	200	41	1,240
CH 15-19	--	--	3.5	9.1	2.1	104	0	8,000	4,100	27,000	140	0	650	120	35	916

Table 1.--Chemical analyses of samples from streams, strip pits, and seeps at selected sites in study area--Continued

Site	Streamflow, instantaneous (ft^3/s)	Specific conductance (μmhos)	pH (units)	Oxygen, dissolved (mg/L)	Acidity, as H+ (mg/L)	Acidity, as $CaCO_3$ (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)	Aluminum, dissolved, as Al (μg/L)	Iron, dissolved, as Fe (μg/L)	Manganese, dissolved, as Mn (μg/L)	Zinc, dissolved, as Zn (μg/L)	Lead, total recoverable, as Pb (μg/L)	Sulfate, dissolved, as SO_4 (mg/L)	Calcium, dissolved, as Ca (mg/L)	Magnesium, dissolved, as Mg (mg/L)	Solids, sum of constituents, dissolved (mg/L)
MAIN BRANCH CHERRY CREEK AND NEOSHO RIVER, APRIL 25-26, 1978																
N-5.5	0.23	2,300	8.2	--	0	0	160	0	20	220	0	0	1,300	260	140	1,920
N-5	14	1,600	6.8	9.0	.1	5.0	43	0	60	4,400	80	20	840	190	66	1,220
N-4.4	14	1,570	7.1	9.8	.1	5.0	45	0	0	3,800	40	0	2,000	190	63	2,370
N-4.2	.12	542	7.4	12.4	.1	3.0	71	100	30	680	0	30	170	34	17	318
N-4	16	1,420	6.8	10.7	.1	4.8	46	0	0	1,200	0	0	770	170	59	1,110
N-3.5	17	1,270	7.3	10.9	.1	4.4	48	0	20	2,700	10	0	730	160	56	1,060
N-3	19	1,230	7.6	11.8	.1	4.6	48	0	20	2,500	10	0	660	160	56	987
N-2.5	.09	330	6.8	10.4	.1	4.9	50	100	250	300	0	10	95	25	8.8	205
N-2	18	1,200	7.5	10.4	.1	5.0	51	0	10	300	0	0	660	150	54	977
N-13	1,870	468	8.1	8.7	.1	3.0	170	0	40	30	10	30	57	59	9.9	263
N-1	2,160	476	8.1	9.9	0	2.0	160	100	10	240	0	20	62	56	9.9	267
CHERRY CREEK BASIN, MARCH 13, 1980																
N-10	17	916	6.6	11.1	0.2	7.8	50	100	90	610	80	0	430	100	43	679
N-6	39	572	5.9	11.3	.2	12	20	1,000	120	1,000	100	0	240	61	21	392
N-4	145	1,100	7.3	9.9	.2	9.8	42	0	50	1,900	50	0	520	120	47	815
S-2	--	1,670	5.7	4.9	3.8	188	0	0	91,000	11,000	30	0	822	94	57	1,180
S-6	--	1,640	4.0	3.4	2.2	110	0	3,800	6,000	7,500	170	0	970	240	54	1,370

1 Sampled 6 feet below surface.
2 Sampled at surface.
3 Sampled 15 feet below surface.

Table 2.--Statistical summaries of selected water-quality data for three major stream sites on Cherry Creek (from Bevans and Diaz, 1980)

[Discharge given in cubic feet per second (ft^3/s), specific conductance in micromhos per centimeter at 25°C (μmhos), and chemical constituents in milligrams per liter (mg/L) or micrograms per liter (μg/L). Sample sites shown in figure 1]

Physical property or chemical constituent	Site	Number of samples	Mean	Minimum value	Maximum value
Streamflow, instantaneous (ft^3/s)	N-4	60	290	0.01	2,520
	N-6	38	125	.40	1,210
	N-10	46	157	.08	1,570
Specific conductance (μmhos)	N-4	425	1,490	50	7,030
	N-6	183	1,380	130	1,980
	N-10	136	1,990	215	3,160
pH (units)	N-4	36	6.6	4.6	7.5
	N-6	30	4.1	3.1	7.0
	N-10	33	7.4	6.9	7.9
Oxygen, dissolved (mg/L)	N-4	30	8.0	3.9	12.6
	N-6	27	9.1	5.9	14.0
	N-10	28	7.3	2.7	12.5
Acidity, as H+ (mg/L)	N-4	31	0.3	0.1	1.0
	N-6	28	1.2	0.1	8.0
	N-10	29	0.3	0.1	0.7
Acidity, as $CaCO_3$ (mg/L)	N-4	31	12	4.0	42
	N-6	28	48	5.0	110
	N-10	29	16	4.8	35
Alkalinity, as $CaCO_3$ (mg/L)	N-4	33	32	3.0	150
	N-6	30	2	0	22
	N-10	32	140	25	230
Aluminum, dissolved, as Al (μg/L)	N-4	36	390	0	5,900
	N-6	30	4,000	0	9,400
	N-10	33	120	0	1,900
Iron, dissolved, as as Fe (μg/L)	N-4	36	160	0	2,400
	N-6	30	1,400	20	5,000
	N-10	33	60	0	390

Table 2.--Statistical summaries of selected water-quality data for three major stream sites on Cherry Creek (from Bevans and Diaz, 1980)--Continued

Physical property or chemical constituent	Site	Number of samples	Mean	Minimum value	Maximum value
Manganese, dissolved, as Mn (μg/L)	N-4	36	3,300	70	16,000
	N-6	30	6,100	140	11,000
	N-10	33	840	80	2,600
Zinc, dissolved, as Zn (μg/L)	N-4	36	60	0	290
	N-6	30	170	0	320
	N-10	33	10	0	100
Lead, total recoverable, as Pb (μg/L)	N-4	30	16	0	100
	N-6	23	16	0	60
	N-10	27	28	0	140
Sulfate, dissolved, as SO_4 (mg/L)	N-4	33	640	45	1,300
	N-6	30	760	47	1,200
	N-10	32	1,200	130	2,000
Calcium, dissolved, as Ca (mg/L)	N-4	32	140	9.0	320
	N-6	29	170	10	260
	N-10	31	270	34	460
Magnesium, dissolved, as Mg (mg/L)	N-4	32	50	2.5	110
	N-6	29	46	3.0	83
	N-10	31	120	14	210
Solids, sum of constituents, dissolved (mg/L)	N-4	30	878	82	1,700
	N-6	27	1,040	86	1,560
	N-10	29	1,750	235	2,800

Certain physical and biological characteristics of the surface water in the study area could be estimated using color aerial photography. In clear water, relative depth and nature of the stream or strip-pit bottom could be observed. Water-surface roughness, optical properties of the water, and the type and amount of suspended organic and inorganic particles determine the apparent water color on aerial photographs. In general, as particle size increases, scattering of light becomes independent of wavelength so that the water color shifts from blue to green. Increased turbidity causes a further shift to yellow-green until the water color approximates the true color of the particles themselves. Large concentrations of inorganic material, such as silt, result in a brownish color. Green coloration of the water may indicate the presence of life forms, such as algae, with specific color being determined by the color of the predominant species (Meyer and Welch, 1975, p. 1487-1488).

The various colors of some strip pits on aerial photographs also may be caused by certain ferrous and ferric compounds in solution. Ferric iron forms stronger complexes with organic substances, chloride, fluoride, sulfate, and phosphate than does ferrous iron (Hem, 1970, p. 116). However, conclusions as to the nature of mineralized waters cannot be drawn from aerial photographs alone, since remote-sensing interpretation techniques have not been sufficiently developed to ascertain exact chemical composition (Meyer and Welch, 1975, p. 1493). Even direct sampling of strip pits can often yield ambiguous results, as the variables of season, temperature, and location within an individual pit can affect concentrations of ferrous and ferric iron in water.

Color-infrared photography was used primarily to study vegetation on mined lands and adjacent areas in the Cherry Creek basin. Color-infrared film is sensitive to reflected energy in the near-infrared as well as in the red and green parts of the electromagnetic spectrum. Color infrared is also called false color due to a color shift used to accommodate the representation on film of the otherwise invisible infrared reflections. Thus, targets that are higly reflective of infrared energy appear red, targets that are red appear green, and green targets appear blue. Vegetation appears on film as a shade of red. Because the intensity of the color depends on the density, type, and health of the plants, evaluations of plant success and degree of progress in reclamation were possible using color-infrared photography. Vegetation under stress due to adverse growing conditions also was detected using this type of film.

Multispectral-scanner data over the Cherry Creek basin were acquired in order to provide additional information through signal enhancement of point sources of acid mine drainage and affected stream reaches. However, the inherently poor resolution of the multispectral-scanner system, compounded by the relatively small stream widths and the masking effects of overhanging riparian vegetation, made most of the scanner imagery of little use in assessing water quality in the study area. The thermal-infrared band, though, was of great use in determining the presence and extent of surface water, especially strip pits. The large temperature difference during predawn hours between the relatively warm water of the strip pits and their cool surroundings causes the strip pits to have a characteristically bright appearance on the thermal-infrared imagery. This contrast allowed the use of a video analyser to electronically separate and measure the surface areas of the irregularly shaped and often labyrinthian strip pits.

The aerial photography of the Cherry Creek basin provided most of the information necessary to prepare maps of surface and hydrologic features related to water quality and the effects of coal mining. The transparencies were studied using a zoom stereoscope and a light table. Low magnification facilitated much of the mapping and inventorying of the strip-mined land, a process which involved the categorization of large blocks of terrain. Under high magnification, the aerial photography was useful for detecting smaller surface effects of coal mining, such as collapse features and "gob" piles. Higher magnification was indispensable for delineating the surface and near-surface hydrology of the study area because many drainage lines, pit outlets, and point sources of acid mine drainage are small and often partially obscured.

Strip-mined lands in each watershed were classified according to the extent of reclamation and to the dominant type and percentage of vegetative cover. A three-digit number was assigned to each type of mined land according to the following classification:

LAND SURFACE	1. Land remains ungraded (abandoned) 2. Land has been graded (reclaimed)
PERCENTAGE OF MINED LAND COVERED BY VEGETATION	1. 0-33 percent 2. 34-66 percent 3. 67-100 percent
DOMINANT VEGETATIVE TYPE	0. Barren 1. Herbaceous and shrubby vegetation 2. Deciduous trees

The classified characteristics were mapped, along with occurrences of dead vegetation. The surface areas of each type of mined land then were calculated using a digitizer. The results were tabulated and summarized for the three major drainage basins upstream from sites N-4, N-6, and N-10, as listed in table 3.

The distribution of underground mines also was noted. Aerial photography was used to locate isolated waste piles, which often occupy sites of abandoned mine shafts. A map of the underground-mining areas of the Weir-Pittsburg coal (Abernathy, 1944, plate 1) was used to verify the locations of these shafts, which are potential sources of acid mine drainage, and to indicate the underground extent of these mines.

Table 3.--Summary of surface and vegetative characteristics for strip-mined areas in drainage basins of Cherry Creek and its two major branches

Characteristics	N-4 Cherry Creek	N-6 Little Cherry Creek (eastern part of basin)	N-10 Big Cherry Creek (western part of basin)
Total drainage area, in square miles - - - - - - - -	83	31	23
Total strip-mined area, in square miles	9.7	3.4	4.8
Percentage of drainage area strip mined	12	11	21
Surface characteristics, percentage of strip-mined area:			
Ungraded (abandoned)	53	79	42
Graded (reclaimed)	25	9	31
Water	22	12	27
Total - - - - - - - -	100	100	100
Land cover, percentage of strip-mined area:			
Barren	6	3	8
Herbaceous vegetation	27	35	23
Deciduous trees	36	50	25
Dead vegetation	9	0	17
Water	22	12	27
Total - - - - - - - -	100	100	100

Particular attention was given to stream reaches discolored by acid mine drainage. Likely point sources of contamination were noted and subsequently checked by onsite inspection. Water samples were collected when possible. Selected chemical analyses of water from two seeps are shown in table 1, along with data for the three major stream sites, which also were sampled during the onsite reconnaissance.

Interpretations of the aerial photography acquired over Cherry Creek basin are presented in a series of maps. Plate 1 is a map showing the mined-land inventory and illustrates the condition of the land surface and vegetative regime. Important elements of the hydrologic system in the study area and major sources of stream degradation are illustrated in figure 4. Cross sections showing the positions of certain geologic formations as they relate to mining disturbances both above and below the ground and the direction of water movement are presented in figure 5.

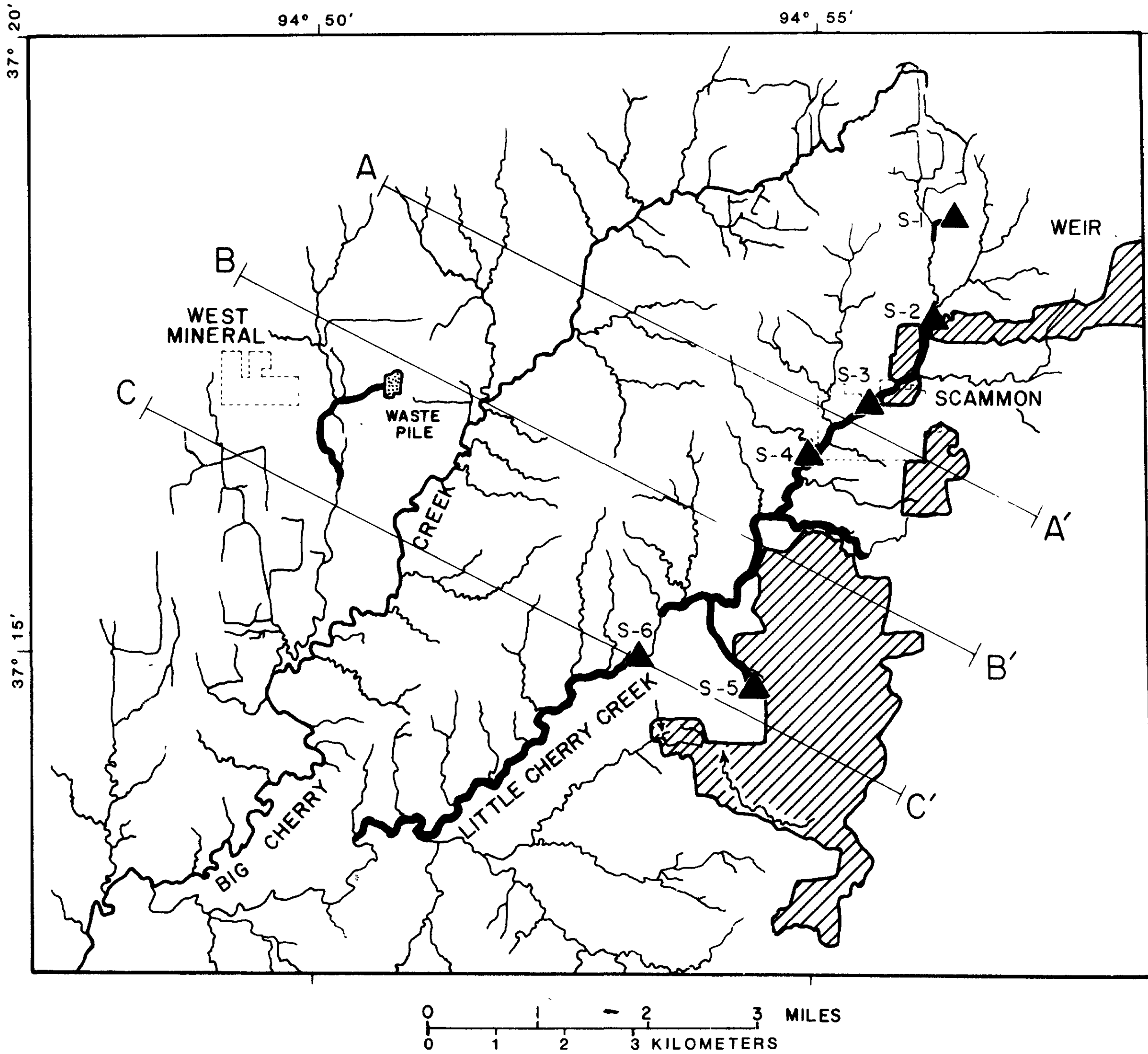
EFFECTS OF MINING AND RECLAMATION

Analyses of aerial imagery, water-quality data, and streamflow patterns indicate that degradation of the Cherry Creek drainage basin is unevenly distributed. Differences in land surface, vegetative type and vigor, and hydrologic characteristics generally distinguish the eastern part of the basin, drained by Little Cherry Creek, from the western part of the basin, drained by Big Cherry Creek. These variations are related to the nature of the coal seams mined, the ages of the mines, the mining methods used, and the state of land reclamation in each part of the basin.

Surface Characteristics

Surface characteristics of land affected by mining are illustrated on plate 1, and described in table 3. A greater percentage of strip-mined land is located in the western part of the basin, upstream from site N-10, than in the eastern part, upstream from site N-6. The types of mined land included in each part of the basin also differ.

The drainage basin of Little Cherry Creek includes the first lands strip mined at relatively shallow depths along the outcrop of the Weir-Pittsburg coal. The majority of this land remains ungraded. Yet these abandoned strip mines are old enough to support well-established deciduous forests, as well as a dense cover of shrubs, briars, and hardy grasses. Very little of this mined land was barren when the aerial photographs were taken, and no dead vegetation was observed.



EXPLANATION

RECHARGE AREA OF UNDERGROUND MINES

STREAM REACH SHOWING VISIBLE CONTAMINATION

S-1 ▲ ACID MINE SEEP

A —— A' TRACE OF GEOHYDROLOGIC SECTION SHOWN IN FIGURE 5

Figure 4.--Hydrology of upper part of Cherry Creek basin.

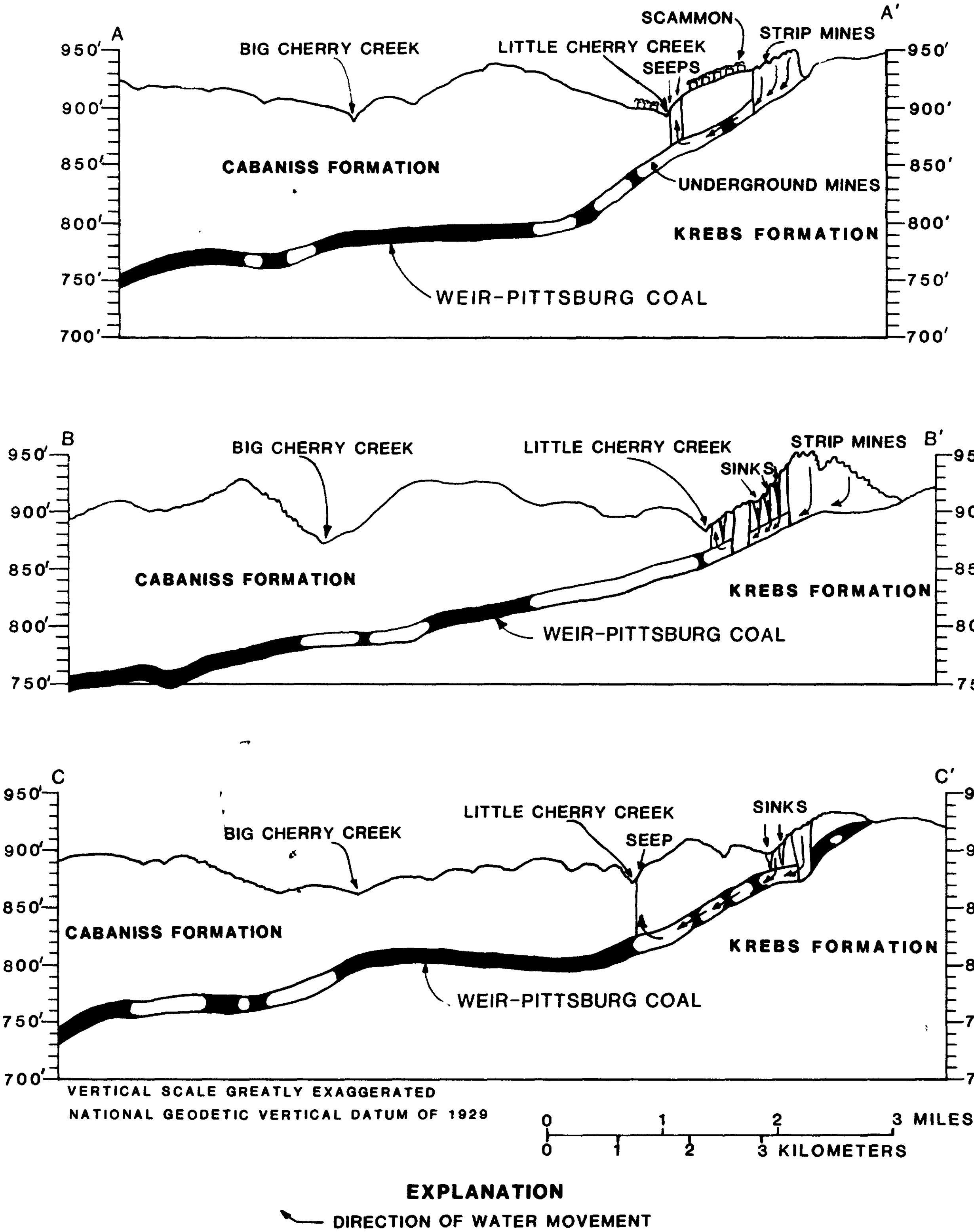


Figure 5.-- Generalized geohydrologic sections through upper part of Cherry Creek basin showing direction of water movement [based on data from Abernathy (1944) and Pierce and Courtier (1937)]. Traces of sections are shown in figure 4.

The drainage basin of Big Cherry Creek includes land strip mined for both the Weir-Pittsburg coal near its outcrop and the deeper Mineral, Fleming, and Croweburg seams. A considerable percentage of the mined land in this basin has been reclaimed, particularly in the vicinity of West Mineral where the overburden is composed of up to 60 feet of shale, limestone, and sandstone. Soil-profile development generally is minimal on these lands, and erosion is a common problem. At the time the aerial photography was acquired, many recently reclaimed areas were devoid of any vegetation or only sparsely covered with herbaceous species. On ungraded lands where plant growth was frequently well-established, coverage was comprised of nearly equal percentages of trees and herbaceous species. Scattered patches of dead vegetation were observed in these unreclaimed areas. Most of the dead vegetation noted in the western part of the basin was adjacent to a large waste pile, which occupies the site of a former coal washing plant 1 mile east of West Mineral.

Two tributaries that flow into Cherry Creek downstream from the confluence of the Big and Little branches drain both abandoned and reclaimed strip-mined land. The mixed vegetative cover, reflecting the different land surfaces and ages of the mines, is similar to that along Big Cherry Creek. However, one ungraded area in the mined land upstream from site N-4.4 is densely covered by kudzu, a type of plant that was not found elsewhere in the Cherry Creek basin.

Surficial disturbances relating to underground mining include the numerous "gob" piles and areas of sinkhole collapse shown on plate 1. "Gob" piles commonly are covered with scrubby vegetation, although nearby land surfaces are often devoid of healthy plant growth due to toxic runoff from the rocky debris. Areas of sinkhole collapse occur only in Little Cherry Creek basin above shallow underground mines near the outcrop of the Weir-Pittsburg coal. Although many of the sinks are quite old, subsidence is still in progress, as indicated by figure 6.

Hydrologic Characteristics

Observations of the hydrologic system from aerial photographs, streamflow measurements, and water-quality sampling corroborate the distinction between the eastern and western parts of the Cherry Creek drainage basin. With the exception of some small areas north of site N-10.2 and around the large waste pile near West Mineral, discoloration due to acid mine drainage is primarily located in the eastern part of the basin, along Little Cherry Creek. Inspection of color aerial photographs, coupled with onsite reconnaissance, indicated that the seeps shown in figure 4 are largely responsible for the conspicuous red to yellow colors persisting throughout nearly the entire length of Little Cherry Creek. One such seep, S-2, is shown in figure 7. From this small hole in a field, a steady flow of acidic, highly mineralized water issues forth and enters Little Cherry Creek about 1 mile northeast of Scammon. Such seeps were important factors in understanding both water movement and water quality in this area.

Figure 6.--Recent sinkhole, sec. 13, T. 32 S., R. 23 E.

Figure 7.--Major seep of acid mine water, sec. 5, T. 32 S., R. 24 E.

Water Movement

Drainage patterns vary greatly within the study area. In the western part of Cherry Creek basin, large strip pits commonly form integral links with stream channels, which were diverted to flow around graded mined areas. Drainage from strip pits into streams occurs by means of spillways and culverts, frequently through road ditches. In the eastern part of the basin, tributaries to Little Cherry Creek typically drain several small, shallow pits. Flow through culverts and ditches also was noted in this part of the basin; however, onsite inspection near the town of Scammon revealed that water from many strip pits drains into the ground through mine shafts or sinkholes. Figure 8 shows a hole at the bottom of a strip pit into which water from several adjacent strip pits disappears. Some streams, denoted by arrows in figure 4, also drain into the ground through such passages. Other pits and sinkholes in the vicinity of underground mines, including some east of the basin boundary, are typically dry. These surface depressions held no water even when checked during periods of high precipitation and runoff. Such phenomena indicate that recharge occurs through shafts and collapse features into the underground-mined areas of the Weir-Pittsburg coal.

The recharge areas mapped in figure 4 encompass areas of sinkhole collapse, dry strip pits, and disappearing drainages. Seeps occur in the area downdip from this recharge, where conduits that connect these mines with the land surface are likely to conduct artesian flow of highly contaminated mine water. These conduits may be fractures, zones of weakness along bedding planes, or manmade features, such as mine shafts, drainage and air shafts, or drill holes. Seep S-6, shown in figure 9, is a large spring in the left bank of Little Cherry Creek from which a large flow of water wells up under hydrostatic head. Like the other seeps in the eastern part of the basin, this spring is to the north and west of an area of unreclaimed strip mines and sinkhole collapse, which provides access for surface water to enter the underground mine workings.

The mechanism by which water is induced to flow from the surface, through underground mines, and out of seeps in the eastern part of Cherry Creek basin is best illustrated by the northwest-southeast geohydrologic sections shown in figure 5. The Weir-Pittsburg coal, the only underground-mined seam in the study area, strikes approximately N. 40° E. and dips toward the northwest at about 20 feet per mile. Both branches of Cherry Creek flow parallel to the strike of this coal seam, but Little Cherry Creek is much nearer the outcrop. This branch also flows at an elevation lower than that attained by the Weir-Pittsburg coal in the area where recharge occurs (fig. 4). Consequently, ground-water discharge to Little Cherry Creek includes highly acidic water that has been in contact with pyritic material in the shallow underground mines. This situation does not occur in the western part of the basin, where the underground mines are isolated both laterally and vertically from any other mines.

Figure 8.--Hole at bottom of strip pit where water recharges subsurface mines, sec. 13, T. 32 S., R. 23 E.

Figure 9.--Large seep in bank of Little Cherry Creek, sec. 23, T. 32 S., R. 23 E.

Streamflow measurements listed in tables 1 and 2 reflect the differences in recharge characteristics between the two branches of Cherry Creek. Base flow per unit area of drainage basin is greater at site N-6 in the eastern part of the basin than at site N-10 in the western part of the basin. However, average streamflow is greater at site N-10, and the range of values more extreme than at site N-6. From these observations it can be concluded that ground-water discharge is a major factor in the flow pattern of Little Cherry Creek, moderating the minimum and maximum streamflow values for this branch. Big Cherry Creek, on the other hand, is characterized by negligible contributions from ground-water discharge during low flows. Overland runoff produces higher streamflows in this branch than in Little Cherry Creek, which is to be expected considering the greater percentage of barren ground in the western part of the basin.

Water Quality

The differences in streamflow sources for Big and Little Cherry Creeks are reflected in disparate water-quality profiles at sampling sites along the two branches. Degradation due to acid mine drainage becomes progressively more severe as Little Cherry Creek flows through areas of seepage. Water-quality analyses from representative strip pits and two major seeps in the eastern part of the basin characterize the type of water which contaminates Little Cherry Creek. At sampling sites N-6 and N-7, the stream is very acidic and contains large concentrations of iron, manganese, aluminum, and zinc. Lead was not detected in any water samples collected from Little Cherry Creek on April 25-26, 1978, except at site N-6, which was sampled after the inflow of water from tributaries measured at sites N-6.2, N-6.4, N-6.6, and N-6.8, where lead was detected in concentrations of 10 μg/L (micrograms per liter). Although the exact cause of this low-level lead contamination could not be determined, possible sources are road grades and railroad ballast composed of rocks quarried from chat material from abandoned lead-zinc mines in extreme southeastern Kansas. These chat piles were quarried extensively for use elsewhere in the State.

Water quality of Big Cherry Creek, in the western part of the basin, is degraded primarily by runoff and seepage from strip mines. The application of lime to many strip-mined areas and strip pits to raise the pH causes dissolved metals, such as iron, manganese, lead, and zinc, to precipitate. Chemical precipitation of aluminum and iron phosphates may be occurring where dissolved phosphates carried into the water from fertilized, recently reclaimed strip mines enters strip pits. Phosphates also may be removed by reaction with metal oxides, particularly ferric oxides, to form insoluble precipitates (Hem, 1970, p. 185). Runoff containing fertilizers from revegetated strip mines also may be responsible for the heavy algal growths noted in many blue- and green-colored strip pits in the western part of the basin. However, further pit sampling, including bottom sediment analysis and biological samples, would be necessary to verify this conjecture.

Specific conductance, alkalinity, and concentrations of dissolved sulfate, dissolved calcium, dissolved magnesium, and dissolved solids are characteristically greater in water samples from the western part of the basin than in those collected from the eastern part (table 2). These phenomena are related to several physical and geochemical aspects of the study area.

First, the western drainage basin of Big Cherry Creek includes a greater area and percentage of strip-mined land than does the eastern drainage basin of Little Cherry Creek; thus, a greater amount of mine spoil is exposed to the weathering forces of wind and water. Weathering reactions are likely to proceed more rapidly in the spoil material of more recently strip-mined areas, such as those found in the western part of the basin, than in the overburden from older strip mines that have stabilized over the years. Those areas lacking well established plant communities are particularly reactive because the oxygen concentration in the soil pores is not decreased by respiration of roots and microorganisms.

Second, the chemical composition of the mine spoil in the western part of the basin offers more opportunity for pyrite oxidation, resulting in larger sulfate concentrations in streams there than in the eastern part of the basin. The common occurrence of fissile black shales in the succession of strata disturbed by strip mining the Mineral, Fleming, and Croweburg coals increases the probability of finely divided, or framboidal, pyritic particles in the spoil material. Finer particles provide greater surface area on which weathering reactions take place.

Third, spoil material in the strip mines in the western part of Cherry Creek basin commonly contains more limestone ($CaCO_3$) than is present in mine spoil in the eastern part due to both natural occurrences of limestone layers and the addition of lime materials for reclamation purposes. Lime products ($CaCO_3$, CaOH) in mine spoil raise soil and water pH, remove acidity and add alkalinity, and lower concentrations of dissolved metals. However, liming does not decrease sulfate concentrations and actually increases the hardness and dissolved-solids concentrations of water leaching from such spoil material (Doyle, 1976, p. 145-147). Consequently, specific conductance also is greater in the streams that drain strip-mined land in the western part of the basin.

The combined flows from Big and Little Cherry Creeks, along with inflows from several tributaries draining mined and unmined lands downstream of their confluence, determine the water-quality conditions at sampling site N-4. As shown by the data in table 2, water samples collected at this site are typically acidic and contain concentrations of dissolved metals that are smaller than those commonly present in samples from site N-6 on Little Cherry Creek but often are much larger than those observed at site N-10 on Big Cherry Creek. Determinations of lead concentrations, however, indicate that the greatest amounts of this contaminant are found in water from Big Cherry Creek.

Water-quality deterioration of Cherry Creek due to coal mining has very little effect on downstream waters during low-flow conditions. As shown by the data collected at sites N-13 and N-1 (table 1), water quality in the Neosho River does not change appreciably between sampling points upstream and downstream from the mouth of Cherry Creek. Nor does the poor quality of surface waters in the Cherry Creek basin affect public-water supplies in Cherokee County, as these generally are derived from deep Ordovician aquifers. However, contamination of Cherry Creek resulting from both point and nonpoint sources of mine drainage and from erosion of poorly revegetated areas, as well as the environmental problems posed by subsidence and abandoned strip mines, severely restrict productive use of certain streams and lands. Solutions to these problems must be as specific as the problems are unique. By uncovering many of the previously unnoticed characteristics of Cherry Creek basin, this study has demonstrated the usefulness of aerial photography in the investigation of a mined area.

CONCLUSIONS

In this investigation, remote-sensing techniques were used to determine the causes of water-quality degradation in an area of both surface and underground coal mining. Aerial color and color-infrared photography and multispectral-scanner imagery in the visible, near-infrared, and thermal-infrared parts of the electromagnetic spectrum were acquired over the study area simultaneously with water-quality samples. These data were useful to varying degrees for mapping of the surface effects of coal mining, inventorying the mined land in the basin, assessing the extent and success of mined-land reclamation, determining the surface and near-surface hydrology of the basin, and identifying water-quality problem areas and point sources of stream contamination.

The most important criterion for evaluating the usefulness of remote-sensing techniques in the study of a coal-mined area is the suitability of the data acquired for solving the problems of that particular area. Cherry Creek basin is relatively small but contains many anomalous disturbances resulting from both surface and underground mining. Adequate mapping of the surface and hydrologic characteristics of this stream basin depended to a large degree on good resolution at high magnification. For this reason, the aerial photography at a scale of 1:10,000 proved more useful than the multispectral-scanner imagery at a scale of 1:21,000. The advantage of viewing the study area on large-scale photographs was most apparent in the detection of point sources of acid mine drainage from underground mines into Little Cherry Creek. For instance, seep S-2 (fig. 7) was discovered first on aerial photography and, when checked by onsite inspection, was found to be issuing from a small, vertical hole, 4 feet in diameter. Such a seep would have been overlooked on smaller scale photographs.

The aerial color photography was judged more useful than the color infrared for most of the interpretations of Cherry Creek basin. In particular, the true representation of water color was essential to the identification of stream reaches contaminated by acid mine drainage. The color-infrared photography, however, was extremely valuable in studying vegetation on the mined lands. Growth that may be overlooked on color photographs is easily detected as a red hue on color infrared.

Thermal-infrared imagery acquired in predawn flights can be very useful in studies of disturbed areas. The sharp tonal contrast between water bodies and surrounding terrain on this type of imagery allows more precise measurement of surface-water areas than is usually possible using conventional photography. Thermal-infrared imagery was especially well suited for assessing the irregularly shaped water bodies and drainage patterns in Cherry Creek basin.

The multispectral-scanner data acquired in the visible and near-infrared bands for this investigation were of little value because most of the work required greater resolution than could be provided by this type of imagery in the small reaches of Cherry Creek, and because of the limited types of data collected in the mined lands. Such scanner data are better suited for image combination involving targets that are large in area and homogeneous in tone and that have been extensively sampled.

Remote-sensing interpretations, in conjunction with water-quality data and onsite inspections of various surface features, proved particularly effective in illustrating the differences between the eastern and western part of Cherry Creek basin. Contamination in Little Cherry Creek in the eastern part of the basin is due largely to circulation of water from unreclaimed strip mines and collapse features through the network of shallow underground mines, and subsequent discharge of acidic drainage through seeps. Contamination in Big Cherry Creek in the western part of the basin is primarily caused by runoff and seepage from strip-mined lands in which surfaces frequently have been graded and limed but generally are devoid of mature stands of soil-anchoring vegetation.

It is concluded that aerial photography, especially color aerial photography, is an extremely valuable tool for environmental studies in regions previously mined for coal. An abandoned strip mine presents a rugged terrain that makes ground reconnaissance difficult and time consuming. Leakage of acidic water from shallow underground mines to the surface through small, often remotely located openings is difficult to detect over a large area. By providing a comprehensive yet detailed view of the terrain, large-scale aerial photography can be indispensable in unraveling these complexities encountered on the ground.

In designing a cost-effective hydrologic investigation of a coal-mined area using remote-sensing techniques, consideration should be given to the type of mining that has been conducted (strip, underground, or both), the ages of the mines, and the physical size of the stream basins involved, as well as the type of data needed to solve the problem. Careful examination of these factors will be helpful in selecting the proper season or seasons for data collection, type of imagery, scale, frequency of overflights, and sampling techniques to obtain related hydrologic data. For example, in Cherry Creek basin, additional investigations into the water-quality problems could involve soil sampling on the reclaimed land, better knowledge of the reclamation practices used, more extensive water sampling of strip-pit lakes, and perhaps biological studies of aquatic organisms, especially algae, to determine whether they affect or merely indicate the ambient water chemistry.

The repeated use of remote sensing for monitoring conditions in coal mined areas is suggested only for areas undergoing physical change. The eastern part of Cherry Creek basin contains many abandoned mines, both above ground and below. The water-quality problems found there will persist as they have for many years until a major effort is undertaken to correct them. Because such an effort does not appear imminent, frequent overflights of this area are not warranted. In the western part of the basin and in areas of the eastern part, reclamation of some strip mines has occurred. These are areas of change involving the maturation of soils, the establishment of vegetation, and an anticipated improvement in water quality. Periodic overflights to acquire aerial photographs on an annual or biannual basis would be useful for monitoring these processes and for detecting new or persistent trouble spots. Finally, previously unmined areas that are opened for coal extraction should be photographed before, during, and following coal mining to adequately document changes in the land and water.

REFERENCES

Abernathy, G. E., 1944, Mined areas of the Weir-Pittsburg coal bed: Kansas Geological Survey Bulletin 52, part 5, p. 213-228, plate 1.

_____ 1946, Strip-mined areas in the southeastern Kansas coal field: Kansas Geological Survey Bulletin 64, part 4, P. 125-144, plate 2.

American Public Health Association, 1975, Standard methods for the examination of water and wastewater (14th ed.): American Public Health Association, 1142 p.

Bailey, E. H. S., 1911, Preliminary report on stream pollution by mine waters in southeastern Kansas: U.S. Geological Survey Water-Supply Paper 273, p. 349-361.

Barnes, Ivan, and Clarke, F. E., 1964, Geochemistry of ground water in mine drainage problems: U.S. Geological Survey Professional Paper 473-A, 6 p.

Bevans, H. E., 1980, A procedure for predicting concentrations of dissolved solids and sulfate ion in streams draining areas strip mined for coal: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-764, 17 p.

Bevans, H. E., and Diaz, A. M., 1980, Statistical summaries of water-quality data for streams draining coal-mined areas, southeastern Kansas: U.S. Geological Survey Open-File Report 80-350, 42 p.

Doyle, W. S., 1976, Strip mining of coal, environmental solutions: New Jersey, Noyes Data Corp., p. 145-147, 171.

Haworth, Erasmus, and Crane, W. R., 1898, Special report on coal: Kansas Geological Survey, v. III, p. 120.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, p. 116-118, 185.

Kansas Department of Health and Environment, 1978, Kansas water quality management plan, 1978, Mineral resource activities in Kansas: Kansas Department of Health and Environment Technical Report, p. 15, 51.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill, p. 108-109.

Langmuir, Donald, and Whittemore, D. O., 1971, Variations in the stability of precipitated ferric oxyhydroxides, in Nonequilibrium systems in natural water chemistry: American Chemical Society, Advances in Chemistry Series No. 106, p. 209-234.

Metzler, D. F., and others, 1958, Cherry Creek stream survey report: Kansas State Board of Health, 18 p.

Meyer, William, and Welch, R. I., 1975, Water resources assessment, chap. 19 of Manual of Remote Sensing, Vol. II, interpretations and applications: Falls Church, Va., American Society of Photogrammetry, p. 1487-1488, 1493.

Nordstrom, D. K., 1982, Aqueous pyrite oxidation and the consequent formation of secondary iron minerals, chapter 3, in Acid sulfate weathering: Madison, Wis., Soil Science of America Special Publication No. 10, p. 37-55.

Nordstrom, D. K., Jenne, E. A., and Ball, J. W., 1979, Redox equilibria of iron in acid mine waters, chapter 3, in Jenne, E. A., ed., Chemical modeling in aqueous systems: Washington, D.C., American Chemical Society Symposium Series 93, p. 51-79.

Pierce, W. G., and Courtier, W. H., 1937, Geology and coal resources of the southeastern Kansas coal field in Crawford, Cherokee, and Labette Counties: Kansas Geological Survey Bulletin 24, p. 71-75, plates 1, 5.

Seevers, W. J., 1975, Description of the surficial rocks in Cherokee County, southeastern Kansas: Kansas Geological Survey Geology Series No. 1, 7 p.

Stumm, Werner, and Morgan, J. J., 1970, Aquatic chemistry: New York, Wiley-Interscience, p. 540-541.

Subcommittee on Iron, Committee on Medical and Biologic Effects of Environmental Pollutants, National Research Council, 1979, Iron: Baltimore, Md., University Park Press, 248 p.

U.S. Geological Survey, 1977-81, Water resources data for Kansas, water years 1976-80 (published annually): U.S. Geological Survey Water-Data Report KS-76-1 through KS-80-2.

Welch, J. E., and Hambleton, W. W., 1982, Environmental effects of coal surface mining and reclamation on land and water in southeastern Kansas: Kansas Geological Survey Mineral Resources Series 7, 131 p.

Young, C. M., 1925, Kansas coal--part 1, Occurrence and production: University of Kansas Engineering Bulletin 13, p. 97.