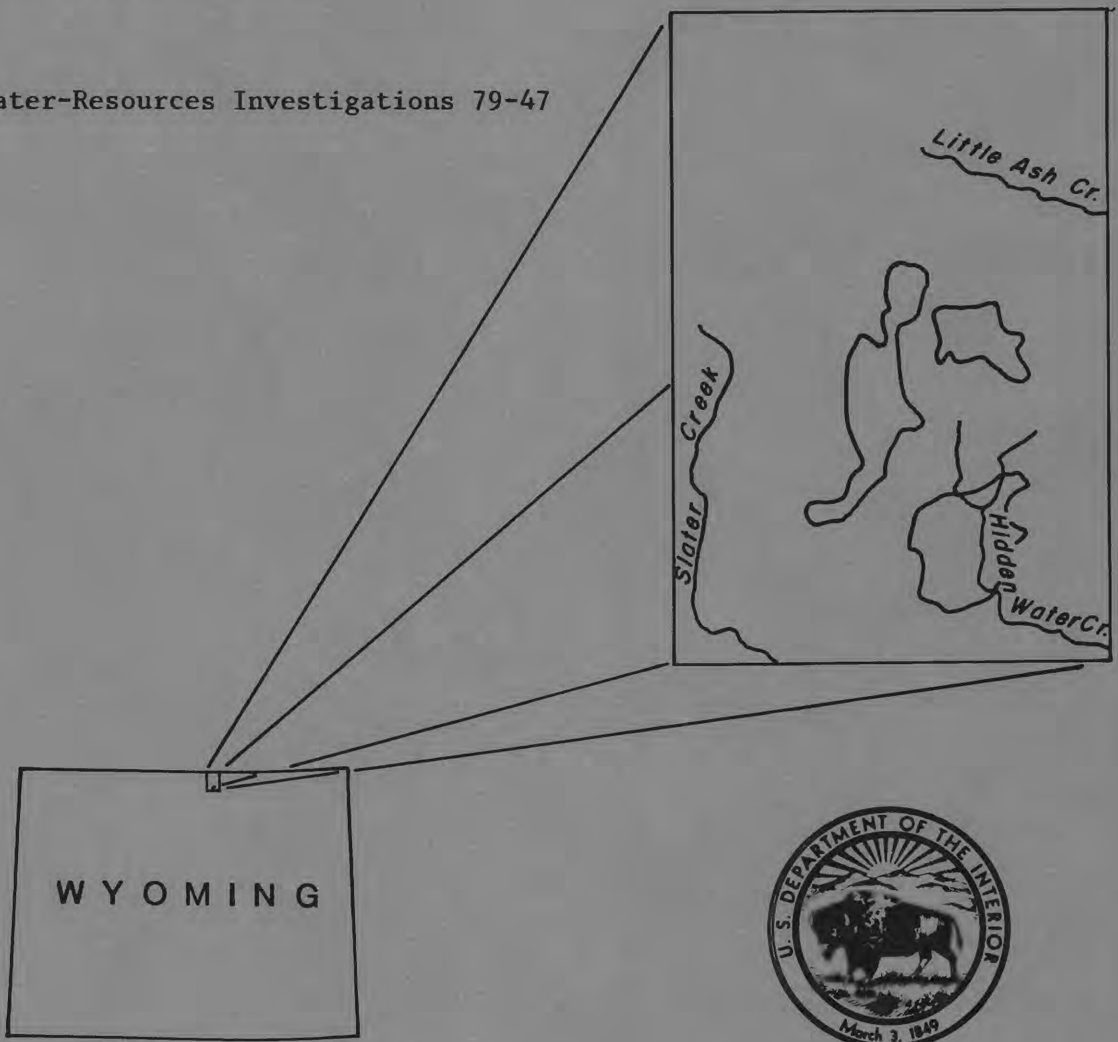
EFFECT ON SEDIMENT YIELD AND WATER QUALITY OF A NONREHABILITATED SURFACE MINE IN NORTH-CENTRAL WYOMING

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 79-47



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by Bruce H. Ringen, Lynn M. Shown, Richard F. Hadley, and Todd K. Hinkley

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The chemical composition of materials from slopes, channels, and pond bottoms of the two basins were similar; however, concentrations of dissolved and suspended matter in waters of the two ponds were different. Low concentrations of dissolved chemical constituents in the pond water below the unmined basin suggest surface runoff as the source. Higher concentrations of dissolved chemical constituents, notably calcium, magnesium, and sulfate, in pond water below the mined area suggest ground-water discharge as the source.

Sediment yield was a better indicator of the effects of disturbance on mined areas than chemical quality of water.

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ABSTRACT

Sediment and chemical quality of water data were collected from two adjacent drainage basins in northern Wyoming to compare some hydrologic differences between an undisturbed basin and a surface-mined, but unrehabilitated basin. Rate of sediment accumulation in a pond located in the basin that was surface mined for coal and left unrehabilitated was more than 11 times greater than in a pond in the adjacent unmined basin. The additional sediment came primarily from barren high walls and roughly graded spoils. No sediment was yielded from the ungraded spoil rows where drainage was to closed depressions. Evidence indicated that most sediment yielded from the two basins was trapped in the two ponds.

The chemical composition of the materials from the slopes, channels, and pond bottoms of the two basins were similar; however, the concentrations of the dissolved and suspended matter in the waters of the two ponds were different. The low concentrations of dissolved chemical constituents in the pond water downstream from the unmined basin suggest surface runoff as the source. Higher concentrations of dissolved chemical constituents, notably calcium, magnesium, and sulfate, in the pond water downstream from the mined area suggest ground-water discharge as the source.

Sediment yield was a better indicator of the effects of disturbance on mined areas than chemical quality of water in this study.

USE OF METRIC UNITS

For those readers who wish to convert Inch-pound units of measurement to the metric system, the following factors may be used:

Multiply Inch-pound units	by	To obtain metric units
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter (mm)

INTRODUCTION

Before reclamation laws were passed, surface coal mines in the Northern Great Plains states were commonly left unrehabilitated following mining. An example of an unrehabilitated mine is in the Hidden Water Creek area about 12 miles northwest of Sheridan, Wyo. (fig. 1). This area, which was mined from 1949 to 1955, provided opportunity to compare an abandoned, unrehabilitated, mine area with an adjacent undisturbed area.

The purpose of this study was to determine the magnitude of some effects of an abandoned surface coal mine on the hydrologic environment. Specific objectives were (1) to define areas of erosion and deposition; (2) to determine if the sediment yield from an undisturbed drainage basin was less than that from a drainage basin partly disturbed by mining activity; and (3) to determine if there were differences in chemical composition of hillslope materials, sediment, and pond water in the two basins.

DESCRIPTION OF AREA

Hidden Water Creek, a tributary of the Tongue River, lies near the northwestern edge of the Powder River structural basin in northern Wyoming. The 0.51-mi^2 study area is near the headwaters of Hidden Water Creek and consists of two small adjacent drainage basins. One of these basins (0.36 mi^2) consists of a rangeland part that was not disturbed and another part that was mined and left mostly unrehabilitated. The other basin (0.15 mi^2) consists of rangeland that was not disturbed (figs. 2 and 3). Drainage from both basins is toward Hidden Water Creek but is intercepted by ponds formed when dams were built across the drainages in 1952 (figs. 4 and 5).

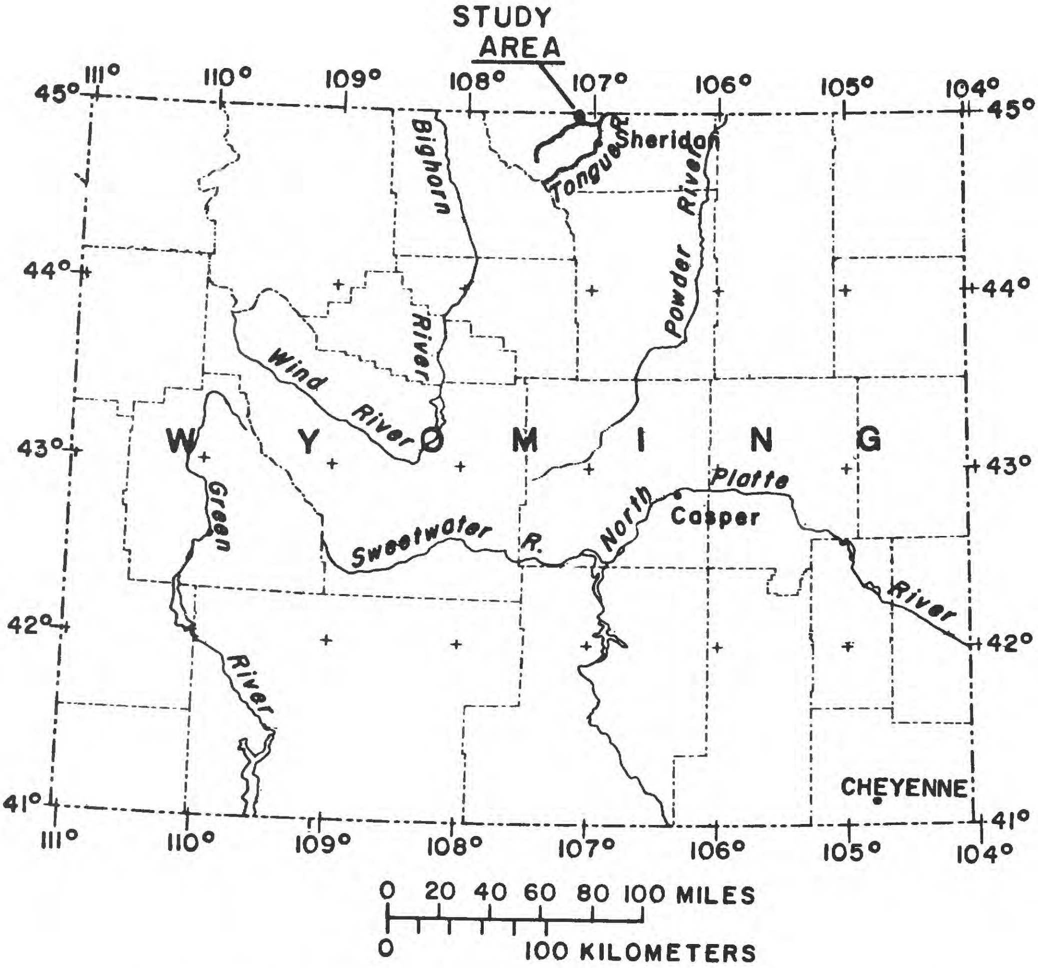

Figure 1.--Location of the Hidden Water Creek basin study aera.

Photograph courtesy IntraSearch Inc., Denver, Colo.

Figure 2.--Aerial photograph taken June 20, 1975, of the study area. Delineated areas are defined as:

1. Naturally broken
2. Partially graded spoil
3. Ungraded spoil rows
4. Pit
5. Highwall failure
6. Rehabilitated
7. Unmined rangeland
8. Barren, scraped area

U Pond below unmined watershed
M Pond below mined watershed
~ Basin divide

Figure 3.--Panoramic view with snow cover in March 1976 looking northeast toward the study area. The area in the foreground is undisturbed, the center area is ungraded spoil rows, and the background is undisturbed hills. Foreground distance is about 50 feet.

Figure 4.--Pond U and lower part of unmined basin. Note the dense vegetal cover and gentle slopes. View is north in September 1976.

Figure 5.--Pond M and lower part of mined basin with rilled spoil pile in the background. Note the areas of sparse vegetal cover and steep slopes. View is north in September 1976.

Disturbance and channel-classification maps were prepared using color-infrared aerial photographs. Using area data from the photograph in figure 2, it is seen that only 31 percent of the mined basin was disturbed. The topography and cover of the undisturbed part is similar to that of the unmined basin. Eleven percent of the mined basin consists of relatively barren spoil rows from which there is little exterior drainage. The slopes of the spoil rows range from 64 to 72 percent. Another 11 percent of the basin consists of the abandoned pit which has very little vegetation growing in it. Nine percent of the basin consists of areas that were graded and partially topsoiled after mining. Vegetation cover on the mined basin ranges from nearly zero in the mine pit to about 80 percent on the graded, topsoiled, and unmined areas.

A failure of the mine pit highwall, which occurred between November 1974 and April 1975, is indicated by area 5 in figure 2; a closeup photograph of this failure is shown in figure 6. Accumulation of surface runoff on the upslope side of a single spoil row, located above the highwall, may have saturated the material and triggered the slippage that resulted in a large quantity of unconsolidated, unvegetated soil material laid across the floor of the mine pit. By September 1976, there has been little erosion of this soil mass.

Rills and gullies have formed on the spoil piles in areas where armoring by sandstone fragments was incomplete. Numerous rills have formed on the pit walls where flows have concentrated in channels prior to falling over the lips of the walls.

Flows in the channel below pond U have caused a headcut to form where the channel intersects the mine pit (fig. 7). Some of the sediment eroded from this headcut has been deposited in a detrital fan on the floor of the pit and some has been transported downstream toward pond M.

GEOLOGY, SOILS, AND CLIMATE

The mineable coal in the study area was near the contact of the Wasatch (Eocene) and Fort Union (Paleocene) Formations and was covered by about 50 to 100 feet of overburden. The coal bed is the apparent source of water that was always present during 1974 and 1976 in potholes in the channel between the coal bed and the pond in the mined basin (fig. 2, pond M). The pond in the unmined basin is located topographically above the coal bed (fig. 2, pond U), and the channel above it is usually dry. Water is present only in response to rainstorm or snowmelt events.

The soils on the slopes of unmined areas are relatively shallow loams and clay loams, mantled in places with sandstone fragments. The alluvial soils in the valleys are fine-textured, silty clays. The soil materials of the spoils are, in general, clays containing some sandstone fragments.

Figure 6.--Highwall failure that occurred during the winter of 1974-75 (area 5, fig. 2). View is east in May 1976. Foreground distance is about 65 feet.

Figure 7.--Headcut at upper end of mine pit (below pond U, Fig. 2). View is southwest in September 1976.

The climate of the study area is semiarid. Weather station records for the period 1953-75 at Sheridan, about 12 miles southeast of the area, show an average of about 16 inches of precipitation per year, of which 74 percent falls as rain during April through October. The driest period includes December through February, when only 13 percent of the annual precipitation occurs.

Precipitation varies widely from year to year, from a minimum of 8.2 inches in 1960 to a maximum of 23.8 inches in 1955. Temperatures also show a wide variation between summer and winter and between daily maximums and daily minimums. The maximum temperature measured was 41°C on July 10, 1954, and the minimum was -37°C on January 13, 1963.

MEASUREMENTS, SAMPLES, AND ANALYSES

Sediment deposition in ponds was measured by probing the depth of sediment with a 0.5-inch steel rod and by constructing a map of equal thickness of sediment deposit. Sediment volumes were converted to annual sediment yields by considering the drainage areas and the number of years of sediment accumulation (table 1).

Samples of surficial materials on slopes, alluvium in both basins, channel-bed materials, and bottom sediment in both ponds were collected for particle-size distribution and chemical analyses. Sampling-site identifications and analytical values are listed in table 2. Sampling-site locations are shown in figure 8.

Concentrations of chemical constituents of pond sediment, channel-bed material, and slope material from both basins are listed in tables 3 and 4. Concentrations of selected chemicals in the pond waters and other surface and ground waters in the area and region are shown in table 5. Seasonal variations of several chemical constituents of the water in pond M are shown in table 6.

DISCUSSION OF RESULTS

Overland and channel flows are the fluvial processes by which sediment is transported within and from the basins. The two major factors governing the quantity and size of sediment in transport are sediment availability and the intensity of flow.

The sediment yield rate from the mined basin is more than 11 times greater than that from the undisturbed basin (table 1). This is primarily due to a greater amount of sediment exposed and available on the barren high walls of the mine site and the roughly graded spoil rows, and to the greater intensity of flow from the steeper slopes.

Table 1.--Sediment yield computed from the volume of sediment accumulated in ponds during 25 years

Pond	Contributing area (km^2)	Pond capacity (m^3)	Volume of sediment (m^3)	Sediment yield rate ($m^3/km^2/yr$)
Unmined (U)	0.39	555	160	16
Mined (M)	.83	2,837	[1]3,836	185

[1] Includes 1,431 m^3 of sediment deposited in low-gradient channel above the pond.

Table 2.--Particle-size analyses of samples collected in the basins

Sample number[1]	Slope gradient (percent)	Percent finer than 0.004 mm	Percent coarser than 0.062 mm	D_{50}[2] (mm)	Description of site
1	1	12	52	0.089	Side slope of valley above pond U; grass cover.
2	1	32	33	.018	Alluvium above pond U; entrenched channel with grassy bed.
3	0	78	2	<.004	Bed of pond U; under water.
4	1	22	58	.230	Alluvium; entrenched channel at lip of headcut at upstream end of mine pit; grass cover.
5	1	24	29	.028	Bed of entrenched channel at bottom of headcut; bare groundd.
6	60	36	42	.016	Foot of talus slope above pit floor near the headcut; bare ground.
7	1	32	47	.048	Detrital fan material on floor of mine pit below headcut; bare ground.
8	76	27	36	.011	Sloping, stony spoil material used to cover exposed coal seam; bare ground; rills and gullies.
9	72	2	93	1.6	Weathered coal bank on side of pit; some cover of annual weeds.
10	68	4	90	1.9	Slope of a nontypical spoil pile; about 20 percent cover of cheatgrass and kochia; armored with sandstone fragments; very few rills and bullies.
11	68	32	44	.035	Slope of a typical spoil pile immediately adjacent to sample 10; bare ground; extensively rilled.
12	0	74	1	<.004	Bed of pond M; under water.

1 See figure 8.

2 D_{50} is the size of particle at which 50 percent, by weight, of the material is finer than that size.

Table 3.--Chemical constituents, in milligrams per kilogram, reported on dry-weight basis, for the unmined basin

[Analyses are semiqunatitative 6-step spectrographic (Nieman, 1976). Results are arbitrary midpoints between geometric brackets as follows: 120,000; 83,000; 56,000; 38,000; 26,000; 18,000; 12,000; 8,300 ...; 1,200; 830 ...; etc.; milligrams per kilogram.]

Element	Composited hillslope material	Channel-bed material, above dam-induced deposit	Channel-bed material, dam-induced deposit	Pond sediment near inlet	Pond sediment near dam
Iron----------	50,000	30,000	30,000	20,000	30,000
Magnesium-----	15,000	7,000	10,000	10,000	10,000
Calcium-------	30,000	10,000	15,000	7,000	10,000
Titanium------	7,000	7,000	7,000	5,000	7,000
Aluminum------	100,000	100,000	100,000	100,000	100,000
Sodium--------	5,000	7,000	2,000	2,000	3,000
Potassium-----	30,000	30,000	50,000	20,000	50,000
Phosphorous---	N	2,000	1,500	N	1,000
Manganese-----	500	300	300	200	300
Silver--------	<.7	<.7	<.7	<.7	<.7
Boron---------	150	200	200	150	200
Barium--------	1,000	1,000	1,000	700	1,000
Beryllium-----	7	7	7	5	5
Cobalt--------	10	10	15	7	5
Chromium------	50	100	70	70	100
Copper--------	50	50	50	30	50
Lanthanum-----	70	100	70	50	70
Molybdenum----	N	N	N	N	N
Niobium-------	10	15	15	10	10
Nickel--------	30	50	30	30	30
Lead----------	30	30	30	30	30
Scandium------	20	20	20	15	20
Tin-----------	5	7	7	7	7
Strontium-----	150	200	150	100	150
Vanadium-------	150	150	100	150	100
Yttrium--------	50	30	30	30	30
Zinc-----------	150	150	100	100	100
Zirconium------	300	300	150	200	200
Cesium---------	100	100	100	100	100
Gallium--------	20	30	50	30	50
Ytterbium------	5	5	5	5	5
Percent Ash----	97	93.9	95.8	96.5	95.6

N = not detected at limit of detection.
Modified from Hinkley and Taylor (1977).

Table 4.--Chemical constituents, in milligrams per kilogram, reported on dry-weight basis, for the mined basin

[Analyses are semiquantitative 6-step spectrographic (Nieman, 1976). Results are arbitrary midpoints between geometric brackets as follows: 120,000; 83,000; 56,000; 38,000; 26,000; 18,000; 12,000; 8,300 ...; 1,200; 830 ...; etc,; milligrams per kilogram. In cases where ash contents were less than 90 percent, the original concentration-in-ash values were multiplied by the percent ash and reported to a compatable number of significant figures.]

Element	Undisturbed Quaternary alluvium	Non-coaly spoil	Coaly spoil	Coaly sediment, channel bed in mine pit	Coaly sediment, upper end of in-channel excavation	Coaly sediment, lower end of in-channel excavation	Pond sedi-ment mear inlet	Pond sedi-ment near dam
Iron----------	50,000	30,000	70,000	50,000	100,000	70,000	30,000	30,000
Magnesium-----	7,000	7,000	7,000	7,000	10,000	15,000	10,000	10,000
Calcium-------	20,000	3,000	10,000	10,000	30,000	50,000	5,000	15,000
Titanium------	7,000	7,000	7,000	7,000	5,000	5,000	7,000	7,000
Aluminum------	70,000	>150,000	100,000	70,000	70,000	70,000	100,000	70,000
Sodium--------	5,000	2,000	2,000	2,000	7,000	7,000	5,000	3,000
Potassium-----	20,000	30,000	15,000	20,000	30,000	20,000	50,000	20,000
Phosphorous---	N	N	N	N	N	N	N	N
Manganese-----	700	200	90	150	3,000	300	300	200
Silver--------	.7	<.7	.3	.5	N	.3	<.7	<.7
Boron---------	100	150	200	100	100	200	200	200
Barium--------	700	700	700	300	500	500	1,000	700
Beryllium-----	3	5	4	5	3	4	5	7
Cobalt--------	15	15	7	7	30	10	20	15
Chromium------	50	70	20	30	30	40	70	50
Copper--------	30	50	20	70	30	30	50	30
Lanthanum-----	70	50	20	30	30	40	70	50
Molybdenum----	N	N	3	3	N	N	N	N
Niobium-------	15	10	3	7	7	3	10	10
Nickel--------	30	30	30	30	50	40	30	30
Lead----------	30	50	30	10	10	20	30	30
Scandium------	15	15	7	10	7	10	20	15
Tin-----------	5	7	4	3	5	4	10	5
Strontium-----	200	70	70	70	100	300	150	150
Vanadium------	150	150	70	70	50	50	150	150
Yittrium------	50	30	10	20	10	20	30	30
Zinc----------	150	150	90	100	100	70	100	100
Zirconium-----	300	150	90	150	70	70	150	200
Cesium--------	100	100	40	70	N	N	150	150
Gallium-------	15	20	10	10	10	10	30	20
Yitterbium----	3	5	2	3	2	3	5	3
Percent Ash---	94.9	93.8	43.8	47.8	45.1	36.2	95.5	93.1

N = not detected at limit of detection.
Modified from Hinkley and Taylor (1977).

Table 5.--Relation of pond-water composition to that of possible source waters

[(concentrations in mg/L) N.D., not determined]

	Pond U[1]	Pond M[1]	Powder River Basin ground water from Fort Union Formation[2]		Well in spoil at study area[3]	Powder River Basin surface waters[4]	
			$Ca-Mg-SO_4$ type	$Na-HCO_3$ type		High discharge	Low discharge
Calcium	29	298	180	1.9	363	32	300
Magnesium	15	378	82	.6	670	14	290
Sodium and Potassium	17	232	260	450	155	38	734
Bicarbonate	158	366	362	1,150	N.D.	86	611
Sulfate	24	2,425	1,100	5.5	3,134	130	2,800
Chlorine	2.8	19	6.7	47	1.7	4.2	19
Dissolved solids	169	3,443	1,830	1,110	5,558	268	4,450
Silicate	2.3	12	11	7.8	31	7.4	4.1
pH	[5] 8.5 [6] 6.7	[5] 8.4 [6] 7.5	6.8	8.3	5.9	8.2	8.2

1 From Wangsness (1977). Each value, except pH, is average of four seasonal samples.
2 From Feder and others (1977). Single analyses of waters representative of each type.
3 From Rahn (1976). Values are average of two samples; one taken 2 hours after pumping started, and the other, 26 hours after pumping started. Depth of well was 50 feet.
4 From Water Resources for Montana (1975, p. 465). Values are from analyses of samples taken from Deer Creek near Decker, Mont., which has a drainage area of 38 mi^2. High-discharge sample was collected Jan. 21 (9.1 ft^3/s) and low discharge was collected April 21 (0.5 ft^3/s).
5 Maximum measured value.
6 Minimum measured value.

Table 6.--Selected chemical constituents in the water of pond M, measured seasonally (N.D., not determined)[1]

	1975 August	1976 February	1976 May	1976 August
Total hardness (mg/L)	2,700	2,100	2,500	2,300
Dissolved sulfate (mg/L)	2,700	2,100	2,300	2,600
Dissolved solids (mg/L)	N.D.	3,150	3,510	3,670
Dissolved silica (mg/L)	13	18	11	7.7
Total iron (μg/L)	190	40	2,000	580
Dissolved manganese (μg/L)	60	290	30	260

[1] Data from Wangsness (1977).

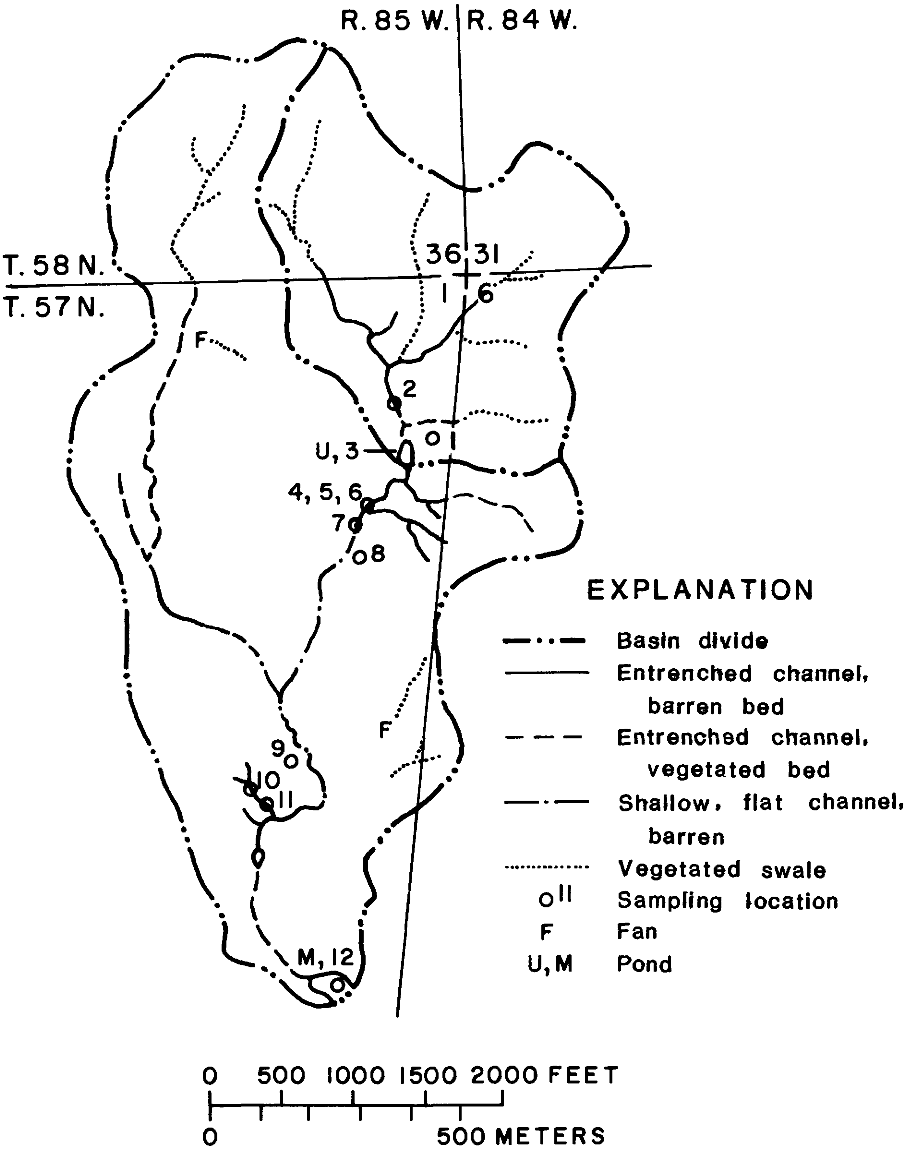

Figure 8.--Channel classification and location of sites sampled for particle-size analyses.

The areas that contribute the greatest sediment yield comprise only 12.5 percent of the basin. The floor of the mine pit and other flat areas of that basin yield sediment at rates similar to those of the unmined basin. An insignificant amount of sediment is yielded to pond M from the sides of most ungraded spoil rows where drainage is not complete to pond M. Sediment yield to pond M would likely have been greater if all the spoil rows had been roughly graded to permit drainage to the pond and if the rows had remained unvegetated.

Apparently, most flows are completely intercepted by pond M. No evidence was seen that only sediment yielded from either basin was transported beyond pond M.

The particle-size analyses shown in tables 2 and 7 indicate three types of materials in the basins: (1) Sandy-clay loam on most undisturbed areas and on typical spoil slopes, (2) stony-sand loam on some of the undisturbed areas and on the surface of nontypical spoil slopes mantled with sandstone fragments, and (3) a mixture of clay and humus on the bottoms of the ponds. Typical and nontypical spoil slopes are shown in figure 9.

Comparison of the analyses of samples 1, 10, and 11 with samples 3 and 12 in table 2 indicated that, although sand (>.062 mm), silt (.062 to .004 mm), and clay (<.004 mm) were on the slopes, only clay and perhaps some silt reached the ponds. Almost all the sand and part of the finer material apparently were being deposited in shallow, flat, barren, channels and on the beds and bars of entrenched channels that are healed with vegetation (fig. 8). For example, locations 4 and 7 in figure 8 are two places where considerable coarse material has been deposited (table 2).

There are few differences in the chemical composition of analogous materials from the two basins (tables 3 and 4). Ash content is generally high except for four samples from the mined basin that contain abundant, visible coaly material (table 4). Some definite differences are apparent in a comparison of the channel-bed materials of the two basins (columns 2 and 3, table 3; columns 4, 5, and 6, table 4). Samples from the mined basin seem to contain about half as much aluminum, potassium, magnesium, chromium, lanthanum, niobium, and gallium as samples from the unmined basin. This may be the result of coaly detritus in the mined basin. The same difference may be noted between coaly and noncoaly spoil material in the mined basin (columns 2 and 3, table 4). This effect of depressed concentration, which is attributed to dilution by coaly material, was not observed for other major, minor, and trace elements in the basins studied, and the reasons are not clearly known.

Table 7.--Particle-size distribution of two types of spoil material

Size range	Typical spoil[1,2] (percent by weight)	Nontypical spoil[2,3] (percent by weight)
<.004 mm	32	4
.004 - 2.00 mm	38	48
>2.00 mm	30	48

[1] Sample number 10, table 2.

[2] See figure 9.

[3] Sample number 11, table 2.

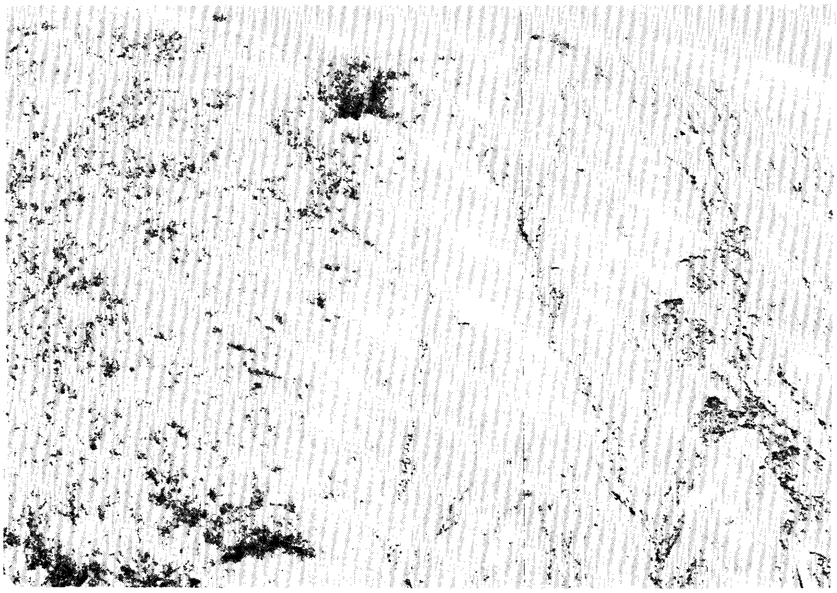

Figure 9.--Two adjacent types of spoil material. Typical shaly material is on the right and nontypical shaly material containing sandstone fragments is on the left. (See table 7.) Note the increased rilling where sandstone-fragment armoring and vegetal cover are lacking. View is west in September 1976. Foreground distance is about 20 feet.

In contrast to the chemistry of the soils and sediment of the two basins, the chemical constituents in the waters of the two ponds are very different. Concentrations of nearly all measured chemical constituents were higher in pond M than in pond U (table 5). The similarity between the chemical concentrations of the water in pond U and that of high-discharge surface waters from a nearby area (table 5) suggests that water in pond U was from surface runoff. The similarity between the chemical concentrations of the water in pond M and ground water from the Fort Union Formation of the calcium-magnesium-sulfate type and local ground water from a well in spoil material suggests that pond M is sustained by ground water (table 5).

Seasonal variations for the selected properties of pond M water shown in table 6 could be due to evaporative concentration, sporadic inflow of waters, changes in redox potential, and metal solubility related to eutrophication and algal activity, or to unknown errors, such as variation in sampling, filtration, or acidification techniques. In general, the consistency in total concentration of dissolved solids hints that seasonal variation in chemical properties is due to processes within the pond environment.

CONCLUSIONS

Sediment is moved by fluvial processes from its point of origin into channels, and then into the ponds. Materials in transport are sand, silt, and clay; however, most of the material transported through the basins is clay. Sediment is yielded from the mined basin at an above normal rate owing to a lack of protective covering on the steep, roughly graded, spoil slopes and to the unconsolidated, fine material lying on the floor of the mine pit. The sediment-yield rate to a pond below the mined area is more than 11 times greater than the sediment-yield rate to a pond below the unmined area. Sediment yield may be used as an indicator of the effects of surface disturbance in mined areas.

Pond M, at the lower end of the study area, intercepted all sediment in the flows. No evidence was seen that any sediment had gone into the Hidden Water Creek channel downstream from this pond.

Differences in chemical composition of sediment and sediment-source material between the two basins were generally small. Concentrations of certain elements, however, were only about one-half as great in coaly samples as in noncoaly samples.

Differences in the concentrations of dissolved chemicals in the water of the two ponds seem to be due to the difference in the origin of the water, surface runoff to the pond below the unmined basin, and ground-water discharge in addition to surface runoff to the pond below the mined basin.

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