PRELIMINARY RESULTS FROM A STUDY OF COAL MINING EFFECTS ON WATER QUALITY OF THE TONGUE RIVER, WYOMING[1]

by

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ABSTRACT

A preliminary assessment survey, preparatory to a comprehensive ERDA sponsored watershed study, was conducted in the vicinity of Sheridan, Wyoming on the Tongue River and its major tributaries during the summer of 1975 to determine the extent and magnitude of aquatic environmental impacts induced by strip mining of coal at one major mine in the western Powder River Basin of Wyoming. Results of detailed physical and chemical analysis of mine discharge and ambient water quality of receiving streams were not conclusive, but suggest that water quality impacts of present mining activities in the area examined are small when compared to other apparent land use impacts observed upstream of the mine.

INTRODUCTION

The Powder River Basin, located in Wyoming and Montana, is a broad, intermontane basin about 250 miles from north to south and 100 miles from east to west. It is bounded on the east by the Black Hills, on the west by the Bighorn Mountains, and on the south by the Laramie Range. Major coal beds are found near the top of the Paleocene Fort Union Formation, just below the Eocene Wasatch Formation. Cenozoic erosion has exposed the coal seams in a belt on the eastern side of the basin from north of Glenrock, Wyoming through Gillette, Wyoming to Colstrip, Montana. On the west side of the Basin, strippable coal deposits are located near Buffalo and Sheridan, Wyoming and Decker, Montana. Approximately 13.3 billion tons of coal lie in Wyoming, and most of this is found in the Powder River Basin. The relatively thick coalbeds (50-100 ft) are overlain by thin overburden in many places.

It is now well established that anticipated energy needs will place increased emphasis on strip mining of coal in the Powder River Basin. This expected increase in resource development will place increased importance on timely identification (and prediction) of environmental impacts resulting from extraction activities. The surface runoff, pumped mine discharge, and subsurface flow in mined areas have significant potential for environmental degradation of surface and ground-water systems. These environmental impacts are predominantly local, but can affect entire watersheds. The magnitude of the impacts will be determined by the mining technology employed, and the associated hydrologic, meteorologic, and geologic characteristics of the mine locality. The principal water pollution problems that have been associated with western coal extraction have included increases in suspended solids, alkalinity and salinity, and heavy metals in water bodies within the mine watershed (Van Voast, 1974; McWhorter et al, 1975).

METHODS, MATERIALS, AND STUDY SITE

Description of Study Area

Preliminary aquatic studies were conducted in the vicinity of the Big Horn Mine during the summer of 1975. The mine is located near Sheridan, Wyoming in the foot hills of the Big Horn Mountains (Figs. 1 and 2). This region is in the northwestern part of the Powder River Basin. The mine has been operated for 20 years by Peter Kiewit & Sons Mining Company and is one of several major mining operations in the Basin. Last year's production amounted to about 825,000 tons. The anticipated yearly production is 1,000,000 tons.

The area is predominantly grassland with some Juniper and Ponderosa Pine present at higher altitudes. Land use is primarily grazing but some irrigated agriculture is obvious along permanent streams. Precipitation averages ca. 14 inches/year, with much of the total as snowfall. The mine site is traversed by two permanent streams, Goose Creek and the Tongue River (a major tributary of the Yellowstone River). Both of these rivers have been diverted through final cuts of past stripping operations, and spoil material as well as highwall areas form banks for the streams where they have been diverted.

Two pits are being actively mined: one is progressing eastward into TV hill (Zowada pit), and another pit has recently been started on the south side of the Tongue River just east of Acme. (Fig. 2) This pit will progress southward, also toward TV hill.

Seepage rate into the new pit is relatively large and primarily derived from groundwater flow from the river through alluvium overburden and into the pit. Lesser amounts of water are seeping into the new pit from the south highwall. As mining in the new pit progresses southward, seepage from TV hill

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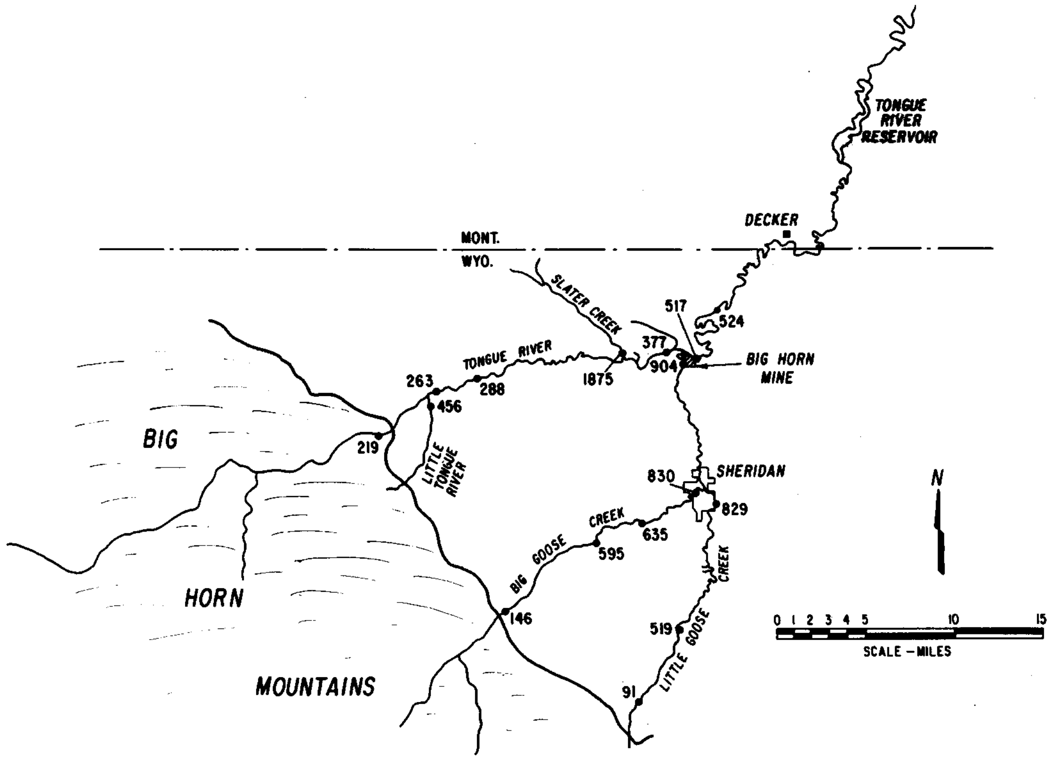

Figure 1. Regional map of upper Tongue River watershed showing sampling locations and data values (μmhos/cm) for spatial survey of specific conductance.

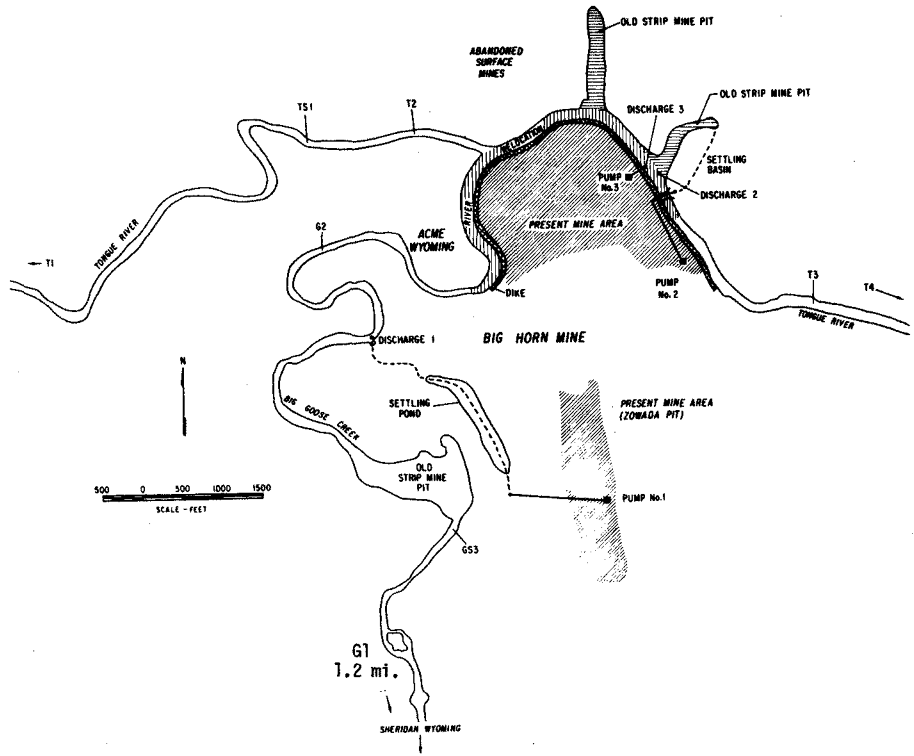

Figure 2. Map of Big Horn Mine and vicinity showing location of sampling sites and pertinent mine features.

could be expected, while subsurface flow from the river should diminish.

Seepage rate into the Zowada pit is less, with nearly all of the flow from the base of the coal in the highwall (east side of pit). Groundwater stored in TV hill is being slowly drained from the more permeable coal beds. Flow rates should decline through time as storage diminishes.

Methods and Materials

The water quality monitoring included measurement of the following parameters at three to six locations upstream and downstream of the mine and at three mine discharge points: turbidity, suspended solids, temperature, pH, specific conductance, alkalinity, hardness, chloride, fluoride, silica, sulfate, nitrogen, phosphorus, and 16 metals. In addition, a spatial survey of specific conductance was :onducted on the Tongue River with emphasis on major tributaries upstream of the mine. Location of the ampling sites is shown in Figs. 1 and 2.

Standard gravimetric, colorimetric and titrametric techniques were used for nonmetal analyses, ıile metals were measured using a combination of flame and flameless atomic absorption spectroscopy '.S.D.I., 1970; U.S.E.P.A., 1971). Samples for nitrogen, phosphorus, and metals were filtered in the eld upon collection. Analyses for ammonium nitrogen, nitrate nitrogen and phosphate were completed thin four hours of collection (except June samples which were analyzed within a few days after pre- :rvation with mercurous chloride). Filtered samples for metal analyses were acidified with nitric acid ml per liter). Specific conductance and temperature were measured in situ using a Yellow Springs ıstruments Model 33. Conductivity readings were corrected to equivalent values at 25 C using a short mputer program.

RESULTS AND DISCUSSION

Surface Hydrology

The annual hydrologic regimes of Goose Creek and the Tongue River are typical of mountain-source streams. Discharge rates are generally low during most of the year and increase by a factor of ca. 10 during the snow melting period, May-June. Both Goose Creek and the Tongue River above the mine have yearly average discharges of ca. 200 cfs with a range from less than 50 to greater than 1500 cfs (U.S.D.I., 1974a). Stream discharges at upstream sites for the three sampling dates are shown in Tables 1-3. Since the confluence of the two streams is on mine property, the Tongue River discharge rate below the mine is the sum of the two individual discharge rates plus pumped mine discharge which is estimated to total less than 5 cfs.

Ambient Water Quality

Water quality of both streams (shown in Tables 1-3) was related to discharge rate. Specific conductance and concentration of major ions was found to be inversely correlated with discharge rate. Ion concentrations in Goose Creek were as much as 50% higher than those in the Tongue River upstream of the mine, although they were qualitatively similar. The water is quite hard (high Ca and Mg) with bicarbonate and sulfate the dominant anions. Chloride concentrations were low, as were concentrations of toxic trace metals. The only trace metals exhibiting substantial concentrations in the streams were Fe, Mn, and Zn. Zinc concentrations were unexplainably high during the June snow melt period when river discharge and sediment load were high.

Nutrient concentrations in the two streams above the mine were distinctly different (Tables 1-3). Concentrations of dissolved nitrogen and phosphorus in Goose Creek exceeded those in the Tongue River above the mine by as much as two orders of magnitude. Dissolved nitrogen in samples collected on August 24 above the mine on the Tongue River contained no detectable ammonium or nitrate nitrogen. It is interesting to note that while dissolved phosphate in samples from upstream sites on the Tongue River was low, particulate (total) phosphate values were quite high, although still well below concentrations observed for Goose Creek samples. The source of the particulate phosphorus is unknown, but could be related to agricultural land use along both streams and to sewage discharge into Goose Creek at Sheridan.

Upstream Survey of Specific Conductance

A spatial survey of specific conductance was conducted on the Tongue River and Goose Creek watersheds from the base of the Big Horn mountains to a point just upstream of the Tongue River reservoir. The results are summarized in Fig. 1. The conductivity of Tongue River water during the late summer survey at the base of the mountains was about 220 μmhos/cm, and gradually increased to a value of 377 μmhos/cm just upstream of the mine. This represents approximately 26 miles of stream. Note that some tributaries of the Tongue had conductivities considerably above these values.

Conductivity rose even more dramatically in Goose Creek and its tributaries. Rapid conductivity changes were observed in both Little and Big Goose Creeks immediately upon leaving the mountains. In Little Goose Creek, for instance, conductivity rose by a factor of 5.7 from a value of 91 μmhos/cm to 519 μmhos/cm in a distance of only 5 miles. The conductivity continued to rise downstream to values near 900 μmhos/cm in the vicinity of the Big Horn Mine, more than double the value in the Tongue River.

Table 1. Summary of Water Quality Data for June 18, 1975

Parameter	Upstream TS1	Upstream GS3	Downstream T3	Calculated Downstream
stream disch. (cfs)	1831	1280	3111	-
spec. cond. (μmhos/cm)	133	132	130	133
temp. (C)	8.2	9.0	8.8	8.5
turb. (FTU)	39	45	45	41.5
susp. solids (mg/1)	65	105	71	81.5
diss. solids (mg/1)	149	157	148	130.9
total alk. (mg/1)	100	70	90	87.7
total hard. (mg/1)	100	90	90	95.9
chloride (mg/1)	4.3	4.3	4.3	4.3
fluoride (mg/1)	.25	.35	.36	.29
silica (mg/1)	7.0	6.8	7.0	6.9
sulfate (mg/1)	18	35	24	25
ammonium-N (mg/1)	.20	.20	.05	.20
nitrate-N (mg/1)	.08	.06	.08	.08
diss.-PO_4 (mg/1)	.55	.43	.43	.50
Ca (mg/1)	23	16	20	20.1
Mg (mg/1)	9.0	9.5	8.8	9.2
Na (mg/1)	9	10	8	9.4
K (mg/1)	1.0	1.2	1.1	1.1
As (μg/1)	<10	<10	<10	<10
Cd (μg/1)	.3	.3	.2	.3
Co (μg/1)	<.5	<.5	<.5	<.5
Cr (μg/1)	1.1	1.0	1.2	1.06
Cu (μg/1)	4.3	8.0	5.2	5.8
Fe (μg/1)	130	300	130	200
Hg (μg/1)	<1	<1	<1	<1
Mn (μg/1)	30.2	40.9	27.4	34.6
Mo (μg/1)	7.2	6.6	6.0	6.95
Pb (μg/1)	< .5	< .5	< .5	<.5
Se (μg/1)	<10	<10	<10	<10
Zn (μg/1)	290	370	230	323

Table 2. Summary of Water Quality Data for August 24, 1975

Parameter	Upstream T2	Upstream G1	Mine Discharge D1	Mine Discharge D2	Mine Discharge D3	Downstream T3	Calculated Downstream
stream disch. (cfs)	176	81	-	-	-	257	-
spec. cond. (μmhos/cm)	352	866	2997	549	961	550	514
temp. (C)	18.0	16.1	18.9	14.9	21.5	19.0	17.4
pH	8.5	8.1	8.4	8.0	7.9	8.7	8.4
turb. (FTU)	6	30	32	2	27	8	13.6
susp. solids (mg/l)	1.7	32.6	32.5	<1	73.1	1.1	11.44
total alk. (mg/l)	184	303	468	236	233	224	222
total hard. (mg/l)	138	288	573	204	300	187	185
chloride (mg/l)	1.5	4.6	7.2	2.1	4.4	3.3	2.5
fluoride (mg/l)	.31	.69	1.28	.61	.69	.47	.43
silica (mg/l)	4.9	1.9	5.6	8.6	9.6	4.6	3.9
sulfate (mg/l)	53	180	1425	140	335	125	93
ammonium-N (mg/l)	0	.38	3.6	.86	.82	.05	.12
nitrate-N (mg/l)	0	.328	.770	.322	.263	.089	.10
total-PO_4 (mg/l)	.42	1.30	.44	.45	1.18	.64	.70
diss.-PO_4 (mg/l)	.08	.65	.20	.275	.27	.19	.26
Ca (mg/l)	39	55	87	44	61	44	44
Mg (mg/l)	22.5	60	135	37.5	57.5	35	34.3
Na (mg/l)	20	45	465	35	50	30	27.9
K (mg/l)	1.6	3.8	27	5.2	6.6	2.5	2.3
As (μg/l)	<10	<10	<10	<10	<10	<10	<10
Cd (μg/l)	.6	.3	.5	.7	.9	.3	.5
Co (μg/l)	3.6	2.4	5.9	7.1	4.3	5.4	3.2
Cr (μg/l)	.9	1.5	2.1	1.1	.9	1.1	1.1
Cu (μg/l)	3.5	9.3	18.4	4.7	5.3	43	5.3
Fe (μg/l)	70	100	90	50	10	110	79.5
Hg (μg/l)	<1	<1	<1	<1	<1	<1	<1
Mn (μg/l)	40.3	105	66.4	101	330	43	60.7
Mo (μg/l)	1.3	<1	8.5	1.5	3.3	1.0	.89
Pb (μg/l)	.8	2.1	1.6	1.2	1.5	7	1.2
Se (μg/l)	<10	<10	<10	<10	<10	<10	<10
Zn (μg/l)	3.7	9.0	27.8	9.8	67	26	5.4

Table 3. Summary of Water Quality Data for Sept. 27, 1975

Parameter	Upstream T2	Upstream G1	Mine Discharge D1	Mine Discharge D2	Mine Discharge D3	Downstream T3	Calculated Downstream
stream disc. (cfs)	97	78	-	-	-	175	-
spec. cond. (μmhos/cm)	420	842	3036	622	1256	574	608
temp. (C)	10.6	10.0	10.5	13.2	15.3	12.0	10.3
pH	8.47	8.01	8.15	8.14	7.72	8.45	8.36
turb. (FTU)	7	12	70	10	17	9	9
susp. solids (mg/1)	1.5	5.3	54	54	22	1.2	3.2
total alk. (mg/1)	207.6	316	401.4	268.6	254	249.4	255.9
total hard. (mg/1)	155.8	291	634	181.6	341.2	207.6	216.1
chloride (mg/1)	0	4.5	16.2	3.0	6.9	2.3	2.0
fluoride (mg/1)	.27	.51	1.08	.53	.74	.39	.38
silica (mg/1)	5.3	4.4	6.4	8.4	9.2	4.2	4.9
sulfate (mg/1)	67	213	1400	168	480	130	132.1
ammonium - N (mg/1)	.15	.55	3.05	1.22	.57	.19	.33
nitrate-N (mg/1)	.005	.38	2.125	.267	.56	.51	.170
total -PO_4 (mg/1)	.385	1.10	.53	.50	.49	.56	.70
diss. -PO_4 (mg/1)	.03	.34	.04	.03	.03	.16	.35
Ca (mg/1)	48	68	180	55	101	52	56
Mg (mg/1)	21.5	50.8	122.5	38	74	36.5	34.5
Na (mg/1)	15	32	410	34	59	22	25.3
K (mg/1)	1.4	3.5	26.5	5.3	8.9	2.4	3.1
As (μg/1)	<5	<5	<5	<5	<5	<5	<5
Cd (μg/1)	.2	.3	.2	.2	.2	.2	.2
Co (μg/1)	1.2	3.0	4.0	4.7	1.5	3.1	2.0
Cr (μg/1)	3.5	1.9	6.2	1.5	3.3	2.5	2.8
Cu (μg/1)	3.1	6.0	11.0	4.5	6.3	3.6	4.4
Fe (μg/1)	40	60	130	170	50	40	48.9
Hg (μg/1)	<1	<1	<1	<1	<1	<1	<1
Mn (μg/1)	7.3	52.3	50.3	44.4	23	27.3	27.4
Mo (μg/1)	2.9	1.6	5.0	3.5	6.0	1.5	2.3
Pb (μg/1)	1.0	.6	11.5	1.4	4.3	2.2	.8
Se (μg/1)	<10	<10	<10	<10	<10	<10	<10
Zn (μg/1)	37.5	25.0	42.0	30	25	15	31.9

These data indicate large changes in dissolved ions in the upper reaches of the watershed. U.S. Geological Survey information suggests that sodium sulfate and calcium bicarbonate are largely responsible for the increases (U.S.D.I., 1974b). The next field season will be devoted in part to isolating the sources of these impacts. One possible source is irrigation return flow, since irrigation is widely practiced in the watershed.

Mine Discharges

Location of the three discharge points for pumped mine effluent are shown in Figure 2. As previously mentioned, seepage into the large Zowada pit flows mostly through the coal seams on the face of the highwall on the east side of the pit, and is primarily ground water stored in the hill east of the pit. The chemical quality of this discharge (discharge D1) is considerably different from discharges D2 and D3 which are pumped from the pit along the Tongue River and are essentially derived from seepage of river water through the overburden dike separating the pit from the Tongue River. The concentrations of all major ions in the D1 discharge were 2 to 5 times those measured in the other two mine effluents, and exceeded ambient river concentrations by even greater amounts (Tables 2 and 3).

Discharge samples (particularly D1) exhibited major increases over ambient river values for sodium and sulfate, and also substantial though lower increases for calcium, magnesium and bicarbonate. The high ammonium and nitrate nitrogen concentrations in the discharge samples could be related to use of ammonium nitrate explosives during coal extraction. Volume of the D1 discharge is estimated to average less than 300 gpm, while the maximum total of discharges D2 and D3 is estimated at ca. 1500 gpm.

EFFECTS OF MINING ON STREAM WATER QUALITY

The most straightforward approach in assessing point source impacts to stream or riverine systems is to simply compare upstream and downstream sites in terms of pertinent water quality parameters. Unfortunately, this simple experimental design could not be used in the present study because of the somewhat complex nature of the aquatic systems in the vicinity of the Big Horn Mine. The presence of two streams (Goose Creek and the Tongue River) with the confluence at or near the points of pumped mine effluent, in addition to the diversion of the streams through old strip mine pits (which essentially created small lakes on the streams) necessitated the use of a simple dilution equation for calculation of anticipated downstream water quality (after complete mixing of the two streams) based on upstream water quality and flow rates. The equation used is shown below:

$$C_d = \frac{C_t D_t + C_g D_g}{D_t + D_g}$$

C_d = calculated concentration of a given parameter downstream on the Tongue River

C_t = observed concentration of a given parameter upstream on the Tongue River

C_g = observed concentration of a given parameter upstream on Goose Creek

D_t = upstream flow rate of Tongue River

D_g = upstream flow rate of Goose Creek

This equation is based on the assumptions that substances act conservatively over the time scale involved and that mixing is complete. Determination of a significant mining impact is based on a comparison of calculated downstream concentrations and actual observed downstream concentrations for any pertinent parameter. A substantially higher observed concentration compared to that calculated (based only on mixing of the two streams) would suggest a mining impact. This comparison is presented in Tables 1-3 for the three sampling dates considered in the present study.

June samples were collected during a period when stream discharges were near the annual maximum and major ion concentrations were low. A comparison of calculated vs observed concentrations for the more conservative (i.e., less reactive) parameters such as specific conductance, dissolved solids, alkalinity, hardness, chloride, fluoride, sulfate, calcium, magnesium, sodium, and potassium, indicates reasonable agreement (Table 1). In no case was the observed value significantly higher than the expected (calculated) value. Measurable increases of chemical constituents in the Tongue River would not be expected during this high flow period since pumped mine effluents would be diluted in excess of 1:1000 upon release to the river.

The August and September sample collections coincided with periods of low river discharge. A comparison of downstream observed vs calculated concentration for August 24 (Table 2) shows that observed values for conservative parameters were slightly higher than would be expected by mixing of Goose Creek and the Tongue River, and suggests that pumped mine effluent may have been affecting the river during that period. Specific conductance and sulfate were respectively 7% and 34% higher than calculated; while alkalinity, hardness, calcium, magnesium, and sodium were 0-8% higher than anticipated. It should be mentioned that specific conductance at the T4 site one mile downstream from T3 was essentially the same as the calculated value, however, sulfate remained 34% high. High observed values were also recorded for copper, iron, and zinc, all of which are nonconservative parameters that might be expected to show high between-site variability.

Stream flow on September 27 was even lower than August, however, the comparison of downstream observed vs calculated concentrations of soluble constituents reveals no significant differences (Table 3). Copper, iron, and manganese concentrations for the comparison were similar, however, zinc was less than half of the expected value, emphasizing the apparently complex chemistry of the less soluble metals. Since the volume of pumped mine discharge is believed to be more or less constant throughout the year, the reason for the apparent differences in mine influences between August and September is not clear, but may involve short term fluctuations in stream discharge (daily averages were used in calculations) or the damping influence of the old mine pits through which the streams now flow. These factors will be examined during future comprehensive investigations of the Tongue River system.

Results of the preliminary study were not conclusive, but suggest that water quality impacts induced by operation of the Big Horn Mine may be small compared to other land use effects in the watershed. While concentrations of some chemical parameters in pumped mine discharge were high, concentration increases measured in the Tongue River downstream of the mine were small in comparison to observed increases upstream in agricultural areas.

While detection of impacts based on use of the dilution equation was not conclusive, it is possible to add an additional term to the equation representing the volume and concentration of mine effluent and to then use the equation as a simple model to predict the effect of increased mine discharge on the Tongue River. The modified equation is shown below.

$$C_d = \frac{C_tD_t + C_gD_g + C_eD_e}{D_t + D_g + D_e}$$

C_e = concentration of a given parameter in mine effluent

D_e = flow rate of mine effluent

Using sulfate as an indicator of mine pollution, the effect of various values of concentration and flow rate can be tested using the model. For example, using the sulfate concentration observed for the D1 discharge (ca. 1400 ppm) it can quickly be determined that increasing the flow rate of this discharge to 10 cfs (present rate is less than one cfs) during periods of low stream flow could result in a downstream sulfate increase of 50% or more. Similar calculations could be carried out for other conservative parameters under a variety of conditions. These calculations would show that while the present water quality impacts of the Big Horn Mine are probably small and inconsistent, substantial expansion of coal extraction activities along the river (assuming similar mine effluents) could result in significant impacts on water quality.

Since expansion of mining activities along the Tongue River are anticipated, Argonne National Laboratory will undertake, beginning in summer 1976, a comprehensive study of the Tongue River (sponsored by the U.S. Energy Research and Development Administration).

The proposed aquatic study will identify and quantify the water quality and aquatic ecosystem impacts related to operation of the Big Horn Mine. The aquatic investigation will include geophysical-geochemical and modeling subprojects to optimize identification and subsequent prediction of pollutant production, transport, and ultimate fate within the aquatic ecosystem. The study results will be compared and integrated with previous and ongoing research efforts on the Montana reach of the Tongue River to investigate the extent and significance of mining impacts in the entire Tongue River watershed.

Results of the multidisciplinary investigation will allow definitive conclusions to be drawn concerning the direct short-term impacts and long-term chronic effects of current strip mining practices in the Tongue River watershed, as well as prediction of impacts that are likely to result from future expansion of surface mining, including alternative mitigating actions necessary to assure proper environmental protection.

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