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of a Western Coal Mine

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ASSESSMENT OF WATER QUALITY IMPACTS OF A WESTERN COAL MINE*

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INTRODUCTION

Anticipated expansion of coal mining in many western states implies the potential for impact to water resources. 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. Information describing historical and/or current aquatic impacts of western coal mining is limited. However, it is clear that because of fundamental differences in coal chemistry, as well as climatic and hydrologic differences, the environmental impacts to aquatic systems will differ significantly from those found in eastern coal regions. At western mines, the small amounts of acid-forming substances (i.e., pyrite) along with the generally alkaline nature of overburden and soils suggests that acid drainage, with associated toxic metals, as is seen in the East, should be minimal. Available research results on western mines indicate that leaching of soluble salts from mine spoils and transport of these salts to receiving surface or groundwater systems is probably one of the principal water quality problems that can be expected (Van Voast, 1974; McWhorter et al., 1975; Van Voast and Hedges, 1975; McWhorter and Rowe, 1976; Thurston et al., 1976).

Of additional concern in arid and semiarid regions are the potential adverse mining impacts to alluvial valley floors. These unconsolidated deposits often exist in a state of delicate hydrologic balance, which if

*Work performed under the auspices of the U.S. Energy Research and Development Administration. The study was undertaken in coordination with Sheridan Community College and in cooperation with Peter Kiewit and Sons, Coal Mining Division.

upset could preclude future use of the area for agriculture and in addition could result in degradation of stream or groundwater quality (ICF, 1976).

STUDY SITE, METHODS, AND MATERIALS

Study Area

This report describes interim results of a water quality investigation carried out during 1975 and 1976 in the vicinity of the Big Horn Mine, an operating surface coal mine in the northwestern part of the Powder River Basin, Wyoming. The mine is located near Sheridan in the foothills of the Bighorn Mountains. The mine has been operated for approximately 20 years and is one of the several operating or proposed mines in the basin. Present coal production is about 1,000,000 tons (~910,000 MT) per year.

The area is predominantly grassland with Juniper and Ponderosa Pine present at elevations above about 4000 feet (~ 1200 m). The primary land use is grazing, but irrigated agriculture (principally hay production) is practiced in alluvial areas along perennial streams. Precipitation averages about 14 inches/year (36 cm/year), with much of the total as snowfall. The mine site is traversed by two perennial streams, Goose Creek and the Tongue River, with the confluence on mine property. Both streams have been diverted through the final cuts of past mining operations, thus forming two small lakes, one on each stream (see Fig. 1).

Two pits are being actively mined, the Zowada Pit east of Goose Creek and the Scott-Haymeadow Pit in the alluvial area south of the Tongue River (Fig. 1). Rate of water seepage into the Scott-Haymeadow Pit adjacent to the Tongue River was approximately 3 cfs (0.085 m^3/s) during the study, primarily due to groundwater infiltration from the river through the alluvium into the pit. Seepage rate into the Zowada Pit was less than one cfs (0.028 m^3/sec) and was derived from flows through the coal seam at the highwall and seepage from surrounding spoil storage areas. Water from the Zowada Pit during 1975 and from the Scott-Haymeadow Pit during the entire term of the study was pumped to settling basins which drained through discharges 1 and 2, respectively, into Goose Creek and the Tongue River (Fig. 1). Zowada Pit discharge during 1976 was pumped to a holding basin in alluvium adjacent to Goose Creek (discharge 5). There was an additional discharge (number 3) directly from the Scott-Haymeadow pit to the Tongue River during portions of this study.

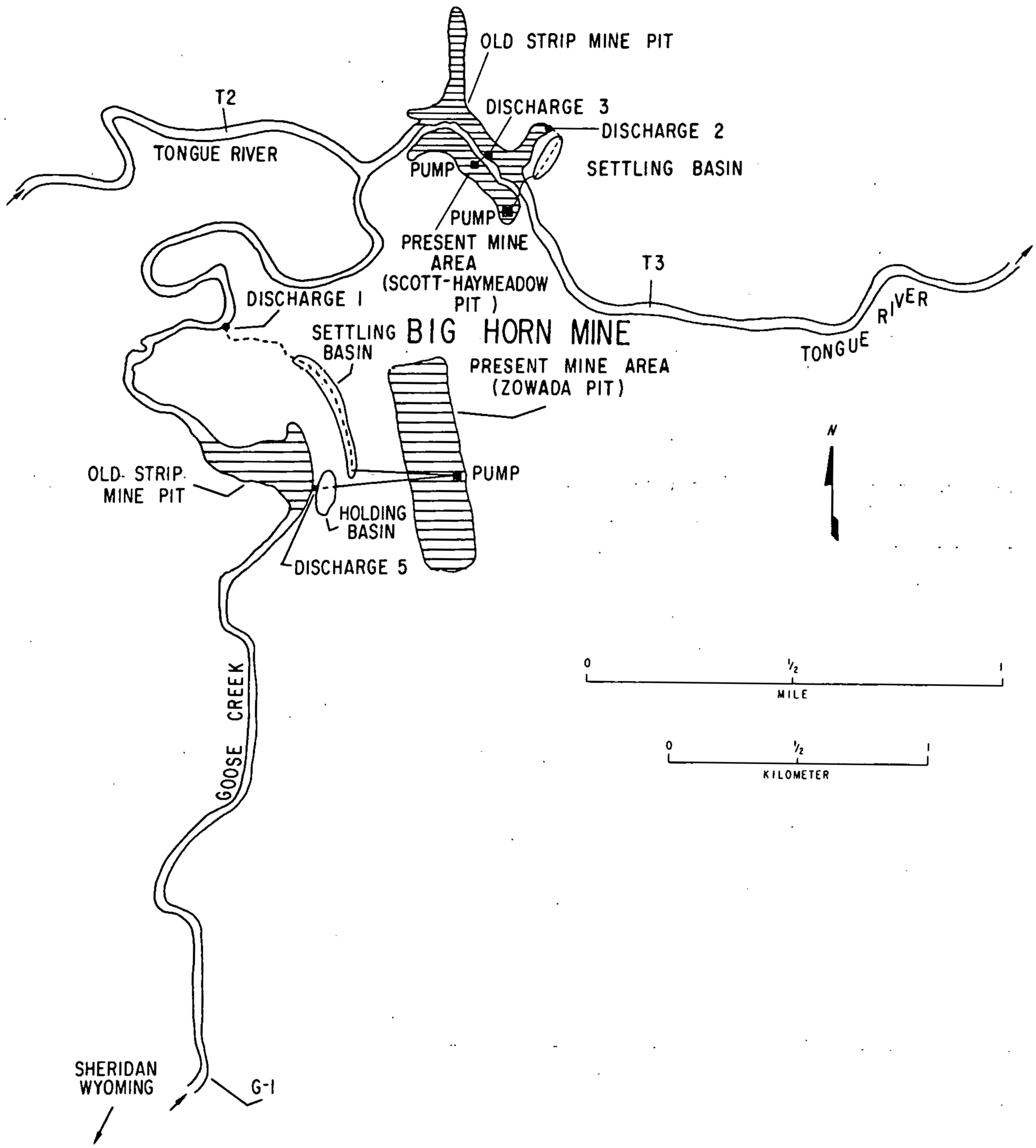

Figure 1. Map of Big Horn Mine and vicinity showing location of streams, discharges, sampling sites, and pertinent mine features

Methods and Materials

The water quality monitoring program included measurements at locations upstream and downstream of the mine and at mine discharge points of the following parameters: pH, specific conductance, alkalinity, chloride, fluoride, sulfate, nitrogen, phosphorus, and 16 metals and trace elements. All samples for a given month were collected on the same day.

Standard gravimetric, colorimetric and titrametric techniques were used for nonmetal analyses, while metals were measured using a combination of flame and flameless atomic absorption spectroscopy (USDI, 1970; USEPA, 1974). Samples for nitrogen, phosphorus, and metals were filtered in the field upon collection. Analyses for ammonium nitrogen, nitrate nitrogen, and phosphate were completed within four hours of collection. Filtered samples for metal analyses were acidified with nitric acid (5 ml per liter). Specific conductance and temperature were measured in situ, and conductance readings corrected to equivalent values at 25°C. Chloride concentrations encountered were quite low, and since the analytic method used had low precision (~ 20-50%) at the levels encountered, chloride values reported here are only approximate.

While an extensive array of water quality parameters were monitored, the results reported here pertain primarily to those which are expected to behave conservatively (Table 1), i.e. those highly soluble constituents and related parameters which do not readily enter into chemical or biological reactions.

Ambient Water Quality in the Tongue River and Goose Creek

Seasonal variations in discharge and specific conductance in the Tongue River are summarized for water year 1975 (October 1974 to September 1975) in Figure 2. The data are for a point approximately 28 miles (45 km) downstream of the Goose Creek - Tongue River confluence (USDI, 1975). The discharge of the Tongue River at this point fluctuated between 150 and 300 cfs (4.2 to 8.5 m^3/sec) during much of the year, with occasional higher flows, but increased by approximately an order of magnitude during the high flow period in late spring and early summer. Mean discharge for water year 1975 was 763 cfs (21.6 m^3/sec).

During this same period specific conductance, a good index of total dissolved solids, fluctuated between 800 and 950 μmhos/cm during most of the

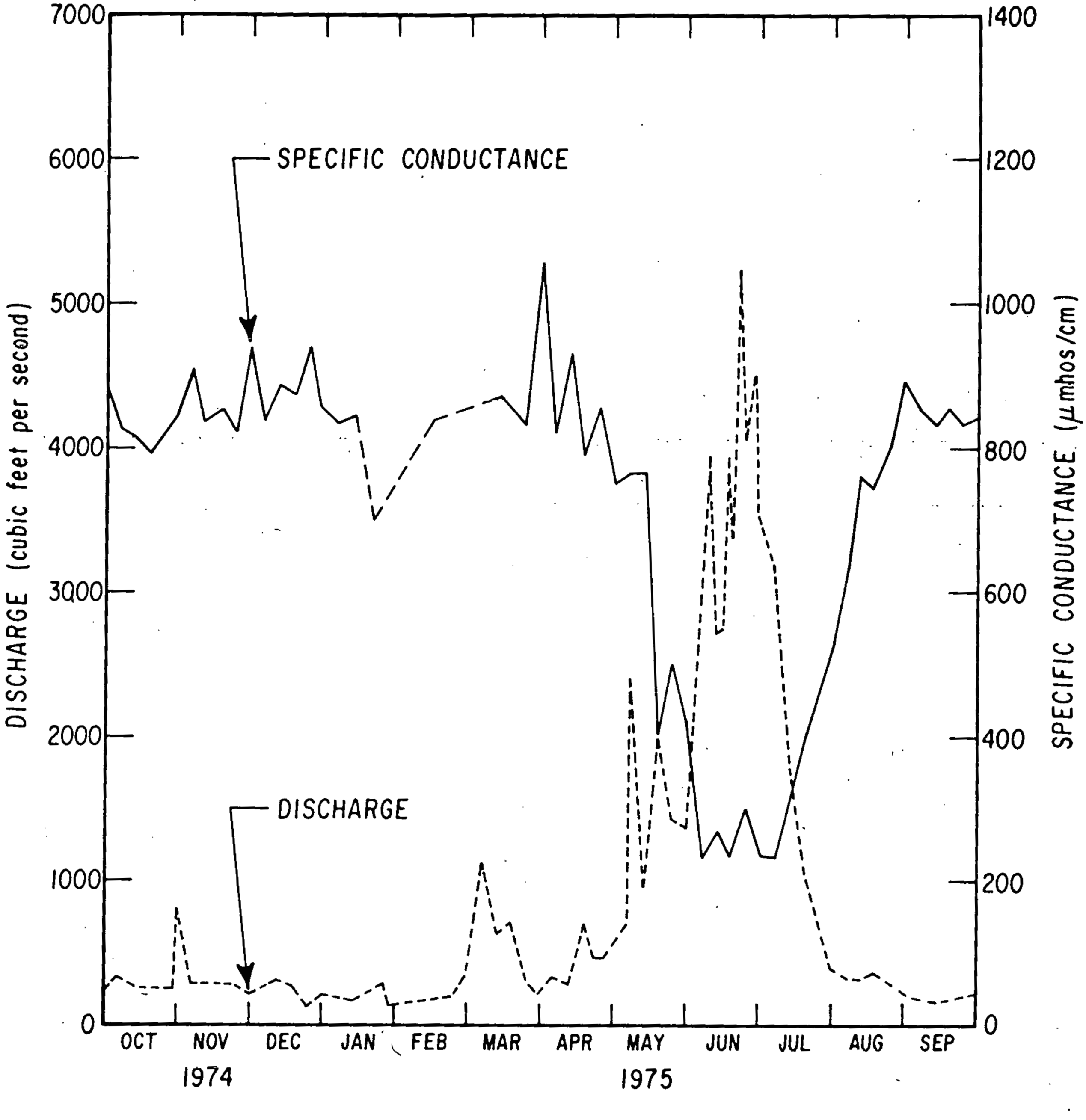

Figure 2. Seasonal discharge and specific conductance of Tongue River at the Wyoming-Montana State Line during water year 1975. (Data from USDI, 1975.)

year and decreased to approximately 250 μmhos/cm during the high flow period, presumably because the dissolved solids are diluted by increased discharge during snowmelt. The same seasonal patterns of discharge and specific conductance hold for the Tongue River and Goose Creek upstream of their confluence.

Mean discharge of Goose Creek at the U.S. Geological Survey (USGS) gaging station below Sheridan, approximately 11 miles (18 km) upstream of the confluence, was 259 cfs (7.33 m^3/sec) in water year 1975. Monthly instantaneous discharge measurements for a USGS gaging station at Monarch on the Tongue River, approximately 4 miles (6.4 km) upstream of the confluence, averaged 454 cfs (12.9 m^3/sec) for water year 1975. This compared with a mean discharge of 359 cfs (10.2 m^3/sec) for Goose Creek on the same dates.

Mean concentrations of conservative water quality parameters in the Tongue River and Goose Creek are summarized in Table 1. Stations G1 and T2 are in Goose Creek and the Tongue River, respectively, upstream of their confluence; station T3 is downstream of the confluence (see Figure 1). The concentrations of most ions are between 1.2 to 2.5 times higher in Goose Creek than in the Tongue River at station T2. As would be expected, concentrations for all conservative parameters at the downstream station T3, representing the combined flow of both streams, lie between the values for the separate streams. These data indicate that Goose Creek has a large effect on the water quality of the Tongue River.

Water Quality of Pumped Mine Discharges

Water quality data for the three pumped mine discharges and Tongue River station T3 are shown in Table 2. Sample standard deviations are included with mean concentrations to indicate variability.

Table 2 includes data on pH as well as conservative parameters. The pH values for the discharges are near 8, and approximately equal to those for the Tongue River. This alkaline drainage appears typical for western coal mines and differs from acid effluents often found at mines for high sulfur midwestern and eastern coals.

Concentrations of all conservative parameters are highest in discharges D1 and D5. While all constituents are present at lower levels in discharges D2 and D3, concentrations are still above Tongue River levels.

Table 1. Mean Concentrations of Conservative Parameters in Goose Creek and the Tongue River

Parameter	Units	Stations			Ratio G1/T2*
		G1	T2	T3	
Specific Conductance @ 25°C	($\frac{\mu mhos}{cm}$)	615	349	451	1.8
Total Dissolved Solids	(mg/ℓ)	552	320	412	1.7
Bicarbonate	(mg/ℓ)	312	207	246	1.5
Chloride	(mg/ℓ)	2.92	0.71	1.99	4.1
Fluoride	(mg/ℓ)	0.36	0.19	0.27	1.9
Sulfate	(mg/ℓ)	147	58	95	2.5
Calcium	(mg/ℓ)	49	40	40	1.2
Magnesium	(mg/ℓ)	40.9	19.1	28.4	2.1
Sodium	(mg/ℓ)	27	12.6	17.8	2.1
Potassium	(mg/ℓ)	2.7	1.3	1.8	2.1

*These ratios are dimensionless.

Table 2. Mean Concentrations and Sample Standard Deviations (in Parentheses) for Conservative Parameters and pH in Pumped Mine Discharges and the Tongue River

Parameter	Units	Discharges						Tongue River	
		D1 and D5		D2		D3		T3	
pH		8.06	(0.23)	7.98	(0.13)	7.78	(0.09)	8.35	(0.23)
Specific Conductance @ 25°C	(µmhos/cm)	3078	(384)	673	(104)	1098	(158)	451	(161)
Total Dissolved Solids	(mg/ℓ)	2730	(394)	606	(41)	915	(105)	412	(158)
Bicarbonate	(mg/ℓ)	554.3	(46.7)	304.5	(13.5)	329.1	(39.6)	246.0	(66.0)
Chloride	(mg/ℓ)	12.0	(5.5)	2.24	(0.79)	5.14	(1.27)	1.99	(1.48)
Fluoride	(mg/ℓ)	0.79	(0.35)	0.43	(0.17)	0.53	(0.32)	0.27	(0.15)
Sulfate	(mg/ℓ)	1411	(266)	166	(23)	363	(81)	95	(44)
Calcium	(mg/ℓ)	161	(45)	53	(6)	83	(18)	40	(15)
Magnesium	(mg/ℓ)	138	(22)	41	(4)	65	(12)	28	(12)
Sodium	(mg/ℓ)	406	(78)	34	(4)	55	(5)	18	(9)
Potassium	(mg/ℓ)	26.2	(4.9)	5.2	(0.4)	7.8	(1.1)	1.8	(0.7)
Sample Size		6 to 8		5 to 9		4 (3 for fluoride)		9 to 10	

Ratios of concentrations in pumped mine discharges to concentrations in the Tongue River are summarized in Table 3. Ions are most concentrated in discharges D1 and D5 and least in discharge D2. Concentrations of all constituents listed exceed those in the Tongue River for all discharges.

While concentrations of most parameters are elevated above ambient levels by a factor of 1.4 to 6.8 for discharges D1 and D5, sulfate and potassium are elevated by a factor of 15 and sodium by a factor of 23. These three ions are also elevated more than other ions with respect to ambient concentrations in the other two discharges. Concentration ratios for discharges D2 and D3, however, are considerably smaller than those for D1 and D5. A large fraction of the effluents from D2 and D3 consists of water seeping from the Tongue River, through alluvial and/or spoil material, into the Scott-Haymeadow pit adjacent to the river. This river water is dilute compared with mineralized water entering the pits from other sources.

Effect of Mining on Steam Water Quality

Concentrations of dissolved substances downstream of the mine and confluence are determined by their upstream concentrations in Goose Creek and the Tongue River, their concentrations in inputs to the stream system, and the volumetric flow rates of these sources. External inputs to the streams may consist of surface runoff and groundwater seepage unrelated to mining as well as mine related sources such as the pumped discharges described above, surface runoff, seepage from spoils, and seepage from aquifers such as coal seams which communicate hydraulically with the streams as a result of mining. An example of the latter category is the aquifers exposed in the mine pits through which Goose Creek and the Tongue River have been diverted.

The total loading rate of any given parameter to the stream reach downstream of the confluence is given by the expression $C_t D_t + C_g D_g + \sum_i C_i D_i$, where:

C_t = observed concentration of the parameter upstream on the Tongue River,

C_g = observed concentration of the parameter upstream on Goose Creek,

C_i = observed concentration of the parameter in the i'th external input,

D_t = upstream flow rate of the Tongue River,

D_g = upstream flow rate of Goose Creek, and

D_i = flow rate of the i'th external input.

Table 3. Ratios of Concentrations of Conservative Parameters in Pumped Mine Discharges to Concentrations in the Tongue River at Sampling Station T3

Parameter	Concentration Ratios		
	D1/T3, D5/T3	D2/T3	D3/T3
Specific Conductance @ 25°C	6.8	1.5	2.4
Total Dissolved Solids	6.6	1.5	2.2
Bicarbonate	2.3	1.2	1.3
Chloride	6.0	1.1	2.6
Fluoride	2.9	1.6	2.0
Sulfate	15.	1.8	3.8
Calcium	4.0	1.3	2.1
Magnesium	4.9	1.5	2.4
Sodium	23.	1.9	3.1
Potassium	15.	2.9	4.3

If one assumes complete mixing and conservative behavior for the parameter of interest, the mass balance can be expressed as:

$$C_d = \frac{C_t D_t + C_g D_g + \sum_i C_i D_i}{D_t + D_g + \sum_i D_i} , \qquad (1)$$

where C_d is the calculated concentration sufficiently far downstream of the confluence and inputs to guarantee complete mixing. The sum of discharges in the denominator gives the downstream discharge of the Tongue River.

While some quality and flow data are available for pumped mine discharges, loading rates from other sources such as spoil pile seepage and groundwater seepage directly into the streams through the pit walls are presently unknown. For this reason, the approach used in assessing impact was to calculate downstream concentrations anticipated only on the basis of ambient upstream water quality in Goose Creek and the Tongue River using the equation below (2), and to compare these expected concentrations with those observed at station T3.

$$C_d = \frac{C_t D_t + C_g D_g}{D_t + D_g} \qquad (2)$$

Calculated and observed concentrations would be expected to agree closely in the absence of significant water quality impacts by the mine, while observed concentrations of conservative substances which consistently exceed calculated values would suggest a source of these materials in the mine vicinity. This procedure is an extension of the commonly used technique of comparison of concentrations of water quality parameters upstream and downstream of a point source, and permits assessment of effects of multiple sources in the complex steam system encountered at this site.

Calculated and observed values of specific conductance and concentrations of total dissolved solids and eight individual ions expected to behave conservatively in this system are compared for eight sampling dates between August, 1975 and November, 1976 (Table 4). Data for two sampling dates in June of 1975 and 1976 were not included in the analysis because substantially reduced concentrations of all ions during the high flow period are atypical. Also, the extremely high streamflows during this period are expected to dilute

Table 4. Mean Deviations Between Observed and Calculated Concentrations at Tongue River Sampling Station T3 and Standard Errors of the Means

Parameter	Mean Deviation $(C_{obs}-C_{calc})$*,**	Standard Error of Mean**	Mean Deviation / Standard Error	Sample Size
Specific Conductance @ 25°C	-2.31	9.98	-0.23	8
Total Dissolved Solids	+0.11	9.11	0.012	7
Bicarbonate	-4.86	2.79	-1.7	8
Chloride	+0.577	0.225	2.6	5
Fluoride	+0.005	0.018	0.28	7
Sulfate	+2.091	5.783	0.36	8
Calcium	-3.619	2.715	-1.3	8
Magnesium	+0.758	0.946	0.80	8
Sodium	-0.363	0.623	-0.58	7
Potassium	-0.071	0.109	-0.65	7

*Observed concentration at Station T3 minus calculated concentration.

**Units for specific conductance are μmhos/cm, units for all other parameter are mg/ℓ.

mine effluents more than usual, thus biasing conclusions by inclusion of data collected when the system is particularly insensitive to mining effects. An analysis which included these additional data points did not alter the conclusions described below.

The data in the first column of Table 4 give the mean of the differences between observed concentrations at sampling station T3 and the concentrations calculated by use of equation 2. Deviations from zero difference could be caused by stream loading (e.g. mine effluents) between the upstream and downstream sampling sites, and by measurement variations within the level of analytical precision. An additional source of potential deviations could be time-dependent changes in ambient concentrations accompanied by time delays in transport, particularly in the two pits through which the steams have been diverted. Since deviations of this sort are expected to be random, mean deviations attributable to them should be small, and could be either positive or negative. Loading by mine effluents or other sources between the upstream and downstream sampling points would lead to observed concentrations at station T3 in excess of those calculated, giving a positive mean deviation. Sulfate, sodium and potassium concentrations may be particularly sensitive indicators of mining impacts since these ions are most elevated in mine effluents.

The second and third columns of Table 4 contain the standard errors of the mean deviations and the mean deviations divided by the standard errors of these mean deviations. Use of a t test (one- or two-tailed) indicates that all of the mean deviations except that for chloride are consistent at the 5% significance level with the null hypothesis that the mean deviations are drawn from a distribution with mean zero. In particular, the mean deviations of sulfate, sodium and potassium, the elements most concentrated in pumped mine discharges, are within 0.36, 0.58 and 0.65 standard deviation of zero.

We conclude that any effect of mining on conservative ions other than chloride during the study was within the range of sampling and analytical precision (estimated at ~ 10%) and short term variations in ambient water quality, and is undetectable using the available data. In view of the low precision of the chloride determination and the fact that chloride is not highly concentrated in mine effluents when compared with sulfate, sodium and potassium, the same conclusion is probably applicable to this ion as well.

Upstream Water Quality Survey

To place potential water quality changes in the vicinity of the Big Horn Mine in perspective, a survey of spatial variations in specific conductance was conducted in the Tongue River and Goose Creek watersheds in the late summer of 1975, beginning at the base of the Bighorn Mountains. The specific conductance of Tongue River water rose from a value of 219 μmhos/cm at the base of the Bighorn Mountains to a value of 377 μmhos/cm just upstream of the mine. This change occurred over a distance of approximately 25 stream miles (40 km).

Specific conductance changed more dramatically in Goose Creek and its tributaries, Little Goose Creek and Big Goose Creek, which join to form Goose Creek in the city of Sheridan. The specific conductance in Little Goose Creek, for example, rose by a factor of 5.7 from a value of 91 μmhos/cm near the foot of the Bighorn Mountains to a value of 519 μmhos/cm in a distance of only 5 miles (8 km). Similar large changes were observed in Big Goose Creek. Specific conductance continued to rise in Goose Creek to values near 900 μmhos/cm upstream of the Big Horn Mine. U.S. Geological Survey data suggest that bicarbonate, sulfate, calcium, magnesium, and sodium ions are largely responsible for these increases (USDI, 1975). Data collection during the next field season will be devoted in part to isolating the causes of these increases in specific conductance. One possible source for these increases is irrigation return flow, since irrigation is widely practiced in the watershed.

Summary and Discussion

The effect of the Big Horn Mine on concentrations of dissolved conservative constituents in the Tongue River is small, and is within the range of analytical precision and short-term variations in ambient concentrations. On the other hand, there are large changes in stream water quality evident in upstream reaches of the Goose Creek and Tongue River watersheds, where intensive agricultural activity exists.

Trace element concentrations are relatively low at all stream and mine discharge sampling points, and it does not presently appear that toxic trace elements will present environmental problems at this site (Olsen and Dettmann, 1976). Ammonium and nitrate concentrations are elevated in the Big Horn Mine discharges (possibly due to use of ammonium nitrate explosives) relative to levels in the streams, but phosphorous concentrations are not. Material balance calculations indicate that present loading by pumped mine discharges from the Big Horn Mine could locally increase ammonium and nitrate concentrations in the Tongue River by approximately 3 and 1 percent, respectively. While this would probably represent no measurable adverse impact, the cumulative effect of nitrogen loading at expanded mining levels should be investigated, particularly the potential for eutrophication in the Tongue River.

Van Voast and Hedges (1975) have estimated the potential water quality impacts of expanded coal extraction at the Decker Mine on the Tongue River. This mine is located adjacent to the Tongue River Reservoir, approximately 30 stream miles downstream of the Big Horn Mine, and with a yearly production of approximately 10 million tons (~9.1 million MT), is presently the largest operating surface coal mine in the U.S. Worst case estimates indicate increases in the range 0. to 3.5% above ambient levels for the sodium adsorption ratio and concentrations of total dissolved solids, sodium, calcium and magnesium in the Tongue River during mining, and increases in the range 0. to 7.4% during the post-mining period.

Studies conducted at the Edna coal mine near Oak Creek, Colorado, found substantial (often severalfold) increases in specific conductance and total dissolved solids for water in a reach of Trout Creek receiving mine effluents (McWhorter et al., 1975; McWhorter and Rowe, 1976). The authors present evidence that a large fraction of the increase is attributable to drainage from areas disturbed by mining. The primary ions in runoff from the Edna Mine site are calcium, magnesium, bicarbonate, and sulfate. The hydrologic regime of this site differs significantly from that of the Tongue River sites. Mean annual precipitation exceeds 20 inches (51 cm), and runoff from the mined area represents a much larger fraction of the total stream discharge than is the case at the Big Horn or Decker sites.

The results obtained by McWhorter et al. at the Edna Mine indicate that salinity increases may represent substantial water quality impacts at some western coal mines. The magnitude of such impacts are, however, sensitive to site-specific hydrologic conditions. Our study and that of Van Voast and Hedges at the Decker site suggest that current mining (i.e. 1975-1976) at the Big Horn and Decker Mines and the proposed Decker expansion will have only a minor effect on water quality in the Tongue River. The small effects observed at the Big Horn and Decker sites appear in large part attributable to the large quantities of dilution water available in the Tongue River relative to mine discharges.

In view of anticipated expansion of energy development in the Tongue River watershed, it should be stated that this conclusion applies only to mining at the indicated levels. Future water quality effects of expanded coal mining and utilization on the Tongue River will depend on both the quantity and quality of energy-related effluents released to the river, and upon perturbations such as consumptive water use and aquifer disturbance. Operation of additional mines along the Tongue River could possibly cause measurable increases in salinity and other parameters.

Acknowledgment

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