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TEMPORAL AND SPATIAL PATTERNS IN TRACE-METAL CONCENTRATIONS OF A MOUNTAIN STREAM IN WEST-CENTRAL COLORADO, USA

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ABSTRACT Thirty-three water-quality sampling surveys were conducted along mountainous-stream reaches during a 18-month period from September 1988 through March 1990, near Vail, Colorado. Streamflow, whenever possible, was measured at the time of sample collection, as were water temperature, dissolved oxygen, pH, and specific conductance. Samples were analyzed for hardness, alkalinity, and a suite of seven trace metals including cadmium, copper, iron, lead, manganese, silver, and zinc. The sampled stream reaches were being impacted by snow-making diversions, withdrawals, and return flows for municipal use on Gore Creek, and abandoned metals mining and tailings on the Eagle River. Trace-metals data were compared to both existing and proposed stream water-quality standards. Relatively high trace-metal concentrations were associated with the following sources: (1) lithologic anomalies in the upper Black Gore Creek watershed (dissolved manganese), (2) treated effluent discharges from the Town of Vail (dissolved cadmium, iron, silver, and zinc), and (3) mining-related flows (dissolved cadmium, copper, zinc, and manganese, and total iron and manganese). Solute concentrations were evaluated with respect to season and stream water-quality standards, as they pertain to existing water use and proposed water management of the Gore Creek system.

INTRODUCTION

A water-quality monitoring program was designed and implemented at selected locations along Black Gore Creek, Gore Creek, and the Eagle River near Vail, Colorado (Fig. 1). Data collection for this program was began in late September 1988. The purpose of this program was to provide a detailed characterization of water-quality conditions in stream segments that potentially were impacted by expanded municipal/snow-making diversions and a proposed Black Lake enlargement. This monitoring program consisted of semi-monthly sampling over a year (through September 1989). Monthly sampling continued for an additional 6-months (October 1989 through March 1990). This provided a detailed data base for a total of 33 surveys at as many as 15 sites for a suite of physical variables, and concentrations of nutrients and trace metals.

The Vail Valley Consolidated Water District has proposed to enlarge the capacity of Black Lake by nearly 280000 m^3. This upstream storage will serve to mitigate impacts of seasonal water use and to replace out-of-priority depletions caused by this use (Hydro-

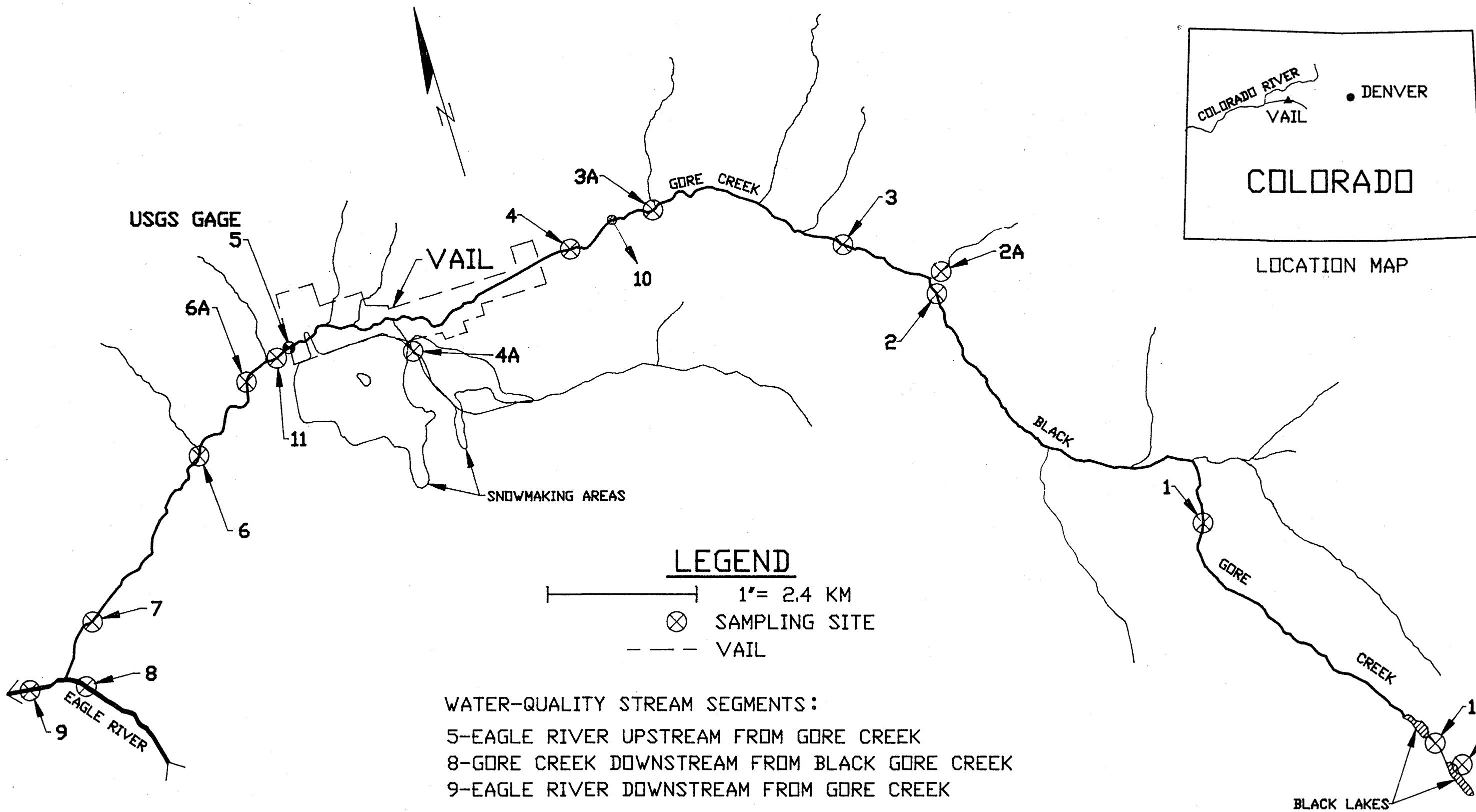

FIG. 1 Location of sampling sites and stream segments, Gore Creek/Eagle River monitoring program.

sphere Resource Consultants, 1990). The District's present and future water-use operations are described in Tipton and Kalmbach, Inc. (1990a).

APPROACH

A detailed interpretive report was prepared by Advanced Sciences, Inc. (ASI, 1990), based on data derived from a 18-month monitoring program. This paper, based upon the results of the more comprehensive study, provides an overview of potential impacts of the Black Lake #1 enlargement on hardness and selected trace-metal concentrations in Gore Creek and in the Eagle River upstream and downstream from Gore Creek. Sampling sites were selected to evaluate potential impacts of the Lake's proposed enlargement at various locations along Gore Creek and on the Eagle River upstream and downstream from the confluence of Gore Creek (Fig. 1). Variables in the monitoring program include:

(a) Physical variables — streamflow, water temperature, dissolved oxygen, pH, and specific conductance;
(b) Nutrients — nitrogen species at only a few sites including nitrate, nitrite, ammonia, and total Kjeldahl;
(c) Water quality variables — alkalinity and hardness;
(d) Trace-metal species — dissolved zinc, cadmium, mercury (site 10 only), copper, lead, manganese and iron, and total manganese and iron.

The monitoring program was designed to characterize dissolved trace-metal concentrations with new standards (or so-called table-value-standards or TVS). These new standards and method was proposed by the Colorado Department of Health (CDH, 1988) for implementation in November 1990.

Streamflow evaluation

Streamflow was measured at the time of sample collection or was estimated using interstation-correlation techniques (especially during high flows). Based on streamflow records at past and present gaging stations and on reservoir-operation studies (Tipton and Kalmbach, 1990a), a 30-day, 3-year average low-flow was estimated at each water-quality monitoring site (Tipton and Kalmbach, 1990b). These low-flow estimates were used to compute the new trace-metal stream standards (CDH, 1988).

Existing stream standards and the proposed TVS method

The existing stream water-quality standards applicable to Gore Creek and the Eagle River upstream and downstream from Gore Creek (CDH, 1980) have been designated as stream segments 8, 5, and 9, respectively (Fig. 1). However, at the onset of the water-quality monitoring program, it was anticipated that a TVS method of computing trace-metal standards and a stream-antidegradation determination procedure would be applicable (CDH, 1988). For the proposed method, each standard is expressed as a function of hardness. The hardness at a site is the lower 95% confidence limit of the predicted hardness associated with the 30-day, 3-year streamflow of a log-log regression of hardness on streamflow (CDH, 1988; ASI, 1990).

DISCUSSION OF RESULTS

Existing streamflow and water-quality conditions

Stream profiles for Black Gore Creek (site 2) and Gore Creek (site 5) are shown in Fig. 2. Seasonal variations and inverse relations between streamflow and concentrations of indicator water quality generally are apparent. However, maximum hardness occurred in the months of January through March 1989 (Fig. 2), just prior to the beginning of spring-period snowmelt runoff. In 1990, maximum hardness occurred slightly earlier (that is, for the December, January, and February surveys).

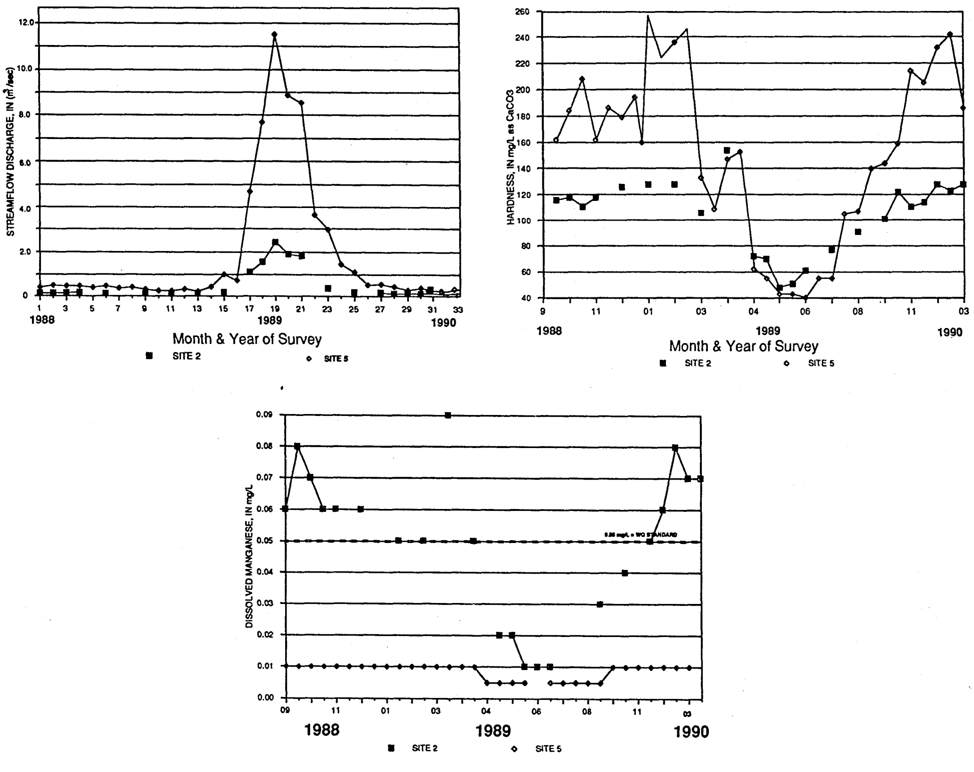

FIG. 2 Streamflow discharges, hardness concentrations, and dissolved manganese concentrations, Black Gore Creek (site #2) and Gore Creek (site #5).

The Eagle River was monitored at site 8 upstream from the confluence of Gore Creek and site 9 downstream from Gore Creek (Fig. 1). For the Eagle River, seasonal variations and inverse relations between streamflow and concentrations of indicator water quality were observed (Figs. 3 and 4) and were similar to those for Gore Creek and Gore Creek. Maximum hardness occurred from January to March 1989 and from December to February 1990. Select trace-metal concentrations at both Eagle River sites have increased dramatically since October 1989, and are much greater than those observed during the same season in 1988-1989 (Fig. 4) (ASI, 1990). This condition is caused by recent and ongoing mine-tailings reclamation activities (CDH, 1990a-d; Dames & Moore, 1990a-d; 1991a-c).

Exceedences of varying degrees occur when the TVS method was applied to trace metals (Table 1). In the case of Black Gore Creek and Gore Creek, the standards derived from TVS method for trace metals, specifically cadmium, copper, lead, and silver, are less stringent (expressed in dissolved form) than the currently applicable standards (expressed in total recoverable form). In Black Gore Creek, dissolved manganese concentrations frequently and dissolved copper concentrations occasionally exceeded previously applied standards. These appear to be caused by the local bedrock mineralogy. For the Eagle River, existing stream standards frequently are exceeded for total manganese, zinc, and cadmium (Fig. 4), as well as total iron (ASI, 1990).

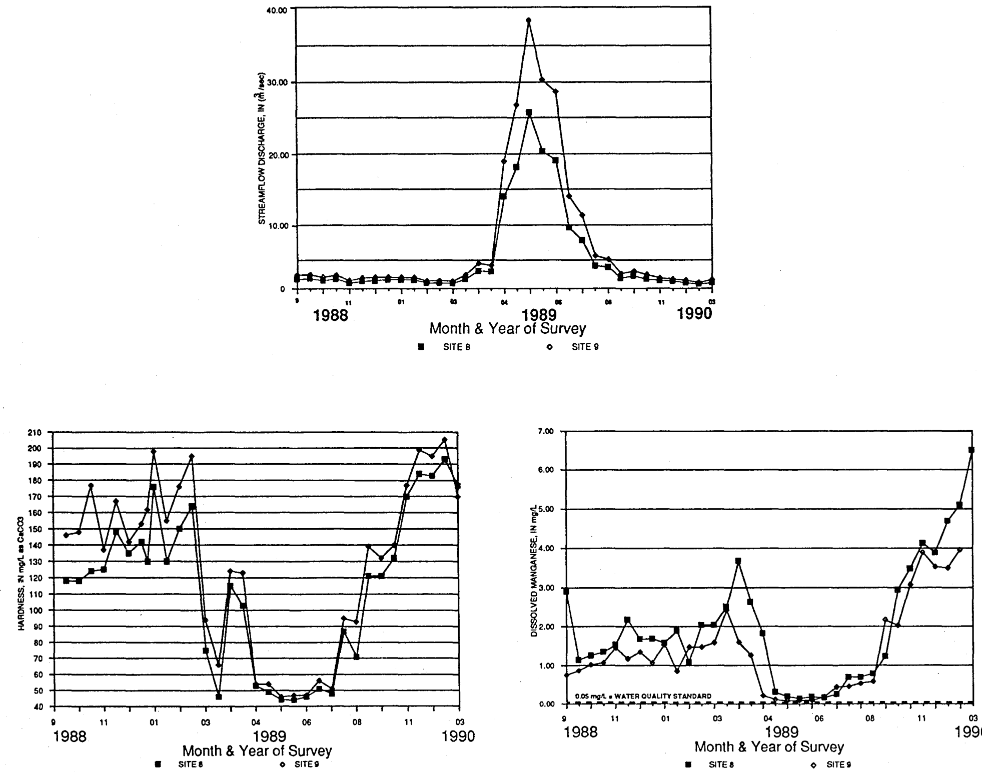

FIG. 3 Streamflow discharges, hardness concentrations, and dissolved manganese concentrations, Eagle River (site #8 upstream and site #9 downstream).

As mentioned above, concentrations of several trace metals have increased substantially in monthly samples collected at both Eagle River sites since September 1989 (see Figs. 3 & 4 and ASI, 1990). The impact in this stream is associated with the remediation of tailings and of a water pump-back system at the Eagle Mine (Dames & Moore, 1990a-b; 1991a-c). Other water-quality data also have substantiated the observed trace-metal concentration increases in the Eagle River (Engineering Science, 1985; CDH, 1990a-d). Inhabitants living in and around the Town of Minturn on the Eagle River have alerted State and Federal regulatory agencies regarding this adverse situation.

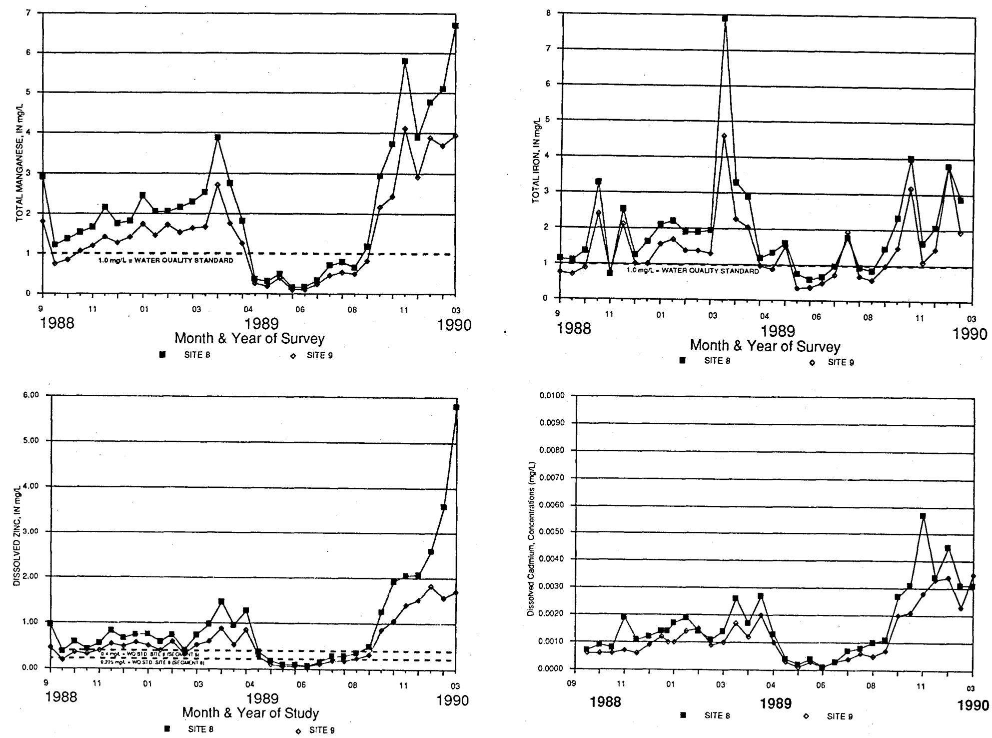

FIG. 4 Total manganese, total iron, dissolved zinc, dissolved cadmium concentrations, Eagle River (site #8 upstream and site #9 downstream). Standards exceedences were based on monitoring-program data.

Exceedences of the previously applicable trace-metal stream standards relative to ambient conditions are noted as follows. For Black Gore Creek, the dissolved manganese standard was 0.05 mg l^{-1} which was exceeded about 50% of the time, i.e. in 6 of 13 samples collected at the inflow to Black Lakes #2, site 1A, and in 11 of 22 samples collected near the confluence with Gore Creek, site 2 (Fig. 2). These exceedences commonly occur during autumn and early-winter. In addition, dissolved manganese concentration for 1 of 2 supplemental samples, which were collected for smaller Black Lake #1 inflows during the September 1989 survey, was 0.17 mg l^{-1} (ASI, 1990). During October 1988, dissolved copper concentrations exceeded the total-recoverable existing stream standard of 0.005 mg l^{-1} at site 1A on Black Gore Creek (0.026 mg l^{-1}) and at site 2A on Gore Creek (0.014 mg l^{-1})(ASI, 1990). A total iron concentration of a sample collected during September 1989 at site 1A on Black Gore Creek (1.9 mg l^{-1}) exceeded the existing stream standard of 1.0 mg l^{-1}. In the lower reach of Gore Creek, dissolved copper concentrations exceeded the total-recoverable stream standard for 1 sample each at site 6A (0.007 mg l^{-1}) and at site 7 (0.060 mg l^{-1}) (ASI, 1990). In Gore Creek, exceedences of the previously applicable total-recoverable standard occurred infrequently for other trace metals; one exception was dissolved silver which exceeded the standard in a sample at site 6A (0.0003 mg l^{-1}) and one at site 7 (0.0002 mg l^{-1}) during the 28 December 1988 survey (ASI, 1990).

The recently implemented CDH statistical-analysis method for determining existing quality (EQ), based on data from the 18-month monitoring program, was compared with proposed TVS concentrations. In general, EQ values were considerably less than TVS concentrations. The new TVS standards may be used for stream standards after CDH's triennial review (ASI, 1990).

For the Eagle River, standards were exceeded frequently when compared with previously applicable standards for dissolved zinc, cadmium, and manganese, and total iron and manganese. Standards were exceeded occasionally for dissolved copper, lead, silver (upstream site only), and iron (both sites).

Water-quality impacts of Black Lake operations

Black Gore Creek and Gore Creek When comparing conditions associated with the development scenarios for Black Lake with present (1985) levels without Black Lake (Tipton & Kalmbach, 1990a), 30-day, 3-year low-flow stream discharges computed for the monitoring sites increased slightly in Black Gore Creek and in the upstream reaches of Gore Creek, due to water management operation of Black Lake, for which water is released during winter (generally starting in February). The estimated flow increases would cause incremental decreases in total hardness concentrations as estimated by the TVS method (Table 1 and associated regression plots given in ASI, 1990). Consequently, trace-metal concentrations will tend to benefit, i.e. decrease, from dilution by the additional water released during low-flow (that is, winter). This pattern would be consistent with the slight decrease (Table 1) in stream-standard concentrations for the four trace metals computed using the TVS method (ASI, 1990). In the lower reach of Gore Creek, the 30-day, 3-year low-flow decrease as development increases, i.e. comparing present level without Black Lake with expected levels from build-out with Black Lake. The streamflow decrease results primarily from snow-making diversions which will occur at Gore Creek just upstream of site 6A. The TVS method estimates higher hardness concentrations and associated higher stream standards. Trace-metal concentrations in this lower reach of Gore Creek are not expected to change significantly because of the Black Lake operations.

In summary, trace metal concentrations in the Gore Creek watershed during the present level of Vail development would exceed standards with an equal probability, in most cases, for the various development scenarios involving Black Lake operations. With respect to the effect of these operations on Gore Creek, trace-metal concentrations are expected to be below analytical detection limits and, hence, the impact would be insignificant. This conclusion is based on the seasonal redistribution of flows, for which minimal consumptive losses are expected to occur relative to ambient streamflow (Tipton and Kalmbach, 1990a), the limits of precision in analyzing the relatively low trace-metal concentrations, and the current trace metal concentrations.

Eagle River For the Eagle River, both upstream and downstream of the confluence of Gore Creek, the aforementioned exceedences by concentrations of total iron and manganese, and dissolved zinc and cadmium were further scrutinized. The beneficial effect of reducing trace-metals concentrations during the November-December periods is decreased somewhat when Black Lake #1 operations are expected to cause the greatest reductions in Gore Creek flows (Tipton and Kalmbach, 1990a). The incremental effects of changes in flow of Gore Creek, which are expected from Black Lake #1 operations, on conditions in the Eagle River for selected water-quality variables were assessed using a mass balance.

TABLE 1 Proposed trace-metal TVS standards (mg l^{-1}) and exceedences.

Development scenario	Hardness	Dissolved Cd	Cu	Pb	Ag	Zn	Total Fe	Mn
			Black Gore Creek above Gore Creek (Site 2)					
Present (1985) level								
Without Black Lake	126	0.0014	0.014	0.005	0.0005	0.045	1.0@	1.0
With Black Lake	110	0.0012	0.013	0.005	0.0004	0.045	1.0@	1.0
Build-out level								
Without Black Lake	126	0.0014	0.014	0.005	0.0005	0.045	1.0@	1.0
With Black Lake	110	0.0012	0.013	0.005	0.0004	0.045	1.0@	1.0
			Gore Creek below Booth Creek above Vail Wellfield (Site 3A)					
Present (1985) level								
Without Black Lake	76	0.0009	0.009	0.003	0.0002	0.045	1.0	1.0
With Black Lake	72	0.0009	0.009	0.002	0.0002	0.045	1.0	1.0
Build-out level								
Without Black Lake	76	0.0009	0.009	0.003	0.0002	0.045	1.0	1.0
With Black Lake	72	0.0009	0.009	0.002	0.0002	0.045	1.0	1.0
			Gore Creek at Vail (Forest Road Bridge) (Site 5)					
Present (1985) level								
Without Black Lake	205	0.0020	0.022	0.011	0.0011	0.047	1.0	1.0
With Black Lake	189	0.0019	0.021	0.010	0.0010	0.045	1.0	1.0
Build-out level								
Without Black Lake	221	0.0021	0.023	0.012	0.0012	0.054	1.0	1.0
With Black Lake	202	0.0020	0.020	0.011	0.0011	0.045	1.0	1.0
			Gore Creek at Dowd Junction (Site 7)					
Present (1985) level								
Without Black Lake	212	0.0020	0.022@	0.011	0.0012	0.050	1.0	1.0
With Black Lake	205	0.0020	0.022@	0.011	0.0011	0.047	1.0	1.0
Build-out level								
Without Black Lake	231	0.0022	0.024@	0.013	0.0014	0.059	1.0	1.0
With Black Lake	224	0.0021	0.024@	0.012	0.0013	0.056	1.0	1.0
			Eagle River above Gore Creek (Site 8)					
All Alternatives	159	0.0016$	0.018	0.007	0.0007	0.045*	1.0*	1.0*
			Eagle River below Gore Creek (Site 9)					
Present (1985) level								
Without Black Lake	175	0.0018$	0.019	0.009	0.0008	0.045*	1.0*	1.0*
With Black Lake	172	0.0017$	0.019	0.008	0.0008	0.045*	1.0*	1.0*
Build-out level								
Without Black Lake	177	0.0018$	0.019	0.009	0.0009	0.045*	1.0*	1.0*
With Black Lake	175	0.0018$	0.019	0.009	0.0008	0.045*	1.0*	1.0*

Hardness concentrations computed by using the 30-day, 3-year streamflow into the appropriate site's regression relationship at the lower 95 percent confidence interval, determined from available data for that site.

See CDH (1988) for chronic-standard functions for calculating appropriate trace-metal concentrations.

Total iron and total manganese chronic table value standards are set at 1.0 mg l^{-1}, that is, at levels identical with existing total recoverable standards (CDH, 1988).

exceedences: * = frequent (>80%), $ = moderate (40-60%), # = occasional (10-20%), and @ = infrequent (<5%).

November and December, 1988 and 1989, were used for a "critical-period" evaluation of water quality in the Eagle River just downstream from the confluence of Gore Creek. This period was critical because it is the time when flows were expected to decrease the most in the lower reach of Gore Creek, according to expected Black Lake #1 operations. Water-quality loadings upstream in the Eagle River and in Gore Creek were added and the sum divided by the flow of the downstream station on the Eagle River for each "critical-period". This provided an estimated water-quality concentration at the downstream station on the Eagle River. One assumption incorporated in the estimate is that the upstream sources are completely mixed by the time the water reaches the Eagle River station. For each water-quality variable considered (hardness, and dissolved cadmium, manganese and zinc), estimates were computed for each of the 7 surveys conducted during the 2-month periods for each year, and averaged. Differences caused by streamflow reductions in hardness and selected trace-metal concentrations in the Eagle River downstream from Gore Creek are within the range of values computed from the mass balance for which flow reductions were not included (ASI, 1990). Considering the effects of the Black Lake enlargement, the trace-metal concentrations are expected to decrease in the Eagle River but to fall within the concentrations differences now observed in that stream (ASI, 1990). The impact therefore is expected to be insignificant, and the effects of the Black Lake #1 enlargement would not adversely impact the Eagle River downstream.

CONCLUSIONS

Relative to existing stream standards, the primary concern in the Gore Creek watershed involves recurring exceedences of dissolved manganese concentrations in Black Gore Creek, a condition which is caused by bedrock mineralogy. Otherwise, standards are infrequently exceeded. A secondary concern involves high ambient concentrations of dissolved copper and silver, and total iron which occasionally exceed standards at a few locations in the Gore Creek watershed. In contrast, trace-metal concentrations exceed existing stream standards frequently for the Eagle River both upstream and downstream of Gore Creek. Despite seasonal benefits of high flows, which correspond with low trace-metal concentrations, concentrations for several trace metals have increased since October 1989, and the increase is caused by mine/tailings remediation of the Eagle Mine. Resolution of these recent adverse conditions in the Eagle River are of concern regarding resultant impacts in the Eagle River. Continued monitoring of water-quality conditions in the Eagle River would be advisable. In summary, impacts of the Black Lakes operational plan on stream water quality are expected to be insignificant in the Gore Creek watershed and the Eagle River.

ACKNOWLEDGMENTS The monitoring program described in this paper was designed and operated on behalf of the Vail Valley Consolidated Water District.

REFERENCES

Advanced Sciences, Inc. (ASI) (1990) Vail-Gore/Eagle water-quality monitoring, Program Results. Completion Report Prepared for the Vail Valley Consolidated Water District, April 27, 16 p., 10 figures, 6 tables, and Appendices A-C.

Colorado Department of Health (1980) Classifications and numeric standards, Upper Colorado River Basin and North Platte River (Planning Region 12). Water Quality Control Commission, Section 3.3.0, June 9, 32 p.

Colorado Department of Health (1988) The basic standards and methodologies for surface water 3.1.0 (5 CCR 1002-8). Water Quality Control Commission, August 9, 89 p.

Colorado Department of Health (1990a) Eagle River Analytical Results., Memorandum from Eagle Mine On-Site Coordinator, April 5, 2 p.

Colorado Department of Health (1990b) Eagle Mine quarterly progress report, Addendum. May 30, 23 p.

Colorado Department of Health (1990c) Eagle Mine quarterly progress report (EAG, 11.12). July 23, 31 p.

Colorado Department of Health (1990d) Eagle River contaminant loading report, (EAG 11.12). August 8, 10 p.

Dames & Moore (1990a) Seventh quarterly progress report, July through September, 1990, Eagle Mine Site Activities. October 12, 21 p., Appendices A and B.

Dames & Moore (1990b) Eagle Mine seventh quarterly progress report addendum., November 16.

Dames & Moore (1990c) Report on loading to the Eagle River for the Eagle Mine, Project, Minturn, Colorado. Prepared for Paramount Communications, Inc., December 3, 59 p., Appendices A and B.

Dames & Moore (1990d) Eagle Mine annual report, April 1989 to March 1990. December 20, 21 p., Appendices A-1 through A-9.

Dames & Moore (1991a) Eighth quarterly progress report, October through December 1990, Eagle Mine site authorities. January 14, 21 p., Appendix A.

Dames & Moore (1991b) Eagle Mine eighth quarterly progress report addendum. February 12.

Dames & Moore (1991c) Ninth quarterly progress report, January through March 1991, Eagle Mine site activities. April 12, 19 p., Appendix A.

Engineering-Science (1985) Eagle Mine remedial investigation. Prepared for the, State of Colorado Department of Law, December 2, 2 vols.

Hydrosphere Resource Consultants (1990) Black Lake No. 1 Enlargement water quality impact assessment. Prepared for the Vail Valley Consolidated Water X &District, August 23, 18 p. plus appendices.

Tipton and Kalmbach (1990a) Gore Creek streamflows and operation of Black Lakes. Prepared for the Vail Valley Consolidated Water District, April, 12 p., 1 figure, 12 tables, 1 plate, and Appendix A.

Tipton and Kalmbach (1990b) Low-flow discharges for Gore Creek and the Eagle River. Prepared for the Vail Valley Consolidated Water District, April 7, 7 p. and 5 tables.