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Bottom sediment chemistry and water quality near Mount Emmons, Colorado

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ABSTRACT Reconnaissance surveys of selected trace-metal concentrations of bottom sediments of two streams in the vicinity of Mount Emmons in south-central Colorado were made during August 1980 and July 1981. Mineral mining has occurred in the study area in the past, and development of a new molybdenum mine is planned. Associated treatment of existing and projected mine drainage along with the construction and operate mine facilities may alter the streamflow and water quality regimes. The data from the reconnaissance surveys were compared to recent water quality data at sites along the same stream reaches. The largest concentrations of arsenic in both water and bottom sediments in both surveys were measured for samples near the headwater reach of Coal Creek, which is approximately 3 miles upstream from the proposed mining activity. Iron concentrations in bottom sediments were slightly greater at sampling sites near the headwaters of both streams and were substantially greater at sites downstream from an old mine discharge into Coal Creek. Stream profiles for manganese and zinc concentrations in bottom sediments gradually increased in a downstream direction along Coal Creek, in contrast to the abrupt increase in concentrations of these trace metals for water samples collected downstream from the old mine discharge. Trace-metal concentrations in bottom sediments tended, in general, to be greater for the 1981 survey compared to the 1980 survey, which may have reflected both the below-normal streamflow which occurred during 1981 relative to above-normal streamflows during 1980, as well as the influence of a sequestriant agent or possibly a residual polymer introduced with the discharge of a heavy metals treatment plant. Profiles of bottom sediment trace-metal concentrations tend to depict a more integrated description of lithological factors affecting water chemistry in contrast to the more highly variable concentrations with season in water.

INTRODUCTION

During the past century, mining of minerals and coal has occurred at numerous locations to the north and south of Mount Emmons near the

Town of Crested Butte, Colorado. Natural lithologic conditions and mining activities during this time period in the Mount Emmons area have affected the water draining into Coal Creek and the Slate River (figure 1). A major site of current activity involves the Keystone Mine in the Coal Creek sub-basin, where records show that numerous mining concerns operated the property intermittently since 1880. This mine historically produced gold, silver, copper, lead and zinc. In 1955, operators built a mill at the Keystone Mine to process ores from it and neighbouring mines. With the advent of this mill came the need for tailing ponds for disposal of wastes. In addition to the natural lithological contributions of trace metals to the stream systems, inputs of trace metals have been contributed by the tailing wastes spoils and mine drainage from adits within Mount Emmons.

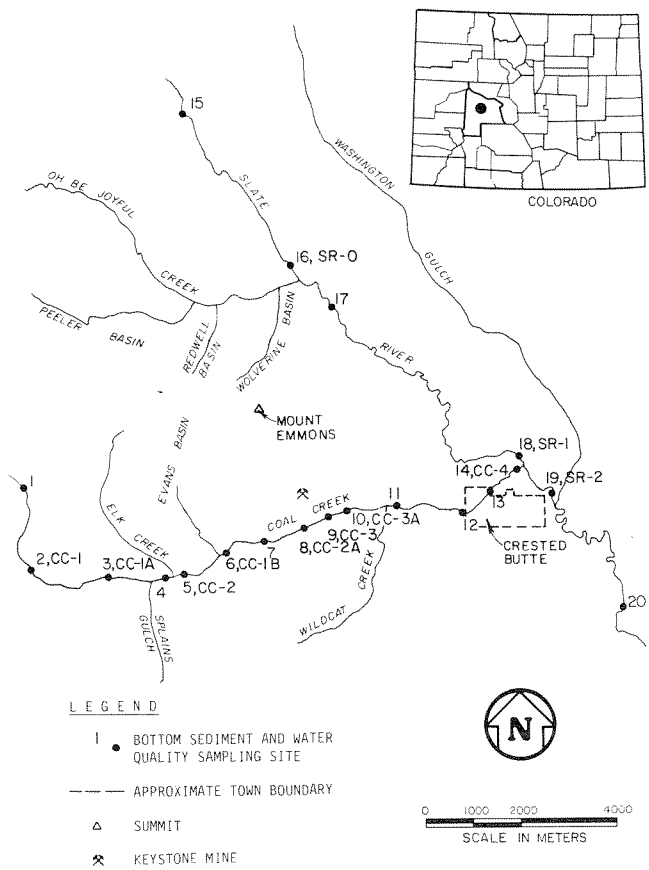

FIG. 1 Bottom sediment and water quality sample sites.

In 1977, Mount Emmons Mining Company, a subsidiary of AMAX Inc., acquired the Keystone Mine property. Adits of the old Keystone Mine have tended to accumulate subsurface flows from a complex system of faults and veins in Mount Emmons and to discharge these accumulated flows to Coal Creek. AMAX Inc. has accepted responsibility of

stabilizing the tailing dams and for mitigating incremental increases in trace metals contributed from mine discharges and tailing sources in this area into Coal Creek. In April 1981, a heavy metals treatment plant was put into operation by AMAX Inc. for treatment of mine drainage and other discharges generally characterized by low pH values and high trace-metal concentrations. The treated effluent from this plant discharges into Coal Creek.

Study Objectives

The purpose of this study is to describe general conditions of water quality and bottom sediment chemistry in major streams in the Mount Emmons area. With the baseline stream quality and reconnaissance survey bottom sediment chemistry data collected during the late-summer low flows of 1980 and 1981, it is hoped that the resultant information derived from these data might provide the means to evaluate subsequent changes that may take place as a result of future planned mining or minerals extraction.

Geographical Setting

General description of climatology and hydrology of the Mount Emmons area has been given by Camp, Dresser & McKee, Inc. (1980, 1981a & b) and Woodward-Clyde Consultants (1979, 1980, 1981, 1982). New mine portal and support facilities have been proposed by AMAX Inc. on the south face of Mount Emmons for the extraction of molybdenum ore and for mill processing in the Ohio Creek basin to the south of the study area (Camp, Dresser & McKee, Inc., 1981a). Major sub-basins in the Mount Emmons area include (figure 1); Coal Creek with a drainage area of approximately 54 km^2: Oh-Be-Joyful Creek with a drainage of over 28 km^2; and the Slate River which below the confluence of both Coal Creek and Oh-Be-Joyful Creek consists of a drainage area of approximately 180 km^2. The Town of Crested Butte is located near the confluence of Coal Creek and the Slate River (figure 1).

Background

The benefit of developing information on bottom sediment chemistry in assessing water-quality conditions has been discussed by Feltz (1980). Trace-metal relationships between bottom sediments and surface waters have been studied in Illinois (Mathis & Cummings, 1971), Tennessee (Perhac & Whalen, 1972), Brazil (Gibbs, 1973), Kansas (Angino *et al.*, 1974), Arkansas (Steele & Wagner, 1975), Canada (Wagemann *et al.*, 1977; Oliver, 1973), Oregon (Rickert *et al.*, 1977), Germany (Neuland *et al.*, 1978; Symader & Thomas, 1978; Thomas & Neuland, 1979), and Texas (Quasim *et al.*, 1980). Demayo *et al.* (1978) have completed an extensive literature review of the forms of trace-metals in water and sediment phases and have made specific recommendations regarding a comprehensive monitoring strategy involving water and sediment sampling for chemical analyses.

Trace-metal sorption by sediments has been the topic of numerous studies (see, for example, Jenne, 1977; Jenne et al., 1980). Rates of cation exchange on clay minerals in sediments and variability with particle-size have been investigated by Malcolm & Kennedy (1970). Biological availability of sediment-bound trace-metals have been evaluated by Luoma & Jenne (1976) and Jenne & Luoma (1979).

Earlier mine drainage studies of streams in Colorado have included those by Wentz (1974a, 1974b) and Moran & Wentz (1974). These involved water quality surveys of the study area. Earlier hydrological studies of the Mount Emmons area have been made by Woodward-Clyde Consultants (1979, 1980).

APPROACHES

Among the environmental concerns in the study are possible changes in stream quality and bottom sediment chemistry that may result from future mining and processing of mineral ores. Because of this overall concern, AMAX Inc. instituted an extensive water quality monitoring programme in the area beginning in December 1977 and subsequently expanded in 1978. All basic water quality data are archived in a computerized data-management system maintained by AMAX Inc. Selected sites dealing with monitoring water quality conditions in Coal Creek and the Slate River are indicated in figure 1. Because of the extremely complex geology of the area, it is important to develop some appreciation for the interaction between the water and the mineral lithology (Ranta et al., 1978; Converse Ward Davis Dixon, 1981).

An evaluation of the trace-metals associated with stream bottom sediments provides information that complements analyzed trace metal concentrations in water samples collected at or near the same stream site. This is because the stream sediments are exposed to varying flow conditions over an extended period of time. As such, the sediments act as integrators (Wentz & Steele, 1980). Trace-metal concentrations in these sediments represent some composite of more highly variable water quality conditions during a prolonged time period of exposure to flowing water.

AMAX Inc. conducted a bottom sediment stream survey in mid-1977 at 25 locations along tributaries of Oh-Be-Joyful Creek and Coal Creek (Willis H. White, written communication, AMAX Inc., August 1980). This initial reconnaissance survey aided in determining possible areas for more detailed mineral exploration.

For the August 1980 and July 1981 reconnaissance surveys, bottom sediment samples were collected for selected trace-metal analyses at 14 sites along Coal Creek and at 6 sites along the River Slate (figure 1). These sites and the laboratory extraction and chemical analysis procedures were identical for both surveys (Woodward-Clyde Consultants, 1981). Sample preparation procedures developed by the U.S. Geological Survey (Skougstad et al., 1980) were used, in that bottom material passing through a 2 mm sieve was taken for analysis so that only the sand, silt and clay fractions were used in the sample analyses. For the 1981 set of samples, a second series of analyses were made on bottom material passing through a 61 μm sieve, passing predominately silts and clays. Hydrogen peroxide was used

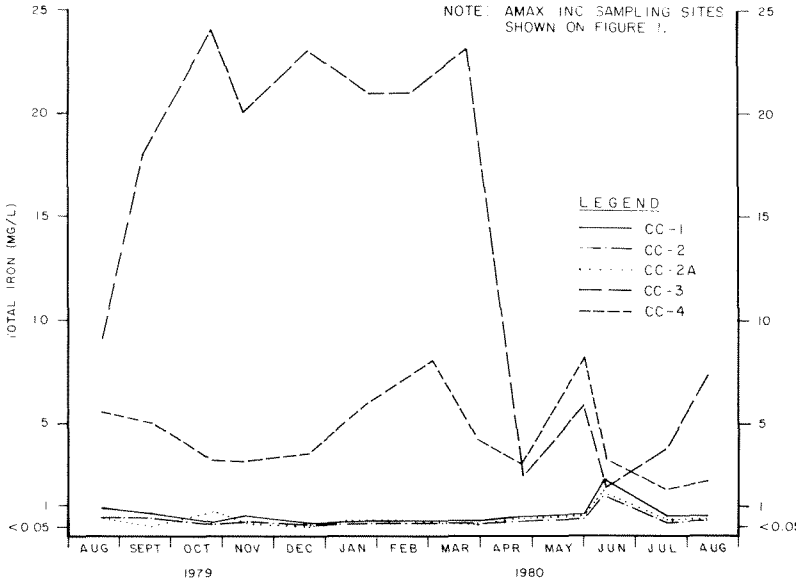

FIG. 2A Total iron concentrations in Coal Creek 1979-1980.

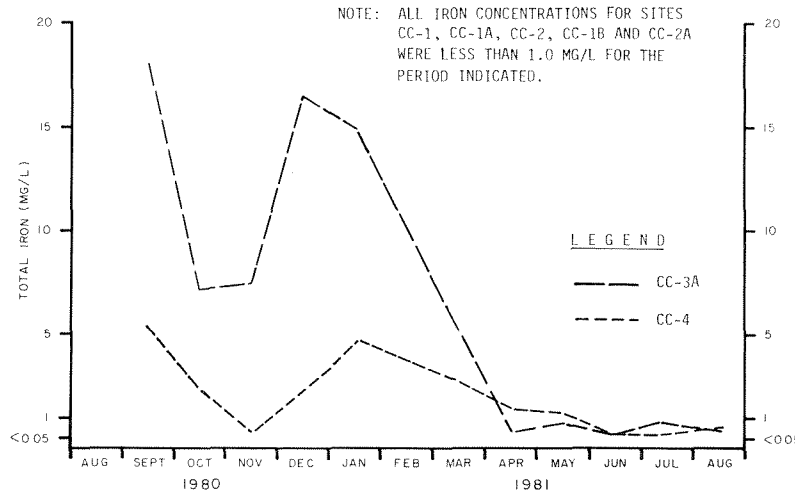

FIG. 2B Total iron concentrations in Coal Creek 1980-1981.

for the removal or destruction of organic matter, and a hot dilute solution of hydrochloric acid was used in the sample digestion for removal of the acid-soluble component on the sediment-bottom material mixture in each sample. In this manner, trace-metals attached largely on the surface of sediment particles are reflected in the acid-extract solution. The following 9 trace-metals were analysed; arsenic, cadmium, chromium, copper, iron, lead, manganese, molybdenum and zinc. Only selected results are reported for the purposes of this discussion. Detailed trace-metal data results of these surveys have been reported by Woodward-Clyde Consultants (1981, 1982).

RESULTS

Upstream-downstream and seasonal variations of total trace-metal concentrations in the waters of Coal Creek are typified by the patterns shown on figure 2A for the 1979-80 period and figure 2B for the 1980-81 period. The variations in water quality concentrations are due largely in response to observed seasonal streamflow fluctuations. The smaller concentrations noted through the 1980-81 period for sampling sites CC-3A and CC-4 may be attributed to a slight decrease in mine-drainage flows entering Coal Creek upstream from sites CC-3 and CC-3A (figures 1 & 2).

When the monthly data for each water quality sampling site are averaged, a time-weighted mean value for a given trace metal is obtained for each sampling site. Comparisons of the trace metal average water concentrations (1979-80) with its associated bottom sediment chemical concentration (August 1980) are indicated in figure 3A for manganese and in figure 3B for zinc. The more gradual contributions of these trace metals in the sampled bottom sediments in a downstream direction can be contrasted against the abrupt increase in concentrations of these trace metals in water between sites CC-2A and CC-3 where mine drainage inflows occur.

Streamflows during the summer of 1981 were considerably less than those measured for Coal Creek and estimated for the Slate River during the previous 1980 summer months (Woodward-Clyde Consultants, 1981, 1982). These differing flow conditions may have affected the bottom sediment chemical results obtained for the 1980 versus 1981 reconnaissance surveys for the two stream reaches.

Comparative stream-reach profiles of Coal Creek for 1980 versus 1981 are given in figures 4A-4D for selected trace-metals on bottom sediments. The maximum arsenic concentration in Coal Creek occurred at the same location (Site 3) upstream from Splain's Gulch for both surveys (figure 4A). However, this maximum arsenic concentration was less in 1981 than in 1980 and smaller peak concentrations occurred downstream at Sites 9 and 12 during 1981 (figure 4A). A review of local geological mapping in the upper part of the Coal Creek sub-basin revealed a source of arsenopyritic compounds, including possibly tennantite (D.E. Ranta, personal communication, AMAX Inc., November 1981).

Cooper and lead concentrations in bottom sediments increased markedly downstream from Site 8 in Coal Creek. Moreover, concentrations of these two constituents on bottom sediments in the down-

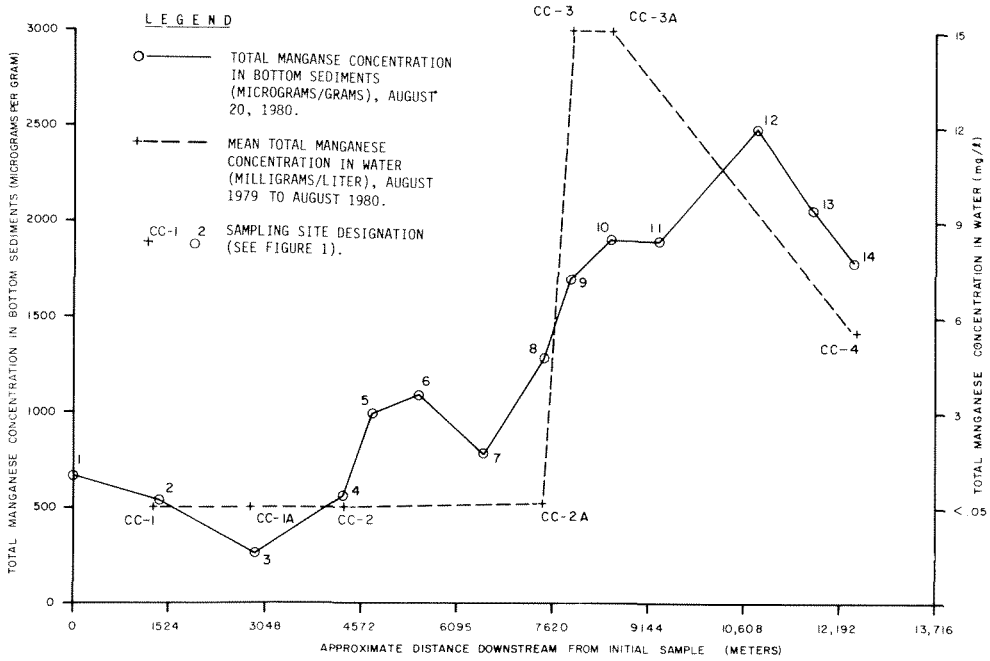

FIG. 3A Manganese concentrations in bottom sediment and water, Coal Creek.

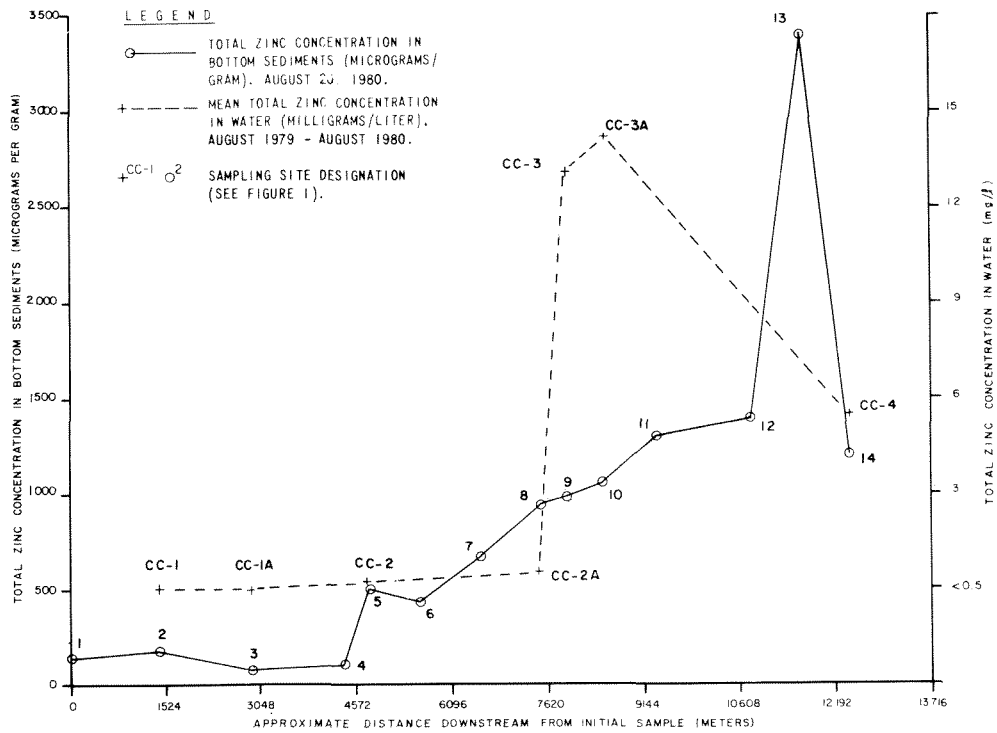

FIG. 3B Zinc concentrations in bottom sediment and water, Coal Creek.

stream reach of Coal Creek were significantly greater in 1981 than in 1980 (Figures 4B and 4C).

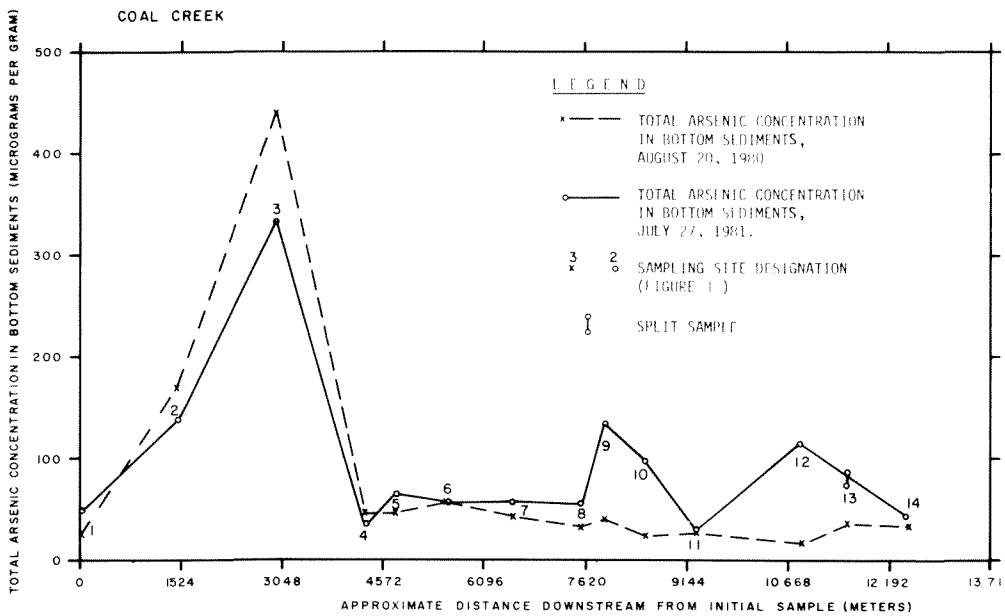

FIG. 4A Comparison of total arsenic concentrations in bottom sediments of Coal Creek 1980 versus 1981.

Bottom sediment iron concentrations were consistently greater throughout sampled reaches of both Coal Creek (figure 4D) and the River Slate. Peak iron concentrations on bottom sediments in Coal Creek were more pronounced in 1981 compared to 1980. For the River Slate, the iron concentrations stream reach profile was quite consistent and showed a minimal impact of Coal Creek inflows. No explanation can be given for the consistently larger iron concentrations for the 1981 analyses compared to the 1980 analyses. In contrast, a significant increase in manganese concentrations occurred on bottom sediments in the River Slate downstream from the confluence of Coal Creek (figure 5A). Increases in zinc concentrations in bottom sediments of the River Slate were gradual in a downstream direction throughout the stream reach sampled (figure 5B). For the August 1980 and July 1981 sampling surveys along the River Slate, noted increases in manganese and zinc between Sites 16 and 17 appear to be attributable to the inflow of Oh-Be-Joyful Creek. Increased manganese and zinc concentrations continued in a downstream direction in comparing bottom sediment trace-metal concentrations at Site 18 on the River Slate upstream from Coal Creek versus Site 19 downstream from Cola Creek (figures 5A & B).

It was anticipated that trace-metal concentrations associated with silt and clay fractions of the bottom sediment samples (that

is, passing through a 61 μm sieve) might be consistently greater than for samples which included sand fractions (that is, passing

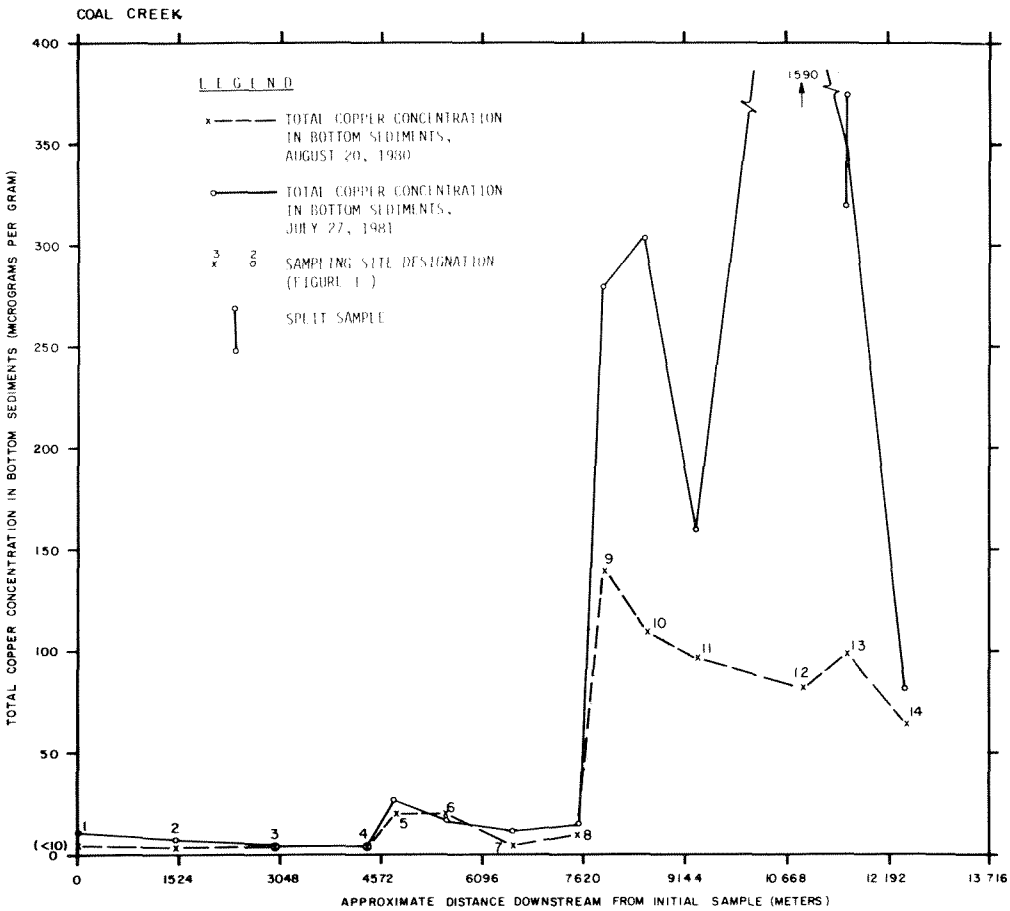

FIG. 4B Comparisons of total copper concentrations in bottom sediments of Coal Creek 1980 versus 1981.

through a 2 mm sieve). This was more or less the case for 8 of the 9 trace-metals analyzed in the 1981 survey (Table 1). Copper and iron concentrations of the fine (silt-clay) fraction samples were all greater than in the sand-silt-clay fraction samples. This was decreasingly the case for manganese, lead, zinc, arsenic, chromium and cadmium. These observations tend to confirm that contributions of selected trace metals are directly influenced by the larger surface areas provided by the finer-sized sediment particles. Only in the case of molybdenum were less than half of the fine-size (silt and clay fraction) analyses of greater concentrations when compared to analyses including the sand fractions (Table 1). In fact, more than half of the molybdenum concentrations showed no change for the 61 μm sieve samples compared to the 2 mm sieve samples, indicating

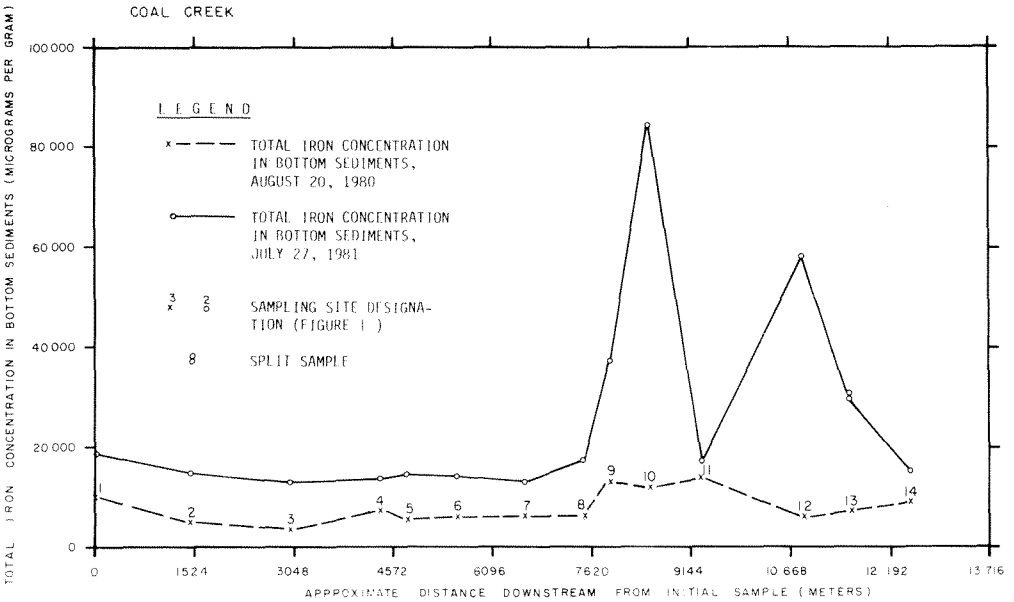

FIG. 4C Comparison of total iron concentrations in bottom sediments of Coal Creek 1980 versus 1981.

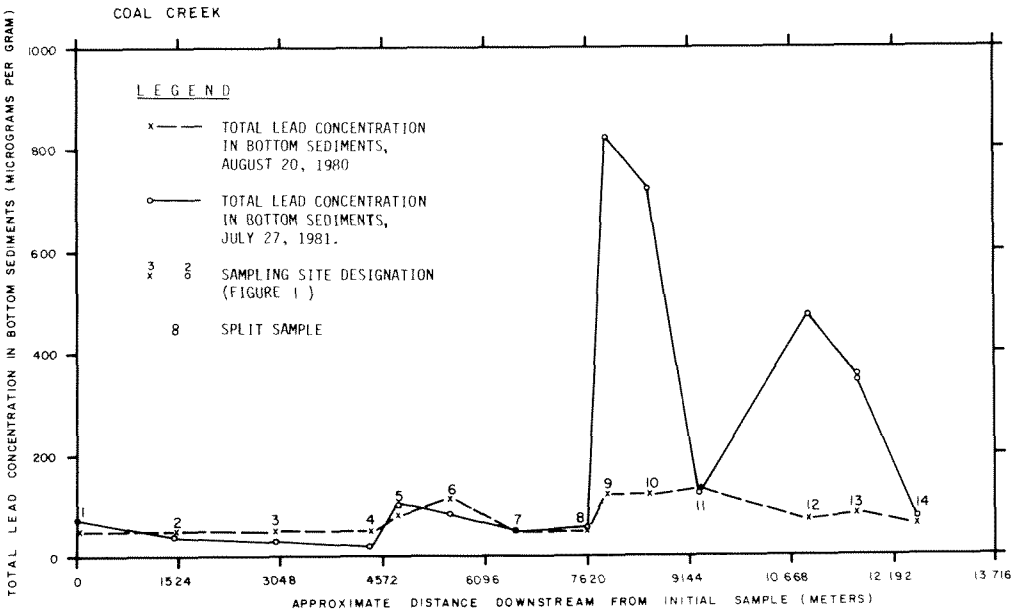

FIG. 4D Comparison of total lead concentrations in bottom sediments of Coal Creek 1980 versus 1981.

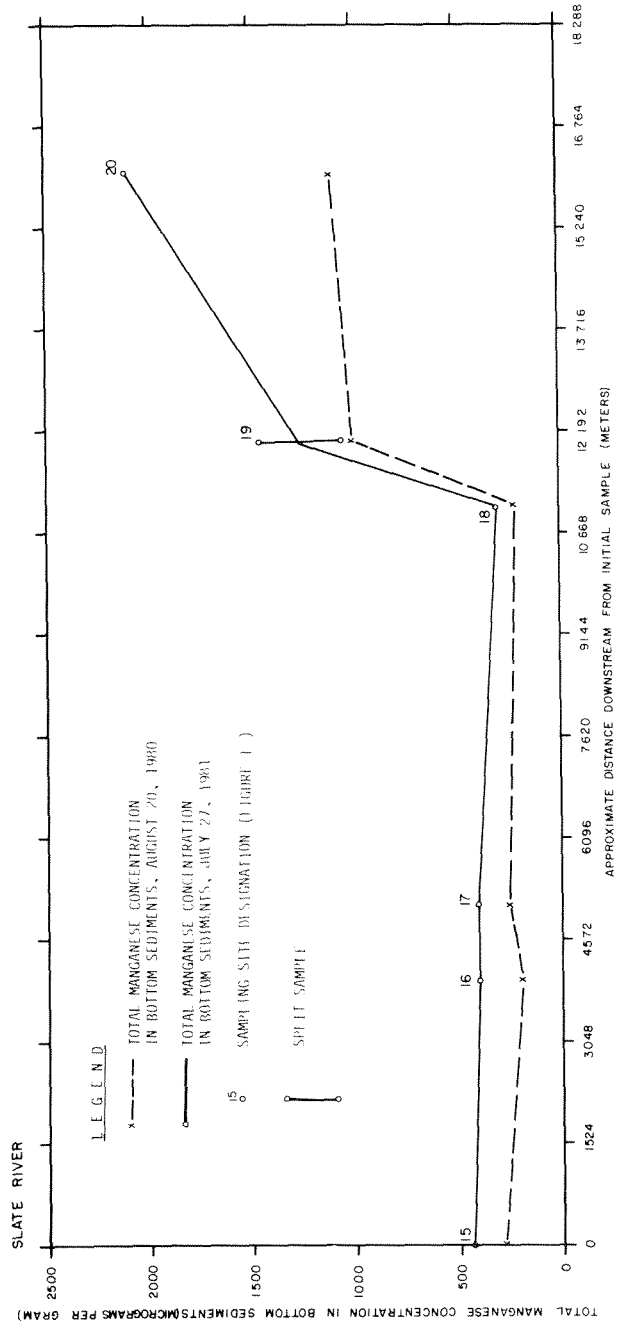

FIG. 5A Comparison of total manganese concentrations in bottom sediments of the River Slate 1980 versus 1981.

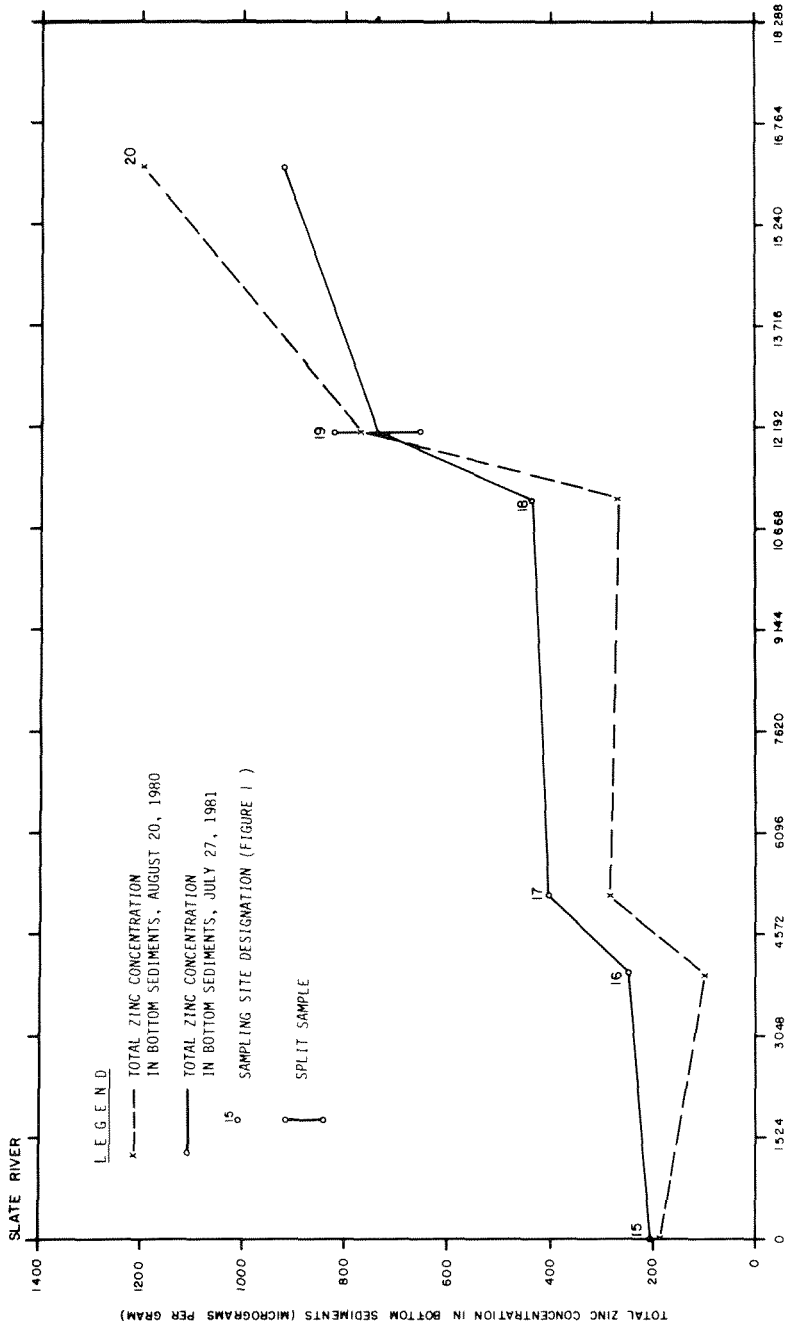

FIG. 5B Comparison of total zinc concentrations in bottom sediments of the River Slate 1980 versus 1981.

that concentrations of this constituent were relatively insensitive to sediment particle size.

TABLE 1 Comparison of silt-clay fraction concentrations to sand-silt-clay fraction concentrations of selected trace-metals on bottom sediments[1]

Trace-Metal	Number of Analyses of Silt-clay Fraction versus Sand-Silt-Clay Fraction in Bottom-Sediment Samples[2]		
Trace-Metal	greater than	equal to	less than
Arsenic	16	0	4
Cadmium	14	4	2
Chromium	14	2	4
Copper	20	-	-
Iron	20	-	-
Lead	17	2	1
Manganese	17	-	3
Molybdenum	7	11	2
Zinc	17	0	3

[1] compiled from data published in Woodward-Clyde Consultants (1982)
[2] comparison of two fractions analyzed for 20 sampling sites (figure 1), 27 July 1981

DISCUSSION

The continued small trace-metal concentrations in water of Coal Creek from April to June 1981 at sampling sites CC-3 and CC-4 (figure 2B) downstream from the mine drainage inflows would not have been expected, especially because of the reduced streamflows during the summer of 1981 relative to 1980. However, this lack of seasonal increased concentrations reflects the impact of treated mine-drainage flows from the heavy metals treatment plant that became fully operational in May 1981 (Woodward-Clyde Consultants, 1982).

In contrast, the relatively greater trace-metal concentrations in bottom sediments of Coal Creek in the 1981 survey were not anticipated, particularly in the sediments downstream from sampling Site 8, where the effluent from the heavy metals treatment plant has been discharging since April 1981. With the reduced flows during the summer of 1981 relative to 1980, one might have anticipated smaller trace-metal concentrations because of the reduced volumes of flows in contact with the sediments. However, in discussions with AMAX Inc. (Jim Cowley, personal communication, November 1981), it was learned that a sequestriant agent was being added to the treatment plant flow stream prior to its effluent discharge into Coal Creek.

This chemical additive apparently may have caused suspended sediments transported by Coal Creek to settle out downstream from Site 8 (figure 1). Use of this chemical agent at this point in the plant flow stream was discontinued in early November 1981. Another possibility is that minute amounts of residual polymer used in the plant's treatment tanks were passing through the plant effluent and discharging into the stream. Possible instream sediment deposition due to this has not been substantiated. From visual inspection of the stream channel it appears that this enhanced settling of Coal Creek sediments has been stopped. The next year's upstream-downstream reach profile for Coal Creek will enable a comparison against sampling results and noted changes for August 1980 and July 1981.

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