

ATTENUATION OF METAL CONCENTRATIONS IN TERRACE RESERVOIR, CONEJOS COUNTY, COLORADO, MAY 1994 THROUGH MAY 1995



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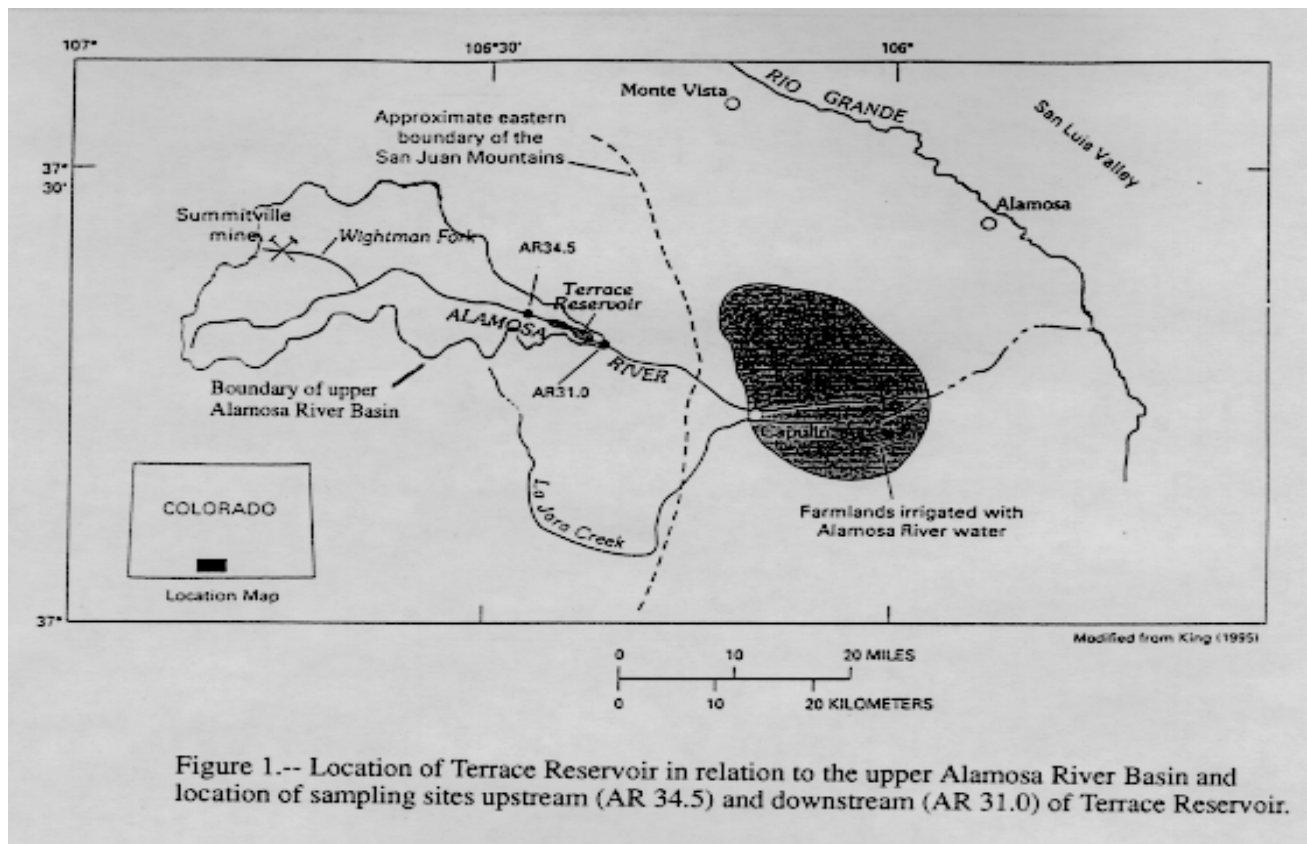
INTRODUCTION

Terrace Reservoir is a small, bottom-draining irrigation reservoir located on the Alamosa River in the San Juan Mountain Range in Conejos County, Colorado (fig. 1). Limited historical water-quality information is available for Terrace Reservoir. However, based on limited sampling conducted by the U.S. Geological Survey (Britton and Wentz, 1980) in 1974, and on comparison to water-quality standards, water quality was good. Historically, Terrace

The drainage basin upstream from Terrace Reservoir contains extensive areas of mineralized rocks, which in some areas have been mined intermittently since the late 1800's. Mining has occurred intermittently at the

Reservoir and the Alamosa River have had populations of brook trout, Rio Grande cutthroat trout, and rainbow trout. In the 1980's, the Colorado Division of Wildlife maintained a rainbow trout fishery in Terrace Reservoir. However, fish populations declined through the late 1980's; by 1990, fish were absent in most of the Alamosa River, including Terrace Reservoir, up to a point near Alum Creek (Woodling, 1995).

Summitville mine site (fig. 1) from 1873 to 1894, from 1926 to 1942, and from 1986 to 1992 (U.S. Environmental Protection Agency, 1993). Terrace Reservoir is located about 15 miles downstream from the Summitville mine site



and receives drainage of low-pH, metal-enriched water. Drainage from the Summitville mine flows into Wightman Fork, a tributary of the Alamosa River. Wightman Fork has been identified as a primary source of aluminum, copper, iron, manganese, and zinc during peak flow and the falling limb of the spring runoff hydrograph (Walton-Day and others, 1995).

The Alamosa River is a primary source of water for crops and livestock in the southwestern part of the San Luis Valley. The extent that metal concentrations in the water column are attenuated in Terrace Reservoir is of interest to downstream users.

A study was conducted from May 1994 through May 1995 in cooperation with the U.S. Environmental Protection Agency to characterize the limnology and the spatial and seasonal distribution of metals in Terrace Reservoir.

Approach

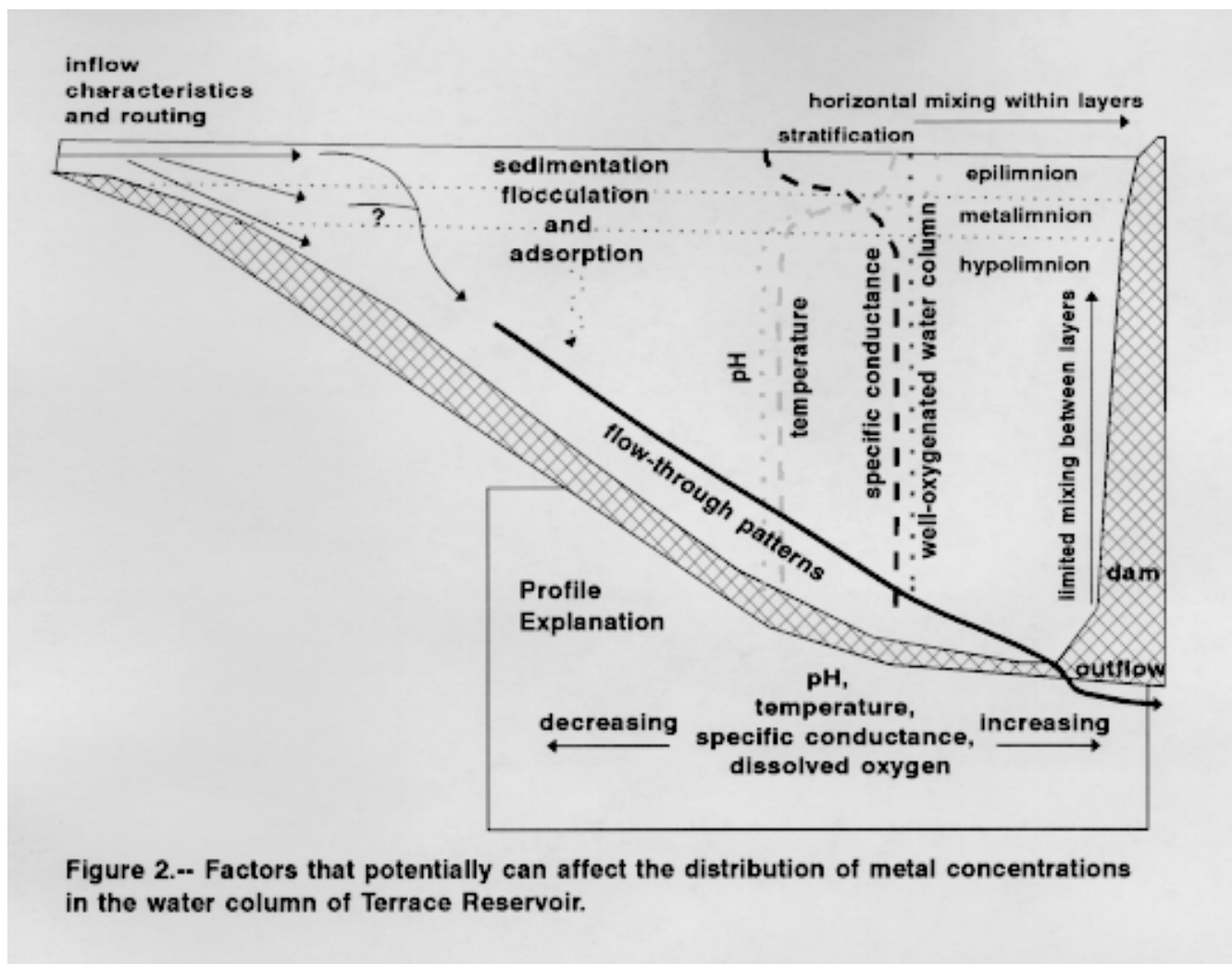
The limnological characteristics of Terrace Reservoir were evaluated using data collected at seven reservoir sites. The sites were selected to provide information on the spatial and seasonal variations of water temperature, specific conductance, dissolved oxygen, and pH. Onsite profile measurements were made biweekly from May 20, 1994, through August 17, 1994. Monthly profile measurements were made from September 1994 through November 1994, January 1995 through March 1995, and during May 1995. Profile measurements are measurements of temperature, specific conductance, dissolved oxygen, and pH made at 3-ft depth increments from the surface to the bottom of the reservoir. In addition to profiling, water-quality samples were collected at three of the seven sites to provide information on the spatial and seasonal variations in metal concentration. Water-quality samples generally were collected at three to four depths: one in the epilimnion, one as close as possible to the reservoir bottom without disturbing the bottom sediments, and one or two intermediate depths to define the vertical variation in chemistry. Water-quality sampling was conducted monthly from June through September 1994, and again in March 1995, just prior to ice off. In addition to the reservoir sites, streamflow data collected by the State of Colorado, Division of Water Resources, and the U.S. Geological Survey from two sites located on the Alamosa River, AR 31.0, Alamosa River downstream from Terrace Reservoir (USGS site identification number 08236500), and AR 34.5, Alamosa River upstream from Terrace Reservoir (USGS site identification number 08236000) were used to provide information on flow into and out of the reservoir. At AR

34.5, inflow chemistry (Patrick Edelmann and Sheryl Ferguson, U.S. Geological Survey, written commun., 1996), and diurnal (over a 24-hour period) variations of water temperature, specific conductance, and pH of water flowing into Terrace Reservoir were sampled. Samples for the analysis of the inflow chemistry were collected in conjunction with reservoir sampling. Reservoir profile data are available through the U.S. Geological Survey, and reservoir chemistry data are available through the U.S. Environmental Protection Agency.

FACTORS AFFECTING DISTRIBUTION OF METAL CONCENTRATIONS

Several factors potentially can affect the distribution of metal concentrations in the water column of Terrace Reservoir (Robert Stogner and Patrick Edelmann, U.S. Geological Survey, written commun., 1996). These factors include the physical and chemical characteristics of the inflow and the physical, chemical, and biological characteristics of the reservoir (fig. 2). Changes in streamflow, water temperature, dissolved-oxygen concentrations, pH, and concentrations of metals in the Alamosa River upstream from the reservoir (Patrick Edelmann and Sheryl Ferguson, U.S. Geological Survey, written commun., 1996) affect the distribution of metal concentrations in the water column of Terrace Reservoir.

Physical processes within Terrace Reservoir that affect distribution of metal concentrations in the water column include thermal stratification, inflow routing and flow-through patterns, reservoir residence times, and the deposition of particulate matter (Robert Stogner and Patrick Edelmann, U.S. Geological Survey, written commun., 1996). Thermal stratification of the reservoir resulted in limited or inhibited vertical mixing between limnetic layers and enhanced horizontal movement within the various limnetic layers. Inflow from the Alamosa River is initially routed to various depths within the reservoir because of density differences between the inflow and reservoir water column. The initial flow routing and the flow-through patterns within the reservoir affect the reservoir residence time of inflowing water. During periods of stratification, water that was routed to the hypolimnion as underflow moved through the reservoir faster than epilimnetic water because the reservoir outlet is located on the bottom of the reservoir near the dam. Water with short residence times has less time for physical and chemical processes to affect metal concentrations of incoming water before being released downstream.



Deposition of particulate-metal concentrations significantly decreased the amount of particulate or suspended concentrations of metals in the water column in Terrace Reservoir. During collection of 30 reservoir-bottom sediment samples, A.J. Horowitz (U.S. Geological Survey, written commun., 1995) observed that "the bottom of the reservoir was covered by a thin, soupy, extremely fine-grained red-orange floc ... Based on color, it was inferred that the floc contained, or was composed of substantial quantities of iron oxide." Based on these observations, a substantial amount of ferric hydroxide has settled out of the water column in Terrace Reservoir. As metals partition to the solid phase and settle from the water column, particulate-metal concentrations in the reservoir water column decrease.

CHEMICAL CHARACTERISTICS

During the study period, the concentration of dissolved oxygen varied longitudinally, vertically, and temporally in response to changes in water temperature. The Alamosa River provided a consistent supply of well-oxygenated water to the reservoir. Dissolved-oxygen concentrations in the reservoir were generally within 0.5 mg/L of the dissolved-oxygen concentration of the inflow. The pH of the water in the reservoir generally ranged from

about 4.0 to 7.0, depending upon time, depth, and location. The highest pH values were measured during May 1994 and May 1995, which coincided with snowmelt runoff. During periods of thermal stratification, May through August, pH generally decreased with depth. Fall turnover in September generally mixed the reservoir waters, and pH was generally uniform with depth through November; however, pH continued to be higher in the upstream reach of the reservoir. During February and March 1995, pH of the reservoir water increased with depth and time.

Metal Chemistry

Dissolved- and total-recoverable-metal concentrations varied spatially and temporally in response to inflow characteristics and physical processes in Terrace Reservoir. For the purpose of the study, dissolved metal was defined as metal that passed through a 0.45- μ m filter. However, numerous investigations of trace-element chemistry have indicated that water filtered through a 0.45- μ m filter may contain substantial amounts of colloidal trace elements (Kimball and others, 1995; Horowitz and others, 1996). The dissolved-metal fraction was the dominant phase observed in the reservoir.

During June, large longitudinal and vertical

variations occurred in metal concentrations. In the epilimnion, the elevated pH and decrease in metal concentrations from the upstream end of the reservoir to the dam was indicative of differences in chemistry of water that entered the reservoir at different times. As a result of underflow and short residence times (Robert Stogner and Patrick Edelmann, U.S. Geological Survey, written commun., 1996), dissolved-metal concentrations ($<0.45 \mu\text{m}$) within the hypolimnion exhibited considerably less longitudinal variation than occurred in the epilimnion. Limited geochemical modeling suggested that concentrations of suspended particulate matter and pH were too small for significant sorption of copper and zinc to the particulate phase to occur in Terrace Reservoir.

During July and August, the dissolved-metal concentrations throughout the water column were generally larger than during June, and the metals were predominantly in the dissolved fraction (Robert Stogner and Patrick Edelmann, U.S. Geological Survey, written commun., 1996). The elevated epilimnetic metal concentrations that were present in the reservoir during July and August were probably the result of mixing of inflow, which had elevated metal concentrations, that entered the epilimnion as overflow. In addition, the small variations in longitudinal metal concentrations that occurred during this period were probably more the result of mixing of water with different metal concentrations than the result of precipitation, co-precipitation, or adsorption. Within the hypolimnion, dissolved-metal concentrations ($<0.45 \mu\text{m}$) were larger during July and August than during June, and the dissolved-metal concentrations in the hypolimnion were noticeably larger than the metal concentrations in the epilimnion; so the water with the largest concentrations was discharged from the reservoir.

During September, metal concentrations were significantly larger in the downstream part of the reservoir than in the upstream part, and little vertical variation in metal concentrations occurred in the downstream part of the reservoir. In the upstream part of the reservoir, iron and aluminum were largely in the particulate fraction, and copper, cadmium, manganese, and zinc were largely in the dissolved fraction ($<0.45 \mu\text{m}$). In the downstream part of the reservoir, all metals were predominantly in the dissolved fraction. During September, mixing strongly affected metal concentrations, as metal concentrations measured during September equaled average metal concentrations measured during August.

During January, February, and March, the reservoir was covered with ice and weakly stratified due to density gradients created by differences in concentrations of dissolved solids between the inflow and reservoir water. In March, reservoir chemistry varied both longitudinally and vertically. The dissolved-metal concentrations in the reservoir during March were generally less than the concentrations measured in the reservoir during September. The largest metal concentrations occurred in the epilimnion. Large decreases in metal concentration occurred with depth

as a result of underflow.

During the study period, most of the suspended particulate matter and colloidal metal hydroxides settled from the water column in the upstream part of the reservoir. The deposition of suspended particulate matter substantially decreased the amount of particulate or suspended concentrations of metals in the water column in Terrace Reservoir.

DISCUSSION

The dominant factors or processes affecting distribution of metal concentrations in Terrace Reservoir during the study were 1) streamflow, temperature, dissolved-oxygen concentration, pH, and concentrations of metals in the Alamosa River upstream from Terrace Reservoir, and 2) physical factors and processes in Terrace Reservoir, which included stratification and mixing, inflow-routing and flow-through patterns, residence times, and sedimentation. The importance of these factors and processes in affecting distribution of metal concentrations in the reservoir varied with time. During periods of thermal stratification, May through August, mixing within layers, initial flow-routing and flow-through patterns affected the distribution of metal concentrations in the reservoir. Variations in metal concentrations in inflowing water and the dominance of underflow altered the distribution of metals in the reservoir. In the fall, September through November, when the reservoir was well mixed, metal concentrations were uniform. In the winter, January through March, when the reservoir was covered with ice, differences in concentrations of dissolved solids between the inflow and reservoir water created density gradients which in turn affected flow routing and distribution of metal concentration.

Attenuation of metal concentrations in the water column in Terrace Reservoir was due to sedimentation of suspended particulate matter and colloidal metal hydroxides in the upstream part of the reservoir. The limited data collected during the study suggest that attenuation of metal concentrations by adsorption or precipitation was not substantial and resulted in little if any changes in dissolved metal concentrations.

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