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AN EVALUATION OF MINING RELATED METALS POLLUTION IN THE UPPER ARKANSAS RIVER BASIN

by

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ABSTRACT

This study evaluates the stream mileage of metals pollution in the Arkansas River Basin attributable to active and abandoned mines. All available stream water quality data were collected and examined to determine the mileage of metals in violation of standards set forth by the Colorado Department of Health Water Quality Control Commission. Metals concentrations were compared to the standards set for aquatic life, agriculture, and domestic water supplies.

The study found a total of 608 stream miles exceeded Colorado Basic Stream Standards for at least one beneficial use. Of the 608 miles exceeding aquatic life standards, zinc, copper, lead, and cadmium were the parameters that deviated from the standards most often. Substandard mileage totals were 199 miles for agriculture, and 154 miles for domestic water supply. Concentrations of manganese impacted these uses most often, with lead and manganese also being important.

The upper Arkansas River basin stream segments deviating from Colorado Basic Stream Standards were evaluated in terms of possible sources for the metals. Geochemical data on river water upstream and downstream of the Leadville district were sufficient to establish its contribution of metals to the Arkansas River. For many

other districts, only an association with mining could be established. This report has developed a procedure that can be utilized to undertake a similar study on a statewide scale. The compilation does indicate where future studies should be focused to determine where remedial work can be effective in restoring beneficial uses to streams.

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Chapter 1

INTRODUCTION

Mining has been an important industry in the development of Colorado. Early miners could not have foreseen the many environmental problems that are now occurring. Several instances of severe acidic and metals pollution of streams passing through mining districts have been identified. Barren aquatic habitats at places such as California Gulch and Bonanza are obvious; other impacts may not be so apparent. Water that looks clean may still contain levels of pollutants that impair its use for public water supplies, agriculture, and warm or cold water aquatic life. Many geochemical studies have been done on stream waters in Colorado for a variety of purposes. A clear need exists to pull together these data from all the different areas of the state and evaluate the statewide scope of the problem.

This study provides a method to update previous statewide studies of water quality problems related to mining through analysis of available information and data pertaining to the Arkansas River Basin. Data from studies on particular streams and various statewide studies were evaluated in relation to the proximity of areas of metals mining that may have contributed to the high levels of metals present. An attempt was made to measure impacts on each of the important uses including recreation, public water supply, agriculture, and aquatic habitats. Impacted stream mileage has been measured along with the metals which are present above standards and the beneficial uses impacted.

The objective of this study has been to provide a means to gain the best possible overall picture of mining impacts on streams in Colorado with the presently available information. Considering the Arkansas River Basin in detail will help establish the types of results that can be expected from a statewide study patterned along these lines and help streamline the process. This study alone cannot provide absolute proof that certain mining districts or mines are causing impacts on streams. More detailed studies in specific areas are required for that level of certainty. Possible impacted stream segments have been defined through application of Colorado Basic Standards (Colorado Department of Health, Water Quality Control Commission, 1984) to chemical analyses of stream waters. Then, mining districts, natural mineral seeps, or geologic terrain were discussed as sources of high levels of metals concentrations or low pH's. With the tables showing the impacted stream segments and relationships to mining districts that are possible causes of pollution, more detailed studies of specific mining areas can be efficiently planned to pinpoint sources of metals pollution. Eventual results will be the identification of the mining areas where resources can be directed most effectively to decrease levels of pollution and restore potential beneficial uses to Colorado streams.

Chapter 2

BACKGROUND

2.1 Previous Work

Presently, the most definitive statewide study of mine drainage is by Wentz (1974), in which acid mine drainage was identified as an important and widespread problem. The role of pyrite in causing acidic conditions which mobilize heavy metals was also discussed. His calculation of 450 miles of Colorado streams impacted by metals from mine drainage sounded a challenge to confront this problem. The Arkansas River Basin accounted for 68 stream-miles of this total. Moran and Wentz (1974) focused on specific mining districts and drainages, further establishing mining impacts and showing a relationship between total and dissolved metals in stream waters and the implications toward metals mobility. For Kerber Creek, a generally applicable sequence of metals mobility was determined: Mn = Zn > Cu > Cd > Fe > Ni > Pb.

Two other studies also tackled mine drainage on a statewide scale. Holm et al. (1977) emphasized natural basin features, land use and overall water quality. They also helped establish a pattern of an annual assessment of statewide water quality in accordance with the 1973 Water Quality Control Act. McLaughlin Waste Engineers (1981) also focused on several problem mine drainage areas, reviewing and presenting raw data from several past water quality studies. It also provided a ranking of hazard potentials of the severely impacted areas based on a variety of factors.

The Water Quality Control Division of the Colorado Department of Health publishes an annual report that assesses water quality statewide (Colorado Department of Health, 1986). The latest study states "Six percent of the state's waters do not support or only partially support their classified uses." Of this total, 53 percent was attributed to drainage from inactive mines and mills. Since the report also stated that there are 14,100 stream miles in Colorado, there are 448 miles of Colorado streams that do not support their classified uses due to drainage from mines. Threatened, impaired, and severely impaired stream segments were listed in the report. Threatened segments met standards but have shown a trend toward deterioration. Impaired segments exceed standards in 10 percent or more of the analyses and severely impaired segments exceed standards in 25 percent of the analyses or have a mean concentration exceeding the standard.

In the annual study above, the Arkansas River was listed as severely impaired by metals from California Gulch to Pueblo Reservoir and moderately impaired below that. The

Purgatoire River was listed as moderately impaired for its entire length. Fountain Creek and the Huerfano River had severe metals pollution. For the upper portion of the basin considered in this study, about 175 stream miles have been impaired by metals in the Colorado Department of Health annual report (1986).

Several studies on thermodynamic and geochemical behavior of hydrogeochemical systems have considered Colorado streams. Boyles et al. (1974) researched mobility of metals in the Argo Tunnel drainage and the sequence of downstream precipitation in Clear Creek. Wildeman et al. (1974) considered the nature of drainage related to mineral zonation in the Central City area. Moran and Wentz (1974b) examined thermodynamic constraints on metals solubilities in drainage from the Bonanza district.

Many State and Federal studies considered specific drainages over various time periods. Colorado Department of Health and district planning commission studies by Kepler (1980), Mars (1979), Woodling (1976a, 1976b, 1976c, 1977), and Holm et al. (1979) dealt with water quality in the Dolores River, Willow Creek, San Miguel River, Red Mountain Creek, Slate River, and other streams. Environmental Protection Agency Remedial Investigations have studied streams in the Leadville, Red Mountain, Idaho Springs-Central City and Eagle River areas (CH2M Hill 1983, Engineering Science Inc. 1986, Geotrans et al. 1986). The Bureau of Reclamation has released two studies on the effects of heavy metals in the upper Arkansas River Basin (LaBounty et al. 1975, Roline and Boehmke 1981). Colorado Mined Land Reclamation Division has reported on the Alice Mine (Schroeder et al. 1986) and has an ongoing program of water sampling that started in 1986, sampling mine drainages and receiving streams throughout the state.

The STORET (hydrogeochemical data storage and retrieval) database is the most extensive source of data for Colorado streams. It includes U. S. Geological Survey (USGS) water analyses and data entered under USGS contract for streams throughout Colorado. This study used retrievals covering the years 1977-1986. The data includes analyses done using a variety of techniques. Less reliable, because of high detection limits, are metals data from hydrogeochemical surveys done to facilitate uranium exploration in the 1970's in the National Uranium Resource Evaluation program (NURE). Only about half of the state was covered in reports of stream water sampling for dissolved copper, molybdenum, iron, manganese, calcium, cobalt, nickel, lead, titanium, uranium, and zinc in several open-file reports (Bolivar and Hill 1979, Warren 1979, Broxton 1979, Shannon

1979a, 1979b). Areas that were sampled were sampled densely so that these data cover some streams not covered elsewhere.

2.2 Mining Districts

Mining districts, including coal and uranium mining areas, have been compiled and located from references such as Henderson (1926), Emmons (1927), Vanderwilt (1947), Behre (1953), Del Rio (1960), Tweto (1968), Bucknam (1982) and Eberhart (1969). The published accounts of mining districts also provide important information on the extent of mining, types of ores, and the associated alteration. Pyrite oxidizes to form acidic waters which can cause release of metals (Wentz, 1974). Mining operations often expose more pyrite to oxidation than under natural conditions. Potential sources of pollution are defined where mining districts occur exposing intensively pyritized rock to oxidation in tailings piles and in mine tunnels where the water table has been lowered. The mine drainage tunnels in the Arkansas River basin are the Canterbury tunnel and Leadville drain which flow into the East Fork, the Yak tunnel which flows to California Gulch, the Roosevelt tunnel flowing into Cripple Creek, and the Carlton tunnel which flows into Fourmile Creek (Crouch et al. 1984).

Some mining districts, even though listed as possible sources of acid and metals in the table of impacted stream reaches, are very small or not extensively mined.

2.3 Mobilization and Dispersion of Metals

Pyrite oxidation causes acidity which leaches heavy metals from rock material. As pyrite is oxidized, ferric ions, sulfate ions, and acidity are released (Wentz 1974, Nordstrom et al. 1979). Since ferric iron is the primary oxidant attacking the pyrite surface, the oxidation of ferrous to ferric iron ions is the rate-determining step (Nordstrom et al 1979). This reaction is catalyzed by the bacterium *Thiobacillus ferooxidans* which increases the rate of oxidation by five to six orders of magnitude (Stumm and Morgan 1970). The generation of acid mine drainage can continue in the presence of bacteria as long as air, water, and pyrite are available to some extent, as is the case in mine workings and waste piles. Not only can the acid formed in these reactions leach metals from ores in a mine to which it is exposed, but many metals such as cadmium, copper, lead, and zinc substitute for iron in pyrite and are released when the pyrite breaks down.

Mine drainage will generally become oxidized upon entering the surface aquatic environment. Often, dissolved iron in mine drainage to oxygenated stream waters will fully oxidize and hydrolyze to form amorphous ferric hydroxide, coating the bottom of the stream and known as "yellow boy". Acidity is released at this stage as well. In surface waters, most metals are not in ionic form but carried in soluble or suspended organic matter or suspended inorganic particles (Perhac and Whelan 1972). Metals in ionic form, in ion pairs, or adsorbed ions, will more readily change from one form to another in response to changes in solution chemistry than metals bound in organic complexes and suspended particles (Engineering Science 1986, Rose et al. 1979).

The free metal ions most able to react to changing solution chemistry are also most available to organisms and most toxic (Sunda and Guillard 1976). Stream waters go through numerous changes as they travel downstream from metals sources and feed into higher order streams. This usually results in a decrease in toxicity. Iron and manganese oxides continue to precipitate downstream, due to oxygenation of the water as is common in rapids in mountain streams. The pH also increases going downstream because contact with carbonate and silicate rocks can neutralize waters. Manganese, iron, cadmium, copper, zinc, and lead in solution can precipitate or be adsorbed onto surfaces as a result of more alkaline or neutral conditions.

Adsorption and coprecipitation are perhaps the most important processes for removing metals from stream waters. Concentrations of zinc and cadmium are usually found at levels far below those allowed by their solubility products. Adsorption on solids has been identified as the mechanism for removal of these metals from solution (Gardiner 1973, O'Connor and Renn 1964). Adsorption of metal cations increases with increasing pH. The pH of adsorption increases in the order Pb < Cu < Zn < Cd < Ag, with lead most strongly bound and silver the least strongly bound (Engineering Science 1986). Adsorbed metals settle from stream waters with sediments which could become remobilized if eroded during periods of higher flow.

Another process that decreases toxicity downstream is dilution from other inflows. If no other metals or acidity sources are encountered downstream, the concentrations should decrease as cleaner waters enter the stream. If alkalinity increases downstream, carbonate complexation will decrease toxicity.

2.4 Colorado Basic Stream Standards

Metals concentrations and pH are the parameters most relevant to mining-caused pollution. Basic standards for metals and pH are listed in Table 2.1. Most of these basic standards refer to total concentrations of metals which include both the dissolved and suspended forms. Aquatic life standards for aluminum and domestic water supply standards for iron and manganese are based on the dissolved form of the metals. Metals which pass through a 0.45 micron filter are often considered dissolved.

Most metals are carried on dissolved organic carbon and suspended organic and inorganic particles (Perhac and Whelan 1972; Rose et al. 1979). However, it is the free metal ion that is most toxic to organisms (Sunda and Guillard, 1976). Basic standards written to reflect the highly toxic free metal ion concentration would be useful, but lab analyses often provide information only on total concentrations. Standards for dissolved iron and manganese in water supply are set for aesthetic, not human health protection, reasons.

Standards written for aquatic life are generally the strictest. These standards vary according to water hardness, as does metals toxicity for warm and cold water biota. Standards for pH and metals are equal for both warm and cold

Table 2.1. Colorado Basic Stream Standards For Metals and pH

USE	Class 1 Aquatic Life (Warm and cold biota)					Agr.	Domestic Water Supply: Class 1, Class 2.
METAL (ug/l)	Water Hardness or Alkalinity (mg/l)						
	0-100	100-200	200-300	300-400	400+		
Al(sol)	100	100	100	100	100	--	--
As	50	50	50	50	50	100	50
Be	10	300	600	900	1100	100	--
Cd	0.4	1	5	10	15	10	10
Cr III	100	100	100	100	100	100	50
Cr VI	25	25	25	25	25	100	50
Cu	5	10	10	20	40	200	1000
Fe	1000	1000	1000	1000	1000	--	300 (sol)
Pb	4	25	50	100	150	100	50
Mn	1000	1000	1000	1000	1000	200	50 (sol)
Hg	0.05	0.05	0.05	0.05	0.05	--	2
Ni	50	100	200	300	400	200	--
Se	50	50	50	50	50	20	10
Ag	0.10	0.10	0.15	0.20	0.25	--	50
Zn	50	50	100	300	600	20	5000

Explanation

sol - Soluble or dissolved form of metal

Agr.- Use for stock watering or irrigation

pH range - 6.5 to 9.0 for Aquatic Life and Class 1 (Primary Contact) Recreational uses.
- 5.0 - 9.0 for Domestic Water Supply

Note: All values other than hardness or alkalinity ranges are expressed in ug/l.

Source: Table III, Colorado Department of Health, 1984 water species. There are no differences in pH and metals basic standards for Class 1 or Class 2 domestic water supply. There are no metals standards for recreational uses. Class 1 (Primary Contact) recreation has a pH range standard of 6.5-9.0. The Colorado Department of Health's Water Quality Control Commission supports the parameter levels in these basic standards by reference to the EPA (1972, 1976, and 1977), Davies and Goettl (1976), Parametrix (1976), American Fishery Society (1978), and the EPA National Interim Primary Drinking Water Standards.

Inspection of Table 2.1. shows that the basic standards for aquatic life were written to place importance on the values of stream alkalinity and hardness. For example, the standards for cadmium and copper double as the alkalinity increases from 100 to 101 mg/l. Allowable lead concentrations change by a factor of six as the alkalinity fluctuates above or below 100 mg/l. Many streams in Colorado are found in the 0 - 100 mg/l alkalinity range. For this reason, certain stream segments listed in this report could change status with small changes in alkalinity.

2.5 <u>Upper Arkansas River Basin</u>

The upper Arkansas River Basin (Plate 1) is a high altitude, intermountain basin flowing through rocks and sediment ranging in age from recent to Precambrian (Crouch et al. 1984). Most agricultural water is obtained from direct diversion of Arkansas River surface water. Agricultural activities consist mostly of grazing and cultivation of hay fields. In the reach downstream of Canon City, truck farming, fruit orchards, corn, and wheat are also important. Elevation ranges from 14,433 feet at Mt. Elbert to 4,670 feet at Pueblo. Precipitation is from 10 to 40 inches annually, increasing with altitude (Crouch et al. 1984). Several cities, including Canon City and Pueblo use water from the Arkansas River for municipal water supply. CF&I Steel Corp. uses water from the Arkansas and St. Charles rivers for industrial purposes.

Streamflow is derived from snowpack meltwater, transmountain diversions, irrigation return flow, and groundwater inflow. Snowmelt results in high flows during spring to early summer, and more moderate flows during the remainder of the year. There are four transmountain ditches and four transmountain tunnels taking water from the Colorado River basin to the upper Arkansas River basin. The East Fork of the Arkansas River, Thayer Gulch, West Tennessee Creek, Lake Fork, Lake Creek, Busk Creek, and Poncha Creek, are all augmented by transmountain diversion flows. The Aurora-Homestake pipeline diverts water from the Arkansas River above Salida to the South Platte River (Crouch et al. 1984).

Except for a stretch of the Arkansas River between Salida and Wellsville, the Arkansas River gains water from groundwater inflow. This groundwater is generally higher in total dissolved solids and specific conductance than the river water. At times of low flow, the groundwater inflows make up a greater proportion of total flow and these parameters are higher. Because precipitation decreases, and the cumulative effects of groundwater inflows increase going downstream, specific conductance, TDS, salinity, and alkalinity all increase going downstream as well (Crouch et al. 1984). Geologic formations between Canon City and Portland contribute a significant quantity of dissolved solids to the Arkansas, along with inflows (Miles 1977).

It is in the upper reaches of the Arkansas River basin, where hardness and alkalinity are at their lowest, that metals pollution can be most toxic to aquatic life. Mining activities often were concentrated in the upstream reaches of Arkansas River Basin.

Chapter 3

METHODS

This study is based on all available information concerning mining districts and water quality in Colorado. Mining districts are listed in Appendix 1 and plotted on Plate 1 utilizing references by Henderson (1926), Emmons (1927), Vanderwilt (1947), Behre (1953), Del Rio (1960), Tweto (1968), Bucknam (1982), and Eberhart (1969) as sources. These mining district locations were used in conjunction with USGS topographic maps to locate and list the most likely receiving streams. Each district was numbered according to the stream basin it affects.

Stream water quality data were compiled from statewide studies and investigations of individual impacted areas. The raw data were collected by various state and federal bodies and their consultants. Sources include scientific publications, USGS papers, NURE hydrogeochemical data, STORET printouts, and reports by the state and EPA and their contractors. Also included are data collected on selected streams by the Colorado Mined Land Reclamation Division during the 1986 field season. Important parameters evaluated are pH, hardness and alkalinity, and concentrations of iron, manganese, arsenic, mercury, lead, nickel, cadmium, silver, copper, chromium, aluminum, and zinc.

The most extensive source of data analyzed in this study is the STORET database which includes data from water quality studies, discharge permits, and regularly sampled stream stations. Some of the data from other studies are also duplicated on the STORET database. The STORET print-outs used include all water sample analyses entered into the federal system from the beginning of 1977 to the end of 1986. All STORET and other data have been evaluated considering sampling techniques (filtered and/or unfiltered), detection limits, accuracy of analysis technique, and total number of samples and sampling intervals. From this, a new statewide picture of acid mine drainage metals pollution in the Arkansas River Basin was constructed.

The work began by recording all metals in violation of the basic stream standards at individual sampling locations on worksheets under the headings of aquatic life, agriculture, and domestic water supply. Since the volume of data was great, the reference and page number of the sampling station were noted along with location in order to refer back to raw data when questions would arise later.

The next step involved plotting the number of each stream station with a violation on a mosaic map of the

Arkansas River Basin made up of twelve 1 by 2-degree map sheets. After plotting, individual stream segments in violation of standards were determined. Only the portion of the Arkansas River Basin to the west of I-25 was considered.

The determination of stream segments and the metals in them violating standards was a critical part of this study. In a few cases, data from nearby stream locations would conflict. These conflicts were solved in part by weighting the data in favor of stations with the greatest number of samples and lowest detection limits for each metal. Mean metal concentration values were used for comparison to standards when several samples were analyzed for metals and pH. The standard deviation with maximum and minimum values for metals concentrations were also used in considering the validity of sampling stations.

Stream reaches with consistent sets of metals in violation of standards, were marked on the map. Stream segments did not necessarily stop or start at stream data stations. Reaches were often extrapolated upstream or downstream to possible sources of metals or changes in stream conditions such as major tributaries and confluences. No extrapolation of metals pollution was made which the data could not support. Segments were measured with string and a distance wheel and double-checked. The distance of the segment and the metals in violation were then recorded on worksheets and formed into a table. After the identification of a stream segment and its metals, mining districts which were potential sources of metals upstream were also recorded in the table for each stream segment.

The data were finally reduced to show the total mileages of individual metals in violation of the three water use classifications (aquatic life, agriculture, and domestic water supply) for the basin. The total mileage of all metals in violation of each standard was calculated and the individual metals were ranked by the percentage of that total for which they were responsible.

Chapter 4

RESULTS

The results for the Arkansas River Basin are presented in two parts, beginning with a listing of stream segments having parameters exceeding Colorado basic stream standards (Table 4.1), followed by a summary table (Table 4.2). The listing includes each reach of stream in the basin which was determined to have parameters in excess of the basic standards. The length of the segment, the metals in violation, the number of beneficial uses impaired or severity, and the potential responsible mining districts are presented for each reach. The summary table lists the total mileage in violation of aquatic life, agricultural, and water supply basic standards for each parameter. This table also shows the percentage of the total mileage exceeded by each metal for each beneficial use category.

The discussion section provides further details on the possible connection between polluted stream reaches and the mining districts located upstream.

Table 4.1. Upper Arkansas River Basin impacted stream segments.

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
Arkansas R. bl Tennessee Cr. ab California Gulch (2a)	2.4			Zn Cd Cu	1	AR46-47 AR44 AR49 AR52
East Fork Arkansas R. bl Leadville Drain ab Tennessee Cr. (2a)	3.0	Mn	Mn	Cu Cd Zn	3	AR47 AR52
East Fork Arkansas R. bl Chalk Cr. ab Leadville Drain (1c)	6.5			Cd Cu	1	AR52
East Fork Arkansas R. bl Climax ab Chalk Cr. (1b)	1.8	Mn	Mn	Cu Cd Zn	3	AR52
Tennessee Cr. bl St. Kevin Gulch ab Arkansas R. (5)	3.0			Cu Cd	1	AR44 AR46
St. Kevin Gulch - mine area to ab Tennessee Cr. (6)	2.0	Cd Zn Mn Fe pH	Mn Cd Zn	Zn Cd Cu Fe Mn Pb pH	4	AR44
Arkansas R. bl California Gulch ab Lake Fork (2b)	1.5	Mn Cd	Mn Zn Cd	Cu Cd Zn Fe Pb Mn	3	AR46-47 AR44 AR49 AR52

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
California Gulch bl Yak Tunnel ab Arkansas R. (6)	4.9	Cd Pb Zn Mn Fe pH	Cd Zn Mn Pb	Zn Cd Cu Pb Mn Fe Hg pH	4	AR47
Arkansas R. - bl Lake Fk. ab Lake Cr. (2c)	9.5		Mn	Cd Cu Zn Fe Pb	2	AR43-52
Lake Fork bl Turquoise Lake ab Arkansas R. (5)	4.0			Cd Zn	1	AR44
Iowa Gulch - Black Cloud Mine to ab Arkansas R. (8b, 9)	6.5	Cd Pb	Cd Mn	Cd Pb Cu Zn	3	AR47
Box Creek - bl W. edge of placer mines ab Arkansas R. (5)	3.5			Pb Cd	1	AR45
Arkansas R. - bl Lake Cr. ab end of Browns Canyon (3)	35			Zn Cd Cu Pb	1	AR1-7 AR9-13 AR15-16 AR43-52
Lake Cr. - bl Twin Lakes Res. ab Arkansas R. (10)	1.7			Cu Cd	1	AR51 AR48 AR15
Lake Cr. - bl S. Fk. ab Twin Lakes (10)	6.5	Cd	Cd	Cu Cd Pb	3	AR15 AR48 AR51

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	 Agr.	 AQLF	Uses	MD
South Fork Lake Cr. nr source to ab Lake Cr. (11)	5.0	Cd Fe Mn Pb pH	Cd Pb	Cd Pb Cu Zn Fe Ni pH	4	AR15
North Fork Lake Cr. nr source to ab Lake Cr. (10)	5.0	Cd Pb	Cd Pb	Cd Pb Cu	3	AR15
Clear Cr. bl Winfield ab Clear Cr. Res. (5)	9.5			Pb Zn	1	AR2
North Fork Clear Cr. nr source to ab Winfield (5)	4.0			Pb Zn	1	AR2
South Fork Clear Cr. nr source to ab Winfield (5)	4.5			Pb Zn	1	AR2
Pine Cr. - nr source to ab Arkansas R. (5)	8.0			Zn	1	AR9 AR2
Cottonwood Cr. - bl Middle Cottonwood Cr. ab Arkansas R. (12)	7.0			Zn	1	AR2 AR7 AR10
North Cottonwood Cr. nr Bear Lk. to ab Cottonwood Cr. (12)	10.0			Zn	1	AR2
Middle Cottonwood Cr. nr source to ab Cottonwood Cr. (12)	9.0			Pb Zn Cu	1	AR7

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
South Cottonwood Cr. nr source to ab Cottonwood Cr. (12)	11			Zn	1	AR10
Trout Cr. - bl Castle Rock Gulch ab Arkansas R. (5)	7.0			Zn Pb Cu	1	AR11
Chalk Cr.- bl St. Elmo ab Arkansas R. (12)	16			Zn	1	AR3
Arkansas R. - bl S. end Browns Canyon ab Canon City (3)	55			Cd Zn Ni Cu Pb	1	AR1-17 AR29-39 AR43-52 U2
S. Arkansas R. bl N. Fk. ab Arkansas R. (12)	11.5			Cu Zn Pb	1	AR8 AR56
S. Arkansas R. bl Garfield ab N. Fk.(12)	6.0			Zn	1	AR8
N. Fk. S. Arkansas R. nr source to ab S. Arkansas R. (12)	7.0			Zn Pb Cu	1	AR8
Poncha Cr. bl Silver Cr. ab Poncha Springs (12)	6.5	Mn	Mn	Zn Pb Cu	3	AR54
Silver Cr. nr source to ab Poncha Cr. (12)	7.0			Zn Cu	1	AR54
Starvation Cr. nr source to ab Poncha Cr. (12)	5.0			Zn Pb	1	AR54

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
Bernard Cr. - Ark. Mtn. to ab Ark. R. (13)	4.0			Zn Cu	1	AR29
Texas Cr. bl Spruce Cr. ab Arkansas R. (15)	9.5			Zn	1	AR17 AR30
Grape Cr. bl Westcliffe ab Arkansas R. (15)	26			Zn Cu Cr Ni	1	AR19-20
Pine Gulch bl West Pierce Gulch	5.0			Hg	1	AR27
Taylor Cr. nr source to ab Grape Cr. (15)	10.0			Zn	1	AR19
Arkansas R. bl Canon City ab Pueblo Res. inlet (4)	30			Zn Cd Pb Fe Cu Ag Hg	1	C2 AR1-17 AR19-20 AR26-39 AR43-52 AR55-56 U2
Fourmile Cr. bl Cripple Cr. conf. ab Arkansas R. (21)	17		Mn	Fe Cd Cu	2	AR55-56
Cripple Cr. nr source to ab Fourmile Cr. (22)	6.0		Mn	Mn Fe Cd Zn Pb Hg	2	AR56

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
Wilson Cr. nr source to ab Fourmile Cr. (23)	7.0	Pb	Mn	Pb Zn Mn Cu Hg	3	AR56
Middle Arkansas River Segments:						
Saint Charles R. bl N. St. Charles R. ab I-25 (7)	21			Fe	1	AR18 AR55
Middle Cr. - Ophir Cr. to ab Beulah (6)	6.5	Pb		Pb Hg	2	AR18
Greenhorn Cr. - source to Rye	7.0			Cd Cu Pb Hg	1	None
Huerfano R. bl Red Wing, ab I-25 (14,15)	24		Mn	Fe Cu Zn Ag Hg	2	AR40 AR42
Cucharas R. bl La Veta ab I-25 (16)	14		Mn	Fe	2	C1 AR41
Middle Cr. - mtn. front to ab Cucharas R.	11	Mn		Hg	2	C1

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
Turkey Cr. bl L. Turkey Cr. conf. ab Teller Res. (24)	5.5	Pb Mn Se	Mn Pb Se	Cd Cu Fe Pb Mn Hg Ag Zn	3	AR22 AR25 U3
Fountain Creek Segments:						
Foutain Cr. - nr source to Monument Cr.	16.5			Cu Cd Fe Ag Hg Pb	1	AR24 AR58
Monument Cr. bl W. Monument Cr. ab Fountain Cr. (5)	9.0	Mn		Fe Cu Zn Hg Cd	2	C3 AR21
Fountain Cr. bl Monument Cr. conf. ab L. Fountain Cr. (2)	17	Mn	Mn	Cu Zn Fe Ag Hg Cd	3	AR21 AR24 AR58 C3
Rock Cr. - nr source to ab Hwy 115(4)	1.0			Pb Cu	1	AR23

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
Rock Cr. bl Hwy 115 ab L. Fountain Cr. (4)	7.0	Pb	Mn	Mn Cu Fe Zn Hg Pb	3	AR23
L. Fountain Cr. bl Hwy 115 ab Fountain Cr. (4)	12	Se	Mn	Cd Pb Fe Ni Zn Hg	3	AR23
Fountain Cr. bl L. Fountain Cr. conf. ab Pinon	13	Mn	Mn	Cu Zn Cd Hg Fe Ag	3	AR23-24 AR21 AR60 C3
Lower Arkansas River Segments:						
Apishapa R. bl Gulnar ab I-25 (3)	9.5	Pb Cr	Cr Pb Cu Mn Ni	Cd Pb Cr Zn Hg	3	AR41 C1
Mid. Fk. Purgatoire R. - source to ab Stonewall (6b)	4.0			Zn Cu Hg Al	1	C1
Purgatoire R. + Mid. Fk. bl Stonewall ab Segundo (5a)	15			Zn Al	1	C1

(continued)

Table 4.1. (continued)

Segment	Miles	Above Standard WS	Agr.	AQLF	Uses	MD
Purgatoire R. bl Segundo ab Trinidad (5a)	15	Pb Cr	Mn Pb Cu	Cu Pb Hg Zn Fe Mn Ni Cd	3	C1

EXPLANATION:

Uses-	No. of uses impaired	MD-	Mining distr. upstream listed in Appendix A
WS -	Domestic Water Supply		
Agr.-	Agriculture	ab-	Above
AQLF-	Aquatic Life	bl-	Below
(1a)-	Stream segment no. from CDH (1986)	nr-	Near

Table 4.2 Arkansas River: Summary of mileages and metals exceeding basic stream standards for each use.

Percent of Total Mileage Exceeding Aquatic Life Stds for Each Metal	Metals Exceeding Basic Aquatic Life Standards	Mileage Exceeding Basic Aquatic Life Standards (608 mi. total)
79	Zn	483.1
66	Cu	400.3
53	Pb	321.4
52	Cd	314.3
38	Fe	229.9
35	Hg	209.9
19	Ni	113.0
15	Ag	89.5
8	Mn	48.9
6	Cr	35.5
3	Al	19.0
2	pH	11.9

Percent of Total Mileage Exceeding Agricultural Stds for Each Metal	Metals Exceeding Agricultural Standards	Mileage Exceeding Agricultural Standards (199 mi. Total)
92	Mn	182.7
22	Pb	44.9
16	Cd	31.4
12	Cu	24.5
5	Ni	9.5
4	Zn	8.4
3	Se	5.5

Percent of Total Mileage Exceeding Water Supply Stds for Each Metal	Metals Exceeding Water Supply Standards	Mileage Exceeding Water Supply Standards (155 mi. Total)
52	Mn	80.2
46	Pb	71.9
20	Cd	31.4
16	Cr	24.5
11	Se	17.5
8	pH	11.9
8	Fe	11.9
4	Zn	6.9

Chapter 5

DISCUSSION

5.1 Impacted Stream Segments

The Arkansas River begins at the confluence of the East Fork of the Arkansas River and Tennessee Creek. This most upstream segment above California Gulch had average levels of total cadmium, copper, and zinc concentrations that exceed Colorado basic aquatic life standards (Colorado Department of Health 1984). Cadmium and copper concentrations were undetected during certain sampling periods (Engineering Science 1986). Roline and Boehmke (1981) sampled this stream segment extensively, finding that copper and cadmium often exceeded basic aquatic life standards. Total zinc concentrations were consistently above basic aquatic life standards in all studies. The probable source of metals is from the East Fork into which flows effluent from the Leadville Drainage Tunnel. Tennessee Creek also contributed metals because of inflows from heavily-polluted St. Kevin Gulch.

The East Fork of the Arkansas River below the Leadville Drain exceeded the basic domestic water supply standard for dissolved manganese and the agricultural standard for total manganese. Basic aquatic life standards were exceeded for cadmium, copper and zinc. The Leadville Drain collects mine waters from portions of the Leadville district and discharges into the East Fork.

Above the Leadville Drain, upstream to Chalk Creek, only cadmium and copper slightly exceeded basic aquatic life standards in the available data (Roline and Boehmke 1981, Moran and Wentz 1974). The source was probably from the Alicante and Climax mining districts. Between Chalk Creek and Climax on the East Fork, manganese exceeded basic domestic water supply and agricultural standards as well as basic aquatic life standards for copper, cadmium, and zinc. Decrease in concentration by dilution and precipitation, settling, or adsorption onto sediments downstream may account for the relatively unpolluted stream reach between between Chalk Creek and the Leadville Drain.

Tennessee Creek between its mouth and St. Kevin Gulch surpassed basic aquatic life standards for total concentrations of copper and zinc. Data from Moran and Wentz (1974) indicated that Tennessee Creek upstream from St. Kevin Gulch is unpolluted, implying that the heavily polluted gulch is the dominant source of metals. Waters in St. Kevin Gulch exceeded domestic water supply standards for total cadmium and zinc, and dissolved iron and manganese. Agricultural standards for manganese, cadmium, and zinc are surpassed as well as basic aquatic life standards for total concentrations of zinc, cadmium, copper, iron, manganese, and lead. The pH of water in St. Kevin Gulch was too low for domestic water supply, aquatic life, or Class 1 Recreational uses. A possible source of metals is mines and waste piles of the St. Kevin district.

One of the most impacted segments of the Arkansas River lies immediately below California Gulch but upstream of the confluence with Lake Fork. Lake Fork increases flow on the Arkansas River by a factor of two (Roline and Boehmke, 1981). This dilutes the effects of pollution from California Gulch. Much of this diluting flow comes from trans-mountain diversions from the Fryingpan River and Homestake Creek which drain into Turquoise Lake. Flow from California Gulch contributed to concentrations of total cadmium and dissolved manganese, which exceed basic domestic water supply standards, and total manganese and zinc which exceed basic agricultural standards. Basic aquatic life standards were surpassed by total concentrations of zinc, cadmium, copper, lead, manganese, and iron on this segment.

California Gulch downstream from the Yak Tunnel is one of the most polluted stream segments in the Arkansas River Basin. Here, concentrations of cadmium, lead, zinc, manganese, and iron exceed domestic water supply standards;

cadmium, zinc, manganese, and lead exceeding agricultural standards; and zinc, cadmium, copper, lead, manganese, iron, and mercury exceeding basic aquatic life standards; based upon data from Engineering Science (1981), Roline and Boehmke (1981), Moran and Wentz (1974), and Wentz (1974). These data also showed the pH of California Gulch to be too low for domestic water supply, aquatic life, and full-contact recreational uses. Sediment in the Arkansas River bed just downstream from California Gulch also showed extremely high concentrations of metals while upstream samples did not (Engineering Science 1986).

Concentrations of metals appeared to decrease in the segment of the Arkansas River below Lake Fork and above Lake Creek. No metals concentrations exceeded domestic water supply standards, but total manganese concentration was above basic agricultural standards for many sampling episodes (Moran and Wentz 1974, McLaughlin 1980). Basic aquatic life standards were exceeded for total cadmium, copper, zinc, iron, and lead concentrations though at somewhat reduced levels from those immediately upstream. Roline and Boehmke (1981) data showed increases of cadmium, lead, and zinc downstream from Lake Fork that could indicate sources of metals from mining districts draining into this stream segment.

The Lake Fork of the Arkansas River, though it does dilute pollution in the Arkansas River, was above basic aquatic life standards for concentrations of total cadmium and zinc in data from McLaughlin (1980). The source may have been the Independence-Sugar Loaf gold, silver, and zinc district, but levels are not high and natural leaching from crystalline rocks and sulfides is also possible. Some of the western slope water diverted to Turquoise Lake may also have been carrying cadmium and zinc possibly originating in the Homestake mining district.

Iowa Gulch, where it has fairly consistent flows from about the Black Cloud Mine to its mouth, had metals levels that would impact three possible uses. Data from Moran and Wentz (1974) and Wentz (1974) indicated concentrations of total cadmium and lead that exceeded domestic water supply standards, concentrations of total cadmium and dissolved manganese that exceeded agricultural standards, and concentrations of total cadmium, lead, copper, and zinc that exceeded basic aquatic life standards. Mines and waste piles in the southern portion of the Leadville mining district are the most likely sources of metals.

Other tributaries to the Arkansas River above Lake Creek may contribute metals. One October sampling at the mouth of Box Creek (Roline and Boehmke 1981) showed concentrations of total lead and cadmium to be above basic aquatic life standards. Placer mining in the Box Creek district may be the source. Lead and copper concentrations showed increases just downstream from Empire and Big Union gulches that may indicate metals pollution in those tributaries which drain the Weston Pass district and southern portions of the Leadville district.

Between Lake Creek and the STORET station north of Salida at the southern end of Browns Canon there are no regularly sampled stations with data on metals available for the Arkansas River. The data available (Roline and Boehmke 1981, STORET-EPA 1986) indicated total copper concentration decreased only slightly and remained above basic aquatic life standards. Total concentrations of lead, zinc, and cadmium also remained above the Colorado basic aquatic life standards. The Leadville district including California Gulch appeared to be the dominant source of metals pollution along this segment as tributaries are not adding to concentrations of these metals.

Lake Creek is also partially diluted by western slope diversion water. Though Lake Creek improved the quality of the Arkansas River, the segment below Twin Lakes had concentrations of total cadmium and copper that exceeded basic aquatic life standards in data from Moran and Wentz (1974).

Engineering Science data (1986) for one sampling episode did not detect cadmium but confirmed the presence of copper at above the basic standards. Above Twin Lakes where Lake Creek has not had the benefit of dilution by western slope water, or possible removal into lake sediments or organisms, concentrations of total cadmium exceeded basic domestic water supply and agricultural standards in data from Moran and Wentz (1974) and Wentz (1974). Basic aquatic life standards were surpassed by concentrations of cadmium, lead, and copper along this segment. Sources of metals are possible from the Twin Lakes, Lackawanna, and Red Mountain metals mining districts or from natural weathering of pyritized rocks in the vicinity of Red Mountain.

The South Fork of Lake Creek was sampled for metals by Moran and Wentz (1974) and Wentz (1974), both times in the fall of the year. The measured pH's were 5 and 5.1, respectively, below basic stream standards for Class 1 recreational, domestic water supply, and aquatic life uses. The concentrations of total cadmium, zinc, iron, lead and nickel were above basic aquatic standards; cadmium and lead were also above agricultural and domestic water supply basic standards. Dissolved concentrations of iron and manganese were also above basic domestic water supply standards. Moran and Wentz (1974) list the source of metals and acid as "abandoned draining mines and tailings piles." Much of the rock in the Red Mountain contains abundant pyrite, weathering to a red color at surface. Natural oxidation by deep weathering of pyritic rock could have contributed to acidic conditions by surface drainage or sub-surface recharge to streams. In spite of the low pH, aquatic life has sufficient habitat to develop a Class 1 community (Colorado Department of Health 1986). Aquatic life may have become acclimatized to these conditions, or the conditions may be limited to a short period in October and November which would still allow aquatic life to thrive.

One sample taken from the North Fork of Lake Creek (Moran and Wentz 1974) also showed total cadmium and lead concentrations above domestic water supply and agricultural basic standards. Total cadmium, lead, and copper were also above basic aquatic life standards. Concentrations of metals were lower than the South Fork with which it joins to form Lake Creek. The North Fork also had a near-neutral pH. The poor quality waters of the South Fork were improved at the confluence. The North Fork drains the eastern portion of the Independence mining district as well as the northern Red Mountain district which may be sources of metals.

Water sampling data from the Clear Creek drainage in Chaffee County as part of the NURE program (Broxton 1979), showed consistently high concentrations of dissolved lead and zinc. The concentrations were high in the North Fork and South Fork of Clear Creek as well. These concentrations were above lead and zinc basic aquatic life standards. Source of metals may have been mines and waste piles of the Winfield gold-silver-lead mining district. Pine Creek, which also drains this district as well as the Pine Creek mining district, was sampled above basic aquatic life standards for zinc.

Cottonwood Creek and its three forks were also sampled extensively during the NURE water sampling program (Broxton 1979). Middle Cottonwood Creek at three sampling locations above its confluence with South Cottonwood Creek, had concentrations of lead, zinc, and copper that were above basic aquatic life standards. The mainstem of Cottonwood Creek, North Cottonwood Creek, and South Cottonwood Creek had concentrations of zinc above basic aquatic life standards. The Riverside, Cottonwood, and South Cottonwood mining districts are possible sources of these metals.

Trout Creek between the Arkansas River and Castle Rock Gulch, showed levels of zinc, lead, and copper concentrations that were above basic aquatic life standards in NURE data (Broxton 1979). Three samples were taken along this segment that showed fairly good agreement, though one copper determination was slightly lower than the basic aquatic life standard. The Trout Creek gold district might have contributed metals, but was only a minor district.

Chalk Creek between the Arkansas River and St. Elmo had concentrations of zinc above basic aquatic life standards in six samples taken during NURE sampling. The source of zinc may be associated with mines and tailings of the St. Elmo district, which lies at the headwaters of Chalk Creek.

The reach of the Arkansas River between Canon City and Browns Canyon, which is about six miles north of Salida, exceeded basic aquatic life standards for total cadmium, zinc, nickel, lead, and copper concentrations. Metals data used for this segment are from USGS-STORET (1986) sampling at Browns Canon and just west of Canon City. Unreleased data collected by the Colorado Department of Wildlife also indicate metals concentrations above basic aquatic life standards (Woodling 1987). One source of metals is probably drainage from many gold, silver, copper, lead, and zinc districts upstream. California Gulch and the Yak Tunnel have been blamed for metals pollution as far downstream as Salida and possibly Canon City (Engineering Science 1986).

NURE data (Broxton 1979) indicated concentrations of total lead, copper, and zinc above basic aquatic life standards along the South Arkansas River below the North Fork. The North Fork of the South Arkansas River also exceeded basic aquatic life standards for concentrations of these metals. Above the confluence with the North Fork, the South Arkansas River exceeded basic aquatic life standards only for concentrations of zinc. The Monarch silver-lead-zinc-gold-copper district is a possible source of metals for these stream reaches. Individual mines should be investigated for possible drainage and impacts on streams.

Northern portions of the Bonanza mining district lie within the Arkansas River Basin in Saguache County. Drainage from some of these mines may have caused concentrations of total zinc and copper in Silver Creek, as well as concentrations of total lead and zinc in Starvation Creek to exceed basic aquatic life standards. Poncha Creek below the confluence with Silver Creek had concentrations of zinc, lead, and copper in excess of basic standards for aquatic life in NURE data (Broxton 1979), and dissolved manganese in excess of basic domestic water supply and agricultural standards (Wentz 1974).

The reach of Texas Creek between Spruce Creek and the Arkansas River exceeded basic aquatic life standards for total zinc in NURE data (Shannon 1979a). This zinc may have been brought in by Spruce Creek or Brush Creek, but these creeks were only sampled once. The Spruce Creek, Gem, and Hillside gold mining districts all are drained by Texas Creek or its tributaries.

Two NURE samples taken on Bernard Creek show zinc concentrations above Colorado basic aquatic life standards (Shannon 1979a). Copper also exceeded the basic aquatic life standard in one sample taken by Wentz (1974). These samples were all filtered, so total concentrations for some metals may have been higher. The Cotopaxi copper-zinc mining district is drained by Bernard Creek and warrants further investigation.

Grape Creek is a possible contributor of metals to the Arkansas River, joining the river immediately above Canon City. The Westcliffe-Silver Cliff mining districts were a major silver, gold, and lead mining area in Colorado. Four NURE water samples taken on Grape Creek showed concentrations of zinc, copper, chromium, and nickel that were above basic aquatic life standards (Shannon 1979a). Pine Gulch, a tributary to Grape Creek, had a mercury concentration above the basic aquatic life standard in one sample (Wentz, 1974). NURE data also show zinc concentrations above basic aquatic life standards in Taylor Creek, a tributary to Grape Creek. Taylor Creek drains the small Verde gold mining district. However, recent unreleased water sampling data at the Colorado Division of Wildlife have not detected any metals in Grape Creek (Woodling 1987). As more studies are done and released on the Grape Creek drainage, the effects of the Westcliffe-Silver Cliff mining district can be better understood.

The Arkansas River from Canon City to Pueblo Reservoir exceeded basic aquatic life standards for zinc, iron, copper, cadmium, lead, silver, and mercury. The Canon City coal field may affect this reach, as mean concentrations of zinc, mercury, and iron increased as tributaries from the coal field were passed near Florence between the STORET sampling stations at Canon City and Portland. Upper Cretaceous units that contribute high-salinity groundwater to the Arkansas (Miles 1977) may also contribute metals.

Fourmile Creek which drains the Cripple Creek gold mining district also joins the Arkansas River along this segment. Fourmile Creek from the Arkansas River to Cripple Creek exceeded basic aquatic life standards for total iron, cadmium, copper, and lead concentrations according to unpublished Colorado Department of Health data. Data from Moran and Wentz (1974), which consisted of only two sampling times above Wilson Creek confirmed these metals levels, except detection limits for lead and cadmium were too high, and zinc also exceeded basic aquatic standards. The Cripple

Creek mining district is a likely source of metals with possible contributions to Cripple Creek, Wilson Creek, and the Carlton Tunnel. Other possible sources are the Fourmile mining district further upstream and natural sources from weathering.

Wilson Creek and Cripple Creek also showed impacts above Fourmile Creek back to the Cripple Creek District. Wilson Creek exceeded basic domestic water supply standards for total lead concentrations in one of two STORET samples taken downstream from Victor. The basic agricultural standard for manganese was exceeded as well as basic aquatic life standards for concentrations of total lead, zinc manganese, copper, and mercury in the two samples as well. More extensive STORET sampling along with unpublished Colorado Department of Health data for Cripple Creek showed the basic agricultural standard for manganese surpassed along with basic aquatic life standards for mercury, zinc, lead, cadmium, iron, and manganese. All of this can be tied to drainage and waste piles of the Cripple Creek gold district.

The St. Charles River was found to exceed the basic aquatic life standard for total iron in four samples taken at a STORET station downstream from the confluence with the North St. Charles River. No other metals exceeded the standard. Possible sources of the iron are the Fairview and

Beulah mining districts. The Fairview district is probably not the source of the iron because similar concentrations of iron were not found in Middle Creek which is closer. Low iron concentrations in STORET samples also indicated that the iron was probably not coming down the North St. Charles River either. Natural weathering from sedimentary strata was also a possible source of iron.

Middle Creek above Beulah surpassed basic aquatic life standards for total lead and mercury, and drinking water standards for total lead. The Fairview gold mining district drains into Ophir Creek, a tributary of Middle Creek and could be the source. However, no STORET sample analyses were available from Ophir Creek to further trace this possibility.

Greenhorn Creek upstream of Rye slightly exceeded basic aquatic life standards for concentrations of cadmium, copper, lead, and mercury. No mining districts lie upstream on Greenhorn Creek, which passes through Cretaceous sandstones and shales and Precambrian gneisses in the Wet Mountains. Natural sources are most likely for the metals levels.

The Cucharas River between La Veta and I-25 had elevated levels of iron and manganese. Total manganese concentrations were above basic agricultural standards and total iron concentrations exceeded basic aquatic life standards.

No other ill effects are evident along this segment, which had possible contributions from parts of the Raton Mesa coal mining area and the Spanish Peaks mining district. The Cucharas flows across the Raton Formation as well as Tertiary sandstones, shales, and conglomerates of the Poison Canyon and Cucharas formations. Iron and manganese may have been easily weathered from these relatively young sedimentary rocks.

Data from Wentz (1974) showed dissolved manganese in Middle Creek, a tributary to the Cucharas, to be above domestic water supply standards. Mercury was also above basic aquatic life standards on this segment. No metals mining districts are upstream, but coal mine areas in the Vermejo Formation are drained by Middle Creek and its tributaries.

The Huerfano River above I-25 surpassed basic aquatic life standards for concentrations of iron, copper, zinc, silver, and mercury; and basic agricultural standards for manganese in STORET data. Upstream are the Malachite and Blanca mining districts. If these were the sources of the metals, this impacted segment includes the Huerfano River to Red Wing as well as tributaries. Immediately above I-25, the river flows through Pierre Shale, and upstream from that a variety of Tertiary units that might have contributed metals also. More sampling could define this further.

Turkey Creek above Teller Reservoir exceeded basic domestic water supply standards for concentrations of total lead and selenium and dissolved manganese in STORET data. The same metals also exceeded basic agricultural standards. basic aquatic life standards were exceeded by concentrations of total cadmium, chromium, iron, lead, manganese, zinc, mercury, and silver. The Turkey Creek and El Paso mining districts are possible sources of the metals, though mean concentrations of metals in Turkey Creek and Little Turkey Creek are much lower upstream of this segment in STORET data. Small stratiform deposits of uranium were mined on the George Avery Ranch in the Dakota Formation in the Turkey Creek anticline (Shannon, 1979a). This area was further disturbed when later used as a tank run as part of Fort Carson operations. These uranium deposits seem to be the most likely sources of metals for this stream segment.

Fountain Creek has had extensive sampling for which there are data in the STORET database. Fountain Creek surpassed basic aquatic life standards for total concentrations of iron, copper, cadmium, silver, mercury, and lead above the confluence with Monument Creek. The Manitou or Pikes Peak mining districts may have been sources.

At Pinon, the dissolved manganese concentration slightly exceeded the basic domestic water supply standard. Farther upstream above the confluence with Little Fountain Creek, the concentration was over four times the water supply standard. Manganese concentrations were also above basic agricultural standards from the confluence with Monument Creek downstream to at least as far as Pinon. Concentrations of total copper, zinc, iron, cadmium, mercury, and silver all exceed basic aquatic life standards. These metals could have come from Colorado Springs wastewater and urban runoff.

In STORET data, Little Fountain Creek exceeded the basic domestic water supply standard for concentration of selenium. The concentration of total manganese exceeds basic agricultural standards. Concentrations of total cadmium, lead, iron, nickel, copper, zinc, and mercury exceeded basic aquatic life standards. Rock Creek, a tributary to Little Fountain Creek, had concentrations of lead above the domestic water supply standard, concentrations of manganese above the basic agricultural standard, and concentrations of total copper, zinc, manganese, iron, mercury, and lead that exceeded the basic aquatic life standards. The Cheyenne mining district is drained by both streams, but STORET data show Little Fountain Creek to meet all standards in the vicinity of this minor district. Rock Creek only slightly exceeded basic aquatic life standards for lead and copper immediately downstream from the Cheyenne district. It is more likely that the streams were picking up metals from friable sedimentary rock units mapped in areas (Tweto 1979) downstream from the mining district.

STORET data for Monument Creek, which joins Fountain Creek at Colorado Springs, indicated a concentration of total manganese above the basic agricultural standard and concentrations of total iron, copper, zinc, mercury, and cadmium above basic aquatic life standards. Metals concentrations were much lower in the reach of Monument Creek above West Monument Creek. So the Colorado Springs coal-mining district and possibly the Blair Athol copper-mining district, which is drained by West Monument Creek, may both have contributed metals to Monument Creek.

The Purgatoire River drains no metal mines described in the mining references for this study. The Raton Mesa coal mining area and outliers appear to be the chief mining-caused source of metals. Above Segundo on the Purgatoire and Middle Fork of the Purgatoire, only zinc, copper, and mercury were slightly above the basic aquatic life standards.

Below Segundo, coal mines were more numerous and tributaries such as Sarcilla Canyon, Mulligan Canyon, and Carpios Canyon brought large amounts of heavy metals into the Purgatoire River. From Segundo to Trinidad, total lead and chromium concentrations were on average several times the domestic water supply limits. Basic standards for agriculture were exceeded by lead, manganese, and copper along this same stretch. Basic aquatic life standards were exceeded by total iron, zinc, nickel, lead, mercury, manganese, and cadmium. The total metals concentrations had an impact on three different uses of water on this segment and at levels many times the standards for iron, copper, lead, nickel and zinc. The segment is classified for Class 1 Cold Water aquatic life, so fish do exist in spite of the high metals levels. Limited data on dissolved metals showed generally low levels, so the metals may be tied up in less toxic particulate forms.

According to the Colorado Department of Health (1986) in its Classifications and Numeric standards, CF&I used a geological basis to explain upstream and downstream water quality. Most of the impacted reaches of the Purgatoire River flow through the Raton Formation, which includes important coal beds and natural weathering could have been a significant factor causing the high metals concentrations.

Mining was a factor to the extent that it may have exposed more of the rock units to weathering through surface disruption and changes in ground water levels and flow patterns.

The Apishapa River between Gulnar and I-25 also flows through the coal-bearing Raton Formation and part of the Raton Mesa coal mining area. The Spanish Peaks metal mining district may also contribute drainage to the Apishapa River. Total lead and chromium concentrations exceed domestic water supply standards on this segment. Basic agricultural standards were exceeded for chromium, lead, copper, manganese, and nickel, and basic aquatic life standards were surpassed for cadmium, lead, chromium, zinc, and mercury. East of I-25 the metals decrease significantly, possibly due to settling of particulates. No data were available to indicate where metals concentrations increased west of Aguilar.

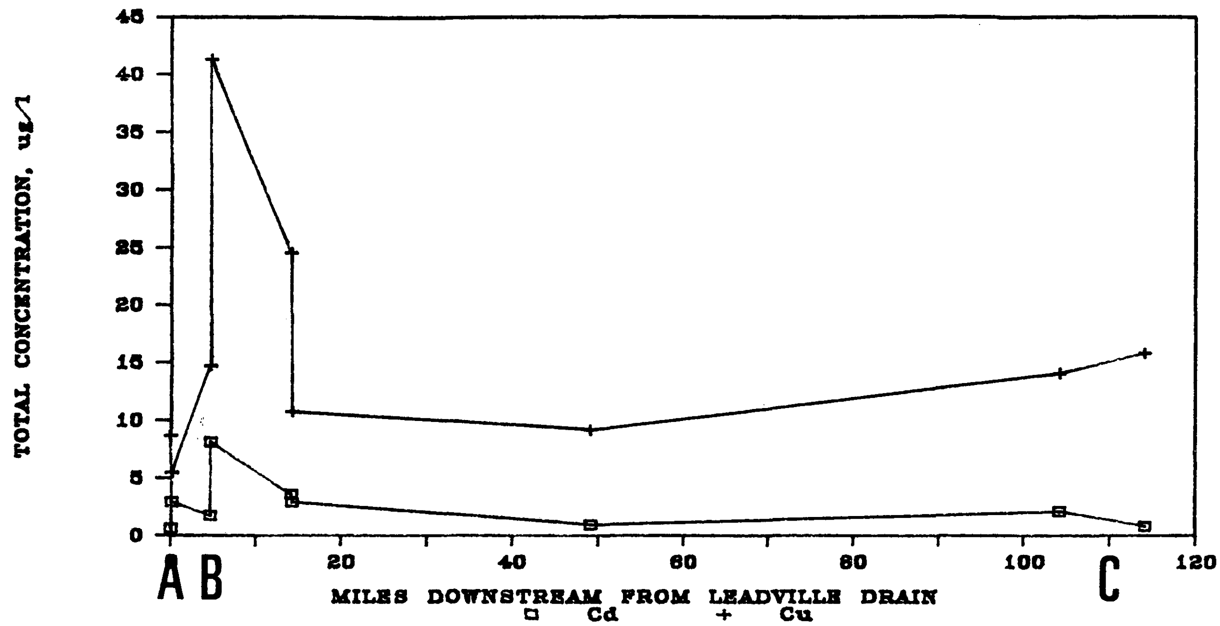
5.2 Metals Contributions to Upper Arkansas River

Since several sampling stations on the Arkansas River mainstem from above Leadville to Pueblo had 19 or more samples collected and analyzed for pH and metals, an attempt was made to determine the most important increases and decreases of metals. Where the text refers to significant differences in concentration of a metal between two stations, confidence levels were determined by one-tailed z and t tests as described by Gray (1983) and Snedecor (1967). These statistical tests are based on assumptions of normal distributions in populations which introduces some error, and the different types of water sampling and analysis techniques used for the STORET database make comparison of populations difficult. However, wherever increases or decreases were significant above a 90 percent confidence level or higher, the difference in mean values was obvious.

Using data from 19 sampling episodes above and below the Leadville Drain (Roline and Boehmke, 1981), significant increases in total concentrations of cadmium, zinc, lead, and manganese were seen downstream from the Leadville Drain to above a 95 percent confidence level on z and t tests. Analyses of waters from the Leadville Drain show high concentrations of cadmium, iron, manganese and zinc (Roline and Boehmke 1981, McLaughlin 1981, Moran and Wentz 1974). The data indicated that flow from the Leadville Drain was an important source of these metals to the East Fork of the Arkansas River.

Tennessee Creek and the East Fork have about equal flows at their confluence to form the Arkansas River (Roline and Boehmke 1981). This Tennessee Creek flow dilutes metals concentrations from the East Fork. Precipitation and adsorption onto solids may be active in the mixing flows. However, concentrations of metals continued to decrease only as far as the mouth of California Gulch. Concentrations of all these metals zinc, cadmium, copper, lead, manganese, and iron increase dramatically just downstream from California Gulch which, is the location of the abrupt increase in concentrations in Figures 5.1 and 5.2. Cadmium, copper, zinc, iron, and manganese increased by above a 99 percent confidence level on z and t tests (Gray 1983, Snedecor and Cochran 1967) using data from Roline and Boehmke (1981).

Metals may have entered the Arkansas River from California Gulch flows suspended or dissolved in surface water, in alluvial ground water, or in the sediment load. Concentrations of total metals increase during high spring runoff below California Gulch, suggesting that metals and metal-rich sediments are scoured and suspended during high flows (Roline and Boehmke 1981). This contributes additional metals loadings to the Arkansas River that would not be seen in just calculating loadings from concentrations of metals in the waters from California Gulch. Speculations have also been made that ground waters traveling in the California Gulch alluvium may also be carrying metals to the Arkansas River (Crouch 1984, Engineering Science 1986).



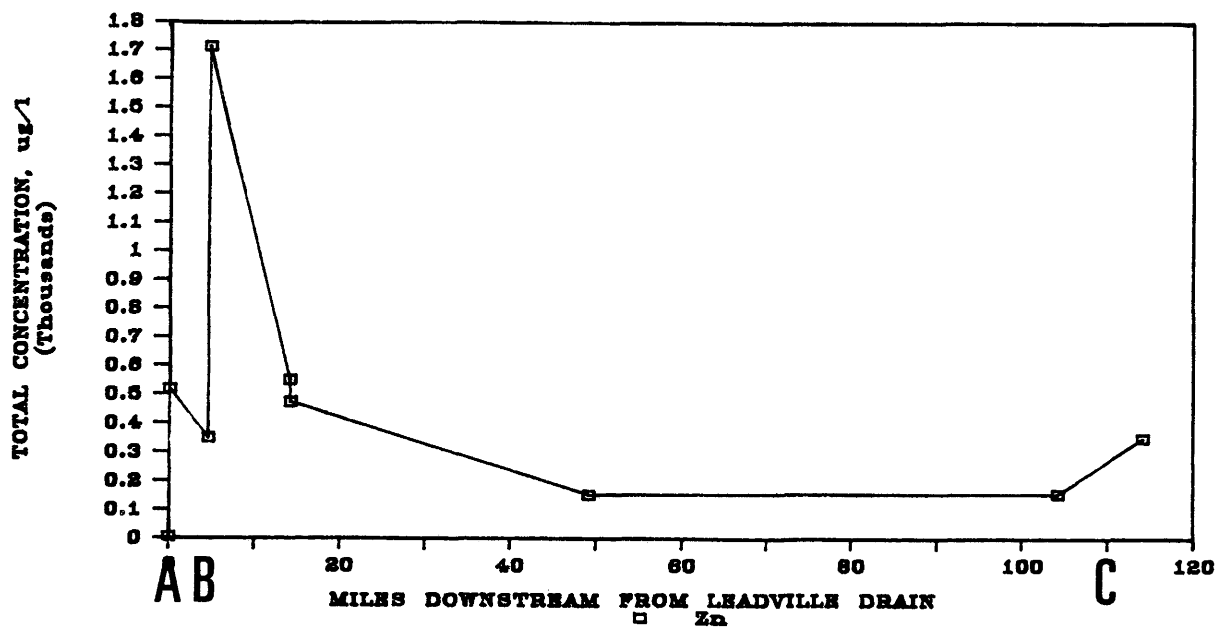


Figure 5.1 Downstream concentrations of copper, cadmium, and zinc in the Arkansas River; Locations of: A- Leadville Drain, B- California Gulch, and C- Canon City.

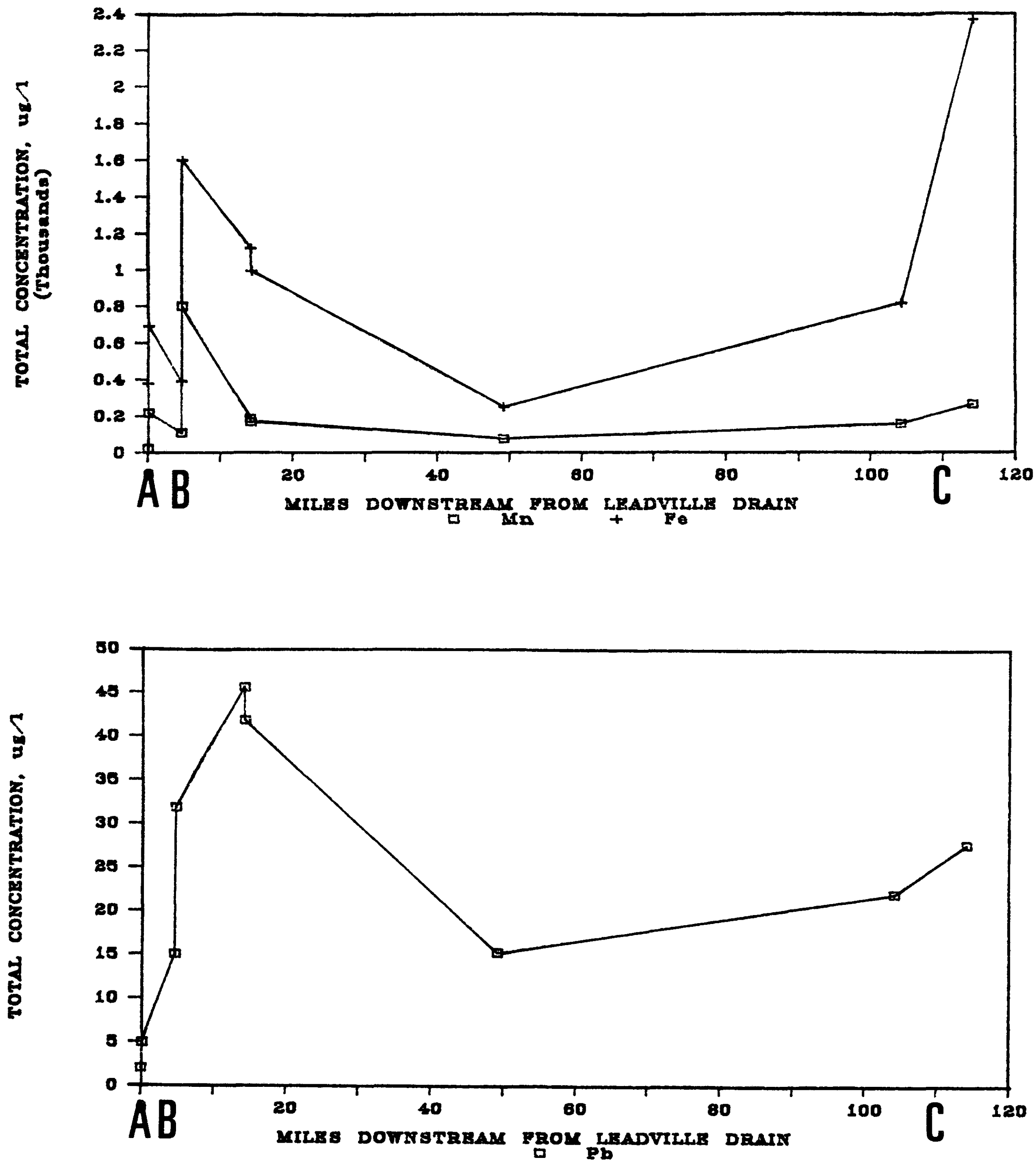


Figure 5.2 Downstream concentrations of iron, manganese, and lead in the Arkansas River; Locations of: A- Leadville Drain, B- California Gulch, and C- Canon City.

Concentrations of metals appeared to decrease in the Arkansas River below the Lake Fork confluence. The Lake Fork of the Arkansas River dilutes pollution in the Arkansas River. Metals removing processes such as adsorption and precipitation occur as well as dilution. Roline and Boehmke (1981) data showed increases of cadmium, lead, and zinc downstream from Lake Fork that could indicate mining sources of metals from Empire and Big Union gulches and Box Creek, draining into this stream segment. However, Box Creek's effect on the Arkansas was probably that of a freshening flow, as diversity indices of aquatic macroinvertebrates were higher below Box Creek than immediately above (Roline and Boehmke, 1981). Periodic scouring and resuspension of metals-bearing sediments may also account for these apparent downstream increases.

Lake Creek is also partially diluted by western slope diversion water, improving the quality of the Arkansas River by dilution. Between Lake Creek and the STORET station north of Salida at the southern end of Browns Canon there were no regularly sampled stations with data on metals available for the Arkansas River. The data available (Roline and Boehmke, 1981; Storet, 1986) indicated significant decreases in concentrations of total zinc, cadmium, iron, manganese, and lead along this segment to a 95 percent confidence level (Gray 1983, Snedecor and Cochran 1967).

The Leadville district was the dominant source of metals pollution along this segment, with tributaries diluting the Arkansas River rather than adding to concentrations of these metals. Establishment of more stations regularly sampled for heavy metals might indicate other sources along this reach, but not of the magnitude of California Gulch.

Below Browns Canon on the Arkansas River, metals concentrations continue to decrease. California Gulch and the Yak Tunnel have been blamed for metals pollution as far downstream as Salida and possibly Canon City (Engineering Science, 1986). This conclusion is based on the assertion that their Storet data retrieval showed metals present "but decreasing in concentration as Canon City is approached". However, their STORET retrieval summarized in Table 6.2 of Engineering Science (1986) shows increases in cadmium, copper, and lead from Salida to Canon City. The STORET retrieval used for this study had concentrations increasing for cadmium, lead, copper, iron, manganese, and zinc between Browns Canon and Canon City (Figures 1 and 2). Only increases of iron and manganese were significant to a 95 percent level of confidence, (Gray 1983, Snedecor and Cochran 1967) though not to a level to surpass any basic stream standards. Other sources of metals than upstream ones are possible along the Arkansas River reach from near Salida to just above Canon City.

No data are available to determine just how far past Browns Canon along the Arkansas River the metals concentrations might continue to decline before other metals contributions from side streams caused increases, if at all. None of the tributaries to this reach of the Arkansas River that were recently sampled by the Department of Wildlife have shown significant metals concentrations (Woodling, 1987). The apparent increase of metals concentrations in Storet data discussed above may simply be an artifact of different sampling techniques, intervals, and stream conditions for values in the STORET database.

Past Canon City, zinc, mercury, and iron increased between two STORET stations, as tributaries from the Canon City coal field were passed. Fourmile Creek, which drains the Cripple Creek gold mining district also joined the Arkansas River along this segment. However, using statistical analysis of mean metals concentrations upstream and downstream of Florence by z and t tests as described by Gray (1983) and Snedecor and Cochran (1967), only the downstream increase in total iron concentration was significant to a 95 percent confidence level. A decrease in concentration might have been expected if areas above Salida were the only sources of metals.

5.3 Impacted Uses

About 608 miles of stream in the Arkansas River Basin were listed as impacted for at least one beneficial use as a result of applying Colorado basic stream standards (Colorado Department of Health 1984) to the available data. Eleven miles showed no connection to mining and 75.5 miles of impacted stream were downstream from small or scattered districts where connections to mining were doubtful. Aquatic life standards were exceeded for all 608 miles while domestic water supply standards were exceeded for 154 miles of streams and agricultural standards were exceeded for 199 miles.

5.3.1 Aquatic Life

For most parameters, the basic aquatic life standards are the strictest because aquatic life is most sensitive to stream chemistry. Not surprisingly, this standard was exceeded for the greatest mileage. In only a few cases, such as California and St. Kevin gulches, were the aquatic life absent. The detrimental effects of California Gulch inflows result in fish being absent immediately below its confluence with the much larger Arkansas River (Roline and Boehmke 1981). That study also showed that aquatic communities in the Arkansas River thrive below freshening flows from clean tributaries. This indicates that there might be potential for aquatic diversity and populations to increase if conditions such as metals concentrations were to show improvement.

Zinc is the metal violating basic aquatic life standards for the most mileage. Copper, lead, and cadmium in that order are also important. Tables 2 and 3 shows that many of these metals occur together. Synergistic effects such as those between zinc and copper, can increase toxicity even more (Moran 1974a).

5.3.2 Agriculture

Manganese concentration is the element most often breaking agricultural standards with 199 miles of impacted mileage. For basic agricultural standards, 128.3 miles or 64 percent of the mileage was due to high manganese concentrations alone. Lead, cadmium, and copper also violate standards in over 10 percent of the impacted mileage.

5.3.3 Domestic Water Supply

In all cases where domestic water supply standards, except for dissolved manganese, were exceeded, a mining district was located upstream. Lead, cadmium, and chromium, in that order were also often exceeded. Of the stream mileage where basic domestic water supply standards were exceeded, 61.3 miles or 37 percent of the mileage was due solely to concentrations of dissolved manganese above 50 micrograms per liter.

5.3.4 Recreation

Metals have no impact on recreational uses of streams in the Colorado basic standards. Low pH's impact water supply and aquatic life uses as well as recreational uses and 11.9 miles of stream had a pH below five. However, it is hard to imagine uses such as swimming becoming popular in places like California Gulch even if the pH were neutral.

5.4 Important Metals Sources

Many mining districts shown on Plate 1 have no impacted stream segments draining from them and others have only minor impacts associated. Mining areas upstream of severely impacted stream segments may be more intensely pyritized, be more extensively worked, be developed to expose more pyrite, and have high relief terrain that helps workings lower the water table of the mineralized areas.

5.4.1 Metals Districts

The Leadville district can be associated with 148 miles of impacted stream, most of which is on the main trunk of the Arkansas River. Much of the pollution comes from the Yak tunnel and the Leadville drain, two old dewatering tunnels which extend underneath portions of the district. The Yak tunnel, which flows into California Gulch, is the chief source of metals from the district to the Arkansas River. Effects on aquatic life can be seen immediately downstream. Elevated metals concentrations and impacts may extend past Canon City and one study states that metals pollution extends to the state line (Colorado Department of Health 1986). The extent of downstream effects is confused by inflows from other mining districts, including Fourmile Creek which drains the Cripple Creek district near Canon City.

The St. Kevin mining district has had a severe impact on St. Kevin Gulch, but only a slight one on Tennessee Creek, which is not significant when mixed in with the Arkansas River. No other metals mining districts appear to have significantly impacted the mainstem of the Arkansas

River, though the Red Mountain district has impacted the South Fork of Lake Creek, the Cripple Creek district has impacted Wilson Creek and Fourmile Creek, and possibly the Westcliffe-Silver Cliff district has impacted upper portions of Grape Creek. These impacts were diminished by downstream metals removal processes before reaching the Arkansas River or masked by metals in the mainstem after joining the mainstem.

About 500 impacted miles in the upper basin can be associated with metals mining in some way. In some cases the mining district's contribution may have been secondary to drainage from coal mines, uranium mines, natural seeps or weathering. On the other hand, an even higher total of mileage might have been calculated if impacts outside the study area on the eastern plains of Colorado had been considered.

5.4.2 Coal Mines

Coal mining was the most probable mining source for 76 miles of impacted streams in this study and may have contributed to 69 more miles. Metals associated with various coal districts include cadmium, copper, zinc, mercury, and lead as well as iron and manganese. The Raton Mesa coal field accounted for nearly all of the undisputed

76 impacted miles. The Colorado Springs coal field is upstream of 39 miles of impacted stream in Monument and Fountain creeks. The Canon City coal field may account for some of the metals pollution of 30 miles below Florence on the Arkansas River, but upstream metals mining districts such as Leadville have already raised concentrations and the coal field's contribution was impossible to determine with any confidence.

5.4.3 Uranium Mines

Most uranium mines are scattered throughout metals and coal mining areas so that their impacts are hard to evaluate. The Tallahassee Creek district, which is located away from hardrock mining areas, does not appear to have caused any significant problems up to this time. The small George Avery Ranch uranium mine was the probable source of metals impacts to 5.5 miles of Turkey Creek above Teller Reservoir. Uranium deposits, like coal and metals deposits, often occur with abundant pyrite, presenting the same potential for mobilization of metals present in the mineralization and surrounding rock. Metals released in addition to uranium, include lead, cadmium, and manganese.

5.4.4 Other Sources

Acid mine drainage is a natural process that is only accelerated by mining disturbances. Similar unmined areas with abundant pyrite can also release quantities of metals to the aquatic environment. Circulating ground waters under certain conditions can bring the necessary oxygen and bacteria to the pyritized rock. Often low levels of naturally-derived metals in a stream cannot be differentiated from diluted mine-drainage.

Eleven miles of stream listed in this report had no solid connections to metals, coal, or uranium districts. Weathering of soft Tertiary sedimentary formations may have also released metals to this stream.

5.5 Methodology

Results and conclusions in this study must be viewed in relation to the limits of what the approach used can draw from available data. Also there is potential for improvement of methods.

5.5.1 Limits of Accuracy

Data for this study were originally collected for a variety of purposes and usually to characterize limited areas. It is difficult to compare stream reaches if metals tested, sampling procedures, detection limits, analysis methods, and reliability of the data are different. Some areas like Leadville, have been studied and sampled several times and other interesting areas have no reliable data available. Some stream segments were compared to standards on the basis of one sample and others had hundreds of analyses available to consider.

Another problem becomes apparent when one reviews data for dissolved and total concentrations of metals at the same sampling site. STORET data show many stations where mean dissolved concentrations exceed total concentrations for certain metals. One expects that dissolved samples having been filtered would always have lower metals concentrations than unfiltered samples. Some error occurs because dissolved and total samples were collected different numbers of times and at different times. However, the same problem was encountered in data representing single sampling episodes. This indicates a certain amount of error in sample collection and analysis for much of the geochemical data used for this study.

When only a few sample analyses are available for metals concentrations on portions of a mountain stream system with varying flow conditions, such as those existing in the study area, a completely accurate assessment of conditions cannot be expected. Mining districts often were developed in the upper reaches of stream valleys where very little sampling has been done. Even where districts have been well sampled, upstream segments are hard to find for comparison, because mining activities extended to the headwaters. This study can only associate impacted stream segments with areas of mining. These data alone cannot be used to prove that any particular source of metals is responsible for the listed impacts. Properly done follow-up sampling could come closer to accomplishing this goal.

This study evaluated the impacts on stream reaches using Colorado basic stream standards (Colorado Department of Health 1984). Any errors in the biological studies upon which the standards were based, or in interpretation of the studies, were incorporated into this assessment. Lax standards would mean that the mileage totals in this report are too low. If the standards allow for an overly large "margin of safety", then the actual impacted mileage was overestimated. Basic aquatic life standards are for total concentrations of metals except for aluminum which has a dissolved concentration standard. If future studies and regulations produce metals standards based upon dissolved concentrations, an assessment such as this one would produce somewhat different results. As discussed in the methods section, effects of alkalinity and hardness on toxicity are handled by having different concentration standards for each 100 mg/l range of alkalinity. Incorrect interpretations may have occurred in borderline cases.

Many streams listed as having metals concentrations in excess of basic aquatic life standards are generally known to have good fishing. These streams may be impacted in more subtle ways or the aquatic life has built up tolerances to adverse stream conditions. Conditions during sampling of a stream during a few brief sampling episodes may not be representative of predominant stream conditions. This study has characterized all streams with the data available and the basic standards or advisory levels most widely applicable to Colorado mountain streams.

Mining areas were located on the map with general references on mining in Colorado. Density of mines was not plotted, only the areas in which one might find mines. Many mines cause no problems, but individual mines may expose large quantities of pyrite-rich rock to oxidation and cause severe problems. The references usually do not provide enough detail to characterize mines that are most likely to have associated water-quality problems. Many mining areas were included that had little production because of the possibility that an individual mine, tunnel, or waste pile may have caused an impact.

5.5.2 Improvement of Methods

The most improvement could be realized by getting more accurate information on water quality, mining district locations, and toxicity of metals. This study utilized work already done. A study where the investigator controlled the way sampling and laboratory analyses were done would have much greater uniformity and a basis for comparison. Metals toxicity guidelines, set with no safety margins and at higher levels of concentrations than the Colorado basic aquatic life standards, would give a more accurate picture of actual impacts. However, to undertake a future statewide water and biological sampling program over the long periods of time required to get data similar to that used in this report and is available in other Colorado basins, would require a much higher expenditure of resources.

5.6 Comparison With Earlier Studies

Two other studies of note have also computed statewide mileage totals for streams in the Arkansas River Basin with acid mine drainage problems.

5.6.1 Wentz (1974)

Wentz (1974) considered the acid mine drainage problem in Colorado and found 450 miles of impacted streams. Of this mileage, 68 miles were in the Arkansas River basin. All of the Wentz report sampling was done on lower order streams, and streams were characterized on the basis of single samples at sampling locations. Dissolved metals data and metals concentrations criteria at the same levels as present Colorado basic aquatic life standards were used for evaluation of streams. The latest Colorado basic stream standards (Colorado Department of Health 1984) only specify dissolved concentrations for aluminum for aquatic life and iron and manganese for domestic water supply.

This study made use of more recent stream standards and a much greater volume of data covering more streams to list a total of over 600 stream miles in the Arkansas River basin exceeding the basic stream standards for at least one use. Impacts were traced much farther down the mainstem of the Arkansas River and other higher order streams. Because of this large volume of data from different sources, however, there is less consistency from one area to another for this study.

5.3.2 Department of Health 305b Report

The Water Quality Control Division's annual report (Colorado Department of Health 1986) attributed 53 percent of stream miles that do not support classified uses, to drainage waters from inactive mines and mills. Since 6 percent of the state's 14,100 miles of streams and rivers do not support their classified uses, this works out to about 450 stream miles impacted by mining. About 175 of these miles were in the Arkansas River Basin. The annual report made use of adopted standards and did not include non-point sources of metals that could not be remedied within 20 years. Adopted standards also allow for relaxation of standards if the standards will pose an economic hardship for an area.

Application of Colorado basic stream standards, which are supported by scientific rather than political or economic reasoning, was considered more appropriate to the goals of the study. Adopted standards are set at the levels of non-point source pollution existing in a stream and may be mining caused. An individual impacted by mining-caused pollution may not care whether it is economically feasible to clean it up within a twenty year time period.

5.7 Future Work

Many of the areas identified in this study are already well-known as metals sources and site-specific investigations and cleanups are proceeding. For certain stream segments, the sources of metals are not as well understood. Follow-up studies on all tributaries to impacted streams that have not been well-sampled is the next logical step. When the major mining-related sources of metals have been determined, then the feasibility of treatment of individual mine discharges or removal of waste piles can be assessed. With a full view of where problems exist, limited funds can be expended where there is the greatest potential of restoring beneficial uses to streams.

A statewide evaluation applying Colorado basic stream standards to available data is in progress and will evaluate the whole state as this study has evaluated the Arkansas River Basin. A new statewide study will result in the listing of areas where acid mine drainage may be a problem and follow-up studies can determine the details and whether present technology can correct these problems.

New sampling will have the benefit of newer and better sampling and analysis procedures. Areas being studied under CERCLA are being sampled rigorously with procedures that will withstand court scrutiny. However, these represent a small fraction of the possible impacted areas which need regular sampling for metals with reliable methods and lower detection limits. Future sampling should present data on both dissolved and total concentrations of metals in stream waters. For aquatic life, a better understanding of how toxic metals affect the interrelated organisms will be required. Metals in the bottom sediments traveling downstream in the bed load may be damaging as well as those in the water. Standards for metals concentrations in sediments may be needed.

Chapter 6

CONCLUSIONS

There is a total of 608 miles of stream in the Arkansas River Basin with mining-related metals concentrations exceeding Colorado basic standards, and impacting at least one beneficial use. Aquatic life is the use for which there is the highest total of substandard stream mileage in the basin also at 608 miles. Miles impacted for domestic water supply and agricultural uses are 155 and 199 respectively.

These mileage totals indicate damages to the stream environment that could have been caused by mining and represent a worst case scenario for mining-caused impacts in the upper basin. Natural weathering of rock units and urban runoff may have also contributed to high stream concentrations of metals. More sampling at more locations in the small, high elevation streams is also needed to better assess impacts.

Zinc, copper, lead, and cadmium (in that order) are the metals whose concentrations exceed basic aquatic life standards for the most stream miles, each exceeding the standard for at least 50 percent of the total miles. Manganese concentrations exceed agricultural standards for more stream miles than all other metals, contributing to 92 percent of violations. Manganese and lead concentrations most often exceed domestic water supply standards, being above the standard concentrations in 52 percent and 46 percent of the 155 miles in the upper basin exceeding domestic water supply standards.

Aquatic life exists in many stream segments with metals concentrations exceeding basic aquatic life standards. These standards may need re-evaluation, but individual stream reaches should be investigated for subtle impacts on aquatic habitat. Margins of safety for aquatic habitats may be threatened and new metals sources to many streams should be avoided.

Follow-up studies are needed to identify mining-related metals sources that can be economically removed, treated, or contained.

REFERENCES CITED

✓American Fishery Society. 1978. A Review of the EPA Red Book Quality Criteria for Water.

Behre, C. H. 1953. Geology and ore deposits of the west slope of the Mosquito Range. U. S. Geological Survey Professional Paper No. 235.

Bolivar, S., and D. Hill. 1979. Uranium hydrogeochemical and stream sediment reconnaissance of the Craig NTMS Quad, Colo. NURE- GJBX 76(79).

Bowen, H. J. M. 1979. Environmental chemistry of the elements, Academic Press, New York, New York.

Boyles, J. M., D. Cain, W. Alley, and R. W. Klusman. 1974. Impact of Argo Tunnel acid mine drainage, Clear Creek County Colorado, In Water res. problems related to mining, Am. Water Res. Assoc. Proc. No. 18.

Broxton D. E. 1979. Uranium hydrogeochemical and stream sediment reconnaissance of the Montrose NTMS Quad. Co. NURE-GJBX-125(79).

Bucknam D. L. 1982. Map-Inactive mines of Colorado, Colorado Inactive Mine Program, Mined Land Reclamation Division.

CH2M Hill. 1983. Draft work plan: remedial investigation-/feasibility Study, Central City/Argo Tunnel Idaho Springs, Co. USEPA Hazardous Sites Control Division.

✓Colorado Department of Health, Water Quality Control Commission. 1984. Basic standards and methodologies.

________. 1986a. Classifications and numeric standards for the Arkansas River Basin.

________. 1986b. Division's 1986 annual report to the Water Quality Control Commission.

________. 1987. Unpublished data, Denver, Colorado.

Colorado Mined Land Reclamation Division. 1986. Unpublished data, Denver, Colorado.

Crouch, T. M. 1984. Water resources appraisal of the Upper Arkansas River Basin from Leadville to Pueblo, Colorado. U. S. Geological Survey Resources Investigation Report 82-4114.

Davies, P. H., and J. P. Goettl. 1976. Aquatic Life Water Quality Recommendations for Heavy Metal and Other Inorganic Toxicants in Fresh Water. submitted to Water Quality Control Commission.

Del Rio, S. M. 1960. Mineral Resources of Colorado, First Sequel, State of Colorado Mineral Resources Board, Denver Co.

Eberhart, P. 1969. Guide to the Colorado Ghost Towns and Mining Camps, Swallow Press, Chicago, Illinois.

Emmons, S. F., J. D. Irving, and G. F. Loughlin. 1927. Geology and Ore Deposits of the Leadville Mining District, U. S. Geological Survey Professional Paper No. 148.

Engineering-Science Inc. 1986. Yak Tunnel/California Gulch Remedial Investigation. Prepared for State of Colorado in co-operation with U. S. Environmental Protection Agency.

Environmental Protection Agency. 1972. Water Quality Criteria, Ecological Research Series, National Academy of Sciences, National Academy of Engineering, EPA-R3-73-033, Washington D. C.

________. 1976. Quality Criteria for Water. U. S. Government Printing Office: 1977 0-222-904, Washington, D. C.

________. 1977. Proposed National Secondary Drinking Water Regulations. Federal Register, 42 (no. 62): 17143-17147.

________. 1986. STORET: Storage and retrieval, Hydrogeochemical data for Colorado streams. 1977-1986.

________. N. d. National Interim Primary Drinking Water Regulations: 40 Code of Federal Regulations, Part 141.

Forstner U. and G. T. W. Wittman. 1983. Metal Pollution in the Aquatic Environment, Springer-Verlag, New York, New York.

Gardiner, J. 1973. The chemistry of cadmium in natural water-II: the adsorption of cadmium on river muds and naturally occurring solids, Water Research. 8:157-164.

Geotrans, Rocky Mountain Consultants, and ERI Logan. 1986. Idarado Mining and Milling Complex Remedial Investigation, Appendix C.

Goettl, J. P., and P. H. Davies. 1978. Water Pollution Studies. Dept. of Natural Resources, Division of Wildlife, Federal Aid Project F-33-R-13.

Gray, S. H. 1983. No-Frills Statistics, Rowman & Allanheld, Totowa N.J.

Henderson, C. W. 1926. Mining in Colorado. U. S. Geological Survey Professional Paper 138, Washington D. C.

Holm, J. D. 1977. Water Quality in Non-Designated Areas of Colorado. 208 Water Quality Planning and Water Quality Control Division, Colorado Department of Health.

Holm, J. D., T. Sullivan, and B. K. Stenulson. 1979. The restoration of Peru Creek. Colorado Water Quality Control Division and U. S. Forest Service.

ICAIR Life Systems, 1986, Priority Pollutants Water Quality Criteria, Technology Summary, ICAIR- Cleveland OH, Arlington VA.

Kepler, K. 1980. Water quality investigations in mineralized areas of the San Juan Mountains: Red Mountain Creek, Howard's Fork, and Henson Creek. District 10 Regional Planning Commission, Montrose Colorado.

LaBounty, J. F., J. J. Sartoris, L. D. Klein, E. F Monk, and H. A. Salmon. 1975. Assessment of heavy metals pollution in the Upper Arkansas River of Colorado. U. S. Department of the Interior, Bureau of Reclamation, Denver Colorado.

Los Alamos Scientific Laboratory. 1979. Uranium hydrogeochemical and stream sediment reconnaissance of the Moab NTMS Quad UT./CO. LASL: NURE GJBX-146(79).

McLaughlin Industrial Waste Engineers. 1981. Colorado inactive Mine Mine Drainage: Water Quality and Abatement. Division of Mined Land Reclamation Dept. of Natural Resources, Colorado.

Mars, J. P. 1979. Investigation of the water quality of the Upper Dolores River May 1978 Through August 1978. Colorado Department of Health Water Quality Control Division.

Miles, D. L. 1977. Salinity in the Arkansas Valley of Colorado. Cooperative Extension Service CSU and USEPA-Region 8, Denver Co.

Moran, R. E. and D. A. Wentz. 1974a. Effects of metal mine drainage on water quality in selected areas of Colorado, 1972-1973, Colorado Water Resources Circular no. 25. USGS and Colorado Water Conservation Board, Denver, Colorado.

________. 1974b, Thermodynamic constraints on metal solubilities in a stream affected by mine drainage, Bonanza, Co. Water Resources Problems Related To Mining. Proc. No. 18, American Water Resources Association.

Nordstrom, D. K., E. A. Jenne, and J. W. Ball. 1979. Redox equilibria of iron in acid mine waters. In E. A. Jenne (ed.) Chemical Modeling in Aqueous Systems, American Chemical Society Symposium Series, No. 93.

O'Connor, J. T., and C. T. Renn. 1964. Soluble-adsorbed zinc equilibrium in natural waters", Journal AWWA, (Aug. 1964).

Office of the State Engineer. 1979. Water Division and District Boundaries, Map: State of Colorado.

Parametrix Inc. 1976. Attachment II, Parametrix reports-toxicology assessments of As, Cu, Fe, Mn, Se, and Zn, Bellevue, Washington, Submitted to Water Quality Control Commission.

Perhac, R. M., and C. J. Whelan. 1972. A comparison of water, suspended solids, and bottom sediment analysis for geochemical prospecting in a northeast Tennessee zinc district. Journal of Geochemical Exploration. 1: 47-53.

Roline, R. A., and J. R. Boehmke. 1981. Heavy metals pollution of the Upper Arkansas River, Colorado, and its effects on the distribution of the aquatic microfauna. U. S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Rose, A. W., H. E. Hawkes, and J. S. Webb. 1979. Geochemistry in Mineral Exploration, Academic Press, New York, New York.

Schroeder, R. E., J. H. Koblitz, and G. M. L. Robinson. 1986. Proposal for the mitigation of health, safety, and environmental impacts of the Alice Mine. CMLRD-Abandoned Mined Lands Program.

Shannon, S. S. 1979, Uranium hydrogeochemical and stream sediment reconnaissance of the Pueblo NTMS Quadrangle Co. NURE- GJBX-14(79)

________. 1979b. Uranium hydrogeochemical and stream sediment reconnaissance of the Tallahassee Creek, Badger Creek, Castle Rock Gulch, and Buffalo Gulch Areas in the Northwestern Part of the Pueblo NTMS Quadrangle, Co. NURE-GJBX-42(79)

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. Iowa State University Press, Ames Iowa.

Stumm, W., and J. J. Morgan. 1970. Aquatic Chemistry: An introduction emphasizing chemical equilibrium in natural waters, Wiley-Interscience, New York

Sunda, W. G., and R. R. Guillard. 1976. The relationship between cupric ion activity and the toxicity of copper to phytoplankton. Journal of Marine Research 34: 511-519.

Todd, J. W., J. Woodling, D. W. Reiser, and G. Andes. 1982. Recovery of a Colorado stream affected by acid mine drainage. In Issues and Technology in the Management of Impacted Western Wildlife, Thorne Ecological Institute, Boulder, Colorado

Tweto, O. 1968. Geologic setting and interrelationships of mineral deposits in the mountain province of Colorado and south-central Wyoming", in Ore Deposits of the United States, 1933-1967 Ridge J. D., Editor, AIME, New York.

________. 1979. Geologic Map of Colorado. U. S. Geological Survey.

U. S. Geological Survey. 1974. Hydrologic Unit Map, 1974, State of Colorado

Vanderwilt, J. W. 1947. Mineral Resources of Colorado, State of Colorado Mineral Resources Board, Denver, Colorado.

Warren, R. 1979. Uranium hydrogeochemical and stream sediment reconnaissance of the Cortez NTMS Quad. Colo/Utah, NURE-GJBX-77(79).

Water Quality Monitoring Program, Ridgway Reservoir---Dallas Creek Project, Colorado, 1977-1980.

Wentz, D. A. 1974. Effect of Mine Drainage on the Quality of Streams in Colorado, 1971-1972, Colorado Water Resources Circular no. 21.

________. 1974b. Stream quality in relation to mine drainage in Colorado, Water Resources Problems Related to Mining, Proc. No. 18, American Water Resources Association.

________. 1977. Quantity and Quality of Drainage from the Argo Tunnel and Other Sources Related to Metal Mining in Gilpin, Clear Creek, and Park Counties, Colorado. App F of Review Report for Met. Denver and S. Platte R. and Tributaries Co. Wy. Neb.

Western Aquatics Inc. for Standard Metals Corp. 1985. Final Report: Use Attainability Analysis of the Upper Animas River.

Wildeman, T. R., D. Cain, and A. J. Ramiriz. 1974. The relation between water chemistry and mineral zonation in the Central City District, Colorado. In: Water Resources Problems Related to Mining. Am. Water Res. Assoc. Proc. No. 18.

Windell, J. T. 1981. Biological and physical habitat evaluation of metal and coal mine drainage impacts in selected stream segments in Colorado. E. P. O. Biology, Univ. of Co. Boulder.

Woodling, John, 1976a, Pollution of the Slate River via a Mine Discharge and Sewage Treatment Plant Effluents. Water Control Division Colorado Department of Health.

________. 1976b. Water quality and biological studies of the Upper San Miguel River Basin. Water Quality Control Division, Colorado Dept. of Health.

________. 1976c, Effects of mining activities on Willow Creek. Mineral County, Co. WQCD, CDH.

________. 1977. Investigations of point sources of acid metals mine drainage locations and water quality effects in the Upper Animas River Basin. Colorado Department of Health, Water Quality Control Division.

________. 1987. Colorado Division of Wildlife, Telephone Communication.

APPENDIX A

MINING DISTRICTS: UPPER ARKANSAS RIVER BASIN

Name	County	Products	Receiving Stream
1. Hope	Chaffee	Au, Ag	Lake Creek
2. Riverside, Winfield	Chaffee	Au, Ag, Pb, Cu	Clear Creek Pine Creek N. Cottonwood Creek
3. Alpine	Chaffee	Au, Pb, Ag, Cu, Zn	Chalk Creek
4. Cleora	Chaffee	Cu	Arkansas R.
5. Turret	Chaffee	Au, Cu, Ag	Ute Creek Turret Creek
6. Coon Park	Chaffee		Castle Rock Gulch
7. Cottonwood	Chaffee	Au, Pb, Ag	Cottonwood Cr.
8. Monarch	Chaffee	Ag, Pb, Zn, Au, Cu	S. Arkansas R.
9. Pine Creek	Chaffee		Pine Creek
10. South Cottonwood	Chaffee	Au	S. Cottonwood Creek
11. Trout Creek	Chaffee	Au	Trout Creek
12. Free Gold	Chaffee	Au	Arkansas R.
13. Fourmile	Chaffee	Au	Fourmile Cr.
14. Calumet, Whitehorn	Chaffee, Fremont	Au, Ag	Ute Creek Badger Creek

(continued)

APPENDIX A (continued)

Name	County	Products	Receiving Stream
15. Red Mountain	Chaffee, Lake	Au, Ag	South Fork, North Fork of Lake Creek
16. Granite	Chaffee, Lake	Au, Ag	Arkansas R.
17. Spruce Creek	Custer	Au	Spruce Creek N. Brush Creek Texas Creek
18. Fairview	Custer	Au	Ophir Creek Middle Creek
19. Verde	Custer	Au	Taylor Creek Grape Creek
20. Westcliffe, Silver Cliff	Custer	Ag, Au, Pb	Grape Creek
21. Blair Athol	El Paso	Cu	W. Monument Creek
22. Turkey Creek	El Paso		Turkey Creek
23. Cheyenne	El Paso		Rock Creek L. Fountain Creek
24. Manitou	El Paso		Fountain Cr.
25. El Paso	El Paso		Turkey Creek
26. Gordon	Fremont		Eightmile Cr. Low Pass Gulch
27. Greenhorn	Fremont	Zn, Pb	Grape Creek
28. Eightmile	Fremont		Eightmile Cr.

(continued)

APPENDIX A (continued)

Name	County	Products	Receiving Stream
29. Cotopaxi	Fremont	Cu, Zn	Bernard Creek Arkansas R.
30. Gem, Hillside	Fremont	Au	Texas Creek
31. Wellsville	Fremont	Cu	Arkansas R.
32. Red Gulch	Fremont	Cu, Ag	Red Gulch
33. Currant Creek	Fremont	Zn, Cu, Au, Ag, Pb	Currant Creek
34. Badger Creek	Fremont	Cu	Badger Creek
35. Bare Hills	Fremont		Cliff Creek High Creek
36. Howard	Fremont		Sand Gulch
37. Hayden Creek	Fremont		Hayden Creek
38. Black Mountain	Park, Fremont		Thirtyninemile Creek
39. East Beaver Creek	Teller, Fremont		Beaver Creek
40. Huerfano, Malachite	Huerfano	Cu, Ag	Pass Creek
41. Spanish Peaks	Huerfano	Au, Ag, Cu, Zn	Wahatoya Cr. Apishapa R.
42. Blanca	Huerfano	Au	Huerfano R.
43. Two Bit	Lake	Au	Arkansas R.
44. St. Kevin, Independence, Sugar Loaf	Lake	Ag, Au, Zn	Lake Fork

(continued)

APPENDIX A (continued)

Name	County	Products	Receiving Stream
45. Box Creek	Lake	Au	Box Creek
46. Missouri, East Tennessee	Lake	Au, Ag	Tennessee Cr. North Fork
47. Leadville	Lake	Ag, Zn, Pb, Au, Cu	Arkansas R. Evans Gulch Iowa Gulch California Gulch Big Union Cr.
48. Half Moon, Lackawanna	Lake	Au, Ag	Halfmoon Creek N. Fork Lake Cr
49. Homestake	Lake		W. Tennessee Creek
50. Iron Hill, Weston Pass	Lake	Ag, Zn, Pb	Big Union Cr.
51. Twin Lakes	Lake	Au, Ag	Lake Creek
52. Alicante, Climax	Lake	Mo, Au, Ag, Pb, Zn	E. Fork, Arkansas R. Birdseye Gulch
53. Beulah	Pueblo		North Creek South Red Cr.
54. N. Bonanza	Saguache	Ag, Pb, Cu	Silver Creek Starvation Cr.
55. High Park	Teller	Au	Little High Cr. Fourmile Creek
56. Cripple Creek	Teller	Au	Fourmile Creek Cripple Creek West Beaver Cr.

(continued)

APPENDIX A (continued)

Name	County	Products	Receiving Stream
57. Mount Rosa	Teller	Cu, Au, Ag	E. Beaver Creek
58. Pikes Peak	Teller	Au	Fountain Creek

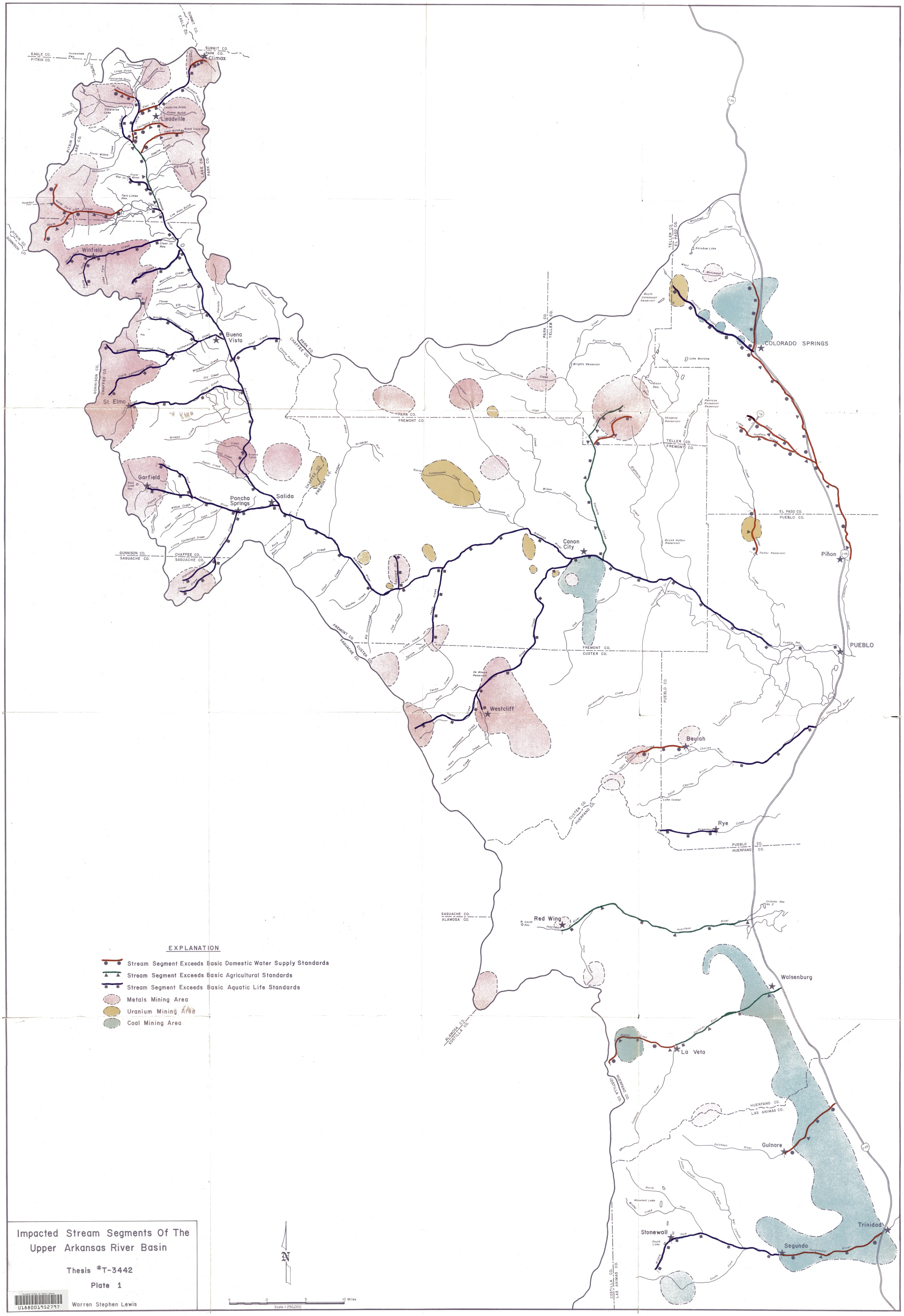
Coal Districts

Name	County	Receiving Stream
1. Raton Mesa	Las Animas Huerfano	Purgatoire R. Apishapa R. Cucharas R.
2. Canon City	Fremont	Arkansas R. Oak Creek Chandler Creek
3. Colorado Springs	El Paso	Monument Creek Fountain Creek

Uranium Districts

1. Front Range	Jefferson Douglas El Paso	Ralston Creek Bear Creek Van Bibber Cr.
2. Tallassee Creek	Fremont	Middle, South, and North Tallahassee Creeks
3. George Avery Ranch	El Paso	Turkey Creek

Miscellaneous small mines and prospects as well as uranium associated with metals in many other mining districts.



Impacted Stream Segments Of The Upper Arkansas River Basin

Thesis #T-3442

Plate 1

Warren Stephen Lewis