RECLAMATION

Managing Water in the West

Technical Memorandum 8220-05-11

A Summary of Existing Reports which have Examined the Leadville Mine Drainage Tunnel (LMDT) Discharge to the East Fork of the Arkansas River, Colorado

U.S. Department of the Interior
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INTRODUCTION

This report summarizes information regarding the East Fork of the upper Arkansas River (East Fork) as related to the Leadville Mine Drainage Tunnel (LMDT) discharge. Information is included for surface water quality, benthic invertebrates, fish populations, and physiology of tree swallows (*Tachycineta bicolor*).

"Control" areas define baseline conditions that would be expected in the absence of mine drainage. In most cases, information from below the LMDT is compared to data for comparable resources above the LMDT.

The Bureau of Reclamation does not vouch for the accuracy of the data or for the conclusion reached in any report that is referenced in this paper.

BACKGROUND

The LMDT is located in Lake County, Colorado, about 1.6 kilometers (1 mi) north of Leadville, Colorado. The tunnel drains water from a portion of the underground workings of the Leadville Mining District.

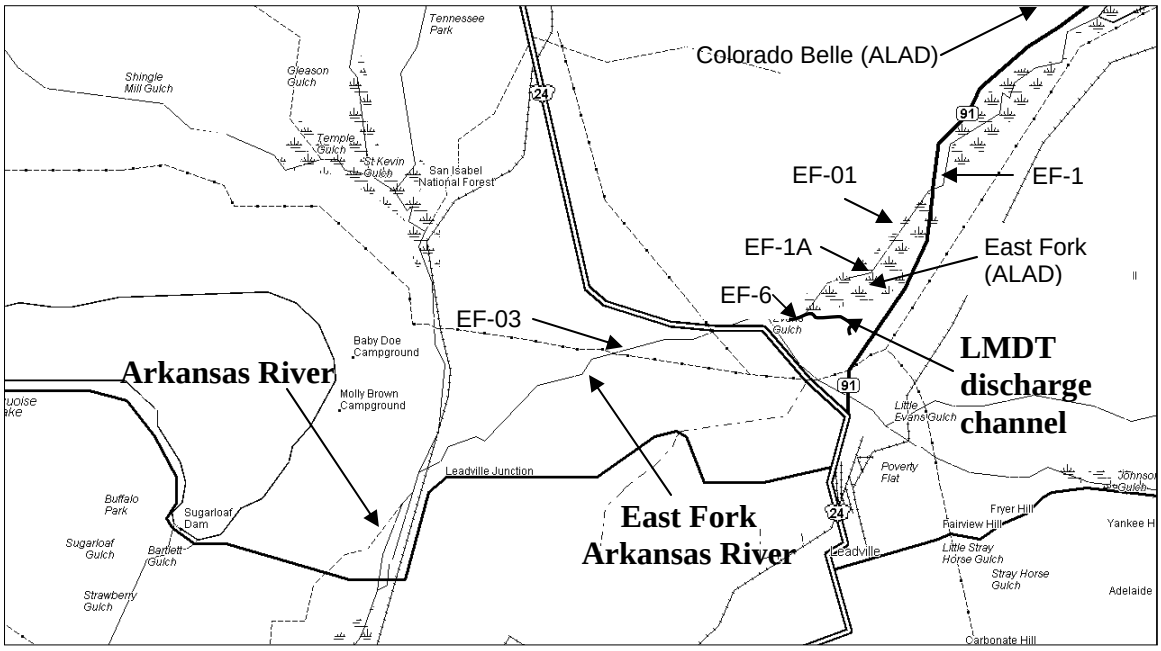
Tunnel construction was initiated in December 1943 by the Bureau of Mines to provide drainage of seepage from some of the underground mine workings in the area so that development of mineral reserves could continue. The portal site was set at an elevation of 3,035 meters (9,957 ft) m.s.l. (mean sea level) to provide adequate drainage along with timely completion. The project was completed in March 1952 at a total tunnel length of 3,444 meters (11,299 ft).

Reclamation acquired the LMDT in 1959 for water rights associated with the tunnel with the intent of including the drainage water as part of the supply for the Fryingpan-Arkansas Project. These waters contained metals, which discharged into the East Fork. To bring the discharge into compliance with the Clean Water Act, a chemical precipitation water treatment plant was constructed and started operating in March of 1992. Information on geochemistry, treatment plant design and operation are presented in Abart et al. (1996).

AREA OF INTEREST

The study area (Figure 1) is in a valley between the Sawatch and Mosquito mountain ranges of central Colorado between elevations of about 2,800 meters (9,500 ft) and 3,050 meters (10,000 ft). Gravel-rubble-type substrate characterizes the riverbed. Existing available information used in this report originated from sampling at stations (EF-1, EF-01, EF-1A, and Colorado Belle) above the LMDT and stations (EF-2, EF-03, and EF-6) downstream of the confluence of the East Fork with the LMDT.

Figure 1. Map of study area showing approximate location of sites.



WATER QUALITY

Several studies were undertaken on the East Fork of the upper Arkansas River prior to completion of the Leadville Mine Drainage Tunnel Treatment Plant (Treatment Plant) (LaBounty et al., 1975; Roline and Boehmke, 1981; Abart et al., 1995; and Abart et al., 1996). Cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn) and zinc (Zn) have been routinely monitored for many years. These data are summarized below.

Table 1. Reported concentrations (µg/L) of selected total metals in the East Fork above and below the LMDT – Mean (M), and Median (MD)

	Upstream of LMDT							Downstream of LMDT						
Year/(Cit.)	Site	Cd	Cu	Fe	Pb	Mn	Zn	Site	Cd	Cu	Fe	Pb	Mn	Zn
1979-1980 (Roline and Boehmke, 1981)	EF-01 (M)	0.33	0.30	405	1.90	27.2	8.61	EF-03	2.73	5.53	713	4.60	226	506
1981-1983 (Abart et al., 1996)	(MD)	--	--	--	--	--	--	EF-03	3.00	--	650	--	590	1065
1989-1991 (Abart et al., 1995)	EF-01 (M)	2.48	5.40	145	6.60	33.2	37.4	EF-03	1.85	5.34	213	7.60	214	439
LMDT Treatment Plant Operation Began March 1992														
1992-1995 (Abart et al., 1996)	(MD)	--	--	--	--	--	--	EF-03	0.15	--	120	--	50	29
1998 (Davies et al., 2001)	EF-01 (M)	0.08	2.11	257	1.49	26.8	11.3	EF-2/ EF-03	0.10	2.55	235	1.20	41.7	18.3
1999 (Davies et al., 2001; Davies et al., 2002)	EF-01 (M)	0.09	1.87	219	1.41	22.6	14.9	EF-2/ EF-03	0.11	1.93	174	1.66	37.8	17.2
2000 (Davies et al., 2002)	EF-01 (M)	0.07	1.37	147	1.00	20.8	14.4	EF-2/ EF-03	0.11	1.24	145	1.00	44.9	15.4
2001 (Davies et al., 2002)	EF-01 (M)	0.08	1.06	274	1.33	29.6	9.4	EF-2/ EF-03	0.11	0.80	170	1.30	42.5	17.8

In a recent report on toxic metals in the East Fork, Davies et al. (2002) found that zinc concentrations, since treatment of the LMDT discharge was initiated in 1992, typically do not exceed established water quality standards year round. Davies et al. (2002) also indicated that multiple metal concentrations in East Fork above and below the confluence with the LMDT were consistently below toxic levels and that BOR "does an excellent job in removing metals from the mine drainage tunnel".

BENTHIC MACROINVERTEBRATES

Data for aquatic invertebrates came from a series of memorandums providing information on benthic communities above and below the confluence of the LMDT with the East Fork from 1988-1991 before treatment plant operation began and 1992-1994 after operation initiation (Roline, 1989; Roline, 1990; Roline, 1991; Nelson and Roline, 1992; Nelson and Roline, 1993; Nelson and Roline, 1993; Nelson and Roline, 1994). Benthic invertebrate samples were collected from surface substrate with Surber samplers and D-frame kick nets in July and October of each of the years. Stations on the East Fork above the confluence with the LMDT were unimpacted by the LMDT (EF-01 and EF-1A). EF-03 was the primary station downstream of the LMDT. Habitat assessment scores were highest at EF-1A (Nelson and Roline, 1996) and this station was designated as the reference station. The two other sites were compared to this station. Data from Surber sampler (quantitative) and D-frame net sampler (qualitative) collections from each site were pooled for each date for determination of richness metric values. Metrics selected for analyses included number of taxa and number of taxa in the disturbance sensitive orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These metrics decline in systems impacted by disturbance. Abundance data were also utilized to quantify biotic condition. Total abundance of all taxa and abundance of the metal intolerant group of Heptageniid mayflies (Nelson and Roline, 1993; Clements, 1994; Kiffney and Clements, 1994, Clements and Kiffney, 1995) were calculated from Surber samplers that sampled a known area. Table 2 shows the response of the selected richness and abundance metrics relative to the reference site EF-1A.

Table 2. Benthic macroinvertebrate biometrics associated with sites above and below the LMDT discharge. Percent comparisons of EF-01 and EF-03 to the reference site (EF-1A) are presented in parentheses.

Year/Month	Community Attributes	Upstream of LMDT		Downstream of LMDT
		EF-01	EF-1A [Reference site]	EF-03
PRE-TREATMENT				
1988/July	Total Richness[a]	18 (95%)	19	12 (63%)
	EPT Richness[a]	10 (91%)	11	9 (82%)
	Heptageniid abundance[b]	193 (158%)	122	190 (156%)
	Total abundance[b]	447 (106%)	423	440 (104%)
1988/October	Total Richness	16 (80%)	20	16 (80%)
	EPT Richness	7 (64%)	11	9 (82%)
	Heptageniid abundance	158 (54%)	294	14 (5%)
	Total abundance	343 (32%)	1081	389 (36%)
1989/July	Total Richness	14 (74%)	19	16 (84%)
	EPT Richness	7 (64%)	11	9 (82%)
	Heptageniid abundance	190 (87%)	219	61 (28%)
	Total abundance	385 (31%)	1228	597 (49%)
1989/October	Total Richness	11 (55%)	20	12 (60%)
	EPT Richness	5 (38%)	13	8 (61%)
	Heptageniid abundance	169 (107%)	158	18 (11%)
	Total abundance	375 (48%)	776	265 (34%)
1990/July	Total Richness	11 (73%)	15	11 (73%)
	EPT Richness	6 (75%)	8	7 (88%)
	Heptageniid abundance	136 (105%)	130	32 (25%)
	Total abundance	291 (59%)	495	258 (52%)
1990/October	Total Richness	16 (84%)	19	15 (79%)
	EPT Richness	8 (80%)	10	9 (90%)
	Heptageniid abundance	384 (119%)	323	14 (4%)
	Total abundance	1732 (99%)	1752	270 (15%)
1991/July	Total Richness	25 (96%)	26	17 (65%)
	EPT Richness	15 (94%)	16	11 (69%)
	Heptageniid abundance	197 (93%)	211	14 (7%)
	Total abundance	444 (68%)	652	130 (20%)

1991/October	Total Richness	34 (87%)	39	22 (56%)
	EPT Richness	23 (96%)	24	13 (54%)
	Heptageniid abundance	174 (72%)	241	26 (11%)
	Total abundance	4219 (64%)	6586	533 (8%)
POST-TREATMENT				
1992/July	Total Richness	31 (100%)	31	19 (61%)
	EPT Richness	21 (110%)	19	13 (68%)
	Heptageniid abundance	122 (86%)	141	100 (71%)
	Total abundance	380 (40%)	959	330 (34%)
1992/October	Total Richness	37 (123%)	30	20 (67%)
	EPT Richness	21 (105%)	20	11 (55%)
	Heptageniid abundance	344 (58%)	596	267 (45%)
	Total abundance	4141 (214%)	1930	1230 (64%)
1993/July	Total Richness	29 (116%)	25	22 (88%)
	EPT Richness	18 (100%)	18	17 (94%)
	Heptageniid abundance	137 (132%)	104	56 (54%)
	Total abundance	296 (133%)	222	174 (78%)
1993/October	Total Richness	29 (76%)	38	32 (84%)
	EPT Richness	18 (78%)	23	17 (74%)
	Heptageniid abundance	378 (95%)	396	229 (58%)
	Total abundance	2670 (62%)	4337	1718 (40%)
1994/July	Total Richness	29 (116%)	25	33 (132%)
	EPT Richness	18 (128%)	14	20 (143%)
	Heptageniid abundance	467 (210%)	222	200 (90%)
	Total abundance	992 (86%)	1156	633 (55%)
1994/October	Total Richness	41 (100%)	41	32 (78%)
	EPT Richness	24 (92%)	26	21 (81%)
	Heptageniid abundance	530 (32%)	1674	752 (45%)
	Total abundance	2281 (40%)	5641	1781 (32%)

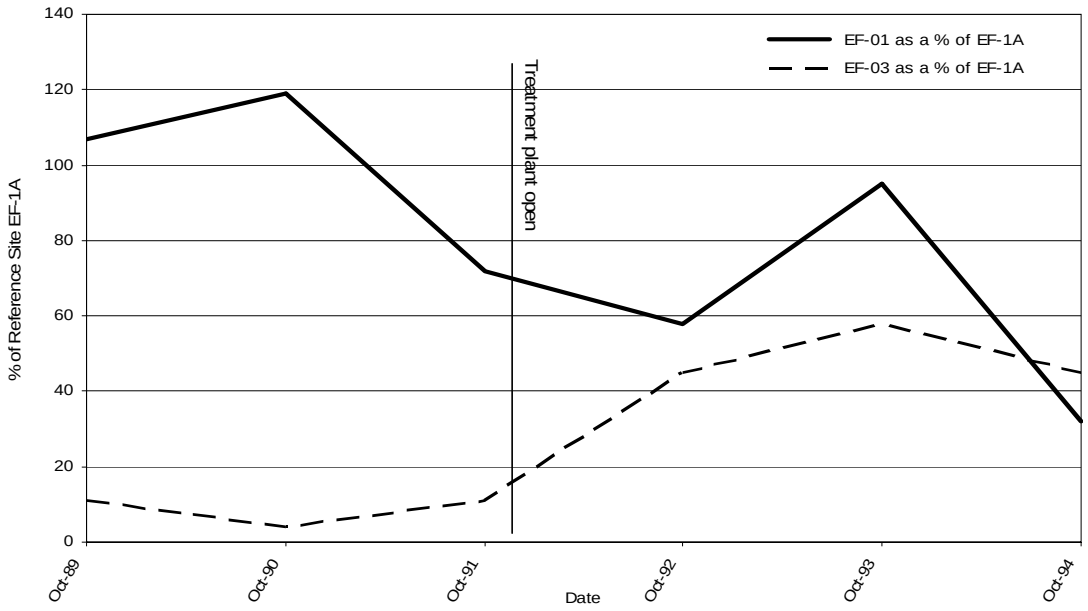
[a]Richness determined from three Surber and one kick-net sample.
[b]Abundance determined from three Surber samples, expressed as mean number per m^2.

A comparison of stations before and after treatment using all the data in Table2 suggests that station EF-03 differed from EF-1A (reference site) before, but not after treatment was initiated. Before treatment average $\pm$ 95% confidence intervals (C.I.) for EF-03 were 54% of EF-1A with C.I. from 41-67%. Post-treatment average was 70% with C.I. from 59-82%. Pre and post-treatment averages at EF-01 were 80% (C.I.=70-89%) and 101% (C.I.=82-120%) of EF-1A,

respectively. Pre-treatment C.I. of data at EF-03 did not overlap with that from EF-01, while post-treatment did.

Heptageniid mayfly abundance and especially *Rhithrogena hageni* abundance has been found to be negatively correlated with metal concentrations in the Arkansas River (Nelson and Roline, 1993; Kiffney and Clements, 1994). Heptageniid abundance in October is largely associated with *Rhithrogena.* Samples in July likely have low immature *Rhithrogena* abundance because adults have only recently emerged and *Rhithrogena* are either in the egg stage or present as early instars that are not retained by the samplers. Abundance at upstream and downstream stations relative to the reference site EF-1A are presented in Figure 2. Prior to implementation of LMDT water treatment, values at EF-03 ranged from 4-11% of the reference site (EF-1A). Post-treatment plant values ranged from 45-58% for EF-03, while values at the upstream station (EF-01) ranged from 32-119% for the entire study period. This change in October Heptageniid abundance (relative to the reference site) is shown in Figure 2.

Figure 2. Change in October Heptageniid abundance relative to an East Fork reference site EF-1A. EF-01 was above the influence of the LMDT and EF-03 below the LMDT.



Other data—Nelson and Roline (1996) used cluster analysis to report that the benthic community at EF-03 changed after treatment to become more like stations upstream of the LMDT. A variety of information was used in a "weight-of-evidence" approach to determine that a major recovery of benthos occurred post-treatment. Nelson and Roline (1996) attributed much of the rapid improvement to the absence of physical habitat damage that often occurs with mine drainage disturbance. Sub-gravel macroinvertebrates also appeared to be recovering according to Nelson and Roline (1999).

FISH POPULATIONS

Fish population estimates, using electrofishing techniques, were made over several years (LaBounty et al., 1975; Roline and Boehmke, 1981; Aquatic Associates, 1991; Davies et al., 1995; Nehring, 2001) in the East Fork downstream of the discharge from the LMDT. It is reported that populations relative to the upstream station were lower below the LMDT prior to water treatment than after treatment initiation (Table 3). The majority of the fish population in this area consists of brown trout (*Salmo trutta*).

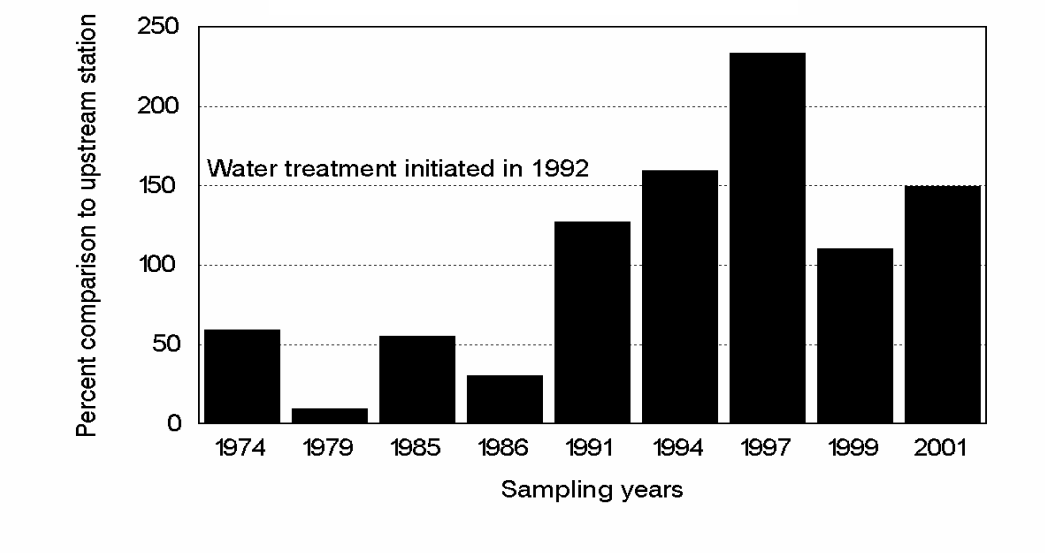
Before treatment was initiated, values below the confluence with the LMDT discharge ranged from 9-127% with a mean of 56% of the upstream station. After treatment, values ranged from 110-233% with a mean of 163%.

Table 3. Reported brown trout populations in the East Fork upstream and downstream of the Leadville Mine Drainage Tunnel discharge.

Station	Sampling date	Brown trout population (N/ha≥15 cm length)	% relative to upstream
PRE-TREATMENT			
EF-01[a] (below CO Highway 91 bridge)	9/74	51 (100 yds of stream, all sizes)	59%
EF-6 (below LMDT and above CO Highway 24)		30	
EF-01[b]	10/2/79	408 (150 m of stream, all sizes)	9%
EF-03 (below LMDT and below CO Highway 24)		39	
EF-1[c] (above CO Highway 91 bridge)	10/85	2369	55%
EF-2 (below LMDT and above CO Highway 24)		1312	
EF-1[c]	9/86	2120	30%
EF-2		641	
EF-1[c]	8/12/91	730	127%
EF-2	8/15/91	933	
POST-TREATMENT			
EF-1[c]	9/14/94	462	159%
EF-2		737	
EF-1[c]	8/12/97	438	233%
EF-2	8/18/97	1019	
EF-1[c]	8/30/99	742	110%
EF-2		820	
EF-1 [c]	8/20/01	883	149%
EF-2		1319	

[a]LaBounty et al. (1975), [b] Roline and Boehmke (1981), [c]Nehring (2001).

Figure 3. Brown trout populations in the East Fork downstream of the LMDT discharge relative to an upstream station.



Recent data collected from the East Fork showed that brown trout populations post-treatment contained older fish and that there was no reduction in survivorship associated with chronic heavy metal pollution (Nehring, 2001).

ALAD ANALYSIS ON TREE SWALLOWS

Field studies to determine trace metal contaminants found in tree swallows nesting in the area of the East Fork (and further downstream) were undertaken in 1997 and 1998 (Custer et al., 2003). Two sampling sites from Custer, 2003 are discussed in this report. The Colorado Belle site is approximately 10 kilometers upstream of the LMDT in the floodplain of the East Fork. The East Fork site is slightly upstream of the Treatment Plant discharge to the East Fork. Tree swallows are now being more widely used as indicators of local contamination because they consume emergent aquatic insects from their immediate surroundings. There is none of this type of data available prior to the operation of the LMDT treatment plant. The primary objective of the study was to determine whether lead was being transferred via the food chain to tree swallows nesting along the upper Arkansas River. It was also designed to document additional trace metal concentrations, if any, and determine whether levels were injurious to the birds or impacted reproduction. Two of the sampling stations monitored during the study performed by Custer et al., (2003) were within the East Fork. The change in blood aminolevulinic acid dehydratase (ALAD) activity was measured in tree swallow nestlings to determine lead exposure. Non-basin reference sites for comparative data used in this study were from Casper, WY; Pueblo, CO; and Agassiz National Wildlife Refuge, MN.

Based on work by Custer and Custer (2000), concentrations of trace elements (other than lead) in tree swallow eggs, livers, and food were generally below known-effect levels based on published

information in other avian species. Custer et al. (2003) stated that inhibition of ALAD is an excellent indicator of lead exposure along the Arkansas River and can aid substantially in the interpretation of tissue lead concentrations. This was shown from the East Fork site when compared with information from reference sites (Custer and Custer, 2000). Tree swallow liver samples collected from the East Fork showed a lower percentage containing lead, and at lower concentrations, in 1998 than in 1997 (0.08 and 0.42 µg lead/g dw, respectively). Overall, these samples indicated that 8% of the nest boxes from the East Fork had nestlings with ALAD inhibition > 50% of the mean activity at the reference site. Natural resource damage assessment (NRDA) regulations define injury as ALAD reductions in the "population" of greater than 50% when compared to a reference site. Overall, the population of swallows sampled at the LMDT did not show ALAD reductions that would constitute an injury as defined in the regulations. The average ALAD reduction for the population of tree swallows sampled at the LMDT was only 26% compared to the reference area.

Table 4. ALAD activity in tree swallows in the East Fork.

Location of sampling site on the East Fork of the Arkansas River	ALAD activity	% ALAD reduction relative to study reference
Colorado Belle (upper East Fork above LMDT)	56 nmol/min/ml RBC	25%
East Fork (near the LMDT)	55 nmol/min/ml RBC	26%
Reference Sites	74 nmol/min/ml RBC	0 %

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