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1995, pp. 323-329. <https://doi.org/10.56577/FFC-46.323>

in:
Geology of the Santa Fe Region, Bauer, P. W.; Kues, B. S.; Dunbar, N. W.; Karlstrom, K. E.; Harrison, B.; [eds.], New Mexico Geological Society 46th Annual Fall Field Conference Guidebook, 338 p. <https://doi.org/10.56577/FFC-46>

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THE EFFECT OF PARTICLE SIZE DISTRIBUTION ON THE GEOCHEMISTRY OF STREAM SEDIMENTS FROM THE UPPER PECOS RIVER, SAN MIGUEL COUNTY, NEW MEXICO

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Abstract—Stream-sediment samples were collected at six sites along the Pecos River in May 1994, in order to study the particle size distribution and its relationship to metal concentrations. Previous studies have shown that stream sediments from the Pecos River are elevated in Cu, Pb and Zn below the abandoned Pecos mine and the Alamitos Canyon mill site. Zinc was also elevated in the area of the Lisboa Springs Fish Hatchery. Higher concentrations of Cu, Pb, and Zn are typically found in the smallest size fraction (silt and clay; .063 mm) which typically represents less than 10% of the stream-sediment sample by weight. The sediment samples were sieved into six size fractions (1–2 mm, 0.5–1 mm, 0.25–0.5 mm, 0.125–0.25 mm, 0.063–0.125 mm, and <0.063 mm) and each size fraction was analyzed by flame atomic absorption spectroscopy (FAAS) for Cu, Pb, Zn, Cd, Fe, Mg and Mn. In three samples exhibiting low total metal values, metal concentrations (Cu, Pb, Zn, Cd) increase with decrease in particle size fraction. The sample from above the Lisboa Springs Fish Hatchery contains elevated concentrations of Zn, which suggests that precipitate leached and suspended material eroded from the upper Pecos River, upper Willow Creek, and the Pecos mine waste dump could be deposited at the diversion dam above the fish hatchery. During sporadic periods of turbulent flow, in the Fall when the Pecos River is at low flow, suspended material elevated in Zn could be entering the fish hatchery and contributing to recent fish kills. In three samples with elevated metal values, the highest metal concentrations (Cu, Pb, Zn, Cd) correspond to the smallest (fine sand, silt and clay; 0.063–0.125 mm, <0.063 mm) and largest (coarse and very coarse sand; 0.5–1 mm, 1–2 mm) size fractions. This suggests that the metals are traveling mainly as suspended material and as larger mineral or other grains weathered from the mine waste pile and the tailings pile.

INTRODUCTION

The Pecos River is a significant source of surface and subsurface water supplies for eastern New Mexico, west Texas, and Coahuila, Mexico, and the water quality depends upon geology and human activities. The Pecos mine and Alamitos Canyon mill site (Fig. 1) have been identified as sources of heavy metal addition to stream sediments of the Pecos River (McLemore et al., 1993, 1995; Brandvold et al., 1995; Johnson and Deeds, 1995). The Lisboa Springs Fish Hatchery, located 18 km downstream of the Pecos mine, has had fish kills in March 1991 and every Fall since 1991 (R. Gallegos, New Mexico Game and Fish Department, personal commun., Feb. 21, 1995); the loss was blamed on heavy metals washed into the river from the abandoned Pecos mine (Neary, 1991; Pugh, 1995). Reclamation of the Pecos mine and campgrounds began in 1990–1991. Zinc was elevated in stream sediments in the area of the Lisboa Springs Fish Hatchery (McLemore et al., 1993, this volume; Brandvold et al., 1995).

Currently numerous multidisciplinary studies are ongoing in the upper Pecos River. This paper is part of a joint effort by New Mexico Bureau of Mines and Mineral Resources (NMBMMR), New Mexico Institute of Mining and Technology (NMIMT), and U.S. Bureau of Reclamation to study the effects of metals from the Pecos mine and Alamitos Canyon mill on the Pecos River and lakes downstream (see papers by McLemore et al., and Johnson and Deeds, this volume, for additional information). AMAX Resources Conservation Company and the New Mexico Environment Department (NMED) are conducting environmental evaluation and remedial studies in the immediate area of the Pecos mine. NMED is overseeing reclamation at the mill site. The U.S. Forest Service (USFS), New Mexico Game and Fish Department (NMGFD), and the New Mexico State Highway and Transportation Department are removing the mine waste materials from campgrounds and roads. The NMGFD and the U.S. Fish and Wildlife Service are studying the fish kills at the Lisboa Springs Fish Hatchery.

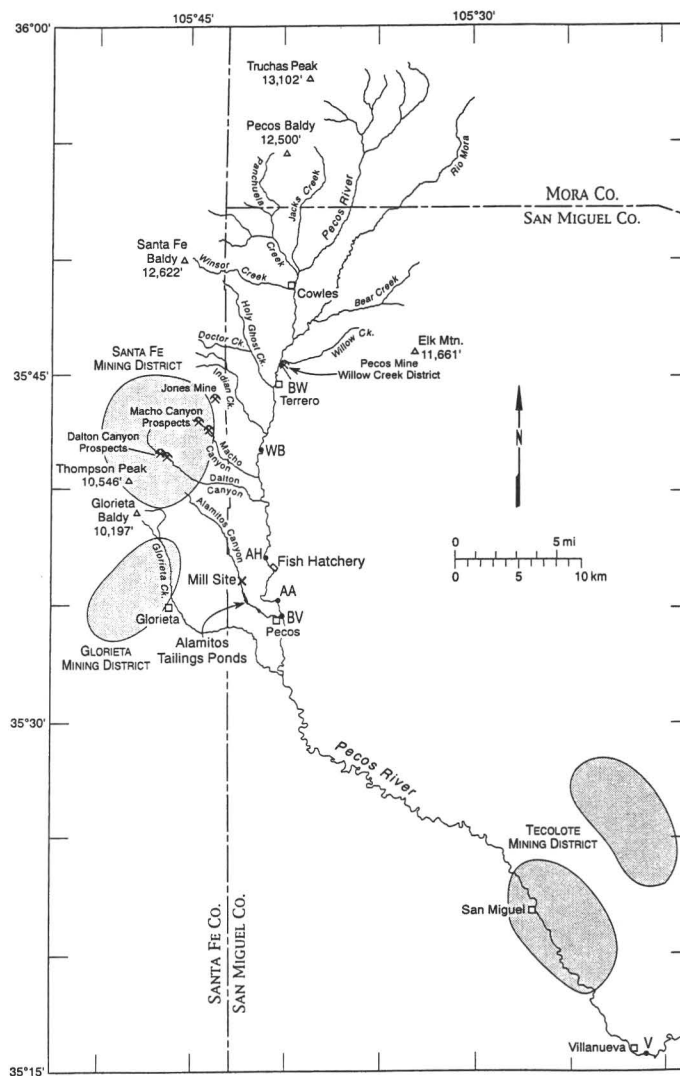


FIGURE 1. Location of sample sites, mining districts, Pecos mine and Alamitos Canyon mill site in the upper Pecos River area, Santa Fe and San Miguel Counties, New Mexico. Key to sites: BW, Pecos below Willow Creek; WB, Pecos at Windy Bridge; AH, Pecos above the hatchery; AA, Alamitos just above Pecos village; BV, Pecos below Pecos village; V, Pecos at Villanueva.

An extensive two-year sampling program was undertaken following a preliminary reconnaissance trip (McLemore et al., 1993) in order to study the concentrations, distribution, and partitioning of Cu, Pb and Zn in stream sediments from the Pecos River, from the Pecos Wilderness (upstream of the Pecos mine) to Villanueva (downstream of the mine) (Fig. 1). Seven sampling trips from September 1992 through September 1994 sampled stream sediments from 31 different sites. Flame atomic absorption spectroscopy (FAAS) and X-ray fluorescence (XRF) analyses confirm that elevated concentrations of Cu, Pb, Zn and Cd occur in stream sediments below the Pecos mine and Alamitos Canyon mill site, compared with samples from the Pecos River above the mine and from tributaries. The metal concentrations were relatively low at sites above the Pecos mine, with the exception of some samples taken at Jacks Creek, Pecos Below Jacks Creek, and Pecos at Cowles, probably because of contamination resulting from cleanup efforts of nearby campgrounds at the time these samples were collected. The stream sediments at sites immediately downstream of the Pecos mine and Alamitos Canyon mill exhibited variations in heavy metals concentrations from the same sample site collected at different times (Brandvold et al., 1995; McLemore et al., this volume). The metal concentrations in sediment samples from San Miguel and Villanueva downstream of Pecos village were lower and near background concentrations.

Preliminary results also indicated that the smallest size fraction (silt and clay; <0.063 mm) typically constituted 10% or less of the total weight of the sample, but typically contained the highest concentrations of base metals (Brandvold et al., 1995). Partitioning studies using partial dissolution techniques indicated that the largest concentrations of Cu and Pb were in a form solubilized by *aqua regia*, but not by extraction techniques designed to estimate metal concentrations in exchangeable, organic and oxide-bound forms. These results suggest that Cu and Pb are partitioned into mineral and amorphous phases. In contrast, the largest concentrations of Zn were associated with Fe and Mn oxide fractions (Brandvold et al., 1995).

Collectively, these studies suggest the distribution and concentration of heavy metals in the Pecos River sediments may be controlled in part by particle size distributions. Therefore, in May 1994, when the Pecos River was at high flow, several kilograms of samples at six sites were collected to determine the chemical and mineralogical composition of various particle size fractions. In September 1994, when the Pecos River was at low flow, additional samples were collected for similar study, but these analyses are not yet completed. This paper summarizes preliminary results from the May 1994 sampling trip.

STUDY AREA

The study area covers the upper Pecos River with its many tributaries, from the southern Pecos Wilderness southward to Pecos and Villanueva (Fig. 1). The headwaters are in the Pecos Wilderness in the southern Sangre de Cristo Mountains. Elevations range from 1800 m to nearly 4000 m. Climate varies from semi-arid in the valley to humid in the mountains. Vegetation and precipitation also vary according to changes in elevation, with greater amounts in the mountains. The study area is summarized here.

The geology is diverse and structurally complex, with rocks ranging in age from Proterozoic to Recent. Proterozoic rocks with overlying Paleozoic limestones and shales occur upstream of Pecos village. Pennsylvanian to Permian red-bed sequences of shales, sandstones and limestones predominate downstream of Pecos. Mining has occurred sporadically in the area. The largest district is the Willow Creek, which includes the Pecos mine (Fig. 1; McLemore, this volume). Total production from the Pecos mine is over 2.1 million metric tons of ore grading 2.9% Pb, 9.2% Zn, 0.4% Cu, 82 g/mt Ag, and 2.7 g/mt Au, worth over \$40 million. The Glorieta, Tecolote and Santa Fe districts also occur in the area, but production has been minor.

The Pecos deposit was discovered in 1881, with production occurring in the early 1900s and again from 1927 to 1939. Production also occurred in 1943–1944 from the dumps. The dumps at the mine site consist of waste rock generated during mining activities and are now a source of

acidic drainage causing elevated metals and other elements to be released to the wetlands below (S.M. Stoller Corp., 1993; Johnson and Deeds, this volume). The dumps cover an area approximately 7.7 ha; estimates of the volume of waste rock ranges from 66,151 to 72,630 m³ of material. The waste pile varies in thickness from 6 to 13 m. The waste pile is mineralogically very heterogeneous and contains chlorite, quartz, calcite, iron and manganese oxides, pyrite, galena, sphalerite, chalcocopyrite, and other minerals.

Numerous discrete and diffuse seeps occur along the base of the mine waste dump. The number of seeps and amount of water varies according to snow melt and daily storm events as well as year to year. The acidic water drains from seeps at the base of the mine waste dump, carries dissolved metals, and drains into Willow Creek, where it is diluted to a neutral pH. The Zn and other metals in the seep water form a precipitate as the pH increases, which travels as a plume of white and brown foam and suspended material in Willow Creek. These precipitates, containing high concentrations of metals, are present along the course of the seeps, the drainage into Willow Creek, and adjacent wetlands, but have not been identified in Pecos River sediments below the confluence with Willow Creek, because they occur in trace amounts. X-ray diffraction (XRD) studies indicate that the precipitates consist of glosserite (ZnSO₄·H₂O) and other heavy metal oxides and sulfates (McLemore et al., 1993; this volume). The precipitates typically fall out of suspension before reaching the Pecos River, except possibly during turbulent flow, when it may enter the river.

The ore mined from the Pecos mine was transported by aerial tramway approximately 19 km to the mill site in Alamitos Canyon (Fig. 1). The material rejected from the mill was conveyed to the tailings pond in the canyon and held in place by two earth dams, 0.7 and 1.5 km downstream from the mill. Today the tailings pile occupies approximately 14 ha in the bottom of Alamitos Canyon. The physical and chemical characteristics of the mill tailings are summarized by Sidle et al. (1991) and McLemore et al. (this volume). During periods of high run-off, discharge from the tailings pile flows through Alamitos Canyon, and could reach the village of Pecos and the Pecos River (site BV, Fig. 1). Reclamation is currently underway with the construction of a stream channel through the tailings pond and stabilization of the tailings by covering with clay, gravel and soil.

The Lisboa Springs Fish Hatchery, located 18 km below the mine site, was built in 1921. In 1933, the Pecos Wilderness was established by the USFS. In 1950 the NMGFD purchased approximately 810 ha in the Pecos mine area. The NMGFD and other government agencies utilized the mine waste materials for road fill and base material in the campgrounds along the Pecos River from the 1930s to the late 1970s, resulting in wide dispersion of material containing Cu, Pb and Zn. In the 1980s the NMED identified the mine and mill sites, campgrounds and roads as environmentally sensitive areas. Reclamation began in 1990–1991 and is still underway in the area.

SAMPLE COLLECTION, PREPARATION, AND ANALYSES

Sample collection

Using a Teflon sampler, several kilograms of sample were collected from six high sediment sites (Fig. 1; Table 1) downstream of the Pecos mine; other sample sites along the Pecos River sampled in May 1994 did not have enough sediment for this study. Samples were collected at mid-stream where possible, but fast stream current and/or water depth made this impossible at many sites, where samples were collected close to the bank. Natural sediment traps, such as bends in the river or behind large boulders, were sampled wherever possible. The Pecos River has many large boulders and pebbles, so an effort was made to collect only coarse-sand size and smaller material. The samples are thus biased in this regard. Water depths varied from site to site; the maximum depth was approximately 3 m. Flow rates of the Pecos River vary; the highest flow is typically during May–June with the snow melt (as high as 12 m³/sec) and the lowest flow is typically during November–March (as low as 0.5 m³/sec). Heavy rainfall in the Summer and Fall also produce sporadic high flow events.

TABLE 1. Description of sample sites along the Pecos River collected for particle size analyses in May 1994. Sample sites are located in Figure 1.

SYMBOL	NAME	LATITUDE	LONGITUDE
BW	Pecos Below Willow Creek	35° 45' 27"	105° 40' 10"
WB	Pecos at Windy Bridge	35° 41' 50"	105° 41' 5"
AH	Pecos Above Hatchery	35° 37' 00"	105° 41' 00"
AA	Pecos above Village	35° 35' 15"	105° 40' 30"
BV	Pecos Below Village	35° 34' 32"	105° 40' 10"
V	Pecos at Villanueva	35° 15' 30"	105° 20' 15"

Sample treatment and analyses

Samples were stored in plastic bags, transported in coolers, air-dried 5–21 days and gently disaggregated. Samples were carefully mixed by forming a cone and dividing the cone into four parts. Each opposite fraction was mixed and then the two halves were mixed. This mixing and splitting method was done at least five times.

A complete particle size analysis was performed on approximately 50 g of each sample split from the original sample, in order to characterize particle size distribution and determine appropriate size intervals for chemical analyses. Analyses were performed using brass-rimmed sieves in quarter phi sizes (mesh sizes 5, 7, 10, 14, 18, 25, 35, 45, 60, 80, 120, 170, 230 and 325). Each sample was weighed to a hundredth of a gram, placed in the sieves, and shaken for 20 minutes using a Ro-Tap machine. Each size fraction was weighed and recorded. Four duplicate samples were collected in the field as separate samples and run independently as a check on the procedures. The duplicate samples agreed with the exception of the Below Willow Creek (BW) and Below the Hatchery (BH) samples. The samples were saved for mineralogical identification.

Chemical analyses were performed on only six size fractions (ie., several quarter-phi sizes grouped together), mainly because of limited amount of sediment and limited amount of time available to separate the fractions. The samples were processed as follows. The >2 mm size fraction was removed with a stainless steel sieve and archived. A portion of <2 mm size fraction was split and designated as "whole" sample and saved for chemical analyses. Size fractions for chemical analyses were obtained from 100 g samples of the <2 mm fraction by sieving for at least 15 minutes on a Ro-Tap shaker with stainless steel sieves into six size fractions (1–2 mm, 0.5–1 mm, 0.25–0.5 mm, 0.125–0.25 mm, 0.063–0.125 mm and <0.063 mm). All fractions were weighed.

The "whole" and the size fractions were analyzed for Cu, Pb, Zn, Cd, Fe, Mg and Mn by flame atomic absorption spectroscopy (FAAS) following an *aqua regia* (15 ml HCl and 5 ml HNO₃) digestion of 1 g samples to dryness and reconstitution to a standard volume of 50 ml with 5% HNO₃. Samples were not crushed for FAAS analyses because the intent was to determine the heavy metals that were environmentally available without mechanical crushing, which could potentially release more metals. *Aqua regia* digestion is a partial extraction method and will not completely dissolve all metals bound in crystal structures or minerals resistant to chemical weathering. However, *aqua regia* digestion more closely estimates the total amount of metals environmentally available. Commercial standards were used to calibrate the FAAS instrument (Instrumentation Laboratory Model 857).

A portion of the "whole" fraction (<2 mm) was pulverized in an automated agate mortar and pestle, made into pressed powder briquettes, and analyzed by X-ray fluorescence (XRF) using standard operating procedures on a Phillips PW 2400 instrument using the methods outlined by Norrish and Chappell (1977) and Hallet and Kyle (1993). Rock standards were used to calibrate the instrument.

Quality control and analytical precision

Replicate analyses were performed on duplicate samples throughout the FAAS and XRF analyses. Agreement between batch duplicates analyzed by FAAS was within a relative 3% for Cu, 8% for Pb and 5% for Zn (Brandvold et al., 1995). Duplicate and triplicate samples were run using XRF. Agreement between duplicates and triplicates was within a relative 7% for Cu, 5% for Pb and 8% for Zn.

Standard stream-sediment samples with known reported acid extraction and total values were analyzed numerous times by both FAAS and XRF in order to monitor accuracy and precision. Two pressed powder briquettes of each standard stream-sediment sample were analyzed numerous times throughout the XRF analyses. Agreement between FAAS and acid extracted values of the standards and XRF and total values is good (Brandvold et al., 1995). Agreement between analyses of the Pecos samples by FAAS and XRF is typically good, with the exception of Zn, Fe, Mg and Mn. For these metals, XRF values are typically higher than values obtained by *aqua regia* digestion and FAAS.

Mineralogy of the sediments

Quantitative mineral identification is tedious and time consuming; therefore only qualitative techniques were employed (visual identification and XRD analyses of sediments, panned concentrates and clay-size fractions). The sediments consist primarily of lithic fragments and quartz (>50% in most sediment samples) and lesser amounts of feldspar, pyroxene, biotite and hornblende. The abundance of biotite, pyroxene and hornblende decreases downstream as a result of increasing distance from the Proterozoic rocks containing these minerals and from chemical instability of these minerals.

Most sediments contain a variety of minor mineral constituents that comprise less than 10% of the sediment sample. These minerals include micas, clay minerals, Fe and Mn oxides, and resistant minerals (magnetite, garnet, zircon, titanite, apatite, monazite, rutile titanium oxides). Clay minerals, predominantly kaolinite and illite, with minor smectite, accumulate in the <0.063 mm size fractions and constitute less than 10% of most sediment samples. Pyrite occurs in trace amounts in at least half of the stream-sediment samples below the Pecos mine.

DISCUSSION

The stream-sediment samples are poorly sorted and range in size from clay (<0.063 mm) to boulders (>1 m in diameter). Statistical analysis confirms that the particle size distribution varies from site to site (Table 2) as well as from sample trip to sample trip, as a result of variations in flow conditions along the Pecos River. Typically less than 10% of the sample is found in the smallest size fraction (<0.063 mm), with a few local exceptions (Below Willow Creek and Villanueva) (Tables 2, 3).

TABLE 2. Grain size distribution in weight percent (%), using 50 g samples and brass sieves. Sample site descriptions are in Table 1 and located in Figure 1.

Sample number	Sample site	pebbles and granules >2 mm	coarse sand 0.417-2mm	medium sand 75 µ-0.417 mm	fine sand 75-63 µ	silt, clay <63 µ
330	BW	5.06	24.04	51.73	7.48	11.70
331	BW	6.99	13.57	72.83	2.85	3.76
336	WB	51.03	23.89	21.01	1.90	2.16
337	WB	43.18	25.97	27.67	1.41	1.77
342	AH	35.91	28.99	30.69	3.37	1.04
343	AH	6.86	22.49	59.89	6.22	4.54
346	AA	0.12	3.40	83.83	9.55	3.10
351	BV	0.08	1.66	85.21	7.15	5.90
352	BV	0.11	2.23	85.95	6.34	5.37
354	V	0.00	0.06	59.31	23.69	16.94

TABLE 4. (continued)

		0.5-1 mm	22	30	320	2.5	1.4	0.3	40
								5	0
		0.25-0.5 mm	12	22	260	1.5	1.4	0.3	26
								5	0
		0.125-0.25 mm	15	21	270	1.5	1.5	0.3	24
								4	0
		0.063-0.125 mm	19	26	270	2.0	2.0	0.3	26
								8	0
		<0.063 mm	38	40	330	2.0	2.0	0.4	32
								2	0
443	V	W (XRF)	8	15	36	na	1.6	0.6	30
								6	0
		W (FAA)	8	24	31	0.5	0.7	0.4	21
								7	0
		1-2 mm	3	10	19	1.5	0.5	0.5	33
								2	0
		0.5-1 mm	3.5	11	24	1.5	0.3	0.3	26
								1	0
		0.25-0.5 mm	3.5	8.5	20	1.0	0.3	0.2	16
								5	0
		0.125-0.25 mm	4.5	9	28	1.0	0.7	0.4	19
								0	0
		0.063-0.125 mm	6	14	37	1.0	1.4	0.4	22
								8	2
		<0.063 mm	11	18	42	1.5	1.5	0.5	25
								5	0

and smallest (fine sand, silt and clay; 0.063–0.125 mm, <0.063 mm) size fractions. This suggests that the metals are traveling as larger mineral or other grains and as suspended sediment weathered from the mine waste and tailings pile.

In three samples with low total metal concentrations (Windy Bridge, Above Hatchery, Villanueva; Figs. 3,4,7), the highest metal concentrations are in the smallest size fraction (silt and clay; 0.063 mm). The sample from the dam above the fish hatchery contains elevated concentrations of Zn (Table 4), which suggests that precipitates leached from and suspended material eroded from the Pecos mine waste dump could be deposited at the diversion dam above the fish hatchery. During sporadic periods of turbulent flow in the Fall, when the Pecos River is at low flow (low volume), suspended material elevated in Zn could be entering the fish hatchery and contributing to the recent fish kills.

We performed a chi-square test on the data in Table 4 to determine statistically if the metal concentration varies with the particle size. The value of the test statistic chi-square is large ($\chi^2 = 456.153$ with 30 degrees of freedom), which confirms that the metal concentration is a function of particle size distribution.

Correlation coefficients were calculated from the geochemical data (Table 5). Excellent correlation exists between Cu, Pb, Zn and Cd (greater than 0.96) regardless of size fraction. However, a difference in correlation coefficients exists between Cu, Pb, Zn and Cd as a group with Fe, Mg and Mn as a group. Cu, Pb, Zn and Cd exhibit moderate to good correlation with Fe, Mg and Mn in the larger size fractions (coarse and very coarse sand, >0.125 mm; Table 5) and poor correlations in the smaller size fractions (fine sand, silt and clay; >0.125 mm). These data suggest that Cu, Pb, Zn and Cd are associated with Fe, Mg and Mn minerals or oxides in the larger size fractions and not the smaller size fractions. Cu, Pb, Zn and Cd possibly may occur as precipitates and/or suspended sediment in the smallest size fractions below the Pecos mine dump and below the Alamitos Canyon mill site. The precipitate and/or suspended sediment may be adhering onto Fe and Mn oxides in the larger particle size fractions.

ACKNOWLEDGMENTS

We thank personnel from the New Mexico Game and Fish Department, Lisboa Springs Fish Hatchery and the U.S. Forest Service for their assistance in collecting samples. We also acknowledge field assistance from Carl Popp, Don Brandvold and Tim Looper and laboratory assistance from David Bright, Doug Jones, Roger Duncan, Patrick Martinez, Catherine O'Connor and Daniel Hack. Special thanks to Jeffery Todd

Below Willow Creek

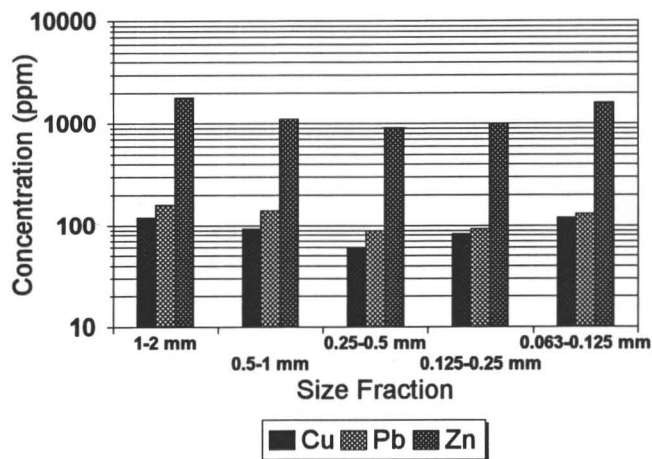


FIGURE 2. Size fraction versus metal concentration for sample collected at Below Willow Creek (BW).

Windy Bridge

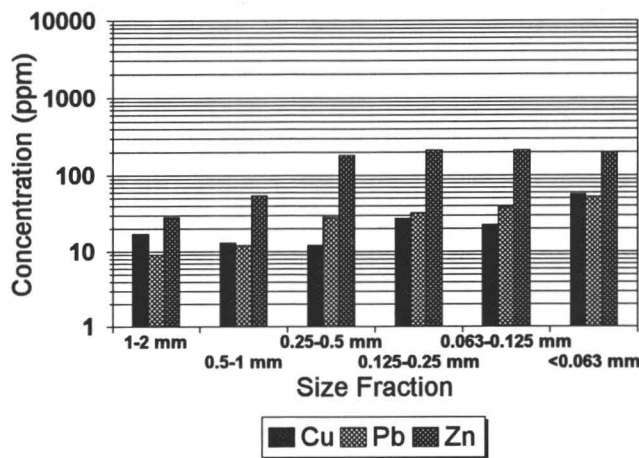


FIGURE 3. Size fraction versus metal concentration for sample collected at Windy Bridge (WB).

Above Hatchery

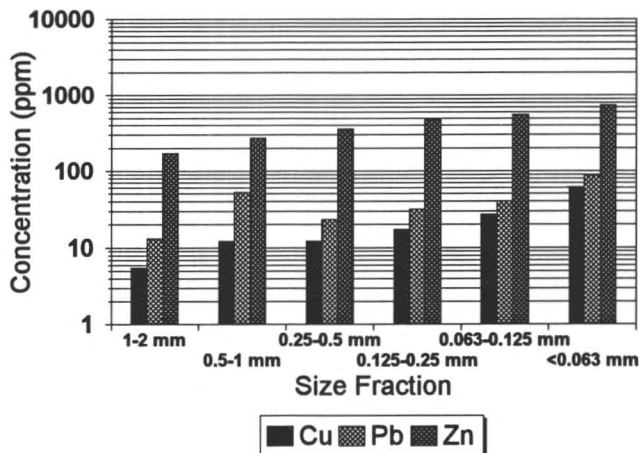


FIGURE 4. Size fraction versus metal concentration for sample collected Above Hatchery (AH).

Above Pecos Village

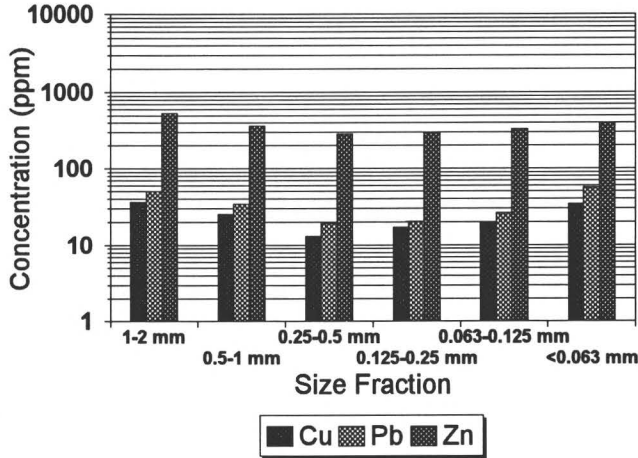


FIGURE 5. Size fraction versus metal concentration for sample collected Above Pecos Village (AA).

Below Village

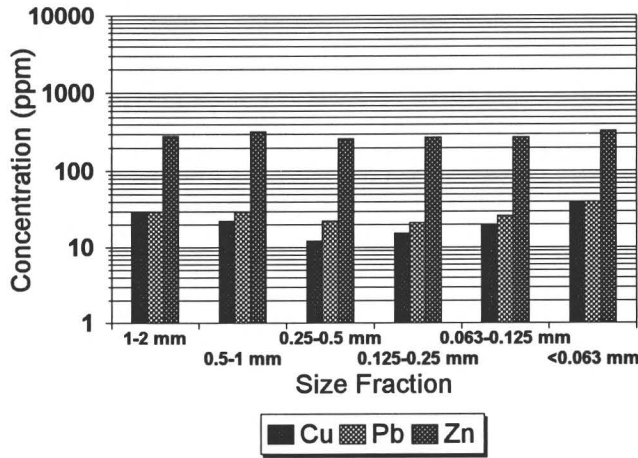


FIGURE 6. Size fraction versus metal concentration for sample collected Below Village (BV).

Villanueva

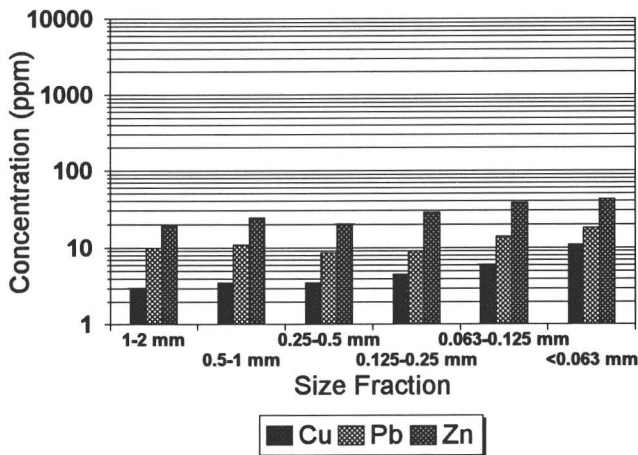


FIGURE 7. Size fraction versus metal concentration for sample collected at Villanueva (V).

TABLE 5. Correlation coefficients of geochemical analyses of Pecos stream sediment samples collected in May 1994.

ELEMENT	Cu	Pb	Zn	Cd	Fe	Mg	Mn
<i>All size frac. N=36</i>							
Cu	1						
Pb	0.99	1					
Zn	0.98	0.99	1				
Cd	0.96	0.97	0.96	1			
Fe	0.62	0.65	0.57	0.71	1		
Mg	0.47	0.5	0.42	0.61	0.86	1	
Mn	0.61	0.64	0.56	0.75	0.9	0.89	1
<i>1-2 mm fraction N=6</i>							
Cu	1						
Pb	0.99	1					
Zn	0.99	1.0	1				
Cd	0.89	0.9	0.88	1			
Fe	0.83	0.81	0.78	0.84	1		
Mg	0.48	0.48	0.43	0.69	0.76	1	
Mn	0.76	0.76	0.72	0.95	0.86	0.84	1
<i>0.5-1 mm fraction N=6</i>							
Cu	1						
Pb	0.97	1					
Zn	0.99	0.99	1				
Cd	0.92	0.93	0.93	1			
Fe	0.92	0.93	0.92	0.95	1		
Mg	0.62	0.64	0.63	0.86	0.82	1	
Mn	0.82	0.81	0.82	0.96	0.93	0.95	1
<i>0.25-0.5 mm fraction N=6</i>							
Cu	1						
Pb	0.99	1					
Zn	0.98	0.98	1				
Cd	0.97	0.98	0.98	1			
Fe	0.83	0.87	0.9	0.92	1		
Mg	0.63	0.68	0.69	0.8	0.89	1	
Mn	0.77	0.82	0.81	0.89	0.95	0.97	1
<i>0.125-0.25 mm fraction N=6</i>							
Cu	1						
Pb	0.99	1					
Zn	0.96	0.98	1				
Cd	0.94	0.97	0.98	1			
Fe	0.78	0.83	0.83	0.88	1		
Mg	0.59	0.65	0.64	0.78	0.87	1	
Mn	0.74	0.78	0.76	0.86	0.94	0.97	1
<i>0.063-0.125 fraction N=6</i>							
Cu	1						
Pb	1	1					
Zn	0.99	0.98	1				
Cd	0.98	0.97	1	1			
Fe	0	0.07	-0.06	-0.07	1		
Mg	-0.63	-0.67	-0.7	-0.7	-0.42	1	
Mn	-0.21	-0.16	-0.32	-0.33	0.88	0	1
<i><0.063 mm fraction N=6</i>							
Cu	1						
Pb	0.98	1					
Zn	0.98	0.99	1				
Cd	0.96	0.98	0.99	1			
Fe	0.19	0.15	0.03	-0.02	1		
Mg	-0.85	-0.88	-0.83	-0.8	-0.52	1	
Mn	-0.24	-0.29	-0.4	-0.45	0.9	-0.12	1

(AMAX) for providing data on the Pecos mine remedial program. This project would not have been completed without financial support from the U.S. Bureau of Reclamation and NMBMMR (Charles Chapin, Director and State Geologist). Dave Love and Pat Phillips assisted with the particle size analyses. The XRF data was obtained by Chris McKee and Phil Kyle using the Phillips PW 2400 instrument which was purchased using funds from NSF (grant EAR-9316467) and NMIMT. Frank Kottlowski, Don Brandvold and Dave Love reviewed this manuscript and Becky Titus and Kathy Campbell drafted the figures.

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